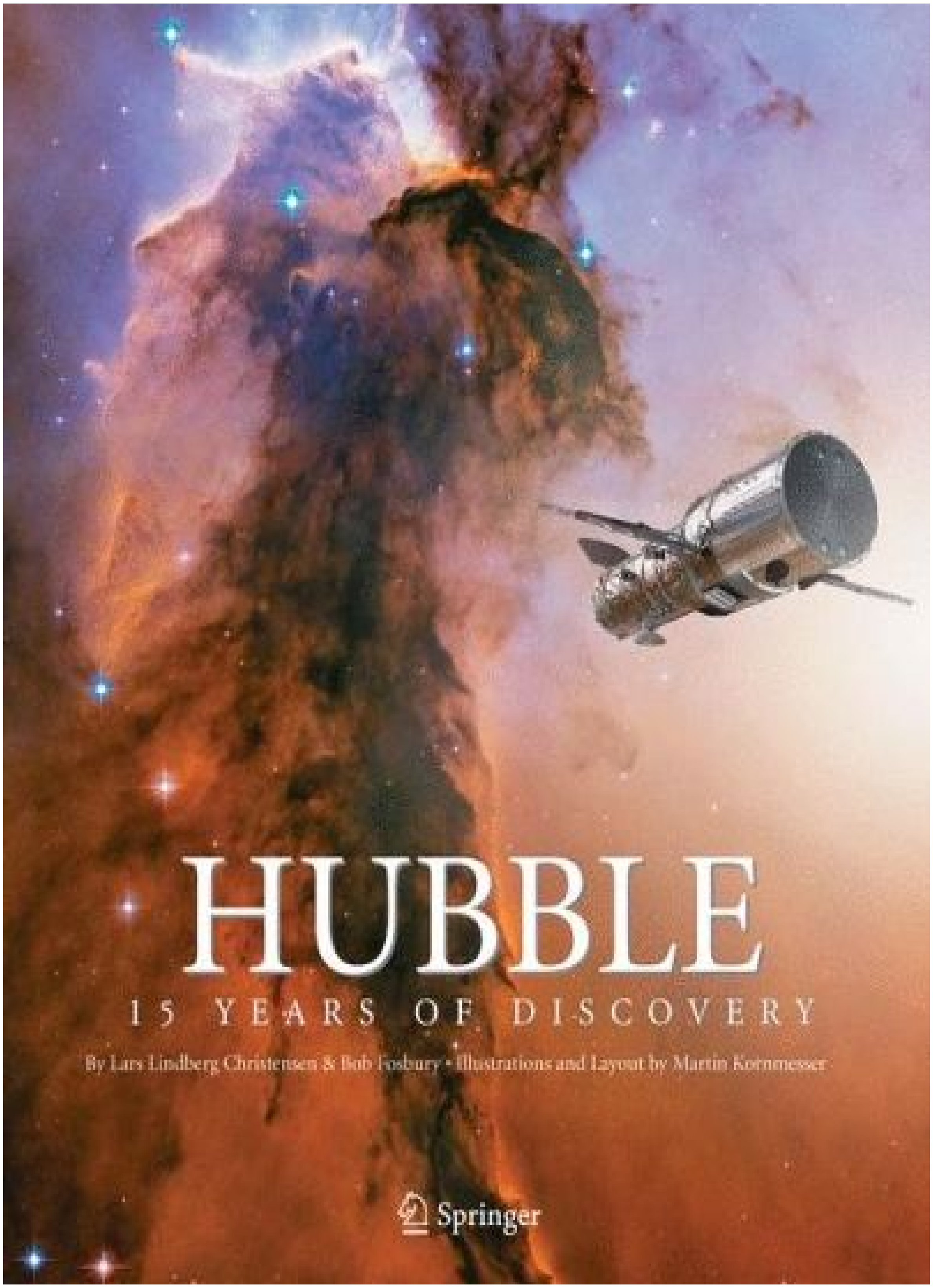

HUBBLE
15 YEARS OF DISCOVERY
By Lars Lindberg Christensen & Bob Fosbury • Illustrations and Layout by Martin Kornmesser
Springer

HUBBLE

15 YEARS OF DISCOVERY

HUBBLE
15 YEARS OF DISCOVERY

BY LARS LINDBERG CHRISTENSEN & BOB FOSBURY
ILLUSTRATIONS AND LAYOUT BY MARTIN KORNMESSER

This book is dedicated to all the hard working people in the USA and Europe who have made the Hubble Space Telescope an incredible scientific success

Lars Lindberg Christensen ESA/ST-ECF
NASA/ESA Hubble Space Telescope
Garching 85748, Munich, Germany
lars@eso.org

Robert A. Fosbury ESA/ST-ECF
NASA/ESA Hubble Space Telescope
Garching 85748, Munich, Germany
rfosbury@eso.org

Library of Congress Control Number: 2005935456

ISBN-10: 0-387-28599-7
ISBN-13: 978-0387-28599-3

Printed on acid-free paper.

Printed in the United States of America. (EVB)

9 8 7 6 5 4 3 2 1

springer.com

HUBBLE

15 YEARS OF DISCOVERY

NASA/ESA and The Hubble Heritage Team (STScI/AURA)

The Sombrero Galaxy

The Sombrero galaxy is one of the Universe's most stately and photogenic galaxies. The galaxy's hallmark is a brilliant white, bulbous core encircled by thick dust lanes comprising the spiral structure of the galaxy.

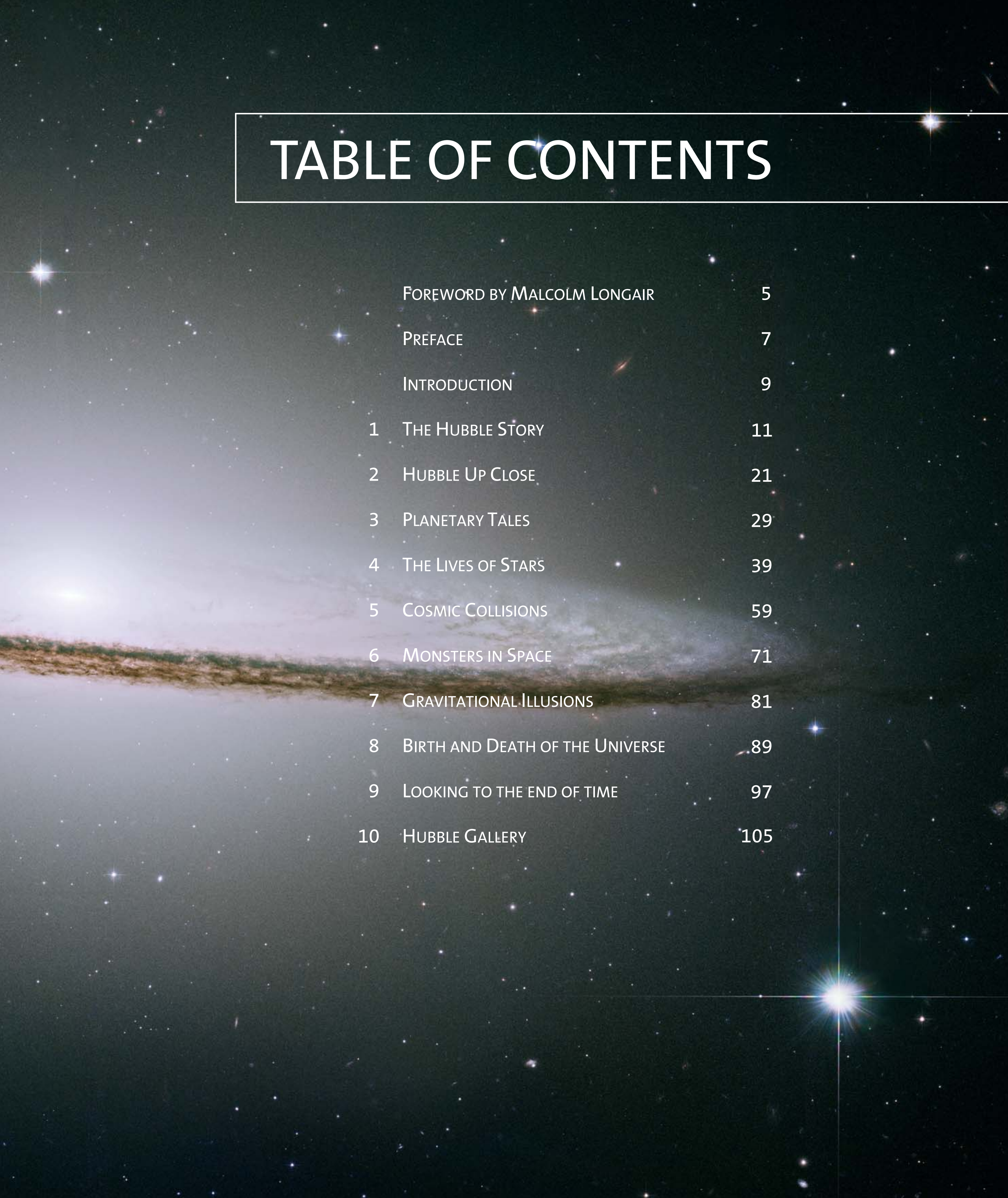
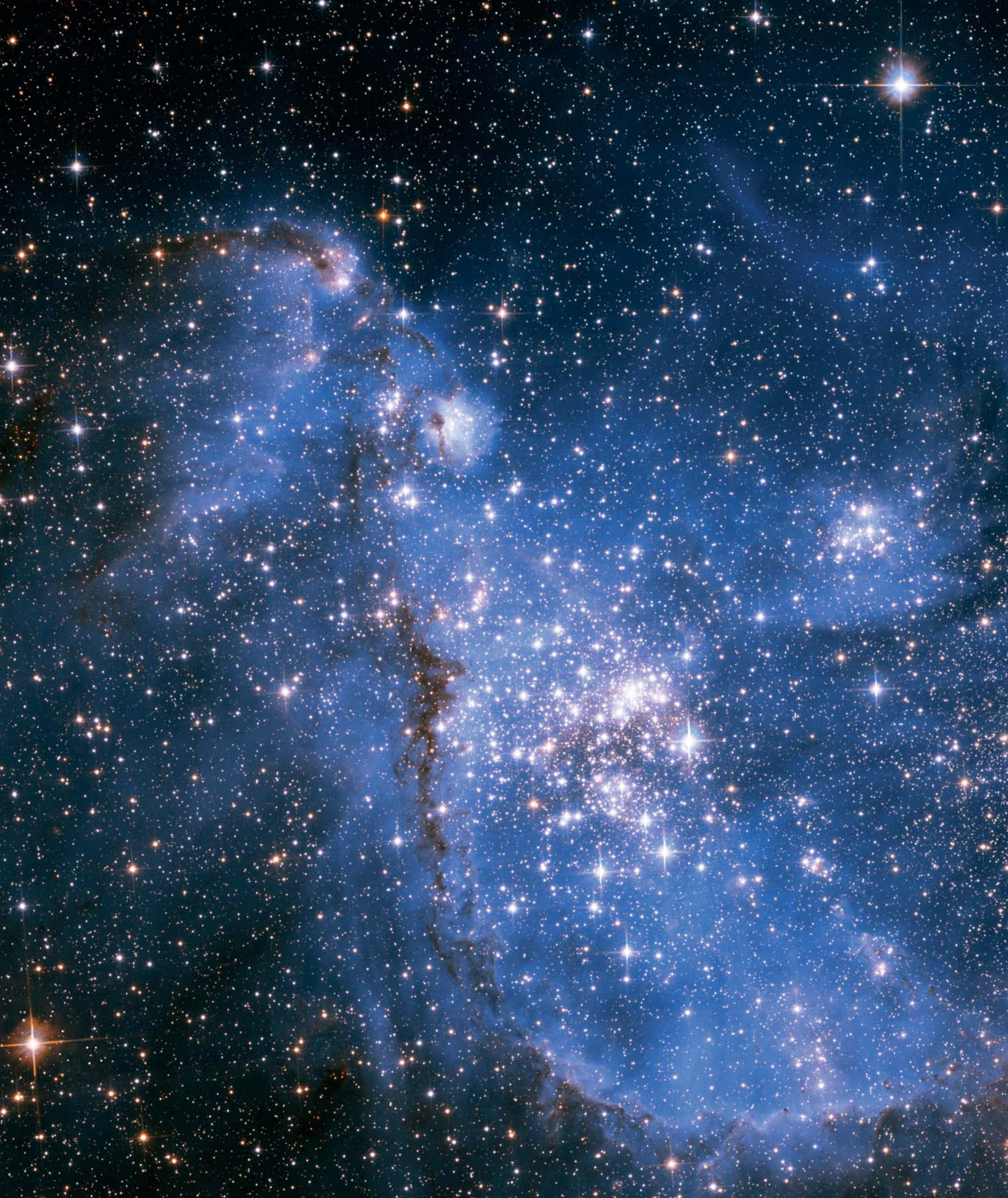


TABLE OF CONTENTS



FOREWORD

NGC 346

Hubble's exquisite sharpness has plucked out an underlying population of infant stars embedded in the nebula NGC 346 that are still forming from gravitationally collapsing gas clouds.

NASA, ESA and A. Nota (STScI/ESA)

The Hubble Space Telescope has undoubtedly had a greater public impact than any other space astronomy mission ever. The images included in this beautiful volume are quite staggering in what they reveal about the Universe we live in and have already become part of our common scientific and cultural heritage.

But what about the science impact? It is no exaggeration to say that the scientific output of the mission has far exceeded the most optimistic expectations of all those involved in the planning and execution of the project. When I joined the project in 1977, I had to describe the astronomy programme I would carry out with the Hubble once it was in operation in orbit. Seventeen years later when I received my first data, I was quite staggered by the quality of the images and also by the totally new science which they revealed about the ways in which relativistic jets can illuminate the environments of active galaxies. This is a repeated theme in essentially all areas explored by the Telescope. The images are not only beautiful, but are full of spectacular new science, much of it undreamed of by the astronomers involved. A good example is the discovery of protostellar discs seen in silhouette against the bright background of the Orion Nebula. Another is the ability to discover distant star forming galaxies by imaging in a number of wavebands. The observation of distant supernovae has enabled the present acceleration of the Universe as a whole to be measured – an undoubted triumph. And then there are the spectacular images of the Hubble Deep and Ultra-Deep Fields which have revealed what are almost certainly young galaxies in the process of forming the galaxies and larger scale structures we observe about us today. But these are only a few random samples of the wealth of scientific knowledge which has accrued from the mission. Every picture tells a wonderful story which has already been built into our picture of the evolving Universe.

What are the lessons to be learned from this spectacular success? The route to new understanding is through the ability to observe the Universe in new ways with techniques, that extend observational capability by a factor of 10 or more. In the case of the Hubble Space Telescope, the gains in angular resolution, or sharpness, and corresponding sensitivity, as well as the remarkable stability of the instruments in the remote environment of space, have given it unprecedented power to uncover new astrophysics. The results are a wonderful tribute to the dedicated efforts of many scientists, astronomers, engineers, managers and administrators, as well as to the vision of NASA and ESA in enabling the Hubble Space Telescope to come about. Long may this vision and the ability to inspire the public imagination continue as an essential means of deepening our understanding of the Universe.

Malcolm Longair

4 April 2005

PREFACE

The Cone Nebula

Radiation from hot, young stars (located beyond the top of the image) has slowly eroded the nebula over millions of years. Ultraviolet light heats the edges of the dark cloud, releasing gas into the relatively empty region of surrounding space.

The long-term wellbeing and cultural development of humanity depend on scientific research and technological development. The communication of scientific discoveries and information about scientists and their work to the public are vital components of the scientific process. However, the competition for attention in today's mass-media market is fierce.

This book takes a closer look at what may be the world's most successful scientific project. The fifteenth anniversary of Hubble's launch, which took place on the 24th April 1990, presented the ideal opportunity for a spectacular project to seize the attention of the public. The story of a journey through space and time revealed by the telescope is told in a way that we hope will appeal especially to the younger generation. It will be their enthusiasm that powers the future of the scientific endeavour.

We should like to thank Stefania Varano, Stuart Clark and Anne Rhodes who all worked on the film manuscript that laid the foundation for important parts of this book. Unless otherwise noted, the images in this book were taken by the NASA/ESA Hubble Space Telescope and should be credited to NASA, ESA and the individual scientists (see www.spacetelescope.org for the exact details).

Lars Lindberg Christensen and Bob Fosbury

Munich, 23 November 2005

NASA, Holland Ford (JHU), the ACS Science Team and ESA

INTRODUCTION

NGC 1300

NGC 1300 is considered to be prototypical of barred spiral galaxies. Barred spirals differ from normal spiral galaxies in that the arms of the galaxy do not spiral all the way into the centre, but are connected to the two ends of a straight bar of stars containing the nucleus at its centre.

On 24 April 2005 the NASA/ESA Hubble Space Telescope will exceed its original estimated lifetime of 15 years in orbit around the Earth. Hubble has been hugely successful in many different areas of astronomy. How does it differ from other famous telescopes?

Hubble orbits 600 km above the Earth's surface, placing it well above our image-distorting atmosphere. It can be upgraded to take advantage of the latest developments in instrumentation and software. The telescope is designed to take high-resolution images and accurate spectra by concentrating light to form sharper images than are possible from the ground, where the atmospheric 'twinkling' of the stars limits the clarity. Therefore, despite its relatively modest aperture of 2.4 metres, Hubble is more than able to compete with ground-based telescopes that have light-collecting (i.e. mirror) areas 10 or even 20 times larger.

As well as being able to take sharper wide-field images, the other huge advantage Hubble has over ground-based telescopes is its ability to observe the near-infrared and ultraviolet light that is otherwise filtered away or masked by the atmosphere before it can reach the ground.

In many areas of astronomical investigation, Hubble has pushed the limit of our knowledge far, far beyond anything possible before its launch.

NASA, ESA, and The Hubble Heritage Team (STScI/AURA)


NASA
GODDARD SPACE FLIGHT CENTER

1 THE HUBBLE STORY

Hubble in Dock

The Hubble Space Telescope in the Shuttle's payload bay during Servicing Mission 3A.

Hubble finally allowed astronomers to realise their dream of escaping the distorting effects of the Earth's atmosphere to make their observations. Achieving an operational observatory in space was no small task: it took decades of planning and construction in a project of such scale and cost that it demanded international collaboration and the work of many dedicated engineers and scientists. The concept of a telescope that could be upgraded and serviced regularly by astronauts has resulted in capabilities and scientific discoveries far beyond the expectations of the designers.

NASA

ESA

For many years astronomers longed for an observatory in space

Hubble has vastly improved our view of the skies, sharpened our perception of the Universe, and allowed us to penetrate ever deeper toward the furthest edges of time and space.

Looking at the night sky we see the familiar twinkle of starlight; light that has travelled enormous distances to reach us. But the stars themselves do not flicker. The Universe is gloriously transparent, allowing light from distant stars and galaxies to travel unchanged across space for thousands, millions, even billions of years. Then, in the last few microseconds before the light reaches our eyes, the fine details in the view of those stars and galaxies are snatched away. This is because, as light passes through our atmosphere, the ever changing blankets of air, water vapour and dust, blur the image that finally reaches us.

To solve this problem, astronomers around the world longed for an observatory in space for many years. As early as 1923, the famed German rocket scientist Hermann Oberth suggested a space-based telescope. However, it was decades before technology caught up with the dream. The American astronomer Lyman Spitzer proposed a more realistic plan for a space telescope in 1946.

From a position in space above the Earth's atmosphere, a telescope could detect the pristine light from stars, galaxies, and other objects before their images become distorted by the air we breathe. The result: much sharper images than even the largest telescopes on the ground could achieve; images limited in sharpness only by the quality of the optics.

In the 1970s, NASA – the National Aeronautics and Space Administration – and ESA – the European Space Agency – began working together to design and build what would become the Hubble Space Telescope. The name is a tribute to Edwin Powell Hubble, the founder of modern cosmology, who, in the 1920s, first showed that not all we see in the sky lies within the Milky Way. Instead, the cosmos extends far, far beyond. Hubble's work changed our perception of mankind's place in the Universe forever and the choice of naming this most magnificent telescope after Edwin Hubble could not have been more appropriate.

