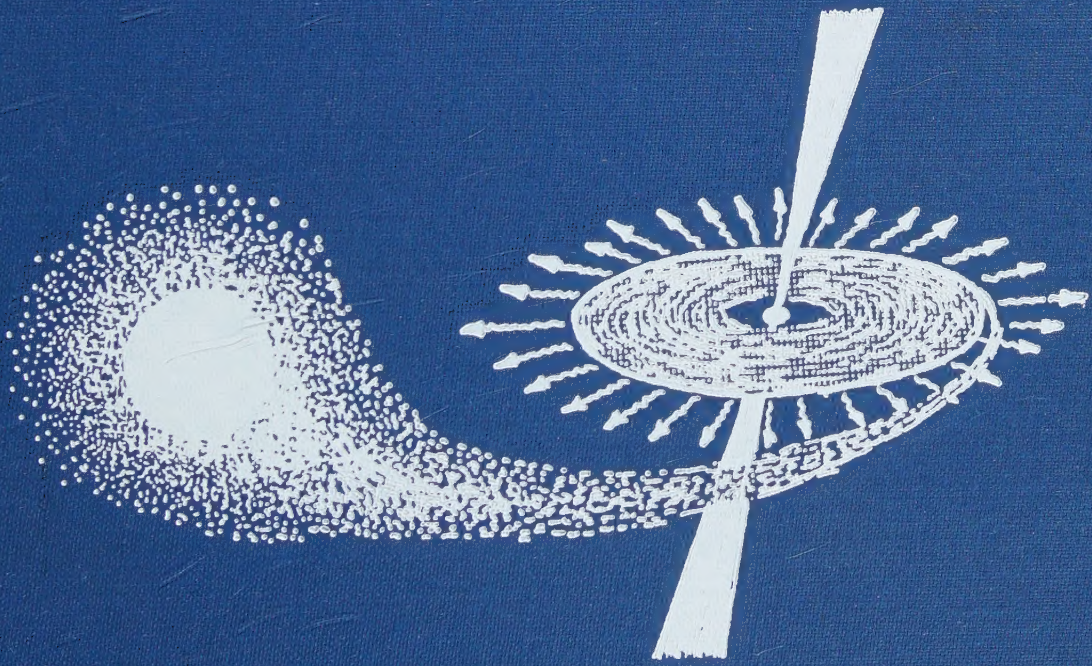
STARS, GALAXIES, COSMOS

Compiled by:

William R. Corliss



A CATALOG OF ASTRONOMICAL ANOMALIES

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TABLE OF CONTENTS

LIST OF PROJECT PUBLICATIONS

CATALOGS: Stars, Galaxies, Cosmos (categories AO, AQ, AT, AW)

The Sun and Solar System Debris (categories AA, AB, AC, AE, AS, AX, AY, AZ)

The Moon and the Planets (categories AG, AH, AJ, AL, AM, AN, AP, AR, AU, AV)

Lightning, Auroras, Nocturnal Lights, and Related Luminous Phenomena (category GL)

Tornados, Dark Days, Anomalous Precipitation, and Related Weather Phenomena (category GW)

Earthquakes, Tides, Unidentified Sounds, and Related Phenomena (categories GH, GQ, GS)

Rare Halos, Mirages, Anomalous Rainbows, and Related Electromagnetic Phenomena (category GE)

HANDBOOKS: The Unfathomed Mind: A Handbook of Unusual Mental Phenomena

Incredible Life: A Handbook of Biological Mysteries

Unknown Earth: A Handbook of Geological Enigmas

Mysterious Universe: A Handbook of Astronomical Anomalies

Ancient Man: A Handbook of Puzzling Artifacts

Handbook of Unusual Natural Phenomena

SOURCEBOOKS: Strange Phenomena, vols. G1 and G2

Strange Artifacts, vols. M1 and M2

Strange Universe, vols. A1 and A2

Strange Planet, vols. E1 and E2

Strange Life, vol. B1

Strange Minds, vol. P1

NEWSLETTERS: Science Frontiers (current anomaly reports)

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P.O. Box 107
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PREFACE

After more than twelve years of scouring the scientific and semiscientific literature for anomalies, my major conclusion is that this is an amazingly fruitful activity. In fact, organized science should have been doing the same searching and compiling for the past 200 years. It is simply astounding that a Catalog of Scientific Anomalies does not already exist to guide scientific thinking and research. It is at least as important to realize what is not known as it is to recognize the well-explained. With this outlook, here is the seventh volume in such a Catalog. It is largely the product of one person's library research, carried forward without grants, contracts, or donations.

Under the aegis of the Sourcebook Project, I have already published 23 volumes, totalling well over 8,000 pages of source material on scientific anomalies. (See page iv for a list of titles.) As of this moment, these 23 volumes represent only about 25% of my data base. New material is being added at the rate of about 1,200 new articles and items per year, about 300 of which are from the current literature. These rates could be easily multiplied several times over by spending more time in libraries. Even after twelve years, only the scientific journals of the United States and England have received my serious attention. There remain the English-language journals of the rest of the world, those journals in other languages, university theses, government reports, the publications of scientific research facilities, conference papers, untold thousands of books, and an immense reservoir of newspapers. The cataloging task has just begun. The anomalies residing in the world's literature seem nearly infinite in number.

Given this rough assessment of the magnitude of the anomaly literature, one can understand why the planned Catalog of Anomalies will require at least 25 volumes of about the same size as the one you now hold. I visualize a shelf of 25 volumes, with master indexes, to be only the initial step in providing scientists with ready access to what is not, in my opinion, well-explained.

Will the Catalog of Anomalies revolutionize science? Probably not---at least not immediately. Quite often the initial reaction to the books of anomalies already published has been disbelief. The data must be in error; the data are mainly testimonial; the data are too old; the supposed anomaly was explained long ago. Germs of truth reside in all these complaints. But for every anomaly or example that can be legitimately demolished, ten more take its place. Nature is very anomalous or, equivalently, Nature is not yet well-understood by science. Much remains to be done.

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February 1, 1987

"ROUND ABOUT THE ACCREDITED AND ORDERLY FACTS OF EVERY SCIENCE THERE EVER FLOATS A SORT OF DUST-CLOUD OF EXCEPTIONAL OBSERVATIONS, OF OCCURRENCES MINUTE AND IRREGULAR AND SELDOM MET WITH, WHICH IT ALWAYS PROVES MORE EASY TO IGNORE THAN TO ATTEND TO . . . . ANYONE WILL RENOVATE HIS SCIENCE WHO WILL STEADILY LOOK AFTER THE IRREGULAR PHENOMENA. AND WHEN THE SCIENCE IS RENEWED, ITS NEW FORMULAS OFTEN HAVE MORE OF THE VOICE OF THE EXCEPTIONS IN THEM THAN OF WHAT WERE SUPPOSED TO BE THE RULES." **William James**

HOW THE CATALOG IS ORGANIZED

Purpose of the Catalog

The Catalog of Anomalies is designed to collect and categorize all phenomena that cannot be explained readily by prevailing scientific theories. Following its definition, each recognized anomaly is rated in terms of: (1) its substantiating data; and (2) the challenge the anomaly poses to science. Next, all examples of the anomaly discovered so far are noted, some of more interesting ones in more detail. Finally, all examined references are listed. Thus, the Catalog is a descriptive guide as well as a compendium of examples and references. Scientific researchers have a substantial foundation for beginning further studies of these intriguing phenomena. This is the basic purpose of the Catalog: the collection and consolidation of the unknown and poorly explained to facilitate future research and explanation.

General Plan of the Catalog

It was tempting to organize this Catalog alphabetically, making it an "encyclopedia" of anomalies." But many of the phenomena have obscure names or, even worse, no names at all. Under these circumstances, access to the data base would be difficult. Therefore, a system of classification was designed based upon readily recognized classes of phenomena and the means by which the observer detects them. Subject matter is first divided into nine general classes of scientific endeavor, as illustrated in the diagram on the following page. Few would have difficulty classifying a phenomenon as biological, astronomical, etc. The second, third, and fourth levels of classification are also based on generally recognized attributes. The similarity of this kind of categorization to those employed in natural history field guides is quite intentional. Like bird identification, phenomenon classification soon becomes second nature. In fact, many of the phenomena described in the Catalog are accessible to anyone with normal senses and, especially in astronomy, a little optical help.

Most catalogs boast numbering systems, and this one is no exception. Rather than employ a purely numerical system, the first three classification levels are designated by letters. The triplets of letters selected have some mnemonic value. Thus, an AQO anomaly is easily recognized as being in the astronomy class (A), involving quasars (Q), and being detected through telescopic observation (O). The number added to the triplet of letters marks the fourth classification level, so that AQO3 signifies superluminal velocities in quasars, the third type of quasar telescopic anomaly. Every anomaly type has such a unique alphanumeric code. All indexes and cross references are based on this system. Catalog additions and revisions are also made easier with this scheme.

The Catalog codes may seem cumbersome at first but their mnemonic value to the compiler has been significant. The codes are simple, yet flexible enough to encompass the several thousand anomalies identified so far in many diverse scientific disciplines.

A glance through this volume will reveal that each example of a specific anomaly bears an X-number, and each reference an R-number. AQO3-X2 therefore specifies the second example of superluminal velocity; and AQO3-R4, the fourth reference to this phenomenon. Indexes and cross references can consequently be made more precise than page numbers.

How Data and Anomalies Are Evaluated

Each anomaly type is rated twice on four-level scales for data "validity" and "anomalousness," as defined below. These evaluations represent only the opinion of the compiler and are really only rough guides.

Data Evaluation Scale

1 Many high-quality observations. Almost certainly a real phenomenon.

2 Several good observations or one or two high-quality observations. Probably real.

3 Only a few observations, some of doubtful quality. Phenomenon reality questionable.

4 Unacceptable, poor-quality data. Such phenomena are included only for the purposes of comparison and amplification.

Anomaly Evaluation Scale

1 Anomaly cannot be explained by modifications of present laws. Revolutionary.

2 Can probably be explained through relatively minor modifications of present laws.

3 Can probably be explained using current theories. Primarily of curiosity value.

4 Well-explained. Included only for purposes of comparison and amplification.

Anomalies that rate "1" on both scales are very rare. Such anomalies, however, are the most important because of their potential for forcing scientific revolutions. As additional Catalog volumes are published, the relative proportion of "double-1s" will increase. especially in the fields of biology and psychology.

Catalog Coding Scheme

First-order classification	Second-order classification	Third-order classification	Fourth-order classification
(A) Astronomy	O Stars	B Distribution, celestial mechanics	1 Quasar fuzz
B Biology	(Q) Quasars	F Radiation, spectroscopy	2 Radio jet structures
C Chemistry & physics	T Cosmos	(O) Extended objects, morphology	(3) Superluminal velocities
E Earth sciences	W Galaxies	X Transit and occultation phenomena	
G Geophysics			
L Logic & math			
M Archeology			
P Psychology			
X Unclassified			

Anomaly Examples

Examples of anomaly types are designated by the letter X in the body of the Catalog. All examples discovered so far are listed. If the example is of the event type, time and place are specified where available. Such data are the foundations of the Time-of-Event Index, which could in principle lead to the discovery of obscure cause-and-effect relationships. Where library research has unearthed many examples of a specific type of anomaly, only the most interesting and instructive are quoted in detail. Direct quotations from eye-witnesses and scientific experts are employed frequently to convey accurately the characteristics of the phenomena.

The References and Sources

Each anomaly type and the examples of it are buttressed by all references that have been collected and examined. Since some references describe several examples, each reference includes the X-numbers of the examples mentioned. When a reference covers more than one type of anomaly, it is repeated in the bibliography following each anomaly type. Actually, there is little repetition of this sort in the Catalog.

Perusal of the Source Index will demonstrate that the great majority of the references comes from the scientific literature. Heavily represented in this volume of the Catalog are such journals as: Nature, Science, the Astrophysical Journal, the Astronomical Journal, and Monthly Notices of the Royal Astronomical Society. Some less technical publications are also mentioned frequently: Astronomy, Sky and Telescope, and the New Scientist. The New Scientist is an important English technical magazine containing many astronomical items. All of the serials mentioned above are generally very reliable, though one must always be wary when unusual events are reported. In addition to these often-referenced publications, there is a wide spectrum of other journals and magazines. In this context, it should be remembered that anomalous phenomena do not seek out scientists, and that the laymen who observe many anomalies do not have access to the scientific journals.

The time span covered by the sources ranges over 100 years. But the great bulk of the reports comes from the past 30 years. This is not surprising because, in contrast to the two previously published volumes of astronomical anomalies, the study of the phenomena of the present volume requires large optical telescopes, arrays of radio telescopes, sophisticated satellite instrumentation, etc. Quasars and galaxies are certainly not readily observed by laymen. Unlike most of the Catalog volumes, we find few eye-witness accounts from the general public. It should also be mentioned here that much of the literature of stellar and galactic astronomy tends heavily toward theory and mathematical modelling. Important though they are to the progress of science, theories are paid little attention here; the emphasis is on data. One final remark: astrophysics and astronomy are moving ahead so rapidly that much herein will be outdated before the books leave the bindery!

The Indexes

Each Catalog volume concludes with five separate indexes. At first glance this may seem to be too much of a good thing. But in the context of a science-wide catalog of anomalous events and unusual natural phenomena, each index has its special utility.

The subject index is essential in any work of this type. It is placed last for easy access. The time-of-event and place-of-event indexes are analytical tools for the anomaly researcher. They help identify phenomena that are reported separately (perhaps in widely different journals) but are really different aspects of the same event. This integrating feature will become more apparent as additional Catalog volumes appear. To illustrate, the effects of large solar flares may be felt throughout much of the solar system. It is possible that judicious indexing will reveal many synchronicities. It is the intent of the Catalog effort to generate a composite set of indexes that will link astronomy to geophysics, to biology, and so on.

The source index shows immediately the dependence of this Catalog upon scientific literature rather than newspapers and other popular publications. Its real purpose, though, is the rapid checking to determine if a specific reference has or has not been caught already in the fishing nets of this Catalog project. The source index is doubly valuable because many footnotes and bibliographies in the scientific literature display sources only; that is, titles and authors are omitted entirely. The researcher also comes across many vague references to such-and-such an article by so-and-so back in 1950 in Nature. The exhaustive and rather ponderous source and first-author indexes can help pin down many references lacking specifics.

All five indexes use the catalog codes described above rather than page numbers. The codes are permanent whereas the page numbers will change as addenda and revised volumes are produced. The mnenonic value of the catalog codes is useful here, too, because the approximate nature of each index entry is readily apparent, while page numbers give only location.

Supporting Publications of the Sourcebook Project

The Catalog volumes currently being published are actually distillations of huge quantities of source material. The Sourcebook Project has already published 23 volumes of this source material, as detailed on p. iv. Phase I of the Sourcebook Project resulted in 10 looseleaf notebooks called "sourcebooks." To meet the objections of librarians, Phase II supplanted the sourcebooks with a series of 6 "handbooks," which are hardcover and much larger and more comprehensive than the sourcebooks. Phase III, now in progress, is the cataloging phase, which involves the systematization of a data base comprising some 30,000 articles. The Sourcebook Project also publishes a bimonthly newsletter, SCIENCE FRONTIERS, which informs customers about scientific anomalies appearing in the current literature.

Catalog Addenda and Revisions

Over 1,200 new reports of anomalies are collected from current and older scientific journals each year. New anomaly types and additional examples of types already cataloged are accumulating rapidly. When sufficient new material has been assembled, Catalog volumes will be revised and expanded.

Request for Additions and Corrections

The Sourcebook Project welcomes reports of new anomalies and examples of recognized anomalies not yet registered in extant Catalog volumes. Reports from scientific journals are preferred, but everything is grist for the mill! Credit will be given to submitters in revised volumes of the Catalog of Anomalies. Send data to the Sourcebook Project, P.O. Box 107, Glen Arm, MD 21057.

AO INTRODUCTION TO STARS AND EXTENDED OBJECTS

Key to Categories

AOB STELLAR DYNAMICS AND DISTRIBUTION
AOF ANOMALIES DETECTED THROUGH STELLAR RADIATION
AOO EXTENDED GALACTIC OBJECTS
AOX STELLAR ECLIPSE PHENOMENA

This chapter, along with those on quasars (AQ) and galaxies (AW), deals with point and extended objects in space. These objects are localized, not pervasive like space radiation (ATF), interstellar and intergalactic matter (AT), and cosmological phenomena (AT). The general approach employed in the Catalog of Anomalies is a form of categorization which avoids theoretical prejudices. When further classifying objects, such as stars, we utilize morphology (AOO), electromagnetic and particulate emissions (AOF), and dynamics and distribution (AOB). This somewhat unorthodox approach is used in all three Catalog volumes on astronomy. It avoids, for a time at least, making classification judgments based on hypotheses.

Over 50 types of anomalies are recognized in this chapter, and many more have doubtless eluded this initial sweep through the literature. The range of phenomena covered is difficult to generalize about in an introduction. It seems more appropriate to list some of the major challenges presented here to the science of astronomy:

- -The validity of stellar age estimates and stellar evolutionary theory
- -The classical separation of stars into two, possibly three, distinct populations
- -The lack of satisfactory existence (origin) theories for stars and globular clusters
- -The unexplained ubiquity of double and multiple stars
- -The possible quantization of redshifts
- -The validity of the current theory of stellar energy production
- -The curious ubiquity of jet phenomena
- -The correctness of General Relativity
- -The questionability of mass exchange theories in explaining binary star phenomena.

AOB STELLAR DYNAMICS AND DISTRIBUTION

Key to Phenomena

AOB0 Introduction

Stars are obviously not distributed randomly. Binary and multiple stars are very common. Below the galaxy level of stellar hierarchy, stars also congregate in clusters of hundreds to even millions of stars. Not only do we need explanations of why these assemblages exist, but we want to know why some, particularly the globular clusters, do not behave according to the dictates of the Law of Gravitation and other physical principles.

In addition to segregating into clusters and other groupings, some stars move in concert while displaying no particular clustering. The star streams and the anomalous motion of the subdwarfs fall into this category.

Two other long-perplexing problems that belong in this section are the very high velocities of pulsars and the surprisingly slow rotation rates of stars when compared to theory.

Finally, the existence of some kinds of stars is predicted by theory, but they have not yet been discovered in sufficient quantities. These are the Population-III stars, which the cosmological outlook based on the Big Bang Theory seems to demand. But, so far, Population-III stars have escaped our searchings. Even nonexistence can create an anomaly.

AOB1 Star Rings

Description. Elliptical aggregations of about 25 to 200 stars. Called "star rings", these aggregations are sharply bounded on the outside, so that high stellar density prevails inside, much lower density outside. These star groupings are much, much smaller than the globular clusters.

Data Evaluation. Only a single report of this phenomenon has been located. With no confirming observations or further discussion available, the objective reality of the star rings is in some doubt. Rating: 3.

Anomaly Evaluation. Since the existence of more than 1,000 star rings is claimed, some specific generative process seems required. None has been suggested in the literature examined. Rating: 2.

Possible Explanations. None.

Similar and Related Phenomena. Globular clusters (AOB3, AOB4, AOB9)

Examples

X1. General observations. "A new form of stellar aggregation has been discovered by the West German astronomer, Theodor Schmidt-Kaler at Ruhr University, Bochum.

While studying the dark clouds of the Milky Way galaxy, Dr. Schmidt-Kaler became aware of large numbers of stellar rings, which appear on photographs as regular elliptical groups of stars that are sharply bounded on the outside. He found that typical rings contain between 25 and 200 stars and that the stellar density averages four times higher than in the surrounding field.

A complete inspection of the Palomar Observatory Sky Survey yielded 1,002 stellar rings, and three more were discovered on the plates of the Lick Observatory Sky Atlas. Statistical tests show that 80 to 90 percent of the rings are real, and only 10 to 20 percent are accidental groupings of stars.

Accurate distances within individual rings could be determined in four cases since they contained stars of known absolute and apparent magnitudes. The diameters of the four turned out to be very similar, roughly 23 light years across, a value supported by determinations in nine other cases, leading to the hypothesis that all rings have nearly equal minor diameters." (R1)

References

R1. "Stellar Rings, A New Type of Grouping," Science News, 93:42, 1968. (X1)

AOB2 Star Streams

Description. The organized, stream-like motion of some stars. Star-stream members are often of the same spectral type and, possibly, of the same age.

Data Evaluation. The mere visual impression of star streams cannot, of course, be admitted as good evidence. Studies of stellar proper motions are needed to validate the phenomenon. The few objective studies that have been found so far come to conflicting conclusions. Rating: 3.

Anomaly Evaluation. Common directions-of-motion in star streams suggest: (1) a common point of origin; or (2) the existence of some external guiding force. The latter possibility in particular is contrary to current astronomical thinking Rating: 2.

Possible Explanations. White holes, if they actually exist, might generate directed streams of new stars.

Similar and Related Phenomena. Galactic jets of matter (AWO1); the streaming of superclusters (AWB8)

Examples

X1. Early notices of star streams. "A few minutes' investigation of the stellar charts published of late years in Knowledge should, to my thinking, have satisfied a very critical mind on this point (the existence of star streams); but it is possible with the results of the Draper catalogue in hand, to apply an even more refined criterion than that of simple lineality. That stars of similar magnitude should be disposed at similar intervals upon a curve is already strong evidence in favour of a physical connection. That such a curve of stars should be distinguished from other stars in the immediate neighborhood of the curve by difference of magnitude in its components, or by the isolation of the curve itself, would seem to afford final testimony as to a physical connection. If, however, the spectroscope enables us to pick out from a confused mass of stars of various types and classes of spectrum, regular curves of stars of uniform magnitude and spectrum, surely there can remain little doubt of the genuineness of the stream.

Take, for instance, the region included between R. A. V. 30 - VI. 30, and Decl. + 15^{o} to - 30^{o}. This space contains some 300 stars, 45 are of the second type, the remainder belonging to the first type. Of the 45 second-type stars, 42 belong to class II, 13 of which form an S-shaped curve passing from Phi Orionis through 5 Monocerotis to Sirius. Upon the immediate track of this curve first-type stars lie in undecipherable confusion, and in the proportion of about 10 to 1. The utter independence with which this second-type curve develops through the congested district; the eveness of magnitude and spacing-out of its components, and the perfect regularity of a curve composed of 13 points occupied by stars of the same spectral type and class, surely leave small room for doubt as to the physical connection of the members of this and similar star streams." (R1)

X2. Kapteyn's star streams. "In 1904, the Dutch astronomer Kapteyn announced that the peculiar motions of the stars around us are not at random; they fall into two streams which move in opposite directions in the plane of the Milky Way with a relative speed of 40 km./sec. The convergent point of one stream was located in right ascension 6h 15m, declination - 12^{o}, between Orion and Gemini. The opposite convergent, in right ascension 18h 15m, declination +12^{o}, near the northern border of Sagittarius, is not far from the currently accepted direction of the center of the galactic system (right ascension 17h 33m, declination -29^{o}).

From their studies of the space motions of more than four thousand stars, Wilson and Raymond at the Dudley Observatory resolved the preferential motion into several somewhat divergent streams. Two prominent ones seem to be due to the Scorpius and Orion groups of stars, as F. D. Miller has shown. The former group, whose common motion toward us was discovered by Kapteyn, comprises many of the bright stars of Scorpius, and spreads into Centaurus and Crux. The Orion group, containing most of the bright stars of that constellation, except, Betelgeuse, is moving away from us. Both groups are composed mostly of class B stars.

Two other conspicuous streams coincide

with the directions in which the well-known clusters of Ursa Major and Taurus are moving." (R5)

Other astronomers did not support Kapteyn's findings: "On the material collected in some of these three forms: proper motions, radial velocities and parallax stars, it is easy to decide whether we are able to explain the observed motions of the stars by the two star streams of Kapteyn or in some other way. Each one of the three methods leads, independently, to the conclusion that the distribution of the velocities of the stars is in full accordance with the general theory of statistical mechanics and is decidedly in contradiction to the existence of the proposed two star streams of Kapteyn." (R4) This conclusion flies in the face of the later work of Wilson and Raymond mentioned in R5. (WRC)

X3. E. E. Barnard's opinion of star streams. "I have before called attention to certain regions of the Milky Way where a stream-like appearance of the stars is evident. There are apparently broad streams of stars which seem to have a common trend. This appearance usually occurs in a very dense region, and resembles that which might be produced by the sweep of a giant broom. In some cases, these 'sweeps' are apparently connected with vacant regions, as if there were a common drift of the stars away from these places. A striking case of this kind occurs in Scutum, where the appearance is that of streams of stars diverging from or converging to a vacant region at this point in R. A. 18h 25m, Decl. -11^{o}, and is also evident in R. A. 21h 15m, Decl. $+57^{o}$. It is best shown in R. A. 16h 55m, Decl. -34^{o}.

From looking at these pictures one gets the impression that the great mass of stars over a considerable region often have common drift in a certain direction.

The detection of a general drift of this kind by looks alone does not seem possible. Yet the impression of such a condition constantly forces itself upon one as a probability when examining certain parts of the Milky Way." (R3)

References

R1. Boraston, J. Maclair; "Star Streams," English Mechanic, 57:561, 1893. (X1)
R2. "Star Streams and Curves of Stars," English Mechanic, 58:36, 1893.
R3. Barnard, E. E.; "Star Streams," Royal Astronomical Society of Canada, Journal, 16:51, 1922. (X3)
R4. Charlier, C. V. L.; "Do the Star Streams of Kapteyn Exist?" Astronomical Society of the Pacific, Publications, 36:212, 1924. (X2)
R5. Baker, Robert H.; "Stellar Motions," Astronomy, p. 359, New York, 1938. (X2)

AOB3 Expansion of Our Galaxy's Globular Cluster Population

Description. The general expansion of our galaxy's population of globular clusters away from the center of the galaxy. Globular clusters on the near side of the galaxy are moving toward us; away from us on the other side.

Data Evaluation. The basic data are line-of-sight measurements of the velocities of 29 globular clusters. Although the sample is rather small, the expansion effect is pronounced. Rating: 2.

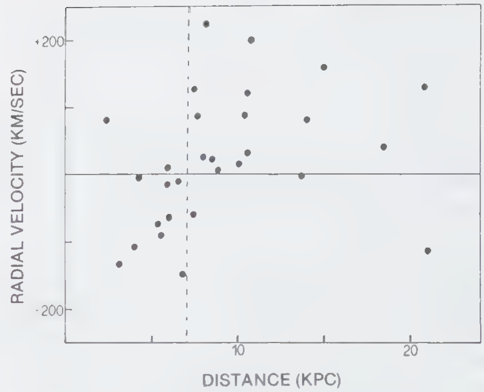
Anomaly Evaluation. V. Clube suggests that a relatively recent galactic "event" propelled the galactic globular clusters away from the center. The nature of this event is a mystery. Rating: 2.

Possible Explanations. An undefined "energetic event" at our galaxy's core.

Similar and Related Phenomena. Star streams (AOB2)

Examples

X1. Study of globular cluster velocities by V. Clube and F.G. Watson. "As is well known, the globular clusters are widely distributed through the halo of our Galaxy, and though it is generally believed that the system is in a steady state---no net radial motion---recent improvements in the estimation of individual cluster distances make the effect clear. Figure 1 shows the observed radial velocities of 29 globular clusters, whose locations in a patch of sky around the galactic centre direction are illustrated in Figure 2 (not reproduced). The galactic centre is at 7 kiloparsecs (kpc) from the Sun, and the objects in front of the centre tend to be coming toward us (they have negative velocities), while those beyond tend to be going away---all with average velocities of up to about 50 km/s relative to the centre. It is extremely difficult to explain these observations by any other kind of model." The "model" referred to is an event, perhaps as recent as 50 million years ago, causing radial dispersion of the globular clusters. (R1)



Velocities of globular clusters as seen from the galactic center. (X1)

References

R1. Clube, Victor; "Do We Need a Revolution in Astronomy?" New Scientist, 80:284, 1978. (X1)

R2. Clube, Victor, and Napier, Bill; "Universe to Galaxy: The Cosmic Framework," The Cosmic Serpent, New York, 1982, p. 41. (X1)

AOB4 Spherical Distribution of Globular Clusters and Their Apparent Nonparticipation in Galactic Rotation

Description. The approximately spherical distribution of globular clusters about the center of our galaxy and their apparent independence of normal galactic rotation. In other words, our galaxy's globular clusters seem to constitute a population of stars that is independent of the galaxy, displaying no flattening or general rotation.

Data Evaluation. At present, the data are not satisfactory. D.B. Larson (R1) makes only general assertions as to the globular cluster population's spherical distribution and nonparticipation in galactic rotation. V. Clube (R2) presents only a very small sample of globular cluster positions in support of sphericity. Rating: 3.

Anomaly Evaluation. The strong implication that our galaxy's population of globular clusters is not an integral part of the galaxy leads to the hypothesis that the globular clusters had an origin different from the rest of the galaxy. This is contrary to current astronomical theory. Rating: 2.

Possible Explanations. D.B. Larson theorizes that the globular clusters were created external to our galaxy and are now being gravitationally pulled into it. V. Clube, on the other hand, maintains that the globular clusters are being expelled from our galaxy (AOB3). Obviously, these theories are contradictory.

Similar and Related Phenomena. Expansion of our galaxy's globular cluster population. (AOB3)

Examples

X1. General observations. "The distribution of clusters around the Galaxy is nearly spherical, and there is no evidence that the cluster system participates to any substantial degree in galactic rotation."(R1) "We see the globular clusters as a roughly spherical halo extending out to a distance of about 100,000 light years from the galactic center. There is no definite limit to this zone. The cluster concentration gradually decreases until it reaches the cluster density of intergalactic space, and individual clusters have been located out as far as 500,000 light years." (R1)

In Figure 2 of Clube (R2), the distribution of the 29 globular clusters plotted around the galactic center show a roughly spherical distribution. (R2)

References

R1. Larson, Dewey B.; "Globular Clusters," The Universe of Motion, Portland, 1984, pp. 37 and 33. (X1)
R2. Clube, Victor; "Do We Need a Revolution in Astronomy?" New Scientist, 80:284, 1978. (X1)

AOB5 Geocentrically Oriented Spectroscopic Binaries

Description. The tendency of the periastron points of spectroscopic binaries to be located farther away from the earth than their apastron points. In other words, orbital axes are oriented preferentially with respect to the earth. This is called the Barr effect.

Background. "Until the time of Copernicus, virtually everyone believed that the earth was the centre of the physical universe. Although we often blame Aristotle and St. Thomas Aquinas for perpetuating this belief, it was a natural and apparently self-evident deduction from simple observations. This, more than any one person's authority, probably accounted for the belief in the central position of the earth being elevated into a dogma. Copernicus began to free us from the false notion, and now we have almost adopted an opposing dogma. Instead of being content to believe that the earth is not in a central position, we often speak as if we believe that it cannot be. Confronted with a result like Barr's therefore, astronomers tend either to be sceptical about it, or to look for some systematic error in the observations that will account for it. In the present instance, these instincts are probably sound; it is most unlikely that some preferred direction exists for the orientation of the major axes of binary orbits with respect to our line of sight from earth." (R1)

Data Evaluation. Although the phenomenon has been verified in measurements of nearly 1,000 spectroscopic binaries, it is possible that the spectroscopic data are skewed by hot gas streams in the binary system, or some similar physical distortion of the data. Since we cannot see visually what the situation is, we can always suppose that such effects exist. Rating: 3.

Anomaly Evaluation. As discussed under Background, any astronomical phenomenon supportive of geocentrism challenges one of astronomy's major tenets. Rating: 1.

Possible Explanations. The binary spectra are shifted by other physical phenomena in the binary systems, such as hot gas streams. However, no one has ever proved that the spectra of hot gas streams can be combined with those of the stars to produce the Barr effect.

Similar and Related Phenomena. Possible rotation of the universe about the earth as a hub. (ATB4)

Examples

X1. Early analysis of J. M. Barr. "Barr stumbled (apparently) on an interesting fact that still has not been fully explained. He found that of the 30 spectroscopic binaries then known to have elliptical orbits, only four had longitudes of periastron between 180^o and 360^o; all the others were between 0^o and 180^o. Geometrically speaking, this means that the orbits of those spectroscopic binaries appeared to be oriented with respect to the earth in such a way that their periastron points were nearly always farther from us than their apastron points." (R1)

X2. 1979 analysis of M.G. Fracastoro. "Studies of much larger samples of binaries have confirmed that the Barr effect really exists. From nearly 1,000 systems, M.G. Fracastoro (in 1979) showed that more than one would expect have w (longitude of periastron) around 0^o, and fewer have it around 270^o." (R1)

References

R1. Batten, A.H.; "The Barr Effect," Royal Astronomical Society of Canada, Journal, 77:95, 1983. (X1, X2)

AOB6 Anomalously Slow Rotation of Stars

Description. The very slow rotation of various classes of stars in comparison with the angular velocities predicted by theory.

Data Evaluation. A well-established phenomenon for many classes of stars, including white dwarfs and neutron stars. Rating: 2.

Anomaly Evaluation. These simple observations of star rotation directly contradict the dominant theory of star formation and evolution. Thus, this is a serious anomaly. Rating: 2.

Possible Explanations. Magnetic braking may slow some stars. D.B. Larson (R1) claims that stellar rotation should be a function of age---the older the star, the faster it rotates. This, however, does not seem to square with X2 below, where old, collapsed stars also possess slow rotations. Possibly, we do not know how to measure the age of these collapsed entities.

Similar and Related Phenomena. None.

Examples

X1. General observation. G. Verschuur as quoted by D.B. Larson: "The simplest calculations for star formation suggest that all stars should be spinning very, very fast as a result of their enormous contraction from cloud to star, but they do not do so. Why not? The answer is far from known at present." (R1)

X2. General observations on collapsed stars. "Abstract. The case of the puzzlingly slow rotation of neutron stars and white dwarfs is examined. Continuing mass loss during formation can rapidly stop rotation of white dwarfs which have magnetic field strengths of at least 10^6 gauss, for mass loss rates consistent with current theories. If mass loss can occur during formation of neutron stars, magnetic braking may be significant in slowing their rotations as well. The observed slow rotation of the 'nonmagnetic' white dwarfs, however, remains a mystery." (R2)

References

R1. Larson, Dewey B.; "Evolution---Galactic Stars," The Universe of Motion, Portland, 1984, p. 144. (X1)
R2. Brecher, K., and Chanmugam, G.; "Why Do Collapsed Stars Rotate So Slowly?" Astrophysical Journal, 221:969, 1978. (X2)

AOB7 The Possible Existence of a Minimum Distance between Stars

Description. The observation that interstellar distances are not only enormous but do not range below certain minimum values. Of course, members of binary star systems are excluded here.

Data Evaluation. By terrestrial standards, interstellar distances are certainly enormous---this is an accepted fact of astronomy. However, the claim that minimum distance limits exist is based upon the controversial work of D. B. Larson (R1). Larson defines a gravitational limit for each star, based upon the star's mass. He provides several examples of stars that fit his scheme. Since the examples given are few and Larson's theory has received scant attention from the scientific community, we can say only that the data are suggestive. Rating: 3.

Anomaly Evaluation. The existence of a minimum distance between stars means that stars do not interact with one another in the sense of collisions or close approaches. Since some astronomical theories depend upon such interactions, we have a significant anomaly here. Rating: 2.

Possible Explanations. D. B. Larson's theory is consistent with this phenomenon. The curious reader is referred to his works, for we do not have the space to expound his theory here. (R1)

Similar and Related Phenomena. Limits in astronomy are rather common. There seems to be, by way of illustration, a definite hierarchy in astronomical systems: stars, galaxies, clusters, superclusters, etc.

Examples

X1. General observations of interstellar distances. "The nearest star system, Alpha Centauri, is 4.3 light years distant, and the average separation of the stars in the vicinity of the sun is estimated to be somewhat less than 2 parsecs, or 6.5 light years. Sirius, the nearest star larger than the sun, has its gravitational limit at 5.3 light years, and the sun, 8.7 light years away, is well outside this limit.

It is evident that such a distribution of a very large number of objects in space, where the minimum separation is two-thirds of the average, requires some kind of barrier on the low side; it cannot be the result of pure chance. The results of this present investigation show that the reason why the stars of the solar neighborhood do not approach each other closer than about four light years is that they can not do so. This finding automatically invalidates all theories that call for star systems making contact or a close approach (as contemplated in some theories of the formation of planetary systems), and all theories that call for the passage of one aggregate of stars through another (such as the currently accepted theory of 'elongated rectilinear orbits' of the globular clusters).

Furthermore, these results show that the isolation of the individual star system is permanent. These systems will remain separated by the same tremendous distances because each star, or star system, or prestellar cloud continually pulls in the material within its gravitational range, and this prevents the accumulation of enough matter to form another star in this volume of space. The immense region within the gravitational limit of each star is reserved for that star alone." (R1)

References

R1. Larson, Dewey B.; "Limits," The Universe of Motion, Portland, 1984, p. 196. (X1)

AOB8 Existence of a Lower Limit to the Number of Stars in Globular Clusters

Description. Globular clusters observed so far do not contain fewer than several tens of thousands of stars. In consequence, no stable aggregates of stars exist between the multiple star systems and globular clusters, a gap of about three orders of magnitude.Note that open clusters are not considered stable aggregates.

Data Evaluation. This lower limit to globular cluster star populations is a well-founded astronomical fact. Rating: 1.

Anomaly Evaluation. Present astronomical theory predicts no lower limit to the star populations of globular clusters, nor is a reason offered for the large gap between multiple star systems and globular clusters. Rating: 2.

Possible Explanations. Globular clusters may require a minimum number of stars for gravitational stability.

Similar and Related Phenomena. The possible existence of a minimum distance between stars (AOB7).

Examples

X1. General observation. "The globular clusters range in size from a few tens of thousands to over a million stars. No stable stellar aggregates have been found between this size and the multiple star systems consisting of a few stars separated by very short distances comparable to the diameters of planetary orbits..... This is a very striking situation for which present-day astronomical theory has no explanation." (R1)

References

R1. Larson, Dewey B.; "Globular Clusters," The Universe of Motion, Portland, 1984. p. 39. (X1)

AOB9 Noncollapsing Globular Clusters

Description. The failure of globular clusters to collapse gravitationally, given the stellar densities at their cores and the force of gravitation. Globular clusters are considered to be very old astronomical objects, and theory predicts they should have collapsed long ago.

Data Evaluation. The structure and dynamics of globular clusters have been observed with high precision. Rating: 1.

Anomaly Evaluation. The apparent long life of globular clusters is contrary to the dictates of the theory of gravitation. Rating: 1.

Possible Explanations. Globular clusters do not rotate at rates sufficient for centrifugal force to be a factor. Some unidentified force at the cores of clusters may be operative. In D. B. Larson's Universe of Motion, the outward progression of the reference system accounts for this phenomenon.

Similar and Related Phenomena. None.

Examples

X0. A succinct statement of the problem of globular cluster structure. "The problem is that only one force of any significant magnitude, that of gravitation, has been definitely identified as operative in the clusters. Inasmuch as the gravitational force increases as the distance decreases, the force that is adequate to hold the cluster together should be more than adequate to draw the constituent stars together into a single mass, and why this does not happen has never been ascertained. Obviously some counter force is acting against gravitation, but the astronomers have been unable to find any such force." (R2)

X1. Analyses of globular cluster dynamics. "As a result of the gravitational forces between stars, a small fraction of stars in a globular cluster should continuously be accelerated up to sufficiently high velocity to escape the gravity of the cluster as a whole, heading out into empty space on a one-way trip. A globular cluster evaporates stars just as a liquid in a low-humidity room evaporates molecules. An unavoidable consequence of all this is that the central region of a globular cluster should collapse, shrinking in size and pulling the remaining stars closer and closer together. In 1958 Ivan King, now at Berkeley, did a rough quantitative calculation of such a collapse. It doesn't happen overnight. According to rough estimates, the globulars now closest to collapse will do so in another billion years, a long time by human standards but only a tenth the ages of these clusters." Later, these rough estimates were verified by computer simulations. (R1)

X2. Survey of globular clusters. Noting that only one cluster, M15, showed the sharp density peak expected for a collapsed core, I.R. King and S. Djorgovski conducted a broad survey. "We have observed at least half a dozen displaying central density peaks we believe to be evidence of core collapse. Still, half a dozen is not very many; theories of cluster evolution predict that a much larger fraction of the ancient globular clusters in the Milky Way halo should have collapsed by now....Why have more central density peaks not been detected?" (R3)

References

R1. Lightman, Alan; "Misty Patches in the Sky," Science 83, 4:24, June 1983. (X1)

R2. Larson, Dewey B.; "Globular Clusters," The Universe of Motion, Portland, 1984, p. 29. (X0)

R3. King, Ivan R.; "Globular Clusters," Scientific American, 252:79, June 1985. (X2)

AOB10 Subdwarfs Move Counter to Galactic Rotation

Description. The general motion of subdwarfs counter to galactic rotation.

Data Evaluation. We have at hand only general statements about this phenomenon---no specific studies of subdwarf motion. Rating: 2.

Anomaly Evaluation. Any distinct population of stars with anomalous motion, such as the subdwarfs, requires a special explanation. No widely accepted explanation has been found. Rating: 2.

Possible Explanations. D. B. Larson considers subdwarfs to have escaped from globular clusters pulled into the galaxy from outer space (R1). In this view, they are interlopers and may possess the anomalous velocity observed.

Similar and Related Phenomena. Anomalous motion of globular clusters (AOB3, AOB4); also pulsars (AOB11).

Examples

X1. General observations by M. and G. Burbidge on the metal-poor subdwarfs. "These subdwarfs...are not traveling with the sun in its giant orbit around the hub of our galaxy, and consequently they are moving with high speeds relative to the sun and in one general direction---that opposite to the direction in which the galactic rotation is carrying the sun." (R1)

References

R1. Larson, Dewey B.; "Evolution---Galactic Stars," The Universe of Motion, Portland, 1984, p. 137. (X1)

AOB11 High Pulsar Velocities

Description. The observation that pulsars, as a class, possess very high velocities. Some pulsar velocities apparently exceed the galactic escape velocity.

Data Evaluation. High pulsar velocities are confirmed by a variety of astrophysical techniques, as outlined in X1 below. Rating: 1.

Anomaly Evaluation. Since we know so little about pulsar origin, we can only speculate on the significance of their high velocities. If, as currently believed, pulsars originated in supernova explosions, we are still ignorant about just how such large energies of translation were acquired. At worst, high pulsar velocities might be interpreted as indications of extragalactic origins. Rating: 2.

Possible Explanations. Pulsars acquired their energy of translation from the supernova that created them. Pulsars may be extragalactic interlopers!

Similar and Related Phenomena. Sundry other pulsar anomalies (AOF9).

Examples

X1. Specific measurements of pulsar proper motions. "The measurement of pulsar proper motions is important to several areas of investigation concerning these objects, including their ages, circumstances of origin, and birthrate. The first such measurements implied a transverse velocity of approximately 100 km s^{-1} for the optical pulsar PSR 0531+21 (Trimble 1971). Three years later Manchester, Taylor, and Van (1974) published the first radio-astronomical proper motion measurement, based on pulse arrival-time observations for PSR 1133+16; in this case the measured angular motion corresponded to a velocity of about 300 km s^{-1}. More recently, interferometric techniques (Anderson, Lyne, and Peckham 1975; Backer and Sramek 1976) have yielded proper motions for six additional pulsars, with inferred transverse velocities ranging from 45 to 500 km s^{-1}. In the present Letter we present a proper motion determination for PSR 1508+55 which implies a transverse velocity of over 500 km s^{-1}, as well as improved data for PSR 1133+16 and useful upper limits for several other sources.

Pulsar proper-motion observations now lend very strong support to tentative conclusions reached from earlier, less direct evidence (such as pulsar-supernova remnant associations and intensity scintillation data) that pulsars, as a class, are high-velocity objects." In some cases, pulsar velocities approach or exceed galactic escape velocity. (R1)

X2. General observations. "It has been found that many, probably most, of them are moving rapidly, with speeds often exceeding 100 km/sec. Furthermore, the average of the height of the pulsars above the galactic plane is considerably greater than is normal for the objects from which they presumably originated. These motions and positions are seemingly inconsistent with the fact that the Crab and Vela pulsars have remained near the center of their respective remnants." (R2)

References

R1. Helfand, David J., et al; "Pulsar Proper Motions," Astrophysical Journal, 213: L1, 1977. (X1)

R2. Larson, Dewey B.; "Pulsars," The Universe of Motion, Portland, 1984, p. 230, (X2)

AOB12 Ubiquity of Binary and Multiple Star Systems

Description. The large fraction of stars that are members of binary and multiple star systems. This fraction may be two-thirds or more. Any viable theory of star formation must be able to account for this phenomenon.

Data Evaluation. Multiple stars near the sun are easily resolved visually or are detected by eclipses and spectroscopic variations. The statistics prevailing in the sun's neighborhood are extrapolated to the rest of the universe. Rating: 2.

Anomaly Evaluation. Several theories have been propounded for the formation of double and multiple star systems: (1) The natural fission of contracting and spinning-up stars; (2) The condensation of two or more stars in close proximity; (3) The capture of one star by another. In (1) and (2), the source of the necessary angular momentum is not clear. In (2) and (3), the required events seem improbable given the large average distance between stars (AOB7).

Possible Explanations. See above for the theories usually considered, but also note that in D. B. Larson's theory of the cosmos, multiple star systems are a natural consequence of stellar formation and evolution. (R3)

Similar and Related Phenomena. Cataclysmic binaries (AOF2); the lack of binaries in globular clusters (AOB19). The popular theories for the genesis of the earth-moon system are essentially the same as those for binary stars.

Examples

X1. General statistics. "In the immediate neighborhood of the Sun (up to a distance of 20-30 parsecs), where all methods can be applied to exhaust the entire binary population, between one-half and two-thirds of all stars appear to form double (or multiple) systems." Binaries have been detected throughout the known universe. (R1)

X2. Other aspects of the "binary" problem. (1) The large percentage of multiple-star systems; i.e., more than two; (2) The great variety of separations of binary stars; (3) Binaries of longer period have, on the average, more eccentric orbits; (4) The large difference in star types among binaries. (R2)

References

R1. Kopal, Zdenek; "Binary Stars," McGraw-Hill Encyclopedia of Science and Technology, 2:187, 1977. (X1)

R2. Baker, Robert H.; "Binary Stars," Astronomy, New York, 1938, p. 378. (X2)

R3. Larson, Dewey B.; "Binary and Multiple Stars," The Universe of Motion, Portland, 1984, p. 83.

AOB13 Pulsar Formation Rate Exceeds Supernova Frequency

Description. Observed pulsar population too large for the observed frequency of supernovas, as based upon prevailing models of pulsar evolution.

Background. According to prevailing theory, pulsars are created when massive stars turn into supernovas, leaving behind their crushed cores of degenerate matter---the neutron stars which we see as pulsars.

Data Evaluation. The wide variation of estimates for pulsar formation rates warns us that all is not well. Pulsar formation rates depend upon observing the present pulsar population and then applying a theory or model of pulsar evolution. These models incorporate many assumptions. We do not really know, for example, when or why pulsars "turn off". Neither do we know if pulsar spin-down age reflects true pulsar age. These facts suggest that our basic knowledge is too shaky to say that an anomaly really exists here. Rating: 4.

Anomaly Evaluation. If pulsar birth rate does exceed supernova frequency by a substantial margin, the anomaly is very significant, for it implies that supernovas may not be the birth places of pulsars. Rating: 2.

Possible Explanations. This anomaly may be only apparent. Once more is learned about pulsars, it may disappear.

Similar and Related Phenomena. See other pulsar anomalies (AOF9).

Examples

X1. General survey of pulsars. Depending upon the value assumed for the average interstellar electron density, it is estimated that one pulsar is born in our galaxy every 6 years or every 40 years, for 0.03 and 0.02 electrons per cm^3. These rates exceed most estimates of supernova occurrences. (R1)

X2. Popular discussion of pulsars. The pulsar production rate is about one every 3 years in our galaxy, compared with one supernova event every 20-30 years. (R2)

X3. Pulsar production rate as estimated by R. Narayan and M. Vivekanand: one every 18 years. (R4; R3)

X4. Pulsar production rate as estimated by H. Ke-liang et al: one every 20 years, which is not too far from observed supernova occurrences. (R3)

X5. Pulsar production rate as estimated by H. Heintzmann, based upon a new model of pulsar slowing: one every 100 years for our galaxy, which matches supernova events even better than X4. (R3)

References

R1. Taylor, J.H., and Manchester, R.N.; "Galactic Distribution and Evolution of Pulsars," Astrophysical Journal, 215: 885, 1977. (X1)

R2. "Pulsar Bonanza Upsets Theories," Star & Sky, 2:10, January 1980. (X2)

R3. "Too Many Pulsars?" Sky and Telescope, 62:543, 1981. (X3-X5)

R4. Narayan, Ramesh, and Vivekanand, M.; "A Lower Limit for the Birth Rate of Pulsars," Nature, 290:571, 1981. (X3)

AOB14 Dearth of Population-III Stars

Description. The lack of evidence, especially "direct" evidence, for the existence of Population-III stars in quantities sufficient to satisfy astrophysical theory.

Background. The existence of two distinct populations of stars is widely recognized. Population-II stars are older, having been formed shortly after the creation of our galaxy. Population-I representatives are younger stars formed from the "ashes" or products of nucleosynthesis of Population-II stars. "Are there any stars older than Population-II? There should be, if our ideas about the early history of the universe are correct. The immediate result of the Big Bang is hydrogen and helium with very little, if any, production of heavier elements. To provide the chemical composition observed in Population-II objects requires a previous generation of stars to perform the necessary nucleosynthesis. Such primordial 'Population-III' stars would contain vanishingly small abundances of heavy elements, and it is possible that some long-lived examples of relatively low mass might still be around and observable." (R2)

Data Evaluation. Direct, visual evidence for Population-III stars is almost nonexistent. This is not proof they do not exist. It may just indicate we haven't looked far enough or in the right places. On the other hand, some infrared spectra (X1) and evidence of "missing mass" in the galaxy (X2) can be interpreted as evidence of Population-III material. The data are not conclusive. Rating: 3.

Anomaly Evaluation. The failure to find Population-III stars or residue from them would remove a vital chapter from the accepted history of the universe---the chapter following the postulated Big Bang. Rating: 1.

Possible Explanations. Population-III stars and/or their ashes are no longer visible; and we detect this material as "missing mass" and dust.

Similar and Related Phenomena. The "missing mass" problem (AWB5); cosmic background radiation (ATF2).

Examples

X1. Implication of cosmic microwave background radiation. "Radiation from Population III stars would be absorbed by dust grains that had condensed out from material ejected by the stars, and would be reradiated at infrared wavelengths. The cosmological expansion would shift this radiation to millimetre wavelengths today, and a bump in the blackbody spectrum has been found in just the expected place." (R1)

X2. Implication of galaxy dynamics. The dynamics of clusters of galaxies suggests that considerable dark matter must exist in the universe---the so-called "missing mass". This matter could be made of in part from Population III stars, which are now dark. (R1)

X3. Searches for stars with vanishingly small abundances of heavy elements. "Are there any such stars at all in our galaxy? In the past decade, extensive searches using objective-prism plates have covered about half the sky down to 11th magnitude. Many metal-deficient objects have been found, most of them being giants because of their great luminosities. However, only two stars seem to satisfy the criterion for Population III, and their abundances are uncertain. Other work has revealed three more possibilities." (R2) If Population III stars exist at all, this vanishingly small visible sample implies that they must be dark. (WRC)

"Abstract. There appears to be no observational evidence for the existence of true Population III stars (zero-metal abundance, first generation stars) in our Galaxy. They may only be found in an earlier generation of galaxies which formed in the denser regions of space, such as the Virgo cluster. High-speed dust ejected from supernovae in these earlier galaxies may have contaminated our Galaxy with metals before any stars formed in it." (R4)

References

R1. Rowan-Robinson, Michael; "Population III---A Cosmological Atlantis?" New Scientist, 95:552, 1982. (X1, X2)

R2. "Where Is Population III?" Sky and Telescope, 64:19, 1982. (X3)

R3. Bond, Howard E.; "Where Is Population III?" Astrophysical Journal, 248:606, 1981. (X3)

R4. Hills, J.G.; "Where Are the Population III Stars?" Astrophysical Journal, 258: L67, 1982. (X3)

AOB15 Curious Distribution of Anomalous Cepheids

Description. The apparent restriction of anomalous Cepheids to nearby spheroidal dwarf galaxies and the Small Magellanic Cloud.

Data Evaluation. Claims of exclusivity in the distribution of stars are always suspect. Previous searches for anomalous Cepheids have not been exhaustive. Rating: 3.

Anomaly Evaluation. The fact of a severely restricted distribution for a special class of star implies that those regions where it is found are somehow special or perhaps have a common origin. At present, astronomers do not seriously entertain either possibility for the dwarf galaxies or Small Magellanic Cloud. Rating: 2.

Possible Explanations. The nearby dwarf galaxies and Small Magellanic Cloud are fragments of a larger aggregation that disintegrated.

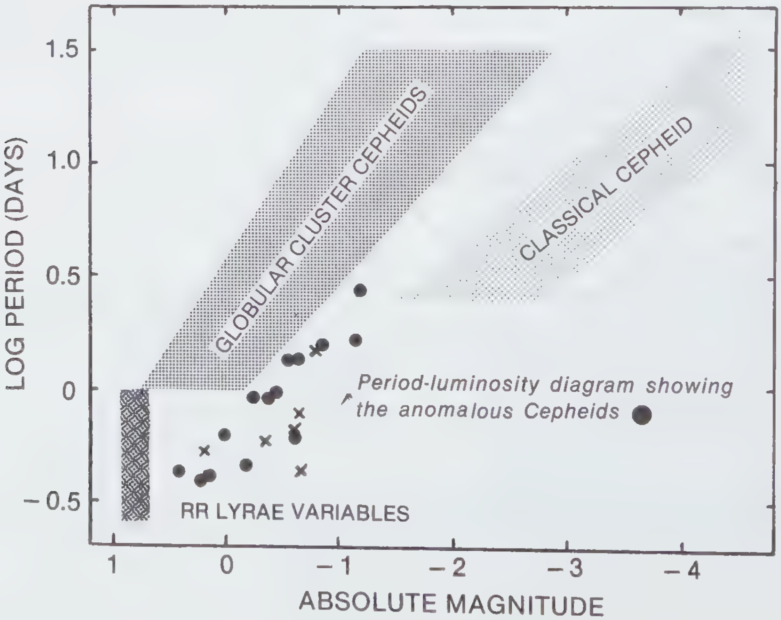
Similar and Related Phenomena. Cepheid anomalies (AOF6).

Examples

X1. General observations. Anomalous Cepheids are those that fall well outside the regions on a period-luminosity diagram occupied by the classical and globular-cluster Cepheids (see figure). "The distribution of the anomalous Cepheids is a bit curious. They are found in all the dwarf spheroidal galaxies near our own that have been searched: the Draco, Sculptor, Leo II and Ursa Minor systems. They are abundant in the Small Magellanic Cloud, but none have been found in the Large Magellanic Cloud. They are also virtually nonexistent in the globular clusters of stars that form a halo around our galaxy. It is this distribution that makes them a mystery so long as they are to be regarded as a single astrophysical class with a common sort of origin." (R1; R2, R3)

References

R1. "The Anomalous Cepheid Mystery," Science News, 110:308, 1976. (X1)
R2. "A Class of Anomalous Cepheid Variable Stars," Mercury, 6:15, 1977. (X1)
R3. Zinn, Robert, and Searle, Leonard; "The Masses of the Anomalous Cepheids in the Draco System," Astrophysical Journal, 209:734, 1976. (X1)



Period-luminosity diagram showing the anomalous Cepheids ●

AOB16 Family of Population-I Stars in Galactic Halo

Description. The existence of a family of young, spectral-type-A, main-sequence stars in the halo of our galaxy.

Background. In the prevailing theory of our galaxy's evolution, the young Population-I stars are confined to the plane of the galaxy, while older Population-I stars may stray small distances from the plane. The very old, Population-II stars, with very low metal contents, form the spherical halo of stars around the galaxy. It is in this halo that the anomalous Population-I stars have been found. Note also that stellar age cannot be measured directly but, rather, is inferred from stellar spectra and assumptions about energy generation.

Data Evaluation. One survey of faint, type-A stars in the direction of the south galactic pole. Obviously, more comprehensive surveys are desirable. Rating: 2.

Anomaly Evaluation. The galaxy-capture scenario introduced below is persuasive, but needs confiming evidence. Rating: 3.

Possible Explanations. The capture of a small, satellite galaxy rich in gas. In the capture process, the stars of the satellite galaxy would interpenetrate those of our galaxy, but the gas would not and would be compressed, stimulating a burst of star creation outside our galaxy's plane.

Similar and Related Phenomena. Other anomalous admixtures of young and old stars (AOF14, AOF26).

Examples

X1. Survey of stars in the galactic halo of spectral type A. "These A stars, lying several kiloparsecs away from the plane of the Milky Way, are well clear of the disk of the galaxy and form part of its halo. The bulk of these stars were expected to be old (about 10 billion years), highly evolved Population II giants, with metal abundances much less than those of the Sun and other disk stars (Population I).

Surprisingly, many of these halo A stars ---perhaps most of them---turned out to have metal abundances and surface gravities similar to those of the Sun. They are, in fact, young main-sequence A stars of very uniform composition, as proved by spectra of moderately high resolution. The only anomalous property possessed by these objects is their location far from the galactic plane.

The stars are clear evidence for a second family in the galactic halo in addition to the Population II giants. But where did they come from? They cannot have been around for much longer than about two billion years, for that is the maximum life span of an A star.

Any explanation has to fit a number of facts. The stars formed after the initial collapse of our galaxy, but they are not forming now. The process probably took place only once, since the composition of the resulting stars is so uniform, and occurred somewhere within eight to 10 kiloparsecs above or below the galactic plane. Finally, a chemically uniform medium similar to the Sun in composition was the raw material." (R1)

References

R1. "Is the Milky Way a Cannibal?" Sky and Telescope, 61:389, 1981. (X1)

AOB17 The Existence of Globular Clusters

Description. The existence of well-defined aggregations of stars called "globular clusters." See X1 for their salient features.

Background. In science it is deemed necessary to explain how any well-defined entity came into being and arrived at its present form. Existence is not a trivial Catalog category, especially when matter, living and nonliving, is involved.

Data Evaluation. Every astronomy textbook mentions globular clusters! Rating: 1.

Anomaly Evaluation. Astronomers are rather vague about the origin of globular clusters. Presumably they are formed by processes similar to those operative during the creation of galaxies. Unfortunately, we know little about how galaxies originate either. Some sort of condensation or aggregation of matter is always profferred, but details are lacking. When no theoretical consensus is at hand, an important anomaly exists. Rating: 1.

Possible Explanations. Inhomogeneous creation (multiple Big Bangs!); accretion and condensation under forces other than gravitation (?).

Similar and Related Phenomena. Other "existence" anomalies: stars (AOB18), galaxies (AWB17), matter per se, life (B).

Examples

X1. General observations. Globular clusters are nicely spherical aggregations of stars containing from about 20,000 to upwards of 1 million stars. Cluster diameters range from 5 to 25 parsecs. Astronomers have estimated that our galaxy's inventory of globular clusters is about 200. Other galaxies have comparable numbers.

Generally, globular clusters have low metallicities and, according to current theory, should be very old. Some astronomers consider them the oldest stellar aggregations in the universe.

Since globular clusters are so well-defined and there are wide numerical gaps between them and the open clusters, on the low side, and galaxies, on the high side, some special theory for their formation, evolution, and survival seems in order. (WRC)

AOB18 The Existence of Stars

Description. The existence of stars as well-defined aggregations of matter. See: Background in AOB17.

Data Evaluation. Who except perhaps for mystics can deny the existence of stars? Rating: 1.

Anomaly Evaluation. The existence of stars may be anomalous because the dust/gas clouds that we see today do not have densities sufficient to enable them to contract gravitationally. In fact, we are not certain just how the existing clouds were created out of the extreme homogeneity of matter predicted by some Big Bang models of creation. Rating: 1.

Possible Explanations. Theoreticians postulate that inhomogeneities will apear "statistically" in a homogeneous gas. Star formation may be triggered by supernovas and other cataclysms, but these events are also dependent upon aggregations of matter.

Similar and Related Phenomena. Other "existence" anomalies: galaxies (AWB17), galactic clusters (AWB1), matter per se, life (B).

Examples

X1. General observations based upon the hypothesized homogeneous consequences of the Big Bang. According to P.E. Seiden, "The standard Big Bang model does not give rise to lumpiness. That model assumes the universe started out as a globally smooth, homogeneous expanding gas. If you apply the laws of physics to this model, you get a universe that is uniform, a cosmic vastness of evenly distributed atoms with no organization of any kind.' No galaxies, no stars, no planets, no nothin'. Needless to say, the night sky, dazzling in its lumps, clumps, and clusters, says otherwise.

How then did the lumps get there? No one can say---at least not yet and perhaps not ever. The prerequisite for a cosmos with clusters of concentrated matter is inhomogeneity---some irregularity, some departure from uniformity, some wrinkle in the smoothness of space-time---around which matter, forged in the primordial furnace, could accrete.

For now, some cosmologists all but ignore this most vexatious conundrum. They opt, instead, to take the inhomogeneity as given, as if some matrix of organization, some preexistent framework for clumping somehow leaked out of the primeval inferno into the newly evolving universe. With lumpiness in place, the laws of physics seem to work fine in explaining the evolution of the cosmos we've come to know." (R1) Although the preceding quotation seems to apply mainly to the formation of galaxies, we do not really know for certain which came first, stars or galaxies, or, actually, whether a Big Bang really did occur. (WRC)

X2. General observations based on the reigning dust/gas cloud contraction hypothesis. "Basically there does not appear to be enough matter in any of the hydrogen clouds in the Milky Way that would allow them to contract and be stable. Apparently our attempt to explain the first stages in star evolution has failed." (R2)

References

R1. Patrusky, Ben; "Why Is the Cosmos Lumpy?" Science 81, 2:96, June 1981. (X1)

R2. Verschuur, Gerrit; Starscapes, Boston, 1973, p. 102. (X2)

AOB19 Absence of Binaries in Globular Clusters

Description. The apparent nonexistence of eclipsing and spectroscopic binary stars in globular clusters.

Data Evaluation. The only allusion to this anomaly uncovered so far is from a popular astronomy magazine. No scientific papers have been located, although a specific search would probabally find them. Rating: 2.

Anomaly Evaluation. The young Population-I stars of our galaxy form binary and multiple systems in more than half the cases; why are the Population-II globular cluster stars so notoriously single? In rating this anomaly, we assume that this difference implies a different process and/or history of stellar evolution for globular cluster stars. Rating: 1.

Possible Explanations. Binaries are formed by capture, and Population-I stars are actually older than Population-II stars---a complete reversal of current thinking.

Similar and Related Phenomena. Globular cluster age anomalies (AOF24); the ubiquity of binary stars (AOB12).

Examples

X1. General observations. "According to Virginia Trimble at the University of Maryland, globular clusters show no convincing examples of eclipsing bin'aries, stars whose brightness fades because a faint companion blocks its light from our view. They also don't seem to harbor spectroscopic binaries, systems in which the gravitational tug of an unseen star creates regular variations in spectral lines.....Although globular clusters contain few, if any, normal binary systems, they harbor 100 times the number of strong X-ray sources and 10 times the number of cataclysmic variable stars found among younger Pop I stars." It is theorized that both the cataclysmic variables and X-ray stars, no matter where they are found, are basically binary systems. (R1)

References

R1. "Companions of Old Stars," Astronomy, 11:60, November 1983. (X1)

AOB20 Alignment of Axes of Young Stars

Description. The tendency of the magnetic fields of young stars to be aligned with structures of nearby (supposedly parental) molecular clouds.

Data Evaluation. The stellar magnetic fields are detected by polarization measurements. Only one study of this phenomenon has been located so far. Rating: 2.

Anomaly Evaluation. Although molecular clouds are widely believed to give birth to new stars, there seems to be no reason why collapses of portions of the clouds should produce magnetically aligned new stars. This nonrandomness implies some sort of internal structure in the cloud, the origin of which is unknown. Rating: 2.

Possible Explanations. Magnetic organization inside molecular clouds.

Similar and Related Phenomena. None.

Examples

X1. Survey of gas jets and discs in Lynds 1641, an elongated gas cloud with a high concentration of young stars. S. Strom reported, "'To our great surprise, when we started looking at a large number of these outflows we noticed a tendency for (them) to be aligned with clearly defined large-scale structures in the parent molecular cloud.' Further measurements---of the polarisation of light from stars behind the cloud---showed that the structures were related to magnetic fields. In about 80 per cent of the cases, the ejected gas was flowing in a direction within about 20 degrees of the magnetic field lines. That indicates that the stars' rotational poles are aligned along the magnetic lines of force." (R1)

References

R1. Hecht, Jeff; "Young Stars Line Up in Magnetic Fields," New Scientist, p. 36, June 26, 1986. (X1)

AOB21 Young Stars with Anomalous Velocities

Description. The observation of young stars with high "peculiar" velocities; that is, large departures from expected trajectories and general galactic motion.

Data Evaluation. Only a brief mention in a science magazine. Rating: 3.

Anomaly Evaluation. Young stars with high peculiar velocities imply unexpectedly large numbers of interactions with other gravitating objects, given the youth of the stars. The two possibilities mentioned below seem quite reasonable, so a low anomaly rating is in order. Rating: 3.

Possible Explanations. Interactions with dark objects, possibly constituents of the so-called "missing mass" of the universe. The sling-shot ejection of young stars from multiple star systems is another possibility.

Similar and Related Phenomena. The missing mass problem (AWB5, AWO11, ATB2).

Examples

X1. General observations. "The older a star, the more encounters it has suffered and hence the larger its peculiar velocity (i.e., deviations from smooth orbits). In general, stars judged, from their chemical composition, to be old, have a higher velocity dispersion. There are some stars, however, that are young and yet have anomalously high peculiar velocities. Astronomers speculate that such stars must have experienced a particularly violent event---perhaps sling-shot ejection from a binary pair." (R1)

References

R1. "Peculiar Velocities and Close Encounters," New Scientist, p. 30, December 19/26, 1985. (X1)

AOF ANOMALIES DETECTED THROUGH STELLAR RADIATION

Key to Phenomena

AOF0 Introduction

The radiation emitted by a stellar object reveals much about its temperature, composition, velocity, and variability. Even though most stars cannot be resolved optically, spectral analysis, measurements of Doppler shifts, and other techniques provide enough information for astrophysicists to build stellar models and hypothesize about the nature and evolution of globular clusters and other subgalactic objects. Some of these models and theories, however, are challenged by well-established facts.

Some of the vital underpinnings of astronomy seem at risk here; viz.:
- -The theory that heavy elements ("metals") in a star's spectrum are a sign of its youth
- -The popular notion that a black hole resides at our galaxy's center
- -The hypothesis that thermonuclear reactions (nucleosynthesis) power stars
- -The conclusion that globular clusters are the most primitive objects in the universe.

Furthermore, several remarkable anomalies seem to resist modelling and theorizing:
- -Spin-up stars
- -Discrete redshifts in stellar spectra
- -Infrared bursters
- -Gamma-ray objects

The lists go on and on; and we still have much more literature surveying to do.

AOF1 Star Color Changes in Historical Times

Description. Star color changes over the past 2,500 years.

Data Evaluation. Modern observations of star colors are precise but those inherited from Greek, Roman, Chinese, and other ancient sources are highly questionable. Copying errors and mistranslations may have transpired. Further, at least in the case of Sirius, contradictory records also exist. The issue is also clouded by the fact that star observations near the horizon are affected colorwise by the earth's atmosphere. Rating: 4.

Anomaly Evaluation. Some of the purported color changes; viz., Sirius; imply that a red giant evolved into a white dwarf in the span of 2500 years. Stellar theory marks such radical changes in terms of many millions of years. Rating: 2.

Possible Explanation. The ancient data are garbled or in error.

Similar and Related Phenomena. The analysis of ancient writings raises the suspicion that the ancients may have been color blind or at least had color perception different from modern man (M).

Examples

X1. Sirius. "It is well known that it is generally supposed that the colour of Sirius has undergone a change since the most ancient recorded observations, from being red to the white we now see it. Thus in the late Rev. T.W. Webb's 'Celestial Objects for Common Telescopes' (4th Edition, p. 259), he says:---'Its colour has probably changed. Seneca called it redder than Mars; Ptolemy classed it with the ruddy Antares. I now see it of an intense white, with a sapphire tinge, an occasional, probably atmospheric, flash of red.'" The author of this 1887 article goes on to show how the ancient red color of Sirius crept into the literature through mistranslation or copying error. (R1)

Virgil mentions Sirius as red in both the AEneid and the Georgics. (R2, R8)

"The Dogon people in Mali have a tradition whereby Sirius and its dark companion have at times appeared red. That this African tribe speak of a dense invisible companion is itself extraordinary, for we now know that Sirius is a binary system containing a faint white dwarf." (R3)

R. H. vanGent notes that ancient Assyrian texts also mention Sirius as being red, but also state clearly that the observations were made as the star was rising and therefore close to the horizon, where color effects often occur. Other ancient texts call Sirius white or bluish. "Most explicit are the observations found in the astronomical chapters of the ancient Chinese dynastical histories, Sima Qian (about 90 BC), Ma Xu (about 100 AD) and Li Shunfeng (about 635 AD), discussing the colours of the planets and selected standard stars, all assign Sirius a white colour." (R5)

The question of Sirius' color in ancient times was reopened in 1985, when a manuscript of Lombardic origin (8th century) was found which contains a lost manuscript of Gregory of Tours (about 538-593 AD). This new source also gives Sirius a red color. The paper discussing this color change remarks on the serious astrophysical implications of a white dwarf (the companion of Sirius) changing to that status from a red giant in just a few hundred years. (R6)

X2. Betelgeuse. "The Chinese document Shih Chi from about 100 B.C. records a white or yellow color for Betelgeuse (Alpha Orionis), according to two Chinese astronomers, Lou Jin Xi and Wang Jian Min....We see Betelgeuse as red and so did Ptolemy in his Almagest written about A.D. 150. The star would not have evolved that much in about 250 years. But there is a shell of gas and dust moving away from Betelgeuse visible now. Suppose, (Kenneth) Brecher says, this shell was ejected from the star about 2,700 years ago as its distance and speed might indicate. That could have heated Betelgeuse's photosphere temporarily so as to make it look white to the observers of the Shih Chi. It would have gone back to red by Ptolemy's time." (R4; R7)

References

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R3. "Red Mystery of Sirius Deepens," New Scientist, 70:701, 1976. (X1)
R4. "Color Changes on a Scale of Centuries, Science News, 117:56, 1980. (X2)
R5. vanGent, R.H.; "Red Sirius," Nature, 216:302, 1984. (X1)
R6. Schlosser, Wolfhard, and Bergmann, Werner; "An Early-Medieval Account on the Red Colour of Sirius and Its Astrophysical Implications," Nature, 318:45, 1985. (X1)
R7. Tang, Tong B.; "Star Colours," Nature, 319:532, 1986. (X1, X2)
R8. See, T.J.J.; "The History of the Color of Sirius," Astronomy and Astro-Physics 11:376, 1892. (X1)

AOF2 Anomalous Variable Objects: A Few Extreme Cases

Description. Objects with extraordinarily variable radiation fluxes, when compared with 'normal' variable stars. The anomalies may occur in any or all sections of the electromagnetic spectrum. The objects themselves may be single stars, multiple stars, stars-plus-nebulas, etc.

Background. Peculiar variable stars are legion. No attempt has been made to catalog all of them; nor is there space to list all of the references, particularly for notorious examples, like SS 433, about which hundreds of scientific papers have been written. The goal of this entry in the Catalog is the description of some of the more anomalous and bizarre variable objects found in our search of the literature. Some astronomers will probably find their favorite anomaly missing; but hopefully they will also find some objects they did not know about.

Data Evaluation. The great bulk of the observations have been made with modern astronomical instrumentation by professional scientists. Rating: 1.

Anomaly Evaluation. The examples listed below are there precisely because they do seem to challenge astronomical theories. In general, though, one can conceive how, as in the case of SS 433, explanatory models may be constructed. Unfortunately, many of these models involve questionable theoretical constructs, such as black holes, which are widely talked about but not verified observationally. Rating: 2.

Possible Explanations. Most examples have theoretical models but generally these are not considered the final explanations. It is impossible to detail all these models here; and the reader is directed to the References.

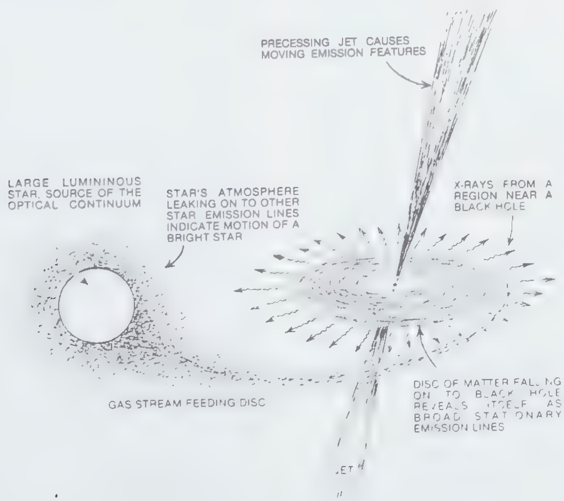
Similar and Related Phenomena. Discordant binaries (AOF14); flare stars (AOF11); flicker stars (AOF12); the various kinds of bursters (AOF11, AOF25, AOF29, AOF30).

Examples

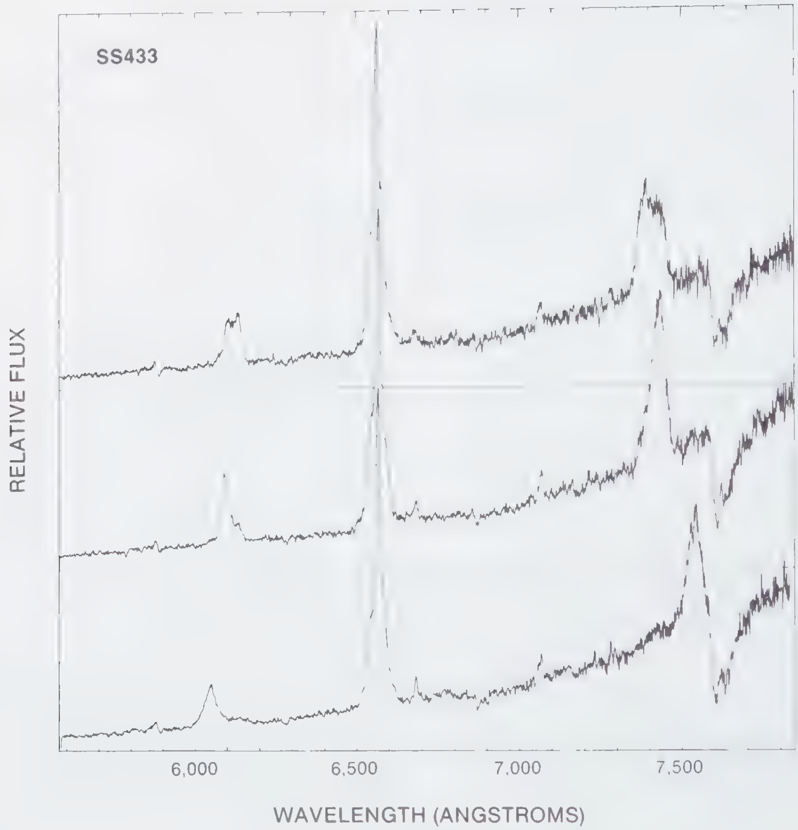
X1. SS 433. The strangeness of SS 433 was first noted in 1978. In that year at least two papers were published; but there were 28 in 1979, 73 in 1980, and 122 in 1981. (R22) It obviously fired the imaginations of many astronomers and theorists.