Hillary Mathis/NOAO/AURA/NSF

NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

Above the Ocean of Air

A ground-based telescope similar in size to Hubble produced the image of the barred galaxy NGC 1300 on the left. From its position in space above the Earth's atmosphere, Hubble obtained the picture on the right of the same galaxy. A technique called 'Adaptive Optics' can be used to sharpen ground-based images and is extremely effective when used with telescopes much larger than Hubble (see box below).

Why is Hubble in orbit around the Earth?

The Earth's atmosphere both absorbs and emits light. Beyond the blue end of the visible spectrum, the presence of ozone ensures that little ultraviolet light reaches the ground. Towards the red end and beyond, into what astronomers call the near-infrared spectrum, there is considerable absorption by water vapour and molecular oxygen but also, the sky is brightened by intense emission from the OH radical (an unstable molecule consisting of an oxygen and a hydrogen atom). The visible spectrum alone remains reasonably free from these effects. The entire spectral range from ultraviolet through the near-infrared remains cleanly accessible to Hubble.

Hubble vs. Adaptive Optics

The technique of Adaptive Optics can sharpen images from large ground-based telescopes to attain a higher resolution and is being vigorously developed by astronomers around the World. Such observations are highly complementary to those made by Hubble since they can exploit the collecting power of much larger telescopes and can be used very effectively to feed such light-hungry instruments as spectrographs. This higher resolution is achieved over a small patch of the sky and and the technique works better at infrared wavelengths than it does in the visible spectrum used by Hubble. Hubble remains supreme for mapping parts of the sky in exquisite detail in ultraviolet, visible and near-infrared light.

It took two decades of dedicated collaboration between scientists, engineers and contractors from many countries before Hubble was finally finished. On April 24, 1990, five astronauts aboard the space shuttle Discovery left on a journey that changed our vision of the Universe for ever! They deployed the eagerly anticipated Space Telescope in an orbit roughly 600 km above the Earth's surface.

On Earth, astronomers waited impatiently for the first results. After extensive technical verification and testing, it soon became obvious that Hubble's vision was anything but sharp. The mirror had a serious flaw. A defect in the shape of the mirror prevented Hubble from taking clear images. The mirror's edge was too flat by only a mere fiftieth of the width of a human hair. But to accomplish its mission, Hubble had to be perfect in every tiny detail. The disappointment was almost too great to bear. Not only amongst astronomers, but also for American and European taxpayers.

Nevertheless, over the following two years, scientists and engineers from NASA and ESA worked together to design and build a corrective optics package, named COSTAR, for Corrective Optics Space Telescope Axial Replacement. They were also able to build in a perfect correction to the replacement camera that was already planned for installation. Hubble's masters now faced another tough decision: which science instrument should they remove so that COSTAR could be fitted to Hubble? They eventually chose the High Speed Photometer.

Hubble's First Servicing Mission, performed in 1993, has gone down in history as one of the supreme highlights of human spaceflight. It captured the attention of both astronomers and the public at large to a degree that no Space Shuttle mission has since achieved. Meticulously planned and brilliantly executed, the mission succeeded on all counts. COSTAR and the new Wide Field and Planetary Camera 2 (WFPC2) corrected Hubble's eyesight more perfectly than anyone had dared to hope.

Hubble's mirror problem

The cause of the problem was a defect in the 2.4 metre diameter primary mirror caused by the incorrect assembly of the optical system used to test the mirror during manufacture. This resulted in what is called 'spherical aberration'. Fortunately, the test system remained untouched in the lab and it was possible for engineers to go back and use it to reconstruct the nature of the error with great precision. This is why the Servicing Missions were so successful in correcting Hubble's optics to near-perfection.

Changing instruments on Hubble

An astronaut exchanging cameras on Hubble during the first Servicing Mission in 1993.

Hubble was finally in business!

The centre of M100

The central regions of this grand-design spiral galaxy taken before and after Hubble's first servicing mission. Left: A picture taken with the WFPC1 camera in wide field mode, on November 27, 1993, just a few days prior to the STS-61 servicing mission. The effects of optical aberration in HST's 2.4-metre primary mirror blur starlight, smear out fine detail and limit the telescope's ability to see faint structure. Right: The same field imaged with WFPC2 in its high resolution channel. The WFPC2 contains modified optics that correct for Hubble's previously blurry vision. For the first time the telescope was able to resolve cleanly faint structure as small as 30 light-years across in a galaxy that is tens of millions of light years away. The image was taken on December 31, 1993.

When the first images after the servicing came up on the computer screens it was instantly clear that the 'glasses' taken up by the astronauts were completely correcting Hubble's vision. Hubble was finally in business!

That was only the first time the Space Shuttle visited Hubble. The telescope was designed to be upgraded, enabling it to take advantage of new technologies and software. When more advanced instruments, electrical or mechanical components became available, they could be installed by the astronauts. So, just as a car needs servicing so Hubble needs tuning-up from time to time. Engineers and scientists periodically send the Shuttle to Hubble so that astronauts can upgrade it, using wrenches, screwdrivers and power tools, just as a mechanic might with a car.

There have been four Servicing Missions so far: in 1993, 1997, 1999 and 2002. All were undertaken by astronauts transported into space by NASA's Space Shuttle. The next one was supposed to occur in 2005, but was unfortunately cancelled in the aftermath of the tragic Columbia crash.

Hubble's future is uncertain. It was originally designed to operate for 15 years, but it is now expected that its life could be extended to 20 years. Hubble is still producing the most astonishing results that astronomers have ever known.

NASA

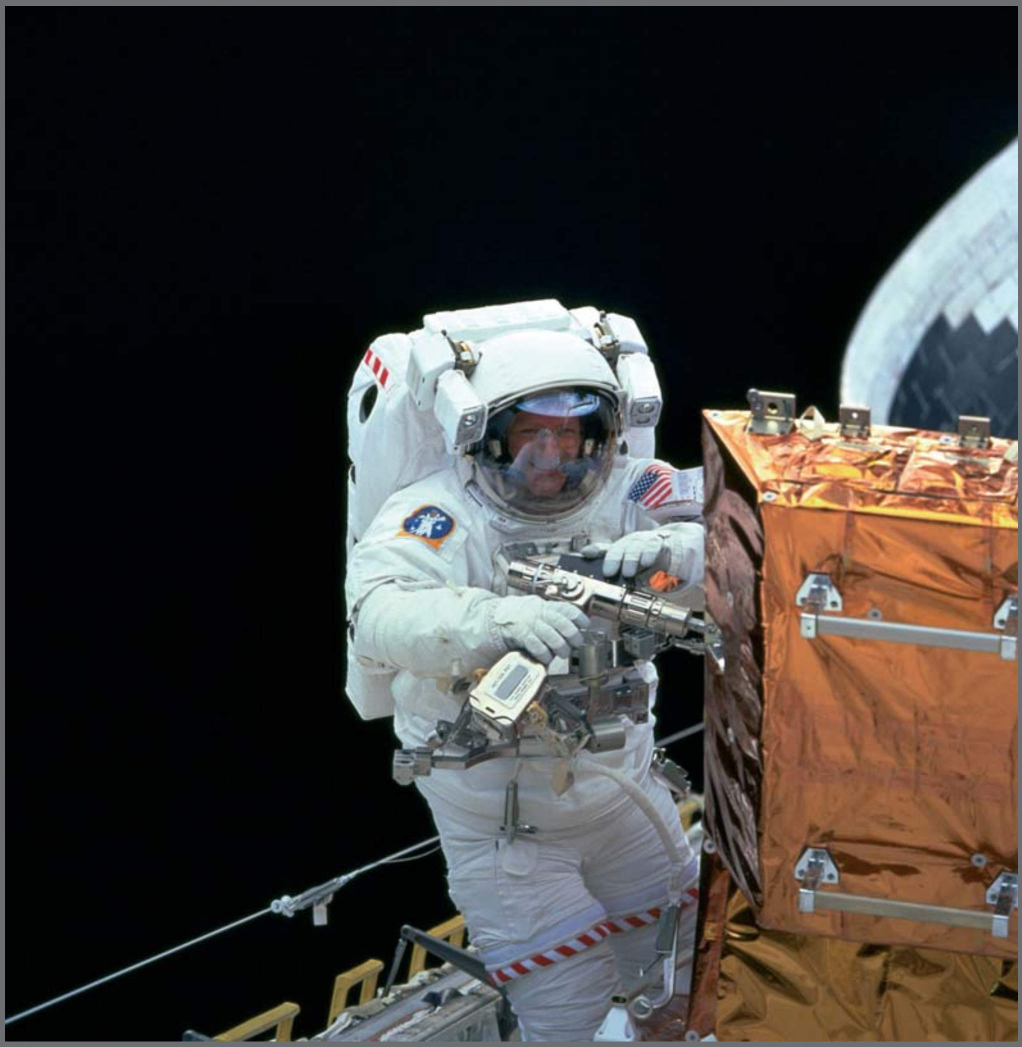
Fine Guidance Sensor

Astronaut Gregory J. Harbaugh on the robot-arm manoeuvring a Fine Guidance Sensor (FGS) during the second Servicing Mission.

Just as a car needs servicing so Hubble needs tuning-up from time to time

Space power tools

Astronaut Claude Nicollier, mission specialist from the European Space Agency (ESA), works at a storage enclosure using one of the Hubble power tools during the second of three extravehicular activities (EVA) of the third Servicing Mission.

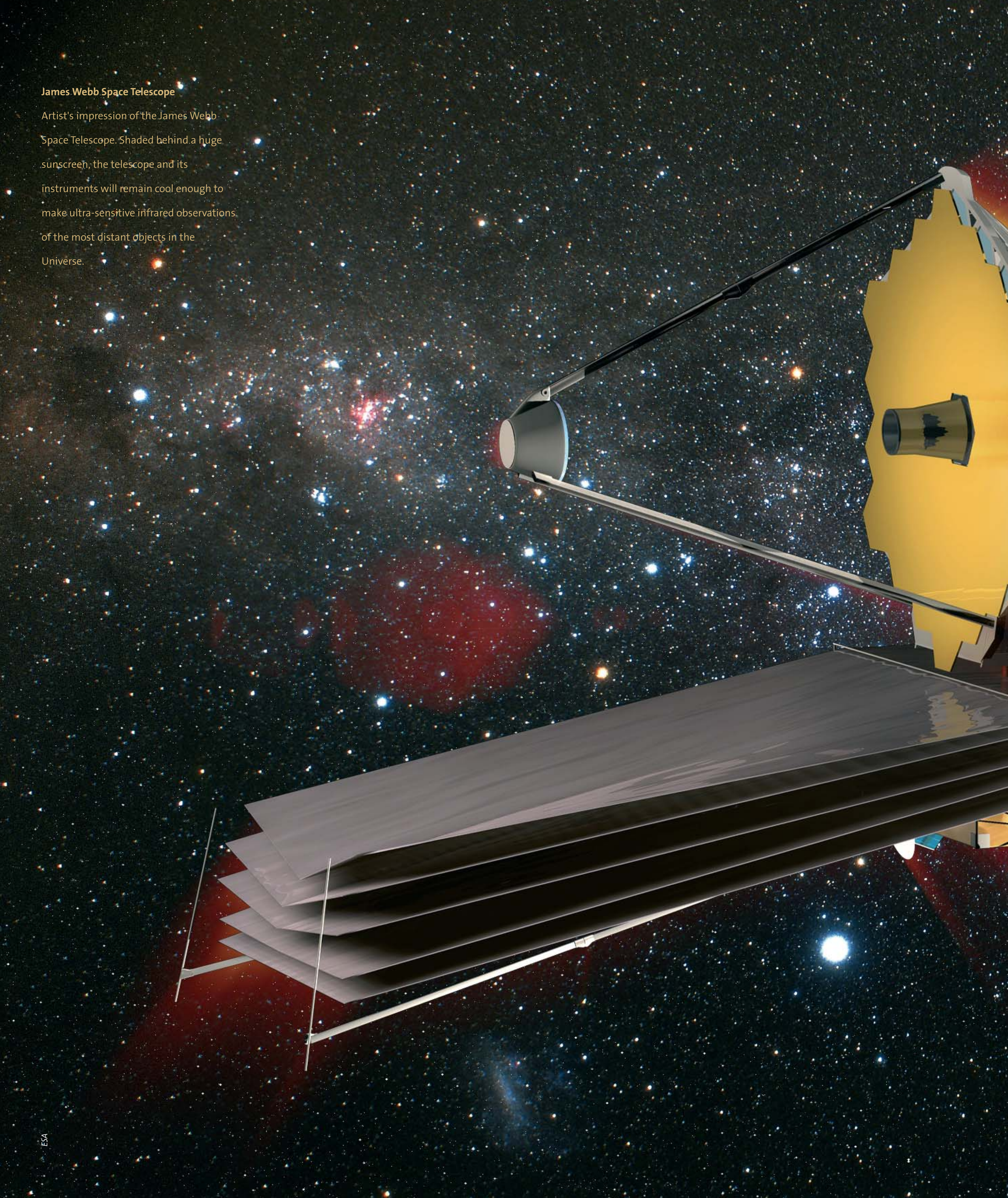


NASA

Eventually, however, Hubble's active life will end and the telescope will have to be guided to a safe resting place in the ocean. It is too massive a spacecraft to burn up completely in the atmosphere on re-entry and an uncontrolled plunge into the atmosphere is a potential danger to residents of regions covering a broad swathe of our planet. The plan is for an unmanned probe to link up with Hubble in orbit and dock with it. The probe will leave behind a rocket-module so that, after some more years of fruitful observing, engineers on the ground can activate these rockets to control Hubble's final descent into the atmosphere.

However, the retirement of the Hubble Space Telescope will not signal the end of our unrivalled view of the Universe. Rather, it will mark a new beginning, an era of even more amazing discoveries and images from space. For Hubble has a successor.

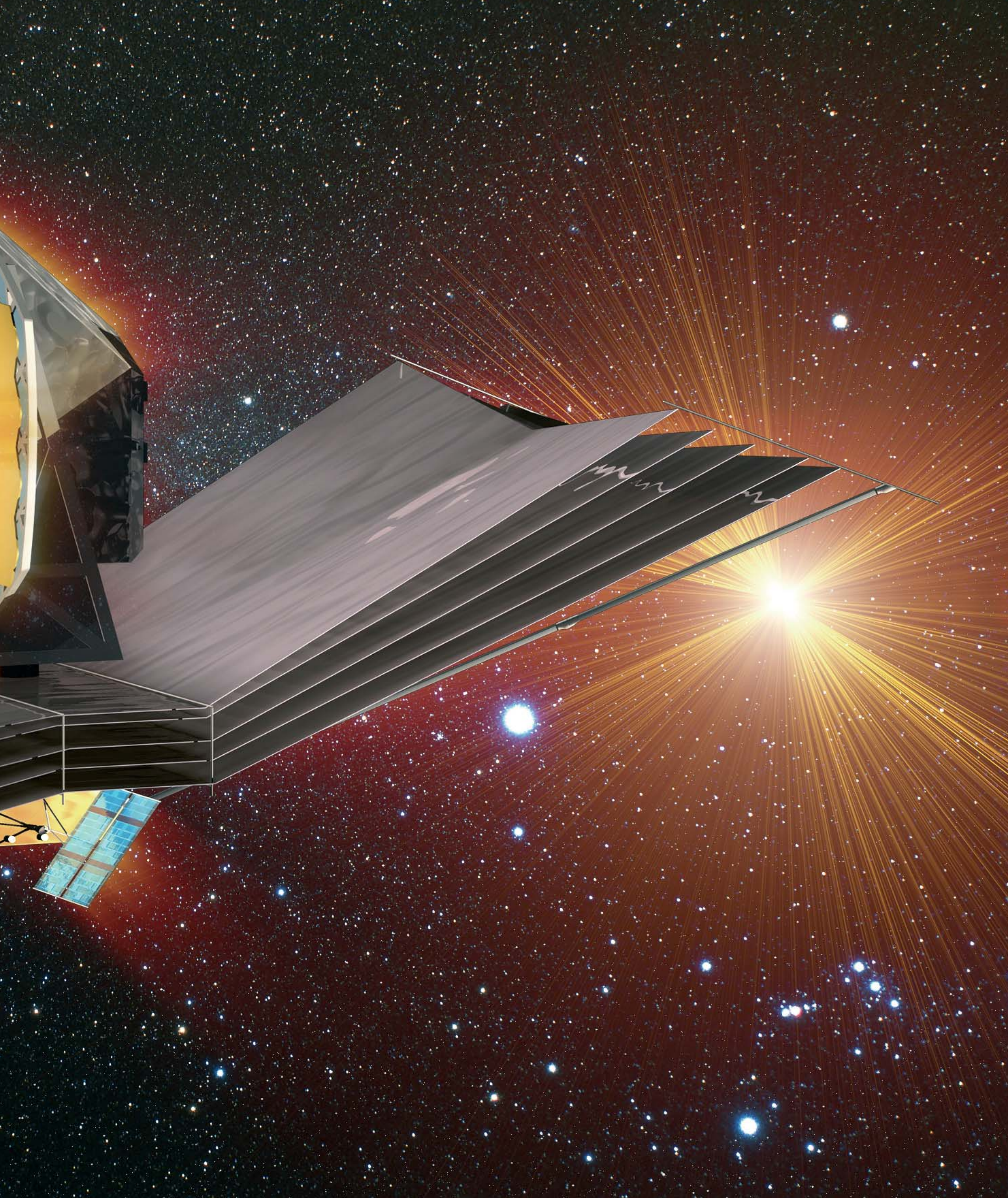
The James Webb Space Telescope is currently being designed and may be launched as early as 2011. When that day comes, scientists using the James Webb Space Telescope hope to discover and understand even more about our fascinating Universe.



James Webb Space Telescope

Artist's impression of the James Webb Space Telescope. Shaded behind a huge sunscreen, the telescope and its instruments will remain cool enough to make ultra-sensitive infrared observations of the most distant objects in the Universe.

ESA



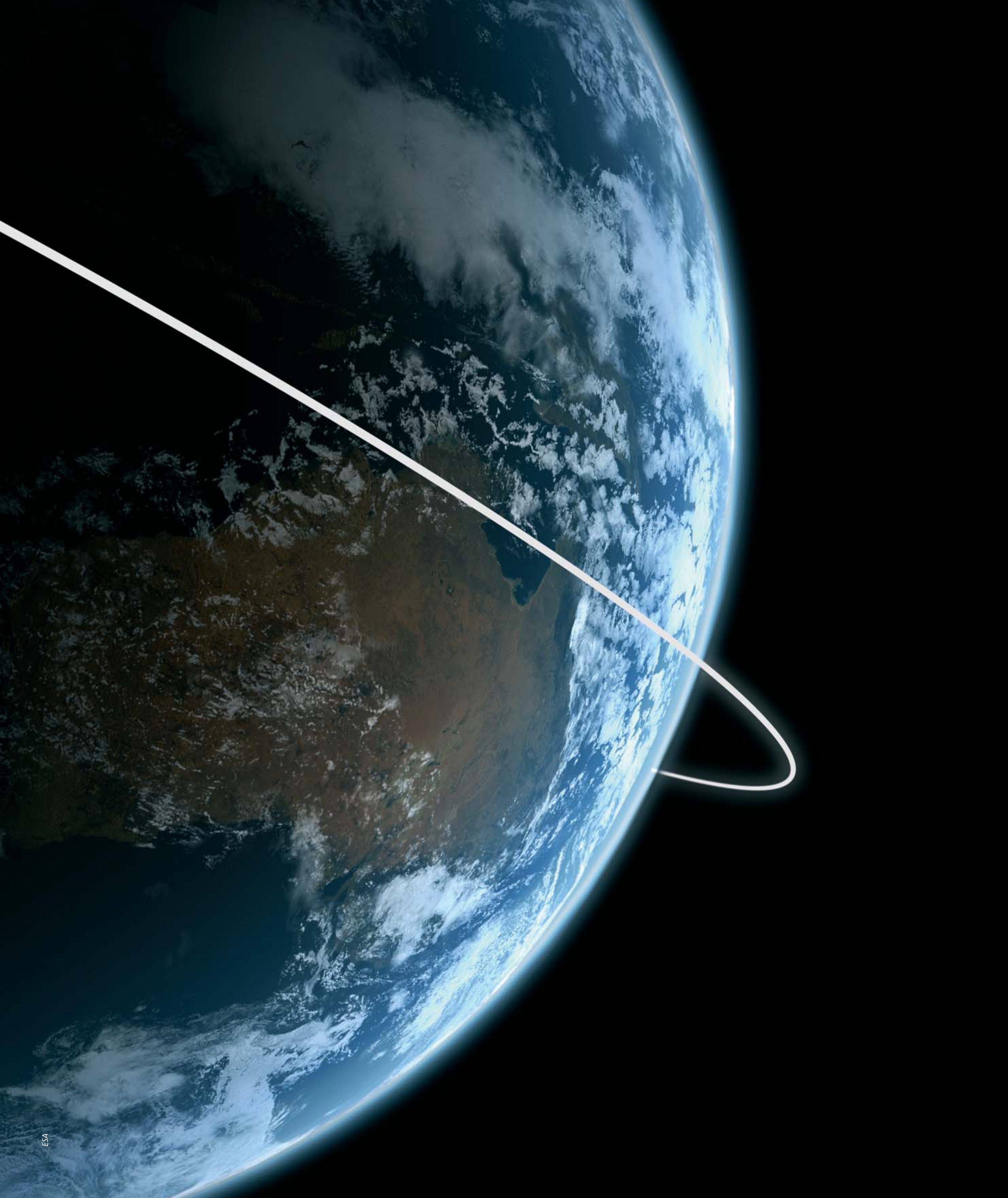
ESA

2 HUBBLE UP CLOSE

The NASA/ESA Hubble Space Telescope

Hubble is a large satellite; about 16 metres long or the size of a small bus. It is also one of the most complicated pieces of technology ever built.

Hubble is a large satellite, about the size of a school bus. As well as the 2.4 metre aperture telescope, it carries six scientific instruments that can be regularly replaced with more modern and capable ones by space suited astronauts in orbit 600 km above the Earth. The systems that allow it to be pointed and stabilised are very sophisticated and are working extraordinarily well. Far from being an isolated resource for astronomers, Hubble has worked in close harmony with other satellites and ground-based observatories to lead, during its 15 years of operation, a huge leap in our understanding of the Universe.


ESA

Hubble is a space-based telescope that is designed to be upgraded

Hubble's orbit

Hubble orbits the Earth every 96 minutes at an altitude of nearly 600 km. The ever-changing aspect of its orbit makes the process of scheduling observations rather complicated.

Hubble is a space-based telescope that is designed to be upgraded and to adapt to changing needs and technologies. It orbits at almost 600 km above the Earth's surface, placing it well above most of our image-distorting atmosphere and takes about 96 minutes to complete each orbit.

It is designed to take high-resolution images and accurate spectra by concentrating starlight to form sharper images than are possible from the ground, where the atmospheric 'twinkling' of the stars limits the clarity.

To gather as much light as possible from the faint objects it studies, any telescope needs the largest mirror it can get. Despite Hubble's relatively modest mirror diameter of 2.4 metres, it is more than able to compete with ground-based telescopes that have mirrors 10 or 20 times larger in collecting area.

Hubble is a large satellite; about 16 metres long or the size of a small bus. It is also one of the most complicated pieces of technology ever built. It contains more than 3000 sensors that continually read out the status of the hardware so that technicians on the ground can keep an eye on everything.

Time on Hubble is a precious commodity. Astronomers across the world regularly ask for much more time than is available. Keeping Hubble working 24/7 is no small task. Not a single second must be lost and all tasks – either observations or so-called 'housekeeping' tasks, such as repositioning of the telescope, or uploading new observing schedules — are meticulously planned.

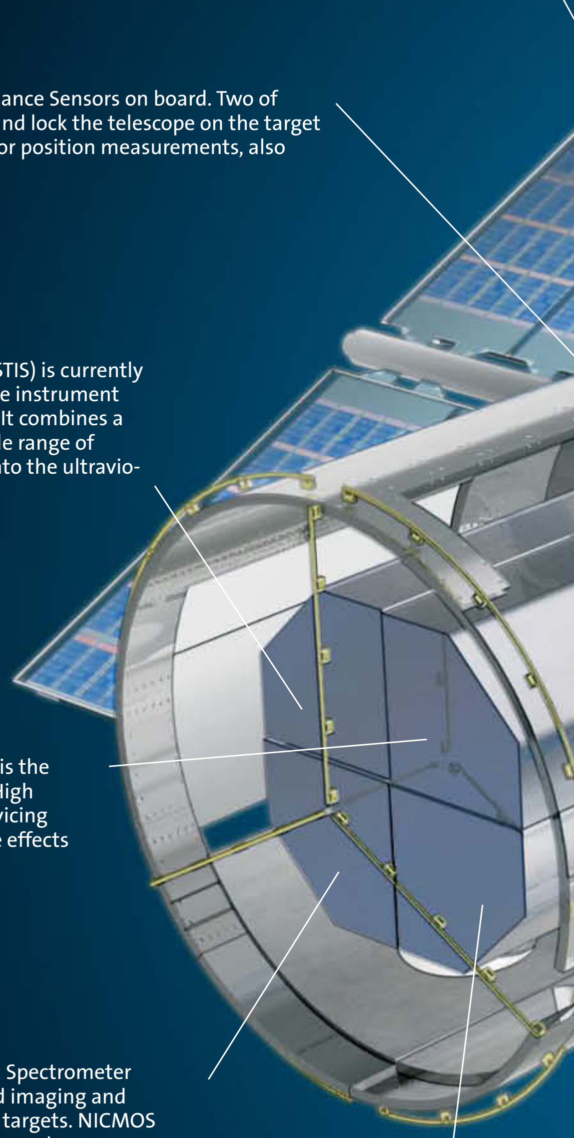
Is there competition between different observatories?

A large and ambitious astronomical research project today would use large amounts of time on a whole range of different telescopes on the ground and in space. These telescopes, far from competing with one another, provide different and complementary views of astronomical sources that greatly increase our ability to understand the physical processes that create them. It is usually a case of "the whole being greater than the sum of the parts". Hubble plays an absolutely pivotal role in many of these programmes.

HUBBLE'S INSTRUMENTS & SYSTEMS

Primary mirror
Hubble's primary mirror is made of a special glass coated with aluminium and a special compound that reflects ultraviolet light. It is 2.4 metres in diameter and collects the light from stars and galaxies and reflects it to the secondary mirror.

FGS
Hubble has three Fine Guidance Sensors on board. Two of them are needed to point and lock the telescope on the target and the third can be used for position measurements, also known as astrometry.



STIS
The Space Telescope Imaging Spectrograph (STIS) is currently not operating, but is a versatile multi-purpose instrument taking full advantage of modern technology. It combines a camera with a spectrograph and covers a wide range of wavelengths from the near-infrared region into the ultraviolet.

COSTAR
COSTAR is not really a science instrument: it is the corrective optics package that replaced the High Speed Photometer (HSP) during the first servicing mission. COSTAR was designed to correct the effects of the primary mirror's aberration.

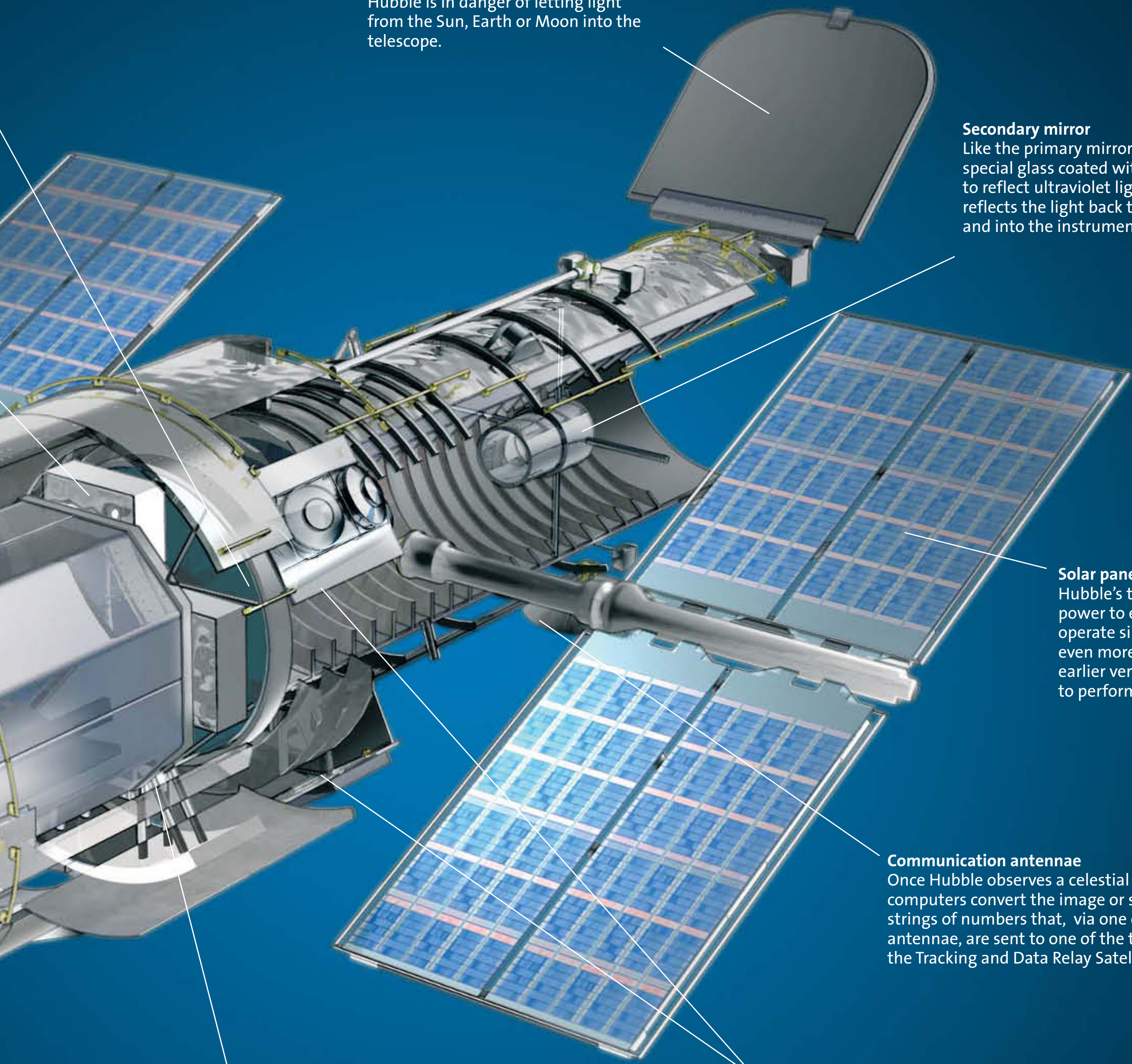
NICMOS
The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) is an instrument for near-infrared imaging and spectroscopic observations of astronomical targets. NICMOS detects light with wavelengths between 800 and 2500 nanometres.

ACS
ACS is a so-called third generation Hubble instrument. Its wide field of view is nearly twice that of Hubble's previous workhorse camera, WFPC2. The name, Advanced Camera for Surveys, comes from its particular ability to map relatively large areas of the sky in great detail.

Hubble exposed

This cutaway view of Hubble shows the configuration of the telescope, the instruments and the many other essential systems that allow it to point, operate and communicate.

ESA



Aperture door
Hubble's aperture door can be closed if Hubble is in danger of letting light from the Sun, Earth or Moon into the telescope.

Secondary mirror
Like the primary mirror, Hubble's secondary mirror is made of special glass coated with aluminium and a special compound to reflect ultraviolet light. It is 1/3 metre in diameter and reflects the light back through a hole in the primary mirror and into the instruments.

Solar panels
Hubble's third set of solar arrays produce enough power to enable all the science instruments to operate simultaneously, thereby making Hubble even more efficient. The panels are rigid and unlike earlier versions, do not vibrate, making it possible to perform stable, pinpoint sharp observations.

Communication antennae
Once Hubble observes a celestial object, its onboard computers convert the image or spectrum into long strings of numbers that, via one of Hubble's two antennae, are sent to one of the two satellites that form the Tracking and Data Relay Satellite System (TDRSS).

Support systems
Containing essential support systems such as computers, batteries, gyroscopes, reaction wheels and electronics.

WFPC2
WFPC2 was Hubble's workhorse camera until the installation of ACS. It records excellent quality images through a selection of 48 colour filters covering a spectral range from far-ultraviolet to visible and near-infrared wavelengths. WFPC2 has produced most of the stunning pictures that have been released as public outreach images over the years.

No single nation could undertake such an enormous project

For astronomers, the most important components of Hubble are its scientific instruments. There are two groups of instruments in Hubble, known as 'radial' – mounted around Hubble's waist; and 'axial' – fitted at the back end of the spacecraft. The different instruments serve different purposes: some are for making images and some are designed to dissect the light from the stars and galaxies by spreading it out to form a rainbow-like spectrum.

Hubble's unique vantage point in space makes it capable of observing over a broader band of wavelengths than ground-based (optical) telescopes. It can observe ultraviolet light that is completely absorbed by Earth's atmosphere. It can also see much more clearly in the near-infrared part of the spectrum where the Earth's sky is very bright and not very transparent. These forms of light reveal properties of celestial objects that are otherwise hidden from us.

Some instruments, like ACS – the Advanced Camera for Surveys – are better for visible and ultraviolet observations, some, like NICMOS – the Near Infrared Camera and Multi-object Spectrograph – are designed for infrared observations.

Different mechanical and electrical components keep Hubble functioning. The power for Hubble comes from solar panels on the side that convert sunlight into electricity. Gyroscopes, star trackers and reaction wheels keep Hubble steady and pointing in the right direction for hours or days at a time: not too close to the Sun, Moon or Earth as they would destroy the light-sensitive instruments; and accurately towards the objects being studied. The Hubble pointing and tracking system is a triumph of engineering and relies on a complex hierarchy of systems that keep the entire spacecraft stable in space to an almost incredible precision. It can point to the same spot on the sky for weeks at a time without deviating by more than a few millionths of the Moon's diameter.

Hubble has several communications antennae on its side that are used for sending observations and other data down to Earth. Hubble sends its data first to a satellite in the Tracking and Data Relay Satellite System, which then downlinks the signal to White Sands, New Mexico, USA. The observations are sent from NASA in the United States to Europe where they are stored in a huge data archive in Munich, Germany.

No single nation could undertake such an enormous project. Hubble has been a major collaboration between NASA and ESA, the European Space Agency, from an early stage in its life. ESA has contributed an instrument, two sets of Solar Arrays, various electronic systems and a substantial group of people to the project.

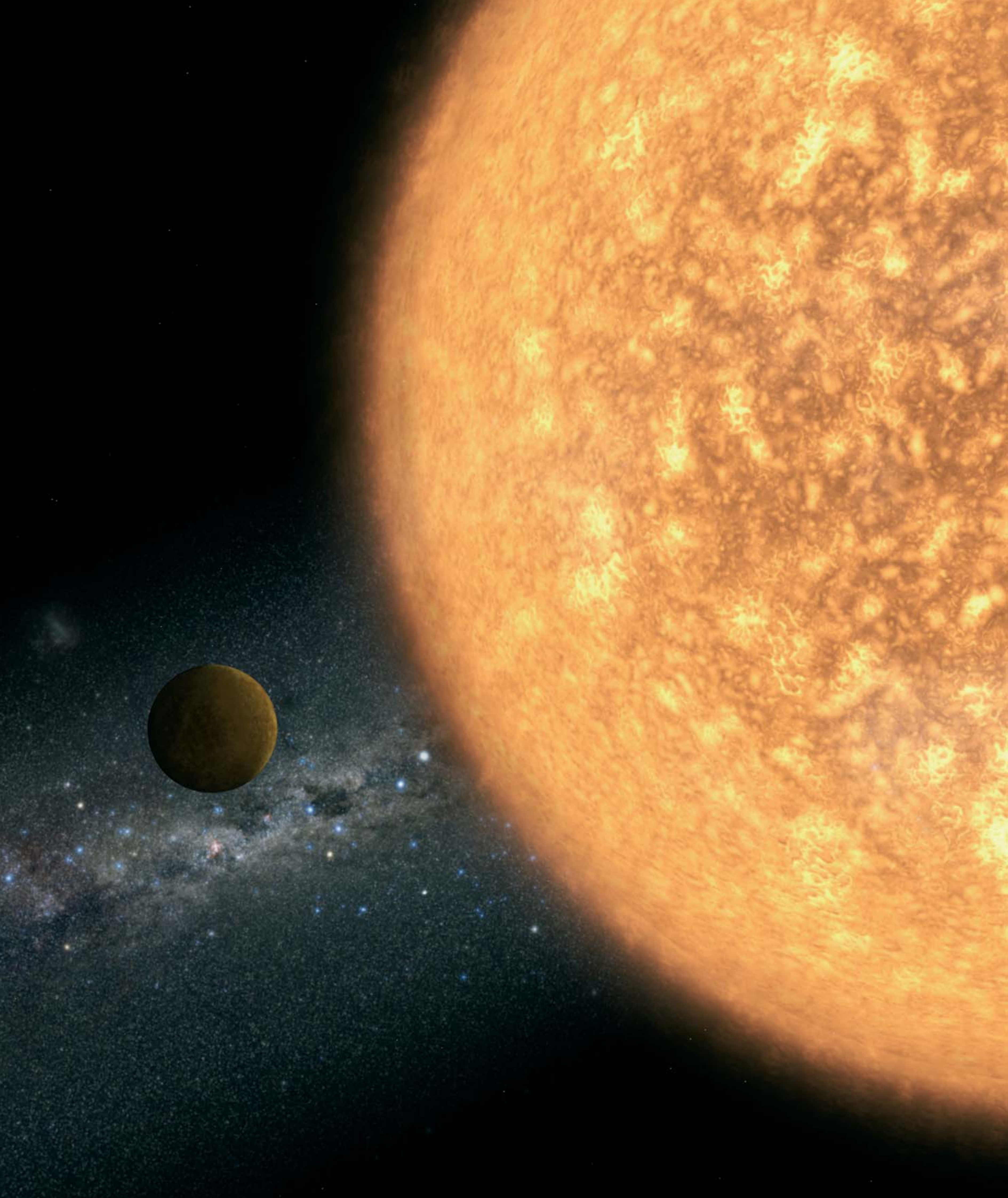
Hubble has been of paramount importance to European astronomy. European astronomers regularly win more than 15 percent of the observing time with Hubble, resulting in several thousand scientific publications over the years. Much of the work done by astronomers with Hubble is complemented by observations made with ground-based and other space telescopes.

Two groups of European specialists work with Hubble. There are 15 people from ESA currently working at the Space Telescope Science Institute in the USA, and 20 others make up the Space Telescope–European Coordinating Facility in Munich, Germany.

Hubble facts

A few of the lesser known facts about Hubble are: it has orbited the Earth more than 80 000 times and travelled nearly 4 billion kilometres – more than 25 times the distance to the Sun. It has made 700 000 exposures of 22 000 different astronomical targets, producing 20 Terabytes of data that have resulted in about 6 000 scientific papers – a very high number even given the considerable outlay on the project.