B. Margon, one of the first students of SS 433, described the object in these terms: "The optical spectrum of SS 433, in addition to very strong, broad Balmer and He I emission lines, contains a number of prominent broad emission features at unfamiliar wavelengths. These latter emissions are due to Doppler-shifted Balmer and He I lines, one set with a very large but consistent redshift and the other with a huge blueshift. The Doppler-shifted features are seen to change in wavelength and drift through the spectrum on a time scale of days as the velocity of the two shifted systems changes smoothly. The variable Doppler shifts achieve impressive magnitudes; a maximum of about 50,000 km s^{-1} in the redshift, and a minimum of 30,000 km s^{-1} in the blue-shifted features. This change in wavelength proves to be periodic, with a time scale of about 164 days, although the underlying clock is somewhat imperfect. The mean velocity of the sum of the red- and blueshift systems remains approximately constant at a value of about 12,000 km s^{-1} throughout the cycle, although the true systemic velocity of the object, as measured from the Balmer and He I 'rest wavelength' emissions, for example, is only about 70 km s^{-1}." (R22)

Additional data and a sketch of the most popular model for SS 433 have been given very succinctly by J.B. Hutchings: "The object SS 433, which was mentioned earlier, is an x-ray emitting binary system within our own galaxy. Its visible spectrum is unique in several ways and appears to arise principally in a highly luminous accretion disk around the compact object in the system. The mass-losing 'normal' star is not seen, but our best guess from orbital parameters indicates that both objects are greater than ten solar masses. But most exotic of all, the visible spectrum contains emission fea-



One model of SS 433. (X1)



The spectrum of SS 433, as recorded on three different nights. The left peak is shifting into the blue; the right to the red. (X1)

tures---radiation enhanced in narrow bands of wavelength---that shift over an enormous range of wavelengths, in a cycle of 164 days. These features have been identified with the Balmer series of the hydrogen line spectrum and are now understood to arise from collimated twin jets of matter beamed out perpendicular to the accretion disk and moving at about 25% of the velocity of light. We see Balmer-line emission from the beams, whose Doppler shift changes as the beams vary their angle to our line of sight. The reason for this change in angle is that the disk and beams precess with a 164-day period.... The beams trace out a biconical pattern in the sky, with an opening angle of about 20°. "(R24)

Further study of SS 433 has uncovered still another curious feature: "One of the greatest astronomical surprises of recent years is the object known as SS 433. This is apparently a binary star system that is shooting out revolving jets of matter. Furthermore it is embedded in the remnant of an old supernova (which is manifested by its radio emission). How a binary system could go through a supernova explosion and not be blown apart is difficult to figure. Now, to make SS 433 even more peculiar, recently discovered gamma ray emissions indicate that thermonuclear fusion processes are going on in the jets." (R20)

SS 433 may not be alone in its bizarreness. P. Gregory reported in 1980 that the object G109.1-1.0 possesses many similarities. (R16)

References R1-R25 all deal with SS 433, but represent only a small fraction of the available papers.

X2. V Sagittae. "One of the most intriguing of variable stars is V Sagittae. Though it varies in a cycle of some 530 days, during which it changes from magnitude about 10 to 13, it also has a superposed shorter variation of a magnitude or so in eight to 18 days. In addition, sudden changes often take place within a few minutes, while on other nights it may remain nearly constant for some time." (R26)

X3. RS Canum Venaticorum-type stars. These binary stars exhibit baffling light variations. It has been postulated that one pair member is rich with surface spots, like sun spots, that add to the variability of the light from the binary. (R27)

X4. Eta Carinae. "Although the nature of Eta Carinae is not understood, many astronomers think this subject may hold important clues to the evolution of massive stars. That the object must contain a massive star is evident from its radiant energy output of at least one million times the solar luminosity; only a mass on the order of 100 solar masses could sustain such an output. Its distance has been variously estimated at between 1200 and 2800 parsecs. The object's greatest mystery lies in its spectacular brightening in visible light to apparent magnitude -1 in 1843, when it was second in brightness only to the star Sirius. It then faded, but had a second, smaller brightening in 1889. By 1940, it had faded to 8th magnitude, but has recently brightened again to about 6th. Spectroscopic observations began in the 1890's, and show that the spectrum is analogous to that of a nova, if the analog of the nova outburst is considered to have taken place in 1889. That is, soon after the outburst the spectrum was similar to that of an F-type supergiant star (a very luminous star somewhat hotter than the Sun). As the brightness decreased, emission lines became more and more prominent in the spectrum." (R28)

Infrared measurements of Eta Carinae demonstrate that today it is one of the brightest objects in the infrared sky. It is possible that its total energy output has not changed within historical times but rather just shifted from visible to infrared wavelengths. Such a spectral shift might arise if Eta Carinae had blown off a shell of debris that intercepted the visible emissions and reemitted them as infrared energy. (R29)

X5. 89 Herculis. "Abstract. BVRI and radial velocity observations of 89 Herculis covering the three seasons of 1977, 1978, and 1979 are presented. In the first season the star showed light and color curves reminiscent of a 68^d pulsation, but no simultaneous velocity curve exceeding 1 km s^{-1} amplitude. A well-developed light curve in 1978 abruptly gave way to low-amplitude fluctuations accompanied by larger changes in radial velocity. During 1979 no light curve was present, only random fluctuations, but there were signs of a velocity curve. No adequate model to account for the observations has been found..." (R30)

X6. R Aquarii. This object consists of a long-period or Mira-type variable star plus a surrounding nebula. The star itself is a red giant, spectral type M7e. The many variable features of R Aquarii, which are very striking and somewhat anomalous follow.

The star itself: Normal Mira behavior, with a period of 387 days, and a magnitude range of 6 to 11. The maxima and minima can each change by two magnitudes, not necessarily together. Variations almost cease during an active state.

The nebula. This feature expands outward and develops new characteristics, such as a spike. The emission lines show a radial velocity variation of about 100 kilometers per second. The hydrogen-line strength and radio power output vary over a period of days. The emission-line intensity ratios also vary.

The blue continuum. Here there are active states lasting several years plus changes in the mission-line structure, which imply mass ejection. (R31)

X7. FG Sagittae. The magnitude of this star was 13.6 in 1894. Its brightness peaked in 1968, when it reached 9.5. Small, irregular variations are superimposed on this long-term trend. "But the most exciting feature of FG Sge emerged when astronomers measured its spectrum. Spectrograms taken in 1955 indicated that the star was a supergiant of spectral type B4. By 1960, FG Sge had advanced to spectral type B9, and in 1967 it had reached A5! The star continued its rapid spectral change as other astronomers monitored it: in 1972 it was F6 and by late 1980 G9. These changing classifications indicated that FG Sge's surface temperature was plummeting---at times falling by more than 300^o Kelvin in a single year. The star has expanded enormously, from 10 times the radius of the Sun in 1958 to 55 solar radii in 1973, after which it ceased expanding. FG Sagittae has changed from a hot blue star to a distended, moderate-temperature yellow star in just 20 years---the only star we know to be racing across the Hertzsprung-Russell diagram." (R32)

X8. K1-16. The central star of the planetary nebula Kohoutek 1-16 shows clear pulsations, demonstrating the existence of a new region of instability in the Hertzsprung-Russell diagram. "K1-16 can change from constant light to fully developed pulsations in less than half an hour; it also relapses into a quiescent state in almost as short a time. Apparently it can switch from its usual 28.3-minute mode to one in which several different periods are present. This behavior may be caused by nonradial pulsations that are present all the time; if many varieties are active at one time, or if they have a complex form, they may cancel each other out and no luminosity variations will be observed." (R33)

X9. FU Orionis objects. "The FU Orionis objects are among the most remarkable variable stars known. The two best studied members of the class, FU Ori and V1057 Cyg, have undergone spectacular increases in visual brightness ($\Delta V \sim$ 5-6 mag in <1 yr) and have remained very luminous for years or even decades. The spectra of FU Orionis objects in outburst are peculiar. Observations in the optical spectral region indicate a rapidly rotating G supergiant, while near-infrared spectra exhibit absorption lines characteristic of M stars." (R34)

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AOF3 Unidentified Objects at the Core of Our Galaxy

Description. Very small, highly energetic objects located almost exactly at the center of our galaxy. These powerful energy sources have dimensions comparable to that of the solar system.

Background. Quasars and active galaxies seem to possess very small, very energetic objects in their centers. Perhaps all galaxies do, and quasars are merely superactive galaxies. It is widely thought that black holes lurk at the centers of quasars and active galaxies. This belief is the basis for supposing that any high density energy sources at the center of our own galaxy must also be black holes. It should be remarked, however, that black holes are theoretical constructs that have not yet been observed directly.

Data Evaluation. The radio interferometers, infrared instrumentation, and other apparatus used to peer into the center of our galaxy are the best available; and they are manned by highly qualified teams of astronomers. Rating: 1.

Anomaly Evaluation. The salient anomaly is the emission of huge amounts of energy from a very small volume, a volume so small that the only theoretical entity capable of accounting for this energy is the black hole, which so far exists only in theory. Compounding the problem is the fact that infrared equipment resolves the object at the galactic center into several small objects---not the single, massive black hole thought to reside there. Rating: 1.

Possible Explanations. A cluster of small black holes, with masses perhaps of 100 suns each, is a possible answer.

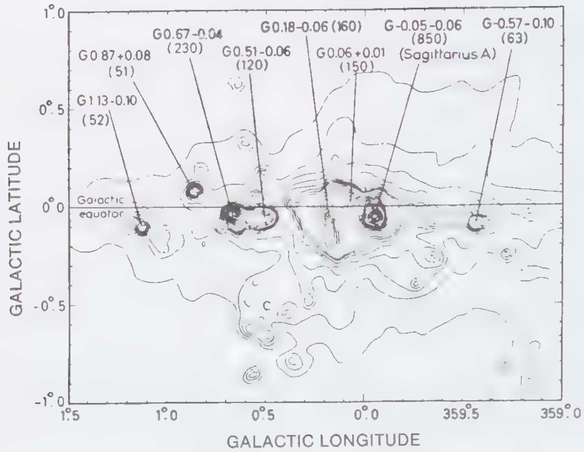
Similar and Related Phenomena. The unknown energy source of the quasar (AQF5); ditto for Seyfert galaxies (AWF2).

Examples

X1. Early radio telescope evidence. "Radio astronomers have found dramatic new evidence that points to the existence of a colossal black hole of perhaps 100 million solar masses at the centre of our Galaxy. In a coast-to-coast hook-up of radio telescopes K.I. Kellermann, D.B. Schaffer, B.G. Clark and B.J. Geldzahler (US National Radio Astronomy Observatory) achieved a baseline of 105 million wavelengths for a radio interferometer. With this they observed the centre of our Galaxy at a wavelength of 4 cm. By combining their results with those from shorter baselines they have built up a rough picture of the structure of the nuclear region.

Two years ago it was shown that the central region was less than 0.02 arc seconds in size (see R1), and now the NRAO collaboration has found that most of the structure is in the range 0.01-0.02". However, they have also discovered a region emitting 25 per cent of the central power that is less than one-thousandth of a second across. Translated into linear measure this is a true size of less than 1000 million miles---smaller than the solar system. No changes have been detected over a six month period, so any expansion of the central mass must be limited to a few tens of kilometers." Many theorists considered this to be evidence for a black hole at the core of the Galaxy. (R2; R1)

By 1982, the Very Large Array of radio telescopes in New Mexico had revealed a remarkable spiral pattern about 3 light years across centered on an exceptionally small, luminous source. "The gas in the spiral pattern appears to be flowing outward



Radio map of the galaxy. (X1)

from the central source at the rate of about one solar mass per 1000 years and at velocities in excess of 350 kilometers per second, said (R. L.) Brown. On one arm of the spiral the gas is approaching the earth, and on the other arm it is receding. This makes sense, he said, if the source is emitting a pair of opposing jets that wobbles with a precession period of about 2300 years.

The source itself, meanwhile varies strongly in intensity from day to day but varies little on a time scale of minutes. Since there is no way for dynamical effects to move faster than light, Brown deduces that the source must be between ten light-minutes and one light-day across---in other words, larger than the earth's orbit, but not much bigger than the solar system. 'We conclude that the central object must be gravitationally collapsed,' he said, 'That is, a black hole.'"(R4)

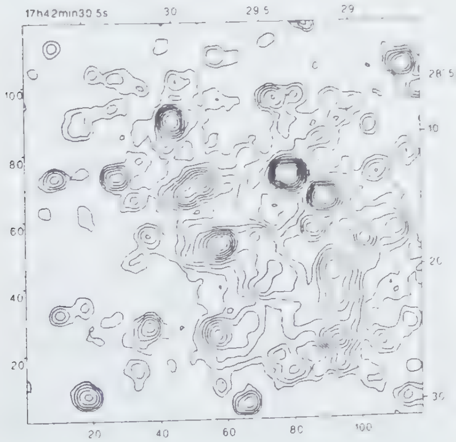
X2. Other indirect evidence of a black hole as of 1983. "Other indirect, but still inconclusive, evidence for a massive black hole at the galactic centre include: the mysterious radio source, IRS16, the X-ray source, and the electron-positron annihilation radiation, all of which appear to originate close to the centre of the Galaxy and may be associated with a black hole. However, the radio source, IRS16, and the X-ray source can also be explained within the context of more familiar stellar objects observed elsewhere in the Galaxy. The annihilation radiation is unique so far as present astronomical observations are concerned and possible mechanisms for its generation near a black hole have been discussed. While this radiation requires a very unusual situation, and considerable progress has been made in analysing characteristics where it must be formed, the source cannot be tied in any unambiguous way to the existence of a black hole." In the way of negative evidence, the extraordinary expanding gas clouds in the region were mentioned. A central black hole could not create, ionize, or disperse these clouds. (R5)

X3. Even more precise radio telescope measurements of the galactic core---1985. "The new development is essentially nothing but a more accurate measurement of the diameter of the radio source known, for the past decade and more, to be located at the galactic centre. The result is startling. At the shorter of the two radio wavelengths (1.35 cm) at which measurements have been made, the angular diameter of the source is merely 0.002 second of arc (2.1 milli-arc seconds), which at the distance of the galactic centre corresponds to a physical diameter of about 20 astronomical units, the size of the Solar System within the orbit of Saturn.... The case for supposing that there is a black hole at the centre rests almost entirely on the difficulty of accounting for such a prolific source of radio emission in any other way." (R9) Similar sentiments were expressed in Science. (R13) The new, more precise measurements referred to were made by Lo et al. (R10)

In a still later paper, K.Y. Lo concluded: "From the conservative but prudent scientific viewpoint, there is no conclusive evidence for a massive black hole at the galactic center. On the other hand, the extraordinary phenomena within the central 1 light-year of the galaxy definitely call for something unusual. With the rapid development of novel techniques and the completion of various new space and ground-based telescopes, the next few years will be exciting times for understanding the intriguing center of our galaxy and for establishing whether a massive black hole is present." (R16)

Discovery of lobes athwart the galactic center. "New radio observations of our Galaxy's troubled centre strongly support ideas that the activity there is fuelled by a massive black hole. Writing in Nature (vol. 322, p. 522), N.E. Kassim, T.N. LaRosa and William C. Erickson of the Astronomy Program at the University of Maryland, report the discovery of two 'lobes' of radio emission straddling the galactic centre itself. This kind of structure is widely observed in radio galaxies and in some quasars, whose central violence is believed to be powered by huge black holes." (R17)

X4. Infrared measurments of the galactic center---1985. Abstract. "A 2.2 μm image of IRS 16, the relatively blue infrared source near the galactic centre, is presented at the highest spatial resolution yet reported. It comprises several discrete, extended sources. By intercomparison of radio and infrared images of the region, the non-thermal radio source Sgr A* can be located relative to IRS 16 without the uncertainty of intermediate astrometric frames. No component of IRS 16 is coincident with Sgr A*. These data preclude the presence of a massive ($\sim 10^6$ $M_\odot$) black hole at the galactic centre. Any black hole present has a mass nearer to 100 $M_\odot$." (R15; R12)



Objects in the galactic center seen at 3.8 μm, on July 11, 1984. Width of illustration: 29.5 arc-seconds. (X4)

X5. Annihilation radiation detected from the center of the galaxy. The HEOS3 satellite and balloon-borne instruments have pinpointed a source of 511-kev gamma rays that can come only from a spot where electrons and positrons are mutually annihilating each other. This region of mutual destruction is about 10^{13} kilometers across. Is it a pocket af antimatter left over after the Big Bang that a sea of surrounding matter is finally wiping out, or is it newly created antimatter in the vicinity of a black hole? No one knows. The mystery has deepened with the discovery that the intensity of the annihilation radiation varies with time. (R18)

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R2. "Evidence for a Massive Black Hole in Our Galaxy," New Scientist, 74:645, 1977. (X1)
R3. Riegler, Guenter R.; "The Great Galactic Centre Mystery," Nature, 297:18, 1982.
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R7. Couper, Heather; "Journey to the Centre of the Galaxy," New Scientist, p. 32, April 26, 1984.
R8. Henbest, Nigel; "Novel Radio Source near the Heart of Our Galaxy," New Scientist, p. 19, January 17, 1985.
R9. Maddox, John; "Black Hole at the Galactic Centre," Nature, 315:93, 1985. (X3)
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R11. Waldrop, M. Mitchell; "Where Are the Dead Quasars?" Science, 228:1185, 1985.
R12. Thomsen, D.E.; "Galactic Centre: A Bunch of IR Sources," Science News, 128:292, 1985. (X4)
R13. Waldrop, M. Mitchell; "The Core of the Milky Way," Science, 230:158, 1985. (X3)
R14. Mulholland, Derral; "The Beast at the

Centre of the Galaxy," Science 85, 6:50, September 1985.

R15. Allen, David A., and Sanders, Robert H.; "Is the Galactic Centre Black Hole a Dwarf?" Nature, 319:191, 1986. (X4)

R16. Lo, K.Y.; "The Galactic Center: Is It a Massive Black Hole?" Science, 233: 1394, 1986. (X3)

R17. Couper, Heather; "Black Hole at the Centre of the Milky Way," New Scientist, p. 21, August 21, 1986. (X3)

R18. "Galactic Positronium Mystery Deepens," Science News, 130:40, 1986. (X5)

AOF4 Anomalies of Wolf-Rayet Stars

Description. The broad emission lines of this class of stars and the very wide angular diameter of the emission line region in comparison with that of the continuous spectrum.

Data Evaluation. The anomaly is spectroscopic in nature; and modern techniques are excellent. Rating: 1.

Anomaly Evaluation. Some astronomers support the interpretation of the broad emission lines as due to high-speed stellar winds, but this is counterindicated by studies of Wolf-Rayet stars in spectroscopic binaries. More serious is the inability to accurately chart the evolution of these stars, as explained in X1 below. Rating: 2.

Possible Explanations. None beyond the stellar-wind interpretation of the emission lines.

Similar and Related Phenomena. Wolf-Rayet stars are associated with circumstellar nebulae.

Examples

X1. High-speed stellar winds and shock-waves. "Wolf-Rayet stars are oddballs---difficult objects to fit into the stellar jigsaw puzzle. They're characterized by very high surface temperatures (50,000 K to 100,000 K) and the presence of super-scale stellar winds. Although some appear related to O and B-type stars (they're often found physically associated with these objects), others pop up as the central stars of planetary nebulae---suggesting a totally different evolutionary track.

It seems in fact, that there are two distinct subgroups of Wolf-Rayet stars. The first consists of luminous high-mass Population I stars that are clearly related in some way to the O-types. The second includes much dimmer and lighter objects that fall more into the older Population II category. Both families of Wolf-Rayet stars can be associated with circumstellar nebulae, but there are very significant differences between the thin bubbles of Pop I Wolf-Rayet stars and the planetary nebula shells of their Pop II cousins." Wolf-Rayet stars are rare in our galaxy, with only about 200 being known. (R1)

The high-speed winds and shock fronts mentioned above are generally taken as the explanation of the extremely broad and bright emission lines of the Wolf-Rayet stars. In support of this contention is the observation that the angular size of the emission-line region is perhaps five times as broad as that of the continuous spectrum region. However, the study of Wolf-Rayet stars that happen to be members of spectroscopic binaries tend to refute the stellar wind explanation. (R2)

References

R1. Darling, David; "Breezes, Bangs & Blowouts: Stellar Evolution through Mass Loss," Astronomy, 13:64, November 1985. (X1)

R2. Greenstein, Jesse L.; "Wolf-Rayet Star," McGraw-Hill Encyclopedia of Science and Technology, 14:601, 1977. (X1)

AOF5 Nova and Supernova Anomalies

Description. Stars that explosively increase in brightness by many orders of magnitude. After many days or even years, they return to obscurity. A few stars are repeating novas. Novas may increase in brightness by 10-15 magnitudes in less than a day. Supernovas are much brighter than novas, having absolute magnitudes of -16 or better. The only novas we can observe occur in our own galaxy. Supernovas, on the other hand, are almost exclusively seen in other galaxies, with perhaps 3 or 4 suspects in our own galaxy. Light curves, spectra, and histories of novas and supernovas can be found in many astronomical texts. See also R1 and R2.

Data Evaluation. Novas and supernovas are unpredictable; most are discovered accidently. The light curves, spectra, and other observational details are of good quality but insufficient to allow astrophysicists to really pinpoint the energy sources and release mechanisms involved when a star 'blows up'. Rating: 2.

Anomaly Evaluation. Novas and supernovas are mentioned in most textbooks on astronomy in familiar terms. Some stars, we are told, are unstable and they explode. Such is not an explanation. The fact is that we do not know why some stars detonate, while the great majority does not. Astrophysicists 'guess' at models and see if theory resembles fact---the reverse of the usual scientific method. One such 'guess' is presented below (X0). Other reasonable candidates exist. Rating: 2.

Possible Explanations. See, for example, X0 below.

Similar and Related Phenomena. Flare stars (AOF11); flicker stars (AOF12); binary star anomalies (AOF14); the missing neutrinos in stellar theory (AOF8); pulsars (AOF9.

Examples

X0. One possible scenario for the evolution of a nova. "Novae are a phenomenon that occurs only in binary systems. They require, in fact, a special type of binary---one where a white dwarf is very closely coupled to a cool, expanding subgiant.

Here's the scenario. The white dwarf has exhausted its original supply of nuclear fuel, its larger companion has recently left the main sequence and is now moving toward its red giant phase. The larger star's atmosphere has expanded to the point where it's strongly influenced by the gravitational pull of the dwarf. Matter is sucked from the large star's bloated atmosphere into an accretion disk centered on the white dwarf.

Material from the accretion disk---rich in hydrogen from virgin regions of the larger star---spirals down onto the white dwarf. Impact with the dwarf heats the small star's surface. More material piles on and the surface temperature of the dwarf gradually increases. At the same time, the heating gives rise to convection currents in the outer layers of the dwarf which circulate old carbon 'ashes' through the newly-acquired hydrogen. When the surface temperature hits 20 million degrees or slightly higher, hydrogen and carbon fusion reactions begin explosively. The result is a nova outburst. Although only a relatively small amount of mass is involved, its runaway fusion---like a colossal thermonuclear bomb, in fact---is enough to turn the white dwarf into a stellar celebrity for a few glorious days or weeks." (R3) Reasonable as this scenario sounds, it is wise to bear in mind that all that can be observed is the nova itself. The interstellar transfer of matter, the accretion disk, circulation of carbon 'ashes', etc. are all hypothetical. The explanation may eventually turn out to be the correct one, but for the moment it is a theory. (WRC)

X1. Anomalous Type-I supernovas. Type-I supernovas lack hydrogen in their spectra. They are believed to originate when a white dwarf explodes, as related in X0. "The clue to the new kind of Type I came in 1983, with the explosion of a supernova in the nearby galaxy M83. Its light curve and the overall look of the spectrum clearly marked it as a Type I. But a more detailed look at the optical spectrum showed that some important lines were missing; and infrared observations showed its brightness was fading much more slowly than a normal Type I. The supernova also emitted powerfully at radio wavelengths, never observed before in a Type I explosion. Infrared observations unearthed another couple of peculiar Type Is over the next couple of years. Then came last year's discovery of an explosion that had ejected an enormous mass of oxygen, later estimated as amounting to 50 times the mass of the Sun." The anomalous Type-I supernovas mimic the behavior of an exploding white dwarf but are caused by stars some 30 times heavier. (R4) Little is known about such stars.

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R2. Mayall, Margaret W.; "Supernova," McGraw-Hill Encyclopedia of Science and Technology, 13:320, 1977.

R3. Darling, David; "Breezes, Bangs & Blowouts: Stellar Evolution through Mass Loss," Astronomy, 13:64, November 1985. (X0)

R4. "Exploding Giants Confound Astronomers," New Scientist, p. 24, July 31, 1986. (X1)

AOF6 Cepheid Anomalies

Description. Cepheid mass anomalies, double frequencies, brightness-radius phase anomaly.

Data Evaluation. Because of their common use as celestial yardsticks, Cepheids are among the most carefully studied stars. Rating: 1.

Anomaly Evaluation. Although we do have a widely accepted theory of stellar energy production with a special addendum to explain Cepheid brightness periodicity, the existence of three anomalies indicates that something is seriously amiss. Waxing optimistic, we assume that the problem is only with the special Cepheid addendum rather than stellar theory. Rating: 2.

Possible Explanations. The theory of stellar pulsation is incorrect.

Similar and Related Phenomena. Anomalous cepheid distribution (AOB15).

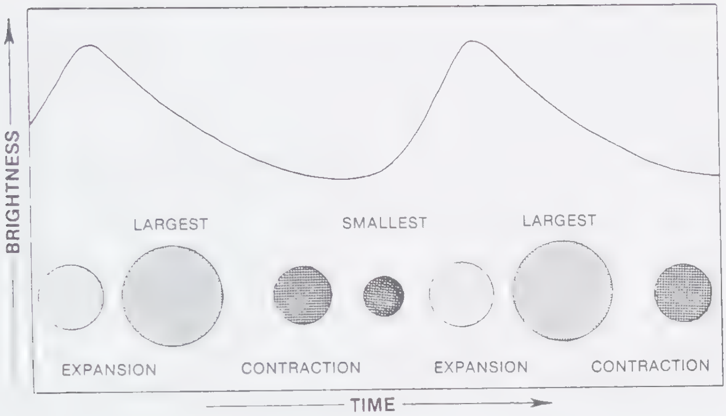
Examples

X1. The mass problem. Cepheid masses are difficult to estimate. Although some Cepheids have companions, these pairs revolve so slowly that accurate masses have not yet been calculated by this method. Instead, mass estimates are based upon the observed luminosities and the prevailing theory of stellar evolution. Mass predictions using such methods are in reasonable agreement. "Unfortunately, when astronomers try to reproduce the shape of a Cepheid's light curve and possible pulsation frequencies, they can do so only if they assume a much smaller mass, perhaps only half of that calculated in other ways. It may be that this Cepheid mass problem results from an unfortunate combination of minor gaps in our knowledge. Or there may be at least one glaring omission in our models, such as neglect of magnetic fields." (R1)

X2. Double-frequency Cepheids. "As unusual as 'normal' Cepheids seem, there are even more puzzling members of this family. About two dozen stars, all with short periods, pulsate at two frequencies simultaneously. The result, as the two pulsations fall in and out of step with each other, is a regular rise and fall in the amplitudes of these stars' brightness variations. No one knows why these so-called beat Cepheids should display such behavior." These beat Cepheids also display the most serious mass problems, as mentioned in X1. (R1)

X3. Phase anomaly. "The other point of interest in the study of cepheids concerns the physical nature of pulsation. Why do some stars pulsate while others, like the Sun, do not? How does a star pulsate? What is the effect of pulsation on the surface layers of a star? All these questions offer interesting and highly mathematical studies.

The theory of stellar pulsation was advanced by Arthur Eddington in 1917-1918. It is assumed that every part of the star



Cepheid brightness variation and cyclic size changes. Periods are usually from several days to several weeks. (X3)

oscillates adiabatically along its radius in unison, although the amplitude of oscillation varies with radius. While the theory predicts the periods of various intrinsic variables quite well, it gives the wrong phase relation between light and velocity variations. For according to this theory, a pulsating star should be brighter and hotter when contracting, and cooler and fainter when expanding. Actually, the converse is true. It is generally understood that the phase difference is due to some phenomenon that occurs in the outer layers of the star." (R3; R2) The last sentence is hardly explanatory. (WRC)

References

R1. Percy, John R.; "Cepheids: Cosmic Yardsticks, Celestial Mysteries?" Sky and Telescope, 68:517, 1984. (X1-X3)
R2. Larson, Dewey B.; "The Later Cycles," The Universe of Motion, Portland, 1984, p. 66. (X3)
R3. Huang, Su-Shu; "Cepheids," McGraw-Hill Encyclopedia of Science and Technology, 2:684, 1977. (X3)

AOF7 Apparent Absence of Bright Carbon Stars

Description. The seeming nonexistence of carbon stars brighter than bolometric magnitude -6, despite theoretical predictions that many should be observed.

Background. Carbon stars exhibit a high ratio of carbon to hydrogen. In 'normal' stars, oxygen is more abundant than carbon; the situation is reversed in carbon stars.

Data Evaluation. Abundant spectroscopic observations of carbon stars and searches for them. Rating: 1.

Anomaly Evaluation. Although the carbon stars make up only one category of stars, it is still significant that stellar theory does not come close to the observed distribution of these stars. Rating: 2.

Possible Explanations. Incorrect nuclear cross sections; the possible masking of bright carbon stars by dust shells.

Similar and Related Phenomena. The possible failure of stellar theory with respect to the 'solar neutrino problem'. (AOF8)

Examples

X1. General observations. "Abstract..... Whatever the dredge-up law adopted, theoretical (N, M_{Bol}) (number versus magnitude) distributions of carbon stars exhibit a substantial fraction of stars with bolometric magnitudes brighter than $M_{Bol} = -6$, whereas the observed distributions show none. Since, with current estimates of the $^{22}Ne(\alpha, n)^{25}Mg$ cross section, AGB (asymptotic giant branch) stars must reach a magnitude brighter than $M_{Bol} \sim -6.5$ before producing significant quantities of s-process isotopes in the solar system distribution, it is suggested that carbon stars bolometrically brighter than $M_{Bol} \sim -6$ may surround themselves with a thick dust shell and thereby escape detection in the near infrared. If this is not the case, one might infer that the effective cross section (at 30 keV) for the $^{22}Ne(\alpha, n)^{25}Mg$ reaction has been considerably underestimated." (R1)

References

R1. Iben, Icko, Jr.; "The Carbon Star Mystery: Why Do All the Low Mass Ones Become Such and Where Have All the High Mass Ones Gone?" Astrophysical Journal, 246:278, 1981. (X1)

AOF8 The "Missing" Solar Neutrinos and, by Extension, Stellar Neutrino Deficits

Description. The large discrepancy between the measured and predicted fluxes of solar neutrinos, which is assumed to also prevail in other stars, especially those of the same type.

Data Evaluation. Over 20 years of terrestrial measurements of solar neutrino fluxes. See ASF3 for more details. Rating: 2.

Anomaly Evaluation. One of the most significant anomalies in astronomy. Again see ASF3. Rating: 1.

Possible Explanations. See ASF3. It is possible that the electron neutrino flux, the only flux measured by terrestrial instruments, is converted inside the sun, in part, to a muon neutrino flux.

Similar and Related Phenomena. This anomaly extends to all theories of stellar interiors.

Examples

X1. General observations. "At least one part of the theory of stellar interiors is probably wrong although there is yet no onservational evidence that the basic ideas of stellar evolution and nuclear fusion in stars are incorrect. We of course do not know which part of the theory is wrong but it seems likely that the solution of the solar neutrino problem may affect other applications of the theory of stellar interiors such as the dating of old globular and galactic clusters or the inferences about chemical abundances made on the basis of spectroscopic observations of the surfaces of stars.

The theory of stellar interiors has proved to be in error, at least quantitatively, for an application involving the sun. I believe deductions from this theory must be treated henceforth with caution. This is especially true since most of the applications and interpretations that are normally made using this theory involve situations in which much less is known about the stars than is known about the sun. Moreover, for many of the applications, the complications of the theory are far greater (and the theoretical assumptions more questionable) than is true for calculations involving the relatively quiescent sun resting on the main sequence. Perhaps we should concentrate less on using the theory and more on testing it, less on representing observations by parameters and more on critical tests of the models." (R1)

Comments by D. B. Larson on the implications of the solar neutrino experiments: "The mere fact that the hydrogen conversion process can be seriously threatened by a marginal experiment of this kind emphasizes the precarious status of a hypothesis that rests almost entirely on the current absence of any superior alternative. The hypothesis of energy generation by ordinary combustion processes held sway in its day on the strength of the same argument. Then gravitational contraction was recognized as more potent, and became the physicists' orthodoxy, defended furiously against attacks by the geologists and others. Now the hydrogen conversion process is the canonical view, resting on exactly the same grounds that crumbled in the two previous instances. In each case the contention was that there is no other tenable alternative. But in both of these earlier cases it turned out that there was such an alternative. Even without the contribution of the theory of the universe of motion, which shows that, in fact, there is a logical and rational alternative, it should be evident from past experience that the assertion that 'there is no other way' is wholly unwarranted. Without this crutch, the hydrogen conversion process is no more than a questionable hypothesis, a very provisional conclusion that must stand or fall on the basis of the way that its consequences agree with physical observations." (R2) Larson's theory receives scant attention from the scientific community---at least at the moment. (WRC)

X2. Solar neutrino observations. See the extensive treatment in ASF3, in the Catalog volume THE SUN AND SOLAR SYSTEM DEBRIS.

X3. Recent theoretical developments. H. Bethe has recalculated the number of electron neutrinos emitted by the sun, based upon new estimates of their interactions with solar material and their consequent conversion into muon neutrinos. It is possible that the low flux of electron neutrinos measured on earth (the experiments do not measure muon neutrinos) may be accounted for by this neutrino conversion within the sun. In this event, the solar neutrino problem would be solved. (R3)

References

R1. Bahcall, John N.; "Some Unsolved Problems in Astrophysics," Astronomical Journal, 76:283, 1971. (X1)

R2. Larson, Dewey B.; "Introduction," The Universe of Motion, Portland, 1984, p. 11, (X1)

R3. Maddox, John; "Hans Bethe on Solar Neutrinos," Nature, 320:677, 1986. (X3)

AOF9 Pulsar Anomalies

Description. Pulsar characteristics that do not square with or severely stretch the accepted explanation of pulsars as rotating neutron stars.

Data Evaluation. The only observational data are measurements of pulses of radiation from various directions in several portions of the electromagnetic spectrum. The basic parameters measured are pulse rate, pulse shape, polarization, and dispersion. The astrophysical techniques for such measurements are excellent. Rating: 1.

Anomaly Evaluation. Collectively, the several pulsar anomalies delineated below (X1-X6) are impressive enough to cast serious doubt on the pulsar/neutron star hypothesis. The pulsar glitches (X1), the unusual pulse shapes (X4), and the very fast pulsars (X6), in particular, stretch the hypothesis by requiring unappealing modifications. The seriousness of these anomalies is, of course, a matter of opinion. The basic integrity of astrophysics is not at stake, but the overturning of the pulsar/neutron star theory would be very embarassing, especially since it is popularly promulgated as fact rather than theory. Rating: **2.**

Possible Explanations. While the pulsar/neutron star hypothesis has been modified to try and explain anomalies, it is possible that the whole concept is in error. Unfortunately, no other theory is waiting in the wings.

Similar and Related Phenomena. High pulsar proper motions (AOB11). The observational status of the black hole is similar to that of the pulsar, neither has been observed directly.

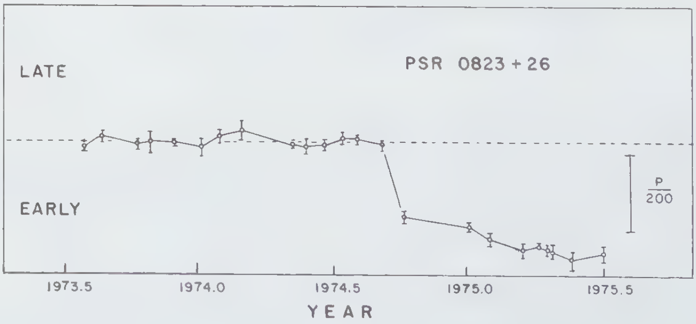
Examples

X0. Philosophical nature of the pulsar/neutron star situation. G. Greenstein writing in 1985 about the discovery of pulsars: "In some ways it was an unsatisfactory discovery. For after all, what direct evidence have we found for the existence of neutron stars? The entire story is based upon a rapid train of radio pulsations whose rate is gradually diminishing. It is a long way from this to the actual observation of a tiny ball of neutronic matter lost in the vastness of space. It has been a purely negative argument that we have recounted. People drew up a list of possible candidates and eliminated all but one. At its heart, the story of the discovery of neutron stars can be reduced to a single question: what else could pulsars be?" (R24) Black holes, too, are not observed directly and owe their (questionable) existence to secondary phenomena which are difficult-to-explain in any other way. (WRC)

X1. Glitches. Glitches are sudden changes in the period of a pulsar. In 1969, the Crab and Vela pulsars, the most-studied pulsars, suddenly increased their pulsing frequencies. After some cogitation, theorists decided that glitches were likely the consequence of "starquakes" during which the pulsars suddenly decreased in diameter and, like a skater pulling in her arms, increased their spin frequencies.

"Nature, however, seems to have reaffirmed its supremacy over the mortal deliberations of the theoretical scientist. Gordon E. Gullahorn and John M. Rankin of Cornell University reported at the meeting of the American Astronomical Society last week in Haverford, Pa., observations using the Arecibo radio telescope that show some anomalous pulsar behavior. They have seen several examples where a pulsar frequency suddenly decreases. This is totally contrary to the established quake model. The observation seems to suggest (if one maintains the starquake picture) that the star suffers a physical change that increases its effective diameter. Under the effect of a pure gravitational field, such a distortion is not energetically preferred.

The same two observers also report that the pulsar PSR 0823 + 26 not only has 'antiglitched,' as described, but also has undergone a sudden 'phase jump,' so that suddenly, one day, its pulses began to arrive earlier than expected (see diagram). The anomalies don't even stop there, however, because whatever caused this pulsar's sudden phase jump has left its frequency unchanged. By the admission of several experts in the field,



A pulsar antiglitch. (X1)

these observed peculiarities may portend the death of the standard starquake model." (R2)

The strange glitches have led to ever more complex models of neutron stars. "Abstract. We call attention to a number of hitherto unexamined regularities in the Vela pulsar timing data and show how these find a natural explanation in a theory of giant glitches in the Vela and other pulsars as the dynamic consequence of catastrophic unpinning events in the pinned crustal neutron superfluid, with postglitch behavior resulting from glitch-induced vortex creep." (R10)

Here is another theoretical approach to the explanation of the Vela pulsar glitches. "For the Vela pulsar, however, the glitches which have been observed so far are so large that they require a change in ellipticity of the order of 1 per cent in a single step. As the ellipticity of the pulsar must be very small to produce its observed rotation period of 0.089 seconds and glitches occur every 2 or 3 years, a different explanation is clearly required. This is provided by a two-component model of the neutron star rather than the single-rigid-body model envisaged above. The outer component is a solid crust while the interior is composed of a liquid which rotates independently, but is loosely coupled to the solid crust." Other kinds of Vela glitches require a third neutron-star component, presumably a second kind of liquid. (R18)

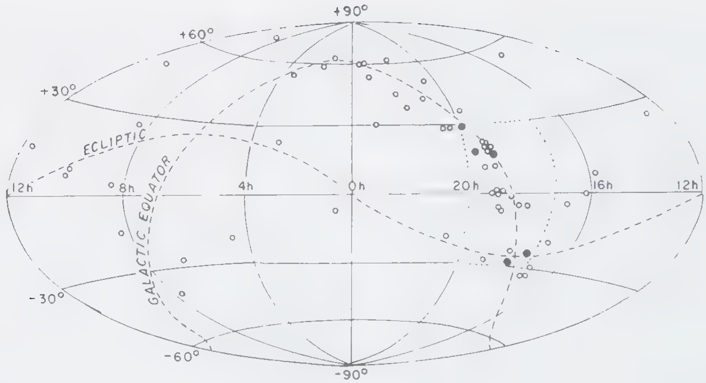
X2. Pulsars that slowly spin up. "According to theory, pulsars are spinning neutron stars. It is said they spin fast when they are formed and slow down as they age, so the spin rate is often used to estimate the age of a pulsar. But there's an unusual pulsar that spins extremely slowly, JP 1953 + 29. According to Victor N. Mansfield and John M. Rankin of Cornell University, writing in National Astronomy and Ionosphere Center publication 64, this pulsar is spinning down so slowly that when the effects of its motion across the sky on its apparent (to us) spin rate are considered, it may actually be spinning up from the point of view of someone riding along with it." (R3)

Pulsar PSR 1937 + 215 rotates 642 times per second, so fast that it must be considered a very young pulsar. If it were born recently, though, it should be associated with the remnants of a supernova---the supposed parent of the neutron star. No such remnant is observed. In addition, this pulsar's magnetic field is very weak. Both factors suggest that PSR 1937 + 215 is very old, contrary to the implications of its rapid spin rate. To preserve pulsar/neutron star theory, it has been presumed that this pulsar once had a companion star, and this star's matter was sucked into the neutron star, increasing its mass, and causing it to spin faster. No evidence of a companion star has been found. (R19)

X3. Possible concentration of pulsars with very low spin-down rates in one portion of the sky. "Pulsars are accurate timekeepers. They are believed to be rotating neutron stars, with strong magnetic fields, and the energy they radiate is at the expense of their rotational kinetic energy. As each pulsar ages, its period P (relative to the Solar System barycenter) slowly increases, and its period derivative $\dot{P}$ (= dP/dt) slowly decreases. Certain interesting pulsars have anomalously small period derivatives, and rather surprisingly, are found grouped together in the same region of the sky (shown in Fig. 1). I suggest here, as an explanation of the peculiar properties of these pulsars, that the barycentre of the Solar System is accelerated, possibly because the Sun is a member of a binary system and has a hitherto undetected companion star." (R4)

Harrison's discovery and interpretation in terms of an undiscovered solar companion evoked considerable interest, with much speculation about the possibility of a black hole or neutron star being a companion of our sun. (R6, R5) Because one would think such bizarre objects, being so close, would have been detected by now, other astronomers considered the unusual distribution of pulsars with small spin-down rates a case of observational bias. (R7)

When Harrison (R4) made his original discovery, he had only 85 pulsars to work with. In 1984, Stephen A. Cowling reanalyzed the situation with a much larger sample. "Cowling had accurate data on 294 of the 330 known pulsars. In addition, he realized that a slow spin-down rate is not in itself unusual: In general, old pulsars spin and slow down more slowly than younger ones. Thus, he searched for areas of the sky containing pulsars with both small period changes and fast rotation. The results of Cowling's analysis, reported in the September, 1983, issue of Monthly Notices of the Royal Astronomical Society, while not entirely contradicting Harrison's idea, did 'not reveal any significant statistical anomalies in the distribution of....pulsars.' However, one particular object, PSR 1952 + 29, has a



Nonuniform distribution of pulsars. Open circles: $10^{-14} > dP/dt > 10^{-16}$. Filled circles: $dP/dt < 10^{-16}$. (X3)

ratio of spin-down rate to period that is inexplicably small." Cowling thought that a solar companion might be invoked to explain this unusual pulsar. (R23, R25)

Harrison's basic discovery was a concentration of pulsars with very small spin-down rates in one portion of the sky. Cowling's study focussed on a combination of small spin-down rates and fast rotation. Since small spin-down rate is supposed to be a sign of pulsar old age, perhaps the real anomaly is a concentration of old pulsars in one portion of the sky. We cannot tell if this might be the case from Cowling's conclusions. (WRC)

X4. Anomalous pulsar pulse shape. From a study of the Crab pulsar by E. Nather and B. Warner: "According to the current theory, though, the shape of the pulse should be symmetric. 'But it doesn't even look close to it,' says Dr. Nather. Instead, the pulse has a 'weird, curious shape.' He says he can describe the shape of the pulse mathematically but he doesn't know 'what the mathematics means..... Some very fundamental physics is going on that we don't understand,' he says. 'We've learned about all we can observationally, but we're too dumb to understand what it means.'" (R8)

X5. Scarcity of pulsars in binary systems. "Most of the stars in the galaxy are binary or multiple systems, two or more stars bound together and revolving around a common center of gravity. Pulsars overwhelmingly do not live in binary systems. This is strange because pulsars are generally believed to be neutron stars, one of the possible kinds of remnant from the supernova explosion of an ordinary star.

A supernova explosion might be expected to break up some kinds of binary systems, but as the four astronomers who now announce the finding of the second reported binary pulsar point out, theoretical calculation shows, perhaps surprisingly in its turn, that binary systems with a wide variety of initial dynamic characteristics should survive supernova explosions. Yet up to now only one pulsar was known to be in a binary system, PSR 1913 + 16." The new binary pulsar is PSR 0820 + 02. (R9)

X6. Very fast pulsars. More precisely, pulsars of the same type as PSR 1937 + 215, which exhibit little slowing, no X-rays, and no associated supernova remnants, in addition to pulse rates on the order of a thousand per second.

PSR 1937 + 215, originally cataloged as 4C21.53, a radio source, pulses at 642 Hz. "The source is remarkable in many ways. The rotation rate is within a factor of about 3 of centrifugal break-up. The star's surface is moving at ~20 per cent of the speed of light and the rotational kinetic energy of the object is nearly 10^{52} ergs, comparable with the entire energy output of a supernova explosion. Furthermore, this superfast pulsar shows no evidence of the encircling supernova remnant expected to accompany the creation of such an object." (R12) Of course the preceeding implications are based upon the hypothetical model of the pulsar/neutron star. (WRC)

According to current pulsar theory, PSR 1937 + 215 appears young by virtue of its high pulse rate, but the missing supernova remnant, the lack of X-rays and magnetic field, and its negligible slowing make it appear old. This apparent contradiction is now resolved by presuming that this pulsar has been rejuvenated by consuming a companion star, as described in X2. For additional references, see R11-R17, R19-R22)

"Recent observations at the Arecibo Observatory have resulted in the discovery of PSR1855 + 09, a pulsar with period P = 5.362 ms, moving in a nearly circular orbit of period 12.3 days. The pulsar is only the third one known with P < 10 ms, and the sixth known radio pulsar in a binary system. ...Three of the seven binaries are among the fastest five of more than 400 pulsars---a fact that provides strong support for the conclusion that fast pulsars are 'recycled' neutron stars, spun up during a phase of mass accretion from an evolving companion star." (R27)

X7. Tev (10^{12} electron-volt) radiation from pulsars. "The discovery of Tev gamma ray pulses from binary X-ray pulsars was quite unanticipated, accoding to Lamb and Trevor C. Weekes of the Harvard-Smithsonian Center for Astrophysics' southwestern station at Amado, Ariz. 'Neither X-ray behavior, nor 100-million-electron-volt observations, nor theoretical models predicted this phenomenon.'....The Tev gamma rays from Hercules X-1 come episodically. There were seven such bursts during the 1984-1985 period of the observations under consideration, and the bursts covered about 8 percent of the observing time." The Tev gamma rays may originate in the atmosphere of HZ Herculis when protons strike neutrons. (R28)

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AOF10 Unidentified Infrared Objects in Our Galaxy

Description. Infrared objects unassociated with any recognized astronomical entity.

Data Evaluation. All observations have been made since 1967; many by the IRAS (Infrared Astronomy Satellite). The data are all of high quality. Rating: 1.

Anomaly Evaluation. Since the unidentified objects could well be any one of the well-known objects listed below, there may be little that is anomalous here. Rating: 3.

Possible Explanations. A cold, Jupiter-sized object within the solar system; a star surrounded by a dust shell; a very dusty galaxy emitting much more infrared radiation than visible.

Similar and Related Phenomena. None.

Examples

X1. Very cold stars? "Recent interest in quasars has somewhat obscured the extraordinary development that has been occurring in infrared astronomy in the past few years. The latest surprise, announced in the most recent number of Astrophysical Journal Letters (149, L1; 1967), is the discovery by D.E. Kleinmann and F.J. Low of a new source of infrared radiation in the Orion nebula. This has been detected at a wavelength of 22 microns and covers an area of sky 30 secs of arc in diameter. Using the observed flux and angular diameter, the brightness temperature of the source is only 70^{o}K (about the temperature at which nitrogen liquefies). But at all wavelengths, its probably emits at least one hundred thousand times as much radiation as the Sun. Looking at 5 microns in another 'window' where the Earth's atmosphere is sufficiently transparent to observe the sky, Kleinmann and Low failed to detect the source, thus confirming its low temperature. Nearby, however, is another source of infrared radiation known as Decklin's star after its discoverer. The latter, with a higher temperature (about 600^{o}K), emits powerfully at 5 microns but is not detected at 22 microns by Kleinmann and Low. The relation, if any between these sources is an exciting puzzle for theorists." (R1)

X2. Variable infrared sources. At 9h 45m 15s, $+13^{o}$ 30'.7, in Leo, is a 5-micron infrared source with a flux greater than any known object outside the solar system. "Since 1965, IRC + 10216 has been observed regularly at 2.2-micron wavelength with the 62-inch instrument. These measurements show a variation of at least two magnitudes on a time scale of roughly 600 days." With no appreciable proper motion, the object is thought to be 100 parsecs or farther. It might be a long-period variable star surrounded by a dust shell. (R3; R2).

X3. Blank field infrared sources. These are infrared sources detected by the Infrared Astronomy Satellite (IRAS) but not immediately associated with any visible objects. "Perhaps the most intriguing and fascinating of the IRAS findings are the unidentified point sources. Out of 8,709 sources found in the minisurvey, at least four have no known counterpart---no stars, nebulae, or galaxies. At a November 9, 1983, press conference J. Houck reported that these objects did not change their apparent positions over a period of many hours, so each must lie more than 30 a.u. away. However, there is no reason at present to assume that they lie outside our galaxy, or even outside our solar system. They could, in fact, be distant planets." Specifically, one of the objects could be the size of Jupiter, with a temperature of 40^{O}K, located at 570 a.u. They could also be dust-surrounded stars or galaxies emitting much more infrared than visible light. (R4; R5)

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AOF11 Optical Bursters and Flare Stars

Description. Objects that flash or brighten by several magnitudes for very brief periods. The so-called "flare stars" brighten for periods measured in minutes; while "optical bursters" flash for seconds or less. In contrast, novas brighten for days and months.

Data Evaluation. Astronomers have observed numerous flare stars, and their general characteristics are well known. They are, however, unpredictable so that planned studied are next to impossible. Optical bursters, on the other hand, have received little attention from professional astronomers. Amateur astronomers have provided most of the eye-witness accounts. Rating: 2.

Anomaly Evaluation. The energy source(s) and release mechanism(s) in flare stars and bursters are not known. Rating: 2.

Possible Explanations. The exchange of matter between binaries may trigger energy releases.

Similar and Related Phenomena. Novas and supernovas (AOF5); flicker stars (AOF12); solar flares; the other types of bursters (AOF25, AOF29, AOF30).

Examples

X1. General observations. "Flare stars are red dwarfs, with emission line spectra, which more than double their brightness in a few minutes. Little is known about the frequency of the eruptions, and most of them have been found by accident. Variable-star observers are making special studies of a group of red dwarfs to accumulate frequency statistics of flares. The best known of the flare stars is UV Ceti, the typical star of its class. It is normally of the thirteenth magnitude and has been observed to increase more than 6 magnitudes in less than 1 min. The decrease is almost as rapid. Many lesser flares have been observed visually, spectroscopically, photographically, and photoelectrically." (R3)

"Very little is known about the properties of the flare stars, aside from those that they share with the other cataclysmic variables. A.H. Joy describes them as 'extremely faint M-type dwarfs' in which the 'light curve rises to maximum in a few seconds or minutes of time and declines to normal in less than a half hour.' These light curves 'are similar in form to the light-curves of novae,' an observation that supports the theoretical identification of the flare stars as junior members of the group headed by the novae." It is remarked further that little progress has been made in understanding the genesis of these outbursts. (R2)

X2. S. Fornacis. Observations on March 6, 1899, suggest that this star may have brightened 2+ magnitudes for a few hours. (R1)

X3. Flashes near W Ari. Over a dozen bright flashes have been noted coincident, or nearly so, with this star's position. The flashes are similar to those of point meteors, but the frequent occurrence at the same spot in the sky makes one suspect that a star is flaring erratically. (R4)

"Abstract. Between 1984 July and 1985 July, 24 bright flashes were detected visually near the Aries-Perseus border by eight different observers at a total of 12 sites across Canada. One flash was photographed (R10), and another was seen, by two observers at different locations. Their duration was usually less than 1 s. The estimated positions of 20 of the events and another seen in 1983 were close enough in the sky to suggest a common celestial origin. The photographed event, which was the brightest seen visually, reached $m_V \sim -1$ and lasted about 0.25 s." (R8)

X4. Optical flashes from the source of the March 5, 1979 gamma-ray burster. "During a five-month period of optical monitoring of the 5 March source, three optical bursts were detected and clearly time-resolved. Their light curves generally resembled the time histories of gamma bursts, although no simultaneous γ-ray activity was noted at the times of the optical bursts (the instruments in orbit at the time were probably not sensitive enough to record it). Thus, the relation between the 5 March gamma bursts and the optical bursts remains tentative." (R5)

X5. Beta Camelopardalis. "The flash, which lasted exactly one-fifth of a second, was detected on a videotape made during television observations of meteors and aurorae from a NASA aircraft flying over northern Canada in 1969. The patrol tapes were recently pulled and examined in order to look for and pinpoint these unexplained optical bursts." The burst occupied a volume of space 64,000 kilometers in diameter, briefly outshone Beta (itself 6,000 times brighter than the Sun), and represented the conversion of 15 million tons of matter into energy. (R11)

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AOF12 Flicker Stars

Description. Stars that vary in brightness by several hundredths of a magnitude or more on a time scale of roughly one-half to several hours. These variations are usually erratic.

Data Evaluation. Only one photographic and one photometric search have been found so far. The older photographic search was, by necessity, rather cumbersome, but it still confirmed the existence of flicker stars. The more recent photometric study showed the variations much more clearly. Rating: 2.

Anomaly Evaluation. Some irregularities in stellar energy production and the transfer of energy to the surface of a star seem intuitively reasonable. Certainly, the physics of stellar interiors does not preclude such turbulence. Rating: 3.

Possible Explanations. Internal turbulence. The vicissitudes of the terrestrial atmosphere can also cause stellar variations in brightness, as can changes in the interstellar medium. The former can usually be factored out experimentally.

Similar and Related Phenomena. Flare stars (AOF11); solar oscillations (ASO10).

Examples

X1. Photographic search for flicker stars. In 1957, H.M. Johnson, using a 48-inch refractor, exposed several series of photographic plates, each plate roughly 16 minutes apart. He then employed a blink comparator to identify stars whose brightnesses varied from plate to plate. Many such stars were found. "The occurrence of high-latitude flicker stars suggests that these objects are not restricted to the spiral-arm population; and the flicker stars of the Ophiuchus-Scorpius field no close relation to the distribution of the dark clouds there. The point of this investigation has not been to furnish physical information about flicker stars, which is very difficult for such faint objects, but to offer some evidence of a statistical nature for their existence and abundance." (R1)

X2. Photometric search for flicker stars. "Do large numbers of stars show small oscillations in size like those recently reported for the Sun? This is one interpretation being discussed for the unpublished observations which reveal erratic brightness changes of a few percent in stars hitherto considered to be constant in light output. When fully available, these results are certain to send astronomers scurrying to their telescopes in search of further additions to this entirely new category of varible stars.

The observations have been made over the past four years by Norman Walker of the Royal Greenwich Observatory. He used a sensitive photometer built by the RGO's electronics department, capable of measuring light fluctuations of a few thousandths of a magnitude. The photometer was attached to the 30-cm telescope at Granada University Observatory in the Sierra Nevada mountains of southern Spain, chosen because its 8600ft (2600m) altitude provides particularly clear observing conditions.

Walker was looking for possible light variations in a rare, chemically peculiar family known as the Lambda Bootis stars. Instead, he found to his amazement that his comparison stars were varying in brightness by a few hundredths of a magnitude, and in one case up to six hundredths of a magnitude."

Walker then measured the brightnesses of stars close to each other every six minutes. Only those changes that were out-of-phase with adjacent stars were considered in order to rule out atmospheric effects. He found that the variations are not regular in amplitude or period, occurring erratically about every 40-60 minutes. The amplitudes of the changes are 10-100 times those expected for the sun. Walker attributed the changes to "large-scale turbulence". (R2)

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R2. "Flickering Stars Signal New Challenge to Astronomers," New Scientist, 70:526, 1976. (X2)

AOF13 Supermassive Stars

Description. Stars with masses hundreds, even thousands, of times that of our sun, as determined by measurements of their luminosities and spectra.

Data Evaluation. Several astronomical objects, notably R136a, have luminosities and spectra that one would expect for supermassive stars. Such data, however, are contradicted by other measurements which suggest instead dense clusters of giant, closely related stars. Obviously, better data are needed to resolve this conflict. Rating: 3.

Anomaly Evaluation. Originally, stars with masses greater than about 60 solar masses were thought to be impossible, but more recent assessments have raised this limit. Nevertheless, stars with masses thousands of times that of the sun stretch even these limits. If suspected supermassive stars ultimately are found to be dense clusters of supergiant stars, as some astronomers predict will happen, an anomaly will still exist because current astronomical theory cannot countenance so many huge stars in such tiny volumes (R136a's diameter may be only a few hundredths of a light year!). Rating: 2.

Possible Explanations. The theory of stellar interiors is incorrect and must be modified to include supermassive stars. Alternatively, the theory of star formation will have to accommodate very-close-knit clusters of supergiant stars.

Similar and Related Phenomena. Quasars (AQ); galactic core objects (AOF2).

Examples

X0. Status of supermassive stars circa 1977. "Supermassive stars. Stars with a mass exceeding about 60 times that of the Sun, never yet observed by astronomers. This upper limit is well understood. The more massive a star, the greater its internal temperature and ratio of radiation pressure to gas pressure. Above 60 $M_\odot$, radiation pressure makes the ratio of specific heats γ nearly 4:3, the value for pure radiation. With γ near 4:3, material is highly compressible and subject to vibrational instability. Pulsations of the star driven, for example, by more rapid burning of nuclear fuel at maximum contraction grow in amplitude and eventually blow the star apart. Other conditions, such as magnetic field pressures and excessive angular momentum, impede supermassive stars from condensing out of the interstellar medium. If supermassive stars ever do form, they do not live long enough for astronomers to observe them except by their consequences." (R4)

The theoretical position mentioned above, however, did not include the effects of General Relativity. When these are factored in, stars much larger than 60 solar masses are permitted. (R3)

X1. R136a. This intriguing object lies within the Tarantula nebula (30 Doradus) in the Large Magellan Cloud. At the center of the nebula is NGC 2070, a cluster of very hot blue stars, and at the center of this cluster is a patch of light, about magnitude 10 and 5 arcseconds across. This patch is designated R136, with its brightest portion labelled R136a. At present R136a is unresolved, but at least two objects seem to be present, one of which is suspected to be a supermassive star by some astronomers.

"R136a is only two or three light-years across, but it emits as much ultraviolet light as several dozen of the hottest type-O supergiants. A cluster of so many bright stars in such a small volume seems implausible to many researchers---especially since R136a has been reported to vary in both brightness and spectrum. Ultraviolet spectra obtained a few years ago by the International Ultraviolet Explorer (IUE) satellite revealed that R136a has a temperature of about 60,000^{o} K, an energy output of 50 to 100 million Suns (most of it in ultraviolet light), and a massive stellar wind flowing out at 3,500 kilometers per second. Some astronomers believe this one object is responsible for ionizing the entire Tarantula nebula. If it is a single star, its observed temperature and luminosity require it to have a diameter of nearly one astronomical unit. It must also have a surface gravity great enough to keep its outer layers from being ejected by radiation pressure. The required mass works out to be at least 2,000 Suns." (R3)

The R136a data are controversial and contradictory: Spectroscopic analysis. The 1982 data of D. Ebbets and P. Conti suggested a supermassive star with surface gravity of about 10 g. But A. F. J. Moffat and W. Seggewiss later found no certain evidence of a supermassive star. For example, they did not confirm the spectral variability mentioned in the above quotation, which was one of the major characteristics of a single star as opposed to a cluster. In fact, J. Melnick found that the spectrum of R136a closely resembled that of a cluster of similar stars. Optical Resolution. Using speckle interferometry. J. Meaburn et al found R136a to be a point source only 0.015 light year across---far too small for a cluster of giant stars with the composite properties of R136a. But G. Weigelt, also using speckle interferometry, discerned a cluster-like background with at least five components. Infrared observations. The infrared luminosity, rate of mass loss, and stellar diameter are consistent with the model of a supermassive star with a mass of 2,000 Suns. (R1-R3) Obviously, the true character of R136a has not yet been ascertained. (WRC)

"The best overall interpretation of R 136 is that it represents the dense stellar core of a populous cluster. If so, it would be the youngest such object in the LMC (Large Magellanic Cloud) which, unlike the Galaxy, has a well-known ensemble of populous clusters with a continuous range of ages." (R5)

X2. Other supermassive star candidates are located in: M33 (the Triangulum galaxy); NGC55, NGC3603, NGC5430, NGC6764, and elsewhere. (R3)

X3. Overview, 1986. "Flower and Hodge (1975) first reported the existence of 'superluminous giant stars' (SLGs) in or near the centers of young globular clusters in the Large Magellanic Cloud (LMC). SLGs have luminosities that put them 1-1.5 mag brighter than these clusters' giant branches and have a wide range of B - V running from B - V less than zero to greater than 1.5. Discussions of the SLGs in NGCs 1868, 2156, 2159, 2164, and 2172 can be found in Flower et al. (1980) and Flower and Hodge (1975), while those in NGC 1866 are discussed in Flower (1981). There are also three possible SLG stars in NGC 2058 (Flower 1976), about ten in NGC 1831 (Hodge 1963), and possibly one each in SL 791 (Baird et al. 1974) and SL 747 (first reported here). (R6)

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R4. Greenstein, Jesse L., and Thorne, Kip S.; "Supermassive Stars," McGraw-Hill Encyclopedia of Science and Technology, 13:317, 1977. (X0)

R5. Moffat, A. F. J., and Seggewiss, W.; "R136: Supermassive Star or Dense Core of a Star Cluster?" Astronomy and Astrophysics, 125:83, 1983. (X1)

R6. Baird, Scott R., and Flower, Phillip J.; "Radial-Velocity Determinations of Six LMC Superluminous Giant Candidates," Astronomical Journal, 91:1336, 1986. (X3)

AOF14 Discordant Binaries

Description. Pairs of stars in which the members have different physical properties that are impossible or at least awkward to explain using current stellar theory.

Background. Binary stars are usually assumed to have formed together during the same condensation of dust and gas. If one member of the pair is larger than the other, it should evolve faster. The two stars would thus move at different rates on the Hertzsprung-Russell diagram. The anomalous pairs described below do not fit the usual evolutionary picture.

Data Evaluation. Most of the binaries described below (the semidetached, Algol-type, and cataclysmic types) are quite common and well-observed. Binary pulsars, however, are rare. Rating: 1.

Anomaly Evaluation. The existence of discordant binaries contradicts the basic theory of stellar evolution. To rescue this important theory, astrophysicists postulate a transfer of matter from one member of the pair to the other. This transfer of mass can vary in amount and direction, and can therefore accomodate just about any physical disparity. One issue here is whether the mass transfer model is only an adjustable, theoretical panacea that saves astrophysicists from having to rework basic stellar theory or whether it is in accord with reality. Rating: 2.

Possible Explanations. The mass transfer model mentioned above is correct. If it is not, the basic theory of stellar evolution is flawed, as claimed by D. B. Larson (R7).

Similar and Related Phenomena. Pulsars (AOF9); novas and supernovas (AOF5); the ubiquity of binaries (AOB12); the various "bursters" (AOF11, AOF25, AOF29, AOF30).

Examples

X1. Semidetached binaries. "One of the most important discoveries in double-star astronomy in the 1950s was the realization that there exists a distinct group of eclipsing systems in which one component has indubitably attained its Roche limit, while its mate is distinctly smaller than this limit. This fact has earned them the epithet of semi-detached systems---consisting as they do of one star well detached from its Roche limit, while its mate (the contact component) is in contact with it. Such systems seem, moreover, to be quite common; from one-quarter to one-third of all known eclipsing systems appear to be of this type. Some of the representatives, such as Algol, U Cephei, and U Sagittae, are well known to astronomers.

The existence of the contact components in binary systems belonging to the old population I stars would thus, superficially, seem to be in agreement with the current theory of stellar evolution in the post-main-sequence stage. Unfortunately, this contact component happens to be the wrong star! The most striking feature of the semidetached binary systems is the fact that, in every single case known, it is the secondary (less massive) component which appears to be at the Roche limit, while its more massive component remains well within the limiting surface. The theory of stellar evolution which ascribes the principal evolutionary features of the post-main-sequence stars to the consequences of hydrogen exhaustion in the interior leads one to expect exactly the opposite; for as the more massive is bound to burn its hydrogen at a faster rate (commensurate with its greater brightness) than its less massive (and less luminous) companion, it is this star which should experience and exhibit the symptoms of hydrogen deficiency long before the companion will reach the same stage. The theory, therefore, would predict the existence of semidetached systems in which the primary (more massive) star should be in the contact component---while, in reality, this type appears to be conspicuous by its absence." Rather than question stellar theory, some sort of mass transfer from the smaller star to the larger is assumed to have occurred in the past. (R8) See also X2, Algol Paradox binaries, which expresses the same anomaly in different terms. (WRC)

X2. Algol Paradox binaries. "In many binary systems the separation between the stars is relatively small, and some interaction between them is a definite possibility (although it should be remembered that where one of the two stars is a white dwarf, there is a separation in time as well as in space, and the stars are not actually as close to each other as they appear to be). But the current tendency is to use the hypothesis of mass transfer from one member of a binary system to the other as a kind of catch-all, to explain away any aspect of binary star behavior that is not accounted for in any other way. The remarkable extent to which this hypothetical mass transfer process is currently being stretched is well illustrated by the purported resolution of what is called the 'Algol paradox.' As noted earlier in this chapter, the two principal components of Algol are a relatively large and hot main sequence star and a less massive, cooler subgiant.

> 'Here lies the paradox. The more massive B or A star should be the one to expand first yet the less massive star is the more evolved giant. Why? Is there a fundamental mistake in our idea of stellar evolution?' (W.K. Hartmann)"

As in X1, it is assumed here that long ago considerable mass was transferred from the now-smaller star to the now-larger star. This unobserved process saves the prevailing theory of stellar evolution. In the case of the cataclysmic binaries (X3), this handy transfer of mass occurs between the two components, but in the opposite direction. Thus are novas explained. (R7)

Algol Paradox binaries are occasionally wondered about in the literature; viz. "Abstract. The four visual double star systems A.D.S. 1262, 2559, 10993, and 11028 are discussed. It is shown that each of them is probably physically connected. A Hertzsprung-Russell diagram was drawn, and it was found that, in each case, the fainter component is further from the main sequence than is the brighter component. This fact appears to contradict present theories of stellar evolution." (R2; R1)

X3. Cataclysmic binaries. "Cataclysmic variables are binaries composed of a main-sequence star and white dwarf companion. The stars are so close that material from the surface layers of the distorted, pear-shaped, but otherwise apparently normal main-sequence star is being gravitationally captured by the white dwarf. Cataclysmic eruptions characterize these stars as novae and related exploding stars, generated both by unstable bursts in the mass transfer process and through runaway nuclear fusion reactions in the accreted hydrogen-rich material on the white dwarf surface.

One outstanding problem is the origin of these variables. Why is a white dwarf. which is formed in the deep interior of a red giant, now so close to a main-sequence star? In order to allow its precursor giant to form, the separation there must have been >200 solar radii ($R_\odot$), whereas now it is $\approx 2\ R_\odot$. Evidently either angular momentum has been lost, and lost relatively rapidly, or an extreme mass ratio originally allowed large separation with the present quota of angular momentum." (R6)

In addition to the angular momentum problems, one finds several other deficiencies with the theoretical models: "There are several sophisticated theories of the nova and dwarf-nova eruptions, but they meet with only partial success when confronted with observations. The physical properties of the accretion disk are unknown. The

Basic model for cataclysmic variables. (X3)

temperatures and densities of the disk cannot be reliably calculated. Even estimates of quantities as basic as the mass transfer rate can be classed more properly as educated guesses. Data on the coherent oscillations are sparse, difficult to obtain, and open to several interpretations. Finally, little or no progress has been made in solving the fundamental problem posed by the very existence of the cataclysmic variables. What is their evolutionary state? We can point with certainty neither to their ancestors nor to their descendents. This litany of unsolved problems constitutes a challenge to observers and theoreticians alike." (R4) Of course, advances have been made since this was written in 1976. Many features of the accretion model cannot be observed directly. (WRC)

X4. Pulsar binaries or close pairs of degenerate stars. "Two midget stars, orbiting around one another at a dizzying 450,000 m.p.h., have astronomers scrambling to their radio telescopes and computers in an attempt to answer some baffling questions. According to current theory, two stars as close together as this pair should not exist." One member of this pair is a pulsar. "Whatever the companion's nature, there is an unexplainable aspect to both of these strange cosmic twins. Black holes, pulsars, neutron stars and white dwarfs are all cadavers of dead stars of huge dimensions. How did these two stars get so close together if they each had come from stars larger than the sun? How did one survive the supernova explosion required to create the other?" The separation of the pair is only about one solar diameter. (R3; R5)

401820 - 30, an even closer binary. "Periodicities in astronomical X-ray sources are legion, but occasionally one is discovered that leads to the postulation of either a new class of astronomical object, or a familiar object in a remarkable configuration. The latter would seem to be the case with the discovery, announced last week, of a bright X-ray source showing a coherent periodicity of 685 seconds. The interpretation is that the source is a neutron star in an orbit of diameter less than a seventh the radius of the Sun about a low-mass white dwarf, making the system , if the interpretation is confirmed, by far the shortest period binary system known." (R10; R9)

References

R1. Hoffleit, Dorrit; "Mass-Luminosity Discordances," Sky and Telescope, 8:125, 1949. (X2)

R2. Batten, Alan H.; "Four Interesting Visual Binary Systems," Royal Astronomical Society of Canada, Journal, 60:177, 1966. (X2)

R3. "Scientists Baffled by Strange Double Star," Astronomy, 2:59, December 1974. (X4)

R4. Robinson, Edward L.; "The Structure of Cataclysmic Variables," Annual Review of Astronomy and Astrophysics, 14:119, 1976. (X3)

R5. "One Little, Two Little...Binary Pulsars," Science News, 121:233, 1982. (X4)

R6. Bath, Geoffrey; "Evolution of Star-Planet Systems," Nature, 216:307, 1984. (X3)

R7. Larson, Dewey B,; "Binary and Multiple Stars," The Universe of Motion, Portland, 1984, p. 90. (X2)

R8. Kopal, Zdenek; "Binary Stars," McGraw-Hill Encyclopedia of Science and Technology, 2:187, 1977. (X1)

R9. Thomasen, D.E.; "A Dizzying Orbit for a Binary Star," Science News, 130:231, 1986. (X4)

R10. King, A.R., and Watson, M.G.; "The Shortest Period Binary Star?" Nature, 323:105, 1986. (X4)

AOF15 Stars Emitting Excess Infrared Radiation

Description. Stars emitting infrared fluxes well in excess of the fluxes predicted from the star's photospheric temperature.

Data Evaluation. Stellar infrared measurements are from the IRAS (Infrared Astronomical Satellite) and high altitude aircraft. The various experiments concur on the existence of infrared excesses for some stars. Rating: 1.

Anomaly Evaluation. Excess infrared radiation would be expected from a star surrounded by a shell of fine particles. These particles would absorb some of the star's electromagnetic radiation and reemit the energy in the infrared. The IRAS experimenters suggested that the infrared excess of the star Vega might be due to particles larger than 1 millimeter in diameter, since smaller particles would be quickly removed by the Poynting-Robertson effect. Reasonable though this explanation sounds, an experiment at very long wavelengths (200 microns) contradicted this model. Instead, particles much smaller than 1 millimeter were indicated; but these are just the particles than are quickly removed by the Poynting-Robertson effect. Rating: 2.

Possible Explanations. See above. It is possible that a dust cloud of very small particles (less than 1 millimeter) could be continuously replenished by the dust emissions from a cloud of comets. (R2)

Similar and Related Phenomena. Unidentified infrared objects(AOF10).

Examples

X1. Vega. Results of the IRAS (Infrared Astronomy Satellite: "The IRAS data indicated that Vega's emissions at a wavelength of 25 microns were about 1.3 times brighter than they should have been for an ordinary star of Vega's type and temperature (about 10,000 kelvin) at 60 microns, they were about 10 times brighter, and at 100 microns, about 20 times. They appeared to be coming from a region extending about 80 astronomical units (some 7.4 billion miles) out from the star." (R1; R3, R4) These results are very striking when compared with the blackbody radiation curve. See R5.

A. Harper and colleagues from Yerkes Observatory have used NASA's Kuiper Airborne Observatory (a C-141 aircraft) to scan Vega at 200 microns. The infrared excess at this wavelength is only a factor of ten, instead of the 25-to-30-fold excess expected if Vega were surrounded by a cloud of sand-sized (1 millimeter) grains. (R2)

One possible interpretation of the Vega IRAS data. "The Vega shell is probably a ring of cometary bodies with an estimated minimum mass of 15 earth masses, analogous to one that has been hypothesized for the solar system. A possible hot inner shell around Vega may be an asteroid-like belt of material a few astronomical units from the star." (R6)

X2. Fomalhaut. IRAS data indicate that this star, too, displays a significant infrared excess. (R2, R5)

References

R1. Eberhart, J.; "Vega & Co.: What's Being Born Out There?" Science News, 124:116, 1983. (X1)

R2. Eberhart, J.; "Solid Material Found around Another Star," Science News, 124:406, 1983. (X1, X2)

R3. "A Solar System at Vega?" Science, 221:846, 1983. (X1)

R4. Couper, Heather; "IRAS Team Discover

Unexpected Radiation," New Scientist, 99: 455, 1983. (X1)
R5. Neugebauer, G., et al; "Early Results from the Infrared Astronomical Satellite," Science, 224:13, 1984. (X1, X2)
R6. Weissman, Paul R.; "The Vega Particulate Shell: Comets or Asteroids?" Science, 224:987, 1984. (X1)

AOF16 Spinning-Up Stars

Description. Stars that spin faster than younger and older stars, suggesting a spin-up stage in stellar evolution.

Background. Generally, stars are believed to slowly spin down as they age.

Data Evaluation. The anomalously high rates of spin are determined by light fluctuations (due to the passage of spots, it is assumed) and doppler shifting of spectral lines. Rating: 1.

Anomaly Evaluation. Not only does this observation confound the expectation of stellar spin-down with age, but it requires a mechanism for adding angular momentum to a whole class of stars. Rating: 2.

Possible Explanations. Angular momentum could be acquired by capturing mass from an invisible companion. At worst, the evolutionary family tree of stars could be incorrect.

Similar and Related Phenomena. Discordant binaries (AOF14), in which mass is thought to flow from one component to the other.

Examples

X1. General observations. Astronomers first noticed that the brightnesses of some, young, faint stars in the Pleiades star cluster varied by more than 10% in a single day. "Young stars tend to have large spots, and these variations in brightness are attributed to the passage of spots (which are darker than the rest of the surface) across our line of sight. But such fast fluctuations would mean the stars were rotating at period less than a day. Spectroscopic study by David Soderblom and John Stouffer of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., of the Doppler-shifted broadening of spectral lines that rotation causes confirmed the ultrafast rotation of 30 percent of the approximately 60 stars they observed in the Pleiades." The period of rotation were less than those of the youngest visible stars, the T Tauri stars, as well as those of older stars, such as the sun with its 25-day period. The fastest of the Pleiades stars, Hz 1883, had a spin period of only 6 hours and seems to be throwing off large amounts of matter. (R1)

References

R1. Thomsen, D.E.; "Stellar Evolution Spins a Surprise Stage," Science News, 125:388, 1984. (X1)

AOF17 Physical Barriers in the Evolutionary Path between Red Giants and White Dwarfs

Description. Observational and theoretical objections to the accepted evolutionary route on the Hertzsprung-Russell diagram from red giants to white dwarfs.

Data Evaluation. The observational evidence mentioned in X1 below consists of two generalizations of experience. One can be verified by refering to the Hertzsprung-Russell diagram, but the second has to be taken at face value. As for the claimed lack of theory describing the red giant-white dwarf transition, particularly the inability to account for mass loss, astronomical authorities can be cited (R1). Rating: 2.

Anomaly Evaluation. The red giant-white dwarf transition is critical in the theory of stellar evolution. To find so many serious objections is unsettling. Rating: 1.

Possible Explanations. None.

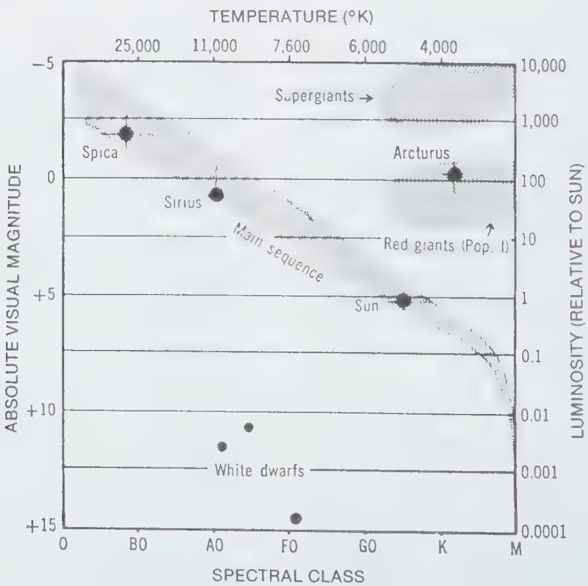
Similar and Related Phenomena. Binary stars with components at different locations on the Hertzsprung-Russell diagram, particularly the cataclysmic variables (AOF14).

Examples

X1. General observations. According to present astrophysical theory, red giant stars evolve into white dwarfs as they move left and then downward on the Hertzsprung-Russell diagram. During these changes, the stars are supposed to shed mass. Unfortunately, this requisite mass-shedding is contrary to the evidence entered on the Hertzsprung-Russell diagram, where stars to the left of the red giants have larger masses than the red giants. To move downward into the white dwarf region, stellar mass must indeed be shed but, "When the issue is squarely faced, it is apparent that there is no evidence of any significant loss of mass from any star system, other than the stars that explode as supernovae. There are, of course, many types of stars that eject mass, either intermittently or on a nearly continuous basis, but they do not give their ejecta anywhere near enough velocity to reach the gravitational limit and escape from the gravitational control of the star of origin. This ejected matter therefore eventually returns to the star from which it originated." (R1) Thus, the proposed path from red giants to white dwarfs is blocked by facts of observation as well as the absence of acceptable theory.