- Orbital altitude: 568 km
- Orbital time: 96 minutes
- Mission lifetime: 20 years
- Exposures: approx. 700 000
- Different objects observed: approx. 22 000
- Data: more than 20 TB downloaded to Earth
- Distance travelled: 80 000 times around the Earth (nearly 4 billion kilometres)
- Number of scientific papers: approx. 6 000
- Angular resolution: 0.05 arc-seconds
- Wavelength range: 110 – 2400 nm (from ultraviolet to near-infrared)
- Mirror diameter: 2.4 m
- Pointing stability: Hubble moves less than 0.007 arc-seconds in 24 hours
- Costs: ESA's financial contribution over 20 years is 593 million Euros
- Dimensions: 15.9 metres long, diameter 4.2 metres
- Launch Date: 24 April, 1990, 12:33:51 UT
- Weight: 11 110 kg



3 PLANETARY TALES

A 'terrestrial' planet orbiting a sun-like star (artist's impression)
In contrast to the successful searches for massive gas giants like Jupiter, finding small, Earthlike, rocky planets around other stars will be a very difficult task. None have been found yet although experiments are being planned to search for, and eventually to study, them. The goal is, of course, to search for signs of habitation.

Planetary systems are made up of material leftover from the formation of their parent star. Astronomers expect the formation of 'debris disks' to be a common result of star formation and so expect there to be many 'Solar Systems' awaiting discovery: indeed, over the last few years, the first hundred or so of these have already been found around nearby stars. Hubble performs long-term studies of members of our Solar System and has made unique observations of planets in others.

ESA

We are just the leftovers of our Sun's birth

There are no boundaries in space. In this vast Universe, our closest relatives are the objects within the Solar System: we share the same origin and the same destiny.

Our Solar System was formed about four and a half billion years ago from a huge gas cloud. Ironically, it could have been the deadly force of a thermonuclear blast from an exploding star in the vicinity that triggered our creation. The devastating force of the blast may have disturbed the precarious equilibrium of the original gas cloud, causing some of the matter to collapse inwards and creating a new star, our Sun. A minute percentage of the collapsing matter became the multifaceted assembly of planets that we have around us today.

We are, in other words, just the leftovers of our Sun's birth. The planets were born in the rotating disk of dust and gas left behind as our mother star was formed. The rocky planets formed in the inner Solar System while the enigmatic gas giants were formed further out. And then, when a fierce wind of smashed atoms began to blow from the Sun – or perhaps from hot nearby stars or a nearby supernova – only sizable planets could maintain their gaseous surroundings and the last wisps of the tenuous cloud between the planets was whipped away. So, in our Solar System's zoo of celestial bodies there are both rocky worlds and giant gaseous planets.

Even now, there is no exact estimate of how much matter or even how many planets exist within our Solar System. Since Pluto's discovery in the 1930s, and its satellite Charon's in the 1970s, astronomers have tried to figure out if there is anything else out there beyond the ninth planet.

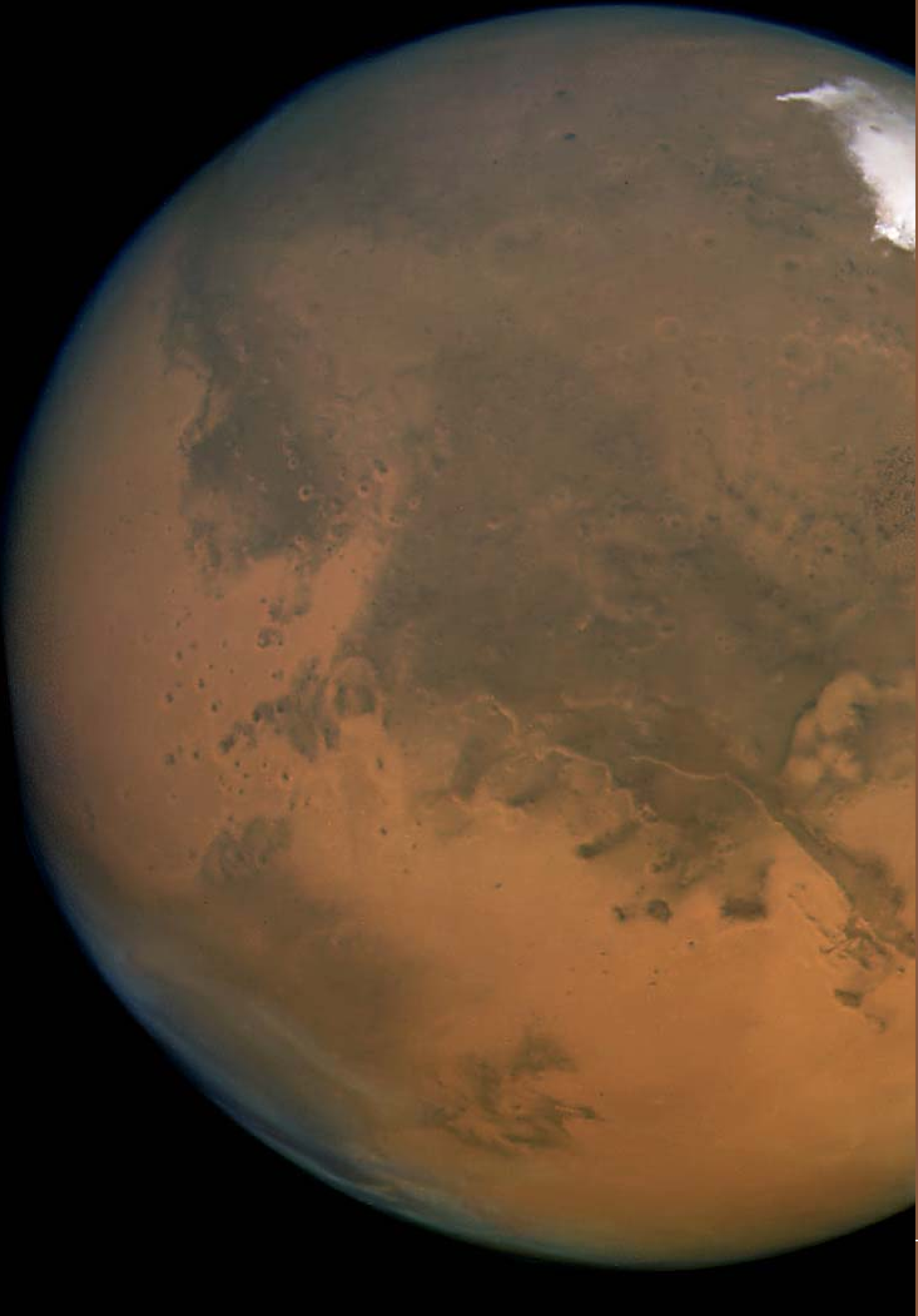
In 2003, Hubble spotted something moving fast enough across the background of faraway stars to be an object within the Solar System. Estimates show that it could be about the size of a planet and it has been named Sedna, after an Inuit goddess. Sedna may be 1500 km in diameter – about three quarters the size of Pluto, but it is so far away that it appears as just a small cluster of pixels even to Hubble. Nevertheless, it is the largest object discovered in the Solar System since Pluto. The Sun is about 15 billion km from Sedna – 100 times further than Earth's distance from the Sun – and barely gives out as much light and heat as the full moon. So Sedna is engulfed in an eternal bleak winter.

Sedna is not the only mysterious object out there. Debris from the formation of the planets is still floating everywhere in the form of asteroids and comets of various shapes and sizes. Sometimes their orbits can lead them on catastrophic courses.

Comet impact

This true colour image of the giant planet Jupiter, taken with Hubble's WFPC2 camera, reveals the impact sites of fragments 'D' and 'G' from Comet Shoemaker-Levy 9.

H. Hammel, MIT and NASA/ESA



NASA/ESA, J. Bell (Cornell U.), and M. Wolff (Space Science Inst.)

Hubble has opened a window on our Solar System that is never closed

Mars up close

This view of Mars, the sharpest photo of it ever taken from the vicinity of Earth, reveals small craters and other surface markings only a few tens of kilometers across. The Advanced Camera for Surveys (ACS) aboard Hubble took this image on the 24th August 2003, just a few days before the red planet's historic 'close encounter' with Earth.

Hubble is able to react quickly to dramatic events occurring within the Solar System. This has allowed it to witness the dramatic plunge of comet Shoemaker-Levy 9 into Jupiter's atmosphere. The comet was torn into numerous pieces by Jupiter's gravitational pull when it passed the massive planet in the summer of 1992. Two years later, these fragments returned and drove straight into the heart of Jupiter's atmosphere.

Hubble followed the comet fragments on their last journey and delivered stunning high-resolution images of the impact scars. Our Earth could easily fit into any of these black bruises. The consequences of the impact could be seen for days afterwards and, by studying the Hubble data, astronomers were able to assemble fundamental information about the composition and density of the giant planet's atmosphere.

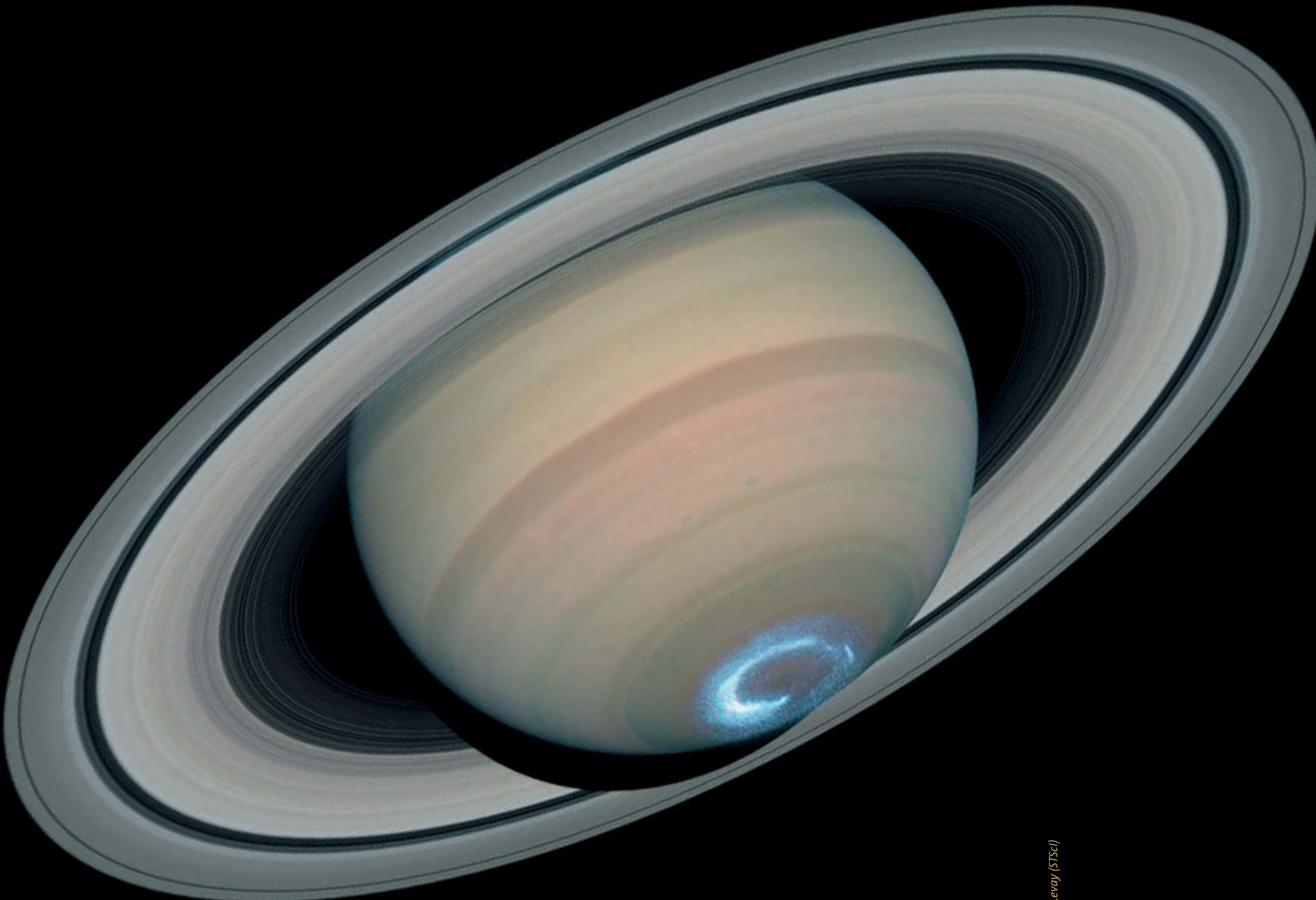
Space probes with sophisticated instruments are frequently sent to the planets of our Solar System. They provide close-up investigations of these distant places. While a few go into orbit around their destination planets and so can monitor them for long periods, most fly by quickly and gather some snapshots on the way. Although Hubble's high resolution images can be surpassed by close-up pictures taken by planetary space probes, Hubble has the advantage of being able to carry out long-term monitoring. This is crucial for the study of planetary atmospheres and geology. Weather systems can reveal much about underlying atmospheric processes.

Hubble provides its own unique service, by opening a window on our Solar System that is never closed. It can be used to monitor almost any planet in the Solar System (Mercury is too close to the Sun) regularly and to provide a long-term view of changes that is impossible to achieve in any other way. This is how we see developing storms on other planets; their changing seasons; and unprecedented views of other atmospheric events, such as aurorae, known on Earth as the northern and southern lights.

Hubble's extremely high resolution and sensitivity have resulted in unique observations of objects within the Solar System, providing amazing images and rich streams of data about the nature of these bodies. Hubble has seen unprecedented detail in Jupiter's aurorae: while similar to those seen above the Earth's polar regions, they are almost 1000 times more energetic and much more complex. Jupiter's aurorae can only be seen in ultraviolet light and, so they can never be studied with ground-based telescopes.

Astonishing images of Saturn's aurorae have also been taken and reveal that the glowing curtains of ultraviolet light rise more than a thousand kilometres above the cloud tops of the planet's north and south poles.

Glowing curtains of ultraviolet light that rise more than a thousand kilometres above the cloud tops



NASA, ESA, J. Clarke (Boston University, USA), and Z. Levay (STScI)

Io's shadow cast on Jupiter

Jupiter's volcanic moon Io zips around Jupiter every 1.8 days. Here, Hubble's WFPC2 captures the 3,640 km diameter moon casting its black shadow on the giant planet.

J. Spencer (Lowell Observatory) and NASA/ESA

Saturn's aurora

Astronomers combined ultraviolet images of Saturn's southern polar region with visible-light images of the planet and its rings to make this picture. The auroral display appears blue because of the glow of ultraviolet light. In reality, the aurora would appear red to an observer at Saturn because of the presence of glowing hydrogen in the atmosphere. The ultraviolet image was taken on 28 January 2004 by Hubble's Imaging Spectrograph (STIS). The ACS was used on 22 March 2004 to take the visible-light image.

Even though the solar system clearly has many more surprises in store for us, Hubble has also turned its eye out towards other stars, looking for planetary systems. Astronomers are beginning their search for life elsewhere in the Universe. The primary objective is to find earth-like planets. These are very much harder to detect than massive 'Jupiters' and, as yet, none have been found.

Hubble had been in orbit for five years when the first planet around a Sun-like star was discovered. Although it was not designed to study these objects, Hubble's versatility has allowed it to make significant contributions to this intensely interesting area of study. For example, Hubble's high resolution has been indispensable in the investigation of the gas and dust disks, dubbed 'proplyds', around the newly born stars in the Orion Nebula. The proplyds may very well be young planetary systems in the early stages of creation. The details revealed by Hubble are superior to anything seen to date with ground-based instruments and, thanks to Hubble's capability, we now have visual proof that dusty disks around young stars are common.

Hubble has also measured the mass of a planet – only the second time such a calculation has been performed with any accuracy – by detecting the way in which the planet causes its star to wobble. Hubble found the oldest planet so far known: it orbits a tiny stellar husk, which was once a blazing star like the Sun, and is located 5,600 light years away. The planet was once like Jupiter and is around 13 billion years old, almost three times older than our own planetary system.

One day we will search for the markers of life beyond Earth

With ground-based telescopes, the gas giant planet HD 209458b, 150 light-years from Earth, was discovered in 1999 through its slight gravitational tug on its 'mother-star'. In 2001 Hubble made highly accurate measurements of the dip in the star's light when the planet passed in front. The first detection of an atmosphere around an extrasolar planet was also made in this object. The presence of sodium as well as evaporating hydrogen, oxygen and carbon was detected in light filtered through the planet's atmosphere as it passed in front of the star.

Measuring the chemical makeup of extra-solar planetary atmospheres will one day allow us to search for the markers of life beyond Earth. All living things breathe and this changes the composition of the atmosphere in readily detectable ways. Light-harvesting plants will impose their own colourful 'biomarkers' on the light reflected from planetary surfaces.

Astronomers believe there are many planetary systems similar to ours orbiting other stars throughout the Galaxy. The birth, life, death and rebirth of stars continues in an unending cycle in which stars, born of gas and dust, will shine for millions or billions of years, die and return as gas and dust to form new stars. The by-products of this continual process include planets and the chemical elements that make life possible.

And so, through the entire vastness of space, the eternal ebb and flow of life continues.

Transiting exoplanet

This artist's impression shows the planet HD 209458b transiting its parent star. Hubble's spectrometer STIS has been used to detect – for the first time – the signature of the giant planet's atmosphere evaporating off into space. Astronomers call HD 209458b a 'hot Jupiter' because it orbits much closer to its star than our own planet of that name.

ESA

4 THE LIVES OF STARS

M17 in Sagittarius

This WFPC2 image, taken in the light of glowing hydrogen (green), oxygen (blue) and sulphur (red), shows a small region within the star-forming Omega or Swan nebula. The wave-like patterns of gas have been sculpted and illuminated by a torrent of ultraviolet radiation from young, massive stars that lie outside the picture to the upper right.

The Sun is a typical star amongst the 100 billion or so in our Milky Way galaxy. Some are more massive – living relatively brief and spectacularly brilliant lives; some are less so and can live longer than the present age of the Universe. Stars are chemical factories, constructing the elements from which we and the Earth are made: most of the atoms in the newly-formed Universe were hydrogen and helium and the stars had to convert this raw material into what we need for life. Some short-lived phases of a star's evolution have produced the most remarkably beautiful structures that Hubble has ever imaged.

European Space Agency, NASA, and J. Hester (Arizona State University)

Jeff Hester and Paul Scowen (Arizona State University), and NASA/ESA

A star is a sphere of glowing gas

Pillars of creation

This image, taken with WFPC2 in 1995, has become a universally recognised icon. Part of M16, the Eagle nebula, these Evaporating Gaseous Globules (EGGs) are protrusions of cool, dusty, molecular gas into hotter, more tenuous material excited by young, hot stars in this nearby star-forming region.

Our Sun, that vital source of energy for life on Earth, is a star. A totally unexceptional star, just like billions of others that we can find throughout the Galaxy.

A star is a sphere of glowing gas. It forms out of a cloud of gas compressed by gravity and releases energy steadily, throughout its life, because a chain of nuclear reactions is continuously taking place in its core. Most stars combine hydrogen atoms to form helium through the process called nuclear fusion; the same process that powers a devastating hydrogen bomb. In fact, stars are nuclear factories that convert lighter elements into heavier elements in a series of fusion reactions. They will keep glowing until they run out of 'fuel'. And that's it; a star's life; a quiet beginning and a steady progress to a sometimes violent end. But how can we be certain of this picture when an individual star like the Sun outlives humans by a factor of a few hundred million?

To investigate the lifecycle of a particular organism on Earth, we don't have to track an individual specimen's entire life. Instead, we can observe many of the organisms at once. This will show us all the different phases of its life cycle. For example, each stage of a person's life is a snapshot of the human experience. And so it is with stars.

Stars live and die over millions, or even billions, of years. Even the most reckless stars live for at least one million years; longer than the entire history of mankind! And this is why it is extremely unusual to be able to track age-related changes in individual stars.

To learn more about stars, we must sample different stars at every stage of life and piece together the whole cycle from birth to death. Hubble's vivid images have documented the tumultuous birth of stars and delivered many astonishing pictures documenting their evolution. The birth of stars in neighbouring stellar 'maternity wards' can be used as a time machine to replay the events that created our Solar System.

Hubble has gone beyond what can be achieved with other observatories by linking together studies of the births, lives and deaths of individual stars with theories of stellar evolution. In particular, Hubble's ability to probe individual stars in other galaxies enables scientists to investigate the influence of different environments on the lives of stars. These are crucial data that allow us to extend our understanding of the Milky Way to other galaxies.

Cosmic recycling

Lighter elements such as carbon, nitrogen, oxygen, silicon are made as a result of fusion reactions taking place in stars. The heavier elements, however, are built during the cataclysmic stellar explosions we know as supernovae. When the Universe was very young — before any stars and galaxies had formed — hydrogen and helium were overwhelmingly its dominant atomic constituents.

Colourful Tarantula

The Tarantula nebula is situated 170,000 light-years away in the Large Magellanic Cloud (LMC), visible to the naked eye in the Southern sky. Supernovae have already detonated in this huge star-forming region and the resulting blast waves have compressed the gas into filaments and sheets. This mosaic of images was created using Hubble archival data by 23 year old amateur astronomer, Danny LaCrue. It was constructed from 15 individual exposures taken through three narrow-band filters.

ESA/NASA, ESO and Danny LaCrue

C.R. O'Dell (Rice University), and NASA/ESA

Hubble's view of Orion

This spectacular colour panorama of the centre of the Orion Nebula is one of the largest pictures ever assembled from individual images taken with the Hubble telescope. The richly detailed tapestry revealed by Hubble shows a churning, turbulent star factory set within a maelstrom of flowing, luminescent gas. Though this 2.5-light-year-wide view is but a small portion of the entire nebula, it includes a star cluster and almost all of the light from the bright glowing clouds of gas that make up the nebula.

Important clues about our genesis lie hidden behind the veil of gently glowing, dust-laden molecular clouds

Hubble has often had to work hard for this information because these important clues about our genesis lie hidden behind the veil of gently glowing, dust-laden molecular clouds where stars are formed.

There are stars forming throughout the Universe. Enormous glowing pillars of dusty hydrogen gas stand sentinel over their cradles, basking in the light of nearby, newly-formed stars.

Hubble's ability to observe infrared light enables it to penetrate the dust and gas and reveal the newly born stars as never before.

One of the most exciting of Hubble's many discoveries was the observation of dust disks surrounding some newborn stars, buried deep inside the Orion Nebula. Here we are actually seeing the creation of new solar systems where planets will eventually form; just as they did in our own Solar System four and a half billion years ago.

In the first stages of their lives, stars can stock up on gas from their original birth cloud. Material falling into the star creates bubbles or even jets as it is heated and blasted along a path that follows the star's rotation axis, like an axle through a wheel.

Often many stars are born from the same cloud of gas and dust. Some may stay together through their whole lifetime, keeping step as they evolve, like the childhood friends that you keep for life.

Mark McCaughrean (Max-Planck-Institute for Astronomy), C. Robert O'Dell (Rice University), and NASA/ESA

Proto-Solar Systems?

Disks around young stars (also known as circumstellar or protoplanetary disks) are thought to be made up of 99% gas and 1% dust. Even that small amount of dust is enough to make the disks opaque and dark at visible wavelengths. These dark disks are seen here because they are silhouetted against the bright backdrop of the hot gas of the Orion nebula.

NASA/ESA, The Hubble Heritage Team (AURA/STScI)

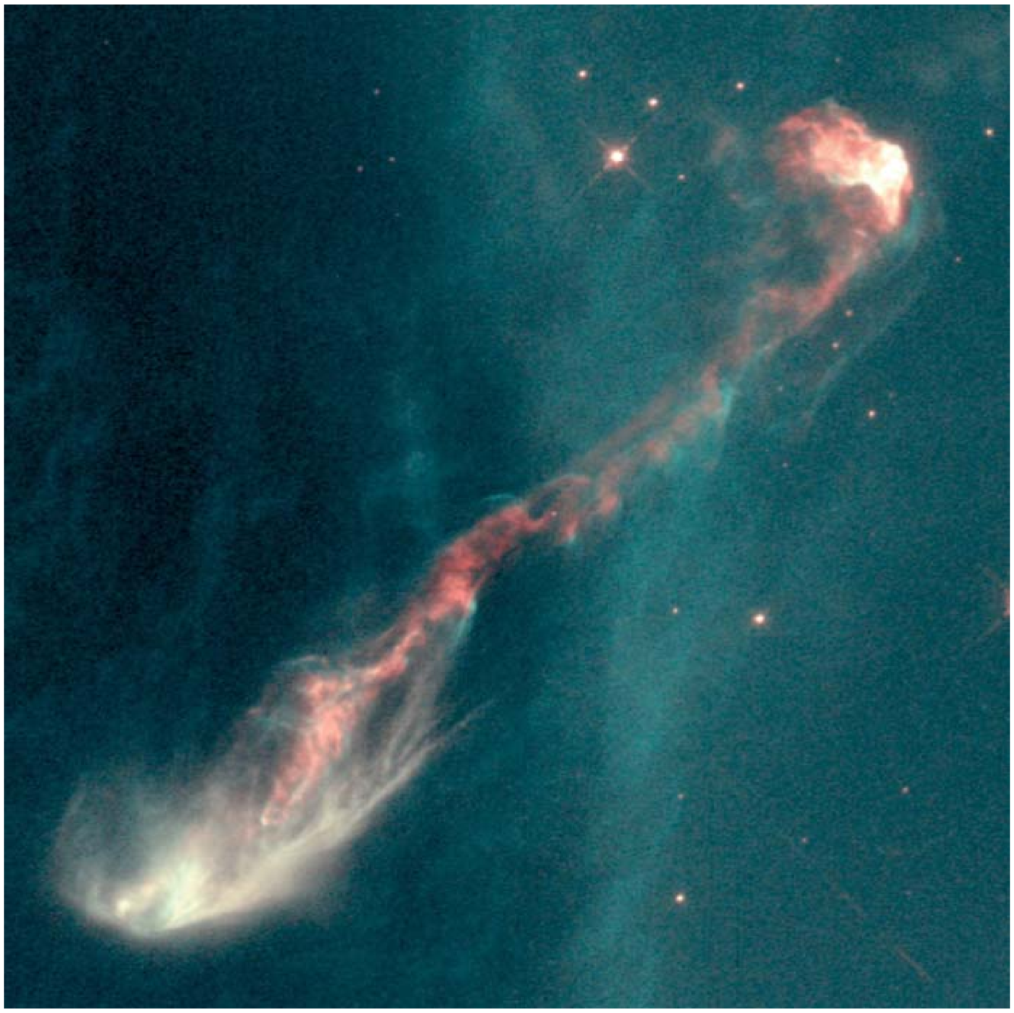
The Carina Nebula

Previously unseen details of a mysterious, complex structure within the Carina Nebula (NGC 3372) are revealed by this image of the 'Keyhole Nebula', obtained using four different pointings of the WFPC2 camera through six colour filters. The picture is dominated by a large, approximately circular feature, which is part of the Keyhole Nebula, named in the 19th century by Sir John Herschel. This region, about 8000 light-years from Earth, is located adjacent to the famous explosive variable star Eta Carinae, which lies just outside the field of view toward the upper right. The Carina Nebula also contains several other stars that are among the hottest and most massive known, each about 10 times as hot, and 100 times as massive, as our Sun.

Human existence is the mere blink of an eye compared with the life of a star

The stars in a cluster will all have the same age, but will have a range of different masses. And this means that very different destinies await them.

Human existence is the mere blink of an eye compared with the life of a star, so the direct observation of a transition between the different stages of a star's life can only come about by lucky chance. Hubble uses its stability and exceptionally sharp focus to



J. Morse/STScI, and NASA/ESA

Young star's jet

This view of a 5 trillion kilometre long jet called HH-47 reveals a very complicated jet pattern which indicates the star (hidden inside a dust cloud near the left edge of the image) might be wobbling, possibly caused by the gravitational pull of a companion star.

reveal changes on cosmic scales over periods of only a few years. From the ground it is usually not possible to see this kind of evolution taking place over such short periods. In the Universe, this sort of action normally takes place on timescales of many thousands or even millions of years, so being able to follow real time changes in astronomical objects is a considerable asset.

At the other extreme of the stellar life cycle, Hubble has monitored Supernova 1987A since 1991, four years after it exploded. The result is a series of stunning observations that show the evolution following the violent explosion witnessed nearly two decades ago.

The regular monitoring of an even older supernova remnant, the Crab Nebula, has enabled Hubble to capture the display of matter and antimatter particles propelled close to lightspeed by the Crab pulsar, a rapidly rotating neutron star. Thanks to Hubble, scientists can directly follow the motion of the gas remnant left behind by the supernova explosion witnessed by Chinese astronomers in 1054.

Not all elderly stars end their lives as supernovae and Hubble has followed the final stages of their lives, with their very different outcomes. One such elderly star V838 Monocerotis, located about 20,000 light-years from Earth put out a brief flash of energy that illuminated the surrounding dust. The progress of the light echo across the dust was captured by Hubble in a film-like sequence of unprecedented clarity.

The stars containing the most mass end their lives cataclysmically, destroying themselves in titanic stellar explosions known as supernovae. For a few glorious months, each becomes one of the brightest objects in the entire Universe, outshining all the other stars in its parent galaxy.

Since its launch in 1990, Hubble has watched the drama unfold in Supernova 1987A, the nearest exploding star in modern times. The telescope has been monitoring a ring of gas surrounding the supernova blast.

Hubble has observed the appearance of bright spots along the ring, like gemstones on a necklace. These cosmic ‘pearls’ are now being lit by supersonic shocks unleashed during the explosion of the star.

The ruins of an exploding star can hide a powerful engine. Hubble has probed the mysterious heart of the Crab Nebula, the tattered remains of an exploding star, vividly described by Chinese astronomers in 1054, and has revealed its dynamic centre. The innermost region of this nebula harbours a special type of star, a pulsar. This star rotates like a beacon, emitting light and energy in a beam. And it energizes and illuminates the vast nebula of dust and gas surrounding it.

Light echo movie

In fifteen highly productive years, Hubble has allowed us to observe some stars ageing in real time. The telescope has produced startling ‘movies’ that allow us to witness how some of them do modify their appearance over this minute span of astronomical time.

NASA/ESA/ASU/J. Hester et al.

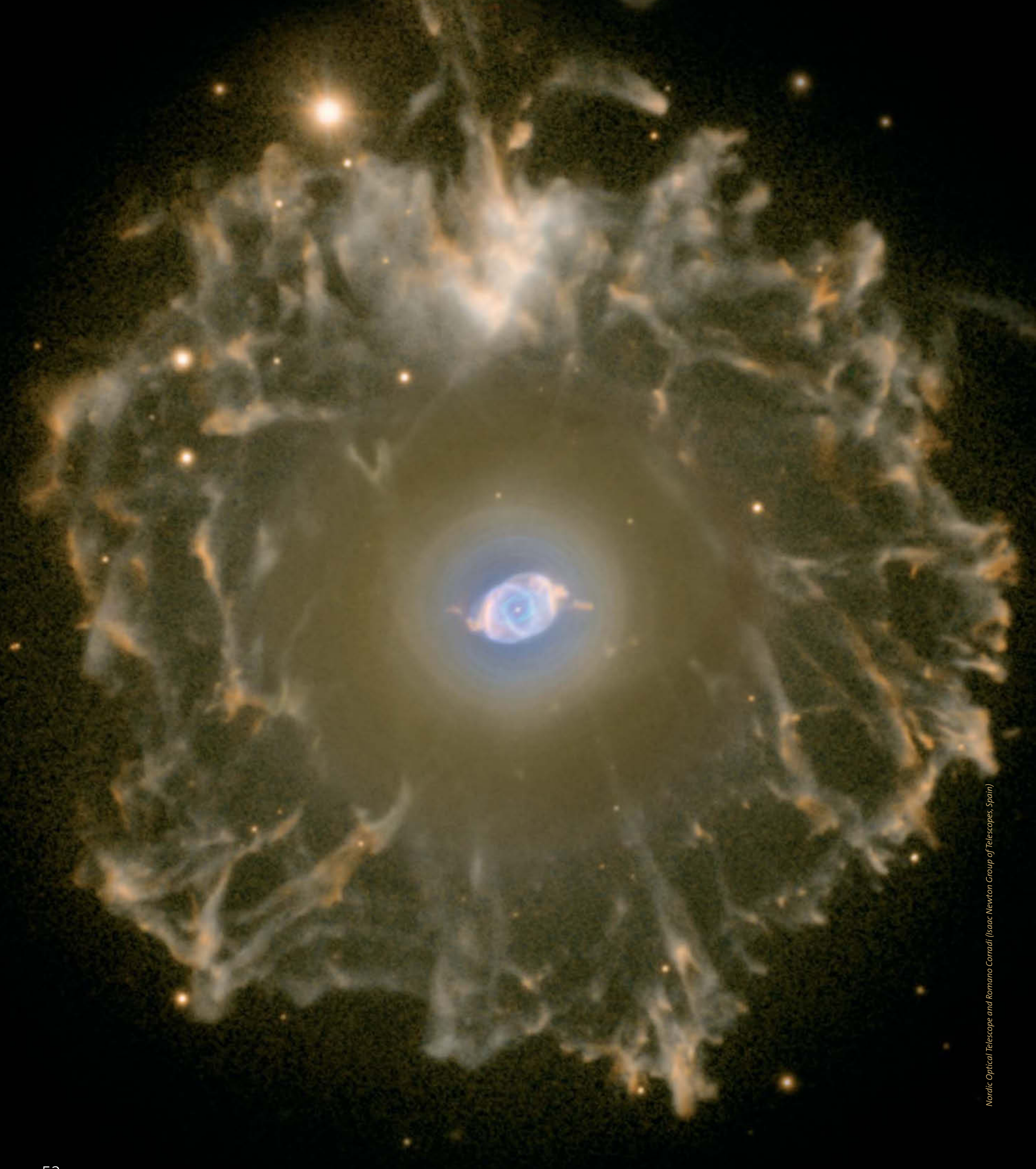
The Crab Nebula

Much of the light emitted by an object like the Crab Nebula comes from what astronomers call a ‘non-thermal’ process. Electrons, travelling at speeds close to that of light, spiral around lines of magnetic field and so produce radiation covering the entire electromagnetic spectrum, from X-rays to radio waves. This is why the pictures of the Crab taken in X-rays and optical light look so similar. This is a composite image of the Crab Nebula showing the X-rays (blue), and optical (red) radiation.

NASA, the Hubble Heritage Team (AURA/STScI) and ESA

V838 Monocerotis

Some of the most impressive celestial 'movies' are created by pulses of light travelling out from a stellar explosion like a flash from a camera. As the 'sphere of light' expands away from its origin, it can illuminate surrounding material to produce what we call 'light-echoes'. These produce the illusion of material in rapid motion while, in reality, it is the pulse of light that is moving.



Nordic Optical Telescope and Romano Corradi (Isaac Newton Group of Telescopes, Spain)

The Sun will swallow Mercury, Venus and our planet as well

Wide angle Cat's Eye

Wide angle view of the enormous but extremely faint halo of gaseous material surrounding the Cat's Eye Nebula showing material ejected during earlier active episodes in the star's evolution. This probably happened some 50,000 to 90,000 years ago.

However, not all stars end their lives so violently. Sun-like stars cool down once they run out of hydrogen. The centre collapses in on itself and the heavier elements are burnt, causing the outer layers to expand and leak slowly into space. At this stage in a star's life, it is called a "red giant".

Our Sun will become a "red giant" in a few billion years. At that time, it will expand so much that it will swallow Mercury, Venus and our planet as well.

But these stars are not finished quite yet. They can still evolve into something extraordinary. Just before they breathe their last breath, stars like our Sun go out in a final blaze of glory.

In its final stages of nuclear fusion, stellar winds blow from the star, causing the remnants of the red giant to swell to an enormous size. At the heart of this expansion, the exposed heart of the star, an intensely hot dwarf, floods the gaseous envelope with powerful ultraviolet light, making it glow in a whole range of beautiful colours.

ESA, NASA, HEIC and The Hubble Heritage Team (STScI/AURA)

Hubble's close up view of the Cat's Eye

Detailed view from Hubble focussing on central regions of the Cat's Eye Nebula seen on the previous page. Although this nebula was among the first planetary nebula ever to be discovered, it is one of the most complex planetary nebulae ever seen in space. A planetary nebula forms when Sun-like stars gently eject their outer gaseous layers to form bright nebulae with amazing twisted shapes.

A Collection of Planetary Nebulae

Hubble's dazzling collection of planetary nebulae show surprisingly intricate, glowing patterns: sprinkling jets, pinwheels, ghostly filaments, supersonic shocks, concentric rings and intricate tendrils of gas and fiery lobes. With their gauzy symmetrical wings of gas they resemble butterflies.

ESA

Since these amazing constructions looked a bit like the newly discovered planet Uranus to early telescopic astronomers, they became known as planetary nebulae. From telescopes on Earth they look like round (planet-shaped) objects with fairly simple geometries. Hubble's keen perception shows that each planetary nebula is a distinct individual. How a normal Sun-like star evolves from a relatively featureless gas sphere to a nebula with intricate glowing patterns is still one of the unsolved mysteries in astronomy. Each additional image of the glowing patterns of gas intrigues astronomers anew.

From its unique position high above the distorting atmosphere Hubble is the only telescope that can observe the swollen outer envelope of these dying stars in full detail.

Hubble has been able to observe the expansion of the nebula itself directly. The Cat's Eye Nebula, for instance, has been observed with Hubble over a period of eight years and is a marvellous example of the resolving power of the telescope.

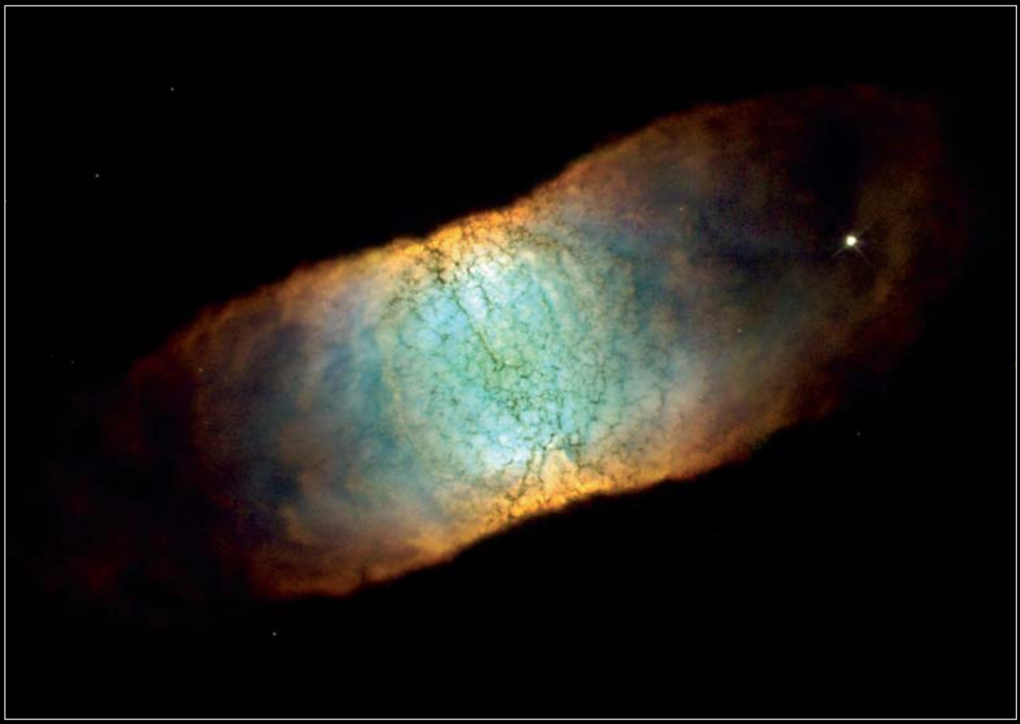
Colours of Planetary Nebulae

The intensely hot stars at the centres of planetary nebulae flood the surrounding volume of gas with ultraviolet light. This causes the atoms in the gas to lose one or more of their electrons. The resulting 'ions' radiate their energy away in a series of discrete colours that astronomers can observe to measure gaseous temperatures, densities, chemical composition and motions.