References

R1. Larson, Dewey B.; "The Dwarf Star Cycle," The Universe of Motion, Portland, 1984, p. 81. (X1)



The Hertzsprung-Russell diagram. (X1)

AOF18 Discrete Redshifts in Stellar Spectra

Description. The occurrence of discrete states of redshift in stellar spectra; i.e., certain values of redshift are favored.

Background. Usually in astronomy, redshifts are automatically interpreted in terms of velocities---linear or rotational---in accordance with the Doppler effect. Our vision of an expanding universe is based upon this assumption. In this view, favored values of redshift imply favored values for linear and rotational velocities. Obviously, the physical and philosophical implications are immense.

This phenomenon of redshift discreteness seems to prevail throughout the universe at various hierarchical levels. To avoid repetition in discussing the implications, there will be brief entries here and in the chapter on galaxies (AWF8), with a more complete treatment in the chapter on cosmology (ATF11).

Data Evaluation. High quality redshift data are available for stars in our galaxy from many sources. Rating: 1.

Anomaly Evaluation. The reality of discrete redshifts---in effect a form of macroquantization ---is radically at odds with contemporary astrophysics, which contemplates continuous, smoothly varying values of stellar velocity and rotation, not radical jumps. Rating: 1.

Possible Explanations. See ATF11 for a comprehensive treatment. Some possibilities are: redshifts in astronomy are generally not measures of velocity and/or some form of quantum mechanics is applicable in astronomy.

Similar and Related Phenomena. Galactic discrete redshifts (AWF8); cosmological considerations of discrete redshifts (ATF11).

Examples

X1. Survey of stellar redshifts. Abstract. "Evidence is examined for effects of multiple-redshift effects in stars within our own galaxy. Four possibilities are considered: interstellar material, pre-main-sequence objects, rotation in massive stars, and highly evolved or peculiar stars. All classes show evidence of the predicted redshift periodicity. Stellar rotation, in particular, is shown to occur preferentially in steps of 72.5 km s^{-1}. Implications of the correlations are briefly discussed." The strongest cases included B star rotation and Nova Herculis as well as redshift periodicities in the Coma cluster. (R1)

References

R1. Tifft, W.G.; "Discrete States of Redshift and Galaxy Dynamics. III. Abnormal Galaxies and Stars," Astrophysical Journal, 211:377, 1977. (X1)

AOF19 Gamma-Ray Sources Correlated with Solar Oscillations

Description. The correlation of the periods of celestial gamma-ray sources with the periods of solar oscillation.

Data Evaluation. Although the period match is very precise, only a single gamma-ray source/solar oscillation correlation has been found. Therefore, the evidence for a causal connection is very weak. Rating: 4.

Anomaly Evaluation. The oscillating gamma-ray source in X1 (below) is presumed to be a binary system in which one member is a gamma emitting condensed object. The eclipsing of the condensed object causes the gamma-ray variations and, in addition, gravitational radiation of the same period. It is this gravitational radiation impinging on the sun that is thought to be the source of the solar oscillations, not the gamma rays. Since calculations based on the only known example (X1) demonstrate that gravitational radiation is inadequate to cause the observed solar oscillations, we have here either a challenge to gravitational theory or some unrecognized causal connection---assuming of course that there is one. Rating: 2.

Possible Explanations. Simple coincidence is most likely, but gravitational theory could be incorrect, or there could be some other "force" involved!

Similar and Related Phenomena. Solar oscillations (ASO10).

Examples

X1. Geminga. Abstract. "The idea that solar oscillations might have been stimulated by gravitational radiation from a nearby binary system has recently been explored by Delache and co-workers. They have announced that the γ-ray source CG195 + 4, known as Geminga, varies in intensity with a period of 159.96 min, and therefore has a frequency just (1 yr)$^{-1}$ greater than the 160.01-min solar oscillation. From this coincidence they have inferred a gravitational connection between the two oscillations. We show here that if the generally accepted ideas of gravitational radiation are correct, the 160-min solar oscillation could not have been driven to its observed amplitude by any binary system of stellar mass. Only if there were a sustained resonance between the incident radiation and a solar mode of oscillation could there be any chance of an observable response." (R1)

References

R1. Fabian, A.C., and Gough, D.O.; "Geminga and the 160-min Solar Oscillation," Nature, 308:160, 1984. (X1)

AOF20 Rapid Variations of Celestial Radio Sources

Description. Intensity and polarization changes on the scale of an hour for celestial radio sources.

Data Evaluation. The data reported in the single reference at hand are rather limited, being restricted to OH emissions and two wavelengths. Rating: 3.

Anomaly Evaluation. The general assumption is that these varying OH emissions are from masers in which the gain (amplification factor) varies. If masers are the true source of these OH emissions, we do not know why the maser gain changes as it does. If the radiation does not come from masers, no other reasonable sources have been suggested. Rating: 3.

Possible Explanations. None.

Similar and Related Phenomena. Superluminal velocities in quasars (AQO3).

Examples

X1. VY Canis Majoris. "Using the National Radio Astronomy Observatory's 140-foot telescope, Drs. W.T. Sullivan and F.J.Kerr monitored the 18-cm emission from the ground state of the OH molecule. They concentrated on two sources which are well known as variables over a time scale of several months, VY Canis Majoris, a peculiar stellar object, and NGC 6334, and ionized hydrogen nebula.

To their amazement, Drs. Sullivan and Kerr observed dramatic changes in total intensity in only one hour. The absolute and relative intensities of different features in the 18-cm OH spectrum varied, and the polarisation of the radiation also altered. A second NRAO group has since confirmed the unusual temporal behavior of NGC 6334 by following fluctuations in the emission at 5.0 cm from the excited state of the OH molecule. .....It is certain that rapid alterations in the gain of some kind of celestial maser amplifier are responsible for the OH phenomenon." (R1)

References

R1. "A Celestial Maser Flashes Dramatically," New Scientist, 49:596, 1971. (X1)

AOF21 Gamma-Ray Objects

Description. Point or slightly extended sources of very strong fluxes of gamma rays with energies over 100 MeV (million electron volts). These objects are concentrated along the plane of the Galaxy. Very few can be correlated with known astronomical objects.

Data Evaluation. Satellite gamma-ray telescopes are the basic data source here; and the quality of their measurements is considered very good. Rating: 1.

Anomaly Evaluation. The great majority of gamma-ray objects cannot be associated with any known objects; therefore, we have little idea what they may be. For those few that can be correlated with pulsars, quasars, or molecular clouds, we do not understand the physical mechanism(s) by which the gamma rays are emitted, especially in relation to the meager fluxes in other parts of the electromagentic spectrum. Rating: 2.

Possible Explanations. In general, none.

Similar and Related Phenomena. Gamma-ray sources correlated with solar oscillations (AOF19); gamma-ray bursters (AOF30).

Examples

X1. Survey of gamma-ray objects. "The high-energy gamma-ray telescope aboard ESA's COS B satellite has been in operation for nearly six years and data used in compiling the second COS B catalogue span more than three years. The 25 sources of gamma rays with energies above 100 MeV which make up the catalogue may be either stellar or extended sources (with diameters up to 2^{o}). Although the COS B survey does not cover the entire sky, it does include the full galactic plane, along which most of the sources are clustered. There is also a concentration towards the inner part of the galaxy. In addition to the simple observation that these sources are galactic, their spatial distribution suggests that they lie within 2 to 7 kiloparseconds of the Solar System and, hence, are radiating on the order of 10^{36} erg s^{-1} in the form of high-energy gamma rays."

Four of the 25 sources can be tentatively identified with known objects: the Crab and Vela pulsars, the quasar 3C273, and an interstellar cloud complex near the star ρ Ophiuchus. The other 21 sources cannot be correlated with any known astronomical objects. "The intriguing possibility is that at least some of these presently unidentified sources may turn out to be a totally new class of galactic object." (R1)

X2. Geminga. This object is one of the brightest gamma-ray objects in the sky. It is located in the constellation Gemini. "Geminga is a veritable γ-ray machine. More than 99 percent of its power output is observed in the γ-ray spectral range and it has the rare distinction that associated optical, X-ray and γ-ray measurements are based on comparable numbers of photons. Discovered 10 years ago by the SAS-II satellite, Geminga has continued to resist positive identification with candidate counterparts at other wavelengths. Even now, after a series of deep surveys in a number of wavebands, it is impossible to discriminate categorically between a neutron star located at 100 pc (parseconds) and a

γ -ray quasar at $\sim$ 5,000 Mpc." (R6)

If Geminga is a quasar, the ratio of its gamma-ray luminosity to luminosity at other wavelengths would be "spectacular"---about 100 times that for 3C273, the other other quasar known to emit gamma rays. (R3) Most astrophysicists seem to think Geminga is a neutron star, possibly a pulsar. (R4, R5, R7)

X3. General observations. "It is apparent that the new observations of gamma-ray sources have enriched astronomy with unexpected and interesting objects, stimulated as much per se as they are for other branches of astronomy. It has been established that this new population is an astronomical reality closely tied to our Galaxy, providing a good fraction of the total gamma-ray emissivity. Moreover, these objects deserve the name of gamma-ray objects because they emit most of their electromagnetic energy in the gamma-ray band, as compared with other standard observational bands.

Identified and unidentified sources alike pose basic unsolved astronomical problems. The identified sources, including pulsars and molecular clouds, have a clear astronomical identity but still lack an agreed upon physical mechanism capable of sustaining the copious gamma-ray production observed. For the pulsars, the basic energy is available from the rotational energy loss, but the exact way in which this energy is channeled into gamma rays is still an open question. For molecular clouds, the problems relate mostly to the 'in situ' cosmic-ray acceleration mechanism: some of the proposals reviewed above appear appropriate for the identified case(s), but they cannot be considered as representative of the average population of sources." (R2)

References

R1. Thompson, David J.; "A Catalogue of Unidentified Objects," Nature, 291:109, 1981. (X1)

R2. Bignami, G. F., and Hermsen, W.; "Galactic Gamma-Ray Sources," Annual Review of Astronomy and Astrophysics, 21:67, 1983. (X3)

R3. Thomsen, D.E.; "Gamma Ray Quasar Could Be a Shock," Science News, 124:167, 1983. (X2)

R4. "Geminga: A Unique Object," Sky and Telescope, 66:213, 1983. (X2)

R5. Strong, A.W.; "The Geminga Enigma Unfolds," Nature, 303:476, 1983. (X2)

R6. Dean, A.J.; "Geminga---The Source That Is Not There," Nature, 308:113, 1984. (X2)

R7. Thomsen, D.E.; "Gamma Ray Source That 'Isn't There'," Science News, 125:37, 1984. (X2)

R8. Maddox, John; "Where Cosmic Rays Come From?" Nature, 310:447, 1984. (X2)

R9. Romani, Roger W., and Trimble, Virginia; "Does Geminga Exist Yet?" Nature, 318:230, 1985. (X2)

AOF22 Galactic Sources of Unidentified Radiation

Description. Sources within our galaxy that emit a form of electromagnetic or particulate radiation that creates showers of muons when it interacts with the terrestrial atmosphere or mantle.

Data Evaluation. The unidentified radiation is implied by showers of muons detected by subterranean experiments. These showers come from the directions of specific celestial objects and have the same periodicity as other radiations (X-ray, infrared, etc.) emanating from these objects. At this writing, only one such celestial source is known: Cygnus X-3. Despite this limitation, the basic data have been widely verified. Rating: 1.

Anomaly Evaluation. The only presently recognized forms of radiation that could cross thousands of light years of interstellar space at the speed of light without being deflected by magnetic fields must be electrically neutral; viz., neutrons, photons, etc. For various reasons, none of these is a candidate for the creation of the muon showers observed on earth. We are left then with the possible existence of an unrecognized kind of radiation, electromagnetic or particulate. Rating: 1.

Possible Explanations. Some astrophysicists have hypothesized that Cygnus X-3 is a binary star, one member of which is a "quark star". (Quarks are the hypothetical, elementary building blocks of matter.) This quark star emits "quark nuggets" or clusters of quarks which are first accelerated, then neutralized electrically, and radiated into space. Those that reach the earth create the observed muon showers. Another hypothetical particle, the "photino", has also been advanced as the explanation for the muon showers.

Similar and Related Phenomena. X-ray and gamma-ray bursters (AOF29, AOF30); gamma-ray sources correlated with solar oscillations (AOF19).

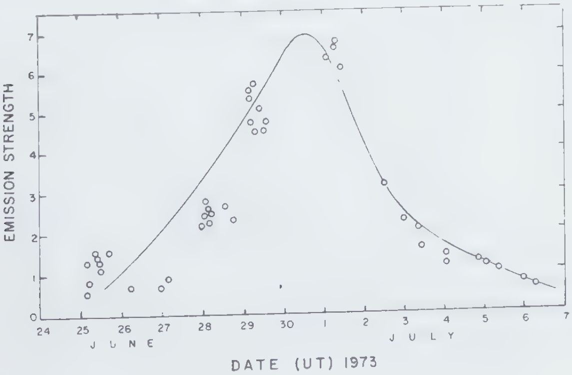
Examples

X1. Cygnus X-3. First, an overview of the problems posed by this remarkable object.

In a 'garage' off the road tunnel running deep under Mont Blanc sits a huge particle detector called Nusex. A second, complimentary experiment resides 600 meters below the surface in a Minnesota mine. Both experiments are tuned to measure charged particles of very high energy, especially muons, which penetrate their thick rocky ceilings with ease. These two arrays of buried detectors have both picked up fluxes of muons coming from the direction of Cygnus X-3. Now Cygnus X-3 is already classed as a remarkable object because it spews out pulses of X-rays and gamma rays, as well as great bursts of radio energy. It turns out that the muon fluxes arrive in phase with the pulses of gamma rays and X-rays, and are thus directly linked to Cygnus X-3. The problem here is that muons are electrically charged particles that would assuredly be thrown far off course by interstellar magnetic fields if they originated at Cygnus X-3. The muons, therefore, must be created by electrically neutral particles arriving at the earth's atmosphere from Cygnus X-3. Neutrons can be ruled out because they would decay in transit. X-rays and neutrinos can also be ruled out. The only alternative left seems to be some unknown neutral particle generated at Cygnus X-3. (R4-R7)

Related facts about Cygnus X-3. Seen from the earth, Cygnus is not particularly bright. This is because it is some 37,000 light years away on a far edge of the galaxy, and it is obscured by interstellar gas and dust. Intrinsically, Cygnus X-3 of one of the top two or three most luminous objects in our galaxy. In 1972, Cygnus X-3 produced a radio burst a thousand times its normal flux level, making it temporarily one of the most powerful radio sources in the galaxy. Smaller outbursts of radio energy recur every 367 days. In the X-ray region of the spectrum, it is the most powerful source in the galaxy, producing 10,000 times as much X-ray energy as the sun generates across the entire electromagnetic spectrum. The X-ray flux has periodicity of 4.79 hours. The gamma rays emitted by Cygnus X-3 have the same period and have energies of about 10^{12} ev, about the highest detected in our galaxy. (R1-R7)

"What makes Cygnus X-3 a particle physics problem, however, is not the astrophysics but the underground data. The first indications came in 1983, when showers of muons from the general direction of Cygnus X-3 began to show up in the prototype proton decay detector operated in the Soudan mine by physicists from the University of Minnesota and the Argonne National Laboratory. The effect was small: when the Minnesota/Argonne group published its results in the spring



Plot of a radio burst from Cygnus X-3. (X1) of 1985, they only had 60 anomalous events from a 3-degree cone around Cygnus X-3 out of a total background of 1200 events. But those 60 events came with a period of precisely 4.79 hours, and stayed precisely in phase with the radio, x-ray, and infrared emissions.'...What made these particular muon showers so striking, aside from their association with an object 37,000 light years away, was that they seemed to have no explanation in terms of known physics. Since muons are unstable and long-lived, they are presumably produced by some kind of primary particle from Cygnus X-3 interacting with the earth's atmosphere or with the rock around the detectors. The fact that the periodicity is detectable over a distance of 37,000 light years, however, means that all the primary particles have to be moving at virtually the same speed, the speed of light; otherwise some would lag behind the others and the signal would be washed out. The fact that the primaries still show some directionality means that they must be electrically neutral; otherwise the galactic magnetic field would have deflected and randomized them." As mentioned earlier, the only candidate particles---neutrons, neutrinos, and photons ---can all be ruled out. (R6)

1986 status of Cygnus X-3 problem. "The notion that a periodic X-ray source may also be giving off streams of massive particles which are unknown from accelerator experiments is still, against the odds, alive." (R15) Negative evidence, however, has accumulated. The unknown particles from Cygnus X-3, called "cygnets" have not been detected by the Frejus detector under the Alps, the IMB detector in a salt mine under Lake Erie, and apparatus located in Utah's Mayflower mine. Some scientists believe that cygnets, if they exist, should also have been seen at some of these other sites. (R17)

X2. Other sources suspected of emitting cygnets. Four binary X-ray sources: Hercules X-1, Scorpio X-1, 4U0115 + 63, and 1E2259 + 586. (R17)

References

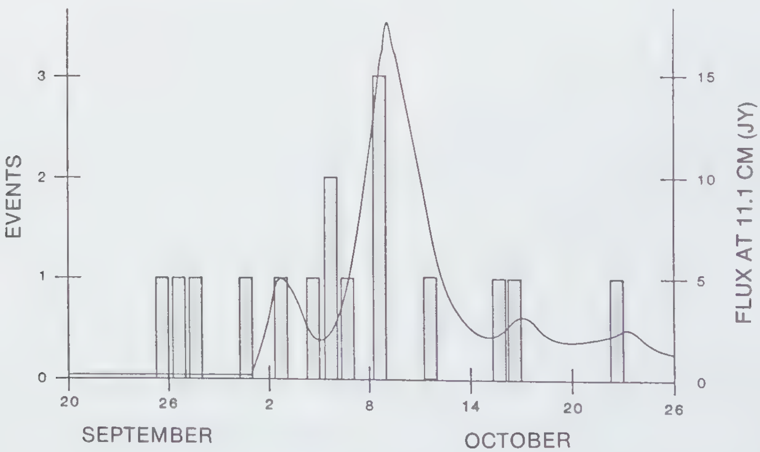
R1. "Another Giant Burst from an X-ray Star," New Scientist, 62:111, 1974. (X1)

R2. Henbest, Nigel; "Cygnus X-3: Mystery Gamma-Ray Powerhouse," New Scientist, 100:888, 1983. (X1)

R3. Eichler, David, and Vestrand, W. Thomas; "Implications of 10^{16} eV γ Rays from Cyg X-3," Nature, 307:613, 1984. (X1)

R4. Barnhill, M.V., III, et al; "Constraints on Cosmic-Ray Observation of Cygnus X-3," Nature, 317:409, 1985. (X1)

R5. Thomsen, D.E.; "Photinos, Quark Nuggets?" Science News, 128:231, 1985. (X1)



Anomalous muon events (bars) and radio flux from Cygnus X-3. Only those events falling within a particular 6-minute interval are shown. Muon data from the Soudan experiment. (X1)

R6. Waldrop, M. Mitchell; "Is Cygnus X-3 a Quark Star?" Science, 231:336, 1986. (X1)
R7. Sutton, Christine; "Subatomic Particles from Space," New Scientist, p. 18, May 23, 1985. (X1)
R8. "Bursts of Cosmic Rays," Astronomy, 11:60, September 1983. (X1)
R9. Hecht, Jeff, and Torrey, Lee; "Scientists Find Sources of Cosmic Rays," New Scientist, 99:764, 1983. (X1)
R10. Thomsen, D.E.; "Cosmic Rays That May Go Straight," Science News, 123:405, 1983. (X1)
R11. Sutton, Christine; "Subatomic Particles from Space," New Scientist, p. 18, May 23, 1985. (X1)
R12. Waldrop, M. Mitchell; "Something Strange from Cygnus X-3," Science, 228:1298, 1985. (X1)
R13. Watson, Alan; "Is Cygnus X-3 a Source of Gamma Rays or of New Particles?" Nature, 315:454, 1985. (X1)
R14. Baym, Gordon, et al; "Is Cygnus X-3 Strange?" Physics Letters, 160B:181, 1985. (X1)
R15. Maddox, John; "What Happens on Cygnus X-3?" Nature, 322:591, 1986. (X1)
R16. Baars, J.W.M., et al; "Outbursts of Cygnus X-3 Observed at 1.3 and 3.3 mm Wavelengths," Nature, 324:39, 1986. (X1)
R17. Thomsen, Dietrick E.; "A Disbelief in 'Cygnets'," Science News, 130:89, 1986. (X1, X2)

AOF23 White Dwarf Anomalies

Description. White dwarf characteristics that are not readily explained by the present-day theory of stellar evolution; specifically, the dearth of cool, red white dwarfs, mass changes in white dwarf evolution, helium-rich and hydrogen-deficient white dwarfs, and white dwarfs with high metallicities.

Data Evaluation. All of the observations summarized below are well-established in the astronomical literature, although we refer only to reviews and surveys. Rating: 1.

Anomaly Evaluation. The cumulative weight of anomalies X1-X5, below, cast serious doubt upon some facets of the theory of white dwarf origin and evolution. Rating: 2.

Possible Explanations. None.

Similar and Related Phenomena. White-dwarf rotation (AOB6-X2); red giant-white dwarf evolution (AOF17).

Examples

X1. Dearth of cool, red white dwarfs. "An anomaly has been found in the number and relative frequency of cool, red white dwarfs. It had been expected that these would be very common but, in fact, objects more than 10,000 times fainter than the sun are rare." (R1)

X2. Mass changes during white dwarf evolution. "...the theorists are experiencing major difficulties in accounting for the reduction in mass that is necessary if the red giant is to evolve into a white dwarf. They have no explanation at all for an increase in mass during the evolution of the star. The existence of main sequence stars smaller than the white dwarf minimum thus puts them into a difficult position." (R2)

X3. White dwarfs with hydrogen-deficient spectra. The spectra of white dwarfs are highly variable, with up to nine classes recognized. The basic distinction is between hydrogen-rich and helium rich stars. "The existence of white dwarfs with non-DA (hydrogen deficient) spectra has not yet been satisfactorily explained." (R2)

X4. Helium-rich white dwarfs. "The existence of nearly pure helium atmosphere degenerates over a wide range of temperatures has long been a puzzle." Furthermore, the cooler, helium-rich dwarfs are the most common variety. (R2)

X5. White dwarfs with high-metal-content atmospheres. To make matters worse, these stars also have too high a concentration of the heavier elements in their atmospheres to be in accord with current theory. "The metals in the accreted material should diffuse downward, while hydrogen should remain in the convective layer. Thus the predicted metals-to-hydrogen ratios would be at or below solar (interstellar) values, yet real DF-DG-DK stars have calcium-to-hydrogen abundance ratios ranging from about solar to well above solar." (R2)

References

R1. Greenstein, Jesse L.; "White Dwarf Star," McGraw-Hill Encyclopedia of Science and Technology, 14:558, 1977. (X1)

R2. Larson, Dewey B.; "Ordinary White Dwarfs," The Universe of Motion, Portland, 1984, p. 170+, (X2, X4)

R3. Van Horn, Hugh M.; "The Physics of White Dwarfs," Physics Today, 32:23, January 1979. (X3)

AOF24 Globular-Cluster "Age" Anomalies

Description. Various lines of evidence that contradict the notion that globular clusters were created soon after the Big Bang, and that all globular clusters (and the stars they contain) have about the same age.

Background. In discussing stellar age, astronomers habitually use the word "metal" to mean all elements heavier than helium. Stars with high "metallicities" are taken to be very young, because the heavy elements they contain could only have been built up over billions of years of nucleosynthesis in older stars. Recently formed stars are created from the "ashes" of very old stars.

Data Evaluation. Although we reference only one survey article, the basic facts employed below have been well-established over many years. Rating: 1.

Anomaly Evaluation. Three of the hypotheses being challenged here are: (1) The place (age) of the globular clusters in the evolutionary history of the universe; (2) The validity of "metallicity" as an indicator of stellar age; and (3) The hypothesis that the fusion of light elements is the basic energy source of stars. Rating: 1.

Possible Explanations. The variations among the globular clusters are sometimes explained as being due to their creation in parts of the galaxy where the compositions of the dust and gas were different---hardly an explanation! The non-zero metallicity of globular clusters has been ascribed to the existence of Population-III stars, which preceded the formation of the globular clusters and accomplished some nucleosynthesis. At the extreme, one can claim, as does D. B. Larson, that the astrophysicists picked the wrong stellar energy source, and that globular clusters are actually very young!

Similar and Related Phenomena. Lack of evidence of Population-III stars (AOB14); the existence of Population-I stars in the galactic halo (AOB16).

Examples

X1. Existence of heavy elements ("metals") in globular clusters. "Even more of a mystery is how globular clusters acquired any heavy elements at all, given that the big bang is thought to have produced only hydrogen and helium. The observed metal abundances, while quite low compared with those of Population I stars, are not insignificant." (R1)

X2. Globular cluster metallicities vary. "...analyses have shown that metal concentrations in globular-cluster stars range from about one two-hundredth of the levels observed in the sun (a typical Population I star) to only slightly less than solar values." (R1) It is not clear whether this range of metallicity represents a range of age or not, or whether a globular cluster star with the same metal content as our sun would overturn the dictum that globular clusters are exclusively old, Population-II stars. (WRC)

X3. Globular cluster Hertzsprung-Russell diagrams vary. "...there is evidence that globular clusters differ from one another in respects other than their heavy-element content: clusters with the same metal abundances often have noticeably different Hertzsprung-Russell diagrams. For example, the 'horizontal branch,' which follows the red-giant stage on the evolutionary sequence, may contain blue stars or red stars or both." (R1) Can these all be of the same age? (WRC)

X4. Young globular clusters in the Clouds of Magellan? The nearby Clouds of Magellan, which one would think would have had histories similar to that of our galaxy, contain young, star-rich aggregations that closely resemble the old, Population-II globular clusters in our galaxy. (R1)

X5. Conflict between globular cluster age and Hubble constant age of universe. Most astronomers believe that all globular clusters originated about 16 billion years ago. But some estimates of the Hubble constant yield ages for the universe of only 12-13 billion years. (R1)

References

R1. King, Ivan R.; "Globular Clusters," Scientific American, 252:79, June 1985. (X1-X5)

AOF25 Infrared Bursters

Description. Pulses of very intense infrared radiation emanating from small galactic sources.

Data Evaluation. Only one such source has been reported in the literature reviewed so far. Fortunately, several groups of astronomers have confirmed its existence. Rating: 2.

Anomaly Evaluation. The anomaly here lies in the extremely high brightness of the source and its pulsating nature. It is very difficult to find astrophysical mechanisms that can produce intense infrared bursts. Some nonthermal process is required because the pulses are so intense and come from such a small region that thermal processes are inadequate. Rating: 2.

Possible Explanations. Bursts of infrared radiation from black holes have been suggested without elaboration. Another theory: the radiation comes from electrons spiralling above the magnetic poles of a neutron star!

Similar and Related Phenomena. X-ray and gamma-ray bursters (AOF29, AOF30).

Examples

X1. MXB 1730-335. "Infrared astronomers have discovered a brand new phenomenon: intense bursts of infrared radiation from a globular cluster (a globe-shaped ball containing thousands of stars held together by gravity) about 30 000 light years away. Now that the bursts have been seen by two independent groups at different observatories, experts are confident that the bursts really exist. The cluster, named Liller 1, contains the source MXB 1730-355, the characteristics of which as an X-ray source have led to its nickname---the Rapid Burster..... The (infrared) bursts are extremely bright---10^{11} times brighter than expected from the known spectrum of the X-ray bursts. Their peak luminosity is a prodigious 2×10^{30} watts in the 2.2 micrometre photometric band, equivalent to the total energy output of 5000 suns." It is not yet known if the infrared and X-ray bursts come from the same source. (R1)

Null observations. "We report partially simultaneous observations of the 'rapid burster' (MXB 1730 - 335) at X-ray, infrared, and radio wavelengths, covering several hundred hours during 1979 and 1980. None of the authors of this report saw any infrared or radio bursts. On several occasions we observed an absence of infrared bursting during X-ray bursting.... The status of the reported infrared bursts also remains ambiguous." (R3)

References

R1. "Globular Cluster Hides a Massive Heat Source," New Scientist, 85:734, 1980. (X1)
R2. Jones, A.W., et al; "IR Flashes from the X-ray Rapid Burster," Nature, 283: 550, 1980. (X1)
R3. Lawrence, A., et al; "X-ray, Radio, and Infrared Observations of the 'Rapid Burster' (MXB 1730 - 335) during 1979 and 1980," Astrophysical Journal, 267: 301, 1983. (X1)

AOF26 Stellar "Age" Anomalies

Description. The presence of stars with high metallicity (i.e., "young" stars) in locations where astrophysical theory predicts old stars.

Background. Astronomers now hypothesize that the Big Bang generated mainly hydrogen and helium. The heavier elements (the "metals") were built up in the universe over billions of years by stellar nucleosynthesis (thermonuclear reactions). As stars died they bequeathed the metals they had synthesized to later generations. In this view, the more metals a star possesses, the younger it is.

Data Evaluation. Although only survey-type publications are referenced below, the basic facts are reputed to be highly reliable. Rating: 2.

Anomaly Evaluation. The increasing metallicities of stars and the stars in globular clusters at the centers of galaxies are approached is in direct conflict with the dicta that central stars in galaxies are old and globular clusters are the oldest aggregations in the cosmos. Rating: 1.

Possible Explanations. Nucleosynthesis is not the primary energy source in stars---but this statement is hardly an "explanation".

Similar and Related Phenomena. Globular cluster age anomalies (AOF24).

Examples

X1. Stars in the centers of galaxies. "There also seems to exist abundant evidence that the stars, at least in our Galaxy and in M 31, have an increasingly great metal abundance as the center of the galaxy is approached. The nuclear region appears to be particularly metal rich, and this seems to indicate that the evolution of chemical elements is somehow speeded up in these regions." (R1)

X2. Globular clusters in our galaxy. Globular clusters are supposed to be the oldest objects in our galaxy, but many have substantial metal content, especially as the center of the galaxy is approached. "Many astronomers are beginning to recognize that this radial dependence of the cluster ages, as indicated by the metal abundances, is inconsistent with present-day astronomical theory. Bok, for example, recognizes that something is wrong here. He states the case in this manner: 'The spread of ages for the globular clusters conflicts with current models of how the galaxy evolved.'" (R2)

References

R1. Harwit, Martin; Astrophysical Concepts, New York, 1973, p. 43. (X1)
R2. Larson, Dewey B.; "Evolution---Globular Cluster Stars," The Universe of Motion, Portland, 1984, p. 117. (X2)

AOF27 Higher Masses of Smaller White Dwarfs

Description. The increase of white dwarf mass with decreasing radius.

Data Evaluation. A general statement in a well-regarded astronomy book. Rating: 2.

Anomaly Evaluation. To say the least, this general observation is curious. One would expect the obvious, even for stars supposedly constituted of degenerate matter. Not enough is known about this phenomenon to determine how serious the anomaly is. Rating: 2.

Possible Explanations. None known, although the theory of degenerate matter may provide some insight.

Similar and Related Phenomena. None.

Examples

X1. General observation. "...the more massive a white dwarf, the smaller the radius." (R1)

References

R1. Shklovskii, I.S.; Stars, San Francisco, 1978, p. 165. (X1)

AOF28 Historical Disappearance of Stars

Description. The fading and ultimate disappearance of prominent stars over periods of hundreds, possibly thousands, of years.

Data Evaluation. One significant case that seems well-entrenched in myth and historical accounts. Rating: 2.

Anomaly Evaluation. Novas flare up, fade, and may disappear in time, but on a time scale of days or, at most, a few years. The fading away of a main-sequence star in the course of a few centuries, without passing through the requisite red giant and white dwarf stages, implies a short-circuiting of the Hertzsprung-Russell diagram. If verified widely, this phenomenon would challenge the accepted theory of stellar evolution in both time scale and route of stellar evolution. Rating: 1.

Possible Explanations. Stellar fading and disappearance may be the result of immersion in dust/gas clouds.

Similar and Related Phenomena. Color changes of stars within historical times (AOF1).

Examples

X1. Pleione, the seventh Pleiade. "Corroboration of a world-wide legend, rooted in ancient mythology, that once the six resplendent star 'sisters' of the Pleiades numbered seven, has been offered by Dr. William A. Calder, of Harvard Observatory. The star 'Pleione', identified by astronomers as 'Number Seven' of this group, has been suspected in the past as the mysteriously disappeared sister, and careful comparative measurements of stellar magnitudes in this region by Dr. Calder tend to confirm this suggestion.

Pleione was observed to diminish in light about a sixth of a magnitude in a slow continuing decline during the winters of 1935-36-37. Before this investigation, slight changes in the brightness of certain numbers of the group had been suspected. In this study, Harvard cameras utilized a potassium-hydride photoelectric cell, permitting very exact detection of slow or minute variations in the star light. In all, the relative brightnesses of twenty-five of the most conspicuous stars in the Pleiades region were observed during the three winters of the survey. The report includes a reminder, which is not elaborate, that the spectrum of Pleione formerly had emission lines and resembled that of P Cygni, a star that was at one time a nova. In recent years the bright lines of Pleione have disappeared.

'That some change has taken place in the Pleiades is borne out by tradition,' Dr. Calder pointed out. 'Almost all nations of the earth have legends about the seven-who-are-now-six. The surprising universality of this impression is difficult to explain unless a now diminished seventh Pleiad formerly was conspicuous.' Six Pleiades are normally visible to the unaided eye, but under exceptional conditions double this number have been noted. Telescopes show a population of several hundred stars which, for the most part, are members of a physically related aggregation, as is shown by a general unanimity of motion." (R2)

References

R1. Lynn, W.T.; "The Lost Pleiad," Observatory, 23:377, 1900. (X1)
R2. "The Seventh Star of the Pleiades," Science, 86:sup 6, July 23, 1938. (X1)

AOF29 X-Ray Bursters

Description. Irregular and transient X-ray objects. The so-called 'X-ray bursters' are the best defined objects in this class. These emit bursts of X-rays with durations from a few seconds to a few minutes. Such bursts recur at intervals of hours to tens of hours. However, very rapid and highly irregular bursters are known. Transient X-ray objects may be active for months before fading out.

Data Evaluation. X-ray instrumentation on several satellites has observed the 30-or-so X-ray bursters known, as well as the transient and irregular X-ray sources. There is no doubt that many erratic X-ray sources exist, but it seems unlikely that they all have the same origin---they are just too different. More data are needed here. Rating: 2.

Anomaly Evaluation. X-ray bursters are explained as thermonuclear flashes caused when a neutron star draws in matter from a companion star. Variations on this theme can account for a wide variety of bursts and transients. In this sense, extant theory accounts quite well for observations, and the deviations listed in X7 do not require a high anomaly rating. But, as discussed in AOF9, one must beware of unobservable, theoretical species, such as the neutron star. Rating: 3.

Possible Explanations. Accreting neutron stars. See X7 below.

Similar and Related Phenomena. Pulsars (AOF9); optical bursters (AOF11); infrared bursters (AOF25); gamma-ray bursters (AOF30).

Examples

X1. 1977 overview. "A year of study by astronomers has moved them little nearer to an understanding of the so-called X-ray burst sources that first captured their attention in 1976. Eighteen bursters are now known that have recurred, with another seven from which only one burst has so far been detected. A plot of their distribution by a joint MIT-Goddard Space Flight Center team in Nature (vol. 267, p. 28) shows the bursters clustering towards the centre of our Galaxy. This distribution is different from that of most other galactic sources catalogued by the Uhuru and Ariel V X-ray satellites, which lie all around the galactic plane. (R12)

In the definition of MIT's Walter Lewin, who first drew attention to them, X-ray bursters have a rise time of under a few seconds, a duration of seconds to minutes, and recur usually at intervals of hours to tens of hours. A spectacular exception has been the rapid burster, reported in Monitor for 25 March, 1976, whose repetitive bursts were described as like gunfire. Most Bursters have been discovered with the SAS-3 and OSO-8 satellites, although the Dutch ANS and British Ariel-V have also been active in the hunt." Some X-ray bursters are associated with known "steady" X-ray sources. (R3) By 1984, at least 30 X-ray bursters had been found. (R7) See X2 for the rapid burster mentioned above.

X2. MXB 1730-335, the so-called "rapid burster" in Sagittarius. "The 'rapid burster' (MXB 1730-335), discovered by Lewin et al, is becoming an object of some controversy. Activity occurs typically for a few weeks out of every six months. When active, the 'rapid burster' can emit thousands of X-ray bursts a day. The bursts are of two types, which are clearly distinguishable by their spectral evolution during decay. Type I bursts are normally separated by several hours, and their spectra exhibit cooling of the neutron star as the bursts decay. The separation between type II bursts range from a few seconds up to tens of minutes, and no significant cooling of the neutron star is observed during the decay. The rapid (type II) bursts can arrive in various, distinct patterns; they all show approximately linear relationship between integrated burst flux and the waiting time to the next burst. When type II bursts are longer than ~20 s, they have flat tops. The longest bursts observed to date are 5-10 minutes." The type I bursts are thought to be due to thermonuclear flashes in the surface layers of an accreting neutron star. Type II bursts probably result from instabilities in the accretion flow. (R6)

X3. MXB 1735-44. "This object produces up to several thousand X-ray bursts per day over intervals of 2-6 weeks in March/April and September/October. Its location near the Galactic Centre means that each burst, of but a few seconds duration, emits in X-rays as much energy as the Sun emits in all wavelengths in one day." (R4)

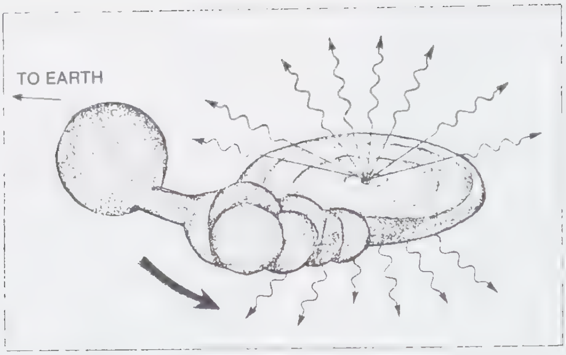
X4. V0332 + 53, an X-ray transient source in Camelopardalis. "A bright transient X-ray source, V0332 + 53, was observed by Vela 5B for 3 months in 1973. It was clearly detected in the 10 day period centered on 1973 June 1, rose to an intensity of 1.4 Crab in July, and was last definitely observed around 1973 August 30. The slow rise and symmetric fall of intensity are unusual for a transient X-ray source. Rapid fluctuations took the source to peak intensities above 2 Crab." No other spacecraft were in positions to observe this event. Note that X-ray intensities are sometimes compared to that of the Crab nebula. (R8) Obviously V0332 + 53 is not an X-ray burster because of its long duration. (WRC)

X5. Unnamed object. "On November 6, 1977, from 29900s to 31000s (UT), the Goddard and Wisconsin experiments on OSO-8 detected an intense X-ray event at 12h 14m 29s, 30° 53' 24" (1950.0 R.A. and Dec.) At peak it was nearly twice as bright as the Crab nebula; its spectrum was highly absorbed; and the light curve appeared very spiky, sometimes varying by a factor of 5 in 10 seconds. The transient was never seen to recur. The properties of this object do not match those of any other identified X-ray transient. Speculations about its origin have ranged from sporadic accretion onto a compact object to a flare from the corona of an accretion disk." No unusual objects within the error box were uncovered during subsequent optical and X-ray searches. (R9)

X6. MXB 1659-29. L. Cominsky and K. Wood claim to have detected eclipse phenomena in this X-ray burster. "Erratic fluctuations occurred in the X-ray signals for about 1½ hours out of every 7 hours. This was immediately followed by a 15 minute eclipse, as a sliver of the companion star blocked the neutron star from view. A steady, uninterupted stream of X-rays followed until the fluctuations returned. The entire cycle repeated itself every 7.1 hours." Given the eclipse parameters, it was determined that the mass ratio of the two stars was 5, not the 1.5 expected. In addition, the stars were much smaller than anticipated. (R7) See X7.

X7. Problems in explaining X-ray bursters. The "standard" explanation: "An X-ray burster is an object in the sky that emits sharp bursts of X-rays from time to time. The theoretical model for such a thing begins with a binary star system, one member of which is a neutron star. The neutron star draws matter from the companion star orbiting around it, and this matter settles onto the surface of the neutron star. When the accreting matter, which is hot ionized gas, accumulates to the critical mass for a thermonuclear explosion, the explosion occurs, emitting a blast of X-rays." (R5)

One problem is that gravitational theory sets a limit, called the Eddington limit, to the amount of radiation that can be emitted. The



A neutron star at the center of an accretion disk pulls matter from the star at the left. As the matter impacts the neutron star, X-rays are emitted. (X7)

X-ray bursters exceed the Eddington limit by a factor of 2 or 3, and thus challenge general relativity. J.W. Moffat's theory, which has been successfully applied to other relativistic phenomena, seems to describe X-ray burster phenomena better than general relativity. (R5)

Another problem with the standard theory of X-ray bursters arises with the dimensions of MXB 1659-29, as derived from eclipse data (X6). "The neutron star is heavier than expected---at least twice the mass of our Sun but only 16 km across. A piece the size of a thumbnail would weigh 2 billion tonnes on Earth. The companion star---about half the mass of the Sun---is smaller, fainter, lighter and cooler than predicted. Also the accretion disc is about 350 000 km thick and at least three times the size current models predict." (R7)

References

R1. "A Weirdly Jittery X-ray Source," Science News, 109:101, 1976. (X2)

R2. Brecher, Kenneth; "Cosmic X-ray Bursts," Nature, 261:542, 1976. (X2)

R3. "X-rays Burst Out, But Not All Over," New Scientist, 74:459, 1977. (X1)

R4. Fabian, A.C.; "More on X-ray Bursts," Nature, 276:561, 1978. (X3)

R5. "Gravity Theory: Moffat 2, Einstein?" Science News, 121:313, 1982. (X7)

R6. Lawrence, A., et al; "X-ray, Radio, and Infrared Observations of the 'Rapid Burster' (MXB 1730-335) during 1979 and 1980," Astrophysical Journal, 267:301, 1983. (X2)

R7. Anderson, Ian; "Eclipses Shed New Light on X-ray Bursters," New Scientist, p. 20, February 16, 1984. (X1, X6, X7)

R8. Terrell, James, and Priedhorsky, William C.; "The 1973 X-ray Transient V0332 + 53," Astrophysical Journal, 285:L15, 1984. (X4)

R9. Connors, Alanna; "Has Anyone Seen This Object?" NRAO Newsletter, no. 25, October 1, 1985. (X5)

R10. Heise, J., et al; "ANS Observations on the X-ray Burster MXB1730 - 335," Nature, 261:562, 1976. (X2)

R11. Lewin, Walter H.G.; "X-ray Burst Sources," Royal Astronomical Society, Monthly Notices, 179:43, 1977. (X1)

R12. Lewin, W.H.G., et al; "Galactic Distribution of X-ray Burst Sources," Nature, 267:28, 1977. (X1)

AOF30 Gamma-Ray Bursters

Description. Intense bursts of gamma rays that typically last 1-10 seconds. The timing and location of the bursts are unpredictable. Rarely can gamma-ray bursters be associated with a known object or with pulsed sources in other parts of the spectrum. The energies involved in a gamma-ray burst are immense, surpassing for a second or so the power levels of whole galaxies.

Data Evaluation. Scores of gamma-ray bursters have been detected by spacecraft. Often several spacecraft will register the pulses at slightly different times, permitting the computation of the source's direction. The burster data are of good quality, but they reveal little about the exact nature of the gamma-ray bursters. Rating: 1.

Anomaly Evaluation. Since dozens of theories are consistent with the available data, we must conclude that we do not really understand the precise mechanism of the gamma-ray bursters. They remain very anomalous. Rating: 2.

Possible Explanations. Neutron stars are probably involved. See X10 below.

Similar and Related Phenomena. Pulsars (AOF9); optical bursters (AOF11); infrared bursters (AOF25); X-ray bursters (AOF29).

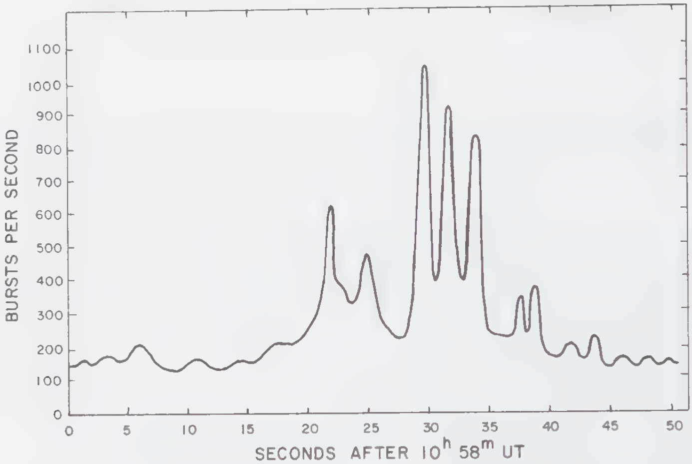
Examples

X1. General observations. "Approximately once per day a burst of very intense gamma radiation emanates from some completely unpredictable part of the sky. The duration of the burst is typically between one second and 10 seconds, although some bursts have been as short as .01 second and others have been as long as 80 seconds. During this time the burst brightens into visibility, varies randomly in intensity and then fades back to invisibility. With few exceptions, no more than one burst has come from exactly the same direction and none has been positively identified with a previously known object." Gamma bursters generate more power per unit volume than any other object in the universe. In one second, they can produce as much energy as the sun does in a week. In spite of their colossal energy-generating capabilities, little is known about gamma bursters; they are unpredictable in time and place. Nearly 40 theoretical models have been proposed to explain them. "It is embarrassing that most of these models are consistent with current observational data." (R23)

X2. The discovery of the Vela satellites; 1973 overview. "Short powerful bursts of gamma radiation originating outside the solar system are reported by three scientists at the Los Alamos Scientific Laboratory in New Mexico. Approximately 20 of these events have been recorded since July, 1969. As a wave of gamma rays passes the earth, it deposits a pulse of energy in the upper atmosphere at rates up to 20 megawatts.

Ray Klebesadel, Ian Strong, and Roy Olson made this discovery while analyzing data from the four most recent Vela satellites, which move around the earth in circular orbits 140,000 miles in diameter. The prime function of the Vela satellites is to act as 'watchdogs' over the limited nuclear test-ban treaty signed in 1963. Each craft carries a nondirectional array of cesium iodide sensors which, linked to sophisticated computers, can recognize sudden short bursts of gamma radiation (wavelength 0.01 angstrom and shorter)." Knowing the positions of the satellites and the times of arrival of the wave of gamma radiation, the direction of the gamma ray source can be computed. (R1; R2-R5) Since the Vela discovery, gamma ray data from several scientific satellites have been employed in studying the gamma ray bursters.

X3. April 27, 1972. This event was detected by several spacecraft, including the Apollo 16 command module, which carried a gamma ray spectrometer. "The burst the Apollo spectrometer detected is shown in Figure 1; a gradual 10-second onset and a 10-second decay phase are evident as well as the multiple spiked burst itself. Vela 6A responded to the same burst, being triggered by the second main spike, about 253 ms before it reached Apollo. The two detector systems were 232 000 km apart---a light travel time of 774 ms. From these figures you can deduce by simple trigonometry that the line of sight to the source of the burst makes an angle of about 71° to the line joining the two detectors." (R4; R8)



Gamma-ray burst of April 27, 1972, as recorded by the Apollo-16 gamma-ray spectrometer. (X3)

X4. January 28, 1976. A burst detected by Helios 2, Velas 5A and 6A, and Ariel 5. (R6)

X5. January 13, 1979. Detected by five satellites, this burst displayed a pulse-afterpulse structure suggestive of periodicity. (R21)

X6. March 5, 1979. Nine spacecraft registered this incredibly strong gamma ray burst. "This flare was a hundred times more intense than any other observed event. After a sharp rise in less than 0.0002 second, the initial burst decayed rapidly for a second or so and then faded slowly over the next minute. Superimposed on the slow dimming was a regular brightness flucuation with a period of eight seconds, the first such behavior detected in this type of source. Additional though weaker bursts from the same direction were recorded 0.6, 29, and 50 days after the main pulse event. In this case the derived location corresponded with the radio source N49, a possible supernova remnant in the Large Magellanic Cloud. If the burster were indeed 55 kiloparsecs away it would, at peak luminosity, have radiated more power than a quasar!" (R18) More specifically: 10^{45} ergs/second, equal to the output of visible radiation from ten entire galaxies the size of the Milky Way. (R7) For additional discussions of this unique event, see R9-R16, R19, R23. Several of these reports suggest that the periodic behavior of this object indicates that it might be a neutron star. But see the following.

Abstract. "The results of the observations of GBS0526 - 66 during 1979 have been reviewed recently primarily in the context of its possible identification with the N49 supernova remnant in the Large Magellanic Cloud (LMC). Observations in 1981 and 1982, however, reveal a still more complex pattern of behavior and show both that the nature of this source of the 5 March 1979 event and its true position in space are far from being clear. Observations from Veneras 13 and 14 reveal that GBS0526 - 66 continues to generate weak recurrent γ-ray bursts. Thus the transient object which during the 5 March burst behaved for several minutes as a flaring X-ray pulsar has since then been exhibiting a peculiar similarity with a hard X-ray burster." (R20)

X7. April 6, 1979. Five spacecraft picked up a gamma burst consisting of a single spike of duration 0.2 second, with a spectral feature near 400 keV. (R17)

X8. December 15, 1984. A gamma burster designated GB841215. From the Abstract: "Here we report the detection on 15 December 1984 at 08.25 UT of an extraordinary outburst, qualitatively different in appearance from all previously observed γ-ray bursts. It is described most conveniently as a 'classical' multi-peaked, hard-spectrum burst that has been compressed in time by a factor of 10-100 while simultaneously having its intensity increased by a like factor (thus conserving fluence). Its peak intensity was much higher than any other known γ-ray burst except for GB 790305b, which had an unusually soft spectrum and other unique features that set it apart from 'classical' γ-ray bursts.'(R22)

X9. January 23, 1985; the Crab pulsar. This object is a source of pulsed photons over a wide range of energies, including TeV gamma rays. On the above date a 15-minute burst was detected by ground-based detectors. (R25)

X10. Possible explanations. As related in X1, some 40 theoretical models have been proposed to explain gamma-ray bursters. Although astronomers have not yet reached a general consensus on a specific burster mechanism, most seem to think that somehow a neutron star is involved. The collision of either an asteroid or a comet with a neutron star is often mentioned as a possibility. Then, too, there is the thought that gamma-ray and X-ray bursters are generically related, being basically the same phenomenon but with different spectra. (R18, R24, R30)

References

R1. "Gamma-Ray Bursts from Deep Space," Sky and Telescope, 46:146, 1973. (X2)
R2. Thomsen, Dietrick; "The Mystery of the Cosmic Gamma-Ray Zaps," Science News, 105:357, 1974. (X2)
R3. Hillier, R.R.; "Nature and Distance of the Sources of Vela Gamma Rays," Nature, 251:375, 1974. (X2)
R4. Fabian, Andrew, and Pringle, James; "Cosmic Gamma-Ray Bursts," New Scientist, 65:313, 1975. (X2, X3)
R5. Strong, Ian B., and Klebesadel, Ray W.; "Cosmic Gamma-Ray Bursts," Scientific American, 235:66, October 1976. (X1, X2)
R6. Cline, T.L., et al; "Helios 2-Vela-Ariel 5 Gamma-Ray Burst Source Position," Astrophysical Journal, 229:L47, 1979. (X4)
R7. "Cloud Burst," Scientific American, 242: 85, January 1980. (X6)
R8. Gilman, David, et al; "The Distance and Spectrum of the Apollo Gamma-Ray Burst," Astrophysical Journal, 236:951, 1980. (X3)
R9. Cline, T.L., et al; "Detection of a Fast, Intense and Unusual Gamma-Ray Transient," Astrophysical Journal, 237:L1, 1980. (X6)
R10. Hartline, Beverly Karplus; "Bursts of Gamma Rays Baffle Astronomers," Science, 207:858, 1980. (X6)
R11. "A Spectacular and Unique Burst of Gamma Rays," Mercury, 9:128, 1980. (X6)
R12. Ramaty, R., et al; "Origin of the 5 March 1979 γ-Ray Transient: A Vibrating Neutron Star," Nature, 287:122, 1980. (X6)
R13. "Gamma-Ray Burst Comes from Outside the Galaxy," New Scientist, 87:776, 1980. (X6)
R14. Terrell, J., et al; "Periodicity of the γ-Ray Transient Event of 5 March 1979," Nature, 285:383, 1980. (X6)
R15. "What Happened on March 5, 1979?" Sky and Telescope, 59:294, 1980. (X6)
R16. Teegarden, B.J.; "The Origin of Cosmic Gamma-Ray Bursts---New Soviet Result," Nature, 290:361, 1981. (X6)
R17. Laros, J.G., et al; "Location of the 1979 April 6 Gamma-Ray Burst," Astrophysical Journal, 245:L63, 1981. (X7)
R18. Schorn, Ronald A.; "The Gamma-Ray Burster Puzzle," Sky and Telescope, 63: 560, 1982. (X6, X10)
R19. Cline, T.L., et al; "Precise Source Location of the Anomalous 1979 March 5 Gamma-Ray Transient," Astrophysical Journal, 255:L45, 1982. (X6)
R20. Golenetskii, S.V., et al; "Recurrent Bursts in GBS0526-66, The Source of the 5 March 1979 γ-Ray Burst," Nature, 307: 41, 1984. (X6)
R21. Barat, C., et al; "1979 January 13: An Intense Gamma-Ray Burst with a Possible Associated Optical Transient," Astrophysical Journal, 286:L5, 1984. (X5)
R22. Laros, J.G., et al; "GB841215, The Fastest γ-Ray Burst?" Nature, 318:448, 1985. (X8)
R23. Schaefer, Bradley E.; "Gamma-Ray Bursters," Scientific American, 252:52, February 1985. (X1, X6, X10)
R24. Tremaine, Scott, and Zytkow, Anna N.; "Can Comet Clouds around Neutron Stars Explain Gamma-Ray Bursts," Astrophysical Journal, 301:155, 1986. (X10)
R25. Bhat, P.N., et al; "A Very High γ-Ray Burst from the Crab Pulsar," Nature, 319:127, 1986. (X9)

AOO EXTENDED GALACTIC OBJECTS

Key to Phenomena

AOO0 Introduction

Most stars cannot be optically resolved to reveal structure; we see them only as points of light. A few objects in our galaxy, however, are extensive enough to show up as patches, rings, jets, and other structures. The constituents of these extended objects always turn out to be dust and gas. The anomalies in this category are generally concerned with accounting for the shapes of these diffuse objects and the energy they emit.

Bipolar jets and biconical nebulas, for example, represent a particularly important class because of their similarity to galactic jets and quasar lobed radio structures. The genesis and interrelationships of these outwardly similar structures are not well-understood. Despite its name, the famous Red Rectangle probably belongs among these bipolar phenomena. The rings, globules, and other geometries mentioned here are apparently unrelated and probably have unique explanations.

AOO1 X-Ray Rings

Description. Large, ring-shaped sources of X-rays. The diameter of the Cygnus X-ray ring recorded below is 13°, equivalent to 450 parsecs---both substantial figures.

Data Evaluation. The Cygnus X-ray data are from the HEAO 1 satellite and are of high quality. Rating: 1.

Anomaly Evaluation. The Cygnus X-ray ring is notable for its large physical size and X-ray power production. The geometry and nature of the emissions suggest a large, expanding bubble; that is, a spherical, X-ray emitting shock wave from some extremely energetic astrophysical event. The nature of the event is not known. One theory requires a series of 30-100 supernovas in the same general locality. Since supernovas are quite rare, such a series is most unusual. The anomaly is in the energy of the event or events. Rating: 2.

Possible Explanations. A series of supernovas, as mentioned above.

Similar and Related Phenomena. Novas and supernovas (AOF5)

Examples

X1. Cygnus. "Abstract. We show that Cyg X-6 and Cyg X-7 are part of a large X-ray ring 13° in diameter. At a distance of 2 kpc this X-ray source lies behind the Great Rift of Cygnus and as such has radiation from its central region absorbed. The diameter of the emitting region is 450 pc. The observed X-ray luminosity is 5 x 10^{36} ergs s^{-1} at about 2 x 10^{6} K. The emitting electron density in the shell is 0.02 cm^{-3} which implies a total thermal energy content greater than 6 x 10^{51} ergs. We show that the X-ray source is associated with a ring of elongated Hα filaments which enclose the Cygnus X radio source. At the center of this region lies the highly luminous Cygnus OB2 association. The region is also coincident with an H I supershell. Analysis of the source in terms of a conventional supernova indicates a 10^{54} erg event. The energy requirement can be reduced below 10^{53} ergs by injecting the energy steadily over a period greater than 3 x 10^{6} years. The structure of the superbubble can be explained by a series of 30-100 supernovae." (R1)

References

R1. Cash, Webster, et al; "The X-Ray Superbubble in Cygnus," Astrophysical Journal, 238:L71, 1980. (X1)

AOO2 Nebular Jets

Description. High-velocity jets of matter emitted from diffuse nebular regions. Note that we separate stellar jets (AOO6) from nebular jets, although the latter may ultimately be found to have stellar sources.

Data Evaluation. Nebular jets have been detected by optical imaging and spectroscopic detection of high-velocity winds. Both types of results are subject to interpretation. Furthermore, only three examples have been recorded so far. Rating: 2.

Anomaly Evaluation. Jets of matter, usually bipolar in character, now seem to be rather common in the cosmos (stars, galaxies, quasars). The basic model for the production of the bipolar geometry is an accretion disk around a central object ejecting jets of matter which are collimated by a magnetic field. Although details remain to be explained, the basic model seems quite reasonable. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. SS 433 (AOF2-X1); stellar jets (AOO6); galactic jets (AWO1); quasar jets (AQO2).

Examples

X1. G109.1-1.0, an object in Cassiopeia resembling a supernova remnant except for its jet structure. "...an intense, compact, central powerhouse from which jets seem to be squirting. The mystery involves the association of these features with a huge glowing shell. The enigma concerns the physical interpretation of what is being seen: a new kind of remnant from a 12,000-year-old supernova, an object accreting matter in the manner of SS 433, or something akin to quasars." This shell, its central source, and jets were imaged by the Einstein X-ray observatory. P.C. Gregory and G.G. Fahlman, of the University of British Columbia "...note that the strongest segment of the jet curves northward to join the outer rim of the shell. Another jet, however, seems to project westward on a straight line from the central source and directly opposite to two regions of singly ionized hydrogen..." (R1; R4)

X2. Crab nebula. "Extending outward from the northern periphery of the celebrated Crab nebula is a curious, faint jet some 45 by 75 arc seconds in size. Discovered by Sidney van den Bergh in 1970, this rectangular feature exhibits several strange properties, as revealed for the first time in deep photographs by Theodore Gull and Robert Fesen of the NASA Goddard Space Flight Center.... The jet is wide and highly collimated; that is, it has bright parallel edges suggestive of a tubular structure. Such an organized feature stands in sharp contrast to the more familiar, twisting filaments that dominate the otherwise diffuse surface of the Crab-nebula supernova remnant. Also, the jet is not, as might be expected, aligned radially to the presumed center of the remnant of the famous Crab pulsar. Finally, it is particularly curious that the jet begins at the outer edge of the remnant and not, for example, deeper within the supernova's debris." (R2; R5)

X3. Orion nebula. This nebula is regarded as a region of active star formation. "D.J. Axon and K. Taylor have described new optical spectra indicating very high-velocity winds in the most famous region of star formation in the heavens, the Orion Nebula. Their spectra point towards the existence of a biconical pattern of outflow and suggest the presence of a substantial disc of molecular gas and dust grains close to a putative stellar source of excitation, located in the giant molecular cloud behind the nebula." Axon and Taylor conclude that the most plausible model explaining the two jets consists of a massive young star obscured by a collimating disk of dust and gas. Bipolar jets create the high-velocity winds. (R3)

References

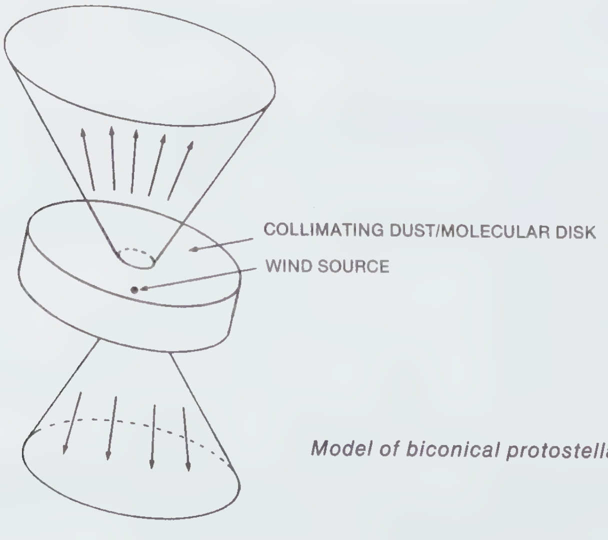
R1. "'A Riddle Wrapped in a Mystery inside an Enigma,'" Sky and Telescope, 61:391, 1981. (X1)

R2. "The Crab's Mysterious Jet," Sky and Telescope, 65:26, 1983. (X2)

R3. Zuckerman, Ben; "High Winds in Orion," Nature, 309:403, 1984. (X3)

R4. Gregory, P.C., and Fahlman, G.G.; "An Extraordinary New Celestial X-ray Source," Nature, 287:805, 1980. (X1)

R5. Gull, Theodore R., and Fesen, Robert A.; "Deep Optical Imagery of the Crab Nebula's Jet," Astrophysical Journal, 260:L75, 1982. (X2)



Model of biconical protostellar wind source. (X3)

AOO3 The North Polar Radio Spur

Description. A curved "spur" of enhanced radio emission rising from the plane of our galaxy. The spur's structure is shell-like and ridged in places. Some X-rays are also emitted.

Data Evaluation. The literature yields several radio and X-ray surveys of this region. Rating: 1.

Anomaly Evaluation. Although the spur's size and geometry are impressive and curious, respectively, a reasonable explanation exists. It seems to be a shock wave or expanding shell of matter. Thus, its anomaly value is rather low. Rating: 3.

Possible Explanations. An expanding shell of shock wave of gas/dust, perhaps from a nova or supernova.

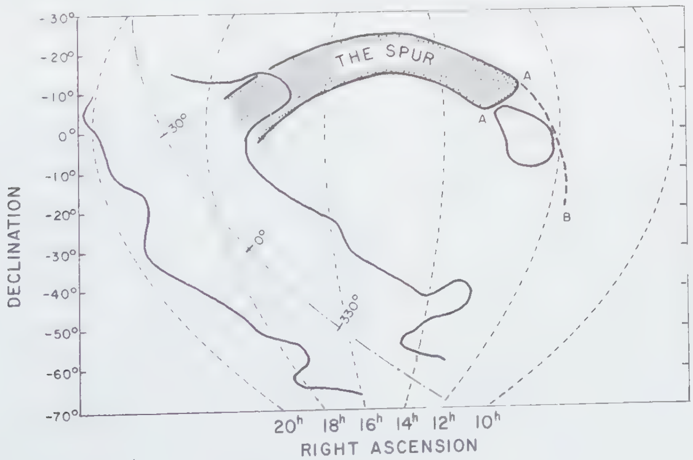
Similar and Related Phenomena. X-ray rings (AOO1).

Examples

X1. General observations. "Radio astronomers have speculated for some years about the meaning of a curious feature of the radio-frequency map of the sky. This is a curved spur of comparatively intense radiation which arises at a substantial angle from the plane of the Galaxy. This phenomenon has a sharply defined outer edge, but the inside parts of it are less distinct. It has not been identified with anything in the sky which is optically observable.

One theory of the spur's origin proposed that it resulted from electrons at relativistic velocities, spiralling round a magnetic field which was aligned along one of the main spiral arms of the Galaxy. A mechanism of this type would give highly directional emission. There are, however, a number of objections to the idea. In particular, it assumes that the spur is part of a galactic great circle. In fact, its shape suggests that it is really a piece out of a smaller, rather patchy loop. Another explanation is that the spur arose from the collision of our own Galaxy with a second nebula. The extreme rarity of such an event makes this unsatisfactory." (R1)

X2. 240 MHz survey. "Summary. The anomalous band of radio emission known as the North Polar Spur poses a problem of theoretical interpretation. To assist theoretical work a 240 Mc/s radio survey has been made of the complex bright region at the base of the Spur, near $l^{II} = 30^{o}$. The survey was reduced in an electronic digital computer by an extension of techniques previously described. It is found that the Spur possesses a remarkably narrow neck near to the galactic plane and a number of ridge-like



The North Polar Radio Spur. (X1)

structures have been detected. Some scans at 408 Mc/s show that the main ridge is entirely resolved with an $0^{o}.8$ beam." (R2)

X3. Radio and X-ray survey. The North Polar Spur seems to consist of distinct shells. The region seems to be the result of a spherical shock that occurred long ago and is no longer expanding. (R3)

References

R1. "Relic of an Exploded Star?" New Scientist, 8:1608, 1960. (X1)

R2. Haslam, C.G.T., et al; "A Radio Study of the North Polar Spur," Royal Astronomical Society, Monthly Notices, 127:273, 1963. (X2)

R3. Heiles, Carl, et al; "A New Look at the North Polar Spur," Astrophysical Journal, 242:533, 1980. (X3)

R4. Brown, R. Hanbury, et al; "A Curious Feature of the Radio Sky," Observatory, 80:191, 1960. (X1)

R5. Seaquist, E.R.; "On the North Polar Spur as a Supernova Remnant," Observatory, 88:269, 1968. (X1)

AOO4 Triangular Appearance of Stars in Telescopes

Description. The appearance of some stars, on some occasions, as triangles rather than discs. The bases of the triangles are parallel to the horizon. Weather seems implicated in some way.

Data Evaluation. On record are several accounts by experienced astronomers, with different instruments. No serious studies of the phenomenon have been found and there seem to be no modern records. Rating: 2.

Anomaly Evaluation. This phenomenon could well have been included in Category GE in the Catalog of Geophysical Anomalies. It seems to involve seeing conditions, the observer, but not the instrument. While intriguing and certainly not explained, its existence does not seem to constitute a serious anomaly, being akin to the anomalous refraction of celestial objects near the horizon. Rating: 3.

Possible Explanations. Abnormal atmospheric refraction; possibly psychological effects.

Similar and Related Phenomena. The distortion of celestial objects near the horizon (GEL4).

Examples

X1. Overview of observations. "In the year 1867 the celebrated observer, the Rev. W.R. Dawes, published a memorable paper on his double star work (Monthly Notices, R.A.S., 27, 232) in which a very interesting paragraph occurs regarding the occasional appearance of star discs as triangles with bases roughly parallel to the horizon. He states that the famous W. Struve had informed him that he also had often seen this but could not account for it in any way. The phenomenon was noted with two object glasses on the same night and was remarked by the great telescope maker Alvan Clark, who was on a visit to Dawes at the time (in 1859), Arcturus appearing strongly triangular to both of them. The most peculiar feature of the occurrence was that the triangular tendency seemed to be strongest always when the wind was in the East or South-East. In the same volume of the Monthly Notices, p. 281, the Astronomer Royal, Airy, has a short paper in which he attributes the phenomenon to a physiological cause, fatigue or indisposition, to be expected, he remarks, with an East wind. An interesting discussion on the matter is reported in the Astronomical Register, 5, 123, 1867, Huggins and Capt. Noble taking part and stating that they had seen the phenomenon but that they did not agree with the physiological explanation suggested by Airy. Certainly its appearance to two observers and through two different object glasses, as mentioned above, does not suggest a physiological or instrumental origin; and that its occurrence is not confined to refractors is shown by Grover's account (in the same journal, 6, 118, 1868) of a triangular disc being once 'strikingly conspicuous in the case of Aldebran, on which occasion the wind was South East'; instrument 6½-inch, with reflector, power 150." (R1)

"The curious tendency of star discs to become triangular, so ably described by the late W.R. Dawes in his valuable Catalogue of Double Stars as observed with various achromatics, is also observed with reflecting instruments, as I have found it occasionally visible: once, about a fortnight since it was strikingly conspicuous in the case of Aldebaran, on which occasion the wind was South East. This was visible with a power of only 150." (R3)

References

R1. Doig, Peter; "A Peculiar Telescopic Phenomenon," British Astronomical Association, Journal, 40:115, 1930. (X1)

R2. Astronomical Register, 5:123, 1867. (X1)

R3. Grover, C.; "On the Use of Silvered Glass Reflectors," Astronomical Register, 6:118, 1868. (X1)

AOO5 Puzzling Nature of Bok Globules

Description. The poorly understood nature of Bok globules, as evidenced by the conflicting characteristics noted below; i.e., insignificant turbulence versus "baby sun" appelation.

Data Evaluation. A small number of radio and infrared observations have been found. These dark assemblages of dust and gas are difficult to study because they emit so little radiation. Bok globules are probably "puzzling" only because the data we have are conflicting and inadequate. Rating: 3.

Anomaly Evaluation. Bok globules are not particularly anomalous from what we now know about them. No astronomical laws seem to be challenged; rather, it seems a matter of not enough data. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Nebular jets (AOO2); Herbig-Haro objects (AOO8).

Examples

X0. Introduction. "In the 1940s, astronomer Bart Bok called attention to compact, spherical dark nebulae that he referred to as 'globules.' Now named for him, these Bok globules generally contain about 10 solar masses of material and are anywhere from 1,000 to 100,000 astronomical units in diameter. The dark spheres of gas and dust were originally thought to be examples of interstellar material collapsing to form new stars. These objects represent the simplest single structures in the dense interstellar medium. Their geometry is regular, and they harbor no strong energy sources---characteristics that make them ideal subjects for comparing observation with theory." (R2)

X1. Radio telescope observations of a Bok globule in Cassiopeia. "According to(R. L.) Dickman and (D.) Clemens, radio observations revealed a temperature gradient from the edge of the cloud to its core: the surface, exposed to the light of nearby stars, is hotter than the dense, shielded central region. They also analyzed the radio spectral lines of the molecules in the cloud.... The molecular lines emitted by the Cassiopeia globule are extremely narrow, indicating that turbulent motions in the object occur at velocities much less than the speed of sound in the gas---less than 40%." (R2) The Bok globules are, according to this, rather placid internally. (WRC)

X2. Infrared survey by the IRAS spacecraft. "Even in the small dust clouds called Bok globules, which dot the Milky Way and were previously believed to be cool and quiescent, too small to make stars, IRAS has detected the telltale heat from baby suns." (R3)

Compiler's comments. First, an obvious contradiction exists between X0 and X2. The latter states that Bok globules were thought to be too small to make stars, but the former puts their chacteristic mass at 10 solar masses. Second, their lack of strong turbulence (X1) seems inconsistent with the heating produced by "baby suns".

References

R1. Spencer, Richard G., and Leung, Chun Ming; "Infrared Radiation from Dark Globules," Astrophysical Journal, 222:140, 1978.

R2. "Inside a Bok Globule," Astronomy, 11:62, November 1983. (X0, X1)

R3. Overbye, Dennis; "The Secret Universe of IRAS," Discover, 5:14, January 1984. (X2)

AOO6 Jets from Young Stars

Description. The association of bipolar jets of matter with stars conventionally designated as very young.

Data Evaluation. A small but growing number of stellar objects with jets have been reported in the literature according to astronomers (R3), although only three specific cases have been cited below. The reality of the jets seems assured from the data, but the attribute of youth is implied from the surrounding gas/dust clouds and stellar spectra. This implication is almost universally believed to be correct, as based upon the conventional scenario of star formation. Rating: 1.

Anomaly Evaluation. The discovery of stellar jets was a surprise to astronomers, who are still lacking a consensus on how they are formed and their role in stellar evolution. Also mysterious is the appearance of similar jets in nebulas, galaxies, quasars, and other astronomical objects. Rating:2.

Possible Explanations. Because jets seem to be a ubiquitous phenomenon in the universe, there is probably some common mechanism at work at several hierarchical levels.

Similar and Related Phenomena. Nebular jets (AOO2); Herbig-Haro objects (AOO8); jets from galaxies (AWO1); jets from quasars (AQO2).

Examples

X1. Hz 1883, in the Pleiades. "It goes around every six hours, a fast clip for a star, and it seems to be throwing off large amounts of matter. The evidence is in the changes, a cyclic shift to the red and the blue, of the spectral emission line hydrogen alpha. The shift toward the red and then back toward blue indicates that the matter emitting the hydrogen alpha light is coming off the star, not in a spherically symmetrical way, but in a bipolar way, in oppositely directed jets. (D.K.) Duncan says the calculated velocity is 400 kilometers per second, just about escape velocity from the star." (R1)

X2. R and T Corona Australis. "Ray Wolstencroft from the Royal Observatory at Edinburgh described fresh clues at the Manchester conference. He has studied two stars, R and T Corona Australis, which are still embedded in the large cloud from which they were born. Wolstencroft found that both have faint jets of gas extending from them, and that these two jets are parallel to each other, and to the long axis of the large 'parent' cloud. By studying the polarisation of light from the stars, Wolstencroft could infer that each has a surrounding disc of dust and gas. The two discs are parallel to each other---but they are not perpendicular to the direction of the jets, as we would expect if the discs are responsible for determining the direction of the jets." Wolstencroft suggested that magnetic fields in the cloud might skew the jets. (R2)

X3. General observations. "One of the most remarkable and unexpected discoveries in astronomy in the past two decades is that very young stars emit energetic jets of material into their surroundings. The large-scale motions corresponding to the relatively gentle collapse of gas and dust to form a star do not predominate in the dark clouds within which stars form. Rather, the more obvious ordered motions are either rotation or those of energetic outflows of material from protostellar objects."

.....

From the Conclusions. "But the question remains: What produces the jets? In some ways these molecular jets resemble the highly energetic outflow phenomena in radio galaxies. Similar mechanisms have been proposed for the collimation. Because the molecular jets are closer at hand, there is a greater opportunity to study and understand them." (R3)

"As a result of a series of remarkable and exciting observational discoveries made across the electromagnetic spectrum during the last five years, a new stage of early stellar evolution of unanticipated astrophysical importance has been identified. It is now generally believed that during the earliest stages of evolution, most, if not all, stars undergo a phase of very energetic mass ejection, frequently characterized by the occurrence of massive bipolar outflows of cold molecular gas. These outflows appear to be driven by strong stellar winds, whose other notable manifestations include rapidly moving Herbig-Haro (HH) objects, high-velocity water maser sources, shock-excited molecular hydrogen emission regions, and optically visible jets appearing to emanate directly from the immediate circumstellar environs of the young driving stars themselves." The kinetic energies of the outflowing gases are huge (10^{43} - 10^{47} ergs). Our understanding of outflow phenomena is still in its infancy. (R4)

References

R1. Thomsen, D.E.; "Stellar Evolution Spins a Surprise Stage," Science News, 125:388, 1984. (X1)

R2. "Young Stars Have Discs and Jets," New Scientist, p. 25, August 22, 1985. (X2)

R3. Welch, W.J., et al; "Gas Jets Associated with Star Formation," Science, 228: 1389, 1985. (X3)

R4. Lada, Charles J.; "Cold Outflows, Energetic Winds, and Enigmatic Jets around Young Stellar Objects," Annual Reviews of Astronomy and Astrophysics, 23:267, 1985. (X3)

AOO7 The Red Rectangle

Description. A biconical infrared feature centered on the star HD44179 in Monoceros. The infrared light forming the hourglass image has been determined to be emitted rather than scattered light.

Data Evaluation. The Red Rectangle has been studied extensively in many wavelengths by several astronomers. Data are abundant, and the references below represent only a sampling. Rating: 1.

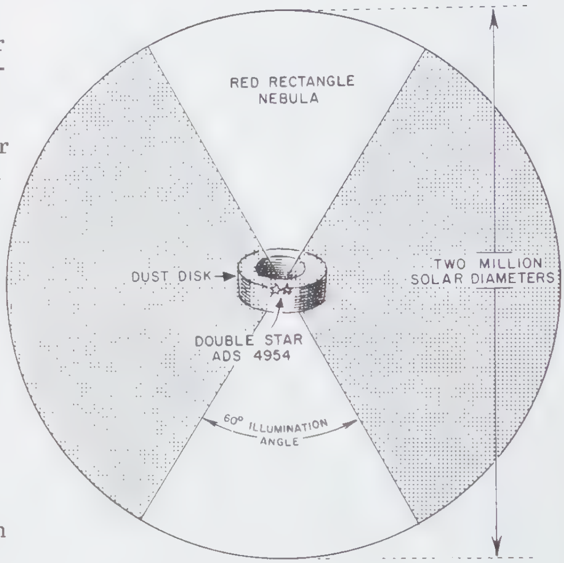
Anomaly Evaluation. The latest explanation of the Red Rectangle's features (X2) states that emission is enhanced in a biconical shell of dust, and that this is emitted light rather than reflected light. No one has explained how a biconical surface of infrared-radiating dust particles is created. It is unlikely, however, that any astronomical laws are challenged by the Red Rectangle---it is more a question of deciding how the dust is concentrated and heated. Rating: 3.