One of the greatest mysteries in modern astrophysics is how a simple, spherical gas ball can give rise to these intricate structures!

IC 4406, the Retina nebula

Hubble reveals a rainbow of colours in this dying star, called IC 4406. Like many other so-called planetary nebulae, IC 4406 exhibits a high degree of symmetry. The nebula's left and right halves are nearly mirror images of one another. If we could fly around IC 4406 in a spaceship, we would see that the gas and dust form a vast doughnut of material streaming outward from the dying star.



NASA/ESA and The Hubble Heritage Team (STScI/AURA)

One of the greatest mysteries in modern astrophysics is how a simple, spherical gas ball such as our Sun can give rise to these intricate structures!

For some planetary nebulae it is as if a cosmic garden sprinkler created the jets that stream out in opposite directions; or could these amazing patterns possibly be sculpted by the magnetic field of a companion star that funnels the emitted gas into a jet?

Whatever their cause, in only ten thousand years these fleeting cosmic flowers disperse in space. Just as real flowers fertilize their surroundings as they decompose, the chemical elements produced inside the star during its life are dispersed by the planetary nebula to nourish the space around it, providing the raw material for new generations of stars, planets and possibly even life.

Because they disappear so quickly on a cosmic timescale there are never more than about 15,000 planetary nebulae at any one time in our Milky Way.

A more lasting monument to the dead star is the tiny heart it leaves behind. Known as a white dwarf, each of these exceptionally dense, Earth-sized stars are fated to spend the rest of eternity gradually leaking their residual heat into space, until eventually, in many billions of years, they approach the frigid -270°C of space. Hubble was the first telescope to observe white dwarfs in globular star clusters directly. White dwarfs provide a 'fossil' record of their progenitor stars that once shone so brightly that they long ago exhausted their nuclear fuel. These measurements make it possible to determine the ages of these ancient clusters – a critical cosmological datum for astronomers.

The Double Cluster NGC 1850

Found in one of our neighbouring galaxies, the Large Magellanic Cloud (LMC), this young globular-like star cluster is an eye-catching object. NGC 1850 is a type of object unknown in our own Milky Way galaxy and is surrounded by a pattern of filamentary nebulosity thought to have been created during supernova blasts.

ESA, NASA and Martino Romaniello (European Southern Observatory, Germany)

5 COSMIC COLLISIONS

The core of the Antennae
Orange blobs, left and right of image centre, crisscrossed by filaments of dark dust are the nuclei of twin galaxies. A wide band of chaotic dust, called the overlap region, stretches between them. Sweeping spiral-like patterns, traced by bright blue star clusters, show the result of a firestorm of star birth activity that was triggered by this monster collision of galaxies. This is a WFPC2 image released in 1997.

On the hundred thousand light-year scale of a galaxy, stars are minute particles. During the long history of the Universe, many galaxies have collided and sometimes merged with one another, but huge interstellar distances mean that a direct collision between two stars is highly unlikely. However, the gas and dust drifting in interstellar space does interact strongly, producing shocks and triggering firework displays of starbirth. Computer simulations of colliding galaxies create a ballet of shape and motion that show the slow, majestic workings of gravity.

Brad Whitmore (STScI), and NASA/ESA

We live inside a huge star system, or galaxy, known as the Milky Way

We live inside a huge star system, or galaxy, known as the Milky Way. Seen from outside, the Milky Way is a gigantic spiral, consisting of a central hub embraced by long arms. The whole system slowly rotates. Between the stars are vast amounts of gas and dust – that we can see – and some unknown material called 'Dark Matter' that is invisible to us.

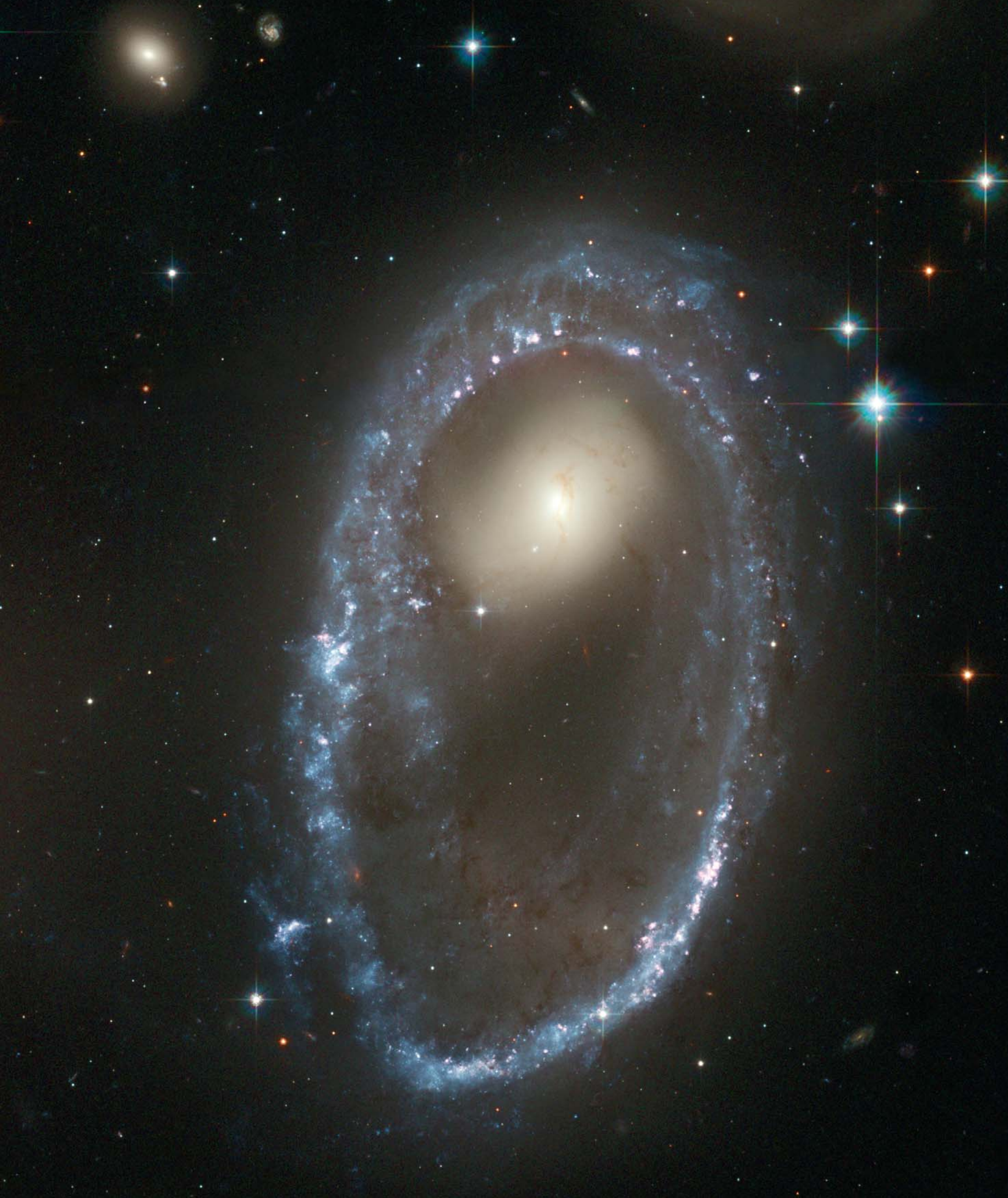
Far from the centre, out in one of the arms, the outer suburbs of the Milky Way, is a tiny star system, our home, the Solar System. When we look up on a clear night, we can see about 5000 of the brightest stars. Most of these are our closest neighbours, but a few are more distant and appear bright because of their great luminosity.

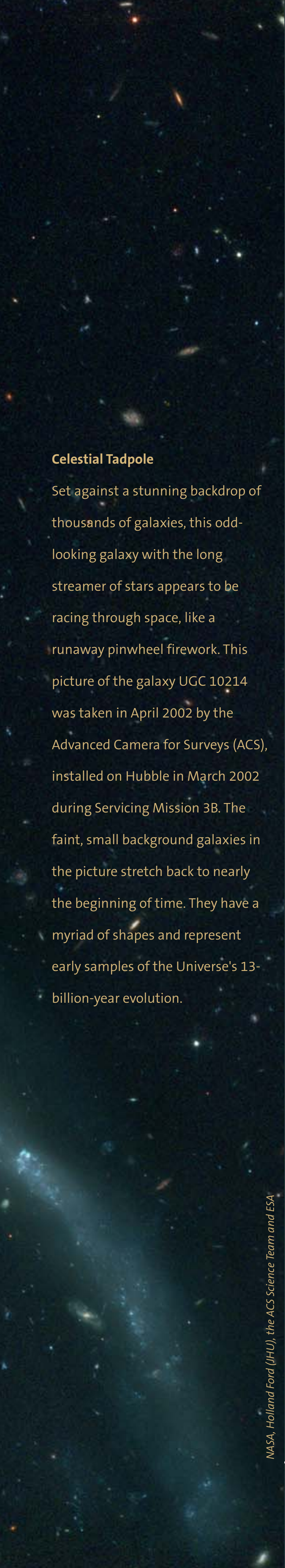
Our eyes struggle to see beyond a thousand light-years because of the dust that blankets space and dims the distant starlight. So without a telescope we can only see a minute portion of the entire 100,000-light-year-wide Milky Way. For the Milky Way contains several hundred billion stars, many like our own Sun! Although several hundred thousand million is an almost unfathomable number, it is only the beginning. Astronomers believe there are more than a hundred billion galaxies in the Universe. How many stars would that be?

In a handful of sand there can easily be 50,000 individual grains of sand. Even so, on an entire beach there are only just enough grains of sand to represent each star in the Milky Way. There are so many stars in the Universe that we would need to count every grain of sand on every beach on the entire Earth to get anywhere near the right number!

Ring galaxy AM 0644-741

Resembling a diamond-encrusted bracelet, a ring of brilliant blue star clusters wraps around the yellowish nucleus of what was once a normal spiral galaxy. The sparkling blue ring is 150,000 light-years in diameter, making it larger than our entire home galaxy, the Milky Way. The galaxy, catalogued as AM 0644-741, is a member of the class of so-called 'ring galaxies'. Ring galaxies are an especially striking example of how collisions between galaxies can dramatically change their structure, while also triggering the formation of new stars. They arise from a particular type of collision, in which one galaxy plunges directly through the disk of another one. The ring is continuously forming massive, young, hot stars, which are blue in color. Another sign of robust star formation is the pink regions along the ring. These are rarefied clouds of glowing hydrogen gas, fluorescing because of the strong ultraviolet light from the newly formed massive stars.





Celestial Tadpole

Set against a stunning backdrop of thousands of galaxies, this odd-looking galaxy with the long streamer of stars appears to be racing through space, like a runaway pinwheel firework. This picture of the galaxy UGC 10214 was taken in April 2002 by the Advanced Camera for Surveys (ACS), installed on Hubble in March 2002 during Servicing Mission 3B. The faint, small background galaxies in the picture stretch back to nearly the beginning of time. They have a myriad of shapes and represent early samples of the Universe's 13-billion-year evolution.

NASA, Holland Ford (JHU), the ACS Science Team and ESA

Our life spans are nothing but brief drops in the universal ocean of time

Let’s take a grain of sand, 1 mm across, and place it to represent the size of the Sun. If we started walking towards the nearest star it would take us the better part of a day to complete the journey because the star would be nearly 30 kilometres away.

So, galaxies are mostly large collections of emptiness. If we could squeeze together all the stars in the Milky Way, they would easily fit into the volume of space between our Sun and the nearest star. In fact, to completely fill that volume, we would have to pack in all the stars from all the galaxies in the entire Universe!

When looking at the night sky, the Universe seems motionless. This is because our life spans are nothing but brief drops in the universal ocean of time. In fact, the Universe is in constant motion, but we would need to watch for vastly longer than a lifetime to perceive that motion in the night sky.

Given enough time, we would see stars and galaxies move. Stars orbit the centre of the Milky Way and galaxies are pulled together by each other’s gravity. Sometimes they even collide. Hubble has observed numerous galaxies crashing together.

Hubble's beautiful images of galaxies excite us for many reasons. The whirlpool forms, pastel colours of stellar and nebular light and dark contrasting dust lanes are aesthetically pleasing, but the immense scale in space and time that these vast islands of stars represent also leaves us awestruck. The intricate patterns in spiral galaxies and especially those systems of galaxies that are apparently interacting evoke a complex dynamic Universe. Hubble's pictures alas are just snapshots capturing a single moment in a slow evolution that lasts much longer than our puny human lifetimes.

What do the colours of the galaxies mean?

Most of the Hubble galaxy images in this book are constructed to represent approximately ‘true’ colour. Most of the light is coming from shining stars. The relatively rare massive stars are hot and blue and so bright that, in spite of their relatively small numbers, they contribute a substantial part of the total light. These massive stars are short-lived and are found in stellar nurseries shrouded in gas and dust. The ultraviolet light from them excites the gas and makes it glow brightly in several discrete colours, most notably the red of hydrogen and the green of oxygen. Less massive — and more numerous — stars shine with pastel shades from blue-white to orange-red, depending on their temperature, which in turn depends on their mass. The palette is completed by the effects of dust. Light shining through the clouds of dust is dimmed and reddened, a little like the setting sun. We generally see this as a rather dirty brown tint associated particularly with the stellar nurseries.


NASA, Holland Ford (JHU), the ACS Science Team and ESA

The Mice

Located 300 million light-years away in the constellation Coma Berenices, these colliding galaxies have been nicknamed 'the Mice' because of the long tails of stars and gas emanating from each galaxy. Otherwise known as NGC 4676, the pair will eventually merge into a single giant galaxy.

Like majestic ships in the grandest night, galaxies can slip ever closer until their mutual gravitational interaction begins to mould them into intricate figures that are finally, and irreversibly, woven together

Like majestic ships in the grandest night, galaxies can slip ever closer until their mutual gravitational interaction begins to mould them into intricate figures that are finally, and irreversibly, woven together. It is an immense cosmic dance, choreographed by gravity. When two galaxies collide, it's not like a car crash or two billiard balls hitting each other, it is more like interlocking your fingers. Most of the stars in the galaxies will pass unharmed through the collision. The chance of two stars actually colliding is miniscule, so vast are the distances between them.

At worst, gravity will fling them out, along with dust and gas to create long streamers that stretch a hundred thousand light-years or more. The two galaxies, trapped in their deadly gravitational embrace, will continue to orbit each other, ripping out more gas and stars to add to the tails. Eventually, hundreds of millions of years afterwards, the two galaxies will settle into a single, combined galaxy.

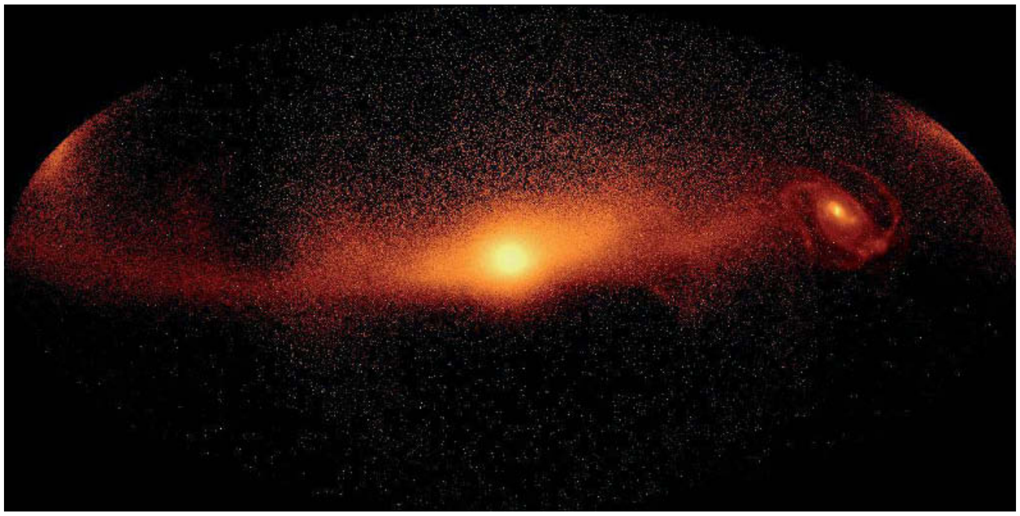
It is believed that many present-day galaxies, including the Milky Way, were assembled from such a coalescence of smaller galaxies, occurring over billions of years.

Triggered by the colossal and violent interaction between the galaxies, stars form from large clouds of gas in firework bursts, creating brilliant blue star clusters.

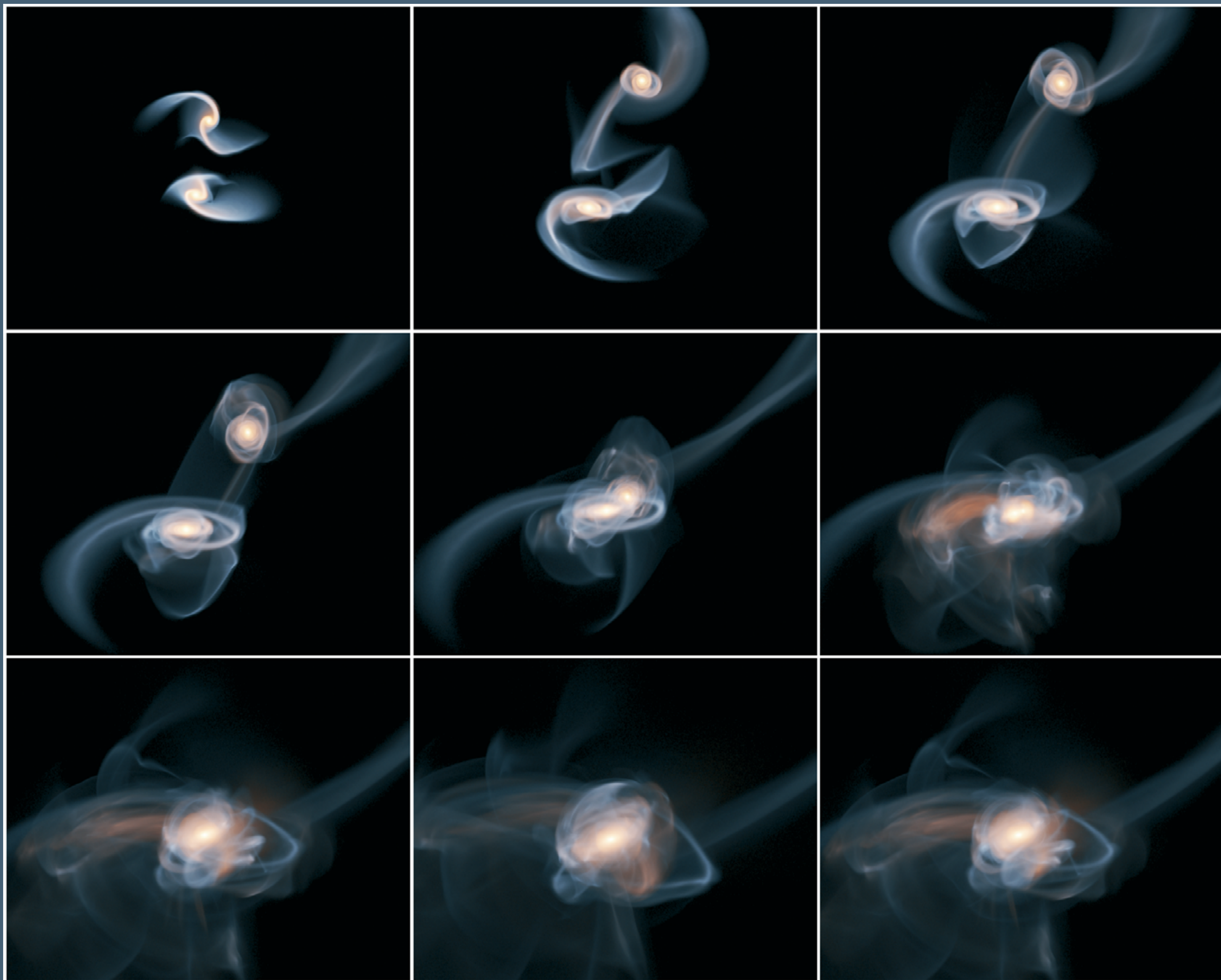
Our own Milky Way is on a collision course with the nearest large galaxy, the Andromeda galaxy. They are approaching each other at almost 500,000 kilometres per hour and, in three billion years, will collide head-on. The direct collision will lead to a magnificent

Andromeda galaxy and the Milky Way collision

Seen from the Earth the collision between the Andromeda galaxy and the Milky Way in three billion years will look something like this.



John Dubinsky



John Dubinsky

Galaxies in close embrace

Modern computer simulations of colliding galaxies reveal the intricate patterns of stellar orbits as gravity plays its part in the grand evolutionary scheme of the Universe.

It is an immense cosmic dance, choreographed by gravity

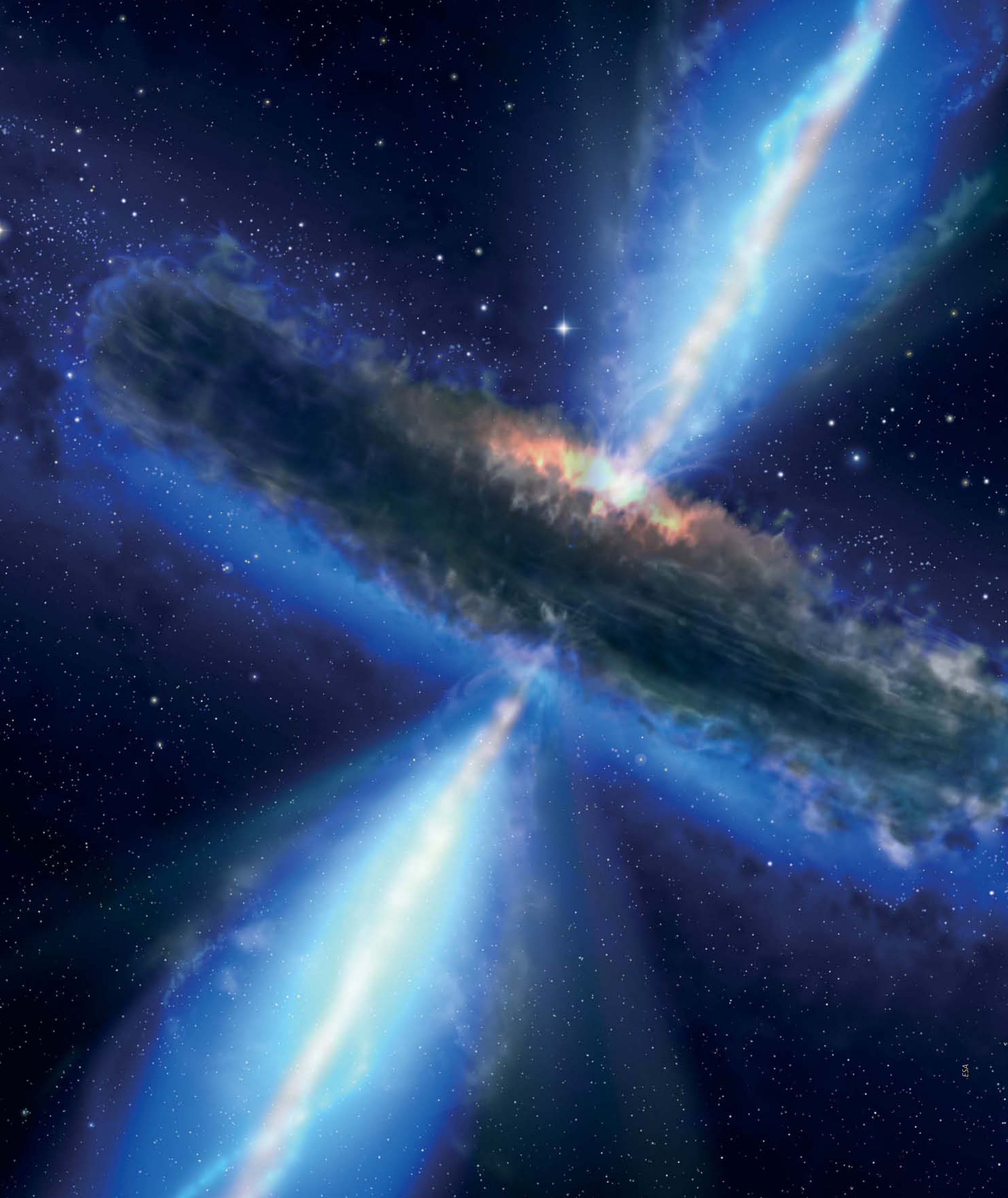
merger between the two galaxies, during which the Milky Way will no longer be the spiral galaxy we are familiar with. Instead, it will evolve into a huge elliptical galaxy, containing its own stars and those of the Andromeda galaxy as well.

Although this will not happen for a very long time, there are other dark forces of nature in play everywhere around us.

NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

Dust and red star clusters in NGC 1316

Surprisingly complex loops and blobs of cosmic dust pervade in the giant elliptical galaxy NGC 1316. NGC 1316's violent history is evident in various ways. The inner regions of the galaxy shown in the Hubble image reveal a complicated system of dust lanes and patches. These are thought to be the remains of the interstellar medium associated with one or more of the spiral galaxies it swallowed. Scattered around the galaxy, the red star clusters provide clear evidence of a major collision of two spiral galaxies that merged together a few billion years ago.


ESA

6 MONSTERS IN SPACE

Doughnuts and supermassive black holes

This artist's impression shows the dust torus around a supermassive black hole. Black holes lurk at the centres of active galaxies in environments not unlike those found in violent tornadoes on Earth. Just as in a tornado, where debris is found spinning about the vortex, so, in a black hole, a dust torus surrounds its waist. In some cases astronomers can look along the axis of the dust torus from above or below and have a clear view of the black hole. Technically these objects are then called 'type 1 sources'. 'Type 2 sources' lie with the dust torus edge-on as viewed from Earth so that our view of the black hole is totally blocked by dust over a range of wavelengths from the near-infrared to soft X-rays.

Black holes are formed when gravity overwhelms all the other forces that shape matter. They are found as remnants of massive stars and, in even more massive versions, at the centres of most – if not all – galaxies. They are fascinating objects with weird properties and impose their influence on the surrounding matter and light. The most spectacular manifestations of such supermassive black holes are quasars. Matter pours into a vast black hole at a galactic core and this accretion results in a brightness that far exceeds the sum of all the hundreds of billions of individual stars that constitute the host galaxy.

There is no way to find out what is in there. Not even light can escape. So how do we know that they are even there?

Although the existence of black holes has been hypothesized for more than 200 years, a central tenet of the theory is that a black hole will be impossible to observe directly. X-ray satellites had hinted that black holes existed by detecting the emission of X-rays from superheated gas as it was consumed by the black hole. Then, along came Hubble: its high resolution made it possible to see the gravitational effects on matter surrounding the largest black holes in the Universe. Hubble has also shown that a black hole is most likely to be present at the centres of most galaxies. This has important implications for theories of galaxy formation and evolution since it implies that the black hole could be the 'seed' that triggers a galaxy's formation.

Black holes are the enigmatic villains of the Universe: swallowing all that comes their way and allowing nothing to escape from within their gravitational stronghold. There is no way to find out what is in there. Not even light can escape. So how do we know that they are even there?

Black holes themselves cannot be observed directly. However, astronomers can study the indirect effects of black holes because the one thing they have in abundance is gravity.

Astronomers believe that black holes are singularities – simple points in space. No volume, no extension, but infinitely dense, black holes can be created during the final collapse of a massive star, many times the size of the Sun.

The stellar corpse left over from the demise and collapse of a massive star can be so heavy that no force in nature can keep it from crumpling under its own weight into an infinitely small volume. Although the matter has apparently disappeared, having been compacted into nothingness, it still exerts a powerful gravitational pull and stars and other objects that come too close can be pulled in.

For any black hole there is a point of no-return, called the "event horizon". Once something – a nearby star say – is pulled in past this point it will never be seen again. On its way towards the event horizon, the doomed star will begin to follow a fatal, spiralling orbit.

As the star approaches the black hole still further, the matter closest to the hole feels a greater attraction than the rest of the star, sucking and stretching the star out towards the hole until the immense tidal forces pull it to pieces and devour it.

There are quirkier aspects to these objects too, a twisting of space and time that warps and slows even the passage of time. All objects with a mass deform the very fabric of space and time, but black holes do this to an extreme degree.

Black Eye Galaxy

A relic of two colliding galaxies, the merged star system, Messier 64 has a spectacular dark band of absorbing dust in front of the galaxy's bright nucleus, giving rise to its nickname the 'Black Eye Galaxy'. Fine details of the dark band are revealed in this image of the central portion of Messier 64 obtained with the Hubble Space Telescope. Hubble has found that black holes reside at the centre of most galaxies, such as the Black Eye Galaxy.

NASA/ESA and The Hubble Heritage Team (AURA/STScI)

A wormhole is essentially a ‘shortcut’ through spacetime

According to Einstein’s famous Theory of General Relativity, an intrepid traveller who could visit a black hole and hang above the event horizon without being swallowed would eventually return to find himself younger than the people he had left behind.

Perhaps the most curious objects astronomers have hypothesized about are wormholes. A wormhole is essentially a ‘shortcut’ through spacetime from one point in the Universe to another point in the Universe. Maybe wormholes, if they exist, will some day allow travel between regions in space faster than it would take light to make the journey through normal space.

Hubble’s high resolution has revealed the dramatic distorting effects of black holes on their surroundings. Hubble has shown that black holes are most likely to be present at the centre of most galaxies. There is one at the centre of our Milky Way – a giant, supermassive black hole, perhaps a million times bigger than those created from the collapse of massive stars. It may have shone much more brightly in the past, making the Galaxy appear very active. This may happen again in the future: we know that such objects can wax and wane over thousands or millions of years.

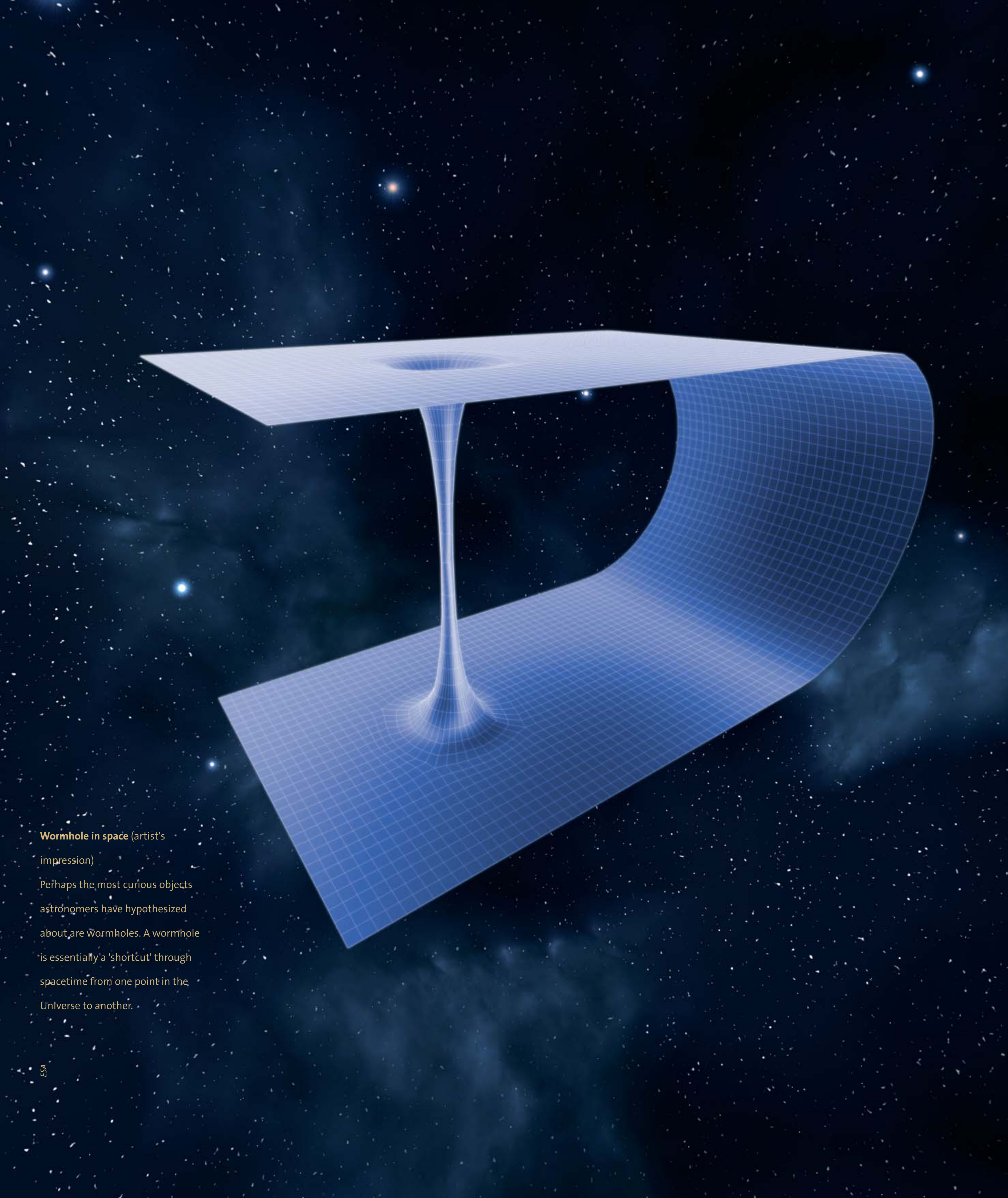
Our black hole could be the result of the merger of many star-sized black holes that were formed during the remote history of the galaxy. When two galaxies collide, the black holes at each of their centres will perform an elaborate dance. Long after the two galaxies have merged into one, their central black holes continue to orbit each other for hundreds of millions of years before their final violent merger into a single, weighty black hole. This final process is so powerful that it changes the fabric of spacetime enough that we may be able to observe it from the Earth with a new breed of gravitational-wave telescopes or from special spacecraft in orbit.

Disks around supermassive black holes

Two active galactic cores, NGC 7052 and NGC 4261 reveal their waist-girdling disks of gas and dust to WFPC2 on Hubble. This material is the reservoir of fuel that powers the quasar.

Roeland P. van der Marel (STScI), Frank C. van den Bosch (Univ. of Washington), and NASA/ESA

L. Ferrarese (Johns Hopkins University) and NASA/ESA



Wormhole in space (artist's impression)
Perhaps the most curious objects astronomers have hypothesized about are wormholes. A wormhole is essentially a 'shortcut' through spacetime from one point in the Universe to another.

ESA

Astronomers thought the Universe was a mostly peaceful place....

However, compared with the millions of years it takes for galaxies to merge, the final cataclysm at the cores would be relatively brief. So the odds of seeing such an event are small.

Until as recently as 50 years ago, astronomers thought the Universe was a mostly peaceful place. But we now know that this is far from reality. Space is often shaken by violent events: cataclysmic explosions of supernovae, collisions of whole galaxies and the tremendous outpouring of energy due to the large amount of matter crashing into black holes.

The discovery of quasars gave us the first clear glimpse of this turmoil. To groundbased telescopes, quasars look like normal stars. And that is exactly what astronomers first thought they were, naming them "Quasi stellar" objects. However, quasars are in fact much brighter and further away than stars. They can shine more brightly than 1,000 normal galaxies and are powered by supermassive black holes.

Hubble has now observed several quasars and found that each resides at the centre of a galaxy. Today most scientists believe that all quasars are powered by a central, supermassive black hole that may weigh as much as a few billion Solar masses.

Stars that orbit too close are pulled apart, draining into the quasar like water into an enormous cosmic plug-hole. The spiralling gas forms a thick disk, heated to a high temperature by its free-fall motion towards the black hole. The gas blasts its energy into space above and below the disk in colossal jets.

Quasars are found in a wide range of galaxies, many of which are violently colliding. There appear to be a variety of mechanisms for igniting quasars. Collisions between pairs of galaxies could trigger the birth of quasars, but Hubble has shown that even apparently normal, undisturbed galaxies harbour quasars.

Quasars are driven by supermassive black holes

The spinning supermassive black holes that drive quasars are generally wrapped in a thick, opaque belt of dusty gas that slowly feeds material into the core. This means that, from some directions, the quasar is hidden from our direct view and we see the results of its prodigious energy production only indirectly. It took several decades for astronomers to realise that these heavily obscured galactic nuclei and the brilliant quasars were actually similar objects viewed from their 'equators' or from their 'poles'.

The Hubble Heritage Team (STScI/AURA) and NASA/ESA

A cosmic searchlight

One of nature's most amazing phenomena, a black-hole-powered jet of electrons and other sub-atomic particles traveling at nearly the speed of light streams out from the centre of the galaxy M87 like a cosmic searchlight. In this Hubble telescope image, the blue jet contrasts with the yellow glow from the combined light of billions of unseen stars and the yellow, point-like clusters of stars that make up this galaxy. Lying at the centre of M87, the monstrous black hole has swallowed up matter equal to 2 billion times our Sun's mass. M87 is 50 million light-years from Earth.

The energy they release is equal to the amount of energy radiated by our whole Milky Way over a couple of centuries.

But quasars are not the only high energy objects astronomers have found. A serendipitous discovery is something you find while you're looking for something else. Such discoveries have often changed the course of astronomy. Gamma Ray Bursts were discovered serendipitously in the late 1960s by US military satellites that were on the lookout for Soviet nuclear tests. Instead of finding the most powerful detonations produced by humans, some of the most powerful blasts in the Universe itself were spotted.

These astoundingly energetic blasts of gamma rays are detected at least once per day from random directions in the sky. Although Gamma Ray Bursts last only a few seconds, the energy they release is equal to the amount of energy radiated by our whole Milky Way over a couple of centuries.