Possible Explanations. None, although the Red Rectangle may be related to the biconical jets of stars, quasars, and galaxies.

Similar and Related Phenomena. The bipolar geometry of nebular jets (AOO2), stellar jets (AOO6), quasar jets (AQO2), galactic jets (AWO1).

Examples

X1. General observations made shortly after the discovery of the Red Rectangle. "An unusual nebula called the 'red rectangle' has been found around a double star known as ADS 4954. Nebulae are clouds of interstellar gas or dust, and several thousand have been identified in our Milky Way galaxy. Only a few, however, such as the Orion Nebula, are bright enough to be visible to the naked eye, the rest are either telescopic objects or dark nebulae that do not shine but are recognizable on sky photographs as black spots in crowded star fields. Most nebulae are soft-edged and either round or very irregularly shaped. The red rectangle, by contrast, has relatively crisp, linear edges and, despite its name, is shaped like an hourglass. It is also an intense source of infrared radiation. (Its not-quite-accurate designation comes from a survey photograph taken in the 1950s on which it appears to be rectangular.) About 1,00 light-years from earth, near the southern border of the constellation Monoceros, 'the Unicorn,' and visibly dim even though it is more than two million times larger than the diameter of our sun, the red rectangle is of interest to astronomers because infrared sources are associated with the poorly understood interstellar and circumstellar dust clouds of our galaxy."(R2)



An early model of the Red Rectangle. (X1)

General observations six years later (1981). "The Red Rectangle is the remarkable bipolar nebular associated with the star HD 44179. The system was discovered as an infrared source in the AFCRL Sky Survey and studied in great detail at a variety of wavelengths by Cohen et al. The appearance of the nebula depends on the waveband in which it is observed. In the blue waveband the nebula is amorphous but generally centered on HD44179. In the red, spikes extend out from the corners of the rectangle centered on the central star. The nebula is biconical with the central star at the apex. The spikes correspond to the edge of the bicone as viewed tangentially (limb brightening) implying that the outer part of the nebula consists of an optically thin biconical surface rather than a filled binconical volume." (R6)

X2. Potential explanations. In 1979, A. Webster suggested that the central object in the Red Rectangle might be emitting bipolar, relativistic jets of gas. The biconical nebula would consist of material thrown out by the jets. (R3)

1981. "In summary, the polarization data imply that the Red Rectangle consists of a central star illuminating a surrounding amorphous dust distribution within which is embedded a biconical surface of enhanced dust density. The red emission feature in the nebular spectrum originates on this surface and is unpolarized. Therefore it does not arise from the scattering of light from the central object, even by grains with a peculiar albedo. Our polarization maps associate the red feature with the enhanced dust density on the bicone, and support the view that the red feature is from a special emission mechanism in the dust in the nebula." (R6)

References

R1. Cohen, Martin, et al; "The Peculiar Object HD 44179 ('The Red Rectangle')," Astrophysical Journal, 196:179, 1975. (X1)

R2. Maran, Stephen P.; "The Red Rectan-

gle," Natural History, 84:93, November 1975. (X1)
R3. Webster, Adrian; "Precessing Jets in the Red Rectangle," Royal Astronomical Society, Monthly Notices, 189:33P, 1979. (X1, X2)
R4. Warren-Smith, R. F., et al; "Peculiar Optical Spectrum of the Red Rectangle," Nature, 292:317, 1981. (X1)
R5. Wdowiak, Thomas J.; "Laboratory Produced Visible Spectral Emission Features Correlate with Those of the Red Rectangle," Nature, 293:724, 1981. (X1)
R6. Perkins, H. G., et al; "The Red Rectangle: Its Polarization and Structure," Royal Astronomical Society, Monthly Notices, 196:635, 1981. (X1, X2)
R7. Thronson, Harley A., Jr.; "Near-Infrared Spectroscopy of Possible Precursors to Planetary Nebulae: The Cygnus Egg and the Red Rectangle," Astronomical Journal, 87:1207, 1982. (X1)

AOO8 Herbig-Haro Objects

Description. Small patches of nebulosity exhibiting bright emission lines characteristic of a shocked gas. These objects are often strung in linear groups. No stars have ever been found at the positions of the Herbig-Haro objects.

Data Evaluation. Herbig-Haro objects have been studied in the visible, infrared, and radio regions of the spectrum, but not as extensively as other cosmic objects; i.e., they have not been popular research targets as, for example, the pulsars. Dust and gas in the neighborhood of the Herbig-Haro objects restrict observation primarily to the longer wavelengths. Rating: 2.

Anomaly Evaluation. Several reasonable models exist for the production of the Herbig-Haro objects. Some details are missing, such as the nature of the gas concentrations that flare up when struck by shock waves, but we do not seem to have a serious anomaly here. Rating: 3.

Possible Explanations. Jets of matter from young stars give rise to focussed shock waves that heat up gas concentrations far from the stars themselves.

Similar and Related Phenomena. Stellar gas jets (AOO6).

Examples

X1. General observations. About 1951, the astronomers G. Herbig and G. Haro independently discovered a new class of cosmic objects in our galaxy. Now known as Herbig-Haro objects, they are bright nebulosities a few seconds of arc across. Their spectra consist mainly of hydrogen emission lines. One of their most interesting properties is their tendency to form in groups, especially chain-like groups. (R1)

At first astronomers thought that the Herbig-Haro objects represented a very early stage in star formation, preceding even the T Tauri stars, but no objects have ever been found at the precise sites of the Herbig-Haro nebulosities. For this reason, the source of their emission lines was long a puzzle. Then, J. Raymond and M. Dopita demonstrated that the Herbig-Haro emission spectra were characteristic of gas cooling after being heated to high temperatures by a shock wave. But the Herbig-Haro objects are usually separated by light years from the nearest stars that might generate the requisite shock waves. Isotropic shock waves could never persist over such great distances. Modern explanations of the Herbig-Haro objects revolve around shock-wave focussing by molecular clouds and the shock waves in the narrow jets emitted by young stars. (R2, R3)

X2. Observational association of gas jets and Herbig-Haro objects. "At a recent conference at the University of Manchester, Reinhard Mundt of the Max-Planck Institut fur Astronomie at Heidelberg reported his discovery of very narrow jets of gas, projecting only about 0.03 light years from several young stars. Mundt was led to these stars by the presence of small bright patches of nebulosity, called Herbig-Haro objects (after their discoverers). These objects produce bright emission lines, from common atoms, such as hydrogen. When Mundt isolated the light from hydrogen, employing special filters, he discovered much fainter jets, and that the Herbig-Haro objects are strung along these jets. The spectra of the Herbig-Haro objects show that they are being heated by the impact of a shock wave, with a speed that is higher than 100 kilometres per second. Presumably the shock wave is produced by these newly found jets travelling outwards from the star at a very high speed. Mundt suggests that the Herbig-Haro objects are simply denser regions of the surrounding gas cloud that are hit by the jet." (R4)

"Like the H_2O masers, the Herbig-Haro objects appear to be small, massive 'bullets' moving at high speeds away from young stars. They are associated with both the CO outflows and the more extended, shock-excited 2-μm radiation from molecular hydrogen. Because it is not likely that a tenuous wind can gradually accelerate such dense condensations to their observed speeds, it is probable that they are somehow set into high speed close to their exciting stars. They are then observed when they collide with dense material at some distance from their source, perhaps when they collide with the wall of the cavity evacuated by the wind, producing the characteristic shock-excited emission." (R6)

References

R1. Gyulbudaghian, A. L., et al; "New Herbig-Haro Objects," Astrophysical Journal, 224: L137, 1978. (X1)

R2. Rodriguez, Luis F.; "Searching for the Energy Source of the Herbig-Haro Objects," Mercury, 10:34, March/April 1981. (X1)

R3. Schwartz, Richard D.; "Herbig-Haro Objects," Annual Review of Astronomy and Astrophysics, 21:209, 1983. (X1)

R4. "Young Stars Have Discs and Jets," New Scientist, p. 25, August 22, 1985. (X2)

R5. Axon, David J., and Taylor, Keith; "Discovery of a Family of Herbig-Haro Objects in M42: Implications for the Geometry of the High Velocity Molecular Flow?" Royal Astronomical Society, Monthly Notices, 207:241, 1984.

R6. Welch, W. J., et al; "Gas Jets Associated with Star Formation," Science, 228: 1389, 1985. (X2)

R7. Raga, A.C., et al; "A New Test of Bow-Shock Models of Herbig-Haro Objects," Astronomical Journal, 92:119, 1986.

R8. Goodrich, Robert W.; "New Observations of Herbig-Haro Objects and Related Stars," Astronomical Journal, 92: 885, 1986. (X1)

AOO9 Molecular Cloud Rings

Description. Immense, ring-shaped clouds of molecules (predominantly CO) circling galactic cores at distances of the order of tens of thousands of light years. The rings are made up of hundreds of thousands of giant CO clouds, each averaging 100,000 solar masses.

Data Evaluation. The data are primarily from the IRAS (Infrared Astronomy Satellite) and are considered to be a high quality. Rating: 1.

Anomaly Evaluation. Prior to the discovery of these large molecular clouds far from the galactic core, the galactic core itself was presumed to be the region where most new stars were born. Now, the focus of star production may have to shift to the ring clouds---a major change in astronomical thinking. Rating: 2.

Possible Explanation. None.

Similar and Related Phenomena. Galactic halos (AWO11); the "missing mass" problem (AWB5)

Examples

X1. General observations. M.A. Gordon and W. B. Burton have discovered an extraordinary "...ring of huge cold clouds of carbon monoxide molecules encircling the galaxy at galactic radii from 12,000 to 24,000 light-years, attaining the greatest density at about 17,000 light years. The ring is not perfectly circular because of displacement by included spiral arms. This molecular ring is 300 light-years thick. Hundreds of thousands of giant carbon monoxide clouds, the most massive objects in the galaxy, averaging 100,000 solar masses each range from 15 to 100 light-years in diameter with an average of 50 light-years. The mean separation of the clouds in the densest regions of the molecular ring is 400 light-years and increases toward the edge. The total mass of all these clouds is estimated at several billion suns....Not only is this discovery a major blow to our understanding of our galaxy by placing the major source of stellar formation precisely where we had thought there would be almost none, but it could very well revamp our thinking as to the possible distribution of life in the galaxy. If one of these incredibly massive but optically invisible clouds moved into the solar system, the reduction of solar radiation between the sun and the Earth would lower the Earth's temperature to the point where ice ages could occur and possibly the extinction of all life. Actually, some astronomers believe such clouds have caused previous ice ages." (R1)

X2. Ring of dust and gas in Andromeda. "IRAS has even found a ring of infrared emission about 30,000 light years out from the core, presumably analogous to a ring of gas and dust in a similar position in our own galaxy. (Why rings? Nobody knows...)" (R3)

References

R1. Villard, Ray, and Gerstman, Larry; "Most Massive Objects in Milky Way Discovered---Huge Gas Clouds of CO," Star & Sky, 1:4, June 1979. (X1)
R2. Kroto, Harold; "Galactic Giants Baffle Star Theorists," New Scientist, 88:292, 1980. (X1)
R3. Waldrop, M. Mitchell; "The Infrared Astronomy Satellite (II)," Science, 221: 43, 1983. (X2)
R4. Bally, John; "Interstellar Molecular Clouds," Science, 232:185, 1986. (X1)

AOO10 Infrared Cirrus Clouds

Description. Extended filamentary clouds of matter emitting primarily infrared radiation.

Data Evaluation. The infrared cirrus was discovered by the IRAS (Infrared Astronomy Satellite). The IRAS data are considered very reliable. Rating: 1.

Anomaly Evaluation. The discovery of the infrared cirrus was quite unexpected. Its origin and significance are unknown. Rating: 2.

Possible Explanations. None.

Similar and Related Phenomena. Molecular ring clouds (AOO9); giant molecular clouds in general.

Examples

X1. IRAS (Infrared Astronomy Satellite) observations. "Among the unexpected results from the Infrared Astronomical Satellite (IRAS) was the discovery of large-scale, extended filamentary emission at 60 and 100μm, described as 'infrared cirrus' by Low et al (1984). They identified several cirrus features with prominent H I clouds but noted the presence of cirrus at some places without prominent H I, and vice-versa. Subsequent investigators have identified other regions of correlated H I and infrared cirrus and noted that cirrus emission is also visible at 12 and 25 μm. It has been suggested that the surprising short wavelength emission arises from very small grains or large polycyclic aromatic molecules." (R3)

X2. Association with molecular clouds. "Abstract. We establish that a close correlation exists between far-infrared 'cirrus' emission observed with IRAS and the CO emission from high-latitude molecular clouds (HLCs). In all cases, the HLCs correspond to the central portions of 100 μm infrared cirrus features. This association firmly establishes at least some of the cirrus as features of the local interstellar medium with typical distances of 100 pc." (R3)

References

R1. Eberhart, J.; "Throwing Wide the IR Window," Science News, 124:324, 1983. (X1)

R2. Low, F. J., et al; "Infrared Cirrus: New Components of the Extended Infrared Emission," Astrophysical Journal, 278:L19, 1984. (X1)

R3. Weiland, Janet L., et al; "Infrared Cirrus and High-Latitude Molecular Clouds," Astrophysical Journal, 306: L101, 1986. (X1, X2)

AOO11 Diffuse Cartwheel-Like Structures

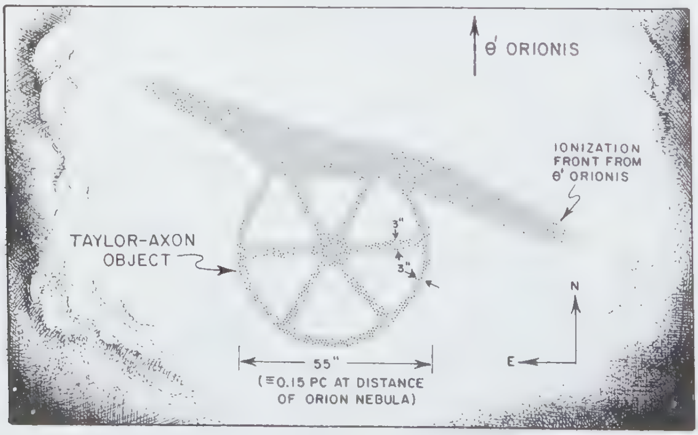
Description. Diffuse clouds of ionized hydrogen in a cartwheel-like configuration; i.e., an outer ring with radial spokes. The nature of the "hub" has not yet been determined.

Data Evaluation. To date, only a single report of this phenomenon has been collected. However, there seems no reason to doubt the fact of the observation. Rating: 2.

Anomaly Evaluation. Since only one example of this phenomenon has been found and the nature of the hub is ambiguous, even speculation is difficult. It may just be fortuitous that the outflow of a young star hidden from direct view in the hub assumes such a regular geometrical pattern. The outer ring of the cartwheel may be merely a snowplow effect, as described in X1. Despite the intriguing geometry, the cartwheels probably have an easy explanation. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Jets from young stars (AOO6).



Cartwheel structure silhouetted against a bright nebula. (X1)

Examples

X1. General observations. "Using the 1 metre telescope at the Wise Observatory in the Negev Desert the authors (K. Taylor and D. Axon) made electronographic observations of the giant glowing cloud of ionised hydrogen (HII region) known as the Great Nebula in Orion. One of their plates revealed a dark object, silhouetted against the bright nebula, consisting of an outer circular ring 55 seconds of arc in diameter and 3 seconds of arc wide connected to an amorphous central object by six narrow radial spokes.... The nature of the object is a mystery." Speculation is that the ring was created via a snowplow effect involving a central star too faint to be seen. (R1)

References

R1. "Cartwheels in the Sky," New Scientist, 83:804, 1979. (X1)

AOX STELLAR ECLIPSE PHENOMENA

Key to Phenomena

AOX0 Introduction

Astronomers have discovered many eclipsing binaries with well-behaved light curves. Indeed, light-curve analysis reveals much about the masses and separation of binary components. A handful of eclipsing binaries, however, have light curves that cannot be explained in terms of simple spheres eclipsing one another. In addition, at least one star, long thought constant, has suddenly commenced eclipsing---the converse has happened, too, that is, sudden eclipse cessation. Such phenomena are not considered particularly anomalous, given the great range and flexibility of occulting bodies and debris clouds. In other words, one can hypothesize rings and clouds of matter than will explain a wide variety of light curves.

Potentially much more serious are anomalies in the precession rates of binary stars. DI Herculis, for example, displays a precession rate that cannot be accounted for by the theory of relativity.

AOX1 Anomalous Precession of Eclipsing Binaries

Description. Substantial deviations of observed rates of orbital precession from those predicted by General Relativity, allowing for tidal and other "classical" effects.

Data Evaluation. A long series of accurate measurements is available for one eclipsing binary. An allusion has been found for one other case. Rating: 2.

Anomaly Evaluation. If this anomaly is confirmed by measurements of other astronomical systems, the theory of General Relativity would be sorely tried. Rating: 1.

Possible Explanations. The nonsymmetric gravitational theory proposed by J. W. Moffat correctly accounts for the DI Herculis data (X1) and also for Mercury's anomalous rate of precession.

Similar and Related Phenomena. The anomalous advance of Mercury's perihelion (AHB1).

Examples

X1. DI Herculis. This eclipsing binary has a period of 10.55 days and a high eccentricity of 0.489. During each orbital period, terrestrial observers detect two sharp dips as the stars eclipse one another. Some 84 years (about 3000 orbits) of very precise data have accumulated. "For most eclipsing binary systems, the apsidal motion is determined principally by classical effects. In DI Herculis, however, we would expect the relativistic component to be larger, because of the high eccentricity, the large total mass of the system and large separation of the two stars. The predicted apsidal advance due to general relativity is approximately 196 times the value for Mercury's orbit---2.34 degrees per century. Classical effects should contribute 1.93 degrees per century. But (E.) Guinan and (F.) Maloney have measured an apsidal motion of only 0.64 degrees per 100 years, only one-seventh the predicted amount for the combined classical and relativistic effect."(R3; R1, R2, R4-R6)

X2. Mu Scorpii. A negative precession has been observed. (R2)

References

R1. Moffat, J.W.; "The Orbital Motion of DI Herculis as a Test of a Theory of Gravitation," Astrophysical Journal, 287: L77, 1984. (X1)

R2. "Starring Moffat Theory," Science News, 125:312, 1984. (X1, X2)

R3. "Double-Star System Defies Relativity," New Scientist, p. 23, August 29, 1985. (X1)

R4. "DI Herculis Relates to Relativity," Science News, 128:105, 1985. (X1)

R5. Smith, David H.; "Testing Relativity with DI Herculis," Sky and Telescope, 71:236, 1986. (X1)

R6. Guinan, Edward F., and Maloney, Frank P.; "Apsidal Motion of the Eccentric Eclipsing Binary DI Herculis---An Apparent Discrepancy with General Relativity," Astronomical Journal, 90:1519, 1985. (X1)

Model of DI Herculis. (X1)

AOX2 Anomalous Stellar Eclipse Light Curves

Description. Eclipsing binaries with irregular light curves. The nature of the light curves suggests unseen objects, opaque clouds, incandescent rings, etc.

Data Evaluation. Due to their idiosyncracies, these irregular variables have been studied in great depth, with over a hundred scientific papers being available on some (Epsilon Aurigae). Rating: 1.

Anomaly Evaluation. Some details remain, but one can say generally that the anomalies of these peculiar variables are yielding rather easily to explanations involving dust/gas clouds. Rating: 3.

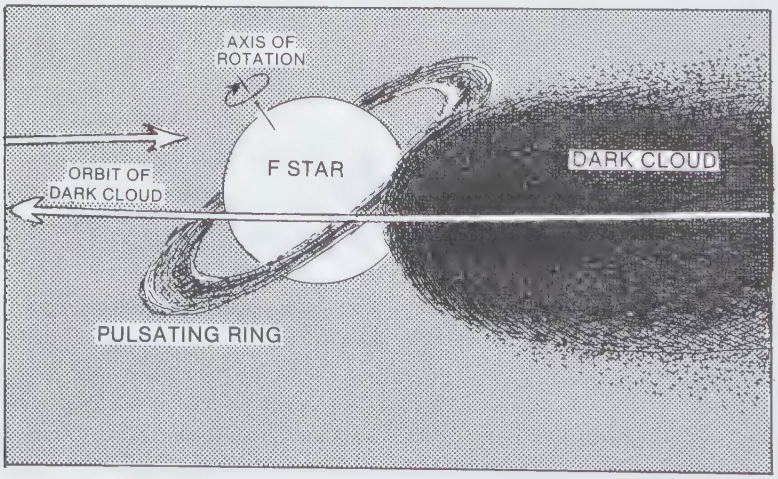
Possible Explanations. The key to accounting for anomalous light curves for eclipsing binaries is the introduction of dust and/or gas clouds, either through expulsion from one of the stars constituting the pair or perhaps through capture. This opaque matter can be tailored to size, placed in many possible positions, and even be made to vary in composition. One might term it an astronomical panacea.

Similar and Related Phenomena. None.

Examples

X1. Epsilon Aurigae. Epsilon Aurigae is one of the brightest variable stars in the heavens. An extremely luminous supergiant, class F0, it shines at magnitude 3 near Capella. Every 27.1 years, something invisible to us seems to pass in front of Epsilon Aurigae and blocks off part of its light. "At first glance the light curve looks deceptively like that of an ordinary, if extremely slow, Algol-type eclipsing binary. The star fades for four months, reaches a minimum 0.8 magnitude below normal, stays there for 14 months, and then returns to full brightness over the next four. But more than 70 years ago astronomers realized they could see no trace of light from the secondary star supposedly causing the eclipses. It seemed to be an unknown type of dark object.''..... ''In the model of Epsilon Aurigae now generally accepted, a dark, elongated body crosses the face of the F star to cause the eclipses. From its effect on the primary star's orbital motion, this dark companion seems to have a mass almost as great as the primary, or 12 to 14 Suns. Why something so massive does not shine has been at the center of the mystery."(R8)

Recently, the IRAS satellite and terrestrial observers have actually detected the postulated dark object in the infrared. To account for the eclipse data, the object must



Model of Epsilon Aurigae. (X1)

be 9 AU long, 1 AU wide, and be constituted of partially opaque dust and/or gas in its outer reaches. The dark object's great mass means that something very massive must be located somewhere in the 'cloud' holding it together gravitationally. Whatever it is, it does not generate much energy---actually only 1% of what a star of 16 solar masses should generate. Now, the core of Epsilon Aurigae's mystery is what could be inside the dark eclipsing object. (R8)

The basic data---the light curve, the spectrum of the primary, the infrared data on the dark object---still permit many interpretations. The history of Epsilon Aurigae is, in fact, littered with discarded theories. (WRC) See also R1, R3-R7.

X2. Beta Lyrae. "We have known for some time that the eclipses in Beta Lyrae could not be produced by two ordinary spherical bodies; it turns out that the two stars are very massive---about 50 and 60 times the mass of the sun---so that their mutual gravitational attractions distort them into elongated, egg-shaped figures with the long axes directed toward one another. These two stars revolve about one another in 12.9 days, each being eclipsed once in this time. The eclipses of such a model explain the grosser features of the light changes, but there are a number of things which do not fit readily into this picture. For example, in this relatively simple system of two mutually eclipsing suns, what could possibly cause their light to vary irregularly between eclipses, as is observed? Also, when the larger star, which contributes about 96% of the total light of the system, is eclipsed by its smaller companion, the light is found to fall off more rapidly when the eclipse begins than it brightens at the end. One would naturally expect the fading and subsequent brightening to occur at the same rate." The smaller star is actually invisible, its light being completely overwhelmed by that of its companion. (R1) Beta Lyrae is considered to be a contact binary. The two stars are so close that a copious stream of matter flows from the larger to the smaller. Both stars spew out streams of matter into space, according to one theory; and it is these streams that cause the irregularities in Beta Lyrae's light curve. (R1, R2)

X3. RW Tauri. "It is a faint telescopic star lying about 5 degrees northeast of the Pleiades, and is known as RW Tauri. Due to the fact that its peculiar characteristics were not recognized until a year or two ago, we do not have as complete a picture of what is going on in this star, especially from the theoretical side, as is available for Epsilon Aurigae and Beta Lyrae. Normally of the eighth magnitude (about a sixth as bright as the faintest naked-eye stars), it was found on the Harvard photographs in 1905 to be variable in its light, and investigation showed that it was an eclipsing variable, with the eclipses recurring at intervals of about 2.8 days. However, there are hundreds of such stars known, so that no particular notice was taken of it until 1933, when the late Dr. A.B. Wyse of the Lick Observatory found bright lines in a photograph of its spectrum taken during eclipse.

Now, this was something unexpected. Bright lines are not found in very many stars, being characteristic usually of such unusual objects as variable stars (not of the ordinary eclipsing variety), novae, and so forth, and usually originate in some sort of extensive atmosphere surrounding the main body of the star. Certainly, the two stars making up the system of RW Tauri seemed to be nothing out of the ordinary: the smaller, white component is both hotter and brighter than its larger, cool, orange companion. One uncommon thing about RW Tauri, however, besides these mysterious bright lines, was the fact that the main eclipse was total. Due to the relative sizes of the two stars and the tilt of their orbits, the large, orange companion completely blocked out the brighter star. When shining with full brilliancy, RW Tauri would appear about 23 times as bright as it does at mid-eclipse. This is a considerably greater change than is encountered in most eclipsing stars. For instance, Algol, the famous eclipsing variable in Perseus, is only 3 times brighter when uneclipsed than when faint." One speculation is that the smaller star of the pair is surrounded with a ring of incandescent gas. (R1)

References

R1. Herbig, George H.; "Peculiar Stars," Griffith Observer, 7:114, 1943. (X1-X3)
R2. "Evolution of a 'Freak' Star," Science News Letter, 72:132, 1957. (X2)
R3. Couper, Heather; "The Invisible Star," New Scientist, 95:262, 1982. (X1)
R4. Reddy, Francis J.; "The Mystery of Epsilon Aurigae," Sky and Telescope, 63:460, 1982. (X1)
R5. Darling, David; "Mystery Star," Astronomy, 12:66, August 1983. (X1)
R6. Croswell, Ken; "Epsilon Aurigae's Secret Companion," Astronomy, 13:60, January 1985. (X1)

R7. Thomsen, Dietrick E.; "A 'Brickbat' in the Sky," Science News, 127:154, 1985. (X1)

R8. MacRobert, Alan; "The Puzzle of Epsilon Aurigae," Sky and Telescope, 70:527, 1985. (X1)

AOX3 Sudden Onsets and Cessations of Stellar Eclipses

Description. The sudden beginning or ending of regular stellar eclipse events.

Data Evaluation. Two well-observed examples have been found; one, a rapid onset, the other, a sudden cessation. The data are skimpy but seem of good quality. Rating: 2.

Anomaly Evaluation. The ejection or capture of a cloud of obscuring matter or even large, single objects is well within the explanatory capacity of modern astronomy. Rating: 4.

Possible Explanations. See above.

Similar and Related Phenomena. Anomalous stellar eclipses (AOX2).

Examples

X1. CV Serpentis. "Much to the surprise of the astronomical community, CV Serpentis, a pair of spectroscopic binary stars which has been observed as an eclipsing system since 1949, has suddenly stopped eclipsing. L. V. Kuhi and F. Schweizer, of the University of California, Berkeley, made this remarkable discovery when they carried out detailed observations of CV Serpentis recently. They were hoping to obtain data about a secondary minimum previously seen in its regular variations. Strangely, they were unable to find any evidence for periodic variation of the spectral lines at present---either at the primary or secondary minima detected before." The explanation offered has the eclipsing star blowing off its surrounding, opaque atmosphere, leaving a tiny core that is too small to produce significant eclipse effects." (R1)

X2. NGC 2346. "From at least 1899 to 1981 November, the central star of the planetary nebula NGC 2346 did not vary in brightness. Then within a time span of roughly one orbital period, large-amplitude eclipse events were observed. Since the eclipses started, the light curve has rapidly evolved, with the general brightness of the system decreasing and the eclipse expanding to cover most of the orbital phase. This paper proposes a model for this unique phenomenon as being caused by dust grain condensation in a clumpy shell ejected by the hot subdwarf in the nucleus." (R2)

References

R1. "An Eclipsing Star Loses Its Potency," New Scientist, 47:119, 1970. (X1)

R2. Schaefer, Bradley E.; "Mysterious Eclipses of the Central Star of NGC 2346," Astrophysical Journal, 295:245, 1985. (X2)

R3. Kuhi, L. V., and Schweizer, F.; "CV Serpentis Has Stopped Eclipsing!" Astrophysical Journal, 160:L185, 1970. (X1)

AQ INTRODUCTION TO QUASARS

Key to Categories

The salient observational features of quasars (also called quasi-stellar objects and QSOs) are:

1. High redshifts
2. Starlike appearance
3. Occasional association with radio sources
4. Brightness variations on the scale of months.

From these few characteristics, an astronomical consensus has given quasars the following derived features:

1. Most quasars are located at great distances from earth (up to 15 billion light years), based upon their high redshifts.
2. Most quasars are prodigious generators of energy (up to 10,000 or more times the energy produced by a Milky Way-sized galaxy), based upon their distances and apparent magnitudes.
3. Most are of relatively small size (only light months in diameter compared to the Milky Way's 100,000 light years), based upon their rapid brightness variations and the finite speed of light.
4. Almost incredible power densities, based upon 2 and 3.

Interestingly enough, quasars would not be such fantastic objects if their redshifts were not taken as measures of their distances from earth. As this chapter will demonstrate, most quasar anomalies impact this long-standing, frequently emotional redshift controversy.

Just what are quasars, assuming they are at the distances demanded by the redshift dogma? To generate fantastic amounts of power in such small volumes we need a fantastic object: the black hole. Are quasars related to galaxies? Some astronomers consider quasars to be galaxies so distant that we cannot discern their structure, or perhaps galaxies at a different stage of evolution. This quasar-galaxy relationship is unresolved.

AQB QUASAR CLUSTERING AND ASSOCIATIONS WITH GALAXIES

Key to Phenomena

AQB0 Introduction

Quasars, it seems, may not be scattered randomly throughout the cosmos. There is evidence that they prefer the companionship of galaxies and each other. In a few instances, quasars and galaxies seem to be physically interconnected. Such associations underscore the claim that quasars and galaxies are either closely related species or, possibly, that one creates and expels the other.

Quasar-galaxy associations also add fuel to the great redshift controversy. Very simply, the physical proximity of quasars and galaxies means they are roughly equidistant from earth and, if they possess significantly different redshifts, as many pairs do, then redshifts cannot be accurate cosmological yardsticks. As one might expect, both data and interpretations are very controversial.

AQB1 Quasar-Galaxy Juxtaposition

Description. The close angular association of quasars and galaxies in numbers above those predicted by chance.

Data Evaluation. Several score quasar-galaxy pairs have been reported, many with discordant redshifts. The sampling methods and statistical approaches, however, leave much room for argument about physical significance. In other words, the reality of this phenomenon has not been well-established. Rating: 3.

Anomaly Evaluation. The far-reaching implications of quasar-galaxy pairs, in above-chance numbers, would make them highly anomalous, should such a scientific consensus develop. The first implication of angular juxtaposition is physical proximity in terms of distance measured in kilometers. In turn, this sort of proximity implies physical relationship, possibly a generic one. (Many astronomers have already speculated that quasars and galaxies possess an evolutionary relationship.) The next implication involves pairs with disparate redshifts. If both members of a quasar-galaxy pair are at the same distance from earth and have markedly different redshifts, the redshifts cannot be cosmological in nature; that is, measures of distance. Observations that would overturn such a fundamental astronomical assumption must be highly anomalous. Rating: 1.

Possible Explanations. Quasar-galaxy pairs may yet be proven chance occurrences to everyone's satisfaction. The minority view may win out, with quasar redshifts turning out to be wholly or partially noncosmological. Since some quasars are definitely not associated with galaxies, more than one kind of quasar may exist.

Similar and Related Phenomena. Other quasar-galaxy associations (AQB2, AQB4, AQB6).

Examples

X0. Introduction. The following material is presented in a historical format to emphasize the enlargement of the data base and changing interpretations.

X1. 1969. "Meanwhile, the redshift/distance relationship of quasars has received convincing support from another quarter. Dr J.N. Bahcall and Professor Martin Schmidt, of the California Institute of Technology, and Dr J.E. Gunn, of Princeton University Observatory, have recently found five quasars actually lying within nearby clusters of galaxies. The redshifts of both quasars and their associated galaxies turn out to be closely similar. In one case, four galaxies with an average redshift of 0.0949 are seen to be physically associated with the quasar B264, which has a redshift of 0.0953---pretty conclusive evidence that the redshifts of both arise from the same physical process. There is little doubt that the redshift of galaxies have a simple doppler origin. Even the one observation must go a long way to convincing cosmologists that the quasars with larger redshifts are indeed at immense distances from us." (R1) But this matter proved to be far from settled. (WRC)

1972. "A further examination of the possibility that there is a physical association between quasistellar objects and galaxies has shown that the QSO-galaxy angular separation for five QSOs which are near bright galaxies is inversely proportional to the redshifts of galaxies. This is reported by G.R. Burbidge and S.L. O'Dell of the University of California at San Diego and P.A. Strittmatter of the University of Arizona, who have examined a number of catalogues of radio emitting QSOs for significant associations with galaxies. The demonstration of a physical connexion between QSOs and galaxies would of course cast doubt on the view that QSOs are at the enormous distances indicated by their large redshifts. A new explanation would have to be found for at least part of the redshifts of QSOs." (R3)

1973. Staring with 280 radio sources, a group of astronomers came up with four cases in which strong cases could be made for the association of quasars and galaxies with discordant redshifts. (R4)

1978. A. Stockton in a study of quasar-galaxy pairs, found that 13 of 25 galaxies had redshifts within 1000 km s^{-1} of the nearby quasars. "The chance probability of eight or more such agreements, evaluated from the redshift distribution of the total sample of galaxies, is shown to be less than 1.5×10^{-6}, making the cosmological nature of QSO redshifts a virtual certainty." (R9) But see the following!

1979. "The galaxy NGC 1073 was investigated after a probable quasar was reported in one of its spiral arms. We confirm this quasar spectroscopically and report the discovery of two additional quasars at about the same distance from the center of the galaxy (< 2'). Each of the three quasars has its principal emission lines at nearly the same wavelength in the region observed. The lines are at 4480, 4555, and 4575A.

Despite this coincidence in observed wavelength, however, each line is identified with a different major quasar line and the redshifts of the three quasars turn out to be z = 0.60, z = 1.94, and z = 1.40, respectively. Previous evidence has indicated quasars to be associated with low-redshift galaxies. The maximum probability that these quasars could accidentally fall close to NGC 1073 is 10^{-3}, significant confirmation of such a physical association." (R10) The physically associated quasars all have different redshifts.

1980. 259 candidate quasars were compared with the positions of 62 bright galaxies. The number of close quasar-galaxy pairs, as predicted from a random distribution, was within one standard deviation of the number actually found. The number of quasar-quasar pairs also agreed with the number predicted by chance. "Dismissing the significance of quasar-galaxy associations on a case-by-case basis in this way has the appearance of a strained effort to defend the paradigm of cosmological redshifts. It is tempting to feel that, while a few of these associations can be explained away, surely they cannot all be dismissed. Yet we see arguments can be made that, indeed, they all should be. Note that these arguments were not forced upon us simply by prejudice in favor of cosmological redshifts. They arose because large samples of quasars now exist, such as those in the Tololo survey, that show no evidence of quasar-galaxy associations. If these associations are physically real, they have to show up in objective samples of quasars." (R13)

1981. "Abstract. Twenty-two new quasars close to galaxies are reported. Most of them are so close to companion galaxies that the probability of accidental occurrence is less that 0.01." (R15) See next item.

1982. "Abstract. Arp has assessed the probability of finding by chance 13 quasars near 34 companions to bright galaxies. A reanalysis is presented which shows that such an occurrence is 10 orders of magnitude more probable that Arp estimates. Taken at face value, the revised estimate of 10^{-7} for the probability still implies that Arp's findings are statistically significant." (R18) This analysis was in response to the foregoing research.

"Abstract. The density of quasars within R = 8-17 kpc of companion galaxies is 10-30 times the currently accepted background density." (R19)

1983. "Summary. We analyze the distribution of the separations between quasars and a complete sample of Arp's companion galaxies, in order to test the hypothesis that the observed set of separations has a very low probability of being due to chance.

The presently available data do indeed suggest that quasars are not positioned at random with respect to the companion galaxies, although at a much lower level of significance than claimed by Arp himself. In particular, if the companion galaxies around which until now a search for quasars has been conducted constitute a random set of the complete sample, then the likelihood that the separations follow the theoretical nearest-neighbour distribution for a random quasar sky is about one per cent. There are significantly more small separations than expected on the assumption of random quasars.

We present arguments that this apparent excess does not necessarily imply a real physical association of quasars and companion galaxies. Rather, the rejection of at least one of the assumptions underlying the null hypothesis of random quasars actually leaves us with several alternatives (the physical association being only one of them), from which a choice can be made only after more data become available." (R21)

1984. T. M. Heckman and colleagues studied 21 apparent companion galaxies to 15 low-redshift quasars and found the overwhelming majority of quasar-galaxy pairs had approximately the same redshifts. "Combining our data with similar data in the literature yields the following: 86% of the apparent close companions ($\lesssim$ 50 kpc projected quasar/galaxy separation) share the quasar redshift, compared to only ~40% of the more distant (in projection) apparent companions. By virtue of its direct and general nature, we believe the present data represent the most convincing evidence yet for a cosmological origin of quasar redshifts." This is from the Abstract. Later on we find: "Apostles of the noncosmological origin of quasar redshift must now... recant, or else maintain that the unknown laws of physics which fix (these) redshifts... extend (over) appreciable distances to apparently normal galaxies." (R26) In this vein, see the first item under X2.

1985. "For many years, one of the strongest pieces of evidence suggesting that many QSOs do not lie at cosmological distances has been the sequence of discoveries by Arp and others of significant numbers of QSOs lying close to bright galaxies. Statistical arguments based on the known surface densities of QSOs have led to the conclusion that far more QSOs are found close to bright galaxies than is expected from chance. Thus, this is strong evidence that they are physically associated. Because of the absence of a theory which can explain how 'local' QSOs are ejected from galaxies, and also explain the redshifts, and for other reasons, the astronomical community has chosen in large part to ignore or decry this radical result." (R28)

X2. General observations. "Burbidge and Arp are upset by what they see as a distressingly one-sided approach to the quasar redshift question by the community of astronomers. 'Observational evidence exists on both sides,' Burbidge argues, "Both sides are probably right. What is unfortunate... is the great prejudice in the field. Arp's papers and others suggesting that some quasars are nearby are held up, interminably refereed or rejected. Heckman's polemic (calling for recantation) would not be published, were it on the other side.'

If Heckman's call for recantation is meant in such 'good humor,' Arp asks angrily, 'why has telescope time been cut off for proponents of the (opposing) viewpoint?

.....

'Much is at stake,' says Burbidge. 'If it is accepted that just one large redshift is not due to the universal expansion, Pandora's box is open. Much of our currently claimed knowledge of the extragalactic universe would be at risk, as would a number of scientific reputations.'"(R27)

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AQB2 Quasar Pairs Straddling Galaxies

Description. Visual and/or radio observations of quasars located approximately equidistant on either side of a galaxy. The quasars and their redshifts are usually similar.

Data Evaluation. Only a handful of observations known, and these might be chance associations, as in AQB1. Rating: 3.

Anomaly Evaluation. The appearance of two similar quasars straddling a galaxy is similar to that of bipolar jet phenomena so common throughout the cosmos. In other words, quasars might be expelled by galaxies by the same sort of mechanism that creates jets. If so, we know little about such quasar generators. Rating: 1.

Possible Explanations. Quasars are ejected, like jets, from galaxies, perhaps in an accretion-disk configuration. A gravitational lens effect may be involved.

Similar and Related Phenomena. Other quasar-galaxy associations (AQB1, AQB4, AQB6); bipolar jet phenomena (AQO2, AOO6, AWO1).

Examples

X1. Survey results. "Abstract. Pairs of radio sources which are separated by from 2^o to 6^o on the sky have been investigated. In a number of cases peculiar galaxies have been found approximately midway along a line joining the two radio sources. The central peculiar galaxies belong mainly to a certain class in the recently compiled Atlas of Peculiar Galaxies. Among the radio sources so far associated with the peculiar galaxies are at least five known quasars. These quasars are indicated to be not at cosmological distances (that is, red shifts not caused by expansion of the universe) because the central peculiar galaxies are only at distances of 10 to 100 megaparsecs...It is therefore implied that ejection of material took place within or near the parent peculiar galaxies with speeds between 10^2 and 10^4 kilometers per second. After traveling for times on the order of 10^7 to 10^9 years, the luminous matter (galaxies) and radio sources (plasma) have reached their observed separations from the central peculiar galaxy..." (R1)

X2. Cluster A1367. "Abstract. Two stellar appearing objects, closely situated on either side of a large galaxy in the cluster A1367, were recently identified as X-ray sources by Bechtold and colleagues. Observations reported in the present paper establish that both objects are quasars of nearly identical apparent magnitude and redshifts of $z = 0.33$ and $z = 0.95$." The quasars are located at distances of r = 73" and 59" from the galaxy NGC 3842 ($z = 0.026$). The chance of accidentally finding two quasars of this apparent magnitude is less than 7×10^{-6}. (R4)

X3. General observations. "A whole class of objects, including quasars, compact galaxies, blank-field radio sources, luminous material, lines of galaxies, and companion galaxies appear to be ejected in opposite directions from the nuclei of large active galaxies." (R3)

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AQB3 Anisotropic Distribution of Quasars

Description. The nonuniform distribution of quasars in the sky. One significant concentration is in the direction of the Local Group of galaxies.

Data Evaluation. Only a few surveys and statistical studies, mostly by one person. Rating: 2.

Anomaly Evaluation. If quasars are direct products of the Big Bang, they should be distributed fairly evenly across the sky. Thus, anisotropy seems to weaken the case for the Big Bang. On the other hand. some recent Big Bang models do incorporate some nonuniformity, as required by the anisotropic distribution of galaxies. More serious is the surprising concentration of quasars in the direction of the Local Group of galaxies. The implication of a physical association between quasars and local galaxies suggests that quasar redshifts are not measures of distance. Rating: 1.

Possible Explanations. Quasar inhomogeneity is a chance phenomenon. Quasar redshifts are not cosmological. Quasars are concentrated in the direction of the Local Group of galaxies because quasars are born of galaxies.

Similar and Related Phenomena. Anisotropy of galaxy distrubution (AWB6); quasar-galaxy associations (AQB1, AQB2, AQB4)

Examples

X1. Survey results. In a survey investigating the possible association of quasars with bright galaxies. J.W. Sulentic found a strong nonuniformity in the density of quasars on the sky, which seemed unlikely to be entirely due to surveying techniques or seeing conditions. (R1) For further discussion of this survey, see AQB1-X1.

X2. Another survey. H. Arp has reported a concentration of quasars in a long, narrow strip of sky in the Sculptor region. (R2)

X3. Quasar inhomogeneity. "Abstract. In an area roughly 20^{o} x 70^{o} on the sky, there exists an excess of bright, high-redshift quasars. Quasars with this distribution of apparent magnitude and redshift have a negligible chance of being drawn from the population of quasars preseht in other areas of the sky. At a mean redshift distance corresponding to their average $z = 2$, these quasars would represent an unprecedented inhomogeneity over enormous volumes of space in the universe." (R3) The concentration is in the direction of the Local Group of galaxies.

X4. General observations on X3 and other inhomogeneities. "The concentration is in a roughly elliptical area of the sky, and if the standard redshift/distance relation is used to work out the distances this must be 1300 million light years wide and 4875 million light years long, implying a 'very marked difference inside a relatively large volume in the Universe'. Alternatively, if the redshifts are not produced solely by the expansion of the Universe, the concentration might be a local phenomenon connected with the Local Group of galaxies itself.

As with so much of Arp's work, this discovery raises questions which cannot yet be answered. But it does seem that the label 'quasar' may be being applied to two different kinds of high redshift object, one associated with the centres of galaxies and the other responsible for the discrepant redshifts painstakingly catalogued by Arp." (R4)

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R4. "Quasars and Quasi Quasars," New Scientist, p. 20, May 17, 1984. (X3, X4)

AQB4 Apparent Physical Connections between Quasars and Galaxies

Description. Quasar-galaxy pairs which seem to be directly connected physically or physically interacting. Often, the pair members have widely different redshifts.

Data Evaluation. Several intriguing examples of physical interaction have been discovered, but it is always possible to write off a few such instances as illusions or chance alignments of objects at radically different distances. There are simply not enough good examples to make a strong case at the present time. Rating: 2.

Anomaly Evaluation. As with the statistical association of quasars with galaxies (AQB1), the implication of physically interacting objects with different redshifts is revolutionary. The redshift distance relationship is a pillar of modern astronomy, and this pillar would be shattered if paired objects had different redshifts. Physically interacting quasar-galaxy pairs also suggest a generic relationship---something suspected from other evidence but not understood or proven. Rating: 1.

Possible Explanations. Galaxies expel quasars, or vice versa; i.e., one is the progenitor of the other.

Similar and Related Phenomena. Other quasar-galaxy relationships (AQB1, AQB2).

Examples

X1. NGC 4319/Markarian 205. This association was reported in 1971 by H. Arp. "A recent spectacular finding concerns the spiral galaxy NGC 4319 which seems to be contiguous with the quasar Markarian 205 (Astrophys Lett. 9, 1; 1971), although their redshifts differ by a factor of ten. The significance of this research is that it runs counter to the usual assumption that the redshift is invariably a distance indicator for extragalactic objects." (R1) This striking example of a possible physical connection between objects with disparate redshifts resulted in considerable controversy. D.W. Weedman called it "the fulcrum of the entire redshift controversy." (R7)

"In 1971 Halton Arp announced that there is a luminous connection between the two galaxies (some astronomers refer to Markarian 205 as a 'compact galaxy'), implying that they are at the same distance. If this were true, it would provide a convincing example of a large redshift that is not due to cosmological causes. There would be profound implications for our interpretations of quasars; these objects might be much closer and thus very much less powerful than generally thought. The importance to extragalactic astronomy of such a connection generated a flurry of effort to study it. The evidence was not conclusive, and astronomers variously suggested that the feature did not exist, was just the overlap of two systems, or was due to a fortuitously located intervening star or galaxy. (J.) Sulentic tested these proposals by examining all of the best available photographs of the duo, and published his results in the February 15, 1983, Astrophysical Journal. He concluded that a luminous connection between NGC 4319 and Markarian 205 does exist and, in fact, can be traced right into the central region of the spiral." (R14; R23, R24)

A more recent study of the data by Cecil and Stockton. "Our observations have convinced us that, contrary to the findings of most previous investigators (including, of the present authors, Stockton), Arp and Sulentic are correct in claiming that there is a real excess of luminous material in the region between Mrk 205 and NGC 4319. Ironically, while thus vindicating Arp's long-standing claim that the feature is real, we shall also show that its morphology, along with that of other structure in the vicinity of Mrk 205, argues fairly decisively against his interpretation of the feature as a physical connection between Mrk 205 and NGC 4319." The authors conclude that "We are indeed dealing here with a remarkable juxtaposition." (R20) That is, not a real connection.

X2. Centaurus A/quasar-like objects. "The quasar controversy (are the beasts local or 'cosmological'?) flares back into life with a report by Dr James Terrell, of Los Alamos Scientific Laboratory. He claims that peculiar objects recently found near the radio galaxy Centaurus A would look like quasars to inhabitants of that galaxy. The basis of this claim is a recent set of photographs of Cen A, obtained using the 4-m telescope at Cerro Tololo. These show 'visible filaments extending away from the galactic centre and blue starlike images never before seen near the galaxy'." (R5; R21)

X3. NGC 5296/unnamed quasar. "Abstract. During a curcory inspection of National Geographic---Palomar Sky Atlas prints a spiral galaxy, NGC 5297, and a smaller companion galaxy, NGC 5296, were noticed. A blue stellar image was looked for in the vicinity of the companion galaxy. A blue image was found, and spectroscopic measures demonstrated it to be a quasar of redshift z = 0.963. Deep photographic plates of the system obtained later reveal a luminous extension from NGC 5296 pointing to the quasar." (R6)

X4. NGC 1199/compact object. "Abstract. A high-surface-brightness emission line object of redshift cz = 13,300 km s^{-1} appears silhouetted against an E galaxy of cz = 2600 km s^{-1}. Photographs with different telescopes show that there is a circular area around the compact object that is darker than the background light of the E galaxy. Spectrophotometric observations show that this obscuration reddens as it absorbs the light of the E galaxy behind it, as would be expected of dust associated with the compact object. Absorption lines from gas at the high redshift are looked for. A probable absorption line at the place of the interstellar K line redshifted by cz = 13,300 km s^{-1} is found at exactly the expected redshift, within the $\pm$1 A accuracy of the wavelength calibration. It is concluded that the compact object is slightly in front of, but at approximately the same distance as, the E galaxy, and that most of its redshift is of origin other than Doppler motion of recession." (R8)

X5. 3C 48/unnamed galaxy. "The superb observations by Boroson and Oke reported in this issue of Nature (see p. 397) reveal that the faint nebulosity to the north and south of the quasar 3C48 is dominated by starlight and that the stars have a redshift close to that determined from the broad emission lines in the quasar spectrum. This provides the first direct evidence that a quasar is associated with a galaxy and lies at a distance corresponding to its redshift, adding to the weight of evidence against non-cosmological quasar redshifts." (R9; R22) Obviously, this observation is counter to most others in this section, particularly X7. (WRC)

X6. Quasar/galaxy survey. Abstract. "In a sample of 45 quasistellar objects (QSOs) with redshift 0.62 or less, a large fraction (>30%) appear to be currently interacting with another galaxy. All but three of the QSOs reside within nebulosity interpreted as a surrounding galaxy, and about one third have spiral galaxy characteristics. About one third appear to reside in clusters or small groups of galaxies. The present observations support the view that the QSO phenomenon is fundamentally linked to interactions between galaxies in clusters or smaller groups." (R15)

X7. 2237 + 0305/unnamed quasar. A high redshift (z = 1.7) quasar appears right in the center of a spiral galaxy with Z = 0.04. This may be the consequence of the galaxy acting as a gravitational lens. (R19) On the other hand, it could be evidence for non-cosmological redshifts in quasars. (WRC)

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AQB5 Quasar Alignments

Description. Groups of three or more quasars arranged approximately along straight lines. Alignment members often possess different redshifts.

Data Evaluation. Several linear triplets have been recorded and confirmed by independent observers. One four-quasar alignment also exists. Statistically, the number of alignments is about what chance predicts. Rating: 3.

Anomaly Evaluation. Quasar alignments, like quasar pairs, imply a common origin or perhaps some other physical relationship. If such is the case, the discordant redshifts of the quasars in the alignments cannot be cosmological; i.e., the quasars cannot be at vastly different distances from earth if they are physically related. Since the redshift distance yardstick is a vital element of modern astronomy, the anomaly value of quasar alignments is high. Rating: 1.

Possible Explanations. Quasars may be expelled from other quasars (or possibly galaxies) in opposite directions, like bipolar jets, to form quasar triplets.

Similar and Related Phenomena. Quasar pairs straddling galaxies (AQB2); quasar pairs and clusters (AQB6); quasar-galaxy associations (AQB1 and AQB4); quasar jets (AQO2); galaxy jets (AWO1).

Examples

X1. NGC 520 quasar chain. In 1970, H. Arp pointed out a conspicuous grouping of quasars in the vicinity of the exploding galaxy NGC 520. Four of these quasars lie with high precision along a straight line that originates at NGC 520. (R1, R8)

X2. Two linear triplets. "The other area is at 11h30m24s and 10°40'17" (1950) and contains two separate triplets of quasars. In each triplet a very bright quasar is at the center and two fainter quasars are aligned exactly on a straight line on either side. The redshift of the central quasar is z = 0.54 in the first case and z = 0.51 in the second case. The flanking quasars are z = 1.61 and 2.21 in the first case and z = 1.72 and 2.15 in the second case. The chances of any of these configurations being accidental is extremely small." (R2; R3, R4)

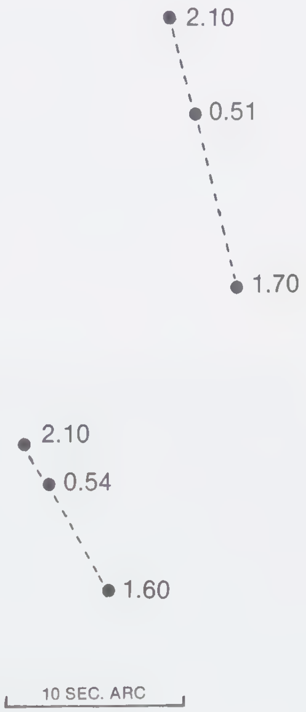

Diagram of two linear quasar triplets. (X2)

X3. Surveys of quasar lines. "Summary. We have undertaken a systematic search in two fields of quasar candidates for alignments similar to those reported by Arp & Hazard (R2) in order to test the statistical significance of these associations. Comparisons with control fields generated by a Monte Carlo technique showed that when appropriate allowance has been made for clustering there is only marginal evidence for a statistically significant excess of aligned triplets over that expected by chance. It has not, however, been possible to examine the significance of the redshift patterns found by Arp & Hazard as reliable redshifts do not exist for the majority of the quasar candidates." (R5)

Another survey of quasar triplets indicated that these alignments have a high probability of occurring strictly by chance. (R6)

Still another survey and statistical evaluation came to the same conclusion. (R7)

References

R1. Arp, Halton; "NGC 520 Chain of Quasars," Astronomical Journal, 79:923, 1974. (X1)

R2. Arp, Halton, and Hazard, Cyril; "Peculiar Configurations of Quasars in Two Adjacent Areas of the Sky," Astrophysical Journal, 240:726, 1980. (X2)

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R4. Edmunds, M.G.; "Quasar Alignments: Chance or Necessity?" Nature, 289:533, 1981. (X2)

R5. Trew, A.S., et al; "An Assessment of the Significance of Quasar Alignments," Royal Astronomical Society, Monthly Notices, 200:785, 1982. (X3)

R6. Webster, Adrian; "Do Quasar Ley Lines Really Exist?" Royal Astronomical Society, Monthly Notices, 201:179, 1982. (X3)

R7. Zuiderwijk, E.J.; "Alignment of Randomly Distributed Objects," Nature, 295:577, 1982. (X3)

R8. Arp, Halton; "Distribution of Quasistellar Radio Sources on the Sky," Astronomical Journal, 75:1, 1970. (X1)

AQB6 Pairs and Clusters of Quasars

Description. Pairs and clusters of quasars in numbers over and above chance.

Data Evaluation. Numerous close pairs and small clusters of quasars have now been recorded. Despite observational uncertainties, these groupings seem to be much more frequent than chance would predict. Rating: 2.

Anomaly Evaluation. The above-chance occurrence of pairs and clusters of quasars implies the existence of astrophysical mechanisms that can create multiple quasars. Further, if these quasar associations are at roughly the same distance and have disparate redshifts, the use of redshifts as cosmological yardsticks is undermined. Rating: 1.

Possible Explanations. Galaxies and/or quasars can expel more than one quasar. The gravitational lens effect may account for some multiple quasars.

Similar and Related Phenomena. All preceding AQB phenomena; possible quantization of redshifts (AQF2).

Examples

X1. Statistical analysis. "An analysis of 150 QSO red-shifts suggests that there are groupings of QSOs extending over large areas of sky. The inference is that QSOs are not at cosmological distances." (R1)

X2. Anomalous close quasar pair with discordant redshifts. "A very curious point is that the apparent wavelength of a given line in the spectrum of one of the quasars is almost exactly twice the wavelength of the same line in the other quasar. 'This difference...is either an unfortunate coincidence or a profound mystery.' The mystery may be, says Wampler, some unknown mechanism that splits photons. If photons can be split, the principle of conservation of energy would require doubling the wavelength. Thus the lower redshift could be due to distance. The difference between it and the larger one would come from photon splitting. But Wampler characterizes the idea as very far out, and cautions against making too much of it. 'It's just that two is a number that makes people sit up and take notice,' he says, whereas 1.69 or 2.5 would not.'" (R2; R9)

X3. General observations. "Pairs of Quasars. Stockton found the first close pair of QSOs separated by 35", with very different redshifts. He calculated a posteriori that the probability that this was due to chance was 6×10^{-3}. The next pair that was found was 1548 + 114a and b, with a separation of 5", a posteriori probability calculation gave the probability of a chance superposition $\sim 10^{-2}$. Bolton et al carried out a systematic search of 100 fields centred on flat spectrum radio-emitting QSOs from the Parkes 2,700 MHz survey. They found eight candidate QSOs within 1.7' of the radio-emitting QSOs, and have confirmed that there are at least four and probably five pairs of which at least four and probably five pairs have different redshifts. As the plate limit in these studies was B = 19-19.5 mag. the number of QSOs per square degree is about 3, and thus the number of pairs expected by chance is 0.76. Since four or five pairs are found, Bolton et al consider that the probability that this is due to chance lies in the range of $6 \times 10^{-3} - 10^{-4}$. Wills and Wills then did a similar survey in the north, searching within 2' of 100 QSOs identified in the NRAO 5,000 MHz surveys. They found two pairs and one is expected by chance. Thus from the two fields together, seven pairs have been found against the 1.76 expected by chance." (R4)

X4. Close clump of quasars. "On a U.K. Schmidt objective prism plate, C. Hazard has found two areas which contain unusual groupings of quasars. One region at 11h46m 14s and $\delta = 11°11'42''$ (1950) contains five quasars brighter than v = 19.5 mag within an 8' diameter circle. The closeness of the grouping and the closeness of four of the five redshifts indicate that these quasars are physically associated. The dispersion in redshift, however, is too great to arise from velocity dispersion in a conventional cluster of galaxies." (R5) See AQB5-X2 for the second unusual grouping mentioned above.

X5. M82 cluster of QSOs. "Abstract. Three QSOs discovered by the grism (grating prism) technique lie in the field of M82. Their similar redshifts ($z \approx 2$) and small angular separations ($\lesssim 3'.6$) suggest a physical association. A cosmological interpretation of the redshifts yields a 'cluster of QSOs' of reasonable physical dimensions of ($d = 3$ Mpc, $\sigma_V = 600$ km s^{-1}). However, the nearness ($\sim 8'$) of the disturbed galaxy M82 may suggest a noncosmological origin for the redshifts." (R6)

X6. Survey of quasar clusters. "Summary. Faint stars with ultraviolet excess are often found to be quasistellar objects (QSOs). We have formed a complete sample of such stars at the South Galactic Pole using machine measurements of UK Schmidt photographs. Statistical analysis of the stars' sky distribution shows evidence both that they are clustered amongst themselves and that they are anti-clustered with respect to faint galaxies." (R7)

X7. Statistical analyses of quasar pairs. Abstract. "Burbidge, Burbidge and O'Dell have proposed a method of statistical analysis of close pairs of quasistellar objects (QSOs) to test the null hypothesis that the redshifts of QSOs are of cosmological origin. Only two close pairs of QSOs were then known, therefore the analysis was inconclusive. Since then a number of close pairs of QSOs have been discovered and the same statistical test can be rediscussed with a greater measure of confidence. Indeed, as we show here, the probability of finding so many close pairs by chance, as required by the cosmological hypothesis, is as small as $\lesssim 10^{-4}$, depending on observational uncertainties." (R8)

P.A. Shaver, noting that other studies of quasar pairs dispute the findings of Burbidge et al (above), initiated his own study. "This discrepancy is explored here and it is concluded that the BNH sample of QSO pairs is biased by selection effects." (R10)

X8. Quasar pairs and clusters in the light of gravitational lensing. Some close quasar pairs may be created through the action of gravitational lenses. Some interesting problems have cropped up in studying this possibility. Perhaps the most puzzling situation occurs with quasar pairs that seem to be the consequence of lensing but no obvious visible lenses are to be found. J.N. Bahcall et al have reported three such instances. (R11)

V. Trimble and L. Woltjer have summarized as follows: "The seven or eight cases of gravitationally lensed QSO's now generally recognized present a number of problems. In several, no trace of the lens has yet been seen; for most of them, the number of images detected is even rather than odd, as expected for reasonable lens geometries, although additional faint images of both QSO and lensing galaxy continue to turn up; and in no case does a simple point or spheroidal lens fit the observed combination of image separations and brightness ratios.'... At present, the main reasonably firm conclusion seems to be that every lens so far identified must include a considerable percentage of nonluminous matter, which is distributed differently from the luminous material." (R12)

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R3. Setti, G., and Woltjer, L.; "Clustering of Quasars," Astrophysical Journal, 218: L33, 1977.

R4. Burbidge, G.; "Redshifts and Distances," Nature, 282:451, 1979. (X3)

R5. Arp, Halton, and Hazard, Cyril; "Peculiar Configurations of Quasars in Two Adjacent Areas of the Sky," Astrophysical Journal, 240:726, 1980. (X4)

R6. Burbidge, E. Margaret, et al; "A 'Cluster' of Quasi-Stellar Objects near M82," Astrophysical Journal, 242:L55, 1980. (X5)

R7. Shanks, T., et al; "Clustering of Quasars," Royal Astronomical Society, Monthly Notices, 203:181, 1983. (X6)

R8. Burbidge, G.R., et al; "The Statistical Significance of Close Pairs of QSOs," Nature, 317:413, 1985. (X7)

R9. Wampler, E.J., et al; "A Double Quasistellar Object," Nature, 246:203, 1973. (X2)

R10. Shaver, P.A., et al; "The Statistics of Quasar Pairs," Nature, 323:185, 1986. (X7)

R11. Bahcall, John N., et al; "Multiple Quasars for Multiple Images," Nature, 323:515, 1986. (X8)

R12. Trimble, Virginia, and Woltjer, Lodewijk; "Quasars at 25," Science, 234: 155, 1986. (X8)

AQF ANOMALIES DETECTED THROUGH QUASAR RADIATION

Key to Phenomena

AQF0 Introduction

The electromagnetic radiation received from quasars informs us that they are all redshifted, often by large amounts. This fact highlights the most crucial of all quasar anomalies: the quasar energy paradox. If the quasars are far away, we have great difficulty in explaining their prodigious outpourings of energy; if they are nearby, our cosmological measuring rod, the redshift, has failed us.

Other problems that seem less serious at the moment are those of multiple absorption lines, rapid variation of quasar luminosity, and the possibility of two separate populations of quasars---faint and bright.

AQF1 Initial Increase of Bright Quasars with Redshift

Description. The rapid increase in the number density of bright quasars with increasing redshift. Faint quasars are excluded here; see AQF4.

Data Evaluation. All surveys of bright quasars and statistical analyses agree upon the reality of this phenomenon. Rating: 1.

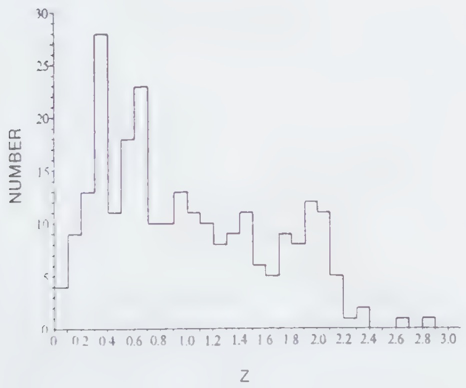
Anomaly Evaluation. A reasonable explanation of this phenomenon is given below in the context of current paradigms and scientific philosophy. Rating: 4.

Possible Explanations. First, one assumes that quasar redshifts are proportional to their distances, and that we are seeing quasars that are increasingly youthful as redshifts increase. Next, one postulates that the Big Bang initially populated with universe with a uniform population of quasars, which possessed short lifetimes. Thus, the region immediately surrounding the earth would seem to have few quasars because they have died off. Farther out---at higher redshifts---the quasars are more youthful, and we see more of them. Note that if quasar redshifts are noncosmological and quasars are a local phenomenon, the earth would be at the center of a quasar-less region. Such geocentrism is much-to-be-avoided in modern scientific philosophy---although it could be true.

Similar and Related Phenomena. The flat distribution of faint quasars (AQF4); possible quasar redshift quantization (AQF2); the rarity of quasars with very high redshifts (AQF3).

Examples

X1. 1973 survey of 237 quasars. See the accompanying figure. (R1)



Histogram of 237 quasar redshifts. The drop-off beyond z = 2 is clearly visible. (X1)

X2. Palomar Bright Quasar Survey, 1982. "Their survey shows that the density of quasars rises rapidly with increasing redshift. (M.) Schmidt points out that if quasars were actually close by, with redshifts caused by something other than cosmic expansion (as some astronomers have suggested), the Milky Way would have to lie at the center of a quasar-free hole. In other words, he said at the AAAS meeting, the earth would have to occupy a privileged position in the universe, which violates everything astronomers have learned since Copernicus. Schmidt, like most astronomers, chooses to believe instead that quasars lie far away." (R4)

X3. General observations. "The extreme evolutionary behavior exhibited by quasars has long been considered to be one of their most remarkable and puzzling properties. Briefly stated, the space density of quasars, considered as 'events' of brief duration on a cosmological time scale, is apparently a very rapidly increasing function of redshift; alternatively, one can consider the luminosity function to be similarly evolving. It has recently been suggested, following the discovery of gravitational lensing of two quasars, that quasar evolution may, in fact, be due in large part or perhaps wholly to the effects of gravitational lensing. Such an idea holds considerable appeal over the usual space density evolution picture because it avoids both the arbitrariness and the uncomfortably rapid time scale associated with the latter; it seems peculiar (if not anti-Copernican), for example, that the number density of quasars should have been greater than at present by a factor of e at the relatively recent epoch of $z = 0.1$, as required by the density evolution law given by Schmidt." (R3)

References

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R2. Green, Richard F., and Schmidt, Maarten; "Evidence for Nonuniform Radial Distribution of Quasars, Regardless of the Nature of Their Redshifts," Astrophysical Journal, 220:L1, 1978.

R3. Chanan, Gary A.; "Do Quasars Have Cosmogonically Long Lifetimes?"

Astrophysical Journal, 252:32, 1982. (X3)
R4. Waldrop, M. Mitchell; "A Boundary for the Quasars?" Science, 215:388, 1982. (X2)
R5. Thomsen, Dietrick E.; "Quasar Evolution: The Fate of the Brightest," Science News, 124:253, 1983. (X2)

AQF2 Quantization of Quasar Redshifts

Description. The clustering of quasars near specific values of redshift. This clustering may be periodic or follow some more complex rule.

Data Evaluation. Early plots of quasar number versus redshift seemed to show peaks at multiples of 0.061, especially at 1.95. Later, though, in the middle 1970s, statistical doubt was cast upon this phenomenon. However, since some astronomers now maintain that galaxies display redshift quantization, and quasars may be closely related to galaxies, it seems wise to retain this category; even though the quasar data at hand are not very convincing. Rating: 4.

Anomaly Evaluation. The quantization of quasar redshifts would imply either the clustering of quasars at particular distances from earth or that quasar redshifts are intrinsic to these objects and not cosmological; i.e., not measures of distance. Both of these possibilities are contrary to major astronomical dogmas. Rating: 1.

Possible Explanations. As explained in X2, below, no anomaly seems to exist, although future studies may alter this.

Similar and Related Phenomena. The redshift quantization of emission-line galaxies (AWF8); the applicability of quantum mechanics to astronomy.

Examples

X1. Burbidge's early suggestions. "Dr. Burbidge reported last year that there was an anomaly in the quasar red shifts. A number of them appeared to group around a single figure, 1.95, indicating that they were all at exactly the same distance from earth. That, said Dr. Burbidge, is too much to believe. Instead, he suggested, the huge shift in frequency could come something intrinsic in the quasars, rather than from their velocities. Now, Dr. Burbidge finds that there 'appears to be a significant red shift peak,' not only at 1.95 but also at 0.06. He has also discovered a suggestion of peaks in the red shifts of some 45 out of a total of 90 objects surveyed at various multiples of 0.061. If these objects were distributed randomly throughout the heavens---a fairly logical assumption ---there wouldn't be any significant peaks." (R1) This was in 1968.

1973. "The existence of peaks (at 1.96 and 0.061) and periodicities in the redshift distribution of QSOs and related compact emission-line objects has been discussed over several years. The most recent investigation involving 346 redshifts suggests that the reality of the clearly visible sharp peaks at 1.95 and 0.061 is questionable from a statistical standpoint, but that a periodicity in the distribution with a wavelength of 0.031 ($\approx 0.061/2$) is highly significant. The existence of sharp peaks or periodicities is difficult to understand in terms of conventional cosmological models, and the existence of any such features suggests a non-cosmological origin for the redshifts of the QSOs and related compact emission-line objects. In this case these numeralogical effects must arise due to the intrinsic properties of the objects." (R4)

X2. Results of surveys. "I conclude that bumps on the red-shift distribution curves can be interpreted as source groupings only and not a red-shift quantization. No evidence for an intrinsic red-shift quantization has been found; instead, red-shift seems to be a function of position in the cluster. No selection effect in known which could produce the red-shift-angular distance relation observed.

But there are several characteristics in the data that do not seem to agree with a cluster interpretation. For example, it is difficult to imagine, in view of the fact that no quantization is apparent, why there might be a periodicity in the red-shift distribution, and also why the bumps in the 0 h direction have about twice the period and twice the dispersion observed for the 12 h direction. The fact that the same 'magic numbers' are observed throughout is also difficult to explain on this basis. One is tempted to suggest that something local (the galaxy, for example) is influencing the observations, but this explanation seems equally hard to accept. I do feel, however, that there is a non-random character in the red-shift that must be interpreted before the true nature of the red-shifts in QSOs can be explained." (R2)

"(R.C.) Roeder notes that the quasar redshifts cluster about values at which particularly bright emission lines are shifted from the ultraviolet into the visible range in which the spectra are recorded. He suggests therefore that the measured redshifts are not a random sample but a selective one that favors redshift values that bring particularly bright lines into the visible range." (R7; R3, R9)

"Dr. K.G. Karlsson, of Uppsala University, has found no less than five peaks at particular redshifts. These critical values at which redshifts congregate form a geometric series, and it is particularly interesting that the most recently determined redshifts lie close to one or other of the peaks." (R8; R6, R9)

"Abstract. A search has been made for peaks and periodicities in the redshift distribution of a sample of quasars and emission-line galaxies independent of that used in earlier work. In agreement with the results of Burbidge and O'Dell, no statistically significant peak was found at a redshift of 1.95, nor any significant periodicity in redshift in either the sample of quasars alone or the sample of quasars and galaxies together. The strong spectral power peak in their distribution of galaxy redshifts, estimated at a confidence level of 97.5 percent, is completely absent in the present analysis. We therefore conclude that the observed redshift distribution is consistent with a random sample of discrete values from a smooth, aperiodic underlying population." (R5)

More recent studies of galactic redshifts show quantization, according to some. The subject is highly controversial. See AWF8. (WRC)

References

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R6. Karlsson, K.G.; "Possible Discretization of Quasar Redshifts," Astronomy and Astrophysics, 13:333, 1971. (X2)

R7. "Quasar Redshifts Not Random," Science News, 100:264, 1971. (X2)

R8. "Quasar Redshifts Seem to Come in Bunches," New Scientist, 51:612, 1971. (X2)

R9. "Selection and Redshifts," Nature (Physical Science), 233:65, 1971. (X2)

AQF3 Possible Redshift Cutoff for Quasars

Description. The apparent disappearance of quasars beyond a certain value of redshift. Originally, this cutoff was thought to be about 2, but it was soon raised to 3.5, and it is now obvious that this value is too low.

Data Evaluation. Hundreds of quasars have now been measured for redshift. The data are considered excellent. Here, however, we are trying to establish the nonexistence of quasars beyond a certain value of redshift. This is difficult, doubly so because higher-redshift quasars are always being found. We cannot say now with any confidence that a cutoff exists. Rating: 3.

Anomaly Evaluation. Some reasonable explanations for the scarcity of high redshift quasars and also the existence of a cutoff level have been proposed. (See below.) In this context, this phenomenon is not particularly anomalous. Rating: 3.

Possible Explanations. The presence of an intergalactic absorbing medium may prevent us from detecting high-z quasars. On the other hand, if redshift is a measure of distance and high redshifts mean that we are looking at the early universe, we may see a universe in which quasars have not yet been created. Of course, we then have to explain why this is so.

Similar and Related Phenomena. The initial increase of quasar density with redshift (AQF1).

Examples

X1. General observations, 1969-1973. "Two facts about quasar redshifts that cry out for explanation are the large fraction clustered around z = 2, and the apparent cutoff in the distribution beyond z = 2. Dr. Martin Rees of Cambridge's Institute of Theoretical Astronomy now suggests that the absence of quasar redshifts substantially larger than z = 2 may indicate the presence of an absorbing intergalactic gas.

Suppose the density of quasars increases rapidly with higher red shift: as we look deeper into space (that is, to areas with bigger redshift) we are also going back in time, and examining earlier epochs in the universe. Perhaps there were many more quasars in the early universe. Taking this view, we expect to see the number of objects with given z to grow rapidly as z increases. This certainly happens until we reach z = 2, but after that there is virtually nothing. If absorption of quasar light by intergalactic hydrogen is important beyond z = 2, then the quasars further out will be invisible." (R1) See figure in AQF1-X1 for quasar distribution with z as of 1973. (R3)

"About 1 year ago, Allan Sandage pointed out that quasars seemed to run out beyond a distance indicated by a red shift of 3. Now that it is clear that quasars definitely exist with red shifts greater than the proposed limit, does it prove there is no well-defined time when the matter in the universe began to shine? Sandage thinks not. The real significance of the red shift limit, he says, is that there are no examples of red shifts of 6, 8, or 10. The 'limit' of 3 has only been exceeded by 5 or 10 percent so far, and the change in the 'lookback' time is even smaller." (R2)

X2. The Palomar Bright Quasar Survey. "Surprisingly, the count found no quasars with a redshift greater than 3.53 (that is, with their spectral wavelengths shifted by more than 353 percent). An extrapolation of the numbers found at smaller redshifts implies that (M.) Schmidt and (R. F.) Green should have seen plenty of quasars beyond 3.53. So translating redshifts into distance and time, this boundary probably marks the era when quasars first turned on, Schmidt said. If so, it happened about 5 billion years after the big bang." (R4; R5)

X3. Quasar with z = 3.8. The quasar 1208 + 1011 possesses a redshift of 3.8. This and other high-z quasars, though few in number, demonstrate conclusively that the proposed cutoff at z = 3.5 is nonexistent. (R7)

X4. Quasars with z = 4 and up. "British astronomers in Australia last week recorded the spectrum of the most distant object ever observed. The object, a Quasi-stellar Object, or QSO, is the first to be found with a red shift greater than four; 4.01 to be exact. Only three objects are known with red-shift as high as 3.8 and many astronomers had begun to think that none would be found further away." (R8)

References

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R2. Metz, William D.; "Quasars: Are They Near or Far, Young Galaxies or Not?" Science, 181:1154, 1973. (X1)

R3. Burbidge, G. R.; "Problems of the Redshifts," Nature (Physical Science), 246: 17, 1973.

R4. Waldrop, M. Mitchell; "A Boundary for the Quasars?" Science, 215:388, 1982. (X2)

R5. Rowan-Robinson, Michael; "The Great Quasar Odyssey," New Scientist, 96:

305, 1982. (X2)
R6. "Astronomers Look Back to the Birth of Quasars," New Scientist, 99:267, 1983. (X2)
R7. Hazard, C., et al; "A QSO with Redshift 3.8 Found on a UK Schmidt Telescope IIIa-F Prism Plate," Nature, 322:38, 1986. (X3)
R8. Chown, Marcus; "Astronomers Break the Red-Shift Record," New Scientist, p. 22, August 28, 1986. (X4)

AQF4 Flat Distribution of Faint Quasars

Description. The fairly flat distribution of faint quasars with increasing redshift. By comparison, bright quasars rapidly become more numerous with larger redshifts.

Data Evaluation. At least two surveys are at hand. However, emphasis has historically been on the bright quasars, so that faint quasars have not been looked for diligently. Rating: 2.

Anomaly Evaluation. The striking difference between faint and bright quasars suggests that two separate quasars populations exist, each with its own evolutionary history. Since we do not yet really know what "ordinary" quasars are, the discovery of two populations compounds the anomaly. Rating: 1.

Possible Explanation. None.

Similar and Related Phenomena. The increase of bright quasars with redshift (distance)(AQF1); the existence of two or more populations of stars (AOB14).

Examples

X1. The Palomar Bright Quasar Survey. "The survey, combined with several earlier ones, yielded statistics that show both that there were more quasars in the distant past and that there were more luminous ones too. The total number of quasars increases with increasing distance (AQF1). As one looks farther and farther back, the rate of increase for bright quasars gets larger and larger, but the faint quasars appear not to increase at all. Thus this is evidence for two classes of quasar, the bright and the faint, that behave differently with respect to evolution over time. (M.) Schmidt and (R. F.) Green say they now want to study overall distribution of the energy output of these 92 quasars in order to learn details of how this evolution goes." (R1)

"The very faint quasars are turning out to have moderately low redshifts, indicating that they are relatively nearby quasars which are intrinsically dim. Astronomers are finding the odd situation that a search for fainter examples of a class is revealing nearer, rather than more distant objects! Schmidt describes the results as 'a big surprise'." (R2) If the quasar redshifts were not cosmological, there would be no 'surprise'. (WRC)

References

R1. Thomsen, Dietrick E.; "Quasar Evolution: The Fate of the Brightest," Science News, 124:253, 1983. (X1)
R2. "Astronomers Look Back to the Birth of Quasars," New Scientist, 99:267, 1983. (X1)

AQF5 The Quasar Energy Paradox

Description. The paradox: If quasars are far away, as required by their large redshifts, and also very small, as implied by their rapid fluctuations, their huge energy densities sorely try astrophysical theory. On the other hand, if quasars are actually close---a situation that greatly alleviates the power generation problem---their redshifts cannot be cosmological; that is, measures of distance. At present, theorists prefer to try and solve the power generation problem rather than jettison their cosmological yardstick.

Data Evaluation. Quasar observations are abundant. Considerable telescope time has been applied to this problem. The data are excellent; the problem is interpretation. Rating: 1.

Anomaly Evaluation. The quasar energy problem is one of the fundamental anomalies of astronomy---a Catch 22 situation. Rating: 1.

Possible Explanations. Black holes are offered as quasar energy sources by most astrophysicists. However, the reality of black holes is still being debated.

Similar and Related Phenomena. The same paradox prevails for other compact luminous objects, such as the Seyfert galaxies (AWF2) and the unidentified objects near the center of our own galaxy (AOF3). Also pertinent are the apparent superluminal velocities measured for some quasars (AQO3).

Examples

X1. General observations. 1970. "Starting with the discovery of radio galaxies in the mid-1950's, astronomers have shown that many types of galaxies and (since 1963) quasars release more energy than can be accounted for by known physical processes. From the beginning theorists have postulated that some form of gravitational energy or matter-antimatter annihilations must be involved in energy production, but observational astronomers have continually placed tighter restrictions on the theories by showing that the energy is greater and the size of the objects is smaller than previously believed. As a result no theory has emerged that has gained the confidence of the astronomical community." (R1)

1978. "The luminous power of quasars is so great that black holes with masses between 10^7 and 10^9 times the mass of the sun would be required to produce the energy that is emitted from them. Martin Rees's 'best buy' theory of quasars, in more detail, is that they consist of black holes with a mass about 10^8 times the mass of the sun in the centers of giant galaxies, with fuel being supplied by the 'capture of gas---or even entire stars ---from their surroundings.' (The brightest quasars are 100 times brighter than giant elliptical galaxies, which are the brightest 'normal' galaxies in the universe.)"

.....

"The size of galactic nuclei is another key characteristic that coincides well with black holes. The most highly resolved radio measurements show that galactic nuclei are less than 30 lightyears across. The rapid fluctuations in the output of active galaxies, particularly BL Lacertae and the most violent quasars, indicate the size may be light-months or -days across. The nuclei are therefore 1 millionth or less the size of a giant elliptical galaxy. Black holes, being the most compressed form of matter known, would be appropriately small." (R5)

From a 1986 overview: "Recent models have largely concentrated on single black holes of 10^6 to 10^{10} $M_\odot$ ($M_\odot = 2 \times 10^{33}$ g, the mass of our sun). These can supply continuous gravitational energy either by accretion of gas from their surroundings of by magnetic extraction of their rotational kinetic energy." Some of the reasons for favoring the black hole model include: (1) the extremely rapid variations in luminosity; and (2) outbursts with total energies exceeding that obtained by converting the mass of an entire star into energy. (R11)

X2. S50014 + 81. This quasar has a large redshift, z = 3.4. The emission lines in its spectrum are shifted 340% from their laboratory values. "Such a large redshift implies that this quasar lies at an enormous distance ---over 10 billion light years---yet it has the surprisingly bright apparent visual magnitude of 16.5. Adopting a value for the Hubble parameter of 50 km per second per megaparsec leads to an absolute visual magntiude of -33! This is brighter than any quasar, including even such 'optically violent variables' as 3C273 and 3C279. Our own Milky Way, which is a fairly typical large spiral galaxy, has an absolute visual magnitude of about -21, which means that S50014 + 81 outshines it by some 60,000 times." (R8)

References

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R6. Rowan-Robinson, Michael; "The Great Quasar Odyssey," New Scientist, 96:305, 1982. (X3)

R7. Turner, Edwin L.; "Quasars and Gravitational Lenses," Science, 223:1255, 1984. (X3)

R8. "Quasar, Quasar, Burning Bright," Sky and Telescope, 68:15, 1984. (X2)

R9. Sulentic, Jack W.; "Are Quasars Far Away?" Astronomy, 12:66, October 1984.

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AQF6 Absence of Blueshifted Quasars

Description. The completely unsuccessful search for blue-shifted quasars.

Data Evaluation. Quasars searches have been extensive, employing a wide spectrum of instruments and facilities. Result: no blue-shifted quasars. Rating: 1.

Anomaly Evaluation. Actually, no anomaly exists here, because the current quasar paradigm requires all quasars to move away from us as part of the general expansion of the universe---i.e., they should all be redshifted. We retain this anomaly category for two reasons: (1)It is still curious that not a single aberrant blue-shifted quasar has ever been found; and (2) The absence of blue-shifted quasars is not incompatible with some models of local quasar generation. Rating: 4.

Possible Explanations. One theory has all quasar radiation generated in a single direction---backwards---so we see only receding quasars.

Similar and Related Phenomena. Blueshifted galaxies (AWF11).

Examples

X1. General observations. In 1966, G. Burbidge and F. Hoyle hypothesized that quasars were ejected from galaxies with active nuclei within about 300 million light years. This hypothesis immediately faced a serious drawback: the blue-shift catastrophe. "If an active nucleus is ejecting quasars randomly in all directions then, if we are far enough away, we should see some quasars moving away from us and some moving towards us. Because of the doppler effect, the latter class of quasars would show blue shift. What is more, the light reaching us from an approaching quasar would be enhanced in intensity because of the blue shift. The light from a receding quasar by contrast gets attenuated by red shift. Therefore we are more likely to pick up quasars with blue shift than with red shift. Detailed calculations by Peter Strittmatter in 1966 showed that we ought to be able to see perhaps 80 times as many blue shifted as red shifted quasars. In actual fact, no blue shifted quasars have yet been found." (R1)

References

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AQF7 Anomalous Redshifts of Quasar Absorption Lines

Description. The presence in quasar spectra of redshifted absorption lines, sometimes several sets, that differ among themselves and from the emission lines in redshift. The redshifts of the emission lines are always greater than those of the absorption lines.

Data Evaluation. Originally, this "thicket" of redshifted absorption lines was difficult-to-decipher, but better techniques and careful study have verified the basic phenomenon repeatedly. Rating: 1.

Anomaly Evaluation. The presence of multiple redshifts from the same object led initially to wild speculation, much of it involving intergalactic matter. Today, most observers consider that several moving clouds of matter, all located near the quasar under observation, create the multiple redshifts seen in the absorption lines. Often, however, the differences in the redshifts of emission and absorption lines are large, implying extremely high relative velocities. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. Quasar jets (AQO2).

Examples

X1. General observations, 1969. "One of the most enigmatic and much debated problems of extra-galactic research is the nature of quasar redshifts. Historically the redshift has always been taken as an indicator of velocity, and of the general expansion of the universe. The trouble with quasars is that they often have more than one redshift. After the spectrum of a quasar is obtained, groups of lines are generally identified with transitions that are well-known from atomic physics. The wavelengths of lines in the quasar spectrum are measured and compared with the rest wavelength of lines from the same atomic transitions. In this way, the Doppler redshift caused by the object's recessional velocity can be measured.

The bright emission lines in quasar spectra usually give a unique value for the redshift---the trouble lurks in the dark absorption lines. When these are used to find a value for the redshift it often differs from the value for emission lines. Why this should be so is not at all clear; if the redshift really is an indicator of velocity, then it means the layers of gas emitting light are moving at vast speeds relative to those absorbing light. If all the emission and absorption actually occurs in the quasi-stellar object, then a complicated and implausible model of quasars is implied.

Recently a distant quasar, PKS 0237-23, was found to need five redshifts to explain the absorption line spectrum adequately." (R4)

By 1969, several explanations of multiple absorption lines were in existence: dead galaxies at different velocities (R4); fractional charges on atomic particles (R2); the passage of quasar light all the way around the universe to create multiple spectra (R3). None of these is taken seriously today. (WRC)

X2. General observations, 1973. "In the past seven years the phenomenon of multiple red shifts in the spectra of QSOs has been discovered. What is found is that in many QSOs, largely those with emission red shifts >1.8, many absorption lines are present. These are identified as absorption redshift systems and in most, but not all, cases $z_{abs} < z_{em}$. In many objects several different redshifts are seen. I shall not discuss these data in detail or possible interpretations, as they have been described elsewhere. In most cases it is accepted that both emission and absorption systems arise in the QSO, so that the difference is in some sense intrinsic to the objects. There is no object in which a good case can be made for the hypothesis that absorption is due to foreground intergalactic gas clouds, or other galaxies, though many have made this proposal. In fact the balance of the evidence favours the view that the absorption lines arise in, or very close to, the QSOs, even in the cases in which ($z_{em} - z_{abs}$) is large." (R7)

X3. General observations, 1984. "The origin of the broad-line clouds is one of the major mysteries of quasars. The gas has a relatively high density, intermediate between normal gaseous nebulae and the density of the outer layers of stars, and a chemical composition not very dissimilar from stars such as our Sun, but these facts tell us very little. It is the motions of the clouds that are potentially the most important indicators of their origin. In the past all possible kinematic conditions have been given serious consideration---rotation in a disc, random orbits, infall and outflow---but it is the radiative acceleration theory that has been worked out in the greatest physical detail. Although it is by no means completely settled there is mounting evidence that the broad-line clouds are indeed preferentially outflowing (rather than orbiting or infalling)." (R11) In other words, clouds of matter ejected by the quasar creates the myserious absorption lines. (WRC)

References

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R3. "Quasar Light May Have Passed This Way Before," New Scientist, 41:81, 1969. (X1)
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R10. "Strange Quasar Spectra," Sky and Telescope, 62:418, 1981.
R11. Gaskell, Martin; "The Origin of Gas in Quasars---Reverse Stellar Evolution?" Nature, 307:210, 1984. (X3)

AQF8 Quasar Variability: Origin and Implications

Description. The rapid, large-scale variation in the energy radiated by some quasars. Substantial intensity variations may occur on a scale of a few minutes. Visual magnitudes may change by 5. Some variations are periodic; others, unpredictable.

Data Evaluation. Variations have been detected in only a handful of quasars. While the general phenomenon seems undeniable, much more research is needed. Rating: 2.

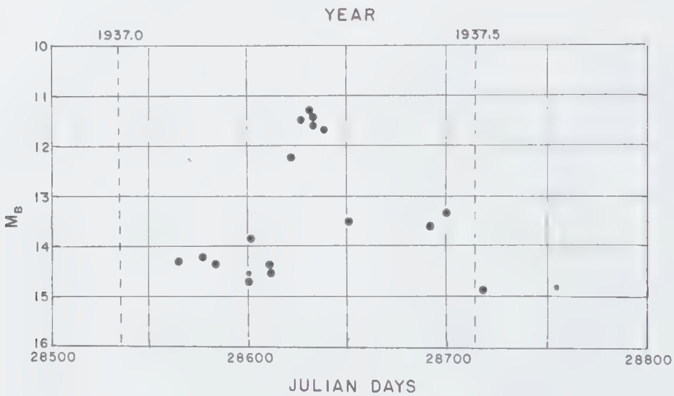
Anomaly Evaluation. Rapid changes in quasar intensity give rise to two serious problems of explanation: (1) The rapid variations imply that the quasar emission areas are only a few light minutes in extent and, consequently, the energy paradox much more severe (AQF5); (2) Quasar energy variations by one or two orders of magnitude are difficult-to-explain in proposed quasar models.. Rating: 1.

Possible Explanations. As in the case of quasar superluminal velocities (AQO3) and the quasar energy paradox (AQF5), explanation would be easier if quasars were near by.

Similar and Related Phenomena. The quasar energy paradox (AQF5); superluminal velocities (AQO3).

Examples

X1. 3C 279. "In April of 1937, quasar 3C 279 intensified very quickly from its normal optical brightness of 15th or 16th magnitude until it reached a maximum brightness of magnitude +11.3. The quasar is thought to be more than 5 billion light-years away, assuming that its red shift (0.536) is equally as good a measure of distance as are the red shifts of normal galaxies. At such a distance the absolute magnitude of 3C279 at the peak of its flare must have been -31.4. (The magnitude scale of optical brightness is logarithmic, with negative values brighter than positive ones, and five magnitudes equivalent to a factor of 100). At such a high optical luminosity, the quasar would have been emitting 10^{48} erg/sec." For comparison, the absolute magnitude of the sun is +4.7; the entire Milky Way, -20; a very bright quasar, -26. The 3C 279 flare was equivalent to turning thousands of giant galaxies on suddenly and then shutting them off. (R1) As the author admonishes us, these figures depend upon the redshift distance scale. (WRC)



Changes in optical brightness of quasar 3C279 in 1937. (X1)

X2. 1525 + 227. "On January 23, 1980, 1525 + 227 was looked at for approximately 1,600 seconds, recording photons with energies from 100 to 2,100 electron volts. Only 107 photons were detected during this interval, but statistical analysis indicates variability on a time scale of 200 seconds. Because of the unusual results obtained in 1980, the quasar was observed again on March 6, 1981. This time, however, 12,500 seconds of data showed no indication of rapid variability." (R2)

X3. 4C 29.45. April 8, 1981. This quasar faded gradually by 0.3 magnitude in blue light and, in addition, flickered by 0.1 magnitude or so over intervals of 20-30 minutes. Two nights later, nearly instantaneous brightness jumps of 0.2 magnitude were observed. (R3)

References

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R2. "The 200-Second Quasar," Sky and Telescope, 64:412, 1982. (X2)
R3. "A Quick Quasar," Sky and Telescope, 68:115, 1984. (X3)

AQF9 Unresolved Nature of Blazars (BL Lacertae)

Description. The unexplained origin, evolution, and exact nature of the bright, quasar-like objects with very weak emission lines called blazars or BL Lacertae. Blazars are usually highly variable and located within galaxies. In contrast, quasars generally do not seem to be embedded in galaxies, although this is very controversial (AQO1).

Data Evaluation. Blazars have been very popular objects of astronomical research. The data are abundant and detailed. Blazars or BL Lacertae, however, are rare objects and difficult to study due to their distances and very weak emission lines. Rating: 2.

Anomaly Evaluation. Most astronomers now consider blazars to be extreme or transitional varieties of quasars and/or, perhaps, "ordinary" quasars seen at some special orientation with respect to earth. Just what these special forms and orientations of quasars might be are puzzles superimposed upon the main quasar anomalies discussed elsewhere in this chapter. In sum, blazars are a bit more anomalous than quasars. Rating: 1.

Possible Explanations. The best-received theory states that blazars are really quasars that are oriented such that terrestrial observers are "looking down a gun barrel". In other words, we may be looking into a polar radiation cone.

Similar and Related Phenomena. Large, rapid quasar variations (AQF8).

Examples

X1. General observations. "There is also a large group of starlike objects that have all the other properties of quasars except that they do not show any spectral lines and so do not have known redshifts. This is a dramatic difference, of course. Such objects are called BL-Lacertae-type objects, or Lacertids, in honour of the prototype, the variable BL Lacertae. Typical of the confusion generated by hindsight is that this prototype is now known to be surrounded by a faint nebulosity that may be a galaxy, but whose questionable nature has absorbed nights of observing time and pages of journals while creating substantial ill will. The first Lacertids were also radio sources, but the connotation has now broadened to include any starlike object with only a continuous spectrum, although some more rigorous opinions hold that the object should also be variable to be called a Lacertid. Clearly, there is little evidence as to just what Lacertids are, but some astronomers already call them quasars." (R2)

X2. The outlook two years later, in 1978. "The developments of the past year and a half have erased these uncertainties and caused astronomers to rethink the role of BL Lacs altogether. BL Lacs have been found to have faint but observable spectral lines and they have been shown to lie in galaxies. Even Burbidge now accepts the conclusion that BL Lacs are at cosmological distances. Thus energy production in BL Lacs must now be seen as a problem at least as challenging as that of energy production in quasars."

The presence of spectral lines, weak though they may be, have made the BL Lacertae even more quasar-like---perhaps "an extreme form of quasar." To underscore the energy problem, in 1975 a BL Lacertae flared up and was for several months the most luminous object in the known universe. (R4) Note, however, that quasars in general have not been shown to be components of galaxies to everyone's satisfaction. See, for background, quasar fuzz (AQO1). (WRC)

X3. 0845 + 51W1: a quasar/blazar (BL Lacertae? "The radio source 0845 + 51W1 has been behaving very strangely. Originally identified as a 19.5 magnitude star, it was found to be nearly four magnitudes brighter only a month later. It had all the characteristics of a blazar (BL Lacertae), including the absence of spectral lines, but as it gradually faded back down below 19th magnitude, emission lines typical of a quasar began to appear. These lines indicated a redshift of 1.86, the highest yet found in a blazar, but not unusual for quasars. Unlike quasars, though, 0845 + 51W1 turns out to be rather red in color---even more so when it is at its faintest." 0845 + 51W1 lies suspiciously close to two interacting galaxies which, however, have redshifts of only 0.07. Is 0845 + 51W1 a peculiar, distant BL Lacertae or a strange variety of quasar? "Could it be a 'missing link' between quasars and blazars?" (R5)

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AQO QUASAR MORPHOLOGY AND COMPONENT DYNAMICS

Key to Phenomena

AQO0 Introduction

Unlike most stars, quasars exhibit some structure, both at optical and radio wavelengths. Through the optical telescope, quasars seem surrounded by nebulous halos---the "quasar fuzz". This fuzz may be the stars of surrounding galaxies, but this is not yet certain. The radio telescope reveals lobes adjacent to the quasar proper, often one on either side. But other quasars have lobes on one side only; still others have highly asymmetric pairs of lobes. These structures are not well-explained. The discovery that some of these radio structures are separating at speeds greater than that of light would seem to compound the problem greatly, but fortunately these "superluminal velocities" seem to be illusory.

AQO1 Quasar Fuzz: What Is It?

Description. A halo-like nebulosity surrounding most low-redshift quasars. High-redshift quasars do not show fuzz, perhaps because they are too far away and the fuzz is not visible. Fuzz spectra resemble those of stars in most cases, but some fuzz spectra have been interpreted as originating in a cloud of gas surrounding the quasar. Quasars and fuzz usually have the same redshifts.

Data Evaluation. Quasar fuzz is faint in comparison to the quasar's light and is difficult to study for this reason. Even so, several dozen quasar halos have been studied spectroscopically. Unfortunately, diverse interpretations exist, so we cannot say that a general consensus exists as yet. Rating: 2.

Anomaly Evaluation. Most quasar fuzz seems to have the shape and spectrum of a galaxy. The question arises, however, whether these fuzzy quasars are really just misidentified Seyfert galaxies. The restriction of quasar fuzz to low-redshift quasars is also suspicious. Astronomers would be relieved if all quasar fuzz could be identified as galactic clouds of stars surrounding quasars. This would demolish the assertion by some that quasars are really nearby and possess noncosmological redshifts. Unfortunately, some quasar fuzz seems due to gas clouds rather than star clouds; and some quasars apparently embedded in galaxies do not exhibit the same redshifts as the host galaxies. At the moment, we do not know for certain just what quasar fuzz is. Rating: 2.

Possible Explanations. Low-redshift fuzzy quasars are really Seyfert galaxies; and real quasars have no fuzz and have high redshifts. Alternately, the claim that some quasars are surrounded by gas, not stars, may turn out to be incorrect; and all quasars inhabit galaxies.

Similar and Related Phenomena. Seifert galaxies (AWF2); the redshift controversy (AQB1, AQB2, AQB4, AQF5)

Examples

X0. Background. "Quasar fuzz is a faint luminosity that surrounds certain quasars. Observers have been able to determine the spectrum of some of this fuzz and find that it resembles starlight. The simplest conclusion, then, is that the fuzz is a galaxy associated with the quasar that appears inside the fuzz or is it somewhere between us and the quasar? Astrophysicists who favor theories that make quasars the centers of galaxies would like to find out that the fuzz is associated with the quasar. Those who believe that quasars are images formed by the focusing of light from some distant object as it passes through the gravitational field of a dense galaxy, the so-called gravitational lens effect, would like to find that the fuzz is an intervening galaxy, that is, the lens. Astrophysicists who do not necessarily believe in gravitational lenses, but who favor theories in which quasars are not at all related to galaxies, would also like to believe that the fuzz is intervening." (R1)

X1. 3C 273. J.A. Tyson and coworkers have observed the fuzz around quasar 3C 273. Using an occulting disk to block out the point source, they found that the fuzz has the color and intensity distribution of a giant elliptical galaxy. However, the quasar point source is about 10 kiloparsecs off the center of the brightness contours. (R1, R2)

X2. 3C 48. Abstract. "Spectra have been obtained of the faint nebulosity north and south of the centre of the QSO 3C48. In addition to the emission lines previously known, a continuum dominated by hot stars is seen at both positions. This suggests that the host galaxy is a spiral and may explain why searches for features indicative of an old stellar population of QSOs have been unsuccessful. The redshift of the underlying galaxy is the same as that of the permitted lines in the QSO but differs from the redshift of the forbidden lines in the QSO by 500 km s^{-1}." (R5; R3) However, Rowan-Robinson states that the fuzz around 3C 48 has been shown to be hot gas rather than stars---a direct contradiction. (R2)

X3. Survey of four fuzzy quasars. "Three of the four fuzzy quasars observed yielded two positive results: the fuzz around the quasar is spectroscopically identical to starlight from ordinary galaxies and the redshifts of the stellar lines and those of the quasar lines are essentially identical to within a percent or less). Subsequent observations using the same instrument indicate that the fourth object is very similar to the other three." (R6)

X4. Study of 24 X-ray emitting quasars. "The resolved fuzz is typically 10 to 30 arc seconds across, symmetrical in shape, and centered on the starlike quasar. This extended emission usually has properties similar to those of a normal spiral galaxy like the Milky Way: color, surface brightness, linear size, ellipticity, and frequent association with small groups---but not populous clusters---of galaxies."(R7) But see X5.

X5. General observations. "Many astronomers regard the luminous halos as proof of the quasars' true redshift distances because the fuzz is visible around most of the low-redshift quasars, but not around those of high-redshift. If redshifts are indeed distance indicators, the low-redshift quasars are closest to us and therefore are the ones in which we would expect to see fuzz. The halos tend to be redder in color than their accompanying quasars---again suggesting that we may be seeing the underlying galaxy which contains a quasar in its center.

Therefore, you might conclude, quasars reside in galaxies---we see the galaxy around nearby quasars, but high-redshift quasars lie too far away to reveal their home galaxy. Presumably, since galaxies obey the 'Hubble law,' the quasars inside them must, too.

A handful of astronomers disagree with this because some galaxies in groups show discordant redshifts (and maybe quasars do, too), and spectra do not yet exist to show that the 'fuzz' represents a galaxy. Finally, the halos are so big that they imply huge galaxies---perhaps four or five times the size of the Milky Way." (R8)

X6. Quasar apparently in galaxy 2237 + 0305. J. Huchra et al have discovered a high redshift quasar ($z = 1.695$) that seems to reside in the nucleus of the galaxy 2237 + 0305, which has a redshift of $z = 0.0394$. In commenting on this quasar/galaxy association, Burbidge notes that many astronomers now interpret quasar fuzz as due to a galaxy surrounding the quasar. He ventures that in many cases "the observers are probably looking at comparatively large-redshift Seyfert galaxies." (R10) The discordant redshifts of galaxy 2237 + 0305 imply that the two are not physically associated and that some quasar fuzz may be the chance superposition of a quasar over a more distant galaxy.

X7. 3C 275.1. "Paul Hintzen of NASA's Goddard Space Flight Center has found that a distant quasar, called 3C275.1, is surrounded by a hot cloud of rotating gas some 300 000 light years in diameter. It is not---as some theories hold quasars to be---the superluminous nucleus of a spiral galaxy." (R11; R13)

X8. M81. P. Barr appears to have found a 'dwarf quasar' in the nucleus of the spiral galaxy Messier 81 (M81). (R11) See also X6.

X9. 1059 + 730. "On examining the images of one quasar, designated 1059 + 730 (after its location on the sky), we discovered that there was a faint star-like image close to the quasar. Our suspicions were aroused when we realized that this faint object was <u>not</u> present in a previous photograph of the same quasar. We had obtained six images, all on one night, and in each of these this new object was clearly visible. Another image, obtained with the 3.6-meter Canada-France-Hawaii telescope in July 1984, showed no sign of this object, so it was clearly a transient event." The authors conclude that the starlike object was a supernova in the fuzz surrounding the quasar. This is strong evidence that quasar fuzz consists of stars. (R12)

X10. Survey of X-ray-selected quasars. From the <u>Abstract</u>: "We have obtained deep red images of 24 X-ray selected quasars, using the SIT Area Photometer on the Palomar 1.5 meter telescope. About half were also imaged through green and violet filters. The images of all 15 of the quasars with redshifts up to 0.4 certainly are extended, the two at $z = 0.45$ probably are, while the remainder, of higher redshift, are unresolved, presumably because they are too distant. The resolved structures are 10"-30" across, symmetric, and centered on the pointlike quasar nuclei. For most of the quasars we can roughly separate the nuclear light and the extended emission. We present evidence that the extended emission is starlight from a surrounding galaxy." (R14)

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R7. "Where the Quasars Live," <u>Sky and Telescope</u>, 67:416, 1984. (X4)
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R11. Hecht, Jeff; "Quasar Fuzz Is Not Like Galaxies," <u>New Scientist</u>, p. 25, July 11, 1985. (X7, X8)
R12. Campbell, Bruce, et al; "A Supernova Explosion in a Galaxy Containing a Quasar," <u>Mercury</u>, 14:184, 1985. (X9)

R13. "Quasar Gas Envelope Detected," Astronomy, 14:78, June 1986. (X7)
R14. Malkan, Matthew A., et al; "The Underlying Galaxies of X-ray-Selected Quasars," Astrophysical Journal, 280: 66, 1984. (X10)

AQO2 Anomalies of Quasar Radio Jet Structures

Description. Difficult-to-explain features of quasar radio jets such as: (1) One-sided varieties; (2) Bipolarity; (3) The existence of hot spots in some; (4) The existence of 'avoidance structures'; and (5) The appearance of radically different jet structures on either side of a quasar, suggesting different modes of formation.

Data Evaluation. The lobed or jet structures adjacent to quasars have been under scrutiny for almost two decades with ever-more precise radio telescopes and arrays. The literature is abundant. Rating: 1.

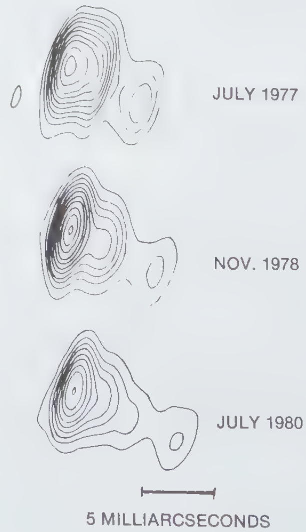
Anomaly Evaluation. First of all, we do not know exactly how quasar radio jets are formed, although the familiar black-hole/accretion-disk model is frequently profferred---as in the case of other bipolar jet structures. Added to the uncertainty of origin are the special features, such as avoidance structures, one-sidedness, asymmetry, etc. Nevertheless, these morphological problems seem tractable, or almost so, in the light of current theory. Rating: 2.

Possible Explanations. The jets are electromagnetically collimated beams of charged particles spewed out by a black hole plus accretion disk.

Similar and Related Phenomena. Galactic jets (AWO1); stellar jets (AOO6); jets from nebular objects (AOO2).

Examples

X1. 3C 273. Abstract. "Although 3C273 was one of the first quasars to be identified, the extended feature 3C273A, which can be detected at radio, optical and X-ray wavelengths, remains an enigma. The source is an extreme example of a one-sided radio source (3C273A has no detectable counter component) and this fact, coupled with the presence of the optical emission, makes it unlikely that 3C273A is a normal (slow-moving) radio lobe. Superluminal transverse motion at milliarc second scales shows that relativistic velocities occur within the quasar itself, 3C273B; it is an open question whether these velocities persist out to 3C273A. It has been widely suggested that Doppler beaming causes the one-sidedness of this and similar sources by suppressing the receding half of the source, but there are no spectral lines by which the Doppler shift of 3C273A could be directly measured...." (R1)



Radio maps of 3C273 at three different times, showing development of a one-sided jet. (Adapted from R8)

X2. 1857 + 566. "Summary. We present total intensity and polarization observations at 6 cm of the high-redshift quasar 1857 + 566. It has an interesting asymmetrical structure with a normal radio lobe containing a warmspot on one side but only a jet without any prominent hotspot on the other. In addition, the jet exhibits two very remarkable bends along its path. The magnetic field lines appear to lie largely along its axis and also follow the bends. We briefly explore a few possible explanations for the morphology of the jet. Ram-pressure bending by the intergalactic medium or the presence of relativistic precessing beams seems unlikely, whereas deflection of the beam by dense clouds appears possible...." (R4)

X3. Evidence for flip-flop radio jets."Some 'classic double' extragalactic radio sources may actually be ejecting material from only one side at a time. In this picture the jets 'communicate' with each other and turn on alternately. Such 'flip-flop' behavior is contrary to accepted ideas and somewhat surprising in objects whose very name comes from the overall symmetry of their extended radio lobes. High-resolution observations of radio galaxies and quasars have, in many cases, revealed substantial differences between the two lobes of a single source. The size, shape, position, and strength of individual components are often entirely different on opposite sides of the nucleus. In particular, 'hot spots' (bright regions) on one side often correspond to gaps or regions of low brightness on the other." (R5)

"Abstract. Analyses of radio galaxy and QSO maps provide evidence for a preferential avoidance of structures at the same nuclear distance on the two sides of a source. We show that such an effect is most likely due to ejections from the nucleus occurring on one side only at a time. Under this model, strict constraints are placed on the ejection velocities, the amount of 'cold' material carried along with the relativistic electrons, and the power supply to jets and hot spots. We discuss some theoretical difficulties raised by this model, and refer to current ideas about forming one-sided sources. We demonstrate the lack of a clear signature in other observational tests, and suggest future work. Throughout the paper, we call attention to the very limited nature in which extragalactic radio sources are symmetric." (R6)

The hypothesis introduced above that extragalactic radio sources eject material from one side at a time predicts a deficit of double sources with outer radio lobes at equal distances from the nucleus. This deficit was not confirmed in a sample of 47 quasars. (R7)

X4. General observations on jet structures. "Summary. Observations now require that there be a continuous supply of energy to the giant extragalactic radio sources. These observations also suggest that the energy input may be in the form of jets of gas emanating from the centers of galaxies and quasi-stellar objects. Current data indicate that the large-scale jet structures are not moving with relativistic speeds, as previously proposed. Slow-moving jets, which possess turbulent interiors and are dominated by relatively cool gas, can account for the observed jet properties at optical and radio wavelengths. Extremely small-scale jets observed adjacent to the central energy source may or may not be in relativistic motion." (R8)

X5. NGC 5128. A faint filamentary structure extends in the form of a jet into the outside northeast lobe of the radio source. (R9)

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AQO3 Superluminal Velocities in Quasars

Description. The apparent separation of quasar components at speeds greater than that of light. Such observations are made with radio telescopes, not visually. Only superluminal separations have been observed, not approaches.

Data Evaluation. At least seven superluminal quasars have been recorded so far. These objects have been measured by different groups working with different instruments. The phenomenon of 'apparent' superluminal velocities is undeniable. Rating: 1.

Anomaly Evaluation. Several explanations have been suggested (see X8). Some of these can account for the basic faster-than-light characteristic very successfully but require improbable situations, such as special quasar orientation with respect to the earth. The anomaly evaluation is based on the likelihood that such 'nonrevolutionary' explanations will ultimately be made to work. Rating: 2.

Possible Explanations. A 'revolutionary' explanation would be one in which quasars are actually close to earth and not at the great distances indicated by their redshifts. If this were the case, the separation velocities of qussar components would not be superluminal, and there would be no anomaly. The price of removing the anomaly would be high, however: the abandonment of the cosmological interpretation of the redshift.

Similar and Related Phenomena. All aspects of the redshift problem, such as quasar-galaxy associations (AQB1, AQB2, AQB4), and the quasar energy paradox (AQF5).

Examples

X0. Overview. "So far, about half the compact radio sources that have been looked at with VLBI (Very Long Baseline Interferometry) have shown superluminal expansions, with separation velocities ranging from 4.2 to 10 times the velocity of light. In every source, the velocity seems to remain constant. No examples of radio sources moving toward each other have been observed. Radio galaxy 3C 120 has shown at least two and maybe three pairs of superluminal objects. In several cases there has been an abrupt brightening of the radio emission from the source just as the two bright objects at the core started their separation, suggesting that the phenomenon may be caused by an explosive event.

Can we explain all this in a plausible way without being forced to accept the existence of superluminal velocities? Many astronomers are trying. The first possibility to consider is that the superluminal motions are misleading and no object is truly moving at the apparently observed speeds. Models along this line are easy to imagine. For example, if you shine a flashlight on a wall and then turn it quickly, the spot of light will move across the wall much faster than the flashlight is moving, but the spot is not an object. No object is moving as quickly as the light. In a like manner, it may be that what we are seeing with our radiotelescopes is, in fact, a rotating beam of particles or some other source of energy sweeping across interstellar clouds in a galaxy." (R17)

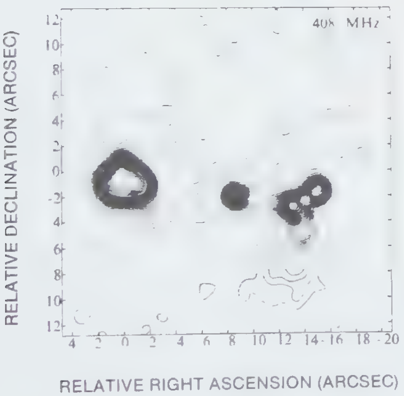
X1. 3C 273. "The compact radio structure of the quasar 3C 273 has been monitored with a VLBI array at 5.0 and 10.7 GHz at 6 month intervals during 1977-1982. On each hybrid map there is a bright 'core' at the east end of the source, and several compact 'knots' extending to the west. Superluminal motion of at least two knots is visible at both frequencies, with apparent speeds $v \approx 6c$ (for $H_0 = 100$ km s^{-1} Mpc^{-1}). These knots decay with half-lives of 1-2 years as they move out from the core; their positions are frequency-independent." (R33; R2, R12, R18, R20, R23, R26, R28, R30)

X2. 3C 279. "Abstract. The compact extragalactic radio source 3C 279 was observed with the Haystack-Goldstone interferometer (λ= 3.8 cm) during six separate sessions spread between 1970 October and 1972 April. The fringe amplitudes from each of these observation sessions were consistent with a two-component model of the brightness distribution of the source. The position angle of the line joining the components remained at 38 $\pm$ 2 deg while the angular separation between the components increased nearly linearly at the rate of 0.5 $\pm$ 0.1 milli-arcsec yr^{-1} during this period. The corresponding apparent expansion speed is (21 $\pm$ 4)c, for $H_0 = 50$ km s^{-1} Mpc^{-1} and

$q_0 = 0.05$." (R19; R2, R4, R12, R18, R26, R28)

X3. 3C 345. "Abstract. The superluminal quasar 3C345 has a curved, one-sided jet-like radio structure. Ejected material has been observed travelling at apparent speeds of 13-17c. We report here new observations at 22 GHz which show that the most recently ejected component is not moving radially away from the compact radio core, but along a trajectory which could be interpreted as either a curved path originating in the compact core, or a straight line, in which case the origin of ejection is not coincident with the compact radio core. The observations provide evidence of acceleration of this component." (R32; R12, R18, R20, R26, R28, R30, R31)

X4. 3C 179. Abstract. "VLBI observations of the quasar 3C179 reveal that its two milli-arc second components have an apparent relative velocity of 7.6 times the velocity of light. This is the fifth radio source in which 'superluminal' motion has been reported but the first which also exhibits double lobe structure on the arc second scale. Statistical arguments which apply to such sources cause difficulties for explanations based on motion in a relativistic jet." (R24; R26, R28, R30, R31)



Radio map of the quasar 3C179, showing the components, some of which move at superluminal velocities. (X4)

X5. NRAO 140. Two roughly equal components moving apart at between 3 and 7 times the speed of light, depending upon the assumptions. (R26; R28, R30)

X6. BL Lac. (R30)

X7. 1642 + 690. (R34)

X8. Suggested explanations. "The range of possibilities is large. There are the 'acausal' models such as the 'Christmas tree' version involving independent sources whose unrelated eruptions mimic expansion and there are models depending on the variation of propagation conditions either close to the source or in the intervening space (gravitational lenses, or scintillation in some intervening medium or galaxy). Neither of these general types seems to explain naturally the common features, particularly the fact that the sources always seem to expand.

The most popular models involve ejection of matter in some form of relativistic jet; there are several variants in which this can lead to high apparent transverse velocities. One particular attraction lies in the fact that the brightness temperatures of some compact radio sources, as implied by their rapid variations and inferred small sizes, are already uncomfortably high for the incoherent synchrotron process; a relativistic expansion eases this problem. (R22)

"(M. J.) Rees holds that superluminal expansion appears to occur when a distant, or cosmological, object expels a jet of matter at relativistic speeds---velocities approaching the speed of light. If such a jet were headed almost directly toward an observer, Rees, says, the apparent difference in arrived time of signals from the moving and the stationary source would make them seem to be separating at a rate faster than the speed of light.

As attractive as it appears, that proposal has at least two difficulties. First, no astronomical object emitting a jet that moves at nearly the speed of light has ever been directly and unambiguously observed; second, if one were, it would be a more-than-remarkable coincidence to find that the jets from all superluminal sources known were pointed with uncanny accuracy almost directly toward earth. The likelihood of that happening, says Kenneth I. Kellermann of the National Radio Astronomy Observatory, has a probability of only a few percent. Nonetheless, even with its improbabilities, adds Kellermann, most astronomers agree that the relativistic cannonball is a likelier explanation than a noncosmological nature for some quasars and galaxies, as Arp and Burbidge offer." (R27)

For further discussion of explanations, see R1, R3, R5-R10, R14-R17, R25)

X9. General observations. A single series of observations has doubled the number of quasars with superluminal velocities from seven to 14. "This sudden population increase means that 'superluminals' can no longer be regarded as rarities. They become a class of astrophysical objects that needs a consistent and believable theoretical explanation." If still more superluminal quasars are found, the standard "relativistic" explanation will become more and more strained. (R35)

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AT INTRODUCTION TO THE COSMOS

Key to Categories

ATB UNIVERSE DYNAMICS AND MASS DISTRIBUTION
ATF COSMIC ANOMALIES DETECTED THROUGH RADIATION
ATO OBJECTS IN INTERGALACTIC SPACE

This chapter is deliberately entitled "The Cosmos" rather than "Cosmology". Actually, in our studies of the astronomical literature, we collected an immense pile of material on "cosmology", but as we subtracted theory and speculation, the stack shrank alarmingly! The residue of observational facts about the cosmos; that is, the universe-as-a-whole; is really rather modest---fascinating, certainly, but still modest.

Our knowledge about the cosmos arrives in the radiations, electromagnetic and particulate, that we intercept. Of course, most of the incoming radiation is assignable to stars, quasars, galaxies, etc., but some components definitely have a cosmical quality---the cosmic background radiation, for example, and the cosmic rays. Although these radiations may have originated with specific objects, we cannot now discern these objects. Instead, these photons and particles bring us information about the universe-as-a-whole and, according to some theories, the actual beginning of the universe itself. The cosmic rays, although studied intensively for decades, are still mysterious. Where do they come from and how are they accelerated? Some single cosmic ray particles have energies approaching 10^{21} electron volts, a truly macroscopic amount of energy for a microscopic particle. The most powerful terrestrial particle accelerators cannot even approach such energies.

This chapter begins with an anomaly carrying deep philosophical implications: the existence of the universe. Is the existence-of-everything an anomaly? Philosophers have always considered it such. This phenomenon of existence is easily observed but exceptionally difficult-to-explain scientifically. In addition to the "property" of existence, the cosmos also possesses mass and, possibly, angular momentum. The "missing mass" problem is ubiquitous in this volume. Again waxing philosophical, we would like to find enough mass in the cosmos to close it; i.e., to eventually stop its expansion gravitationally. Unfortunately for philosophy, the missing mass is also elusive on the cosmical scale. The existence of universal rotation is hotly debated. If it does occur, there must be an axis of rotation and the universe would not be the same in all directions---another philosophical taboo.

We end this brief introduction as we began it, with much speculation and too few facts.

ATB UNIVERSE DYNAMICS AND MASS DISTRIBUTION

Key to Phenomena

ATB0 Introduction

In keeping with the other "existence" phenomena, we place in this section the most important observation of all: that of the universe-as-a-whole. While we cannot produce a satisfying explanation for the anomaly of existence, the question should not, as some recommend, be relegated to the realm of the meaningless and nonsensical.

The "missing mass" problem also appears at the cosmological level. Taken as a unit, the universe just doesn't seem to have enough mass.

The universe-as-a-whole provides a few hints of collective rotation. If verified, this phenomenon would be of tremendous scientific and philosophical import. The universe-as-a-whole would also be the last point on that remarkable straight line appearing on a plot of log Q vs. log mass (see ATB3). At least it would be the last point that we can observe with today's scientific instruments.

ATB1 The Existence of the Universe

Description. The simple fact that we and the universe are here!

Data Evaluation. A "commonplace" observation to say the least. However, we have no direct knowledge of the universe beyond a few thousand years ago. All prehistory is inferred. The "existence experience" is therefore very short, with no direct observation of a beginning, if there was one. Rating: 1.

Anomaly Evaluation. All creation theories, including our baseline hypothesis of the Big Bang, begin with something. Cosmologies do not come to grips with what happened "before" or how something arose from nothing. Actually, the more sophisticated theories maintain that such questions are meaningless and that the "beginning" is merely a boundary condition for the equations. (See, for example, X2's final paragraph.) Anomalousness here is a matter of personal preference. Are boundary conditions a satisfying explanation of creation, or do you insist upon extending common cause-and-effect experience back to the birth of the universe and earlier? The compiler thinks that the boundary-condition viewpoint is contrived. Rating: 1.

Possible Explanations. Big Bang theories; steady-state theories; supernatural creations.

Similar and Related Phenomena. The other "existence" anomalies: stars (AOB18) and galaxies (AWB17).

Examples

X1. The most important observation ever made: We are here! Cosmologists recognize this remarkable fact by requiring that all scientific theories be compatible with this fact. The so-called Anthropic Principle is a modern statement of this exigency: "The observed values of all physical and cosmological quantities are not equally probable but they take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirement that the Universe be old enough for it to have already done so." (R5, as quoted in R4)

Although the Anthropic Principle is a statement of the obvious, it is useful to put such things down in black and white. Note that the Anthropic Principle states implicitly that our universe has evolved and has an "age" and consequently a "beginning". These are, of course, assumptions. (WRC)

X2. Theories of existence. If supernatural creation is excluded (as "nonscientific"!), the most important creation theory is the Big Bang hypothesis. (Steady-state universes are not considered here because science has generally discarded them, and they therefore cannot serve as a basis for determining anomalousness.) Does the Big Bang explain existence? Of course it does, for it was designed to do just that! The real question is whether the Big Bang hypothesis is a satisfactory theory. The Big Bang is buttressed by observations of the cosmic background radiation and the redshifts of astronomical objects. It does, however, contain what some see as a singularity; that is, an impossible physical situation at t = 0, the point of creation. Since we cannot observe what happened at t = 0, the importance of this singularity, or even the reality of the singularity, is a matter of personal preference. Three different views are presented below.

D. B. Larson. "The Big Bang is pure presumption. There are no physical principles from which it can be deduced that all of the matter in the universe would ever gather together in one location, or from which it can be deduced than an explosion would occur if the theoretical aggregation did take place... Theorists have great difficulty in constructing any self-consistent account of the conditions existing at the time of the hypothetical Big Bang. Attempts at mathematical treatment usually lead to concentration of the entire mass of the universe at a point. 'The central thesis of Big Bang cosmology,' says Joseph Silk, 'is that about 20 billion years ago, any two points in the observable universe were arbitrarily close together. The density of matter at this moment was infinite.' This concept of infinite density is not scientific. It is an idea from the realm of the supernatural, as most scientists realize when they meet infinities in other physical contexts. Richard Feynman puts it in this manner: 'If we get infinity (when we calculate) how can we ever say that this agrees with nature?' This point alone is enough to invalidate the Big Bang theory in all its various forms." (R2)

J. Narlikar, in a discussion of the Big Bang and its scale factor, S. 'I begin with a philosophical point, although I will soon move on to hard facts. What is the physical implication of S = 0? At this epoch, which is denoted by t = 0 on the cosmic time axis, the separation between any two galaxies was zero. The entire Universe was therefore confined to zero volume. In fact it is argued that the entire Universe burst out at time zero in a tremendous explosion (hence the 'big bang') and the present apparent recession of the galaxies is an indication of the early violent activity. But how did this explosion occur? Why did it occur when it did? And what preceded it? Did matter exist prior to t = 0, or was it created in the explosion? If the latter version is correct, how was matter created in apparent violation of the law of conservation of matter and energy? Questions like these are either conveniently relegated to 'domain outside physics' or dismissed as philosophical nonsense." (R3)

S. Hawking. "What happened at the beginning of the expansion of the Universe? Did spacetime have an edge at the big bang? The answer is that if the boundary conditions of the Universe are that it has no boundary, time ceases to be well defined in the very early Universe just as the direction 'north' ceases to be well defined at the North Pole of the Earth. Asking what happens before the big bang is like asking for a point one mile north of the North Pole. The quantity that we measure as time had a beginning, but that does not mean spacetime has an edge, just as the surface of the Earth does not have an edge at the North Pole, or at least, so I am told: I have not been there myself." (R3)

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ATB2 The Low Mean Density of the Universe

Description. The low density of detectable matter in the universe. The mean density is only about one-third that required to close the universe, as determined by observations of galactic clusters.

Data Evaluation. The mean density of the universe is usually estimated from observations of galactic clusters; but underestimation is possible here, because observations are limited mostly to visible objects. Other means of estimation (see X2 below) lead to conflicting results. Rating: 3.

Anomaly Evaluation. Basically, the low mean density means that some important cosmological models (notably the Einstein-de Sitter model) are incorrect or the formation of galaxies by gravitational condensation is wrong. Rating: 1.

Possible Explanations. Most mass in the universe escapes observation (the "missing mass" problem); forces other than gravitation are important on the cosmological scale; the expanding universe hypothesis is incorrect.

Similar and Related Phenomena. The origin of galaxies (AWB17); the "missing mass" problem (AWB5, AWB13, AWO11); the redshift controversy (AQB1, AQB4, AWB1-AWB4, AWB7, AWF8).

Examples

X1. General observations. Abstract. "Obsevations of galaxy clustering indicate that the mean mass density is only about one-third of that predicted by the popular Einstein-de Sitter cosmological model. Theory and observation can be reconciled if there has been large-scale segregation of galaxies from mass, but the gravitational instability of the expanding universe would tend to destroy such a segregation. Thus either conventional ideas about galaxy formation are wrong, or the Einstein-de Sitter model is not a useful approximation." (R2)

The consequences of insufficient mass density in the universe has also been noted by T. Gold and F. Hoyle: "Attempts to explain both the expansion of the universe and the condensation of galaxies must be largely contradictory so long as gravitation is the only force field under consideration. For if the expansive kinetic energy of matter is adequate to give universal expansion against the gravitational field it is adequate to prevent local condensation under gravity, and vice versa. That is why, essentially, the formation of galaxies is passed over with little comment in most systems of cosmology." As quoted in R1.

X2. Conflicting density estimates. "Abstract. This Letter reports a new measurement of the density parameter Ω, which is the mass density of the universe relative to the critical density. We have measured the redshifts and fluxes of 1000 field galaxies with a median redshift of 0.5. With this sample we determine Ω by measuring the volume element (to a scale factor H_0^3) as a function of redshift. Our measurement is sensitive to any kind of matter, luminous or dark. We find that $\Omega = 0.9^{+0.7}_{-0.5}$ (95% confidence), consistent with the Einstein-de Sitter model ($\Lambda = 0$, $\Omega = 1$). (R3)

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ATB3 An Angular Momentum-Mass Relationship for a Wide Range of Astronomical Objects

Description. A universal relationship between the angular momentum of an object and its mass. This relationship apparently holds for objects from small asteroids to large galactic clusters.

Data Evaluation. The masses of some astronomical objects, particularly galaxies and clusters of galaxies, are difficult to estimate because we see only the visible component of mass. In other words, "missing mass" may seriously affect the situation. In addition, one must ask whether an underlying, unrecognized physical law exists or coincidence reigns. However, the fact that so many astronomical objects, over such a wide range of mass aggregations, fall on the curve (see below) argues strongly that a real physical law is operating. Rating: 2.

Anomaly Evaluation. If the angular momentum-mass relationship is only a coincidence, no anomaly exists. The data, though, seem to transcend coincidence and suggest an unrecognized physical law. In modern physics, there seems to be no basis for the implied relationship. Rating: 1.

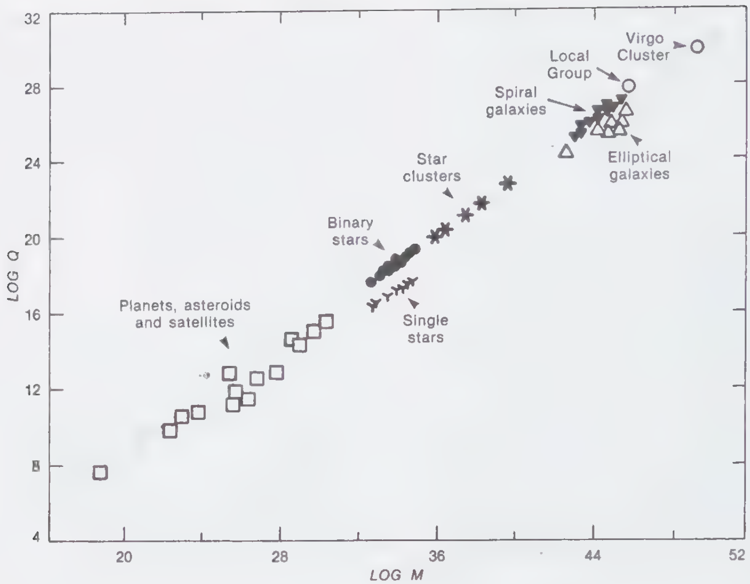
Possible Explanations. None.

Similar and Related Phenomena. None.

Examples

X1. General observations. "Pick any astronomical object. Divide its angular momentum by its total mass and also by its average density raised to the 1/6 power. The resulting number (call it Q) will be equal to the mass itself raised to roughly the 0.7 power.

Numerological hocus-pocus? No, it seems that this is a universal property of bodies. Whether you pick a lowly asteroid, a star, a galaxy, or even the mighty Virgo



An apparently universal relationship between the angular momenta and masses of astronomical objects. (X1)

cluster of galaxies, it works. The relationship is decisively shown by the straight line on the logarithmic chart...prepared by L. Carrasco, M. Roth, and A. Serrano at the Mexican Institute of Astronomy." (R1; R2)

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ATB4 Evidence for Universal Rotation

Description. The slow, ponderous rotation of the entire cosmos.

Data Evaluation. Data come from two independent sources: (1) The position angles and polarizations of radio sources; and (2) Vorticity discerned in the cosmic microwave background radiation. Pro-rotation papers, such as R1, seem more than counterbalanced by those that find no rotation or assign very low upper limits to the angular velocity. Rating: 3.

Anomaly Evaluation. Universal rotation would imply that the universe is not the same in all directions. Mach's Principle would also be violated. Further, a favored axis or point of rotation would be implied. These are all extremely important scientific and philosophical challenges. Rating: 1.

Possible Explanations. The pro-rotation data are either incorrect or can be explained without restorting to universal rotation.

Similar and Related Phenomena. The relationship between an object's angular momentum and mass (ATB3); the isotropy of the cosmic background radiation (ATF1).

Examples

X0. Background. "If the universe does have a measurable spin, such behavior would raise profound scientific and philosophical questions. It would imply, for example, that the cosmos is not the same in all directions and invalidate many of the popular inflationary cosmologies. It would also question the physical significance of Ernst Mach's conjecture that an object's inertia depends on the distribution of matter in the universe." (R6) One should add that universal rotation also implies a hub or center of rotation---a "preferred" spot in the cosmos. (WRC)

X1. Studies of radio sources. "From the study of the position angles and polarization of high luminosity classical-double radio sources, it appears that the difference between the position angles of elongation and of polarization are highly organized, being generally positive in one half of the sky and negative in the other....Such a phenomenon can only have a physical explanation on a cosmic scale; an attractive theory is that it demonstrates the existence of a universal vorticity, that is, that the Universe is rotating with an angular velocity $\sim 10^{-13}$ rad yr^{-1}." (R1; R2)

S. Phinney and R. Webster subsequently performed computer simulations to check the statistical significance of the results presented above. They found "no evidence for an asymmetry in the sense of a twist" and blamed systematic errors for the other asymmetry found. P. Birch, who made the original discovery, remained unconvinced, "The evidence I adduced remains strong and unexplained except by universal rotation." (R3; R4)

M. F. Bietenholz and P. P. Kronberg also did not support Birch's finding: "Abstract. We investigate claims in the recent literature for the existence of a large-scale (out to $z \lesssim 1$) anisotropy in the properties of extragalactic radio sources in the universe and conclude, from an independent analysis of a new, enhanced sample of radio sources, that there is no evidence for a large-scale anisotropy of this type, or for universal rotation." (R5)

"Summary. Birch (R1) reported an apparent 'statistical asymmetry of the Universe'. The authors here develop 'indirectional analysis' as a technique for investigating statistical effects of this kind and conclude that the reported effect (whatever may be its origin) is strongly supported by the observations. The estimated pole of the asymmetry is at RA 13h30m, Dec. -37°. The angular error in its estimation is unlikely to exceed 20-30°." (R8)

X2. Analysis of the uniformity of the microwave background radiation. "Observations of the uniformity of the 2.7° Kelvin microwave background radiation imply that today the universe as a whole cannot be rotating faster than 2×10^{-16} arc second per second (about one revolution every 10^{17} years). Why the universe rotates so slowly, if at all, can be considered another cosmological mystery." Inflationary cosmologies can account for such slow rotation, because a rapidly inflating universe, like an iceskater extending his arms, slows down in angular velocity. (R3; R7)

D. Kendall and A. Young made an independent investigation of the microwave background. "Using the latest measurements of the 3° radiation, they sought to find what new limits could be placed on vorticity. They found that if the universe is open, that is, if it will expand forever, then it can spin no faster than about 10^{-9} arc second per year. This immediately rules out any rotational explanation of the Birch effect." (R6)

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ATF COSMIC ANOMALIES DETECTED THROUGH RADIATION

Key to Phenomena

ATF0 Introduction

The electromagnetic and particulate radiation we receive from the universe-as-a-whole (with the emanations of the stars, galaxies, and other sources edited out) has coded into it some surprising anomalies. No fewer than four anomalies involve background radiation. The microwave background radiation, for example, is too isotropic and may deviate a bit from a purely blackbody spectrum. Is it really the "echo" of the purported Big Bang? In contrast, the infrared background is skewed, indicating perhaps some otherwise undetected concentration of mass.

Cosmic rays contribute most of the other anomalies in this section. There mere existence is anomalous in the sense that no consensus exists as to their origin(s). And whence those cosmic rays with energies over 10^{19} electron volts? Are they messengers from other galaxies? The unexpectedly large flux of antiprotons seems to imply a primary source for these particles. We have no inkling of what this could be. In addition to these unexpected radiations, astronomers half expected to observe the annihilation radiation from interactions between matter and antimatter. If matter and antimatter were created in equal quantities, as symmetrists would like, the antimatter is remarkably hard-to-find.

Germane to the redshift controversy, broached so often in this volume, are those data that suggest that redshifts indeed may be explained with resorting to the Big Bang and the expanding universe.

ATF1 Isotropy of Cosmic Background Radiation

Description. The remarkable uniformity of the cosmic background radiation received from all portions of the sky, once the effects of the earth's motion and hot gas concentrations are subtracted out.

Data Evaluation. The extreme isotropy of the cosmic background radiation, especially in the microwave portion of the spectrum, has been confirmed by many experimenters. Rating: 1.

Anomaly Evaluation. Stated briefly, the cosmic background radiation is too isotropic to be explained in terms of known physical principles. Regions of space that could never have been in causal contact seem to be in equilibrium. Further, this isotropy is inconsistent with the present small-scale clumpiness of the universe, given the estimated age of the universe and the aggregating effects of gravitation. Rating: 1.

Possible Explanations. The standard Big Bang scenario, which is usually assumed in all cosmological reasoning, is incorrect. A popular modification of the Big Bang leads to the so-called "inflationary universe", which supposes a rapid expansion of the universe to a much larger size.

Similar and Related Phenomena. The X-ray background radiation (ATF3); deviations of the cosmic background radiation from the black-body law (ATF2).

Examples

X0. Introduction. "Proponents of big-bang theories of the origin of the universe have usually worked from the assumption that the universe at the moment of origin was isotropic and homogeneous---that is, the same in all directions and with a smooth distribution of matter and energy throughout. There is a relic of that time present now, the famous three-degree blackbody microwave background radiation that pervades the cosmos, that could give us information on whether those assumptions are correct. If it is isotropic, so was the primeval universe." (R5) Note that the cosmic microwave background is not necessarily a consequence of a Big Bang. See X4.

X1. Dipole anisotropy and its explanation. Measurements of the microwave background usually involve the flight of radiometers on high-altitude aircraft and balloons. Such experiments have consistently shown a very slight dipole anisotropy, as summarized by A.K. Finkbeiner:

"In areas on opposite sides of the sky, they find what is called a dipole anisotropy. 'Half the sky is warm,' as David Wilkinson of Princeton puts it, 'and the other half is cool.' The dipole anisotropy had been predicted by Peebles: A Doppler-shift effect of the motions of the solar system through the Milky Way galaxy and of the galaxy relative to the background; the Milky Way galaxy is heading toward the constellation Lyra at 350 kilometers a second. In the direction of motion, the radiation is warmer by 0.003 degree Kelvin. In the opposite direction, it is cooler by the same amount." (R18) Most other reports on this phenomenon state that we are headed toward the Virgo cluster! (WRC)

Although the explanation of the dipole anisotropy seems highly satisfactory, there exist alternate Big Bang models in which the early universe is not isotropic, and which lead to the observed anisotropy of the microwave background without invoking some hidden mass in the direction of Virgo dragging our galaxy toward it. (R7) Furthermore, the derived velocity of our galaxy in the Virgo direction "...is much higher than expected, and raises a number of cosmological problems." (R4)

X2. Quadrupole anisotropy and its insignificance. In 1980, F. Melchiori and his colleagues, at the University of Florence, working in the infrared portion of the spectrum, found a small quadrupole variation in the amount of about nine-tenths of a millidegree Kelvin. (R10, R13) Such infrared measurements, however, are difficult to make. Subsequent attempts to measure quadrupole anisoptropy at microwave wavelengths ended in failure. (R15, R16) The present consensus assumes the quadrupole anisotropy to be negligible.

X3. Minor variations in the cosmic background radiation. "In areas near each other, Juan Uson and his colleague David Wilkinson find fluctuations in the microwave background measuring just a fraction of the dipole anomaly. This is not intrinsic to the microwave background, but rather an effect predicted in 1972 by Yakov Zeldovich and Rashid Sunyaev, who said that when the photons of the microwave background go through clouds of hot, ionized gas that typically exist near clusters of galaxies, the photons' own temperature should be changed accordingly. A group at Kitt Peak reported in 1977, and a British group confirmed in early 1984, the presence of the Sunyaev-Zeldovich effect in the direction of three clusters. A few months later in 1984, Uson and Wilkinson refined the measurements of the effect to an accuracy of 0.00025 degree Kelvin, a change of 0.001 degree." (R18; R17)

X4. The isotropy anomaly. "The incredible uniformity of the microwave background causes theorists a lot of trouble. One trouble: How does something that smooth grow the lumps seen on smaller scales? All the clumping since the radiation decoupled has been the consequence of gravity pulling matter into stars and galaxies, galaxies into clusters and superclusters. Gravity is an anti-isotropy device par excellence.

'When we talk about scales of isotropy,' says George Lake of Bell Laboratories, 'we're really talking about the scales on which gravity has had time to restructure the universe.' If the universe were as smooth as the background insists, and if astronomers are right about the rate at which gravity can work, then even gravity has not had time in the 15 billion years since creation to grow galaxies, let alone clusters or superclusters. Cosmologists have ingenious alternative theories, but so far, nothing works. They cannot get the universe from there to here." (R18)

Strange as it may seem, the isotropy anomaly was defined more clearly in the highly scientific Astrophysical Journal: "There is a mystery concerning the evolution of the universe which is of profound and fundamental significance. When we look out over the sky, we can see radiation that was emitted when the universe was very young and which last scattered off the matter content of the universe some 15 x 10^9 years ago. At that time, it had a temperature some $\sim 10^3$ times its present temperature of ~ 3 K, i.e., it last scattered at a redshift $z \approx 10^3$, orders of magnitude higher than the redshift of the farthest quasar. But the ultimate source of the radiation, annihilation of particles and antiparticles with all masses allowable at corresponding temperatures, lies at much earlier, hotter epochs. The 3 K microwave background radiation is remarkably isotropic---to within better than one part in a thousand.

The puzzle comes in when we consider that as time goes on we see more and more of the universe as distant regions come within our 'particle horizon,'.... Thus, we are now seeing 3 K microwave background radiation from parts of the universe which apparently were never in causal contact, since even radiation traveling at the speed of light would not have had time to cross from one region to another. How then could they be in such apparent thermal equilibrium? Or, putting it another way, how could one region have known to adjust its temperature to that of the unknown other region?" (R6) All the preceding discussion takes for granted a Big Bang type of origin. Other cosmologies can also produce the observed background radiation. For example, S.V.M. Clube has described a type of steady state theory "involving recurrent activity in galaxies caused by hypermassive nuclei." In Clube's theory a cold "material vacuum" provides a natural explanation of the microwave background. (R11)

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ATF2 Deviations of the Cosmic Background Radiation from the Blackbody Curve

Description. Significant departures of the measured cosmic background radiation flux from the theoretical blackbody curve for $\sim 2.75^{\circ}$K.

Data Evaluation. Reported deviations from the theoretical blackbody curve have usually been in the infrared portion of the spectrum---a region where high precision measurements are difficult. Additionally, such measurements must be made outside the atmosphere and are subject to contamination from other sources of infrared radiation; viz., infrared stars. Generally, the measured blackbody curve (flux v.s. wavelength) has the proper theoretical shape. Some researchers, however, have reported significant deviations; others confirm theoretical expectations very closely. The tendency, of course, is to accept the latter. Rating: 3.

Anomaly Evaluation. The cosmic background radiation provides crucial experimental support for the prevailing Big Bang hypothesis. Large deviations from the blackbody law would represent serious anomalies. Rating: 1.

Possible Explanations. Spurious infrared sources contaminating the background radiation. There is also the possibility that the cosmic background radiation might not be genuine blackbody radiation, originating instead from pregalactic stars, "tired light", etc.

Similar and Related Phenomena. Other infrared sources (AOF10, AOF25); X-ray background radiation (ATF4).

Examples

X0. 1986 overview: cosmic blackbody radiation. "Calculations show that the radiation should survive the general expansion with little distortion or contamination of its spectrum. The best evidence that we are indeed looking at Big Bang radiation is the excellent agreement of spectral measures over three decades in wavelength---1 m to 1 mm. The measures fit well on a blackbody curve of temperature 2.75 K. Three recent observations, made by entirely different techniques and among them covering most of the spectrum, are consistent with a temperature of 2.75 ± 0.05 K. Most older measures also agree with this temperature. No other cosmological model has explained this spectrum, and no known astrophysical radio source (other than the hot Big Bang) has such a spectrum." (R12)

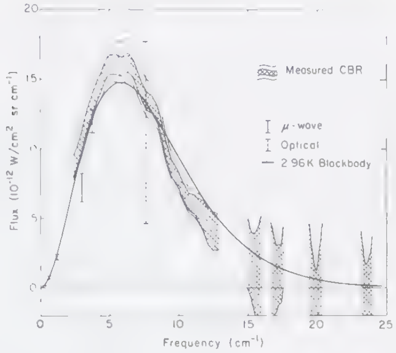
Despite these very strong statements, there do exist measurements from well-executed experiments indicating deviations from the ideal blackbody. Such deviations do not seem to have been explained in the literature so far examined. Further, other theories have been proposed to account for the background radiation (R6, R10).

X1. Deviations in the infrared. In 1968, J.R. Houck, M.O. Harwit, and K. Shivanandan flew an experiment on an Aerobee rocket that indicated a significant departure from the blackbody curve in the infrared. (R1) Houck and Harwit subsequently flew another experiment that verified this result. (R2) "What needed to be verified was the observation that above the absorption of the atmosphere the infrared flux between 0.4 and 1.3 mm fails to correspond to the predicted level by nearly two orders of magnitude. Instead of falling on the spectrum for a black body at 3 K---the temperature of the background radiation which Penzias and Wilson discovered at microwave frequencies---the far infrared measurement corresponded to a temperature between four and six degrees greater. In the latest experiment Houck and Harwit used a slightly altered telescope, launched by the same type of rocket as before, to produce an identical result." (R2; R13)

The MIT experiment, 1969. "Last September, Dr. Dirk Muehler and Dr. Rainer Weiss of MIT observed the infrared radiation with a balloon-borne radiometer flying at 40 km. They have now reported their results in Physical Review Letters (vol. 24, p. 742). Recordings taken with three different spectral responses did not correspond to a single black-body temperature, their data showing variations from 3.6°K to 7°K. Although they mention that their results are inconsistent with a thermal spectrum, the damage can be partially repaired by assuming that there exist stellar sources which emit a strong discrete spectral line in the infrared. With this assumption, Muehler and Weiss can manipulate their data to agree with 3°K thermal radiation." (R4)

H.P. Gush has described a bump in the background radiation spectrum between 0.5 and 1 mm, using rocket-borne equipment. Gush says that, "no convincing explanation for this feature can be offered." (R9)

X2. General deviations from the blackbody curve. "...David P. Woody and Paul L. Richards of the University of California at Berkeley report a measurement of the spectrum of the cosmic background radiation with a balloon-borne spectrophotometer that fol-



Measured background radiation conforms closely to blackbody radiation except for a few places. (X2)

lows the general shape of a Planck distribution over the broad frequency range from 2.54 to 24 cm^{-1} (or 3.9 mm to 0.42 mm) but shows significant deviations. The long-standing question of whether the spectrum falls at frequencies above the peak has been effectively laid to rest, Richards told us, but tantalizing evidence for deviations from the Planck curve have appeared. The deviation ranges smoothly from about 10% above a 2.96-K Planck spectrum near its peak at 6 cm^{-1} to 20% below it at 11 cm^{-1} (see figure). The measured spectrum differs from the Planck curve by five standard deviations." (R8; R5, R7, R15, R16)

Explanations for the deviations from the blackbody curve reported by Woody and Richards range from "tired photons" (R6) to radiation generated by pregalactic stars (R10)

In conflict with the above, several recent measurements of the cosmic background radiation tend to confirm a purely thermal origin. (R18-R20)

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ATF3 The Existence of Cosmic Rays

Description. The existence of cosmic rays with energies below 10^{19} electron volts. These cosmic rays are thought to be mostly galactic in origin, in contrast to those above 10^{19} electron volts, which may be extragalactic (ATF5).

Data Evaluation. Cosmic rays have been studied intensively for over 70 years via balloons, satellites, and ground-based instrumentation. Below 10^{15} ev, their characteristics are well-known. Rating: 1.

Anomaly Evaluation. Even today there is no consensus regarding the source of the lower-energy cosmic rays, although it is generally believed that they come from within our galaxy. Since several reasonable mechanisms have been proposed (see below) for generating these energetic particles, the anomaly here is mainly one of proper identification, rather than any confrontation with physical laws. Rating: 2.

Possible Explanations. The lower-energy cosmic rays may be accelerated by supernovas, exploding stars, shock waves in interstellar gas, collapsing binaries, collisions among black holes, etc.

Similar and Related Phenomena. The ultra-high-energy cosmic rays (ATF5).

Examples

X0. Overview. "Cosmic rays were discovered by Victor Hess in 1912 and it is true to say that today, 70 years later, the origin of the bulk of the radiation, or, to be more specific, the manner and location of the acceleration of the particles is still largely a matter of speculation.....It should be stated immediately that the cosmic radiation does not represent some tiny phenomenon on the cosmic scale; the energy density in the primary radiation above the atmosphere is about the same as that in starlight (and in other astronomical entities, too, as we shall see). At the rather parochial level of interaction with human beings one can remark that there are about five secondary cosmic rays (mainly muons) passing through our heads every second. We really ought to know where they are coming from." (R1)

X1. General observations. "The energy spectra of the major components of the cosmic radiation are shown in Fig. 1. Starting with nuclei, not surprisingly, protons and helium predominate and many other nuclei have also been identified. The shape of the energy spectrum carries with it information about particle production and propagation. Starting at the lowest energies, there is curvature below about 10^{10} eV nucleon^{-1} due to the modulating effect of the solar wind and the intensity in this region is sensitive to solar activity. Continuing to higher energies there is evidence for a power law with constant exponent...up to about 10^{15} eV nucleon^{-1}, above which γ increases to about 3.15. Finally, there is good evidence for a remarkable flattening of the spectrum above about 10^{19} eV." (R1)

"In the past, astronomers have suggested several possible sources of cosmic rays in the Galaxy. These sources include shock waves in the interstellar gas or in the halo of gas surrounding the Galaxy; explosions in the centre of the Galaxy; pulsars (rapidly spinning neutron stars); and supernovae. A supernova is the explosion of a star, with the release of an energy of 10^{44} joules---equivalent to 10^{28} megatons of TNT." (R3) Today, the most popular explanations of cosmic rays involve supernovas. (R2)

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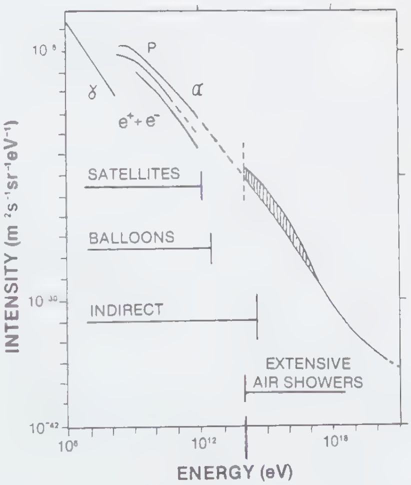
The literature on cosmic rays is, of course, immense---so large that this Catalog cannot cope with it.



Energy spectra of the major components of cosmic radiation. (X1)

ATF4 The Isotropic Cosmic X-Ray Background

Description. The existence of a highly isotropic flux of X-rays. Wavelengths are less than 1 nanometer and characteristic of radiation from a gas at 500 million K.

Data Evaluation. Numerous rockets and satellites have confirmed the existence of this cosmic X-ray background. Rating: 1.

Anomaly Evaluation. Although the precise origin of the X-ray background is not known, it may come from hot intergalactic gases and/or many distant, discrete X-ray sources too weak to resolve. If the former is the case, the heat source for the gas is a mystery; if discrete sources are the answer, the isotropy of the X-ray background is puzzling, given the observed inhomogeneity of the universe. These problems are important but not of a revolutionary nature. Rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. The cosmic blackbody radiation (ATF1, ATF2); X-ray bursters (AOF30).

Examples

X1. General observations. "Unlike visible wavelengths, the x-ray sky has a second component in addition to the individual point sources of galactic and extragalactic x-rays; the diffuse x-ray background radiation. There is a small amount of x-radiation observable from every location on the celestial sphere, regardless of direction. This effect has been recognized since the initial rocket surveys and has since been extensively studied from both rockets and satellites. At longer wavelengths (1-5 nm), the absorptive power of the galactic interstellar medium implies that the x-ray background is relatively local in origin; x-rays of this wavelength cannot travel more than a few hundred light-years before absorption by the gas. It seems probable that this component of the diffuse x-ray background is due to nearby, very hot (approximately 10,000,000 K) interstellar gas. At shorter wavelengths (less than 1 nm), however, observations of the background radiation indicate that its spatial distribution is uniform and isotropic to a very high level of accuracy. This implies a very distant origin for this component of the background. There is no general agreement as to the nature of the source; it may be either truly diffuse, or a superposition of numerous distant point sources which are individually too weak to observe. If the former case is correct, the intergalactic material responsible for this emission could be either hot gas or very-high-energy particles, as is the case of the extended x-ray sources associated with clusters of galaxies. If distant point sources are responsible, it seems likely they are similar to the already known extragalactic x-ray emitters: clusters of galaxies, radio galaxies, and quasistellar objects." (R1)

B. Parker has pointed out some of the problems associated with ascribing the diffuse X-ray background to the intergalactic medium: "How hot would this medium have to be to generate the observed amount of x-rays? Calculations show that the plasma would have to be about 500 million degrees! Our real problem, then, is the temperature. Where would the energy to heat an intergalactic medium to such a high temperature come from? And even if it could get so hot, why hasn't it cooled off? Astronomers don't have answers to these questions." Interestingly enough, the mass of the intergalactic medium needed to generate the X-ray background is roughly the same as the famous "missing mass"! (R2)

References

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ATF5 Ultra-High-Energy Cosmic Rays

Description. The existence of cosmic rays with energies above 10^{19} electron volts.

Data Evaluation. Several wide-area cosmic-ray detectors, located at various spots around the world, using different experimental approaches, have detected over ten cosmic rays with energies over 10^{19} electron volts.

Anomaly Evaluation. This anomaly has two aspects: (1) The source of the ultra-high-energy cosmic rays is believed to be extragalactic, but none of the accelerating mechanisms proposed so far even approach the required energies; and (2) Particles with such high energies react so strongly with the cosmic background radiation that only those cosmic rays younger than 10^8 years now survive; that is, they are all very young! Rating: 1.

Possible Explanations. None.

Similar and Related Phenomena. The origin of ordinary, lower-energy cosmic rays (ATF3).

Examples

X1. General observations. "Protons, nuclei, and electrons in the energy range 10^9-10^{12} eV account for most of the energy of the cosmic-ray flux and have attracted most attention. Plausible models have been proposed for their acceleration (popularly supernovae), of their entanglement by galactic magnetic fields, and of their eventual escape from the Galaxy ('leaky box' models). However, the energy spectrum of cosmic rays extends to $\sim 10^{20}$ eV (and smoothly to 10^{19} eV). This poses a challenge to these models, because (a) the ultra-high energies of these particles rule out most of the accelerating mechanisms that have been discussed, and (b) such particles cannot be retained in the disk of our Galaxy by its magnetic fields. Regrettably, the observations also cast doubt on the importance of the most popular shock-wave process for accelerating particles to ultra-relativistic energies." (R2)

A. Watson has made the following observations. "High-energy fragments of matter originating beyond our Solar System bombard the Earth's atmosphere continuously. These fragments, which are mainly atomic nuclei, are called cosmic rays, and the most energetic have energies well above the highest reached by particle accelerators. How Nature arranges to give single atomic nuclei kinetic energies up to 25 joules---energy sufficient to raise a 1-kg weight to a height of $2\frac{1}{2}$ metres ---is one of the outstanding mysteries of high-energy astrophysics. Recent results suggest that the most energetic particles come from outside our Galaxy; if so, high-energy cosmic-ray sources are as powerful as some of the most powerful X-ray and radio sources." (R1)

In the early 1960s, J. Linsley, employing an array of scintillation detectors at Volcano Ranch, New Mexico confirmed a cosmic-ray event of 10^{20} eV (16 joules). "No one had recognized the significance of this single event when the first phase of the experiment at Volcano Ranch ended in 1963. But in 1966, Kenneth Greisen from Cornell University and Georgi Zatsepin from Moscow pointed out that the discovery of even one event with an energy of 10^{20} eV, during the observations at Volcano Ranch, was totally unexpected.... Greisen and Zatsepin argued that at 10^{20} eV, a proton moving through the 2.7 K radiation field sees the microwaves doppler-shifted to gamma-ray wavelengths. At high enough energies a gamma ray interacts with a proton to produce a nucleon and a pion, and the resultant nucleon (proton or neutron) has less energy than the original proton. The probability for this reaction is so high, and the microwave density so great, that protons with energies above 5×10^{19} eV must interact with the background radiation in less than 10^8 years. This is such a relatively short time on cosmic scales that the observation at Volcano Ranch was quite remarkable." (R1)

X2. Centauro events. "...certain rare cosmic ray events, including the so-called Centauro events seen from the Andes in the 1970's, are characterized by a primary particle that penetrates surprisingly deep into the atmosphere and then dissociates into a surprisingly rich spray of hadrons; it is at least conceivable that a fragment of quark matter would behave in exactly this fashion." (R3)

References

R1. Watson, Alan; "Messengers from Outer Space," New Scientist, 99:257, 1983. (X1)

R2. Hillas, A.M.; "The Origin of Ultra-High-Energy Cosmic Rays," Annual Review of Astronomy and Astrophysics, 22: 425, 1984. (X1)

R3. Waldrop, M. Mitchell; "Is Cygnus X-3 a Quark Star?" Science, 231:336, 1986. (X2)

R4. Bhat, Chaman, et al; "In Search of the Source of Cosmic Rays," New Scientist, p. 48, February 6, 1986.

ATF6 The High Flux of Low-Energy Antiprotons

Description. The measurements of approximately one hundred times more low-energy antiprotons in the cosmic-ray flux than can be accounted for through secondary production by primary cosmic rays interacting with interstellar matter.

Data Evaluation. Several modern measurements by various groups have verified this anomaly. Rating: 1.

Anomaly Evaluation. The anomalous flux of antiprotons could imply one or more of the following: (1) Unexpected primary sources of antiprotons; (2) Much larger secondary production of antiprotons due to the presence of much more interstellar matter than currently contemplated and/or errors in reaction cross sections; and (3) Some completely unknown nuclear process. Items (1) and (3) would be highly anomalous since they conflict directly with important astronomical dogmas. Item (2) is less serious but still implies fundamental errors in our knowledge of cosmic-ray production and history. Rating: 1.

Possible Explanations. Possible primary sources of antiprotons might be: antimatter galaxies (not part of modern cosmological theory) (R3); black hole explosions (R3, R4)

Similar and Related Phenomena. Annihilation radiation sources (ATF8); antineutrino pulses (ATF7)

Examples

X1. Experimental data. In 1979, two teams of scientists, S. L. Golden et al and E. A. Bogomolov et al, found a small flux of antiprotons in the cosmic-ray flux. Although they found only about 2 antiprotons for every 10,000 protons, this was more than they expected, assuming that all antiprotons are secondary; that is, they are created when primary protons interact with interstellar gas. Subsequently, A. Buffington and S. M. Schindler measured the number of antiprotons at lower energies. It was expected that the antiproton/proton ratio would be much less at lower energies, but it turned out to be 2.2, about the same as Golden and Bogomolov had found at high energies, per 10,000 protons.

"This large discrepancy at low energies prompts Buffington and Schindler to suggest that 'a primary antiproton hypothesis cannot be ruled out.' Primary antiprotons might have been made in the big bang and stored somewhere. They might be made in a part of the universe that is dominated by antimatter as ours is dominated by matter. Or they might come from some exotic source yet to be described. The breath-taking consequences of adopting any of these hypotheses lead other people in the field to want to explain the antiproton flux by secondary production, but that requires rethinking some of the theory of how ordinary cosmic rays behave." (R2; R8)

X2. 1986 overview. "It is usually believed that the antiprotons ($\bar{p}$) in cosmic rays result from collisions between high-energy protons (p) and ambient interstellar gas. Recent measurements of $\bar{p}$ cosmic-ray fluxes between 0.1 and 10 GeV are, however, inconsistent with such a secondary source, if the observed p fluxes are assumed to illuminate the 5-7 gm cm^{-2} of interstellar material that has been deduced from studying heavier cosmic rays. Moreover, there is a kinematic cutoff for the reaction threshold of interstellar gas 'target-at-rest' interactions that predicts a dramatic drop in the $\bar{p}/p$ ratio below a few GeV, but the measurements show a practically constant ratio of 3×10^{-4}. The discrepancy factor at higher energy is about 5 but grows to about 100 close to 0.1 GeV." (R6)

References

R1. "Antimatter Arrives from Outer Space," New Scientist, 84:253, 1979. (X1)

R2. "Are Cosmic Ray Antiprotons Primary?" Science News, 91:223, 1981. (X1)

R3. Henbest, Nigel; "Low-Energy Antiprotons: A Puzzle for Astronomers," New Scientist, 92:864, 1981.

R4. Turner, Michael S.; "Could Primordial Black Holes Be the Source of Cosmic Ray Antiprotons?" Nature, 297:379, 1982.

R5. "Antimatter Galaxies," New Scientist, p. 19, May 24, 1984.

R6. Buffington, Andrew; "Where Do Antiprotons Come From?" Nature, 319:178, 1986. (X2)

R7. Davies, P.C.W.; "Antimatter from Space," Nature, 282:130, 1979.
R8. Buffington, Andrew, and Schindler, Stephen M.; "Recent Cosmic-Ray Antiproton Measurements and Astrophysical Implications," Astrophysical Journal, 247:L105, 1981. (X1)
R9. Stecker, F.W., and Wolfendale, A.W.; "The Case for Antiparticles in the Extragalactic Cosmic Radiation," Nature, 309: 37, 1984.

ATF7 Antineutrino Pulses

Description. The detection of series of antineutrino pulses coming from outer space.

Data Evaluation. Only one observation has been reported. Further, no other detectors, such as those on the Vela satellites, recorded anything unusual. Rating: 3.

Anomaly Evaluation. If bursts of antineutrino pulses do occur, they have a ready explanation from prevailing astronomical theory: they are the birth pangs of neutron stars. However, as expressed elsewhere in this book, neutron stars are theoretical constructs, and we really know little about their life histories, especially from an observational point of view. We therefore retain antineutrino pulses as a mild anomaly. Rating: 3.

Possible Explanations. Theory suggests that a star collapsing into a superdense neutron star may oscillate several times, producing in the process pulses of antineutrinos and other radiations.

Similar and Related Phenomena. Pulsar anomalies (AOF9).

Examples

X1. January 4, 1974. "A strange event, recorded by an array of Cerenkov counters deep underground in South Dakota on 4 January, may have represented the birth pangs of a new neutron star collapsing under a strong gravitational field from a normal star. Such, at any rate, seems to be one of the only plausible ways to account for a series of antineutrino pulses lasting for about a microsecond each, and separated by roughly a millisecond." The equipment consisted of a battery of water Cerenkov counters located 4850 feet underground in the Homestake Gold Mine. Vela satellites, however, did not detect any accompanying gamma rays. (R1)

References

R1. "Was a Neutron Star Born on 4 January?" New Scientist, 63:500, 1974. (X1)

ATF8 Apparent Absence of Appreciable Antimatter in the Observable Universe

Description. The lack of any evidence in the fluxes of radiation observed in the vicinity of the earth that significant quantities of antimatter exist in the universe. In fact, the universe seems almost totally unsymmetric in this respect.

Data Evaluation. Negative evidence is fundamentally bad. Here, for example, well-isolated antimatter galaxies and even entire antimatter universes could exist without our knowledge. Rating: 3.

Anomaly Evaluation. Scientists are fond of symmetrical laws and situations, perhaps because so many highly successful physical laws are symmetrical. Nevertheless, many physical phenomena do turn out to be unsymmetrical, even though the applicable physical laws are symmetrical. No theory or philosophical consideration requires matter-antimatter symmetry. Really, there is no anomaly here. Rating: 4.

Possible Explanations. None necessary.

Similar and Related Phenomena. Unsymmetrical physical phenomena, such as weak reactions, the passage of time, chirality in biology.

Examples

X0. Introduction. Comments by G. Lake: "There is a second problem inherent in starting up the Universe: where did the matter come from? In our Galaxy, the absence of antimatter in low-energy cosmic rays leads us to conclude that the Galaxy is all matter. At present we have no way to refute the hypothesis that the nearest Galaxy, the Andromeda nebula, is pure antimatter. To arrange for the degree of homogeneity that must have been present in the early Universe and yet separate matter and antimatter on scales of galaxies or clusters of galaxies seems an impossible task after nearly two decades of effort. Why then is there a pronounced matter-antimatter asymmetry in the Universe?" (R3)

One could answer Lake's question with another question: Why shouldn't there be a matter-antimatter symmetry in the Universe? The usual answer is that the particle-antiparticle symmetry of the laws of physics is very well established. From this and also from philosophical considerations, many scientists think that there should be an antiparticle for every particle. However, G. Steigman remarks that the solutions to the equations of physics need not display the same symmetry as the laws themselves. Symmetry can be broken through an appropriate choice of boundary conditions. Indeed, "interesting" physical systems tend to be unsymmetrical, and the real universe may be this way, too. (R2)

X1. Direct evidence of antimatter. F.W. Stecker et al claimed, in 1971, that cosmic gamma rays detected at earth contained a component with a spectrum similar to that calculated for matter-antimatter annihilation. Such annihilation would generate large numbers of pions, which would then decay into gamma rays. (R1; R5) This is the only direct evidence found so far that antimatter may exist in large quantities in the universe. (WRC)

X2. General observations on the absence of antimatter in the universe. "That the Moon and Venus are made of ordinary matter is clear from direct observations. That the solar system in general contains no antimatter follows from the lack of solar-wind induced annihilation gamma rays. An 'antiplanet,' for example, would have been the strongest gamma-ray source in the sky. Similarly, gamma-ray observations show that no nearby star ($<$ 30 pc) is an 'antistar.' Indeed, that the Galaxy can contain no interesting amounts of antimatter is strongly suggested by the absence of antinuclei in the cosmic rays, by the observations of Faraday rotation, and by the observations of galactic gamma rays." Extending this reasoning, the lack of gamma rays from X-ray emitting galactic clusters suggests that "interesting" quantities of antimatter are truly absent. "The inexorable conclusion indicated by the overwhelming weight of the evidence is that the Universe is unsymmetric. The reader who finds this state of affairs 'unsatisfying' may well recall that our Universe is the only one available for us to study. Symmetric Universes may be possible in principle, but perhaps only when the symmetry is broken will an 'interesting' Universe emerge." (R2)

References

R1. "Cosmic Antimatter and Gamma Rays," Science News, 100:374, 1971. (X1)
R2. Steigman, Gary; "Observational Tests of Antimatter Cosmologies," Annual Review of Astronomy and Astrophysics, 14: 339, 1976. (X0, X2)
R3. Lake, George; "Windows on a New Cosmology," Science, 224:675, 1984. (X0)
R4. Guillen, Michael; "The Paradox of Antimatter," Science Digest, 93:32, February 1985. (X2)

R5. Stecker, F.W., et al; "Possible Evidence for the Existence of Antimatter on a Cosmological Scale in the Universe," Physical Review Letters, 27:1469, 1971. (X1)

ATF9 Exceptional Increases in Cosmic-Ray Intensity

Description. Prolonged enhancements of cosmic-ray flux in the absence of magnetic disturbances. The enhancements may amount to 25% and last for several hours.

Data Evaluation. The only example found in the literature so far is from 1943, a time when cosmic-ray instrumentation was not as well-developed as it is today. The nature of the particles in the enhanced shower is not known. Obviously, more data are needed to better define this phenomenon. Rating: 3.

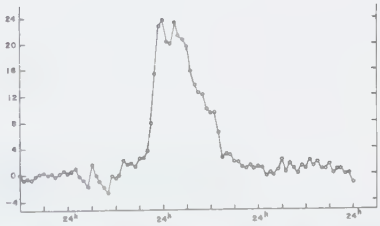
Anomaly Evaluation. Since no unusual magnetic activity is involved, solar cosmic rays are probably not contributory. Such large, prolonged enhancements are uncharacteristic of cosmic rays. Rating: 2.

Possible Explanations. Instrument malfunction.

Similar and Related Phenomena. Gamma-ray bursters (AOF29); X-ray bursters (AOF30).

Examples

X1. August 13, 1942. A battery of Geiger counters was registering threefold coincidences. "The records generally show that changes in cosmic rays from day to day are more or less what can be expected from well-known geophysical influences. However, last August a transient change was recorded which apparently cannot be attributed to any of these influences. The points on the diagram of Fig. 1 represent the hourly counting rate for the period August 12-15, 1942. The scale is in percentages from the normal value. The rapid and quite unusual increase which began at about 18h. (G.M.T.) August 13 was preceded by fluctuations in the counting rate which are not common in the absence of magnetic activity." Greenwich magnetic records during this period showed no activity of any consequence. (R1)



An exceptional increase of cosmic radiation, 1942. (X1)

References

R1. Duperier, A.; "An Exceptional Increase of Cosmic Rays," Nature, 151:308, 1943. (X1)

ATF10 Asymmetry of Infrared Background Radiation

Description. A "subtle asymmetry" of the infrared background. Detected by satellite infrared surveys, quantitative data are not provided in the literature at hand.

Data Evaluation. The data are from the IRAS (Infrared Astronomical Satellites) and are generally considered to be of good quality. Details about the asymmetry will undoubtedly be found as literature examination continues. Rating: 2.

Anomaly Evaluation. The infrared asymmetry is assumed to be galactic in origin and the consequence of a large concentration of unseen mass. If this assumption is correct, the mass might represent the long-sought "missing mass". There would be no anomaly here if this turned out to be correct. However, the situation is not resolved, and a low anomaly rating seems in order until the phenomenon is clarified. Rating: 3.

Possible Explanations. Cold, invisible matter inside our galaxy.

Similar and Related Phenomena. Other anomalies associated with the "missing mass" hypothesis: the anomalous rotation of matter in galaxies (AWB5); the apparent rapid dispersal of galactic clusters (AWB13); galactic halos (AWO11).

Examples

X1. IRAS measurements. "Mysterious background emissions. Showing up only as a subtle asymmetry in the 100-micrometer IRAS (Infrared Astronomical Satellite) scans, these emissions appear to represent a large component of galactic material of an unknown nature. The finding could have great significance, considering that so much of our galaxy (and other galaxies) appears to consist of 'missing mass'. That is, the galaxy is rotating much too fast for the visible stars to hold it together gravitationally, and there must be a great deal of invisible matter making up the difference." (R1)

References

R1. Waldrop, M. Mitchell, and Kerr, Richard A.; "IRAS Science Briefing," Science, 222:916, 1983. (X1)

ATF11 Nondoppler Redshifts

Description. The redshifting of light from astronomical sources due to physical effects other than the Doppler effect.

Background. Redshift observations are, of course, crucial to our modern view of the evolution of the cosmos. Usually, it is assumed that the observed redshifts are entirely due to the Doppler effect. If this assumption is incorrect, our cosmology must be drastically revised. At least five major classes of observations exist which tend to undermine the Doppler-effect assumption: (1) Laboratory measurements of spectral noninvariance; (2) Astronomical redshifts that can be correlated with large-scale mass distributions; (3) General comparisons between Doppler-redshift (expanding universe) cosmologies and cosmologies based on other redshift phenomena, such as 'tired light', showing the inferiority of the Doppler hypothesis; (4) Observations of redshift differences between objects thought to be at the same distance; and (5) Observations of quantized redshifts. Only the first three classes are considered here; see below for cross references for classes (4) and (5).

Data Evaluation. The examples provided below reveal only skimpy data. Possibly this is due to the strength of the Doppler-redshift dogma and the consequent lack of searching for contradictory data. Be that as it may, data in the first three classes above are scarce and not replicated. Rating: 3.

Anomaly Evaluation. Any bona fide contradiction of the Doppler-redshift (expanding universe) hypothesis would be a matter of the utmost gravity in astronomy in particular and our whole scientific concept of the universe in general. Rating: 1.

Possible Explanations. Light can be redshifted by its propagation through space occupied by mass. Light emitted by some astronomical objects, such as quasars, may be spectrally noninvariant; i.e., redshifts evolve naturally as the light travels due to source correlations.

Similar and Related Phenomena. Quantization of redshifts (AWF8, AOF18, AQF2); different redshifts for objects at the same distance (AQB1, AQB2, AQB6, AWB7).

Examples

X1. Observations of "tired light". "For several classes of objects, it seems that in different regions of sky different apparent redshift-distance relations exist. (If the class of objects is defined narrowly enough, they will all have about the same intrinsic brightness, and so distance can be estimated from the apparent brightness of each, independent of redshift.) At first this seemed to indicate a possible lopsided expansion, but now three astronomers at the Institut Henri Poincare in Paris, Hiroshi Karoji, Laurent Nottale and Jean Pierre Vigier, say the matter goes beyond that. Their latest results point toward a belief in the so-called 'tired-light' hypothesis.

Their latest paper, which has been submitted to Astrophysical Journal Letters, deals with the apparent motion of faint radio galaxies (magnitudes 13.0 to 15.5). These observations show 'an even more curious distribution' of redshifts than observations of other classes of objects. In summary, they say, 'Everything goes as if light emitted from distant sources is redshifted when it travels through clusters of galaxies." (R1)

X2. Comparison of tired-light and expanding universe models. "Abstract. The no-evolution, tired-light model and the no-evolution, $q_0=0$, expanding universe cosmology are compared against observational data on four kinds of cosmological tests. On all four tests the tired-light model is found to make the better fit to the data without requiring the ad hoc introduction of assumptions about rapid galaxy evolution. The data may be interpreted in the simplest fashion if space is assumed to be Euclidean, galaxies cosmologically static, evolutionary effects relatively insignificant, and photon energy nonconserved, with photons losing about 5%-7% of their energy for every 10^9 light years of distance traveled through intergalactic space. The observation that redshifts are quantized may be accommodated by a version of the tired-light model in which photon energy decreases occur incrementally in a stepwise fashion." (R4; R3)

X3. Tired-light theory. D. F. Crawford has published a theory based on tidal stresses exerted on photons by curved space-time. "...the interaction of the photon with curved space-time causes it to lose energy in the form of very low energy secondary photons." This accounts for the Hubble redshift. (R2)

X4. The spectral variance of light--a new theory, with supporting observations. "Physicists have generally assumed that once light leaves its source, its spectrum does not change. However, (E.) Wolf suggests that spectra from 'unconventional light sources...and stellar objects of an unfamiliar kind' may vary or 'evolve' during the journeys across the great intergalactic distances. That the spectra of light emitted by common sources like lightbulbs and flames are invariant on propagation, Wolf comments, 'is undoubtedly responsible for the commonly held, but nevertheless incorrect, belief that spectral invariance is a general property of light.'"

.....

"The essential point is that the coherence properties of the source are...put into the light right at the beginning when it is starting from the millions of elementary sources," Wolf explains. As the emitted light travels through space, the spectrum evolves, adding a non-Doppler component to the redshift detected on Earth. The changes that occur in the spectrum are 'sort of coded into the light due to correlations in the source.'" (R6; R5)

Emil Wolf, who is at the University of Rochester, has stated that two of his colleagues have obtained noninvariant spectra in the laboratory. (R6) Apparently these experimental data have not yet been published. (WRC)

References

R1. "The Geritol Universe: Tired Light," Science News, 108:277, 1975. (X1)
R2. Crawford, D. F.; "Photon Decay in

Curved Space-Time," Nature, 277:633, 1979. (X3)
R3. "New Study Questions Expanding Universe," Astronomy, 14:64, August 1986. (X2)
R4. LaViolette, Paul A.; "Is the Universe Really Expanding," Astrophysical Journal, 301:544, 1986. (X2)
R5. "Funny Light," Sky and Telescope, 72: 237, 1986. (X4)
R6. Amato, I.; "Spectral Variations on a Universal Theme," Science News, 130: 166, 1986. (X4)

ATF12 Spectroscopic Evidence of Life in Space

Description. The close matches between interstellar absorption spectra and absorption spectra of life-associated molecules and simple life forms, such as bacteria.

Data Evaluation. The quality of the data is good, but there is considerable disagreement concerning whether the interstellar spectra really match terrestrially measured spectra of such materials as polysaccharides and dried bacteria. The general consensus is the matches observed are inadequate to prove the existence of polysaccharides, bacteria, and other life-associated substances in interstellar space, although there are notable holdouts. Rating: 3.

Anomaly Evaluation. Since many complex molecules have been found in interstellar space from absorption spectra, it is surprising to find so much opposition to the claim that polysaccharides are also out there, even nonbiogenic polysaccharides. However, the presence of bacteria in interstellar space would definitely be highly anomalous, because current scientific dogma assigns life to favorably endowed planets, like earth, rather than in the (supposedly) inimical environment of interstellar space. This seems to be more a philosophical position than one based on logic and data. Rating: 1.

Possible Explanations. Absorption spectra are often difficult to interpret; and combinations of nonbiological materials can be found that will duplicate interstellar absorption spectra. Although a nonbiological explanation is possible, even probable, the life-in-space alternative must not be dismissed completely, for data from other fields, such as epidemology, are also consistent with the life-in-space hypothesis.

Similar and Related Phenomena. The existence of dark, organic material in space (ACO23, AYE2); anomalies of terrestrial epidemics (series B catalogs).

Examples

X1. Prebiotic and life-related molecules. "Observations over the infrared waveband 2-30 μm available for a number of astronomical objects are shown here to be reconcilable with the transmittance properties of polysaccharides. Using an experimentally determined transmittance spectrum for cellulose we can readily relate astronomical data in the 2-4-μm and 15-30-μm wavebands and we obtain close fits to astronomical spectra in these several bands. From this detailed spectral agreement we consider it reasonable to infer the detection of interstellar polysaccharides. The identification of this highly complex macromolecule, presumably formed by an abiogenic processing of interstellar formaldehyde could have a profound bearing on interstellar chemistry including the evolution of prebiotic molecules." (R8; R1)

From another article by the same authors (F. Hoyle and N.C. Wickramasinghe): "We conclude the following: Infrared sources exhibiting polysaccharide absorption features may be associated with massive stars of the kind discussed by Hoyle et al. Mass flows from such stars can lead to the production of polysaccharides in the first instance, followed by the condensation of nitrogenated heterocyclic carbon compounds. The composition of carbonaceous condensates from these sources may well determine the course of interstellar chemistry.

Low molecular weight organic compounds and radicals detected in interstellar clouds, often involving a number of linked carbon atoms are probably the products of the ultraviolet and cosmic-ray degradation of much more complex structures.

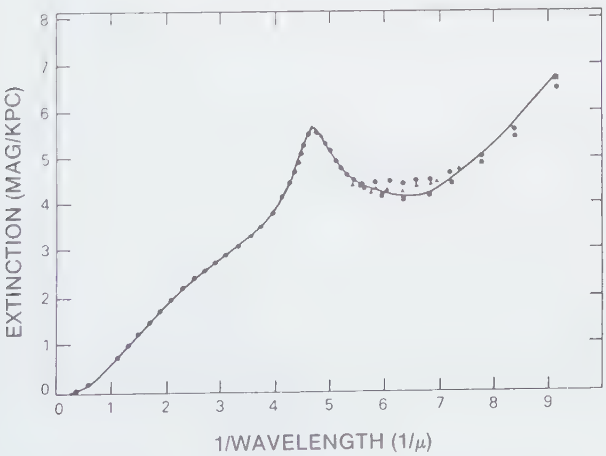
We also speculate that carbonaceous materials formed in the mass flows from stars provided the chemical basis for the origin of life. It is not as hard as it has usually been supposed to understand how interstellar materials could have by-passed the destructive high temperature of the solar nebula and could have arrived undamaged at the Earth. We suggest that the origin of life on the Earth involved essentially the assembly of complex chemical components which had already been provided in the last stages of the accumulation of the Earth, and which exist widely and in comparatively great quantities within the interstellar medium." (R2)

X2. Bacteria. "We have hinted in former chapters that bacteria might possibly be an important component of the interstellar dust, contributing to the blocking of starlight.... The amount of bacteria could be exceedingly large. With ten Earth masses from each of the estimated 200 000 million stars in our galaxy, the amount would be about 6 million times the mass of the Sun, which is quite comparable to the total quantity of all the interstellar grains in the galaxy."

The accompanying figure illustrates the basis of the claim of bacteria in space by Hoyle and Wickramasinghe. The calculated absorption curve for a mixture of bacilli (65%), mycoplasmas (25%), and graphite spheres (10%) compares well with observations of interstellar absorption.

"It is remarkable that all the diverse properties of the interstellar grains become immediately explicable in terms of bacteria. Unlike previous unsuccessful theories no ad hoc mixture of several widely different kinds of particle is required. The different components discussed above all follow from biology itself.... The facts of astronomy point strongly to interstellar space being chock-a-block with biological material." (R4)

The hypothesis of Hoyle and Wickramasinghe naturally generated much discussion. Most of the criticism has centered on the reality of the match between astronomical data and absorption curves measured in terrestrial laboratories and calculated theoretically. (R5, R6, R9) D.C.B. Whittet has nicely summarized the general reaction of the scientific community: "The ultraviolet data are thus in satisfactory agreement with other evidence which may be used to test the bacterial grain model. These include modelling of the infrared spectral feature at 10 μm, experiments on the survival of bacteria in simulated interstellar conditions, and abundance considerations for crucial elements,



The best fit (solid curve) that can be achieved is with a mixture of bacilli (65%), mycoplasmas (25%), and graphite spheres (10%). (X2) particularly phosphorus. All of these results argue against bacteria as significant constituents of interstellar grains." (R7)

References

R1. Wickramasinghe, N.C., et al; "Prebiotic Polymers and Infrared Spectra of Galactic Sources," Nature, 269:674, 1977. (X1)
R2. Hoyle, F., and Wickramasinghe, N.C.; "Origin and Nature of Carbonaceous Materials in the Galaxy," Nature, 270:701, 1977. (X1)
R3. Hindley, Keith; "Tar among the Stars May Make Interstellar Molecules," New Scientist, 76:23, 1977. (X1)
R4. Hoyle, Fred, and Wickramasinghe, Chandra; "Interstellar Bacteria," Space Travellers: The Bringers of Life, Cardiff, 1981, p. 75. (X2)
R5. "Life from Space: Two Peaks Don't Make a Microbe," New Scientist, 99:556, 1983. (X2)
R6. Hoyle, F., and Wickramasinghe, N.C.; "Bacteria in Space?" New Scientist, 101:46, 1984. (X2)
R7. Whittet, D.C.B.; "Bacteria in Space: A Limit Based on Ultraviolet Absorption," Observatory, 104:159, 1984. (X2)
R8. Hoyle, F., and Wickramasinghe, N.C.; "Polysaccharides and Infrared Spectra of Galactic Sources," Nature, 268:610, 1977. (X1)
R9. "New Light on Bacteria from Space," New Scientist, 100:578, 1983. (X2)

ATO OBJECTS IN INTERGALACTIC SPACE

Key to Phenomena

ATO0 Introduction

Searches of intergalactic space yield no isolated stars or other self-luminous aggregations of matter. Absorption spectra do tell us that some diffuse gases and particulate matter occupy the gulfs between the galaxies. The only "object" found so far in intergalactic space is a giant cloud of neutral hydrogen, with the mass of a billion suns, and of uncertain origin.

ATO1 Intergalactic Clouds

Description. Large clouds of matter located in intergalactic space. Such clouds rival galaxies in terms of mass and are much larger in extent.

Data Evaluation. One large intergalactic cloud has been discovered to date. Since its detection was by the Arecibo radio telescope, there seems little reason to question the reality of the phenomenon. Rating: 1.

Anomaly Evaluation. Astronomers cannot account for such large intergalactic aggregations of matter. Are these clouds leftovers from the galactic condensation phase? If so, one wonders why the diffuse gas did not disperse long ago, or why it did not condense given its mass of a billion suns. Further, no reasonable mechanism has been suggested for the generation of such large clouds by galaxies themselves. The anomaly is that we have a large-scale phenomenon without a theory of origin. Rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. The giant molecular clouds within our galaxy and presumably within other galaxies, too. Intergalactic clouds may contribute substantially to the mass needed to close the universe; that is, eventually halt its expansion.

Examples

X1. General observations. Despite considerable searching, only one significant object has been discovered in intergalactic space. In 1983, a huge cloud of neutral hydrogen was found by accident in the middle of a group of galaxies in the constellation Leo. "Even though the cloud is 30 million light-years distant, it extends over an area of the sky larger than the size of the full moon. Some 300,000 light-years across, it contains over a billion solar masses of neutral hydrogen. More recent observations have shown smaller cloudlets extending over an even larger region. There is no obvious explanation for this sort of feature in the simple models of matter expelled from galaxies by collisions or gravitational tides, although perhaps some complicated scenario might yet explain the cloud as having a galactic origin. Then again, it might be older than the galaxies, a remnant of their formation. Its presence emphasizes that we do not yet fully understand the evolution of galaxies, and perhaps underscores how little we yet know about the intergalactic medium."(R3; R1, R2, R4)

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AW INTRODUCTION TO GALAXIES

Key to Categories

AWB DISTRIBUTION AND DYNAMICS OF GALAXIES
AWF ANOMALIES DETECTED THROUGH GALACTIC RADIATION
AWO MORPHOLOGY AND STRUCTURE OF GALAXIES
AWZ GALACTIC MAGNETIC FIELDS

Galaxies are thought by many astronomers to be the "natural unit" in astronomy, something akin to the "species" in biology. It is true that most galaxies seem to be isolated islands in space, independent aggregations of anywhere from millions to trillions of stars. Actually, the galaxies are complex morphologically, displaying a variety of spiral shapes and elliptical accumulations, as well as "irregular" configurations. Perhaps the species analogy is not particularly apt!

Looking beyond the individual galaxies, we find that they are not really as isolated as once thought. Most reside in clusters boasting from a dozen or so to hundreds of galaxies. Physical interactions between galaxies seem to be common, as evidenced by tails and similar bridges of matter between adjacent galaxies. And beyond the galactic clusters we have the superclusters and perhaps even greater aggregations: the families and genera of astronomical taxonomy.

Some themes that loomed important in the chapters on stars and quasars appear again here. We find once more the vexing redshift problem, the possible quantization of redshifts, the question of galactic origins, the source of galaxy rotation, the difficulty in accounting for intense energy generators like the Seyferts, and objects that apparently move faster than light. Galaxies, however, also highlight special anomalies of major significance, such as the "missing mass" mystery. Even more fascinating is the seeming fecundity of the giant ellipticals, with their jets of matter, the double radio lobes, exterior shells of stars, and lines of spirals trailing off into the distance. For all their external simplicity, the ellipticals may harbor fabulous wellsprings of matter and energy.

AWB DISTRIBUTION AND DYNAMICS OF GALAXIES

Key to Phenomena

AWB0 Introduction

Galaxies, each comprising billions of stars, have their own aggregations---and even super-aggregations. In fact, some astronomers consider galaxies rather than stars to be the basic unit of organization in the universe. The stars are merely building blocks of the fundamental structures. The galaxies themselves are first grouped into clusters, then the clusters are organized into superclusters, and there is some evidence for even larger structures. Just why we have this apparent hierarchy of galactic aggregations is one of the major problems of astronomy. Most believe that this hierarchical organization conveys information about the nature of the Big Bang and the universe's subsequent evolution. Or, if the Big Bang is a false hypothesis---this is not an impossibility despite the assurances conveyed in the text-books---then the hierarchy of galaxies may help us formulate better theories.

Again in this section, the validity of the redshift-distance relationship rears its ugly head. For example, some galaxies that seem physically related and thus at the same distance have substantially different redshifts. If redshifts cannot be employed as astronomical yardsticks then the three-dimensional picture of galactic organization sketched in the first paragraph collapses. In addition, our astronomical dating scheme would also be compromised. We would be back to a two-dimensional universe without age markers. Naturally, such ideas dismay astronomers, and much emotion attends the discussion of the redshift-distance paradigm.

Another popular astronomical hypothesis is that of "missing mass". The dynamics of galaxies and galactic clusters are such that if they are in dynamic equilibrium they must contain much more mass than we observe in the form of visible stars. But despite careful searching, the missing mass remains missing. Actually, the missing mass literature is extensive, but it is mainly concerned with exotic forms of mass we cannot see readily. The need for missing mass disappears if one admits that galaxies and galactic clusters might not be in equilibrium. Unfortunately, this avenue seems to lead us to a very young universe, because the galaxies and their aggregations should have dispersed long ago given their present dynamic states and a 15-billion-year-old universe.

Obviously, the anomalies of this section, and those in the rest of this chapter, have some unthinkable implications.

AWB1 The Existence of Galactic Clusters

Description. The existence of aggregations of galaxies ranging in number from several to hundreds of thousands. Typical galactic clusters have diameters between 2 and 5 megaparsecs (Mpc). Galactic clusters tend to be much more spherical than the filamentous superclusters.

Data Evaluation. The celestial coordinates of galaxies (two angles) are known with high precision. The distances of galaxies can be estimated roughly from their luminosities or, as is prefered, redshifts can be measured. Redshifts are presumed to be proportional to distance, but the constant of proportionality, the Hubble Constant, is but poorly known. Further, a few astronomers question whether redshifts are measures of distance at all. Rating: 2.

Anomaly Evaluation. The origin of galactic clusters, like the origins of superclusters and the galaxies themselves, has been the subject of much debate. As described in X4, below, one can assume that either large or small fluctuations existed after the Big Bang. In the former instance (the "top down" approach), superclusters form first; in the latter case (the "bottom up" approach), the galaxies are created first. In all cases, the fluctuations as well as the Big Bang, or the singularity that preceded it, must be assumed; that is, their origins are not known. Rating: 1.

Possible Explanations. As above and in X4. However, we are getting close to the point where scientific explanation ceases and where one must assume something, whether it be a primordial singularity or God!

Similar and Related Phenomena. The existences of superclusters (AWB2), voids in the distribution of galaxies (AWB3), the overall fabric of the cosmos (AWB4), galaxies (AWB17); stars (AOB18).

Examples

X1. Early survey. "Evidence has accumulated in favor of the hypothesis, first advanced by Zwicky, that clusters or more precisely 'cluster cells' are 'space fillers' that occupy all space available as 'suds in a volume of suds'. Indeed, in a recent systematic, exhaustive survey of the 55 nearest groups of galaxies (those within 16 megaparsecs), there were very few galaxies that could not be assigned to a definite group or cluster. Isolated, intercluster galaxies (or, if you will, clusters of N = 1 member in statistical terminology) are apparently very rare, a fact that has obviously important, if still hidden, physical as well as cosmological implications. Diameters of typical groups are generally between 1 and 3 megaparsecs; clusters have diameters between 2 and 5 megaparsecs; and there is now good evidence for clustering on a much larger scale of, say, 30 to 60 megaparsecs, that is, for 'superclusters.'" (R1)

X2. Our Local Group, a small example of a cluster. "Our own Milky Way Galaxy is itself a member of a cluster of galaxies---the 'Local Group,' as astronomers call it. Because we are embedded in it, the Local Group is more difficult to recognize than the great cluster in Virgo. It was only when the actual distances of galaxies were measured (by estimating the luminosities of stars in them) that several dozen, including the Magellanic Clouds, the Great Galaxy in Andromeda, M-33, and numerous dwarf galaxies, were found to be close neighbors of ours.

The Local Group is a small and sparsely populated cluster, containing only a few dozen members. Rich clusters, like the one in Virgo, contain hundreds or thousands of galaxies of all types. These rich clusters invariably contain near their center one or two of the largest types of galaxies known ---giant elliptical galaxies, which may contain as much material as 50 spiral galaxies like our Milky Way." (R4)

X3. General observations. "Galaxies form clusters rich and poor, the Coma cluster contains on the order of 10^6 galaxies, while in our Local Group the latest count is only 21. The clustering tendency is quite marked; isolated field galaxies are exceptional (not more than 3 in 20 in the Reference Catalogue of Bright Galaxies), and indeed Fritz Zwicky proposed a model 40 years ago in which all galaxies belong to a larger association. The average rich cluster contains 1000 galaxies with a total of 10^{15} solar masses, spans 5 megaparsecs (about 15 million light years), and lies some 10 megaparsecs (Mpc) from its nearest neighbor. Poor clusters need not have smaller diameters, but contain a sparser population distributed less symmetrically with a greater degree of subclustering." (R2)

X4. Some clustering theories. "Three main theories make the attempt. One proposes that superclusters emerged soon after the Big Bang as results of large fluctuations in the overall smoothness of the primordial universe. Over time, the superclusters fragmented to form galaxy clusters and galaxies. Another theory suggests that early galaxies exploded, propelling clusters at the high speeds observed.

An equally promising theory, according to (N.) Bahcall, postulates that small fluctuations in the smooth early universe coalesced into galaxies under their own gravitational pull; later, gravity pulled galaxies together into clusters and superclusters. Not enough time has passed, however, for gravity alone to have formed the large structures now seen, says Bahcall. This leads to speculation that huge clumps of dark matter (black holes, neutrinos or other invisible matter) may help pull the galaxy clusters along." (R6)

The most recent (and highly popular) theory involves "cosmic string". "Most theories assume that the universe started out smooth and undifferentiated, but for galaxies to have formed, there had to be some kind of flaw in the smoothness, around which matter could gather. One very new suggestion is that these were topological flaws in space-time itself, the so-called cosmic string. Now a calculation shows that cosmic strings will cluster hierarchically and this clustering closely resembles the distribution of galaxies seen in what astronomers call Abell clusters." (R8)

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AWB2 The Existence of Superclusters

Description. Aggregations of galactic clusters. One level higher than galactic clusters in the cosmic hierarchy, superclusters consist of long string-like groups of galactic clusters, which some have likened to beads on a string. Superclusters usually contain several dozen galactic clusters, and the largest may span a billion light years.

Data Evaluation. As with the galactic clusters (AWB1), the proof of the existence of superclusters depends upon the three-dimensional mapping of the universe. Vital to such maps is the assumption that redshifts are proportional to distance. Beyond this, the statistical treatment of the data may be a bit tricky, with the structures one sees being dependent upon the sampling techniques. Even the use of mosaics of photographic plates may introduce artefacts. (See X9 below.) Despite these caveats, an astronomical consensus seems to favor the existence of superclusters. Rating: 2.

Anomaly Evaluation. The discussion in AWB1 of galactic cluster anomalies is also appropriate here. Rating: 1.

Similar and Related Phenomena. The existences of galactic clusters (AWB1), voids in the distribution of galaxies (AWB3), the overall fabric of the cosmos (AWB4), galaxies (AWB17), stars (AOB18).

Examples

X0. Introduction to superclusters. "The largest structures found and mapped so far, superclusters, are long filaments or shells that are themselves made up of many clusters of galaxies. Clusters of galaxies tend to be approximately spherical in shape and may contain hundreds or thousands of galaxies each; superclusters may consist of tens of clusters linked like beads on a string. The largest supercluster is more than a billion light years long. Voids, which are hundreds of times less dense than the superclusters, separate superclusters from one another." (R18)

X1. Early supercluster surveys. "Some controversy has arisen concerning the concept and reality of 'superclusters,' that is, of condensations of galaxies on a scale much larger than conventional groups or clusters which typically do not exceed a few megaparsecs in diameter. On the one hand, Zwicky and his collaborators have repeatedly asserted that clusters of (globular) clusters do not exist and their evidence is not denied. On the other hand, Abell---working from his catalog of clusters based on plates from the same Mount Palomar 48-inch camera---has given definite statistical evidence that at least some of these large clusters have a (nonrandom) clumpy distribution on a typical clustering scale of 50 megaparsecs; he has offered specific examples of such associations or loose groups of clusters, all having about the same red shift." (R1)

"Between 1950 and 1954 the entire northern sky was mapped with the wide-angle 1.2-meter Schmidt telescope on Palomar Mountain. Soon thereafter George O. Abell of the University of California at Los Angeles compiled a catalogue of 2,712 rich clusters of galaxies. Abell pointed out that many of the clusters seemed to be members of superclusters with an average of five or six clusters each." As related above Zwicky's conclusion, using the same data, came out against the existence of superclusters. However, the disagreement seems to exist because Zwicky was looking for larger associations than Abell. (R7) The recognition of superclusters is sensitive to sampling techniques, as we shall see in X9. (WRC)

X2. The Local Supercluster. "The northern galactic hemisphere---that portion of the sky lying to the north of the Milky Way---is rich in bright galaxies; the southern hemisphere is relatively barren. For a generation or more, astronomers have debated why. Their consensus today is that our galaxy lies at the edge of a much larger assemblage of galaxies, a structure some 60 million light-years across. They call it the Local Supercluster. The northern galactic hemisphere appears overpopulated because our own galaxy happens to lie almost face on to the supercluster core.

The core itself is a swarm of galaxies lying 50 million light-years from the earth in the direction of the constellation Virgo. Some 60 luminous galaxies and hundreds of not-so-luminous galaxies are contained there within a spherical region no more than

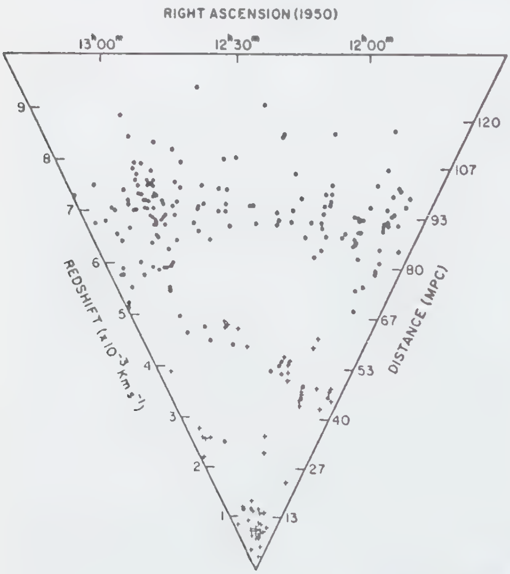
10 million light-years across. (A similar volume centered on the Milky Way contains just two large neighbors, the spiral galaxies in Andromeda and Triangulum. "(R4; R2, R18) The Virgo cluster is a particularly rich example of a galactic cluster, and it forms the center of the Local Supercluster, which also contains our Local Group of galaxies, a "poor" cluster of galaxies.

X3. The Coma/A1367 Supercluster. S.A. Gregory and L.A. Thompson have found that the space between the galactic clusters Coma and A1367 is occupied by roughly ten times as many galaxies per unit volume of space than the foreground. They take this as a demonstration that the two clusters are bridged by galaxies, welding them together into a supercluster. (R2)

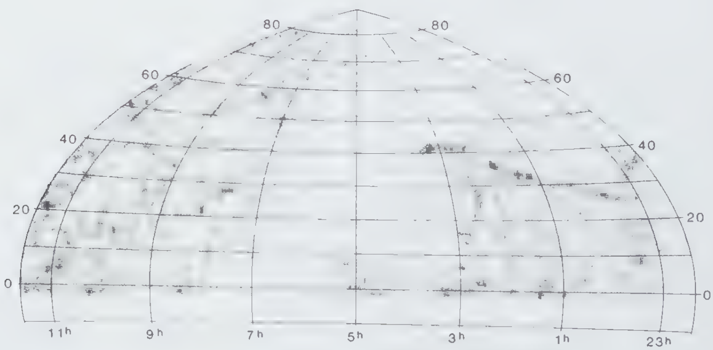
X4. 1451 + 22. H.C. Ford and his colleagues have measured the line-of-sight velocities of galaxies in the region of 1451 + 22. "These velocities allowed true supercluster members to be identified and revealed that each of the systems extended over 300 million light-years. The differences in velocity from galaxy to galaxy enabled the total mass (both visible and invisible forms) of the superclusters to be determined. The density of matter present is only a small fraction, six to 16 percent, of that needed to halt the overall expansion of the universe. Thus, unless the intergalactic voids contain vast amounts of invisible material, our universe will continue to expand for all time." However the superclusters themselves seem to possess enough mass to prevent them from expanding as fast as the universe itself. (R3)

X5. 1615 + 43. Same discussion as X4. (R3)

X6. The Lynx-Ursa Major/Pisces-Perseus supercluster chain. The two superclusters in Lynx-Ursa Major and Pisces-Perseus seem to be aligned and have similar radial velocities (similar distances). However, because they lie on the other side of the Milky



Map of galaxies near the Coma cluster, as projected onto the plane of the celestial equator. The Coma/A1367 supercluster shows up clearly at 97 Mpc. (X3)



Map of the angular distribution of the bright galaxies from Giovanelli and Haynes. The shade density in each cell is proportional to the logarithm of the surface density of galaxies brighter than apparent magnitude m ~ 15.7. The blank zone in the middle is due to dust obscuration. (X6)

Way, any physical connection is obscured by the interstellar dust in the plane of the galaxy. Radio waves can penetrate this dust shield, and they suggest that the two superclusters are indeed bridged by more galaxies. "If the Lynx-Ursa Major and Pisces-Perseus chains really are part of one giant feature, its angular extent would be approximately 180°. It literally would extend from horizon to horizon across our sky. The corresponding linear size of 700 million light-years is 10 times greater than the largest clumps of cosmic material known until recently. These large filaments seem to be the rule rather than the exception. They can be traced among the clusters of galaxies in Hercules and Cancer, for example." (R8; R5, R13, R20)

X7. The Perseus-Pegasus filamentary supercluster. "Shaped like a long, thin tube or filament, the supercluster is more than one billion light-years in length and roughly between 10 and 50 million light-years in cross-section. (The diameter of the Milky Way, our own galaxy, is 100,000 light-years). The supercluster consists of densely packed clusters of galaxies, all receding from the earth at similar velocities, an effect due to the overall expansion of the universe. The supercluster lies in the northern sky in the direction of the constellations Perseus and Pegasus." (R16; R12, R15)

X8. General observations. "Superclusters are unrelaxed structures. They have no symmetry and no central concentration. Their complicated nature is illustrated by the Local (Virgo), the Coma, Perseus, and Hercules superclusters. Their space frequency and general properties can be derived from the Redshift Catalog of the Center for Astrophysics (cf. Section 4). Many superclusters seem very elongated. Typical (baryon) masses for the larger structures are 10^{15}-10^{16} $M_{\odot}$. The very large sizes---up to 350 Mpc---indicate that they descend from primeval density fluctuations.

There are indications that the great majority of galaxies are concentrated in superclusters, and that the spaces in between are virtually devoid of luminous matter.

Particularly interesting is the evidence for segregation of galaxy types in the Perseus supercluster, and the indication that the major axes of rich clusters tend to be oriented along the major features of the superclusters. These facts suggest that superclusters formed by a collapse in the gaseous stage, prior to the birth of galaxies, and that they came from adiabatic perturbations in the early Universe. The fact that no corresponding fluctuations are seen in the microwave background radiation indicates either that the main mass of the Universe consists of weakly interacting particles, such as heavy neutrinos, or that the background fluctuations have been washed out by a reionization of intergalactic gas fairly soon after decoupling." (R9)

X9. Questions about the reality of superclusters. A map of the universe called One Million Galaxies has been used widely in cosmological studies. Originally prepared by J. Peebles and his colleagues, the map shows many chains of galaxies and filamentary superclusters. "But (M.) Geller and coworkers aren't so sure the strings of galaxies on the map are real. While preparing for their own partial sky survey, the astronomers became suspicious of the Peebles map and decided to use Shane and Wirtanen's data to make a flat projection---unlike the 1977 domelike projection. What had appeared as filaments in the domelike map suddenly looked like rectangular patches: rectangles that contain few galaxies border rectangles filled with them. The scientists soon discovered that the rectangles follow the mosaic pattern of the original photographic plates." The different plate sensitivities and weather conditions could account for these effects. (R14)

"There is yet another possibility to consider; if galaxies were placed in a clustering pattern according to a random statistical process that had no preference for lines, the occasional filament would be produced by chance and, because the eye is so sensitive to patterns, we might attach undue significance to these accidents." This might be termed the Martian canal effect; that is, an artifact of human perception. The filamentary galaxies claimed by some observers and analysts may be real but researchers should be aware of statistical accidents. (R13)

X10. Supercluster theories. See AWB1-X4.

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AWB3 The Existence of Large Voids in the Universe

Description. The existence of large volumes of space nearly devoid of bright galaxies. In such "voids" the density of galaxies may be a factor of four or more less than that in the surrounding space. Void volumes, according to some measurements, may approach a million cubic megaparsecs.

Background. Voids in galactic distribution are often equated with the well-popularized Swiss cheese or "bubbly" concept of universe structure. However, the void phenomenon is not dependent upon the Swiss cheese universe. A few voids could exist in an otherwise homogeneous cosmos.

Data Evaluation. The evidence for voids is of the same type as that for superclusters (AWB2). It is, however, negative evidence; that is, the nonexistence of galaxies with brightnesses above a certain level stipulated by survey parameters. So-called voids may actually contain many dim galaxies. Voids may also seem to exist due to the controversial redshift quantization phenomenon (AWF8), which may be unrelated to galactic distances. The data supporting the existence of voids are weakened by such possibilities. Rating: 2.

Anomaly Evaluation. The same theories offered in explanation of supercluster formation are apply here. See AWB1 discussion. Rating: 1.

Similar and Related Phenomena. The quantization of redshifts (AWF8); the Swiss cheese structure of the universe (AWB4).

Examples

X1. The great void in Bootes. "Abstract. In the course of a redshift survey of galaxies brighter than R $\approx$16.3, 133 redshifts were measured in three fields, each separated by roughly 35^{o} from the other two. In the galaxies in these fields were distributed uniformly, the combination of a galaxian luminosity function and our magnitude limits predicts that the distribution of redshifts should peak near 15,000 km s^{-1}. In fact, only one galaxy of the 133 was observed with a redshift in the 6000 km s^{-1} interval centered on 15,000 km s^{-1}. One plausible interpretation is that a large volume in this region of order 10^6 Mpc^3 is nearly devoid of galaxies." (R1)

"The hole's diameter, about 300 million light years, is a few per cent of the size of the observable Universe, but not big enough to upset the Cosmological Principle, which says that the gross properties of the Universe are the same everywhere. The galaxies in this region may all be much fainter than galaxies elsewhere, so giving the appearance of a void. This would be just as interesting to astronomers as the void itself." (R2)

The Bootes void did not go unchallenged. "Last year's claim that there might be a 'hole in the Universe'---a huge tract of space empty of galaxies---understandably created a stir both in the astronomical trade and the popular press. But further studies of the region of the sky around the constellation Bootes now show no shortage of galaxies in the 'hole' reported by a team from the Kitt Peak Observatory in Arizona." This counterclaim originated with V. Balzano and D. Weedman, of Penn State. (R5; R13)

"The conflicting nature of the two groups' findings is due to the different techniques used in each study. Whereas Kirshner's group looked for galaxies in sample patches within the suspect region, the Penn State team investigated the region as a whole. It appears that the samples just weren't representative of the overall area." (R6)

Other astronomers claimed that the Bootes void was nowhere near as large as Kirshner's group maintained. N. Bahcall contributed the observation that the region of space surrounding the supposed void had an excess of galaxies, and that these might have been drawn from the void. (R7)

Additional studies of the Bootes region by the Kirshner group. "In following up this discovery, Kirshner told us that his group has now obtained redshifts for a complete magnitude-limited sample from a grid of 282 fields, each 15 square arcminutes in size, interior to the triangle formed by the original survey regions. The 231 galaxies found assiduously avoid the velocity range 12 000 to 18 000 km/sec throughout the area, although it now appears that the original three regions are at the very edge, or perhaps even just outside this void. Other workers have claimed to find emission-line galaxies within the original triangle, but Kirshner claims that none lie within the newly defined empty region centered at 14h 48m and +47°. The density of galaxies in this 10^7 cubic light year void is a factor of more than about four lower than in the surrounding areas." (R10; R14)

Galaxies confirmed in the Bootes void. "Astronomers announced yesterday that they have discovered seven rare galaxies in a part of the universe once thought to be an enormous void.

The void---an area 300 million light-years in diameter---still appears to be the biggest vacant area in the universe, the researchers said, but the new discovery shows that it is not totally empty.

.....

The National Science Foundation, which sponsored the work and announced the discovery, said the rare galaxies will have repercussions for theories concerned with how matter is distributed in the universe." (R15)

X2. The void between Cancer and Lynx. N. Bahcall and R. Soneira "...describe a hole in the distribution of nearby clusters of galaxies, centered on the boundary between Cancer and Lynx and stretching about 100° across the sky. This corresponds to a region of space 600 million light-years distant and about one billion light-years wide by 500 million deep (assuming a Hubble parameter of 100 kilometers per second per megaparsec), devoid of rich clusters and depleted in low-density clusters." (R9)

X3. Possible statistical origin of the voids. "The treatment of the problem of voids by David H. Politzer and John P. Preskill of the California Institute of Technology (Phys. Rev. Lett. 56, 99; 1986) should be read by all those embroiled in arguments like these. Briefly, the conclusion is that the voids so far described on the surface of the sky are almost as likely to be consistent with randomness as with some physical process for concentrating galaxy clusters elsewhere, away from the voids." (R12)

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AWB4 The Swiss-Cheese Structure of the Universe

Description. The distribution of superclusters of galaxies on the surfaces of a bubble-like matrix. This distribution of matter is much like that in Swiss cheese or a mass of bubbles.

Data Evaluation. As with superclusters and voids (AWB2 and AWB3), the basic data supporting the Swiss cheese nature of the universe is essentially the same as that described in AWB1: angular positions of galaxies plus their redshifts. Some astronomers think, however, that redshifts may not be infallible measures of distance, as discussed in several places in this volume; viz., AWF8, AQB2, AQB4, AQF2, AQF5. If the redshift-distance law should be proven incorrect, the bubbly universe might deflate. Rating: 2.

Anomaly Evaluation. While some cosmological models can explain the formation of clusters of galaxies and superclusters, the Swiss cheese universe, by the admission of several astronomers, is especially challenging to the theorists. Astronomers and astrophysicists, though, are most inventive, and better models are doubtless being formulated. Until these are proffered and evaluated, our inability to account for the basic fabric of the universe remains a serious matter. Rating: 1.

Possible Explanations. One suggestion that has been advanced replaces the Big Bang with a multitude of Little Bangs. In this view, the galaxies resulting from each Little Bang are concentrated on the surface of an expanding shell.

Similar and Related Phenomena. The three preceding "existence" phenomena: clusters of galaxies (AWB1), superclusters (AWB2), and voids (AWB3).

Examples

X1. Genesis of the concept. "Many of the superclusters now known are flat or elongated. In maps of the locations of galaxies on the sky, the superclusters appear to form chains, which in turn link themselves into nets, which surround the cell-like voids. Thus, the maps give the impression that the large-scale structure of the universe is cellular, with the superclusters forming the walls of the cells. This idea was first proposed in 1977 by M. Joeveer, J. Einasto, and E. Tago. Its verification will require large-scale studies of the spatial distribution of galaxies and clusters of galaxies in our part of the universe, studies that would involve the obtaining of redshifts for many galaxies and would take years." (R1)

X2. 1982 survey results. "Abstract. We have finished a redshift survey of galaxies complete to 14.5 m_B in the north and south galactic polar caps above declination = 0^o and containing some 2400 galaxies. We present here various projections of the resulting redshift-space maps. While different in detail, the statistical nature of the redshift-space distribution is very similar between the north and south. The space distribution of galaxies is frothy, characterized by large filamentary superclusters of up to 60 Mpc in extent, and corresponding large holes devoid of galaxies. We also present redshift-space maps generated from n-body simulations, which very roughly match the density and amplitude of the galaxy clustering but fail to match the frothy nature of the actual distribution. Our results present a severe challenge to all theories of galaxy and cluster formation." (R3)

X3. A slice of the universe. "Abstract. We describe recent results obtained as part of the extension of the Center for Astrophysics redshift survey to m_B = 15.5. The new sample contains 1100 galaxies (we measured 584 new redshifts) in a 6^o x 117^o strip going through the Coma cluster. Several features of the data are striking. The galaxies appear to be on the surfaces of bubble-like structures. The bubbles have a typical diameter of ~25 h^{-1} Mpc. The largest bubble in the survey has a diameter of 50h^{-1} Mpc, comparable with the most recent estimates of the diameter of the void in Bootes. The galaxy density in the region of the largest void contained in the survey is only 0.20 of the mean. The edge of the largest void in the survey is remarkably sharp." Such features challenge current models of the structure of the universe. (R10; R11-R14)

X4. General observations on galaxy maps. "The maps show features quite unlike those of most other astronomical objects: the galaxies are concentrated in enormous sheets and filamentary structures whose greatest dimension, roughly 100 million light-years, is an order of magnitude larger than its lesser dimensions. Such a structure can include as many as a million galaxies; its mass is of the order of 10^{16} suns. Moreover, within each structure the galaxies are not evenly distributed: one can distinguish more densely populated clumps and strings, many of them at the intersection of two sheets. Finally, interspersed among the largest structures are huge voids, virtually free of galaxies, that are between 100 and 400 million light-years across." (R6)

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R3. Davis, Marc, et al; "A Survey of Galaxy Redshifts. II. The Large Scale Space Distribution," Astrophysical Journal, 253:423, 1982. (X2)
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R8. Bartusiak, Marcia; "The Bubbling Uni-

Map of observed velocity plotted against right ascension in the declination wedge 2.65 to 32.5°. Note the bubble-like structure. (X3)

verse," Science Digest, 94:64, February 1986.
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R12. Thomsen, D.E.; "Blown Away: Froth of Cosmic Bubbles," Science News, 129: 38, 1986. (X3)
R13. Hecht, Jeff; "Is the Universe Made of Froth?" New Scientist, p. 25, February 13, 1986. (X3)
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AWB5 The Anomalous Rotation of Matter in Galaxies

Description. The high circular velocity of stars and gas in the outer reaches of galaxies. From Kepler's laws, we would expect the circular velocity to decrease with increasing distance from the galactic centers, as they do in the solar system and planetary systems.

Data Evaluation. Circular velocities in the Milky Way are rather difficult to measure and results are controversial. However, the situation is much better for other galaxies, where the Doppler dispersion of spectral lines and other phenomena provide good measures of circular velocities as functions of distance from galactic centers. Rating: 1.

Anomaly Evaluation. To explain this unexpected anomaly, many theorists have proposed that the outer reaches of galaxies are occupied by a "halo" of dark matter. Calculations reveal that the mass of this dark matter must be several times that of the entire galaxy. Unhappily, despite its bulk, careful searches have come up empty-handed. Even more awkward are the suggestions that the Law of Gravitation and/or Newton's second Law of Motion be modified to account for the anomalous rotation of matter in galaxies. The "missing mass" problem is thus most serious. Rating: 1.

Possible Explanations. The many, diverse explanations that have been proposed are listed in X6 below.

Similar and Related Phenomena. Galactic halos (AWO11); the anomalous rotation of galaxies in galactic clusters (AWB13); the apparent absence of enough matter to reverse the outward expansion of the universe (assuming, of course, that this is what it is doing) (ATB2).

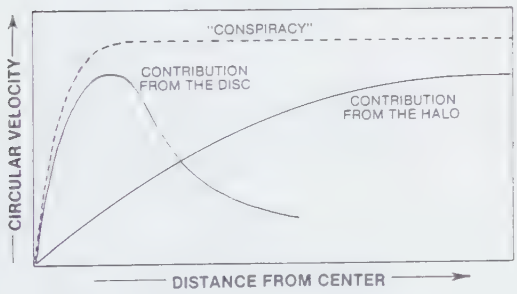
Examples

X0. Historical introduction. "The first hint that something was amiss in the universe came 50 years ago. Astronomer Fritz Zwicky noticed some peculiar goings-on in a rich group of galaxies known as the Coma cluster, located 300 million light years from Earth. The galaxies were moving about in the cluster much faster than expected. Zwicky added up all the light being emitted by the cluster and realized that there was not enough visible matter to bind the galaxies together, yet the cluster was obviously not flying apart. Where was this other mass that was providing the gravitational glue? It seemed to be missing---hence the tag 'missing mass.' 'It's not really missing,' stresses Jeremiah Ostriker, a Princeton astrophysicist. 'There's something there, you know it's there, but you just can't see it. It's missing light.'" (R9) Although this introductory quote specifies clusters of galaxies (AWB13), it applies equally well to the 'missing mass' problem of galaxies themselves. (WRC)

X1. Some general observations on the missing mass conundrum.

"In the past few years radio and optical astronomers have painstakingly measured the rate at which stars and gas clouds in the outer parts of spiral galaxies are orbiting the center of mass of those galaxies. Optical photographs show these spiral galaxies to be graceful pinwheels of billions of stars, with the light falling off steadily from the central to the outer regions. Since the light is produced by stars, we naturally expect the matter and its associated gravitational force field to show a similar concentration. It follows then that the speed of rotation of the stars and gas should decline as one moves from the inner to the outer regions.

Much to the surprise and consternation of astronomers, this is not what is observed. As radio and optical astronomers have extended the velocity measurements for the stars and gas to the outer regions of such a galaxy, they have found that the stars were not slowing down, but were moving at the same speed as the ones closer in! A substantial part of the mass of the galaxy is not concentrated toward the center of the galaxy, but must be distributed in some dark, unseen halo surrounding the visible galaxy. The outer regions of



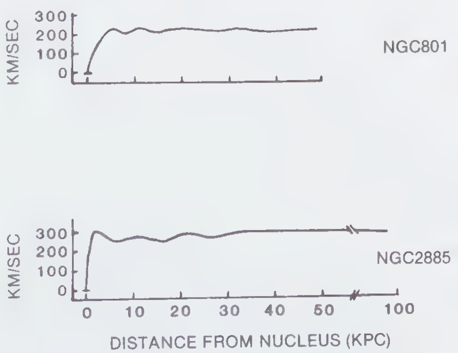
Idealized rotation curve for spiral galaxies. (X1, R22)

galaxies, faint and inconspicuous on a photograph, may actually contain most of the matter." (R3) In X2, a study of galaxy M87 provides data that are consistent with a central black hole. (WRC)

The scope of the problem has been sketched by J. Gribbin. "Dark matter betrays itself by the gravitational effect it has on the matter we can see. Dark matter is present on all distance scales, from the close neighborhood of the Sun in our own Galaxy, the Milky Way, to the rotation of the galaxies themselves (including the Milky Way), the dynamics of clusters and superclusters of galaxies, and in the expansion of the Universe itself. Every time we move to a larger distance scale, we need proportionately more dark matter to explain our observations of how the bright matter is distributed and how it moves. At the upper limit, on the scale of the whole Universe, it seems that only one-tenth of all the gravitating mass can be concentrated in the bright stars and galaxies that we can see by their electromagnetic radiation." (R22)

Next, J. Maddox, editor of Nature, justifies the hunt for the universe's missing mass. "First, it is known from observations of spiral galaxies that individual stars appear to experience gravitational forces greater than can be accounted for by the masses of other visible stars as well as gas and dust clouds. Even the motion of the Solar System perpendicular to the plane of the Galaxy seems to be governed by a gravitational force twice as great as that inferred from the known distribution of massive objects. And the in-plane velocities of stars in other spiral galaxies do not decrease with distance from the centre as quickly as expected, surrporting the idea that spiral galaxies have massive haloes. The most recent but perhaps most persuasive evidence that there is missing mass on a substantial scale comes from the behavior of clusters of galaxies, which appear uniformly to be more tightly bound gravitationally than the sizes of their members would suggest. So the hunt has seemed a hunt for something real." (R14) Galactic cluster missing mass is covered in AWB13.

For additional general observations see R7, R11, R17, R19. In these and the preceding references, the inverse-square law of gravi-



Velocity profiles of matter in two galaxies. According to Newtonian dynamics, they should not be flat. (X1, R11) tation is supposed to hold with increasing distance. As mentioned in X6, this may not be so and, conceivably, there may be no 'missing mass.' (WRC)

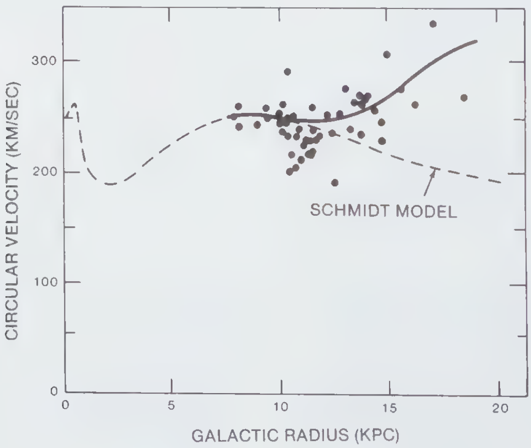
X2. M87. Velocity studies of this elliptical galaxy produce results that "are entirely consistent with the presence of a central black hole of $\sim 5 \times 10^9 M_\odot$." (R1) In contrast, most other astronomers conclude (for spiral galaxies, at least) that the missing mass is residing in an external halo. (WRC)

X3. NGC 3067. The rotational velocity of this small spiral galaxy rises slowly out to near the limit of the optical disk. However, NGC 3067 is located within 2 arcminutes of the quasar 3C232. A suspicious absorption line has been detected in the quasar's spectrum. If this line originates in gas orbiting around NGC 3067, geometrical considerations require that this gas's velocity will continue to increase well beyond the optical image. The overall implication is that 94% of NGC 3067's mass is located beyond the optical image. Observations at 21 centimeters have revealed no hydrogen clouds in this region. (R4)

X4. Our galaxy, the Milky Way. The variation of circular velocity with radius in the Milky Way is difficult to measure because the earth itself is immersed in the flow of matter. However, by measuring the velocity of a pervasive medium, such as atomic hydrogen, the rotation curve for our galaxy can be plotted from about 7 kiloparsecs out to the sun's position (10 kiloparsecs), but not beyond. This type of measurement shows a maximum at about 8 kpc, and the best model of mass distribution in the Milky Way, as of 1965, the Schmidt model, predicted a steady decrease in velocity out beyond the sun's radius.

More recently, astronomers have made velocity estimates for giant molecular clouds that exist much farther out in the galaxy. "The rotation curve to 18 kpc from the galactic center is shown in Fig. 3 (see illustration). Although the detailed shape of the curve depends somewhat on the exact value of the galactocentric distance and orbital velocity of the sun, the curve deviates markedly from the expectation of the Schmidt mass model, shown as a dashed curve in Fig. 3. The implication is that there is much more mass in the outer region of the Milky Way than was thought to exist in stars. Or, to put it another way, the dark matter that was predicted on theoretical grounds, and was found to be common in other spiral galaxies, has been detected gravitationally in the Milky Way." (R10)

"The rotation curve of the Milky Way currently cannot be traced much beyond the Sun's distance from the center. However, studies of the motions of globular clusters and dwarf-spheroidal satellite galaxies suggest that our system, too, has a massive halo with a large M/L (mass-to-light) ratio. These investigations argue for a total mass as great as a trillion (10^{12}) Suns, a factor three or four times larger than the traditional value. However, inter-



Galactic rotation curve for the Milky Way, showing deviations from the Schmidt model. (X4, R10) pretations of the very difficult observations are still being hotly debated." (R12)

X5. Studies of spiral galaxies. From the Abstract. "The large-scale data (velocity dispersions and rotation curves) show that this nonluminous component becomes increasingly important with increasing galactocentric distance, and is the dominant mass in the outer regions of galaxies, and in total. It is usually assumed that both the local and global missing mass are the same substance although no plausible candidate for this substance is known." Of the many possibilities, brown dwarfs seem the most conservative. (R6)

However, consider this survey. "John Bahcall and Stefano Casertano, of the Institute for Advanced Study, Princeton, have studied accurate rotation curves for several spiral galaxies. These show that there is no overall change in the nature of the rotation of a galaxy to mark a transition between the inner region, dominated by bright matter, and the outer region, dominated by dark matter. There seem to be only two possible explanations for this smooth transition from one region to the other." The first possibility discussed is the failure of the Law of Gravity over large distances; the second is that the dark matter is essentially the same as the bright matter and is distributed among many small, planet-like bodies or black holes. (R17)

X6. Overview of possible explanations. The literature contains a huge amount of speculation. Here, since our charter covers anomalous data only, we simply list a few of the possibilities:

-Baryonic matter: dark planets, rocks, dust, black and/or brown dwarfs, black holes of various sizes, neutron stars. (R1, R10-R12, R16-R18, R20, R25). Because none of these varieties of baryonic matter has ever been found in quantity in galactic outskirts, theorists have been looking elsewhere.

-Nonbaryonic matter: various neutrinos (especially "heavy" neutrinos), protons, photinos, axions, gravitinos, magnetic monopoles. (R2, R11, R12, R16, R20, R21)

-Neither of the above. This is no "missing mass", and all anomalies of galactic rotation and internal motion can be attributed to the failure of the Law of Gravitation at large distances. (R10, R11, R17, R20) And/or Newton's Second Law of Motion (F = ma) fails for stars and galaxies. (R8, R20)

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AWB6 Large-Scale Anisotropy in Galaxy Distribution

Description. Departures from the uniform distribution of galaxies on a scale larger than the size of superclusters.

Data Evaluation. A very few studies are at hand; and these all measure some different aspect. In addition, these studies have not been replicated. Rating: 3.

Anomaly Evaluation. The large-scale anisotropy of the universe would conflict directly with the Cosmological Principle, which insists that the universe be homogeneous everywhere. Anisotropies on the supercluster scale (AWB4) already press the Cosmological Principle, clumpiness on still larger scales would be highly anomalous. Of course, in assessing "scales" one always assumes that our universe is finite and that no Big Bangs occurred elsewhere. Rating: 1.

Possible Explanations. In example X3, the reported mass anisotropy may be related to the acceleration of our galaxy within our local supercluster, in which case the scale of the anisotropy would be too small to qualify here.

Similar and Related Phenomena. The anisotropy of the cosmic microwave background (ATF1); lower-scale hierarchical clustering (AWB1, AWB2, AWB3, AWB4).

Examples

X1. Strong versus weak pairs of radio sources. "By analyzing pairs of radio sources from the 4C (fourth Cambridge) catalog he (J.E. Solheim) finds that significantly more of the fainter sources lie nearly opposite to one another in space than do the stronger, and presumably nearer ones." Solheim suggests that we may be seeing the same pairs of sources twice; first, directly, and then, fainter, after the radio signals have circuited the universe.(R1)

X2. Luminosity/redshift anisotropy. "If one has a class of objects of the same intrinsic luminosity (and one can be fairly sure of that if the class is narrowly defined), the apparent luminosity will decrease regularly with distance. For isotropic expansion there should be a relationship between redshift and apparent luminosity that is the same in all directions. It appears that for several classes of objects the sky can be divided into two regions, and the relationship differs between them. First evidence came from a study of galaxies of the class Sc1 by Vera C. Rubin, W. Kent Ford Jr., and J.S. Rubin. It has since been found for the brightest cluster galaxies, supernovas and Markarian galaxies. The latest addition is compact galaxies with absorption lines in their spectra." (R2)

X3. IRAS point-source anisotropy. "Abstract. The IRAS (Infrared Astronomy Satellite) point-source catalog provides a unique opportunity to generate a galaxy catalog uniformly selected over most of the sky (~ 9.5 sr). We have generated such a catalog of 6730 sources and find a small (4%-7%) but robust dipole anisotropy in the galaxy distribution that points toward $l = 235^o$, $b = 45^o$, within 30^o of the microwave dipole anisotropy." The anisotropy in galaxy distribution may thus be related to the anisotropy in the microwave background, which has been attributed to our motion in space. (R3)

IRAS "observations indicate that there are 20 percent more galaxies (detected as far-infrared sources) in the vicinity of the north galactic pole than in the south.

.....

It is not clear whether the asymmetry is just a random fluctuation caused by the tendency of clusters to cluster, or the result of an inhomogeneous distribution of sources on a scale bigger than that of superclusters. If the IRAS galaxies in the northern cap belong to a single large-scale feature, it must have a diameter of at least 600 million light-years." (R5)

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R5. "The Crowded North," Sky and Telescope, 72:465, 1986. (X3)

AWB7 Seemingly Related Galaxies with Discordant Redshifts

Description. Pairs and larger groups of galaxies which seem physically related, and therefore at approximately the same distance from earth, but possess one or more members with radically different redshifts. Physical relations, besides simple angular proximity, include connecting filaments of material, apparent mutual disturbances, and the silhouetting of high-redshift objects against low-redshift galaxies.

Data Evaluation. Dozens of examples have been cataloged, primarily by H. Arp. Suggestive though this mass of data may be, it is weakened by the fact that, except possibly for the silhouette cases, chance may have located distant (high-redshift) galaxies near closer (low-redshift) galaxies and, in addition, produced illusory physical connections. Rating: 2.

Anomaly Evaluation. As with many other phenomena in this volume, the issue is the correct interpretation of redshifts. Are they cosmological, partially cosmological, or mostly non-doppler? If galactic redshifts are not almost totally cosmological, the anomaly is of the highest order, because our celestial yardstick would then be worthless. Rating: 1.

Possible Explanations. The discordant galaxies are actually at their redshift distances, but by chance they seem to be physically associated with low-redshift galaxies. On the other hand, some portion of the galactic redshifts may be noncosmological.

Similar and Related Phenomena. Some other anomalies bearing on the redshift question are: the hierarchical cosmos (AWB1 through AWB4); quasar-galaxy juxtaposition (AQB1); physical associations of galaxies and quasars (AQB4); the possible quantization of redshifts (AWF7 and AQF2); the quasar energy paradox (AQF5).

Examples

X0. Introduction to the phenomenon. "It has been claimed for some time that there is a class of bright galaxies with fainter companion galaxies physically associated to them, where the redshift difference is far larger than is consistent with ordinary dynamics. The alternative and more conventional explanation is that the small companions of higher redshift are distant background galaxies whose much larger velocities are normal Hubble recession velocities; the claimed association is held to be a chance projection effect. This idea is usually countered by morphological arguments based on apparent disturbances in the bright galaxy, the existence of 'bridges' or spiral arms leading directly to the companion, and in one case (NGC 1199) by the apparent silhouetting of the high-redshift companion against the low-redshift bright galaxy. If these associations were to be supported by other, preferably dynamical, evidence, it would clearly be of great scientific moment; conversely, if independent evidence can be adduced in favor of a projection effect, the case for the existence of a noncosmological redshift will be gravely weakened. This is an interesting problem, which deserves further study; regrettably, unconventional claims are most often dismissed out-of-hand." (R20)

X1. IC 3258/Virgo cluster. "The small irregular galaxy IC 3258 is a member of the rich Virgo Cluster of galaxies. A recent spectrogram taken by Margaret Burbidge and Marie Helene Demoulin, at the suggestion of Cambridge radio astronomers, shows that IC 3258 is approaching our own Galaxy at nearly 500 km per second. They conclude that a catastrophic event in the Virgo ter may have blasted out the whole galaxy at around 1500 km per second." Blueshifted objects are extremely rare. The blueshift velocity equivalent of 500 km per second, when combined with the 1000 km per second recession velocity of the Virgo Cluster, provides the 1500 km per second relative velocity of IC 3258 and the Virgo Cluster. (R1) In this case, an explanation has been found within the bounds of the cosmological interpretation of redshifts. Note also that IC 3258 does not seem to have any stars and may turn out to be a cloud of hot gas. (WRC)

X2. NGC 772/companion galaxies. Abstract. "Several smaller galaxies in the vicinity of NGC 772 are connected to this disturbed Sb spiral by luminous filaments. The redshift of NGC 772 is 2,430 km/sec. Redshifts of three of the interacting galaxies are 2,450, 20,200, and 19,700 km/sec. It is concluded that the latter two are further examples of small companion galaxies which have redshifts that do not correspond to the standard cosmological-velocity redshifts."(X2)

"This conclusion holds great significance for quasars, since Arp and other---though not yet all---astronomers believe that these objects could also have been ejected from normal galaxies. We still cannot explain their very large redshifts if they are produced by this means, but we now know for certain that not all observed redshifts are 'cosmological' in origin. It will probably require a few more observations of this kind before most astronomers are convinced, but judging from Arp's previous record it is only a matter of time before the theoreticians are converted."(R3) This item was written in 1970. Since then Arp has found many more suspicious associations of galaxies, but far from being 'converted' almost all astronomers now hold all redshifts to be entirely cosmological! (WRC)

X3. NGC 7603/companion galaxy. "In Astrophysical Letters (vol 7, p 221), Arp lists his redshift measurements on a disturbed galaxy NGC 7603. This object is peculiar because there is a diffuse, luminous bridge of matter joining it to a smaller companion galaxy, and the whole system appears to be interacting tidally. The evidence strongly suggests that both galaxies are at the same distance from us. But the redshift evidence, taken at face value, directly contradicts this conclusion. The spectra establish the velocity shift of NGC 7603 as 8800 km per second, and that of its semi-detached neighbor as 16 900 km per second. So, the companion has a redshift intrinsically different from the main galaxy." (R4; R11, R15, R21)

The larger galaxy shown (NGC 7603) is connected to a companion galaxy by a luminous bridge. The redshifts are 8,700 and 16,900 kilometers per second, respectively. (X3)

But N. A. Sharp, after a careful study of deep plates of NGC 7603 and its surroundings, believes there is no evidence for tidal action between NGC 7603 and its anomalous companion; i. e., the two are not physically associated and are at the distances indicated by their different redshifts. Sharp's conclusion: "No strong anomalies have been found which would force us to accept the existence of a noncosmological redshift." (R20)

X4. Stephan's quintet. Although one galaxy in this quintet possesses a discordant redshift, H. Arp argues that is physically associated with the other four. J. Bahcall, on the other hand, sees no physical connections, even after marshalling all the photographs, spectrograms, and radio astronomy data. (R5; R6, R14, R24)

X5. NGC 1199/silhouetted galaxy. "The E galaxy NGC-1199 is the brightest member of a small cluster of galaxies. Among its companions is a galaxy so compact that, at first glance, it looks like a star. Such a galaxy is not likely to appear by itself in space, nor is it part of a more distant cluster of galaxies. It would be expected---by its appearance---to be a member of the small group of bright galaxies of which NGC-1199 is the dominant member. But the redshift of the compact peculiar galaxy is 13,300 km per second, whereas the redshift of the central NGC-1199 galaxy is only 2,600 km per second.

In the beginning, an investigation of possible interaction between the compact galaxy and NGC-1199 revealed a circular shadow around the compact as if it were in front of NGC-1199 and absorbing the light of the E galaxy behind it. From 1965 to 1976, I photographed it with the 200 inch telescope at Palomar, the four meter telescope at Kitt Peak National Observatory and the four meter telescope at Cerro-Tololo Interamerican Observatory until I was certain that I had the best photographic representation of this silhouetted galaxy." Arp also measured the absorption ring. These data convinced him that this is an example of a high-redshift object in front of a low-redshift object. (R9; R8)

X6. NGC 53/companion galaxy. The two galaxies seem to be connected by luminous filaments. Redshifts: 4,600 and 37,300 kilometers per second, respectively. (R11)

X7. NGC 1232/NGC 1232A. The spiral galaxy NGC 1232 and its smaller, barred companion NGC 1232A were long considered to be physically associated due to their similar redshifts and resolutions. However, further redshift measurements showed that that of 1232A was in error, and that it was actually 4,800 kilometers per second higher than 1232. Reexamining this pair of galaxies, H. Arp found a disturbed region in one of NGC 1232's spiral arms. NGC 1232A is located just above the disturbed region, suggesting strongly that the two are physically close despite their different redshifts. (R15, R13)

X8. AM 0213 - 2833/companion galaxy. "Examples found even more recently are AM (Arp-Madore) 0213 - 2833, AM 0328 - 222, and AM 2006 - 295, illustrated on these pages....AM 0213 - 2833 is a spiral with an interacting companion at its northern (upper) edge. The companion has a strong emission-line spectrum, characteristic of excited gas, and a redshift some 14,000 km per second greater than that of the larger galaxy." (R15)

N. A. Sharp investigated 0213 - 2836 and concluded that there was no evidence of tidal distortion or other interaction between the spiral galaxy and the companion with the discordant redshift. Since the anomalous companion is located near two other galaxies with the same redshift, he believes the companion is a member of a galaxy group in the background which happens to coincide with the foreground spiral. (R18)

X9. AM 2006 - 295/companion galaxy. AM 2006 - 295 "..., which had been classified as a three-armed spiral, is a particularly startling case. I observed the prominent knot in one arm purely out of curiosity, expecting it to be some kind of ionized-hydrogen (H II) emission region with the same redshift as the galaxy. In fact, the knot showed an absorption-line spectrum, indicating a stellar composition, and it had a redshift four times that of the spiral galaxy." (R15)

X10. Analysis of small groups of galaxies. "Abstract. Redshift measures at 21 cm wavelength have been made on over 100 galaxies in more than 40 different groups with the Arecibo radio telescope. These groups generally consist of a large spiral galaxy with one or more companions. This list of galaxies is supplemented with over 160 galaxies in more than 40 groups with a dominant galaxy that is brighter than 11.8 mag. These latter galaxies are gathered from the literature and have redshifts generally accurate to better than $\pm$ 8 km s^{-1}. The entire sample, when analyzed, shows that a typical structure in intergalactic space is one in which a large central galaxy has smaller and fainter companions extending from about 20-900 kpc around it.

It is shown that the companion galaxies in these groups have significantly higher redshifts than the brightest galaxy in the group. This confirms the result which has emerged from every analysis made of physical groups of galaxies to date, namely that the companion galaxies are systematically redshifted with respect to the dominant galaxy. The most accurate redshifts available in the Local Group (M31) and in the M81 group are analyzed. It is shown that all 21 of the best-known physical companions have significantly higher redshifts than the central galaxies. Since neither the values of the redshifts nor the physical association of these companions is in doubt, it is suggested that these companions contain a component of nonvelocity redshift." (R17) Nonvelocity redshift = noncosmological redshift.

G. G. Byrd and M. J. Valtonen have responded to claims such as that above. "Abstract. Sulentic has found a statistically significant excess number of higher redshift companions relative to the brightest galaxy in spiral dominated groups in Huchra and Geller's catalog of galaxy groups. Of the explanations discussed, he favors non-Doppler redshifts in the spiral groups. Instead, we propose that the excess results from most of the group population being composed of unbound expanding members and from a mistaken tendency to pick a galaxy of brighter apparent magnitude from the nearer portion of the expanding group population rather than the true primary, which would generally be in the middle of the population. Using the known galaxy number versus luminosity distribution, and the assumption that most spiral group members are unbound, we calculate the expected redshift excess for the spiral dominated groups." The calculations agree with observations. (R16)

X11. 4030 - 11/companion galaxy. "Abstract. New observations are reported for the discordant redshift pairs 4030 -11 and 4151 - 46. Both direct and spectroscopic evidence is advanced that the galaxies in each pair are interacting. Direct evidence consists of luminous connections and perturbations particularly in the higher redshift components of each pair. Spectroscopically, we observe an asymmetric distribution of Hα emission in both lower redshift components. The low-redshift Hα emission in both pairs is observed to extend from the low-redshift galaxy into the high-redshift companion. In addition an unusual double component Hα emission line is observed in one of the high-redshift galaxies, 4030 - 11." (R19)

X12. 4151 - 46/companion galaxy. See X11. (R19)

X13. Survey of companion galaxies. A group of 87 companion galaxies associated (apparently) with 61 larger galaxies was studied. The companions tend to have more emission, higher excitation, and earlier type absorption spectra. In associations where redshift differences are small, ± 800 kilometers per second, and where the components would conventionally be accepted as physically associated, positive redshift differences outnumbered the negative 36 to 15. (They should be equal.) For the remaining groups the redshift differences ranged from +4000 to +36,000 kilometers per second. "The nature of these companions indicates not many can be accidental projections of background galaxies." (R12)

In another paper, Arp tabulates and discusses in some detail a total of 37 galaxy associations with large discordant redshifts. (R13) We have selected above only some of the more interesting examples.

X14. Statistical analysis. "Abstract. The density of compact quartets of galaxies has been estimated using the Palomar Sky Survey and previously published surveys.... The quartet surface density is used to determine the likelihood that the discordant redshift groups, Stephan's Quintet, Seyfert's Sextet, and VV 172, are accidental associations. The results indicate that on a statistical basis, these groups are not chance configurations." (R14)

X15. General observations. H. Arp in reviewing his findings and the reception thereof by the scientific community comments as follows about the claim that he has found only accidental associations of discordant redshift objects. "But in the end, no matter how convincing the connection is, it would be possible to take the position that it is an accident. If the companions were, in fact, physically connected, there would be no possible observations that could be made that could not be explained as an accident. If this is the situation it is an impasse. No further observations could be decisive one way or the other.

If the cases so far do not compel belief, then the only way we can make progress is to test the principle involved that galaxies can have components of intrinsic redshifts, by other, independent observational means. Such other kinds of observations have been made:"

1. Two cases where high-redshift galaxies are silhouetted in front of low-redshift galaxies.

2. In the Local Group and M81 group of galaxies, the small companions have systematically higher redshifts than the central galaxy.

3. In general, companion galaxies have higher redshifts than the large galaxies.

4. In galactic clusters, the spirals tend to have higher redshifts than the E galaxies.

5. Evidence exists for the quantization of galactic redshifts.

6. There is considerable evidence that quasars, which seem related to galaxies, have large noncosmological redshifts.

"In the end, perhaps it comes down to whether by believing that the above kinds of observational results are correct researchers can make more discoveries and progress in understanding astronomy than those who believe that none of the above results are correct." (R11)

References

R1. "A Galaxy Ejected from a Cluster Hurtles toward Us," New Scientist, 44:62, 1969. (X1)

R2. Arp, Halton; "Companion Galaxies Connected to NGC 772," Astrophysical Letters, 5:257, 1970. (X2)

R3. "No Simple Connection for Redshifts," New Scientist, 47:177, 1970. (X2)

R4. "Enigmatic Redshifts Cause Cosmic Chaos," New Scientist, 50:368, 1971. (X3)

R5. Reis, Richard, and Arp, Halton; "The Quasar Controversy," Mercury, 3:6, 1974. (X4)

R6. Morrison, David, and Morrison, Nancy D.; "Are the Redshifts of Galaxies and Quasars of Cosmological Origin?" Mercury, 1:14, 1972. (X4)

R7. Metz, William D.; "Quasars: Are They Near or Far, Young Galaxies or Not?" Science, 181:1154, 1973.

R8. "An Odd Couple," Science News, 112: 11, 1977. (X5)

R9. Arp, Halton; "NGC-1199," Astronomy, 6:15, September 1978. (X5)

R10. "X-Ray Quasars Fit Theories... But Some Galaxies Refuse to Play Ball," New Scientist, 88:22, 1980.

R11. Arp, Halton; "Three New Cases of Galaxies with Large Discrepant Red-Shifts," Astrophysical Journal, 239:469, 1980. (X3, X6, X15)

R12. Arp, Halton; "Characteristics of Companion Galaxies," Astrophysical Journal, 256:54, 1982. (X13)

R13. Arp, Halton; "Further Examples of Companion Galaxies with Discordant Redshifts and Their Spectral Peculiarities," Astrophysical Journal, 263:54, 1982. (X2, X7, X13, X15)

R14. Sulentic, Jack W.; "On the Density of Galaxy Quartets and The Statistical Likelihood of Discordant Redshift Groups," Astrophysical Journal, 270:417, 1983. (X4, X14)

R15. Arp, Halton C.; "Related Galaxies with Different Redshifts," Sky and Telescope, 65:307, 1983. (X3, X7, X8, X9)

R16. Byrd, Gene G., and Valtonen, Mauri J.; "Origin of Redshift Differentials in Galaxy Groups," Astrophysical Journal, 289:535, 1985. (X10)

R17. Arp, Halton, and Sulentic, Jack W.; "Analysis of Groups of Galaxies with Accurate Redshifts," Astrophysical Journal, 291:88, 1985. (X16)

R18. Sharp, N.A.; "Anomalous Redshift Companion Galaxies: 0213 - 2836," Astrophysical Journal, 297:90, 1985. (X8)

R19. Sulentic, Jack W., and Arp, Halton; "Evidence for Interactions in Two Discordant Redshift Pairs of Galaxies," Astrophysical Journal, 297:572, 1985. (X11, X12)

R20. Sharp, N.A.; "Anomalous Redshift Companion Galaxies: NGC 7603," Astrophysical Journal, 302:245, 1986. (X0, X3)

R21. Arp, Halton; "NGC 7603, a Galaxy Connected to a Companion of Much Larger Redshift," Astrophysical Letters, 7:221, 1971. (X3)

R22. Sulentic, Jack W., et al; "Interacting Nonequilibrium Systems near Bright Galaxies. I.," Astrophysical Journal, 220: 47, 1978. (X10)

R23. Arp, H., et al; "Pairs of Spiral Galaxies with Magnitude Differences Greater Than One," Astronomy and Astrophysics, 121:26, 1983.

R24. "Stephan's Quintet: New Light on an Old Puzzle," Sky and Telescope, 69:396, 1985. (X4)

R25. Byrd, Gene G., and Valtonen, Mauri J.; "Origin of Redshift Differentials in Galaxy Groups," Astrophysical Journal, 289:535, 1985. (X10)

AWB8 Large-Scale Streaming of Superclusters

Description. The large-scale, collective motion of superclusters in a specific direction at roughly the same velocity. So far, velocity measurements range from 700-1000 kilometers per second.

Data Evaluation. Several methods have been employed to separate the streaming velocity from the assumed general expansion of the universe. In these studies assumptions must be made regarding such factors as luminosity-distance relationships and, of course, the redshift-distance proportionality. To date, the different methods have produced a rather large spread of velocities and directions. Rating: 2.

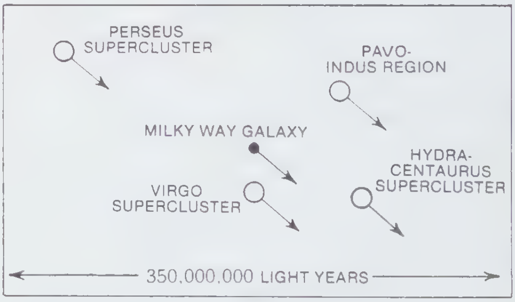
Anomaly Evaluation. The collective streaming of structures as large as superclusters reveals anisotropy on a scale larger than the superclusters themselves. Thus, the Cosmological Principle is denied on an even larger scale than superclusters, which may individually span a substantial fraction of the known universe. Either the Cosmological Principle is incorrect or the universe is much larger than we believe. In addition, the cause of the coordinated flow of superclusters is unknown. Rating: 1.

Possible Explanations. The Big Bang was anisotropic, and the supercluster streaming is a relic of this condition. Another possibility, hinted at above, is that superclusters are not at the top of the hierarchy of cosmic structures, and we may be dealing with a universe that is much larger than we now believe. It might be infinite.

Similar and Related Phenomena. Large-scale anisotropy in galactic distribution (AWB6); anisotropy in the cosmic microwave background (ATF1).

Examples

X1. Infrared photometry. C.A. Collins and colleagues obtained infrared photometric data for an all-sky sample of Sc-class galaxies at a mean distance of 50 h^{-1} Mpc. By using known correlations between their derived distance-dependent parameter (the infrared luminosity) and distance-independent parameters (the infrared color or central velocity dispersion), either absolute distances or Hubble velocities. "Comparison of Hubble velocity with the observed recession velocity for about 45 galaxies led Collins and colleagues to infer a bulk streaming velocity of 970 ($\pm$300) km s^{-1} in a direction towards $l = 305^o$, $b = 47^o$." (R2) "In the context of current speculation regarding non-baryonic particle species which may dominate the mass of the universe, such large velocities on these spatial scales appear to exclude cold dark matter models." (R1)



The Local Group, including the Milky Way, are moving in about the same direction at roughly the same speed relative to the cosmic background radiation. (X2)

X2. Study of elliptical galaxies. "The discovery was made by David Burstein and a team of six other American and British scientists, engaged in an extensive observational study of elliptical galaxies. From spectroscopic and photometric data for about 400 objects, they were able to determine distances to individual galaxies with accuracies of better than 25 percent and infer the general streaming motion." The streaming here includes all galaxies, galactic clusters, and superclusters in a volume of space 400 million light-years across. All this matter appears to be moving in the direction of the Southern Cross at about 700 kilometers per second. (R5; R2-R4, R6)

X3. The Rubin-Ford effect. In 1976, a group headed by V.C. Rubin discovered large-scale motion at 500 kilometers per second in the direction of Perseus for the Local Group with respect to 96 spiral galaxies. (R5) "The large-scale motion amounts to a confirmation of the Rubin-Ford effect, a motion of the Local Group relative to a shell of Sc galaxies at ~50 h^{-1} Mpc that, following its initial discovery in 1976 by Vera Rubin and Kent Ford, has generally been disbelieved until now. After all, the inferred direction of motion was nearly orthogonal to the apex of the Local Group relative to the CMB." CMB= cosmic microwave background. (R2)

X4. University of Arizona study. A team led by M. Aaronson measured our velocity relative to ten nearby galactic clusters as 800 kilometers per second in the direction of Hydra. (R5)

References

R1. Collins, C.A., et al; "Large-Scale Anisotropy in the Hubble Flow," Nature, 320:506, 1986. (X1)

R2. Silk, Joseph; "What Makes Nearby Galactic Clusters All Move as One?" Nature, 322:207, 1986. (X1-X3)

R3. Thomsen, D.E.; "Getting the Drift of Galaxies," Science News, 129:182, 1986. (X2)

R4. "Streaming Galaxies Challenge Uniform Expansion Theories," Astronomy, 14:73, July 1986. (X2)

R5. "Streams in the Cosmic Flow," Sky and Telescope, 72:28, 1986. (X2, X3)

R6. Waldrop, M. Mitchell; "The Currents of Space," Science, 232:26, 1986. (X2)

AWB9 The Origin of Galactic Rotation

Description. The fact of galactic rotation. The source of angular momentum is unknown.

Data Evaluation. Not only do the shapes of galaxies appear to be moulded by rotation, but Doppler measurements confirm their ponderous spinnings. Rating: 1.

Anomaly Evaluation. The prevailing Big Bang hypothesis gives matter radial linear motion but no angular momentum, either at galactic or universe-as-a-whole levels. Thus, a key feature of the universe has no widely agreed upon explanation. Rating: 1.

Possible Explanations. The universe-as-a-whole was created with angular momentum, which was then communicated to lower hierarchical levels. This, of course, just pushes the need for explanation farther back in time!

Similar and Related Phenomena. Virtually all material objects in the universe possess angular momentum. See also: universal rotation (ATB4); angular momentum-mass relation (ATB3).

Examples

X0. Introduction. "Galaxy rotation and how it got started is one of the great mysteries of astrophysics. In a Big Bang universe, linear motions are easy to explain: They result from the bang. But what started the rotary motions? To convert linear motions to rotary ones usually takes some trickery, so that at least one astrophysicist has suggested that the universe as a whole rotates and so transmits some of its rotation to objects within it." (R3) Some evidence does exist for the rotation of the universe-as-a-whole (ATB). If such does occur, one must contend with explaining the origin of this primordial angular momentum. (WRC)

X1. Observations supporting galactic rotation. Most galaxies "look" like they must be rotating. The spiral galaxies, especially, seem to be swirling, and their flattened shapes suggest centrifugal forces are present. Many, but not all, elliptical galaxies are oblate masses of stars; such flattening also "seems" the consequence of rotation. (WRC)

X2. Possible explanations. In Astrophysical Journal (vol. 155, p. 393) he (P.J.E. Peebles) now shows how galaxies can start to spin after they have begun to condense from the primaeval plasma. The key to his solution lies in the tidal forces in the early universe and he draws the following picture:

Proto-galaxies are clustered close together in the early universe, little expansion has occurred, so the galaxies interact quite strongly through their gravitational fields. Gradually they stop orbiting around each other, and begin to rotate instead; the orbital motion of whole clusters of galaxies is turned into rotational motion of individual galaxies by gravitational tidal forces." (R1; R5) In the above, the question arises: How did the galaxies acquire their angular momenta around each other. (WRC)

N.A. Sharp et al object to the tidal hypothesis on other grounds. "Summary. The hypothesis that the spin angular momentum of each galaxy in a binary results primarily from tidal interaction with its companion during galaxy formation is shown to imply a non-random distribution of the angle between the major axes of the images of disc galaxies in pairs. The observed distribution of this angle is inconsistent with the tidal hypothesis." (R2)

References

R1. "Did Early Tidal Forces Make Galaxies Rotate?" New Scientist, 42:193, 1969. (X2)

R2. Sharp, N.A., et al; "A Test of the Tidal Hypothesis for the Origin of the Galactic Angular Momentum," Royal Astronomical Society, Monthly Notices, 187:287, 1979. (X2)

R3. Thomsen, Dietrick E.; "Galaxies That Came in from the Cold," Science News, 128:316, 1985. (X0, X2)

R4. Peebles, P.J.E.; "Origin of the Angular Momentum of Galaxies," Astrophysical Journal, 155:393, 1969. (X2)

AWB10 Lines of Galaxies Associated with Elliptical Radio-Bright Galaxies

Description. The frequent association of strings of galaxies aligned with radio-emitting elliptical (E) galaxies. These lines are colinear with the lines of elongation of the radio components. The disposition of the lines of galaxies encourages one to think that the galaxies were forcibly ejected from the elliptical galaxies.

Data Evaluation. Essentially all bright, radio-emitting, elliptical galaxies are associated with strings of galaxies. Arp lists over a dozen in R1. However, comments and confirming studies are lacking in the literature surveyed so far. Rating: 2.

Anomaly Evaluation. The frequent association of radio-emitting ellipticals with string of galaxies cries for explanation, but nothing has surfaced beyond H. Arp's surmise that the strings of galaxies might have been ejected bullet-like from the elliptical galaxies. Rating: 2.

Possible Explanations. Elliptical galaxies eject globs of matter that evolve into galaxies. Or, perhaps, the elliptical galaxies and the strings of galaxies were created in situ and were/are aligned by unidentified forces.

Similar and Related Phenomena. Quasar pairs straddling galaxies (AQB2); jets emitted by galaxies (AWO1).

Examples

X1. Survey of elliptical galaxies. Abstract. "All E galaxies brighter than $m_{pg} = 15$ magnitude which are radio sources stronger than $S_{1410} = 5$ flux units have been investigated. In essentially all cases there are lines of galaxies originating from these radio E galaxies. The typical case is that the largest galaxy in a cluster is a radio E, and the other bright galaxies in this cluster are aligned on either side of this central galaxy along the line of elongation of the radio components.

It is argued that this general physical

phenomenon can only be explained by having the line of galaxies, or their progenitors, ejected from the central galaxy along with the radio emitting material. The redshifts of the galaxies in these lines exhibit ranges between 1000 and 3000 km/sec. This result necessitates either the drastic reduction of the presently accepted ages for the galaxies in the lines, by a factor of 100, or an interpretation of part of the redshift as non-Doppler." Arp agrees that it is difficult to conceive of a fully developed galaxy being ejected as such from another galaxy, and he considers it more likely that the matter constituting the galaxies was first emitted as a compact body, which later expanded into the density state we see today. (R1)

X2. NGC7752/NGC7753. This "line of two" galaxies is considered pertinent because it has been cited as an example of a companion galaxy located at the end of the spiral arm of another galaxy. The relative velocity of the companion is 341 kilometers per second; and this companion galaxy may have been ejected from the end of the spiral arm. In any event, we have a case of an unstable galaxy pair. (R2)

References

R1. Arp, Halton; "Lines of Galaxies from Radio Sources," Astronomical Society of the Pacific, Publications, 80:129, 1968. (X1)

R2. "An Unstable Galaxy Pair," Nature (Physical Science), 242:113, 1973. (X2)

R3. Arp, Halton, and Madore, Barry F.; "Preliminary Results from the Catalogue of Southern Peculiar Galaxies and Associations," Royal Astronomical Society, Quarterly Journal, 18:234, 1977.

AWB11 Spirals and Ellipticals Have Markedly Different Population Densities

Description. The presence in elliptical galaxies of many more globular clusters per unit mass than in spiral galaxies.

Data Evaluation. A general observation in an article in a popular science magazine. Rating: 2.

Anomaly Evaluation. No theory accounts for this disparity. Indeed, it contradicts that popular hypothesis that elliptical galaxies are created when spirals collide and merge. Rating: 2.

Possible Explanations. None.

Similar and Related Phenomena. None.

Examples

X1. General observations. "Nor is it understood why elliptical galaxies seem to have many more globular clusters per unit of mass than spiral galaxies. The observation is of particular significance because it argues against a popular theory of how the ellipticals formed. Alar Toomre of the Massachusetts Institute of Technology and other investigators have proposed that the elliptical galaxies are formed when spiral galaxies collide and merge. The strongest evidence against this hypothesis is the higher proportion of clusters in the ellipticals." (R1)

References

R1. King, Ivan R.; "Globular Clusters," Scientific American, 252:79, June 1985. (X1)

AWB12 Smooth Background Population of Lone Galaxies

Description. The presence between the clusters and superclusters of galaxies of a uniformly distributed population of unattached galaxies.

Data Evaluation. A single study reported in a popular astronomy magazine. Since some studies of galaxy distribution state or imply that essentially all galaxies are members of clusters, this phenomenon requires confirmation. Rating: 3.

Anomaly Evaluation. Since galactic clusters and superclusters are thought to condense due to gravitational instabilities or perturbations in the uniform sea of matter created by the Big Bang, it is remarkable that a background population of galaxies should remain unaffected by these forces. Rating: 2.

Possible Explanations. None.

Similar and Related Phenomena. None.

Examples

X1. General observations. "The Universe appears to be split into two distinctly different distributions of galaxies---those galaxies that travel in groups or clusters, and those galaxies that are 'loners'. The loners make up a smoothly spread field of galaxies surrounding the galaxy clusters.

This surprisingly uniform galaxy background was accidentally discovered during a cataloging of galaxy clusters by Caltech astronomer Edwin Turner and J. Richard Gott of the Institute of Astronomy in Cambridge, England. " Current theories of galaxy formation do not predict this smooth background of loners. In fact, it would seem difficult to account for it knowing that it exists. Turner stated, "We don't know why half the galaxies should 'feel' each other's gravitational attraction and fall into clusters and why the other half should apparently ignore gravitational attraction and just sit there in space." (R1)

References

R1. "Lone Galaxies Discovered," Astronomy, 3:66, June 1975. (X1)

AWB13 Apparent Rapid Dispersal of Galactic Clusters

Description. The seeming expansion and dispersal of the galaxies in galactic clusters on a time scale shorter than the age of the universe.

Data Evaluation. No one denies the velocity measurements for cluster members and the appearance of rapid dispersal. The information crucial to this anomaly is the time necessary for a cluster to disperse assuming that the clusters are not in equilibrium. Opinions differ on this matter, as recorded below; some saying the time is longer than the age of the universe, others maintaining that it is short. Most astronomers choose the latter, which leads directly to the missing mass problem. Rating: 3.

Anomaly Evaluation. If galactic clusters really take a very long time to disperse, there is no anomaly and no need for missing mass to keep them from dispersing on a short time base. Generally, though, astronomers have opted for missing mass, possibly because several other situations in the universe seem to require it also. Since no one has observed the missing mass, it constitutes a first class anomaly. Other possible explanations, such as modification of physical laws or the assumption of a young earth/universe (a particularly unsavory thought), would also imply this anomaly is extremely important. Rating: 1.

Possible Explanations. See the above discussion and possible explanations in X4 below.

Similar and Related Phenomena. Anomalous rotation curves of galaxies (AWB5); galactic halos (AWO11); the "unclosed" universe (ATB2).

Examples

X0. Introduction. Back in the 1930s, F. Zwicky suspected that galactic clusters did not possess enough mass to account for their dynamic behavior. This was the beginning of the "missing mass" problem. See AWB5-X0 for more details.

X1. General observations. Abstract. "Some clusters of galaxies contain over one thousand members, all in random motion with respect to each other. These random motions should have 'dispersed' the clusters long ago so that the galaxies should not be nearly as close together as we observe them to be. This dispersion is thought to be counterbalanced by the gravitational force of all the matter in the cluster. But observations indicate that only ten to twenty percent of the required mass is in the form of galaxies. The rest is unaccounted for and the understanding of this discrepancy is likely to alter some of our fundamental concepts of the universe." (R2) In this overview, B. Margon assumes that the galactic clusters are very old. (WRC)

Here is a later overview: "Velocity measurements can also yield mass estimates for giant clusters, where the individual galaxies dart about randomly like swarming bees. Assuming that a cluster is stable, the overall gravitational field must keep the fastest-moving galaxies from flying away. By this measure... the total mass in large clusters is as much as 100 times the visible mass in the galaxies." (R3) Note here the presence of another assumption critical to the formulation of the "missing mass" problem. (WRC)

X2. The Coma cluster. "For the galaxies measured in the Coma cluster, the average velocity of recession is about 6900 kilometers per second. However, each individual galaxy generally has some smaller, randomly directed motion within the cluster, typically several hundred kilometers per second with respect to its neighbors. Why then don't most of the members eventually 'escape' from the Coma cluster and wander off elsewhere in intergalactic space? Although cosmologists argue about conditions in the early Universe, we know from dating rocks on earth that the Universe is at least 4.5 billion years old, and probably substantially older. In this time we can calculate that the random motions of the galaxies should have 'disrupted' the cluster, and the galaxies could not possibly be as close together as we now observe them to be." Thus, the velocity dispersion of the galaxies in the Coma cluster demand the counterbalancing force of additional mass---the missing mass. (R2) But M. J. Valtonen and G. G. Byrd maintain that the Coma cluster is in fact dispersing and needs no missing mass to account for the cluster's dynamics. These astronomers agree that the Coma cluster is old, but believe that its dispersal takes much longer that the age of the universe---conflicting views obviously. (R11) See X3, following, for a more general denial of the missing mass problem.

X3. Analysis of cluster dispersal. "The center of a large cluster is often dominated by a supermassive galaxy with one or more massive companions. By running computer simulations of such arrangements, (M. J.) Valtonen's group found that orbital energy is tranferred from the heavy central objects to the rest of the galaxies, making the cluster expand and disperse. The added velocities give the illusion that the cluster contains very large amounts of invisible mass, if it is wrongly assumed to be in equilibrium. Complete dispersal takes longer than the age of the universe, which is why such groups are still abundant." (R11; R10, R12)

X4. Overview of possible explanations. The reader is referred to AWB5-X6, where a list of missing mass candidates is presented in connection of galaxy dynamics. (R3, R6, R8) To which, we add A. Finzi's modification of the Law of Gravitation:

"Summary. An attempt is made to solve the longstanding problem of the stability of clusters of galaxies by assuming a law of gravitation that implies a much stronger attraction at a long distance than that predicted by the law of Newton. It is further shown that the same hypothesis could provide a solution to a number of other problems in different fields of astrophysics." (R1)

References

R1. Finzi, Arrigo; "On the Validity of Newton's Law at a Long Distance," Royal

Astronomical Society, Monthly Notices, 127:21, 1963. (X4)
R2. Margon, Bruce; "The Missing Mass," Mercury, 4:2, 1975. (X1, X2)
R3. Waldrop, M. Mitchell; "Massive Neutrinos: Masters of the Universe?" Science, 211:470, 1981. (X1, X4)
R4. Waldrop, M. Mitchell; "The Large-Scale Structure of the Universe," Science, 219:1050, 1983.
R5. Bartusiak, Marcia; "Missing: 97% of the Universe," Science Digest, 91:51, December 1983. (X0)
R6. Milgrom, M.; "A Modification of the Newtonian Dynamics as a Possible Alternative to the Hidden Mass Hypothesis," Astrophysical Journal, 270:365, 1983. (X4)
R7. Milgrom, M.; "A Modification of the Newtonian Dynamics: Implications for Galaxy Systems," Astrophysical Journal, 270:384, 1983.
R8. Burns, Jack O.; "Dark Matter in the Universe," Sky and Telescope, 68:396, 1984. (X4)
R9. Schneider, Stephen E., and Terzian, Yervant; "Between the Galaxies," American Scientist, 72:572, 1984.
R10. "Expanding Clusters Confuse Astronomers," New Scientist, p. 13, March 21 1985. (X3)
R11. MacRobert, Alan; "No Missing Mass," Sky and Telescope, 70:22, 1985. (X3)
R12. Valtonen, M.J., et al; "No Missing Mass in Clusters of Galaxies?" Astronomy and Astrophysics, 143:182, 1985. (X3)

AWB14 Structures Larger Than Superclusters

Description. The large-scale correlation of superclusters, suggesting even larger structures.

Data Evaluation. A single statistical correlation by a respected team of astronomers.Rating: 2.

Anomaly Evaluation. Since some superclusters approach 1 billion light years in extent---an appreciable fraction of the known universe---the confirmation of even larger aggregations either severely weakens the Cosmological Principle or implies we know only a very small portion of the universe. Rating:1.

Possible Explanations. The universe is much bigger than presently believed.

Similar and Related Phenomena. Superclusters (AWB2); supercluster organization (AWB4).

Examples

X1. Analysis of superclusters. "Abstract. "A positive spatial correlation is observed among a complete sample of superclusters on a scale of ~100 h^{-1} Mpc. The correlation is significant at about the 95%-99% confidence level, suggesting the possible existence of the largest structures yet detected. The correlation appears to be stronger than that of galaxies and galaxy clusters, indicating a continuation in the increasing strength of clustering with richness." (R1)

References

R1. Bahcall, Neta A., and Burgett, William S.; "Are Superclusters Correlated on a Very Large Scale?" Astrophysical Journal, 300:L35, 1986. (X1)

AWB15 Anomalous Gas Motion in Elliptical Galaxies

Description. The rotation of gas in elliptical galaxies independent of stellar motion.

Data Evaluation. Two reports at a symposium, still unpublished. Rating: 2.

Anomaly Evaluation. The independent rotation of gas in elliptical galaxies, with different axes of rotation, could imply one of at least two things: (1) The gas had a different origin than the stars (perhaps it was captured); or (2) Some force within the galaxies causes independent rotation. These implications make this an important anomaly. Rating: 2.

Possible Explanations. An independent origin for the gas; a motive force within the galaxies.

Similar and Related Phenomena. Rotation curves for galaxies, which often are based on the motion of gases (AWB5).

Examples

X1. Axes of rotation. "F. Bertola (University of Bologna) showed that the gas and the stars in some elliptical galaxies have systematically different rotation axes, and can both be different from the optical axis of the galaxy." (R1)

X2. Differential rotation. "(R.) Fosbury has mapped the velocity field of the gas with Taurus, an imaging tuneable Fabry Perot, and is able to say that the gas rotates and the stars do not. This leads to a model of a warped disk of gas cutting through an elliptical galaxy---the prototype is Centaurus A, some new Taurus observations of which were presented by P. Atherton (Imperial College, London)." (R1)

X3. Counterrotation of gas and stars. "...one elliptical has recently been found to possess an equatorial gas disk that rotates in the opposite direction from the stars." (R2)

References

R1. Lawrence, Andrew; "The Outer Regions of Galaxies," Nature, 298:421, 1982. (X1, X2)

R2. Schweizer, Francois; "Colliding and Merging Galaxies," Science, 231:227, 1986. (X3)

AWB16 Preferred Orientation of Galaxies in Clusters

Description. The tendency of galaxy major axes to be parallel to the major axes of their clusters

Data Evaluation. Most data at hand consist of almost off-hand remarks, with only one specific survey found to date. Rating: 2.

Anomaly Evaluation. Any strong tendency for the axes of member galaxies to align with cluster axes could imply: (1) The galaxies and their cluster were subject to the same formative force; or (2) The aligned galaxies were ejected from the cluster's dominant member. (Most clusters boast a giant galaxy at their centers, and its axis is often parallel to the cluster's major axis.) The first implication is probably consistent with theories of universe formation involving perturbations of the matter created by the Big Bang. In this case, there is little that is anomalous here. The second implication, though, involves galaxies ejecting galaxies and is much more radical. Composite rating: 2.

Possible Explanations. See above.

Similar and Related Phenomena. Lines of galaxies emanating from radio galaxies (AWB10); quasar pairs straddling galaxies (AQB2).

Examples

X1. General observations. B. Binggeli "... observed, as have others, that the long axis of the central brightest galaxy in a cluster tends to line up with the long axis of the cluster." Other galaxies in a cluster, however, show little such tendency. (R2) But see X2.

X2. The Coma cluster. "...Stanislav Djorgovski of the University of California used photometric observations of galaxies in the Coma cluster to show that the long axes of individual galaxies are generally aligned parallel to the major axis of the cluster." (R3)

X3. Survey of linear clusters. "Abstract. Seven linear clusters of galaxies from the catalog of Rood and Sastry have been studied primarily to determine whether the principal axes of the member galaxies exhibit any tendency toward alignment. The major axes of galaxies in two of the clusters (Abell 999 and Abell 2197) showed a distinct tendency to lie along the cluster major axes. Examination of all the galaxies in our seven-cluster sample reveals that the major axes of these cluster members tend to lie either along or perpendicular to the cluster major axis and avoid intermediate position angles." (R1)

References

R1. Adams, Mart T., et al; "Linear Clusters of Galaxies," Astrophysical Journal, 238:445, 1980. (X3)
R2. Peebles, P.J.E.; "The Origin of Galaxies and Clusters of Galaxies," Science, 224:1385, 1984. (X1)
R3. Parker, Barry; "Mystery of the Missing Mass," Astronomy, 12:9, November 1984. (X2)

AWB17 The Existence of Galaxies

Description. The existence of isolated aggregations consisting of hundreds of billions of stars, occupying volumes of space on the order of 50,000 light years in diameter. Dwarf and giant galaxies also exist. The most common galaxies have spiral and elliptical configurations.

Background. Since galaxies are often taken to be the basic "units" of matter in astronomy, it is rather embarrassing that no one has explained their origin(s) to everyone's satisfaction. Since we cannot determine whether galaxies are forming or dispersing from our direct observations over the short history of extragalactic astronomy, we have to be satisfied with theories that are consistent with physics and general facts about the cosmos; e.g., the cosmic microwave background radiation and the laboratory-determined properties of subatomic particles. Although most popular astronomy books declare that the galaxies coalesced from the debris of the big bang, such theories have run into theoretical difficulties.

Data Evaluation. The existence of galaxies is a basic fact of astronomy. Rating: 1.

Anomaly Evaluation. Most astronomers and cosmologists freely admit that no satisfactory theory of galaxy formation has been formulated. In other words, a major feature of the universe is without explanation. Rating: 1.

Possible Explanations. Today, the most prominent theories are termed the "bottom-up" and "top-down" hypotheses; but they both have major defects. (See X2 below.) A more recent theory has jets emitted by galaxies causing the collapse of molecular clouds into aggregations of stars.

Similar and Related Phenomena. The other major "existence" anomalies: stars (AOB18); globular clusters (AOB17); galactic clusters (AWB1); superclusters (AWB2); voids (AWB3).

Examples

X1. General observations. "Finally, we come to the vexed question of the origin of galaxies. As the big bang bandwagon has gained momentum, as increasing number of investigations have been carried out in which attempts are made to explain the condensation of dense objects from an initial cloud of matter and radiation which is expanding. It has been known for many years that this is very difficult to understand, and the investigations have now reached the point where it is generally accepted that the existence of dense objects cannot be understood unless very large density fluctuations in a highly turbulent medium, or otherwise, are invoked in the first place. There is again no physical understanding of the situation; it is a condition which is put in, in a hypothetical state, to explain a major property of the universe. Thus these 'theories' amount to nothing more than the statement that protogalaxies have a cosmological origin, and their origin cannot be understood any better than can the original baryons and leptons in an evolving universe. .....What the debate largely reduces to is that on one side there is an apparent belief by the majority that creation in the distant past is acceptable, but that creation at recent epochs is unthinkable, while on the other it is thought that there is little to choose between the two points of view, and that only with much more original work can we hope to resolve the issue. It is clear that the evolving universe concept gains no support from attempts to understand either the origin of the elements or the origin of galaxies." (R1) An assessment from 1971.

A 1975 evaluation. "The real problem of galaxy formation remains very much unsolved. The greatest difficulty is that we have no idea what induced the formation of the first bound objects in an expanding Universe. One suspects that the origin of these local inhomogeneities in the structure of the Universe will be understood only when we know why the Universe is so remarkably smooth and homogeneous on a large scale and a major effort is now going into the possibility that this isotropy is the result of quantum effects back in the period when the Compton wavelength of an elementary particle was comparable with the radius of the then visible Universe. The other urgent task in cosmology is to understand how in the more recent past great masses of gas collapsed to form galaxies and clusters of galaxies. This task is particularly exciting because there is every reason to believe that we should be able to actually see this happening by looking out into distant space. What we require are detailed models of the collapse to enable us to identify a nascent galaxy when we see one." (R2)

In his book Cosmology Now, L. John observed: "Despite the optimism of the preceding chapters, there are a great many things that the cosmologist not only does not know, but find severe difficulty in envisaging a path towards finding out. Even if we beg the question of how the universe started, how did it become as it is now? In particular, how did the galaxies form? The encyclopaedias and popular astronomical books are full of plausible tales of condensations from vortices, turbulent gas clouds and the like, but the sad truth is that we do not know how the galaxies came into being." (R3)

X2. A sampler of theories. In the "bottom-up" theory, galaxies formed first, collected later into clusters, and then superclusters. Unfortunately this theory runs into the so-called "smoothness" problem. Recent measurements of the density fluctuations in the cosmic microwave background radiation show no fluctuations greater than 2.5 parts in 100,000. No galaxy could grow from a fluctuation that small---even in 15 billion years. (R6) Commenting on this theory, L. John notes a fundamental difficulty: "Now some writers have discussed the possibility that some irregularity of density was present in the universe from the outset and that this led ultimately to the occurrence of galaxies. This idea has not achieved any success, since it assumes practically all that is to be inferred." (R3)

In the "top-down" theory, galaxies occur in clusters because they were formed as parts of large aggregations, which then fragmented into smaller aggregations, and ultimately individual galaxies. (R6)

A recent theory has elliptical galaxies expelling enormous jets of gas, which ram into cosmic clouds, triggering star formation. These stars, formed in a small volume of space, organize themselves into galaxies. (R7)

References

R1. Burbidge, G.; "Was There Really a Big Bang?" Nature, 233:36, 1971. (X1)
R2. Binney, James; "Oddballs and Galaxy Formation," Nature, 255:275, 1975. (X1)
R3. John, Laurie, ed.; Cosmology Now, New York, 1976, p. 85, 92. (X1, X2)
R4. Peebles, P.J.E.; "The Origin of Galaxies and Clusters of Galaxies," Science, 224:1385, 1984. (X2)
R5. Larson, Dewey B.; "Introduction," The Universe of Motion, Portland, 1984, pp. 4, 8. (X1)
R6. Finkbeiner, Ann K.; "Cold Dark Matter and the Origin of Galaxies," Astronomy, 13:67, April 1985. (X2)
R7. Anderson, Ian; "A New Way to Make

Galaxies," New Scientist, p. 19, January 10, 1985. (X2)

R8. Waldrop, M. Mitchell; "Why Do Galaxies Exist?" Science, 228:978, 1985.

AWF ANOMALIES DETECTED THROUGH GALACTIC RADIATION

Key to Phenomena

AWF0 Introduction

Once again, the redshift-distance relationship, the famous cosmological nature of the redshift, is a target in this section of the Catalog. The correctness of this well-entrenched dogma is challenged on three fronts: (1) The apparent quantization of redshifts (AWF8); (2) The systematically greater redshifts of spirals over ellipticals in the same galactic clusters (AWF9); and (3) The redshift dispersion in lines of galaxies (AWF10). All three of these anomalies suggest at least a noncosmological component of redshifts.

Although cosmologists confidently put the age of the universe at 15-18 billion years, two anomalies cast shadows of doubt on these figures. First, distant galaxies appear to be far too mature for their "real" ages, as measured by their redshifts. Second, the galaxies in the lines of galaxies strung out next to radio sources, and pegged at 10 billion years of age, have such velocities of dispersion that they should have broken formation in the first 100 million years of their alignment.

In the guise of Seyfert galaxies, the quasar energy paradox appears once more, but in a less severe form. Seyfert galaxies are generally two magnitudes less energetic than quasars, but this is still too much for the well-recognized energy-generating mechanisms. Readers should note here that black holes are not recognized as "well-recognized" in this Catalog, although this reactionary stance may eventually change.

AWF1 The Slight Blueness of Distant Galaxies

Description. The lack of expected blueness in distant galaxies.

Background. When we observe galaxies with redshifts greater than z = 1, the redshift-distance relationship tells us we are seeing stellar systems more than 10 billion lightyears away. Since the universe is thought to be 16-18 billion years old, these distant galaxies must be only 6-8 billion years old, for we are looking back into time. The anomaly here is that these young galaxies do not seem much bluer than nearby old galaxies, 16-18 billion years of age. One would expect the younger galaxies to be much hotter (bluer) and more active.

Data Evaluation. The two surveys of distant galaxies reported below directly contradict one another. Therefore, the existence of this anomaly is very shaky. More data are needed. Rating: 4.

Anomaly Evaluation. Theories of galaxy evolution and "maturation" are not far advanced and do not yet occupy an important place in astronomical dogma. Astronomers only "expect" young galaxies to be bluer and brighter than older ones. Under these conditions, this anomaly cannot be considered very important. Rating: 3.

Possible Explanations. This anomaly would vanish if the data of X2, below, are confirmed. A more radical development would be the consensus that redshifts are not entirely cosmological; i.e., proportional to distance. Then, the "distant" galaxies would be closer and older.

Similar and Related Phenomena. Several anomalies in this volume bear on the validity of the redshift-distance relationship: AQB1, AQB4, AQB6, AQF5, AQO3, AWB7, AWF8, and others.

Examples

X1. Study of four distant galaxies, including 3C 13 and 3C 427.1. These galaxies have redshifts of just over z = 1, making them 6-8 billion years old, if a Hubble constant of 50 is assumed. Their spectra were compared with those of similar, but nearby, elliptical galaxies with ages of about 16 billion years. "Comparison of the two groups yields the surprise that the far distant galaxies look more modern and mature than they were expected to. Their light appears not much bluer than that of the nearer galaxies. This indicates that star formation began and ran its course in the distant galaxies quite early, earlier than many theorists would have expected. If star formation was early, formation of the galaxy itself, which necessarily preceded star formation, had to be early too. This evidence indicates that both processes took place within two billion years of the moment of origin." (R1) Assumed here are the usual redshift-distance proportionality and the formation of galaxies before stars. The results described in R1 are contradicted by those in R2; see X2 below.

X2. Survey of 90 distant galaxies, mostly with redshifts greater than z = 1. "Red shifts that are this large shunt most of the visible light from the galaxy into the infrared part of the spectrum. To search for evidence that galaxies change as they age, astronomers must therefore compare nearby galaxies' light with the infrared received from distant galaxies. (M.) Longair thus looked in detail at each of the galaxies with the 3.8-metre UK Infrared Telescope (UKIRT) on Hawaii, and then compared the infrared with the optical colours. All the distant galaxies were much bluer than their present-day counterparts. Although the analysis has to allow for the anomalous production of ultraviolet light by elliptical galaxies, this effect is not enough to account for the extreme blueness of the distant galaxies and Longair attributes their intense colour to much more activity, such as the rapid formation of stars in the past." (R2)

References

R1. "Most Distant Galaxies: Surprisingly Mature," Science News, 119:148, 1981. (X1)

R2. Couper, Heather; "Youthful Blues and Distant Galaxies," New Scientist, p. 21, March 1, 1984. (X2)

AWF2 The Seyfert Energy Problem

Description. The problem: If the bright nuclei of Seyfert galaxies are as small as their rapid fluctuations in luminosity suggest, their very high energy densities challenge astrophysical theories, although not as severely as in the case of quasars (AQF5). In general, the energy liberated by a Seyfert nucleus is 10^{43} - 10^{45} ergs per second, about two orders of magnitude less than for quasars. Nevertheless, the energy problem remains, because Seyfert luminosities vary on a scale of minutes, implying a very small active nucleus.

Background. Seyfert galaxies are definitely galaxies because Seyferts are close enough for us to distinguish spiral formations of surrounding stars. But the Seyfert nuclei mimic quasars. Quasars could, in fact, be galaxies so distant that the surrounding stars cannot be identified with certainty. Indeed, many astronomers consider quasars to be galaxies, and Seyferts to be quasars. When this taxonomic problem is fully resolved, the relevant parts of this Catalog will have to be rearranged.

Data Evaluation. Seyfert galaxies, although not common celestial objects, have been observed intensely. Their general characteristics are now well known, especially their luminosities and variabilities, which define the Seyfert energy problem. Rating: 1.

Anomaly Evaluation. As with quasars, the energy problem consists of finding an energy-generating mechanism that can produce the energy of, say, 10^{12} suns in a volume as small as 100 light-seconds (30 million kilometers) across. Until exotic mechanisms, like black holes, have been definitely proven to exist, this phenomenon will retain a high anomaly rating. Rating: 1.

Possible Explanations. Almost everyone, including astronomy book writers, believes that black holes lurk in the cores of Seyfert galaxies, as well as in quasars and possibly other galaxies.

Similar and Related Phenomena. The quasar energy paradox (AQF5).

Examples

X0. Introduction and background. Seyfert galaxies are extraordinarily active galaxies that display some quasar-like properties. The taxonomic problems with these Active Galactic Nuclei (AGNs) are rather complex, so we add a little background here.

The 1968 definition of a Seyfert galaxy. "The following are the characteristics of Seyfert galaxies. First, there is a small nucleus described as stellar or nearly stellar; the word 'nucleus' here designates a small, separate feature in the center of the galaxy.

. . . . . .

Second, a Seyfert galaxy is characterized by a strong emission spectrum, very rich in forbidden lines. The third criterion is that the lines are very wide, their widths ranging up to 6000-8000 km/sec." (R2)

"The most striking spectroscopic feature of Seyfert galaxies (and quasars) is the conspicuous emission lines.. While weak emission lines are often found in the nuclei of galaxies, the emission lines of greatest intensity relative to the underlying continuum are found in Seyfert galaxies. One of the initial defining characteristics of a Seyfert galaxy was that the emission lines were also broad. This is a qualitative characteristic that has led to some confusion because there is no defined width at which an emission line is considered to arise in a Seyfert galaxy. In most cases, however, the appearance of emission lines in Seyfert galaxies is so noticeably different from those in other galaxies that the classification as a Seyfert is straightforward. The extraordinary intensity as well as the greater width of the lines in a Seyfert galaxy is evident. Whereas the emission lines in other galaxies rarely exceed 100 km s^{-1} full width to half maximum intensity, this width in galaxies called Seyferts is generally 1000 km s^{-1} or more for some emission lines." (R3)

By 1983, Seyfert taxonomy had become more elaborate. "A Seyfert galaxy is a very low-luminosity quasar. Such galaxies are recognized by strong emission lines from photoionized gas clouds in the nucleus of the galaxy. They show two types of line emission: 'narrow' lines whose small Doppler widths imply velocities of a few hundred kilometres per second, and 'broad' lines with Doppler widths of many thousands of kilometres per second. A galaxy is called a Seyfert 1 galaxy if the strong hydrogen lines are dominated by the broad-line component and a Seyfert 2 galaxy if the broad-line component is absent...The two components of line emission come from physically distinct regions: the broad-line region and the narrow-line region." (R11)

In at least one Seyfert-2 galaxy, examination in polarized light revealed the unmistakable spectrum of a Seyfert 1, which had been hidden from direct view. Seyfert 2s, therefore, may all contain hidden Seyfert 1s. (R14)

The Seyfert 1s, however, are so nearly like quasars that some astronomers speculate that quasars are really Seyfert 1s that are imaged by gravitational lenses. (R5)

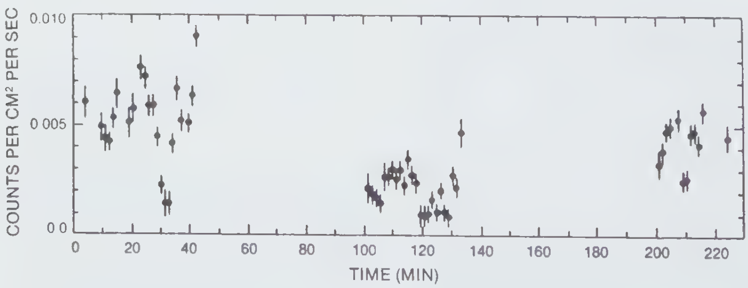
X1. Statements of the Seyfert energy problem. "The purpose of this review has been to summarize the facts now known about Seyfert galaxies, but the reason for their existence remains one of the most pressing astrophysical mysteries. The primary difficulty in explaining Seyfert nuclei is in accounting for their energies. Many have bolometric luminosities as great as 10^{45} ergs sec^{-1}. Even this is 10^{12} solar luminosities, which has to arise in a volume about a parsec in diameter. Such a nucleus can be visualized by imagining the Crab Nebula radiating 10^7 as much energy as it does, since the absolute size, nonthermal radiation, and filamentary structure of the Crab likely resemble that of Seyfert nuclei. Obviously, some very efficient mechanism of energy production that can arise in a small volume is called for." (R4)

"Ordinarily, what astronomers find extraordinary in these objects are the very large continuum luminosity (10^{43} - 10^{45} erg s^{-1} in Seyferts, 10^{45} - 10^{47} erg s^{-1} in quasars) and the very strong, broad (10^3 - 10^4 km s^{-1}) emission lines coming from an optically unresolved source believed to be no more than a few parsecs in size." (R6)

X2. NGC 6814, a rapidly varying Seyfert. "Observations of the variability of the light output of quasars and Seyfert galaxies have been of great importance as probes of the physical conditions in these 'active galactic nuclei'. New evidence has been reported that the Seyfert galaxy NGC6814 varies on the amazingly short time scale of 100 s, not only revealing the smallest dimsensions so far for an active galactic nucleus, but at last beginning to place constraints on the physical processes responsible for the prodigious rate of energy output." (R7)

X-ray data on NGC 6814 provided by the HEAO 1 satellite. Refer to figure. "The X-ray luminosity of this AGN (active galactic nucleus) varied as much as 2½ times between one spacecraft orbit and the next (a period of 1.5 hours); no associated spectral changes were detected. Variations at a much faster rate were clearly present, and statistical analysis revealed a characteristic time scale of about 100 seconds for these quick changes. The average X-ray luminosity of NGC 6814 is about 10^{43} ergs per second (about 100 billion times greater than the Sun's total luminosity at all wavelengths)." (R8)

X3. NGC 4151, an anomalously variable Seyfert. This is the most variable of all the known Seyferts, and may contain a gargantuan black hole. (R9) This Seyfert has also exhibited significant 2000-second drops in its X-ray intensity. (R13) Even more curious, between 1974 and 1984, NGC 4151 lost its broad emission lines and changed from a Seyfert 1 to a Seyfert 2. (R12)



Variability of the X-ray brightness of Seyfert galaxy NGC6814. (X2)

X4. Fairall 427, a Seyfert-2 galaxy with strange spectral changes. A. P. Fairall has reported that the forbidden lines in this galaxy exhibit 30-minute variations. "The problem is that the forbidden lines Fairall observes must come from a large region perhaps 1,000 light yr across. Such a large region cannot produce variations in half an hour....no conventional physical conditions can explain the observations and the physical conditions are well understood." (R11) Until this phenomenon is explored further, we will classify it with the "energy" problem of Seyferts, with the recognition that it may be a distinct anomaly on its own. (WRC)

References

R1. Kinman, T.D.; "Variable Galaxies," Science, 162:1081, 1968.

R2. Pacholczyk, A.G., and Weymann, R., eds.; "Proceedings of the Conference on Seyfert Galaxies and Related Objects...," Astronomical Journal, 73:836, 1968. See "Introductory Remarks," p. 842, by R. Minkowski. (X0)

R3. Weedman, Daniel W.; "Seyfert Galaxies, Quasars and Redshifts," Royal Astronomical Society, Quarterly Journal, 17:227, 1976. (X0)

R4. Weedman, Daniel W.; "Seyfert Galaxies," Annual Review of Astronomy and Astrophysics, 15:69, 1977. (X1)

R5. "Gravitational Lens Effect Make Quasars an Optical Illusion," Science News, 120:325, 1981. (X0)

R6. Krolik, J.H.; "A Particularly Anomalous Seyfert Galaxy," Nature, 294:13, 1981. (X1)

R7. Lawrence, Andrew; "Breaking the Active Galaxy Speed Record," Nature, 296:706, 1982. (X2)

R8. "The 100-Second Seyfert Galaxy," Sky and Telescope, 64:411, 1982. (X2)

R9. Waldrop, M. Mitchell; "NGC 4151: The Monster in the Middle," Science, 222:1003, 1983. (X3)

R10. Weedman, Daniel W.; "Toward Explaining Seyfert Galaxies," Astrophysical Journal, 266:479, 1983.

R11. Gaskell, C. Martin; "Spectra That Defy Explanation," Nature, 304:212, 1983. (X0, X4)

R12. Henbest, Nigel; "Galactic Secrets Bared by Isaac Newton's Spectra," New Scientist, p. 21, May 10, 1984. (X3)

R13. Whitehouse, D.R., and Cruise, A.M.; "EXOSAT Observations of a 2,000-s Intensity Dip in Seyfert Galaxy NGC4151," Nature, 315:554, 1985. (X3)

R14. Gaskell, C. Martin; "A Hidden Quasar Revealed," Nature, 320:398, 1986. (X0)

R15. Tennant, A.F., et al; "Rapid X-ray Variability in the Seyfert Galaxy NGC 6814," Astrophysical Journal, 251:15, 1981. (X2)

AWF3 Superluminous Infrared Galaxies

Description. Galaxies with very high infrared/visible luminosity ratios. Such galaxies may emit 100 times the total energy of a normal galaxy, with almost all of it concentrated in the infrared portion of the spectrum.

Data Evaluation. The IRAS (Infrared Astronomical Satellite) pinpointed most of these galaxies, which were then found in the visible in many instances. These data are considered highly reliable. Rating: 1.

Anomaly Evaluation. Since the total energy production of the superluminous infrared galaxies is so high, the energy problem that attends the quasars and Seyfert galaxies exists here, too. The major anomaly, however, is the unknown mechanism producing the immense quantities of infrared radiation. Probably, some veil of dust or gas converts visible light into infrared, as suggested below. Plausible mechanisms are available, but the correct one has not yet been identified. Rating: 2.

Possible Explanations. Seyfert galaxies hidden by dust clouds, which convert the Seyfert's radiation into infrared radiation. Also possible are shock waves emanating from regions of intense star formation.

Similar and Related Phenomena. Stars emitting excess infrared light (AOF15); unidentified infrared objects (AOF10)

Examples

X1. Early observations of superluminous galaxies. "Frank Low and his colleagues at the University of Arizona, observing with new techniques in the infrared wavelengths, have discovered galaxies whose massive cores radiate 100 times more energy than the most luminous galaxy previously known. This is startling enough, but if these new type galaxies are distributed uniformly in space, calculations show they will supply enough microwave flux to account for what is known as the 3°K thermal background radiation. This removes a major objection to the steady state cosmology." (R1) It is not crystal clear that these galaxies are the same kind of objects reported in X2.

X2. IRAS discoveries. Abstract. "Deep charge-coupled device imaging has been used to identify a number of IRAS (Infrared Astronomical Satellite) blank field sources with distant galaxies, and indicates that most high-latitude unidentified IRAS point sources have an extragalactic origin. The present sample of galaxies seems to include some with the largest known ratios of IR-to-optical luminosity, with values of L(IR)/L(B) ranging upwards of 200. A redshift obtained for one source, 0422 + 009, indicates that this object has ~35 times the absolute IR luminosity of the starburst galaxy M82." (R2)

"Infrared Bright Galaxies: In most galaxies, including our own, the infrared and visible luminosities are roughly the same. However, IRAS discovered a new class of galaxies, comprising about 5 percent of all galaxies, that are a bit like a hot frying pan: dim in the visible and bright in the infrared, by a factor of 50 to 100. In fact, their total luminosity puts them in the quasar class. The most dramatic example, Arp 220, has power output equivalent to 2 trillion suns." Possible explanations: shock waves produced in star formation or Seyfert galaxies shrouded in dust. (R3)

Later studies have identified six of the IRAS sources with visually faint galaxies with total luminosities in the range 5×10^{11} to 5×10^{12} solar luminosities. Almost all the energy is in the infrared. "The origin of the luminosity, which is one to two orders of magnitude greater than that of 'normal' galaxies, is not known at this time." (R5)

References

R1. Plagemann, Stephen; "A New Vision of the Heavens," New Scientist, 37:576, 1968. (X1)
R2. Aaronson, Marc, and Olszewski, Edward W.; "Optical Counterparts of Unidentified IRAS Point Sources: Infrared Luminous Galaxies," Nature, 309:414, 1984. (X2)
R3. "IRAS," Science, 225:38, 1984. (X2)
R4. "Superluminous Infrared Galaxies," New Scientist, p. 25, June 7, 1984. (X2)
R5. Houck, J.R., et al; "Unidentified IRAS Sources: Ultrahigh-Luminosity Galaxies," Astrophysical Journal, 290:L5, 1985. (X2)

AWF4 Luminosity Changes in Ordinary Galaxies

Description. Changes in the luminosities of ordinary, apparently stable, galaxies on a time scale of days or months.

Data Evaluation. The data so far are only anecdotal or casual in nature. Rating: 3.

Anomaly Evaluation. Quasars, Seyferts, and other extragalactic objects vary rapidly in luminosity, so it would not be overly surprising to find ordinary galaxies varying on a modest scale. Of course, no one knows why AGNs (Active Galactic Nuclei) vary as they do or just what powers them. This would be true here, too, if this is a valid phenomenon. Rating: 1.

Possible Explanations. Black holes are suspected in the core of our own galaxy, but this is a hypothesis and not really an explanation in factual terms.

Similar and Related Phenomena. Seyfert galaxy variability (AWF2); quasars (AQF).

Examples

X1. Seventeenth century. The astronomer Bullialdus seems to have noticed changes in the brightness of the Andromeda nebula. (R1)

X2. General observation. "...it is a well known that some galaxies reveal discrepancies in brightness exceeding one magnitude when measured by different observers in the same photometric system but at different times." (R1)

X3. Blink comparator results. When comparing plates taken several days apart for novas, using the blinking technique, some galaxies have been seen to blink, too. But this has never been investigated in depth. (R1)

References

R1. "Do Some Ordinary Galaxies Pulsate?" New Scientist, 41:467, 1969. (X1-X3)

AWF5 Variable X-Ray-Bright Galaxies

Description. Galaxies with nuclei that emit copious X-rays at variable rates.

Data Evaluation. One example found so far. Rating: 2.

Anomaly Evaluation. No known astrophysical process seems capable of generating such large quantities of X-rays; i.e., 1 million times the sun's power in all wavelengths. Rating: 2.

Possible Explanations. When faced with explaining the generation of immense quantities of energy at variable rates, the astronomer's reflex is to suggest neutron stars, black holes, etc., perhaps several of them.

Similar and Related Phenomena. None.

Examples

X1. M33, a spiral galaxy in Triangulum. Measurements by the Einstein satellite reveal that the nucleus of M33 emits X-rays in prodigious quantities. The X-ray power of M33 equals 1 million times the sun's power in all wavelengths. Between August 1979 and January 1980, M33's X-ray luminosity dropped by 50%, suggesting that a single neutron star, black hole, or other exotic object is involved. (R1; R2)

References

R1. "M33's X-Ray Powerhouse," Sky and Telescope, 68:14, 1984. (X1)

R2. Markert, Thomas H., and Rallis, Andrew D.; "X-ray Observations of M33 with the High Resolution Imager on the Einstein Observatory," Astrophysical Journal, 275:571, 1983. (X1)

AWF6 Ultraviolet Radiation from Elliptical Galaxies

Description. The detection of more ultraviolet light from elliptical galaxies than expected based on their age and lack of star-forming dust and gas. Ultraviolet light is typical of hot, new stars, and it is a puzzle how the old ellipticals generate it.

Data Evaluation. Observations from the International Ultraviolet Explorer satellite. Rating: 1.

Anomaly Evaluation. As mentioned above, elliptical galaxies are supposed to be very old and largely devoid of the dust and gas required to make new stars. The anomalousness of the ultraviolet emissions, however, is diminished by the possibility that some double stars, which are very common, may exchange material, in effect rejuvenating one member of the pair. Gas from a red giant might, for example, be gravitationally transferred to a nearby companion making it appear like a younger star. Rating: 3.

Possible Explanations. As above, but this rejuvenation is difficult-to-verify given the distance of elliptical galaxies.

Similar and Related Phenomena. Discordant binaries (AOF14)

Examples

X1. General observations. Elliptical galaxies contain little of the dust and gas that combine to form hot, new stars. In these galaxies, star formation is thought to have ceased long ago. Consequently, ellipticals should emit little of the ultraviolet light characteristic of hot, young stars.

"However, the International Ultraviolet Explorer satellite has found that all elliptical galaxies produce some UV light---and in some cases, the strength of the radiation increases as we go to the very short UV, shorter than a wavelength of 250 nm.

There has been no adequate explanation for these surprising results. One possibility is that as the stars change from dwarfs to giants, they spend a long period as fairly compact and hot stars---in astronomers' jargon, 'blue horizontal branch stars'. We see some such stars in old star clusters in our Galaxy, but the stars in an elliptical galaxy would have to evolve in an unexplained fashion to produce so many blue horizontal branch stars."

Another proposal is that the ultraviolet light comes from stars that have been rejuvenated by matter torn from their companion stars, especially from red giants in double star systems. (R1)

References

R1. "Why Elliptical Galaxies Produce UV Light," New Scientist, p. 23, February 23, 1984. (X1)

AWF7 Anomalous Radio Pulses from Galaxies

Description. Powerful pulses of radio energy emitted from galaxies. Since these pulses exhibit rapid changes in dispersion, their source(s) is in doubt.

Data Evaluation. One study of a single galaxy using a technique based on interstellar dispersion. Replication needed. Rating: 3.

Anomaly Evaluation. The characteristics of the pulses are consistent with radiation that would be emitted from a group of "hot spots" situated on the rotating accretion disk of a black hole. This sounds like a reasonable explanation, but we are not sure yet that black holes really do exist. Until then, we have to consider this phenomenon mildly anomalous. Rating: 3.

Possible Explanations. See above.

Similar and Related Phenomena. None.

Examples

X1. M87, a galaxy in the Virgo cluster. Using the 305-meter Arecibo radio telescope, I.R. Linscott and J.W. Erkes discovered that M87 pulses at radio frequencies. "The pulses come approximately every 50 ms, each lasts a few milliseconds and contains about 10^{30} joules of energy---a thousand million times more energy than an ordinary pulsar. The new technique also revealed a wide range of dispersion from pulse to pulse, and all much higher than can be accounted for from material in our own Galaxy alone. Linscott and Erkes say that no single source of radiation can possibly explain the rapid fluctuations in dispersion measured. They believe they are seeing an 'ensemble' of sources, each popping off independently of the rest and seen through differing amounts of gas." (R1; R2)

References

R1. "Radio Pulses May Close the Universe," New Scientist, 86:394, 1980. (X1)

R2. Linscott, I.R., and Erkes, J.W.; "Discovery of Millisecond Radio Bursts from M87," Astrophysical Journal, 236: L109, 1980. (X1)

AWF8 Quantization of Galaxy Redshift Differences

Description. The clumping of galactic redshift differences at multiples and submultiples of about 72 kilometers per second. This phenomenon was initially found in galactic clusters, but it appears to extend to other groupings of celestial objects.

Data Evaluation. A massive quantity of data has been accumulated for galactic clusters, galaxy pairs, stars, and other objects, primarily by W.G. Tifft and his colleagues. Although the catalogs of data on galaxies is not suspect, the analysis of these data in a way that supports redshift quantization has not been well-received. Supporting studies by other astronomers would generate more confidence in the reality of this phenomenon. Rating: ?.

Anomaly Evaluation. Redshift quantization is an anomaly of the highest order. The implications are profoud: the expanding universe is contradicted and the formation of galaxies by gravitational attraction is denied. Quantized states of galaxies are predicted, as are different states of matter. Much of our astronomical edifice is at risk here. Rating: 1.

Possible Explanations. Redshift quantization might be an artifact in the data due to the way it is processed, but this now seems unlikely, given the large collection available. Basically, there are no explanations for redshift quantization given present astronomical and physical concepts.

Similar and Related Phenomena. Nondoppler redshifts (ATF11); stellar redshift quantization (AOF18); quasar redshift quantization (AQF2).

Examples

X0. Introduction. The thought that the redshifts of some celestial objects might be quantized did not begin with galaxies. As far back as 1968, G.R. Burbidge suggested that quasar redshifts might be quantized. See AQF2 for details.

X1. The Coma cluster. In AWB1, the so-called "missing mass" problem was mentioned in connection with the surprisingly high internal velocities of galaxies in clusters. Unless there is some missing mass to hold these clusters together, they will fly apart. "This is totally inconsistent with theories of galaxy and cluster formation as such configurations are supposed to have formed by self-gravitation, in which case they must initially been contracting rather than expanding systems. The clusters are therefore assumed to be stable, and a good deal of theoretical effort has gone into devising other sources of matter to help bind the cluster. As these efforts have so far been unsuccessful, it is only fair to question whether the galaxy redshifts really do correspond to internal velocities.

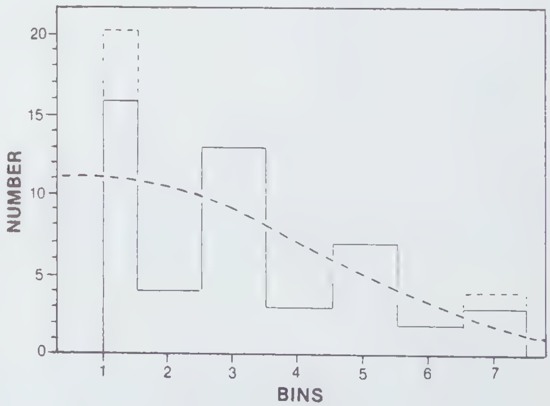
(W. G.) Tifft formulated such questioning from a consideration of the redshift-magnitude plot for galaxies within clusters. If redshifts are attributed to internal velocities, there should be no correlation between redshift and magnitude. But Tifft found a correlation, primarily in the Coma cluster, that was evidenced by a few parallel groupings of points that tended toward higher redshifts with fainter magnitudes. There was no such trend for the entire assemblage of points, only subgrouping of the points into these bands..... Tifft was convinced that these bands were real correlations arising from some unknown physical cause with profound consequences..... Most of Tifft's effort has gone into demonstrating that the bands are something other than statistical freaks and that the properties of the Coma cluster bands can be related to other galaxies and even quasars. All of this implies that redshift has nothing to do with distance for any galaxy and that we cannot use any redshifts to demonstrate an expanding universe. Tifft therefore threw a substantially larger wrench into the works than did Burbidge or even Arp, who really only worried about quasars and a few selected galaxies." (R1) This introduction to the work of Tifft by D. W. Weedman is from an extensive paper demonstrating that redshifts are assuredly cosmological after all; i.e., valid distance yardsticks.

Weedman subsequently checked the Coma cluster using different magnitude measurements than Tifft, expecting that the redshift quantization might disappear. It did not. "The results were about the same as Tifft's; my magnitude-redshift diagram looked much like his although the bands weren't any better defined and seemed a little fuzzier. There was no question but that the Coma bands were still there, although the new data were no help in deciding if they were physically real rather than statistical accidents." (R1; R13, R14) Weedman then decided to examine another cluster, Perseus. See X2 following.

X2. The Perseus cluster. "The next obvious thing to do was to check out another cluster, and I chose the Perseus cluster because it, like Coma, is dominated by compact elliptical galaxies and had a lot of measured redshifts. The Perseus results were inconclusive as they showed no bands comparable to those in Coma. Finally, I obtains nuclear magnitude measures in a total of nine clusters of galaxies and put them all together to see if nuclear magnitudes in general behaved the same as the total galactic magnitudes used by Hubble and Sandage to demonstrate the redshift distance relation. They did, so I concluded that there was no further evidence beyond the Coma bands for redshift anomalies associated with the nuclei of conventional cluster galaxies." (R1; R14)

X3. Emission-line galaxies. R. F. Green and D. O. Richstone searched for peaks and periodicities in the redshifts of quasars and emission-line galaxies. They concluded "...that the observed redshift distribution is consistent with a random sample of discrete values from a smooth, aperiodic underlying population." (R2) Another negative study.

X4. Galaxy pairs and groups. From the Abstract. "In this paper, galaxies in pairs and groups are shown to manifest no evidence of gravitational interaction. Redshift differentials between pairs of galaxies and between galaxies in clusters are found to take on preferred values which are various multiples of a basic 72.5 km s^{-1}. There is also direct evidence that the redshift periodicity phases together between groups to imply that there is no large-scale motion between clusters of galaxies." (R3)



Redshift differences for double galaxies, from the work of S. Peterson. Galaxies are counted in bins 36 kilometers per second wide. Every other bin centers on multiples of 72 km/sec. (X4)

Groups of galaxies: radio data. "Abstract. Radio data (21 cm) on the redshifts of galaxies in small groups are analyzed for the previously reported 72 km s^{-1} quantization. The redshift differentials definitely clump about multiple of 72 km s^{-1}, at a confidence level of 99.5%. The detailed deviations of the data from exact quantization are discussed in terms of the superposition of redshift states." (R7)

X5. M82, an active galaxy. "The redshift pattern in M82 is shown to be consistent with the multiple-redshift concept, as are redshift differentials in other active objects. The presence of multiple-redshift states and the general lack, therefore, of violent motion appear consistent with all types of galaxies." (R4)

X6 Double galaxies. "Abstract. An improved sample of 31 double galaxies with accurate radio redshifts is defined and analyzed for the 72 km s^{-1} discrete redshift interval effect. The effect is present at the 99.8% confidence level. Some doubles show significant deviations from the principal peaks and are consistent with a population of small peaks midway between (i.e., at 36 km s^{-1} intervals." (R6)

Later, W.G. Tifft found the 72 km s^{-1} periodicity in 200 galaxy pairs, at or above the 99% confidence level. (R8)

X7. Generalization of the redshift quantization phenomenon: theory. "Abstract. A consistent 3-dimensional form of a preliminary theory of extragalactic redshift quantization is developed. The results are applied to the dynamics of an isolated galaxy component, by means of a Schroedinger equation. The interpretation of the wave function is discussed, and it is possible to associate the coefficients of the expansion of a wave function in terms of redshift eigenfunctions with observed redshift components...." (R11)

X8. General observations. After reviewing data supporting redshift quantization, W.G. Tifft made these comments: "The immediate implications of the presence of the discrete pattern are (1) distinct limitations on real motion, and (2) the necessity to give properties to matter such that the multiple redshift can arise, i.e., 'multiple states of matter.' The secondary conclusion that follows from the limitations of motion is that there must be limitations on the forces between (and within) galaxies, hence noninteraction of galaxies and perhaps unknown forces between states. Finally, the simple existence of the Hubble law plus the stellar effects implies that transitions of matter can occur between states." Tifft notes that redshift quantization is inconsistent with the concept of an expanding universe and also the evolution of galaxies by collapse. (R4)

J. Gribbin, reviewing the work of Tifft and others on redshift quantization has this to say: "This rather startling indication that the redshifts of galaxies are quantised, rather like the atomic spectral lines by which the redshifts themselves are measured, has a pedigree that goes back more than 10 years. Since 1972, W.G. Tifft, of the University of Arizona, has been producing evidence for the redshift quantisation from analyses of various catalogues of galaxy redshifts and, as his collection of data has mounted, this idea, unpalatable though it seemed at first, has become steadily more respectable. It has not taken the astronomical world by storm, and even Tifft has no definite idea why the redshifts should be grouped like this. But it is no longer possible to dismiss the evidence out of hand." Noting how important the redshift-distance formula is to astronomy, Gribbin continues: "So any suggestion that the simple interpretation of the redshift might be wrong, or at least incomplete, sends shivers down the spines of conventional cosmologists. But just suppose, Tifft argued in the mid-1970s, that the redshift is somehow an intrinsic property of a galaxy that is not related to expansion velocity at all (and, he also pointed out, it could still be related to distance even if it is not caused by expansion). If it is an intrinsic property of galaxies then the redshift might take up preferred states, like the quantized energy levels within an atom." (R12)

References

R1. Weedman, Daniel W.; "Seyfert Galaxies, Quasars and Redshifts," Royal Astronomical Society, Quarterly Journal, 17:227, 1976. (X1, X2)

R2. Green, Richard F., and Richstone, Douglas O.; "On the Reality of Periodicities in the Redshift Distribution of Emission-Line Objects," Astrophysical Journal, 208:639, 1976. (X3)

R3. Tifft, William G.; "Discrete States of Redshift and Galaxy Dynamics. II. Systems of Galaxies," Astrophysical Journal, 211:31, 1977. (X4)

R4. Tifft, W.G.; "Discrete States of Redshift and Galaxy Dynamics. III. Abnormal Galaxies and Stars," Astrophysical Journal, 211:377, 1977. (X5, X8)

R5. Tifft, W.G.; "Periodicity in the Redshift

Intervals for Double Galaxies," Astrophysical Journal, 236:70, 1980. (X6)
R6. Tifft, W.G.; "Quantum Effects in the Redshift Intervals for Double Galaxies," Astrophysical Journal, 257:442, 1982. (X6)
R7. Cocke, W.J., and Tifft, W.G.; "Redshift Quantization in Compact Groups of Galaxies," Astrophysical Journal, 268: 56, 1983. (X4)
R8. Tifft, W.G.; "Double Galaxy Investigations. II. The Redshift Periodicity in Optically Observed Pairs," Astrophysical Journal, 262:44, 1982. (X6)
R9. Gribbin, John; "Quantized Quasars and a Spinning Universe," New Scientist, 100: 526, 1983. (X8)
R10. Tifft, W.G., and Cocke, W.J.; "Global Redshift Quantization," Astrophysical Journal, 287:492, 1984. (X7)
R11. Cocke, W.J.; "Theory and Interpretation of Quantized Extragalactic Redshifts," Astrophysical Journal, 288:22, 1985. (X7)
R12. Gribbin, John; "Galaxy Red Shifts Come in Clumps," New Scientist, p. 20, June 20, 1985. (X8)
R13. Tifft, W.G.; "The Correlation of Redshift with Magnitude and Morphology in the Coma Cluster," Astrophysical Journal, 175:613, 1972. (X1)
R14. Weedman, Daniel W.; "Nuclear Magnitudes for Galaxies in the Coma and Perseus Clusters," Astrophysical Journal, 195:587, 1975. (X1, X2)
R15. Tifft, William G.; "Discrete States of Redshift and Galaxy Dynamics. I. Internal Motions in Single Galaxies," Astrophysical Journal, 206:38, 1976. (X4)

AWF9 Cluster Spiral Galaxies Have Higher Redshifts Than Ellipticals

Description. The generally higher redshifts of spiral galaxies residing in clusters than the elliptical galaxies in the same clusters. Since all of the galaxies in a cluster are roughly equidistant, this systematic redshift difference is a puzzle.

Data Evaluation. All we have is a general statement that this systematic difference has been remarked by several astronomers. More specific data are needed here. Rating: 2.

Anomaly Evaluation. The implication of this phenomenon is that redshifts, or a portion of them, are innate properties of galactic types and not entirely cosmological. Rating 1.

Possible Explanations. None.

Similar and Related Phenomena. The possible quantization of redshifts as an expression of the different "states" of a galaxy (AWF8); apparently related galaxies with discordant redshifts (AWB7).

Examples

X1. General observations. "In clusters of galaxies the spirals tend to have higher redshifts than the E (elliptical) galaxies." (R1)

"It is shown that E, SO and Sa galaxies have excessive negative and Sb and Sc ones excessive positive residual redshifts. At the same time, for the latter there were several statistically significant correlations between the redshift and other parameters. The result means that in some part even for normal galaxies, of late Hubble types, with small colour indices and small inclinations, part of the redshift cannot be explained by systematic velocity." (R2)

"A reexamination of the galaxy redshift data in the Virgo I cluster reveals that the mean velocity of the (S) component is significantly higher than that for the (E/L) component." (R3) In the above S refers to spirals, and E to ellipticals.

References

R1. Arp, Halton; "Three New Cases of Gal-

axies with Large Discrepant Redshifts," Astrophysical Journal, 230:469, 1980. (X1)
R2. Jaakkola, Toivo; "On the Redshifts of Galaxies," Nature, 234:534, 1971. (X1)
R3. Sulentic, Jack W.; "Redshifts in the Virgo Cluster," Astrophysical Journal, 211:L59, 1977. (X1)

AWF10 Apparent Velocity Dispersion in Lines of Galaxies

Description. The large velocity differences (redshift differences) among the galaxies comprising the remarkable lines of galaxies seeming to emanate from radio sources. A paradox arises because the galaxies in the lines are reckoned to be about 10 billion years old, but their different velocities should have dispersed them in only 100 million years. Either the galaxies are very young or the redshifts are not cosmological.

Data Evaluation. Evidently this is a well-recorded phenomenon, although we have so far found only passing references to it. Rating: 2.

Anomaly Evaluation. The paradox defined above cannot be resolved without altering the age of the universe or the redshift-distance relationship. Rating: 1.

Possible Explanations. Lines of galaxies, "apparently ejected" from radio sources, might be just chance alignments. Unfortunately, these lines seem to be a general phenomenon and well beyond the realm of chance.

Similar and Related Phenomena. Lines of galaxies supposedly ejected from radio sources (AWB10); the high velocities of galaxies in clusters (the "missing mass" problem)(AWB1); the many other challenges to the cosmological nature of the redshift; viz., AQB1, AQB6, AQF2, AQF5, AQO3, AWB7, AWF8, AWB9.

Examples

X1. General observations following a discussion of lines of galaxies associated with radio sources. "The consideration of age brings us to our most formidable problem. Most of the galaxies involved in the lines presented here are E galaxies or allied classifications. They are supposed to be almost totally composed of stars of the order of 10^{10} years of age. The dispersions of the redshifts of galaxies in these lines, however, indicates velocity differences of thousands of km/sec. Now a velocity of 10^3 km/sec amounts to a displacement of 10^7 pc in 10^{10} years. Displacements of more than 1/100 of this would lead to disruption of the linear configurations which are observed in the present paper. (This is related to the paradox pointed out by Ambartsumian; namely, that the redshifts in tight clusters of E galaxies and in the M81 group indicate that these E galaxies and the radio galaxy M82 have ages only of the order of 10^8 years.) Therefore we are faced with either accepting that the galaxies in the lines considered here are only of the order of 10^8 years old or discarding the interpretation that all the redshift is due only to Doppler velocities." (R1)

References

R1. Arp, Halton; "Lines of Galaxies from Radio Sources," Astronomical Society of the Pacific, Publications, 80:129, 1968. (X1)

AWF11 Blueshifted Extragalactic Objects

Description. Extragalactic objects, possibly galaxies, with blueshifts rather than the usual redshifts.

Data Evaluation. While the measurement of the blueshift itself is probably reliable, we have only one extragalactic object on record so far with a blueshift. The nature of this object is uncertain; it could be a gas cloud, a galaxy, or something else. In this sense the data are deficient. Rating: 3.

Anomaly Evaluation. A single extragalactic object with a blueshift cannot be considered anomalous. Even if this object is actually a galaxy---the only blueshifted one---one can always explain it in terms of gravitational slingshot action in a nearby cluster of galaxies, or by some other rare but reasonable effect. But, since blueshifted extragalactic objects are exceedingly rare, it is worthwhile cataloging it. Rating: 4.

Possible Explanations. A high-velocity gas cloud; an aberrant galaxy expelled from a cluster.

Similar and Related Phenomena. None.

Examples

X1. IC 3258. "Abstract. Observations of IC 3258 show it to have an emission-line spectrum with a blueshift of -490 km sec^{-1}. If it is in the Virgo cluster, it has a high velocity relative to the average for the cluster (it might possibly be a large gas cloud ejected from the radio galaxies M84 or M87). If it is a foreground galaxy, it is a low-luminosity dwarf with a large random velocity." (R1)

References

R1. Burbidge, E.M., and Demoulin, M.H.; "IC 3258, a Small Extragalactic Object with a Blueshift," Astrophysical Journal, 157:L155, 1969. (X1)

AWO MORPHOLOGY AND STRUCTURE OF GALAXIES

Key to Phenomena

AWO0 Introduction

The most-often illustrated galaxy is the beautiful spiral in Andromeda. It certainly looks like a stately island universe splendidly isolated in space. Astronomers are wont to imply that we know all about this classic galaxy in Andromeda. In truth, we do not know how it originated or even why it has a whirlpool appearance. Things get worse when we examine other galaxies. Many are barred, clumpy, have warped edges, or are just plain "irregular". Other galaxies are surrounded by mysterious rings and halos of matter. These spiral galaxies are the source of many anomalies in this section.

Surely the other major class of galaxies, the great ellipticals, will be easier to account for, if only because they seem rather featureless externally. Closer examination, however, reveals that the ellipticals have suspicious associations with long lines of spirals and often sit solitary amid clusters of spirals, almost as if they were the progenitors of the spirals. In addition, elliptical galaxies eject jets of matter, which seem to connect with immense radio galaxies on either side. They also seem to expel concentric shells of stars from alternate ends of their ovate structure. Somewhere inside the benign facades of the ellipticals there may be prodigious generative forces at work.

AWO1 Galactic Jets

Description. Luminous structures, usually linear, emanating from galactic nuclei. Galactic jets are very common in radio galaxies, where they are aligned with the radio-emitting lobes. Some jets display knots or bright regions at regular intervals. Most are straight, but twisted and "dogleg" varieties exist. Jets often occur in oppositely directed pairs (bipolar jets), but many others are single. It is not known for certain that the matter in the jets is in outward motion, although it certainly "looks" that way.

Data Evaluation. Galactic jets are very common and have been under observation for decades. Rating: 1.

Anomaly Evaluation. Jets seem ubiquitous in astronomy, being associated with galaxies, quasars, and even young stars. There is at present no consensus as to how the jets get their energy and how they are collimated. However, it seems doubtful that either of these considerations really constitute serious challenges to astronomical theory. Our rating is based on this fact. One potential implication of galactic jets, however, could be extremely important; do these structures play an important role in the creation of stars within galaxies? Rating: 2.

Possible Explanations. In an almost automatic reaction, astronomers attribute galactic jets to the activity around black holes in galactic nuclei. A few astronomers, though, favor the gravitational slingshot explusion of matter and the thermodynamic expansion of gas and plasma through magnetic nozzles.

Similar and Related Phenomena. Quasar jets (AQO2); stellar jets (AOO6); nebular jets (AOO2).

Examples

X1. NGC 1097, a barred spiral galaxy. "For many years Halton Arp has been trying to convince his fellow astronomers that perfectly normal galaxies are in the habit of ejecting sizable objects---perhaps even quasars---into intergalactic space. On the whole he has not succeeded. But now he presents some prize specimens which, if not very sizable, have evidently been ejected from the nucleus of an archetypally normal spiral galaxy, called NGC 1097." (R1)

From Arp's Abstract: "Luminous features pointing at the spiral galaxy NGC 1097 were discovered with the U.K. 48 inch (1.2 m) Schmidt telescope. A series of deep, high resolution photographs have now been taken with the 4 meter CTIO reflector in Chile. These plates show (1) three luminous jets, two of which are aligned in exactly opposite directions, and all of which emanate from the center of NGC 1097; (2) that where the jets pass through the spiral arms of NGC 1097, they disrupt the gaseous component of those arms." The jets seem to be 10^7 years of age, with an ejection velocity of 5,000 kilometers per second or higher, and composed of some compact bodies and plasma. (R2)

"How could the nucleus of NGC 1097---which looks fairly innocuous now---have produced these jets? If they really do lie in the plane of the galaxy, then most of the current ejection models will not do, because they are designed for radio galaxies---which probably spurt out their symmetrical radio lobes each way along the rotational axis, not along the equator. But there is one process which does eject things in the equatorial plane. This is the gravitational slingshot, in which colossal superstars in the nucleus fling each other out as they pass in a near-collision." (R1)

Other speculations: "Summary. We have measured the surface brightness of the broad 'dog-leg jet' which appears to be associated with the bright barred spiral galaxy NGC 1097, in the B, R, J and H wavebands. The colours of the jet, together with published radio upper limits, appear to rule out both synchrotron and thermal Bremsstrahlung as the source of the emission. We suggest that the optical emission comes from stars near type G. The most promising explanation of this feature is that it is a tidal remnant; alternatively it might consist of stars formed from cooling plasma in a jet." (R12)

X2. M87, a giant elliptical galaxy in Virgo. "The galaxy M87 has several features which point to a large invisible mass lurking in the nucleus. First there's the famous jet, a streamer of electric blue light, that has been shot out of the nucleus. Secondly, the galaxy is anomalously energetic, pumping out 10^{35}

watts more than it should be. Finally, radio astronomers have located minute centres of activity, some only a dozen light weeks across. It all adds up to a scenario of excessive energy generation in a very compact region." (R5)

"The jet-like feature in the centre of M87 has been known for 60 yr. The term 'jet' was originally just a descriptive one. There is now mounting evidence, however, that continuous collimated outflow is a characteristic property of active galactic nuclei; indeed, the M87 jet may delineate a channel along which power from the nucleus is fed into the more extended radio structure. This note suggests how the remarkable optical and radio structure can be interpreted on this basis.

The jet of M87. (X2) (Hale Observatories)

The optical jet has an angular extent of ~20 arcsec, corresponding to a projected length of ~1500 pc. The light comes primarily from a rather regularly spaced series of bright 'knots', which may be unresolved, implying individual dimensions $\lesssim$ 25 pc. The blue continuum is polarized, indicating synchrotron-type radiation; the luminosity of the strong 'knots' is a few times 10^{42} erg/s. There is a corresponding jet-like feature in the radio band. However, although the optical 'knots' stand out as regions of high radio surface brightness, the radio emission is much smoother than the optical, and extends almost twice as far as the detectable optical jet. A very small ($\lesssim 10^{-3}$ arcsec) radio source coincides with the nucleus of M87. Whereas the remarkable optical jet has no counterpart on the opposite side of the nucleus, there is a radio component of comparable overall flux density and extent (~40 arcsec) on the opposite Sf side.". (R3)

D. H. Smith remarks that M87's jet has knots that are extremely regular, with gaps 600 light-years wide between them. There has also been a more or less consistent reduction in the jet's brightness between 1956 and 1980. In less than 30 years, the whole jet has faded by at least 2.5 magnitudes. (R24)

X3. NGC 6251, a radio galaxy. "The most striking feature is a jet of matter that seems to be emerging from the nucleus. The axis of this jet lies along the same line as the axis of two large radio-emitting lobes that lie outside the visible part of NGC 6251 on either side of the galaxy. It seems likely that this jet in the nucleus and the two large lobes that lie in the same line are produced by one and the same phenomenon, something in the center of the galaxy that pumps out matter along that line." (R4) Speculation follows concerning the possibility of a black hole being the energy source. However, other astronomers favor a gravitational slingshot source. (R6)

X4. 3C449. "This is the radio source associated with a giant elliptical galaxy having a redshift of 5,400 km s^{-1}. The radio galaxy is typical of its class and has large outer radio lobes extending to 160 kiloparsecs on each side of the galaxy. What is particularly evident from the new results is the dominance of an inner jet structure lying symmetrically on either side of an unresolved nuclear source. These jets show a constant opening angle of about 7^{o} which is most readily interpreted as arising from fast radial outward flow of emitting plasma in which there is also a transverse flow representing expansion at the speed of sound in the medium. A consistent picture emerges with a radial flow of about 1000 km s^{-1} which leads to a lifetime of 10^{7} years for the bright inner jets." (R7)

X5. 3C348, known also as Hercules A. This is a very bright radio galaxy identified with a visible galaxy of magnitude 18.5. Detailed mapping of 3C348 with the VLA (Very Large Array) led to the discovery of its curious jet structure. "Her A possesses an unusual jet-dominated morphology instead of the Cygnus-A-like morphology expected for such a powerful radio source. Its two jets are quite different in appearance; one appears to be a continuous twisting jet, while the other suggests repeated ejection of individual plasmons by the central object. The presence of such different morphologies in the same source raises interesting questions concerning the generation and evolution of extended extragalactic radio sources. Variations in the central engine provide the simplest interpretation for some of the features of this object; the role of environmental effects is less clear." (R13)

X6. NGC 3310, a spiral galaxy in Ursa Major with "exotic" jets. "...this system contains a more or less linear chain of bright regions connected by a continuous component---the 'jet'---as well as unusual bright arcs and rings having intense emission lines in their spectra. The jet, which begins some distance from the nucleus, appears to be a beam coming directly from the galaxy's center. It spans 85 arc seconds, corresponding to a length of about 13,000 light-years at a distance of roughly 30 million light-years." The jet is thought to be the consequence of a violent, one-sided explosion in the galaxy's nucleus. (R18)

X7. NGC 541, an elliptical galaxy connected via a jet to Minkowski's object, both in Cetus. Minkowski's object seems to be an irregular galaxy displaying a violent burst of star formation stimulated by the impinging jet from NGC 541. The brilliant blue color of Minkowski's object leads astronomers to speculate that it consists of hundreds of thousands of new stars, some 100 times the mass of the sun. "The stars are apparently formed when the jet stream collides with the clouds of gas containing hydrogen, helium, carbon and other elements. The jet of high-energy matter compresses the clouds and causes them to collapse, eventually igniting their hydrogen fuel---they are about 60 per cent hydrogen. The phenomenon, according to the astronomers, occurs over a vast area ---about 20,000 light years, a distance roughly equivalent to the diameter of the jet." (R26; R21, R23)

X8. 3C 75, a double galaxy, about 20,000 light years apart, orbiting each other. Each galaxy emits two jets. Each pair of jets seems to interbraid, rather than being straight like most other galactic jets. (R22, R25)

X9. General observations: a summary.

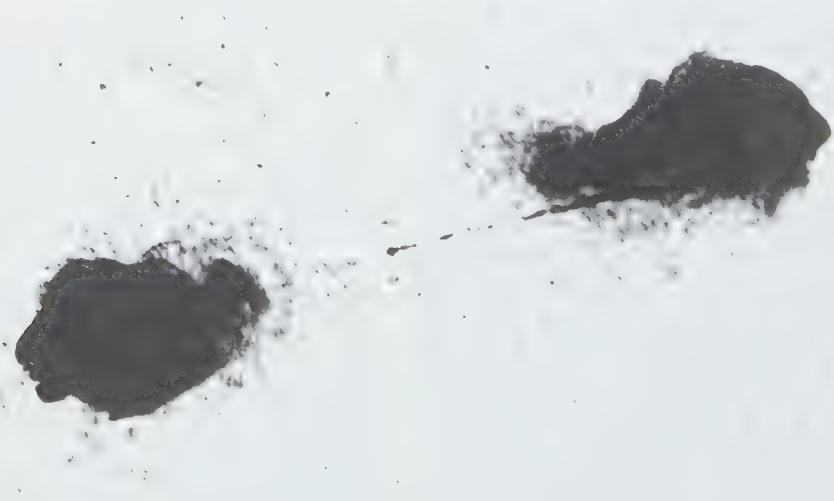
---Morphology. Most jets are straight, although a few are twisted. Some jets have bright knots equidistant from one another. Many jets are two-sided (bipolar), but one-sided jets are not uncommon. There is some evidence that two-sided jets are activated alternately, in a flip-flop mode. (R16, R19)

---Relation to radio structures. "Observations now require that there be a continuous supply of energy to the giant extragalactic radio sources. These observations also suggest that this energy input may be in the form of streams or jets of gas emanating from the centers of galaxies and quasi-stellar objects." (R14)

---Relation to star formation. Jets may stimulate widespread star creation. (X7)

---Frequency of occurrence. Jets are very common, being found associated with about 60% of nearby radio galaxies. (R9)

X10. M89. "An optical jet, extending 10 arc min from the elliptical galaxy M89 (NGC4552)



Cygnus A, the tiny spot in the center, is connected by jets to two giant radio lobes.

is reported here. Two low surface brightness shells partly surround the galaxy and a much fainter arc, 13 arc min away has also been detected. The jet was found on five deep plates of the Virgo cluster obtained by the 1.2-m UK Schmidt Telescope." (R27)

References

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R2. Arp, Halton; "Ejection from the Spiral Galaxy NGC 1097," Astrophysical Journal, 207:L147, 1976. (X1)
R3. Rees, M.J.; "The M87 Jet: Internal Shocks in a Plasma Beam?" Royal Astronomical Society, Monthly Notices, 184: 61P, 1978. (X2)
R4. "A Jet Black Hole in a Radio Galaxy," Science News, 113:180, 1978. (X3)
R5. "Black Hole in Nucleus of Giant Galaxy," New Scientist, 78:84, 1978. (X2)
R6. Valtonen, M.J.; "Brightness and Shape of Radio Jets," Astrophysical Journal, 227:L79, 1979. (X3)
R7. Davies, R.D.; "Jets in Radio Galaxies," Nature, 281:630, 1979. (X2, X4)
R8. Hardee, Philip E., "On the Configuration and Propagation of Jets in Extragalactic Radio Sources," Astrophysical Journal, 234:47, 1979.
R9. Elvis, Martin, and Wilson, Andrew S.; "Active Galaxies: Dragon Hunting in Arizona," Nature, 290:10, 1981. (X9)
R10. Scheuer, Peter; "Extragalactic Jets: Facts and Fancies," Nature, 293:336, 1981. (X9)
R11. Hardee, Philip E.; "The Jet in M87," Astrophysical Journal, 261:457, 1982. (X2)
R12. Carter, D., et al; "The Jets in NGC 1097," Royal Astronomical Society, Monthly Notices, 211:707, 1984. (X1)
R13. Dreher, J.W., and Feigelson, Eric D.; "Rings and Wiggles in Hercules A," Nature, 308:43, 1984. (X5)
R14. De Young, David S.; "Jets in Extragalactic Radio Sources," Science, 225: 677, 1984. (X9)
R15. Henbest, Nigel; "Rings and Wriggly Jets Tell More about Radio Galaxies," New Scientist, p. 22, March 22, 1984.
R16. Rudnick, L., and Edgar, B.K.; "Alternating-Side Ejection in Extragalactic Radio Sources," Astrophysical Journal, 279:74, 1984. (X9)
R17. Bridle, Alan H., and Perley, Richard A.; "Extragalactic Radio Jets," Annual Review of Astronomy and Astrophysics, 22:319, 1984. (X9)
R18. Schorn, Ronald A.; "Galactic Jets: Two Exotic Cases," Sky and Telescope, 68:410, 1984. (X6)
R19. "Flip-Flop Radio Jets?" Sky and Telescope, 68:506, 1984. (X9)
R20. Larson, Dewey B.; "Pre-Quasar Phenomena," The Universe of Motion, Portland, 1984, p. 373. (X2)
R21. "Minkowski's Object---A Jet Hits the Jackpot," Sky and Telescope, 70:548, 1985. (X7)
R22. Thomsen, D.E.; "Two Centers Yoked Together in One Galaxy," Science News, 127:52, 1985. (X8)
R23. "Minkowski's Jet," Scientific American, 252:70, March 1985. (X7)
R24. Smith, David H.; "Mysteries of Cosmic Jets," Sky and Telescope, 69:213, 1985. (X2)
R25. Hecht, Jeff; "Astronomers Puzzled by Cosmic Twisters," New Scientist, p. 19, February 21, 1985. (X8)
R26. Anderson, Ian; "A New Way to Make Galaxies," New Scientist, p. 19, January 10, 1985. (X7)
R27. Malin, David F.; "A Jet Associated with M89," Nature, 277:279, 1979. (R27)

AWO2 Radio-Luminous Rings Associated with Galaxies

Description. Stacked rings of matter, radio-bright, and coaxial with galaxies. These rings "appear" to be ejected from the galaxies like "smoke rings"!

Data Evaluation. Only one example has been found to date. The radio telescope data, however, are considered very reliable. Rating: 2.

Anomaly Evaluation. The phenomenon is rare and difficult to evaluate. We cannot tell if the rings have been expelled by the galaxy or just something left over after galaxy formation. Even though no theories seem to explain them, the rings seem only minor galactic structures and pose no serious challenges to astronomical theory. Rating: 2.

Possible Explanations. None.

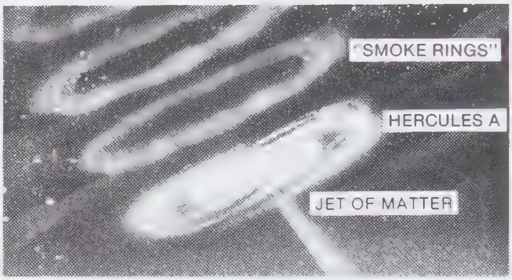
Similar and Related Phenomena. Galactic halos (AWO11); galactic jets (AWO1).

Examples

X1. 3C348, a bright radio galaxy also known as Hercules A. "Astronomers studying a distant galaxy have discovered a puzzling feature never seen before---a system of giant rings, each larger than our Milky Way, apparently being puffed out of one side of the galaxy. On the other side, the galaxy is emitting a twisting jet of hot matter. Such jets are not uncommon in radio galaxies, but this is the first time giant rings have been observed." (R1) The rings are thought to be composed of subatomic particles that are glowing with radio energy. (R2)

References

R1. "Giant Rings from Hercules A," Astronomy, 12:62, October 1984. (X1)
R2. "Galaxy Puffs Rings: Astronomers Baffled," Science Digest, 92:85, October 1984. (X1)



Radio-luminous rings associated with the galaxy Hercules A. Note the jet below. (X1)

AWO3 Radio-luminous Threads inside Galaxies

Description. Long, narrow threads of matter in the central regions of galaxies detected by radio telescopes.

Data Evaluation. The luminous threads have been discerned only in our own galaxy and, even here, they are difficult-to-observe. Their distance and constitution are unknown. Rating: 3.

Anomaly Evaluation. The constitution and origin of the threads are mysteries. They may be composed of stars or gas. But like the galactic rings (AWO2) they are probably not serious anomalies. Rating: 2.

Possible Explanations. Shock waves and jets have been suggested.

Similar and Related Phenomena. The galactic filaments that seem to trace out the galactic magnetic field (AWZ1).

Examples

X1. Milky Way radio surveys. "Finally, there are the central region's most mysterious new features, which (M.) Morris and (F.) Yusef-Zadeh have dubbed 'threads'. The name is apt. The threads---there are at least three of them---are more than 30 parsecs long and less than 0.5 parsec wide. They are dim, gently curved, and quite smooth. And they differ from the filaments of the arc in that they are isolated. Indeed, although they do not appear to cross the arc, they are not obviously associated with anything else in the region." The 'arc' mentioned consists of thin, parallel filaments that appear to be organized by a galactic magnetic field (AWZ). The 'threads' do not seem to be shock fronts or jets. (R1; R2)

References

R1. Waldrop, M. Mitchell; "New Mysteries at the Galactic Center," Science, 230:652, 1985. (X1)

R2. Morris, Mark, and Yusef-Zadeg, F.; "Unusual Threads of Radio Emission near the Galactic Center," Astronomical Journal, 90:2511, 1985. (X1)

AWO4 Bridges and Tails Connecting Galaxies

Description. Streams of material emanating from one galaxy leading to an adjacent galaxy. The bridges and tails often seem to be extensions of galactic spiral arms, and are thought to be composed of stars. These structures seem to be quite young---only 500 million years old.

Data Evaluation. Dozens of these luminous connections between pairs of apparently adjacent galaxies are recorded. Rating: 1.

Anomaly Evaluation. The bridges and tails are telling us something, but no one knows what! Are they tidal remnants of past close encounters; or do they reflect the process that created the galaxies? The apparent youth of the bridges only compounds the mystery, as does the fact that some of these "connected" pairs have radically different redshifts. Rating: 1.

Possible Explanations. Recent tidal encounters; recent ejection of matter along galactic spiral arms; recent formation of galaxies. When the paired galaxies have different redshifts, the bridges and tails are considered to be chance alignments of unrelated galaxies and their external structures.

Similar and Related Phenomena. The apparent youth of lines of galaxies associated with radio sources (AWF10); the redshift controversy, especially physically interconnected galaxy pairs with different redshifts (AWB7).

Examples

X1. General observations. "With the construction of the giant telescopes on Mt. Palomar, much fainter levels of starlight became visible. Zwicky surprised the astronomical community with the discovery of a number of close pairs of galaxies with faint streams of stars between them, tens of thousands of light-years long. Vorontsov-Velyaminov and Arp later cataloged hundreds of bizarre 'antennae,' 'tails,' 'plumes,' and 'bridges' among interacting galaxies. Even our own galaxy appeared to be interacting with the Magellanic Clouds, dwarf companion galaxies of ours, creating the long, gaseous Magellanic Stream." (R3; R4)

"Although the origin of the luminous bridges that join many galaxies is not known, one can discuss their eventual fate once their physical structure is properly understood. Recent studies by Vorontsov-Veliaminov and by Zwicky have clarified the nature of bridges. It appears that:

1. There is a similarity between intergalactic bridges and spiral arms of galaxies. The bridges often appear to be extensions of spiral arms; further, one sometimes observes galaxies condensed along bridges just as there exist galaxies condensed on spiral arms in systems of the M 51 type.

2. Among 'interacting' galaxies spectral types F0 to F5 dominate. Zwicky has noted the unusual blue color of bridges and a lack of spectral emission lines; he suggests that the bridges are populated by stars.

3. The age of the bridges is of the order of 5×10^8 yr. This can be estimated, very roughly, by dividing the (transverse) length of the bridges by the difference in (radial)

recession velocities of the parent galaxies." (R1) See AWF10 concerning the age of galaxies in lines associated with radio galaxies.

X2. Possible explanations of bridges and tails. "This paper argues that the bridges and tails seen in some multiple galaxies are just tidal relics of close encounters." (R2)

References

R1. Hoyle, Fred, and Harwit, Martin; "On the Fate of Intergalactic Bridges," Astronomical Society of the Pacific, Publications, 74:202, 1962. (X1)

R2. Toomre, Alar, and Toomre; "Galactic Bridges and Tails," Astrophysical Journal, 178:623, 1972. (X2)

R3. Schneider, Stephen E., and Terzian, Yervant; "Between the Galaxies," American Scientist, 72:572, 1984. (X1)

R4. Zwicky, F.; "Luminous Intergalactic Matter," Astronomical Society of the Pacific, Publications, 64:242, 1952. (X1)

AWO5 Partial Shells of Stars around Elliptical Galaxies

Description. The existence of sharply defined, concentric shells of stars around elliptical galaxies. The shells may number 20 or more and are often located at great distances from the galaxy proper. The shells are partial and frequently interleaved.

Data Evaluation. Several surveys of elliptical galaxies confirm that roughly 11% of all elliptical galaxies possess these shells of stars. Rating: 1.

Anomaly Evaluation. Three reasonable explanations have been profferred (see below), reducing the (first-glance) anomalousness of this phenomenon. Rating: 3.

Possible Explanations. The shells may be ripples of stars created when a spiral galaxy falls into an elliptical galaxy. Star shells may be ejected from ellipticals or created in surrounding gas by shockwaves emanating from the elliptical galaxies.

Similar and Related Phenomena. The formation of galaxies by jets from elliptical galaxies (AWB17); the possible alternating activity of lobes associated with radio galaxies (AWO1); possible ejection of galaxies from giant ellipticals (AWB10); ring galaxies (AWO6).

Examples

X1. Early survey of normal elliptical galaxies. In 1980, D. F. Malin and D. Carter reported on their survey of 43 isolated elliptical galaxies. Abstract. "Photographic enhancement of deep IIIaJ and IIIaF plates taken with the UK Schmidt and Anglo-Australian telescopes reveals the existence of giant ellipsoidal shells within and around the envelopes of several normal elliptical galaxies. The dimensions of these features are vast; they occur at radii of up to 180 kpc (assuming $H_0 = 50$ km s^{-1} Mpc^{-1}). We report here that these features probably consist of stars and are either the result of a burst of star formation indicated by a powerful shock wave in an intergalactic medium, perhaps during the formation of the galaxies, or are old stars displaced from the nucleus by an explosive event." (R1) In X5, we shall see that the currently favored theory invokes galactic cannibalization.

X2. NGC 1344. A detailed study of one shell located 180 kpc from the center of NGC 1344, indicates that the shell is likely composed of normal stars, which are just slightly bluer than the central stars in the galaxy itself. (R2; R10)

X3. Survey of early-type galaxies. Data on 55 galaxies gathered by the Einstein X-ray satellite show that these highly luminous systems are surrounded by extensive envelopes or coronas of hot gas. Such coronas have temperatures of about 10,000,000° Kelvin and a mass equal to a billion suns. If this gas is in gravitational equilibrium, the central galaxies must be much more massive than currently estimated to hold on to all this material. (R6) Although no shell structure has been indicated, this item bears on the general phenomenon of matter surrounding galaxies. Of course, it also relates to the "missing mass" problem. (WRC)

X4. General observations. Investigations of many elliptical galaxies, using different telescopes, have confirmed the existence of concentric shells in about 11% of all ellipticals. No spiral galaxies have so far been found to have them. "The shells are generally aligned with the major axis of the galaxy, but do not completely surround it. Around a single galaxy there can be up to twenty shells, ranging over a factor of 30 in radius. Particularly intriguing is the observation that where several shells occur, they are generally interleaved, such that the next shell out in radius from the centre is on the opposite side of the nucleus. The colours of the shells are consistent with the colours of the population of stars in the galaxies, so it seems that the shells are composed of stars." The shells are sharp-edged. (R4)

Drawing of NGC 3923's shells.

"Shells have been detected around both normal (NGC 3923, NGC 1344) and abnormal ellipticals (NGC 5128, NGC 7070A) but not around spirals and very rarely around S0s. They seem to occur preferentially around galaxies in the field. The shells are presumably three-dimensional structures, since there are no examples of thin, pointy shells, as would be expected if they were intrinsically planar. They do not completely encircle the central galaxy, but rather can be described as roughly concentric arcs, which for higher ellipticity galaxies, e.g. NGC 1344 and NGC 3923, are aligned with the major axis of the galaxy. Shells are found over a large range of radii, with shell separation increasing with radius, and they are staggered or interleaved, i.e. the next outermost shell is on the opposite side of the nucleus. The total number of shells can be quite large, and they can extend to very large distances; for example, NGC 3923 has about 20 shells, the outermost about 180 kpc away from the center ($H = 50$ km s^{-1} Mpc^{-1}). The shells are bluer than the nucleus of the parent galaxy and have little luminous mass." (R8)

X5. Theories. In their 1980 paper describing the discovery of the shells, Malin and Carter suggested that they originated either when shock waves expelled from the galaxy triggered star formation or old stars were expelled from the galaxy. They discounted the possibility that the merger of a spiral with the elliptical galaxy could have created the shells because the galaxies they studied showed no color peculiarities suggesting mergers with blue galaxies. (R1)

The stellar shells around elliptical galaxies can be explained in terms of a blast wave associated with an active nucleus phase early in a galaxy's history. Multiple shells may be produced when there are repeated episodes of shell cooling and supernova heating. (R7)

Although not intuitively obvious, theoretical analysis has shown than when a disk galaxy plunges into an elliptical, concentric ripples of stars can be created---much like those actually observed. (R5, R9) Generally, this theory is now ascendant. "One lingering question is, Why do shells and rings not form around all types of galaxies?" (R8)

D.M. Greenberger has applied quantum mechanical theory to astronomical phenomena. Rather remarkably, the theory produces "suggestive but not definitive" results when applied to the shells around elliptical galaxies. (R3)

References

R1. Malin, David F., and Carter, David; "Giant Shells around Normal Elliptical Galaxies," Nature, 285:643, 1980. (X1, X5)

R2. Gilmore, Gerard; "The Nature of Galactic Shells," Nature, 295:97, 1982. (X2)

R3. Greenberger, Daniel M.; "Quantization

in the Large," Foundations of Physics, 13:903, 1983. (X5)
R4. Edmunds, M. G.; "Galaxies in Collision," Nature, 311:10, 1984. (X4)
R5. Quinn, P. J.; "On the Formation and Dynamics of Shells around Elliptical Galaxies," Astrophysical Journal, 279:596, 1984. (X5)
R6. "Hidden Mass in Elliptical Galaxies," Sky and Telescope, 70:28, 1985. (X3)
R7. Williams, R. E., and Christiansen, W. A.; "Blast Wave Formation of the Extended Stellar Shells Surrounding Elliptical Galaxies," Astrophysical Journal, 291:80, 1985. (X4, X5)
R8. Athanassoula, E., and Bosma, A.; "Shells and Rings around Galaxies," Annual Reviews of Astronomy and Astrophysics, 23:147, 1985. (X4, X5)
R9. Schweizer, Francois; "Colliding and Merging Galaxies," Science, 231:227, 1986. (X4, X5)
R10. Carter, D., et al; "Nature of the Shells of NGC1344," Nature, 295:126, 1982. (X2)

AWO6 Ring Galaxies

Description. Vast rings of stars with or without central stellar nuclei. Most ring galaxies have companion galaxies.

Data Evaluation. Although rare, ring galaxies are accepted as a class of "peculiar" galaxies. Rating: 1.

Anomaly Evaluation. Several theories exist for the formation of ring galaxies, the most prominent involving a small elliptical galaxy colliding with a disk galaxy and punching a hole out of the center. The theories are appealing but the details are sketchy and the evidence circumstantial. Rating: 3.

Possible Explanations. Collisions of disk galaxies with either small ellipticals or gas clouds. Another possibility is the expulsion of a ring of stars from a central galaxy. Generally, the explanations parallel those for elliptical galaxy shells (AWO5).

Similar and Related Phenomena. Polar rings around galaxies (AWO7); partial shells around elliptical galaxies (AWO5).

Examples

X1. Hoag's object, in the constellation Serpens. "This peculiar object, discovered in 1950 by Arthur Hoag, appears to be a halo surrounding a diffuse nucleus. Hoag remarked that although it looks like a planetary nebula (a ring of gas puffed off from a star) its color was not typical of such nebulae. Recently three astronomers studied this object more closely and agreed that it is a distant galaxy located about 500 million light-years from us. The core is about 15,000 light-years across and the ring has inner and outer diameters of 70,000 and 110,000 light-years..... Other galaxies like it are known although they are very rare. The ring is apparently shining because it consists of stars. But where this type of galaxy can fit into current theories of galaxy formation is totally mysterious."(R1)

In a later study of Hoag's object, N. Brosch ventured that the ring of stars was formed between 1 and 3 billion years ago when the dynamical forces in a lenticular galaxy with a central bar expelled the stars into a ring. (R7; R8, R9) We classify Hoag's object as a ring galaxy until its nature becomes more clear.

X2. General observations. "In a systematic analysis of this class of objects, Theys & Spiegel (R2) concentrated on the more regular-looking ring galaxies in order to ensure their true membership in this category. They distinguished RE galaxies with crisp empty rings, RN galaxies having a ring with an off-centered nucleus, and RK galaxies with a single dominant knot or condensation in their rings..... An important result, which fueled subsequent theoretical efforts, was the realization that the companion galaxy lies preferentially near the minor axis of the ring. The colors of the rings were found to be similar to those of Magellanic irregulars, and several lines of argument indicated that the masses of the ring galaxies should be of the order of 10^{11} $M_{\odot}$."(R6) Most ring galaxies have companion galaxies. (R2). Theys and Spiegel, in a dynamical study of the ring galaxies, concluded that their age should be about 10^{8} years. (R4)

X3. Theories. "Two rival schemes have been put forward to explain their origins. Both explanations involve a normal spiral galaxy, with one scheme requiring collision with an intergalactic gas cloud, and the other collision with an elliptical (by contrast with the mechanism of shell formation (AWO5), in the scheme for forming ring galaxies, the elliptical is much smaller than the disc galaxy). The critical ingredient is the gas, which is physically shocked and much of it forced over into gravitational collapse to form new stars." (R5; R2, R4, R6)

Refer to X1, where the stars forming the ring were hypothesized to have been expelled from the galaxy. (R7)

X4. Survey of the Hercules supercluster. "Four ring galaxies and two candidates have been discovered in the Hercules supercluster of galaxies by applying the photographic contrast-enhancement technique to deep IIIa-J or IIIa-F Schmidt plates. They appear to belong either to cluster halos or to a field population. IC 1194 has been found to have the largest linear diameter ($\sim$133 kpc; on the scale of H_0 = 55 km s^{-1} Mpc^{-1}) and the brightest magnitude (M_V = -22.2) so far found." This specific ring galaxy may have had a gas-free S0 galaxy as its progenitor. (R10)

References

R1. "Very Peculiar Galaxy," Astronomy, 2:60, December 1974. (X1)
R2. Theys, J.C., and Spiegel, E.A.; "Ring Galaxies, I; Astrophysical Journal, 208: 650, 1976. (X2, X3)
R3. Arp, Halton, and Madore, Barry F.; "Preliminary Results from the Catalogue of Southern Peculiar Galaxies and Associations," Royal Astronomical Society, Quarterly Journal, 18:234, 1977.
R4. Theys, J.C., and Spiegel, E.A.; "Ring Galaxies. II," Astrophysical Journal, 212:616, 1977. (X2, X3)
R5. Edmunds, M.G.; "Galaxies in Collision," Nature, 311:10, 1984. (X3)
R6. Athanassoula, E., and Bosma, A.; "Shells and Rings around Galaxies," Annual Reviews of Astronomy and Astrophysics, 23:147, 1985. (X2, X3)
R7. "Hoag's Object Revisited," Sky and Telescope, 72:126, 1986. (X1)
R8. Gribbin, John; "Nature of Hoag's Object," Nature, 250:623, 1974. (X1)
R9. O'Connell, Robert W., et al; "The Nature of Hoag's Object," Astrophysical Journal, 191:61, 1974. (X1)
R10. Wakamatsu, Ken-Ichi, et al; "Interacting Galaxies in the Hercules Supercluster of Galaxies. I. Ring Galaxies," Astronomical Journal, 92:700, 1986. (X4)

AWO7 Galaxies with Polar Rings of Material

Description. Elliptical and spiral galaxies surrounded by rings of gas, dust, and stars oriented perpendicular to the galaxy itself; i.e., the angular momentum vectors are at 90°.

Data Evaluation. Two dozen or so of these unusual galaxies have been recorded; several have been studied in detail. Rating: 1.

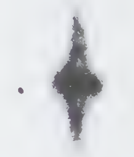
Anomaly Evaluation. The presence of two massive galactic components rotating at right angles to one another poses a dynamical problem, because the collapse of a gas cloud cannot be expected to produce such a two-component system. The two explanations suggested below are not particularly convincing because, if galaxy-galaxy collisions were the source of this phenomenon, we would expect to find the two components at angles other than 90°. Rating: 2.

Possible Explanations. As in X3 below, collapse of a gas-rich galaxy and capture of material from another galaxy during a near-collision.

Similar and Related Phenomena. Ring galaxies (AWO6); galactic tails and bridges (AWO4).

Examples

X1. AO136, the so-called "gyroscope" galaxy. This is an ordinary S0-type spiral galaxy with an incandescent ring surrounding the entire galaxy. The external ring is polar; that is, it it at right angles to the plane of the galaxy and passes through the galaxy's poles. (R1, R2, R5)



A galaxy with a polar ring of material. (X1)

X2. General observations. "In recent years, astronomers have discovered still another category of galaxies whose peculiar structures seem to be due to collisions and mergers. The (figure) shows samples of these galaxies, which have been described variously as 'spindle,' 'cigar through ring,' and 'Saturn-like.' They are rare, with barely two dozen specimens known; these specimens are, on average, distant and faint. ....the surrounding rings pass nearly over the poles of the S0 disks, and measurements demonstrate that the two components rotate approximately at right angles (unlike the body and rings of Saturn, which share the same rotation axis). How did these S0 galaxies acquire polar rings made of gas, dust, and young stars?" (R4)

X3. Theories. Since the collapse of a gas cloud is very unlikely to produce two galactic components rotating at right angles, galactic collisions have been invoked. (1) A small gas-rich companion galaxy might have disintegrated over the poles of an S0 disk; and (2) A near-collision between two galaxies might have drawn material from one into polar orbit around the other. (R4)

References

R1. Ripka, John; "Gyroscope Galaxy," Astronomy, 10:64, October 1982. (X1)

R2. "Ringed Galaxy Clue to Cosmic Riddle," Science Digest, 91:22, February 1983. (X1)

R3. Katz, Neal, and Richstone, Douglas O.; "Orbital Characteristics of Polar Rings of Galaxies," Astronomical Journal, 89:975, 1984.

R4. Schweizer, Francois; "Colliding and Merging Galaxies," Science, 231:227, 1986. (X2, X3)

R5. Schweizer, Francois, et al; "Colliding and Merging Galaxies. II. S0 Galaxies," Astronomical Journal, 88:909, 1983. (X1)

AWO8 Disk Galaxies with Warped Edges

Description. Disk galaxies displaying a turned-up edge on one side and a turned-down edge on the opposite side. As many as three-quarters of all spirals may be warped. The warping occurs in well-isolated galaxies.

Data Evaluation. A widespread, well-observed phenomenon. Rating: 1.

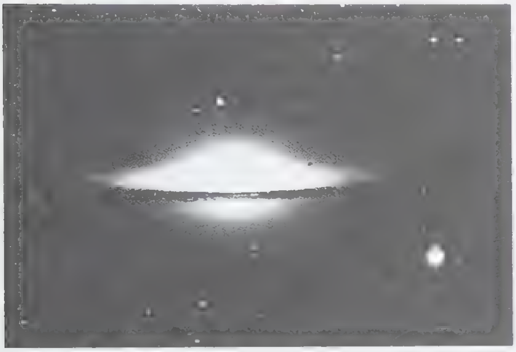
Anomaly Evaluation. Since these distortions of disk galaxies are unlikely to be the consequence of their formation from a collapsing gas cloud, external influences have been sought. A non-coplanar halo of dark matter could cause the observed warping, but such halos have never been detected. Thus, the mystery persists. Rating: 2.

Possible Explanations. A tilted halo of dark matter.

Similar and Related Phenomena. Galactic halos (AWO11); the missing mass phenomenon.

Examples

X1. General observations. "Astronomers have known for years that some spiral galaxies have an odd shape. Instead of being flat as a pancake, they are warped at the edges, one edge bending slightly up and the opposite edge down, forming a gentle S in cross section.



The Sombrero galaxy shows upwarping on the left side. (X1)

In recent years, though, it has become apparent that this hat-brim shape is the rule, not the exception. Observations made with radio telescopes have shown that as many as three out of four spiral galaxies---including our own Milky Way---are warped." It had been thought the the gravitational influences of nearby galaxies might be the cause of the warping, but even isolated galaxies, such as NGC 5301, are warped. (R2; R3)

NGC 2712 is another isolated galaxy with warped edges. (R3)

X2. Theories. Several astronomers have proposed that the warped spirals are surrounded by halos of dark matter which are not coplanar with the visible galaxies. The gravitational influence of these hypothetical halos of dark matter would warp the edges of the galaxies. (R1, R2)

References

R1. White, Simon D. M.; "Galactic Irregularities---Nature or Nurture?" Nature, 302:756, 1983. (X2)
R2. Regis, Edward, Jr.; "Unseen Matter Warps Galaxies," Science Digest, 92:16, December 1984. (X1, X2)
R3. Krumm, N., and Shane, W. W.; "Neutral Hydrogen in Two Extremely Isolated Galaxies," Astronomy and Astrophysics, 116: 237, 1982. (X1)

AWO9 Asymmetrical Galaxies

Description. Disk galaxies with strongly asymmetric distributions of matter.

Data Evaluation. A commonly observed phenomenon. Rating: 1.

Anomaly Evaluation. Strong galactic asymmetries would be smeared out in just one or two rotations. If the asymmetry is congenital, the galaxies must be very young---a completely unacceptable situation. If the asymmetries were introduced by recent internal or external perturbations, we have no inkling as to what sort of events might have occurred, especially in the case of well-isolated galaxies. Rating: 2.

Possible Explanations. Some undefined internal perturbation! Another possibility is the ingestion of a small companion galaxy, which is now in the process of being smeared out. However, no other evidence of such mergers has been found.

Similar and Related Phenomena. Clumpy galaxies (AWO10); ring galaxies (AWO6); galaxies with polar rings (AWO7). All of these involve the possibility of external influences.

Examples

X1. General observations. "Asymmetries in the distribution of light in spiral galaxies have been known for a long time. The distribution of neutral gas is now known for a number of spiral galaxies and in several cases it is also lop-sided, i.e. the gas extends further out on one side of the galaxy than on the other. Such departures from symmetry are expected to be very short-lived if the gas is in circular orbits in the disc. Measurements of the rotation curves in the outer parts of many galaxies show that the asymmetries would be destroyed by differential rotation in less than one or two rotation periods. In particular cases it may happen by chance that the galaxy is seen shortly after some transient perturbation, such as gravitational tidal intercation. But if many lop-sided galaxies with no companion are seen, then it is possible that the phenomenon is a general one in spiral galaxies and some explanation is needed to account for the persistence of the asymmetries over long periods." (R1) Asymmetric galaxies well-isolated from other galaxies have been found. (R2)

References

R1. Baldwin, J.E., et al; "Lopsided Galaxies," Royal Astronomical Society, Monthly Notices, 193:313, 1980. (X1, X2)

R2. White, Simon D.M.; "Galactic Irregularities---Nature or Nurture?" Nature, 302:756, 1983. (X1)

AWO10 Clumpy Galaxies

Description. Galaxies possessing large, irregular clumps of stars and/or gas concentrations. Given the age of the universe (15 billion years or so) and the period of rotation for galaxies (in the 100 million-year range), primordial clumps of stars and other matter should be dispersed rather smoothly. Spiral galaxies, in particular are noted for large, bright clumps in their arms.

Data Evaluation. A frequently observed phenomenon; examine any photograph of a spiral galaxy. Rating: 1.

Anomaly Evaluation. Galactic clumps, as indicated above, are probably not ancient phenomena. Although internal perturbations; viz., "white holes"; might conceivably have generated clumps in recent times; external perturbations are favored today, perhaps because they can explain a wide variety of irregularities by their very nature. Galactic clumps, therefore, are thought to be recently captured companion or satellite galaxies. Such ingestion is not unreasonable. Rating: 3.

Possible Explanations. The recent merger or ingestion of companion galaxies or other matter. Within the conceptual framework of present-day astronomy, the recent birth of large numbers of galaxies cannot be considered.

Similar and Related Phenomena. Ring galaxies (AWO6); galaxies with polar rings (AWO7); asymmetrical galaxies (AWO9).

Examples

X1. General observations. "...a number of spirals have semi-detached masses, or abnormal concentrations of mass within the spiral arms, that are difficult to explain as products of the recent development of the spiral itself, but could easily be the result of recent captures. The outlying mass NGC 5195 seemingly attached to one of the arms of M 51, for example, has the appearance of a recent acquisition (although there is some difference of opinion as to the true status of this object). The lumpy distribution of matter in M 83 gives this galaxy the aspect of a recent mixture which has not yet been thoroughly stirred; NGC 4631 looks as if it contains a still undigested mass; and so on." (R3)

X2. Markarian galaxies (objects listed by B.E. Markarian as possessing excess radiation in the near ultraviolet). "What we found was that our Markarian galaxies had a very peculiar morphology; they were made up of half a dozen or so bright clumps loosely scattered in a common luminous envelope, quite different from the appearance of classical irregular galaxies which are more thinly patched, with just one or two strong optical condensations." (R1)

References

R1. Heidmann, Jean; "Clumpy Irregular Galaxies: An Astronomical Adventure," Mercury, 11:170, 1982. (X2)

R2. White, Simon D. M.; "Galactic Irregularities---Nature or Nurture?" Nature, 302:756, 1983.

R3. Larson, Dewey B.; "Galaxies," The Universe of Motion, Portland, 1984, p. 23. (X1)

AWO11 Galactic Halos

Description. Spheroidal halos of radio and visible luminosity surrounding spiral and elliptical galaxies.

Background. Spheroidal radio halos were detected around galaxies soon after radio telescopes were developed. Charged particles and magnetic fields were thought to combine to generate this radiation. Later, extremely sensitive photometers and other optical instruments found very faint luminous halos around some galaxies. In this context of spheroidal halos of matter surrounding galaxies, it should also be noted that globular clusters form spheroidal distributions around our own galaxy and other spirals as well (AOB4). However, when galactic halos are discussed today, most astronomers think of halos of dark matter, which have been hypothesized to explain anomalously high rotation in the outer reaches of spiral and other galaxies (AWB5). This, of course, is a facet of the missing mass problem.

Data Evaluation. Indirect data, such as that supporting the reality of missing mass, are always unsatisfactory. It may turn out that the so-called missing mass may ultimately be found to be nonexistent, with the data that led to its hypothesis having been explained in a better way; viz. modifications in the theory of gravity. The direct data supporting the reality of galactic halos, both radio and visual, have been confirmed by several groups but only for a few galaxies. Rating: 2.

Anomaly Evaluation. If the halo of dark matter truly exists, we have no consensus at all as to its nature. As discussed at more length in AWB5, this is a first class anomaly. However, here we treat only the anomaly generated by the direct observation of halos of the spheroidal type around spiral galaxies. Like the spheroidal distribution of globular clusters around galaxies (AOB4), the matter responsible for these halos seems to have a different origin from the matter in the plane of the spirals. We do not know what the source of this spheroidally distributed matter is. Rating: 1.

Possible Explanations. The spheroidal halos may be composed of matter expelled from the galaxies due to supernovas or other explosive events. On the other hand, it could be infalling matter being gravitationally collected by the galaxies' gravitational fields.

Similar and Related Phenomena. All missing mass anomalies (AWB13, AWB5); the spheroidal distribution of globular clusters (AOB4).

Examples

X1. Our galaxy, the Milky Way. A roughly spheroidal radio halo has been observed. (R1)

X2. M31, a spiral galaxy. Ditto X1.

X3. M33, another spiral galaxy. Ditto X1.

X4. NGC 253. The radio halo observed for this galaxy is confined to the plane of the galaxy. (R1)

The halo of this spiral galaxy has also been observed at visible wavelengths: "Abstract. Photographic and photoelectric photometry of three representative edge-on spiral galaxies NGC 4594 (Sa), NGC 4565 (Ab), and NGC 253 (Sc) shows that each has an extensive faint spheroidal component qualitatively similar to that of an elliptical galaxy. However, their exterior surface brightnesses decline more rapidly, as power laws, with $I \sim r^{-2.5}$ or r^{-3}, and the ellipticity tends to decrease with increasing radius. The total spheroidal luminosity is comparable to or greater than the disk luminosity in all cases. .....Most of the mass appears to reside in a component having a very large value of $(M/L)_V$ and, at present, a totally unknown nature." (R11; R4) M/L = mass/luminosity ratio.

X5. NGC 4594, an edge-on spiral with a luminous halo like that of NGC 253. (R11)

X6. NGC 4565. another edge-on spiral galaxy with a luminous halo. (R11)

D. Hegyl also reported, in the same year, the discovery of a spherical luminous halo around NGC 4565. He employed an annular scanning photometer. Hegyl ventured that the halo was composed of "billions of previously unseen stars." (R3)

X7. Inference from many galactic mass/light ratios. Refer to AWB5 for the basic treatment of this phenomenon. Briefly, the high rotational velocities of matter in the outer portions of spiral galaxies are anomalous, and can be explained by assuming a massive halo of dark matter surrounding these galaxies. (Other explanations exist, too.)

V.C. Rubin has summarized the situation in this way: "There is accumulating evidence that as much as 90 percent of the mass of the universe is nonluminous and is clumped, halo-like, around individual galaxies. The gravitational force of this dark matter is presumed to be responsible for the high rotational velocities of stars and gas in the disks of spiral galaxies. At present, the form of the dark matter is unknown. Possible candidates span a range in mass of 10^{70}, from non-zero-mass neutrinos to massive black holes." (R7; see also R5, R6, R8-R10)

X8. Theories. In the early 1960s, before the "missing mass" problem gained ascendance, the radio halos observed around galaxies was considered to be the consequence of "fluxes of relativistic electrons and magnetic fields." G.R. Burbidge and F. Hoyle thought the halos were probably transient: "A new model is then proposed in which it is argued that the halos about normal galaxies such as our own and M31 may be transient phenomena which have been produced as the result of a violent outburst in the nuclear region of a galaxy. The time scale to be associated with such a halo will lie in the range 5×10^7-10^9 years, depending on the conditions that are developed in the gas following the outburst. On this picture the explosion at the center has also been responsible for the outward-moving gas which is seen in the disk of our galaxy, and it appears from this that the outburst took place about 10^7 years ago. The high-energy particles which fill such a halo may have come from the intergalactic medium, or they too may have been produced in the outburst. Violent events of this type may be recurrent in some galaxies." (R1) The mass of the halos envisioned by Burbidge and Hoyle would probably have been inadequate to account for the "missing mass" of X7.

Twenty years later, in 1983, the halos were thought to be much more massive than the visible portions of the galaxies: "Most of the mass of the Milky Way and of spiral galaxies in general thus appears to be contained in the dark spheroidal halos.(J.E.) Gunn has argued that elliptical galaxies also have dark, massive halos. Most of the mass in the universe therefore seems to be in the form of nonluminous matter, which has so far been detected only by the gravitational effect it has on the matter we can directly observe. What can we infer about such matter?"

L. Blitz et al, authors of the above quotation, speculate as follow: (1) Low-mass stars are not entirely ruled out; (2) The halos cannot be gas, because it would have to be so dense that we could detect it easily; (3) Fine dust cannot be the missing mass either, because the resulting extinction of starlight would be obvious.

"Whatever the form of the massive halos in the Milky Way and in other galaxies, at least two things seem clear: the halos are exceedingly transparent and nonluminous at all wavelengths and the matter that comprises them is probably the dominant form of matter in the universe." (R8)

References

R1. Burbidge, G.R., and Hoyle, Fred; "The Galactic Halo---A Transient Phenomenon," Astrophysical Journal, 138: 57, 1963. (X1-X4, X8)

R2. Rood, Herbert J., and Welch, Gary A.; "On the Origin of the Galactic Halo," Astrophysical Journal, 165:225, 1971.

R3. "Physicist Discovers Galaxy Circled by Stars," Astronomy, 6:70, February 1978. (X5)

R4. "Spiral Galaxies Take On Air of Mystery," New Scientist, 80:174, 1978. (X4-X6)

R5. Fabricant, D., and Gorenstein, P.; "Further Evidence for M87's Massive Dark Halo," Astrophysical Journal, 267:535, 1983. (X7)

R6. "Spiral Galaxies: Inside and Out," New Scientist, 99:21, 1983. (X7)

R7. Rubin, Vera C.; "The Rotation of Spiral Galaxies," Science, 220:1339, 1983. (X7, X8)

R8. Blitz, Leo, et al; "The New Milky Way," Science, 220:1233, 1983. (X7, X8)

R9. Frenk, Carlos, and White, Simon; "More Missing Matter Mystery," Nature, 317:670, 1985. (X7)

R10. Efstathiou, George; "Galactic Haloes Need Computers," Nature, 322:311, 1986. (X7)

R11. Spinrad, Hyron, et al; "Halos of Spiral Galaxies: Photometry and Mass-to-Light Ratios," Astrophysical Journal, 225:56, 1978. (X4-X6)

AWO12 Oblateness of Elliptical Galaxies

Description. The oblate appearance of many elliptical galaxies despite the fact that their rotational velocities are far less than that required to produce the observed flattening.

Data Evaluation. Many ellipticals are reputed to be flattened, but our survey has found few surveys or detailed studies as yet. Complicating the investigation of this phenomenon is the difficulty of measuring star velocities in ellipticals, as compared with spirals. Good data are hard to find here. Rating: 2.

Anomaly Evaluation. Although the oblateness of a slowly rotating elliptical galaxy would seem to challenge the basic laws of motion, there are ways to explain this phenomenon without restructuring any laws, as described below. This possibility reduces the anomalousness of the situation. Rating: 2.

Possible Explanations. The initial distribution of the stars (and their velocities) comprising an elliptical galaxy was anisotropic, and this condition persists still. Some astronomers think that elliptical galaxies that appear oblate are really prolate---the two forms would appear the same superficially. Prolateness is favored dynamically. Neither "explanation" explains in terms of well-accepted facts. For example, why would the stellar distribution in an elliptical galaxy be anisotropic?

Similar and Related Phenomena. The origin of spiral galaxies (AWB17).

Examples

X1. NGC 4473, a very flattened elliptical galaxy (E5 class) with a minor axis only about half as long as its major axis. P. Young et al have made detailed measurements of the velocities of the galaxy's stars. "The implied ratio of kinetic energy in the rotational motion about the center to the kinetic energy in the random motions was found to be much smaller than would be required for the ellipticity of the galaxy to be maintained by rotation as an oblate spheroid. The result reinforces the similar, but less accurate, findings of G. Illingworth for other nearby ellipticals. In a sample of 13 galaxies he found only 1 with sufficient rotation to be a rotationally supported oblate spheroid, the other 12 having only a third or less of the required rotational energy." (R1; R2, R3)

References

R1. Edmunds, M.G.; "What Flattens Elliptical Galaxies?" Nature, 274:841, 1978. (X1)

R2. Illingworth, Garth; "Rotation (?) in 13 Elliptical Galaxies," Astrophysical Journal, 218:L43, 1977. (X1)

R3. Young, Peter, et al; "Dynamics of the Flattened Elliptical Galaxy NGC 4473," Astrophysical Journal, 222:450, 1978. (X1)

AWO13 Anomalies of Spiral Galaxies

Description. The unexplained origin and persistence of the spiral arms of galaxies. This Catalog entry is actually a collection of several closely interrelated questions: (1) Why do disk-shaped galaxies form when the natural shape for a condensing gas cloud would seem to be spheroidal?; (2) Why do so many disk galaxies possess long, winding spiral arms?; (3) Why do many spiral galaxies display bars across their nuclei?; (4) Why are spiral galaxies so long-lived when their pattern should be destroyed by rotation in times very short compared to the ages of the stars in them? See X1-X4 for more detailed coverage of these points.

Data Evaluation. Spiral galaxies are exceedingly common and have been observed for centuries. Rating: 1.

Anomaly Evaluation. Spiral galaxies are usually explained in terms of spiral density waves which stimulate the formation of new stars. But we cannot say why spiral density waves should exist in the first place. Taking another tack, numerical simulations of galaxies reveal that barred spirals seem to be a 'natural' consequence of stellar interactions for many different starting configurations---just why, we are not sure. Speaking generally, we still lack a comprehensive explanation for the origin, evolution, and persistence of spiral galaxies. Rating: 1.

Possible Explanations. Spiral density waves (origin unknown) stimulate star formation and/or help maintain the spiral configuration. The percolation theory (R6).

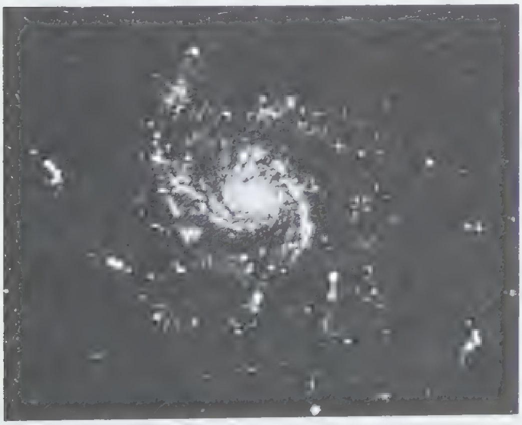
Similar and Related Phenomena. Disk galaxies have an overall resemblance to the accretion disks of the hypothesized black holes. The existence of galaxies (AWB17); the rings of Saturn, which may also be shaped by spiral density waves, and even analogs of companion galaxies---shepherd moons (ARL).

Examples

X1. Origin of disk morphology. "Another remarkable property of spiral galaxies is the extreme flatness of the dust and gas plane containing the arms. Thus, although the central star system possesses an 'oblate spheroidal' structure, the disc and the arms, as we have remarked already, seem to project out of this in an exceedingly thin plane. Its thickness is at most about one-hundredth of its diameter. This property reminiscent of the solar system, has been none too easy to explain theoretically. Why should so many stars be confined to a flat disc when the natural shape of a collection of these objects is the spheroidal distribution we observe nearer the centre of the galaxy?" The popular idea is that the galaxy begins as a rotating cloud of gas that collapses under the influence of gravity. Some gas is supposed to settle into a thin disc, followed by the formation of stars. Unfortunately for this view, the stars in the arms of the spirals seem very young---not nearly as old as the galaxy. Also, no one has yet found any proto-galactic clouds to support this theory. (R5)

X2. Origin of spiral arms. "One of the most vexing problems in theoretical astrophysics has been the explanation of the beautiful spiral patterns seen in many galaxies. It is easy enough to produce spiral structure in both galaxies and coffee cups: because they rotate differentially (the inner parts revolve faster than the outer parts), an irregular gas cloud or a dribble of cream is rapidly sheared into a spiral feature which looks very similar to a galactic spiral arm. The difficulty is that by now most galaxies have undergone 50-100 revolutions, so that any primordial spiral arms would have been wound up beyond recognition.

The most likely resolution of the winding problem for differentially rotating galaxies is that the spiral arms are not material objects, but waves of gravitational potential which propagate around the galaxy. As the interstellar gas passes through the wave it is shocked and forms bright blue stars which we see as a spiral arm; the spiral arm appears narrow because the lifetime of the stars is short compared to the time the wave needs to propagate around the galaxy. This part of the theory is comparatively well understood, but understanding the origin and persistence of the underlying wave pattern in the gravitational potential has been surprisingly difficult." (R4)



The spiral galaxy NGC 5457.

Another view of the problem: "The old puzzle of the spiral arms of galaxies continues to taunt theorists. The more they manage to unravel it, the more obstinate seems the remaining dynamics. Right now, this sense of frustration seems greatest in just that part of the subject which it advanced most impressively during the past decade: the idea of Lindblad and Lin that the grand bisymmetric spiral patterns, as in M51 and M81, are basically compression waves felt most intensely by the gas in the disks of those galaxies. Recent observations leave little doubt that such spiral 'density waves' exist and indeed are fairly common, but no one still seems to know why. To confound matters, not even the N-body experiments conducted on several large computers since the late 1960s have yet yielded any decently long-lived regular spirals." (R3)

Some astronomers doubt the correctness of the density-wave theory. V. Clube and B. Napier remark: "One problem is that the density waves seem to be incapable of compressing diffuse gas into the cold dense clouds actually observed in spiral arms." (R5)

X3. Origin of bars in spirals. A 1939 assessment of the situation. "Why some of the spiral nebulae, great galaxies of stars in outer space like our own Milky Way, have a luminous bar extending across their central portion remains an astronomical mystery, Dr. Edwin Hubble, of Mt. Wilson Observatory, told the meeting. About four fifths of all the spiral nebulae are barred. 'In the fully developed barred spiral,' Dr. Hubble said, 'a luminous bar extends diametrically across the central lens, and spiral arms spring abruptly from either end of the bar. In all other respects, the two types of spiral appear to be strictly comparable, and to follow the same pattern of evolutionary development. Since the bars do not seem to be correlated with any other physical features, their origin is sometimes attributed to tidal action or other external forces. This interpretation, however, is not supported either by the orientation of the bars with respect to neighboring systems, or by the distribution of the nebulae themselves.'" (R1)

Later investigations, however, have suggested that the bars are the 'normal' configuration and may even be necessary for the generation of the spiral arms. "Abstract. A physical process accounts for the origin and widespread occurrence of two-armed spiral patterns with a high degree of symmetry extending from the nucleus to the outermost part of a galaxy. Self-gravitating systems, starting from a wide variety of initial conditions, settle down into two-fold symmetries through a sequence of forms that were identified in numerical experiments. Twofold symmetries rarely develop directly. Instead, the systems pass through a sequence of more complicated shapes. The computer experiments and the sequence leading to twofold symmetries are described. At the end of this process a two-armed spiral density wave with a 'grand design' has been set up in the galaxy, and the stage has been set for some mechanism, such as that of Lin and Shu, to take over to assure a long lifetime for the pattern." R.H. Miller, author of this paper, views the hypothesized spiral density waves as accounting for the persistence of spiral patterns rather than their origin. (R2)

A survey of spiral galaxies by J. Kormendy and C. Norman suggests that bars or close satellite galaxies are necessary for the development of well-defined spiral patterns. (R4)

X4. Persistence of spiral arms. Echoing the first paragraph of X2, V. Clube and B. Napier observe: "Spectroscopic measurements indicate that the arms are commonly rotating around the centre with velocities of nearly 300 km per second. The revolution periods are thus a few hundred million years, considerably less than the average ages of stars. These are more like a few billion years. At first sight then, it seems the arms have lasted for ten or a hundred revolutions since they were formed. If such were the case, one would probably be envisaging the arms as the locus of a large spiral wave running through the galactic disc in which the local excess pressure continually compresses gas into forming new stars. This is because, if a wave of this kind were not involved, the observed differential rotation would very soon tear the arms to shreds." They also remark that the supposed density waves do not seem powerful enough to maintain the pattern. (R5)

References

R1. "Mysterious Luminous Bars," Science News Letter, 36:117, 1939. (X3)
R2. Miller, R.H.; "Predominance of Two-Armed Spirals," Astrophysical Journal, 207:408, 1976. (X3)
R3. Toomre, Alar; "Theories of Spiral Structure," Annual Review of Astronomy and Astrophysics, 15:437, 1977. (X2)
R4. Jones, Bernard, and Tremaine, Scott; "The Spiral Structure of Galaxies," Nature, 277:516, 1979. (X2)
R5. Clube, Victor, and Napier, Bill; "Universe to Galaxy: The Cosmic Framework," The Cosmic Serpent, New York, 1982, p. 24. (X1, X2, X4)
R6. Schulman, Lawrence S., and Seiden, Philip E.; "Percolation and Galaxies," Science, 233:425, 1986.

AWO14 Origin and Persistence of Double Radio Sources

Description. The existence of immense double sources of radio energy. Often but not always, these objects are athwart giant elliptical galaxies and are often aligned with them. Double radio sources may stretch for millions of light years; they are among the most energetic phenomena in the universe. In some cases, stars seem to have formed recently in the lobes.

Data Evaluation. Although discovered relatively recently, hundreds of double radio sources are now known to exist. They have been studied thoroughly with radio telescopes. Rating: 1.

Anomaly Evaluation. Astronomical consensus now seems focussed on the galaxies centered between the double radio sources as the wellsprings of energy and matter sustaining them. Somehow energy and matter, perhaps in jets, are conveyed to the radio lobes and keep them 'fueled' on a continuous or sporadic basis. The big puzzle here is that there are no convincing mechanisms for getting galaxies to expel matter and energy in a bipolar manner. Rating: 1.

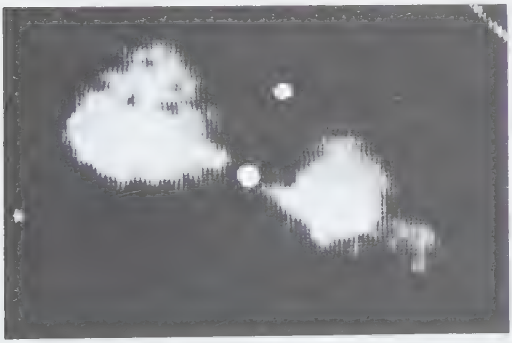
Possible Explanations. Black holes have bipolar morphology, but they are generally considered as sinks of matter rather than sources. The antithesis of the black hole, the 'white hole', a concept that has not gained much favor, would seem appropriate here. A gravitational 'slingshot' effect has been suggested by some, but this random mechanism is not consistent with the long life and aligned nature of the phenomenon.

Similar and Related Phenomena. Galactic jets (AWO1); quasar pairs athwart galaxies (AQB2);

bipolarity of quasar jets (AQO2); shells around elliptical galaxies (AWO6); lines of galaxies trailing from ellipticals (AWB10); black holes, which are also bipolar.

Examples

X1. General observations. "Far larger than giant galaxies, which are in turn much larger than the Milky Way, are the hundreds of double radio sources that astronomers have found in the last 15 years. Like cosmic light bulbs glowing with radio wave emissions, these powerful radio sources are usually found on opposite sides of a giant galaxy. The peculiar objects have defied explanation in spite of the fact that they are among the largest and most energetic phenomena in the universe.....But some very important questions are still not satisfactorily answered. Why are the radio sources so often double, what provides the energy to make them so bright, how long have they been the way we now see them?" (R1)



The two-lobed radio source DA240.

X2. 3C236. "The source is a sharply defined double radio structure that breaks all previous records for size by extending more than 18 million light years from one end to the other.....The radio emissions of 3C236 are produced by relativistic electrons as they spiral about the magnetic field lines locked into the dilute gases found in the radio lobes. The same mechanism---synchrotron radiation---is generally accepted as the explanation for radio emissions from all double sources. Thus the radio astronomers from Westerbork are probably not stretching the truth when they claim, like scientific P.T. Barnums, that the lobes of 3C236 are the 'largest reservoirs of relativistic gas known to man.' The central galaxy in the 3C236 system is a very bright radio emitter, strong enough to be listed in the '3C' catalog, and has been known for some time. But the huge radio lobes that constitute the double source are fainter and were just observed last year by A.G. Willis and associates at the Leiden Observatory, Netherlands." The immense size of 3C236's radio lobes means that they must contain enormous amounts of energy. It is estimated that they store at least 10^{60} ergs, which if converted to mass would equal a half-million suns. (R1)

X3. Centaurus A. "Centaurus A was the first radio galaxy discovered and remains the nearest known radio galaxy, about 10 million light-years away. Its shape is typical of the breed. Visibly, Centaurus A is a bright, compact ellipse with a dark lane or band of dust across its middle. In radio Cen A has two teardrop-shaped lobes extending at right angles to the dust band and reaching far beyond the bright disk to a distance of 50 or 60 kiloparsecs (160,000 to 200,000 light-years). The question is what makes these lobes and what maintains them?" (R3)

References

R1. Metz, William D.; "Double Radio Sources: Energetic Evidence That Galaxies Remember," Science, 188:1289, 1975. (X1, X2)
R2. De Young, D.S.; "Extended Extragalactic Radio Sources," Annual Review of Astronomy and Astrophysics, 14:447, 1976.
R3. Thomsen, D.E.; "Radio Galaxies: Supernova to Synchrotron," Science News, 120:390, 1981. (X3)

AWO15 Anomalous Gravitational Distortion of Galactic Images

Description. The anomalous distortion of the images of background galaxies by the gravitational fields of foreground galaxies. The distortions measured imply that the foreground galaxies do not possess the "missing mass" necessary to the explanation of galaxy rotation data.

Data Evaluation. To date, only one study of this phenomenon has been reported. Although it is thorough and extensive, replication is desirable. Rating: 2.

Anomaly Evaluation. This phenomenon, when analyzed, denies the existence of the halo of dark mass postulated to exist around galaxies to account for their anomalous rotation curves (AWB5). If "missing mass" is not the explanation of these curves, the actual explanation may be more extreme, such as the modification of the law of gravitation at long distances. Since "missing mass" is widely believed to exist and is vital to current astronomical thinking, we have here a very important anomaly. Rating: 1.

Possible Explanations. The postulated "missing mass" does not exist.

Similar and Related Phenomena. Anomalies related to "missing mass": the dynamics of galactic clusters (AWB13) and galactic rotation curves (AWB5).

Examples

X1. Survey of close pairs of galaxies. "Abstract. A fundamentally new technique for measuring galaxy mass based on the gravitational deflection of light is described. The method does not require spectroscopic detectability or virial or orbital assumptions and is applicable to galaxies of all types. We have examined images of 46,954 background galaxies for a particular coherent image distortion associated with the gravitational lenses of 11,789 foreground galaxies. Using 27,802 background-foreground pairs within 63" angular separation, we determine an equivalent statistical circular velocity as a function of the mass cutoff radius for the foreground galaxy set...." (R2) The fundamental effect assessed by Tyson et al is the distortion of the images of distant galaxies by the gravitational fields of foreground galaxies, as described by the theory of General Relativity. The image distortions are measures of the masses of the foreground galaxies.

J. Maddox has discussed the results of the above survey in the context of the long, unsuccessful search for "missing mass" in galaxies, galactic clusters, and elsewhere: "For the mass-hunters, the outcome is disconcerting. Distant galaxies in pairs separated by more than 10 seconds of arc are undistorted, but smaller angular separations bring misshapen images of the more distant galaxies. Tyson and his colleagues say that their estimates (of the mass of the nearer galaxy) would have to be in error by two or three standard deviations to be consistent with the larger estimates of mass produced by other methods. Their best estimate of the density of the Universe is a mere three per cent of the critical density (with a two standard deviation chance that the two densities are the same)." (R1) In other words, the hoped for missing mass is not there.

References

R1. Maddox, John; "Hunting for the Missing Mass," Nature, 310:627, 1984. (X1)

R2. Tyson, J. Anthony, et al; "Galaxy Mass Distribution from Gravitational Light Deflection," Astrophysical Journal, 281: L59, 1984. (X1)

AWZ GALACTIC MAGNETIC FIELDS

Key to Phenomena

AWZ0 Introduction

Planets and stars can generate magnetic fields, so it is not surprising to find evidence that a magnetic field pervades our own galaxy and very likely other galaxies, too. In the cases of planets and stars, we can conceive of physical mechanisms that could account for the existence of the fields, but, so far at least, we have little inkling as to what generates the Milky Way's magnetic field and its unusual features.

AWZ1 Magnetic Field Anomalies in Our Galaxy

Description. Difficult-to-explain features of the Milky Way's magnetic field: (1) The time-of-generation paradox; and (2) The existence of a large-scale magnetic structure superimposed upon the background field.

Data Evaluation. Both the background field and the large-scale magnetic structures are detected by the well-developed methods of modern radio astronomy. Rating: 1.

Anomaly Evaluation. A perusal of X1 and X2, below, reveals that we do not known when of how our galactic magnetic field was created. Since no conventional generator, such as dynamo action, can be observed, we can only speculate about hypothetical black holes and the like. This is symptomatic of an important anomaly. Rating: 1.

Possible Explanations. It is common to blame black holes for anomalous astronomical phenomena, but here the magnetic field structures seem too large.

Similar and Related Phenomena. Radio-luminous threads (AWO3).

Examples

X1. The time problem. "One of the most baffling of all astronomical phenomena is the magnetic field known to exist in our Galaxy, and suspected in other galaxies. In order to generate coherent fields of this magnitude by any reasonably conventional means, a time of around 10^{26} years would be needed---yet the age of the whole universe as we know it is only 10^{10} years. Clearly some drastically powerful generating mechanism must have been at work when these fields formed, and opinion amongst astronomers generally favours the idea that the galactic magnetic field, like the Galaxy itself, was created when the universe began, and must therefore remain largely inexplicable." (R1)

X2. Bizarre nature of our galaxy's field. Radio surveys of the core of our galaxy, the Milky Way, have revealed a large-scale magnetic field of unknown origin. The first hint of a large-scale field came in 1984, when a narrow strip of radio emission lying perpendicular to the plane of the galaxy about 40 parsecs from its center was examined in detail. "...the arc actually consists of thin, parallel filaments. Furthermore, at the northern end of the arc the filaments merge with a second, less regular set of filaments that curve back down into Sagittarius A West, the radio source that marks the center of the galaxy. More recent work suggests that the arc may be part of a still larger structure. The filaments mean that the arc is almost certainly shaped by a magnetic field." They are uniform over great distances which seems to rule out shock waves as a cause. Also, polarization measurements of the arc are consistent with synchrotron radiation, which requires a magnetic field. "The polarization measurements also give an estimate of the magnetic field: 10^{-4} gauss, which is very large relative to the overall magnetic field of the galaxy. Thus the central question: what is producing the field?" Black holes seem ruled out because of the arc's huge size. If this large-scale field is generated by dynamo action, no one can locate the dynamo. (R2; R3)

References

R1. "Did the Galaxy's Rotation Wind Up Its Magnetic Field?" New Scientist, 42:567, 1969. (X1)

R2. Waldrop, M. Mitchell; "New Mysteries at the Galactic Center," Science, 230: 652, 1985. (X2)

R3. Thomsen, D.E.; "Galactic Dynamo-ism: A Radiation Belt?" Science News, 126: 20, 1984. (X2)

TIME-OF-EVENT INDEX

FIRST-AUTHOR INDEX

SOURCE INDEX

SUBJECT INDEX