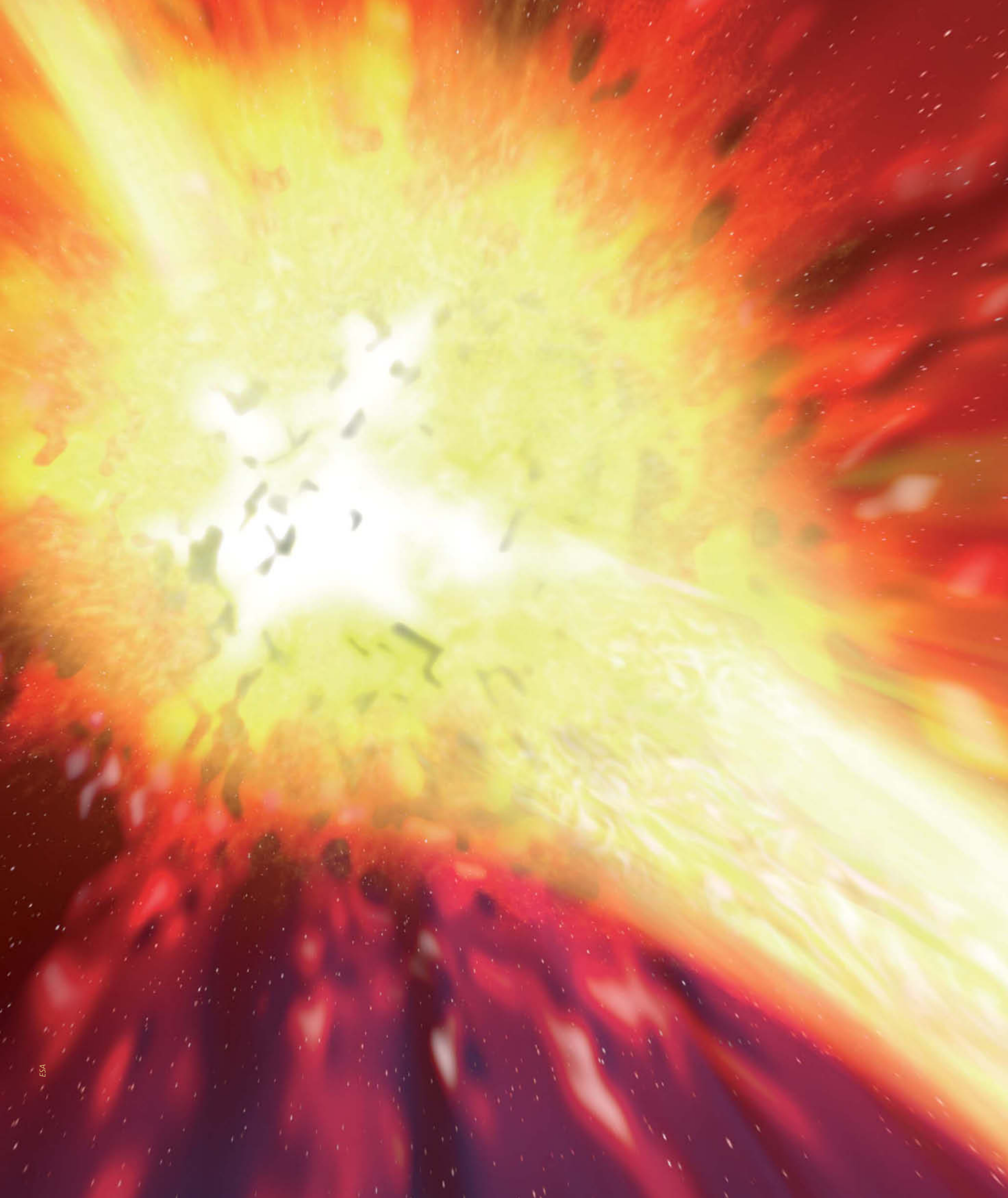
Gamma rays are not visible to the human eye, and special instrumentation is needed to detect them. For 30 years, no one knew what caused these bursts. It was like seeing the gamma-ray bullet fly by Earth without ever glimpsing the weapon that fired it. Together with nearly all other telescopes in the world Hubble looked for the 'smoking gun' for many years. It observed the positions in the sky where gamma ray explosions had been seen, trying to find any object at that location. But all efforts were in vain, until, in 1999, Hubble observations were fundamental in determining that these monstrous outbursts take place in far distant galaxies. After Hubble's observations of the atypical supernova SN1998bw and the Gamma Ray Burst GRB 980425, scientists began to see a physical association between these two phenomena.

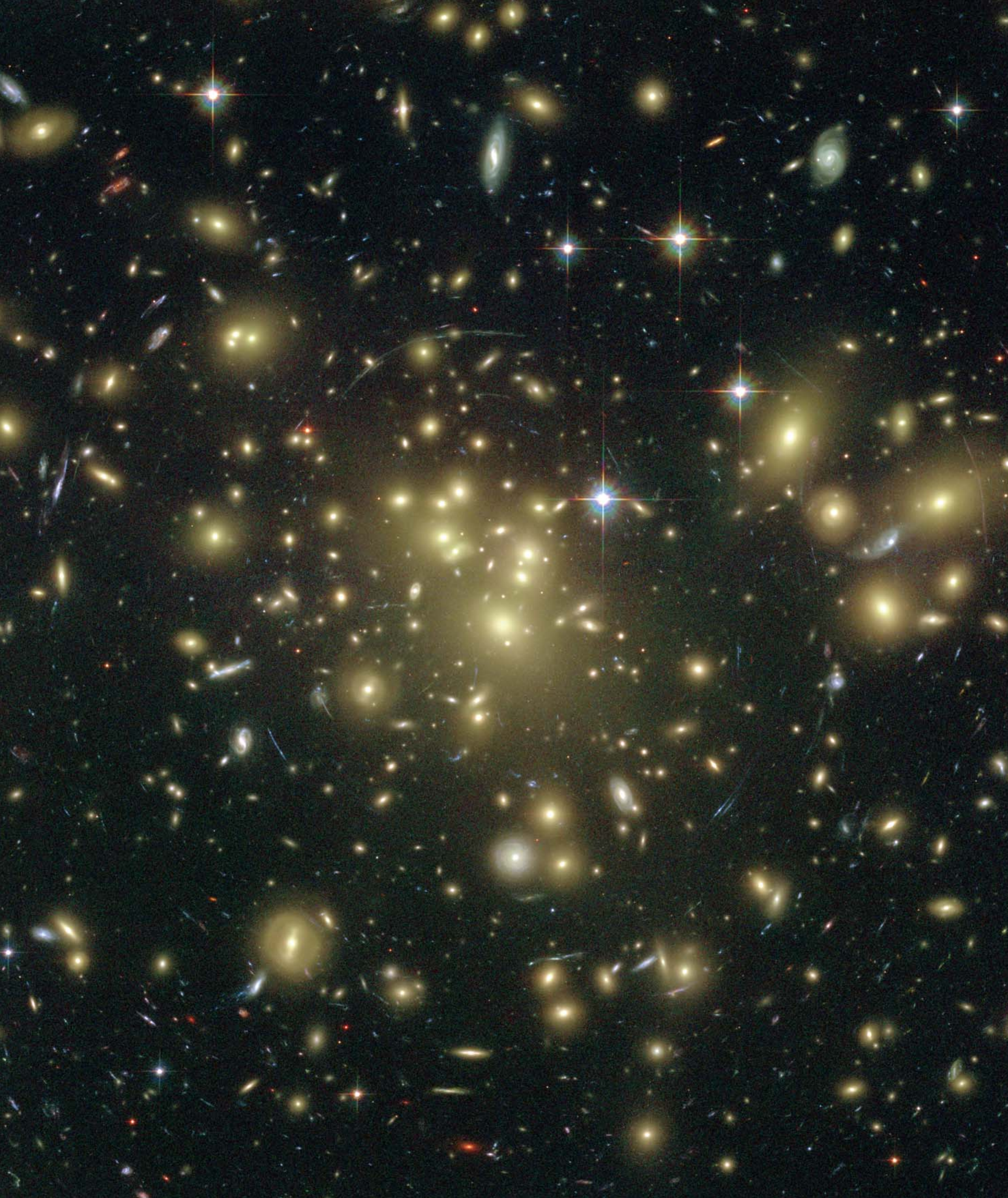
The cause could be the blast produced in the final cataclysmic collapse of a massive star or the dramatic encounter of two very dense objects, such as two black holes, or a black hole and a neutron star.

Black holes are certainly some of the most exotic objects in the Universe. As well as affecting matter they can also show up in some other spectacular ways because their enormous gravitational fields can also deflect light.

In fact, rays of light that pass close to a black hole will not follow straight lines, but will be bent onto new paths, creating a natural telescope that can peer further into space than ever thought possible.

Gamma Ray Burst (artist's impression)
Discovered by military satellites and for many years a complete mystery, Gamma Ray Bursts appear at random places in the sky. With the aid of Hubble these enigmatic sources have now been identified as exploding sources in galaxies throughout the Universe. This artist's impression illustrates the devastating influence such an event has on its host galaxy.


ESA



7 GRAVITATIONAL ILLUSIONS

Gravitational lensing in Abell 1689
Light does not always travel in straight lines. Einstein's Theory of General Relativity predicts that sufficiently massive objects such as a cluster of galaxies will deform the structure of space itself so that when light passes one of these objects, its path is curved slightly. The effect is called gravitational lensing. The galaxy cluster Abell 1689 is so heavy that it bends the light from background galaxies into hundreds of gravitational arcs.

NASA, ESA and the ACS Science Team

Einstein realised that concentrations of mass could bend passing light rays. He would have been delighted – and staggered – to see the stunningly beautiful images taken by Hubble of clusters of galaxies: the largest aggregations of mass in the Universe. These clusters act as 'gravitational lenses' that magnify and distort the images of more distant galaxies into arcs and multiple images that can be measured to map the distribution of mass – both luminous and dark – in space. Sometimes, these gravitational lenses act as telescopes that amplify the feeble radiation from objects beyond the limit of normal detection, rendering visible the most distant objects ever detected in the young Universe.

Gravity warps space and therefore distorts rays of light

Just as a wanderer in the desert sees a mirage when light from remote objects is bent by the warm air hovering just above the sand, we may also see mirages in the Universe. Those that we see with a modern telescope such as the Hubble Space Telescope do not arise from warm air, but instead from remote clusters of galaxies – huge concentrations of matter.

Long ago some people thought the Earth was flat. This is in some way understandable since in our daily life we can't see the curvature of our planet. Space itself is actually curved, although we can't see this for ourselves on a starry night. But the curvature of space does create phenomena that we can observe.

One of Albert Einstein's predictions is that gravity warps space and therefore distorts rays of light, in the same way that ripples on a pond create a warped honeycomb pattern of light on the sandy bottom.

Light from distant galaxies is distorted and magnified by the gravitational field of massive galaxy clusters on its path to Earth. The effect is like looking through a giant magnifying glass and the result is called gravitational lensing.

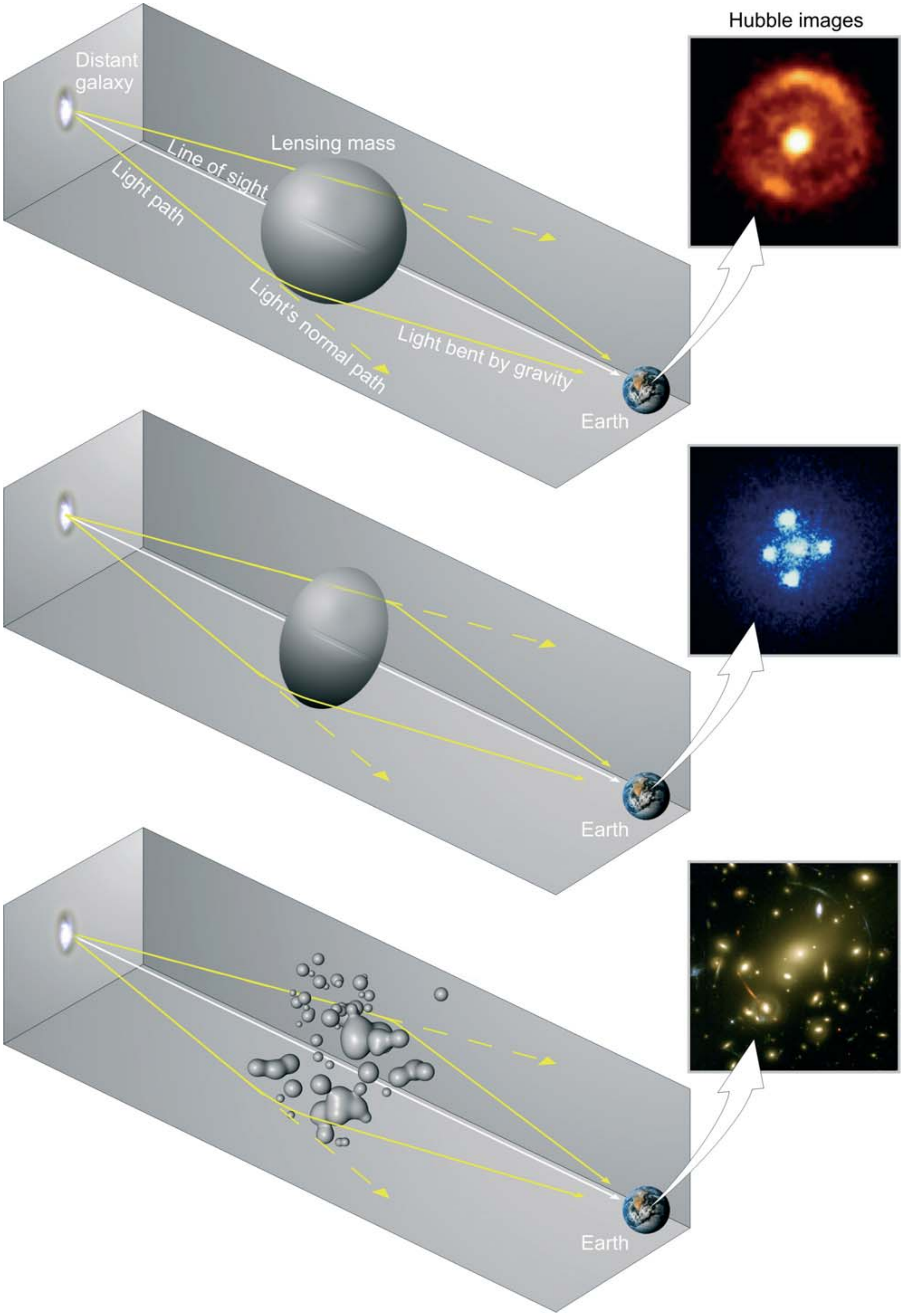
The weird patterns that rays of light create when they encounter a weighty object depend on the nature of the 'lensing body'. Thus, the background object can appear in several guises.

Though Einstein realized in 1915 that this effect would happen in space, he thought it could never be observed from Earth. However, in 1919 his calculations were indeed proved to be correct. During a solar eclipse expedition to Principe Island near the west coast of Africa, led by the renowned British astronomer Arthur Eddington, the positions of stars around the obscured solar disk were observed. It was found that the stars had moved a small but measurable distance outwards on the sky compared with when the Sun was not in the vicinity.

Nowadays, faint gravitational images of objects in the distant Universe are observed with the best telescopes on Earth and, of course, with the sharp-sighted Hubble.

Hubble's sensitivity and high resolution allow it to observe numerous faint and distant gravitational lenses that cannot be detected with ground-based telescopes due to the blurring introduced by the Earth's atmosphere. The gravitational lensing results in multiple images of the original galaxy, many with a characteristically distorted, banana-like shape. Hubble was the first telescope to resolve details within the multiple arcs, revealing the form and internal structure of the lensed background objects directly.

ESA



Gravitational lenses

Gravitational lenses produce different shaped images depending on the shape of the lensing body. If the lens is spherical then the image appears as an Einstein ring (in other words as a ring of light) (top); if the lens is elongated then the image is an Einstein cross (it appears split into four distinct images) (middle), and if the lens is a galaxy cluster then arcs and arclets (banana-shaped images) of light are formed (bottom).

The galaxy cluster Abell 2218

This image shows the full WFPC2 overview of the galaxy cluster Abell 2218. It was taken by Hubble in 1999 immediately after Servicing Mission 3A. Acting like a cosmic magnifying glass, the massive cluster produces a myriad arclets: distorted images of much more distant galaxies.


NASA, ESA, A. Fruchter and the ERO Team (STScI, ST-ECF)

The first heavy elements

Artist's impression of a quasar located in a primeval galaxy (or protogalaxy) a few hundred million years after the Big Bang. Astronomers used Hubble to discover substantial amounts of iron in three very distant quasars. This was the first time that anyone had found elements believed to have been created exclusively by the first generation of stars to illuminate the young Universe.

ESA

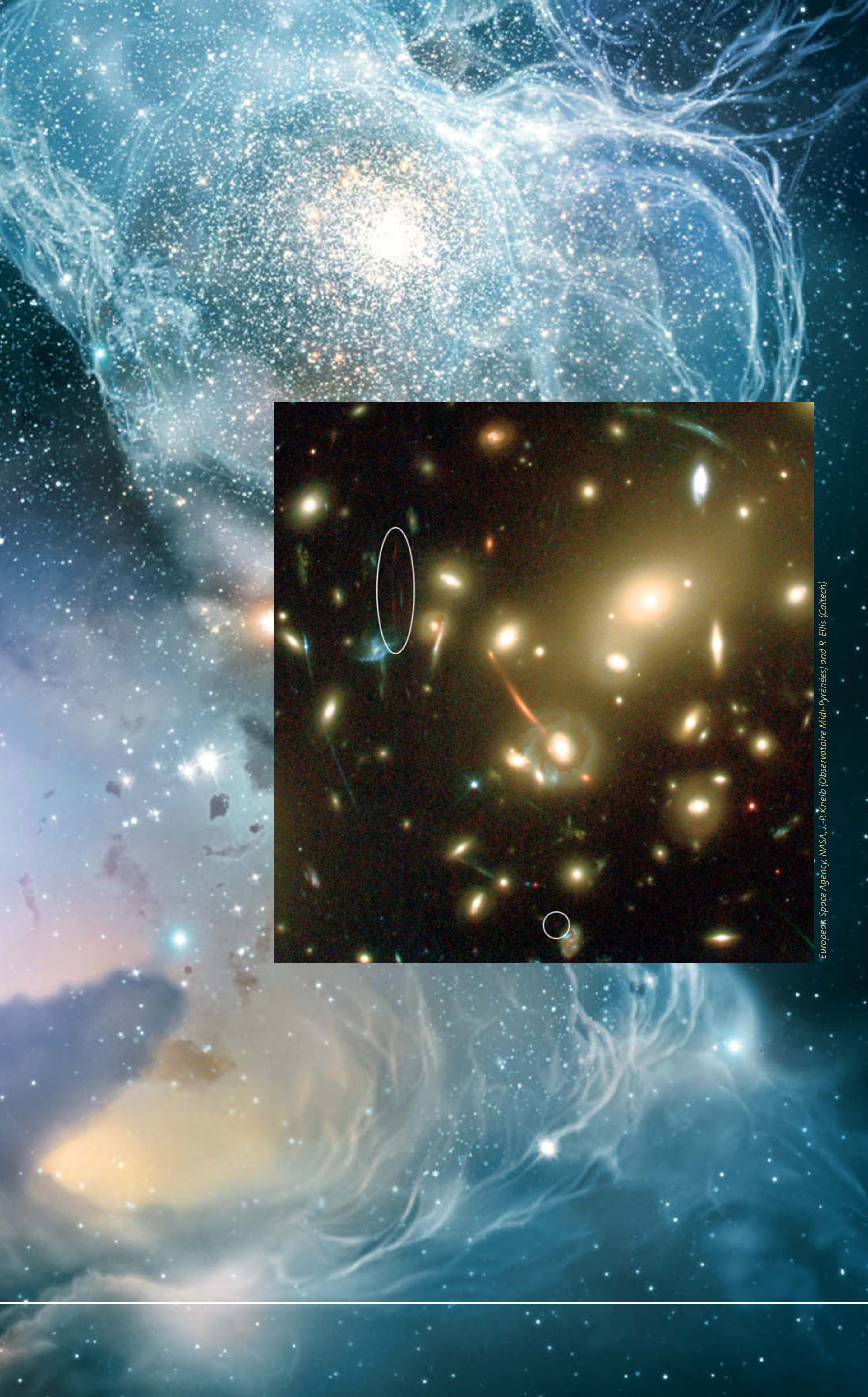
In 2003, astronomers deduced that a mysterious arc of light on one of Hubble's images was the biggest, brightest and hottest star-forming region ever seen in space.

It takes fairly massive objects, for example, clusters of galaxies, to make space curve so much that the effect is observable in deep images of the distant Universe even with Hubble's astonishing resolution. Gravitational lenses have mainly been observed around clusters of galaxies - collections of hundreds or thousands of galaxies. They are thought to be the largest gravitationally bound structures in the Universe.

Astronomers know that the matter we see in the Universe is just a tiny percentage of the total mass that must be there. For matter exerts a gravitational force, and the visible material is simply not enough to hold galaxies and clusters of galaxies together.

Since the amount of warping of the 'banana'-shaped images depends on the total mass of the lens, gravitational lensing can be used to 'weigh' clusters and to understand the distribution of the hidden dark matter. On clear images from Hubble one can usually associate the different arcs coming from the same background galaxy by eye. This process allows astronomers to study the details of galaxies in the young Universe and too far away to be seen with the present technology and telescopes.

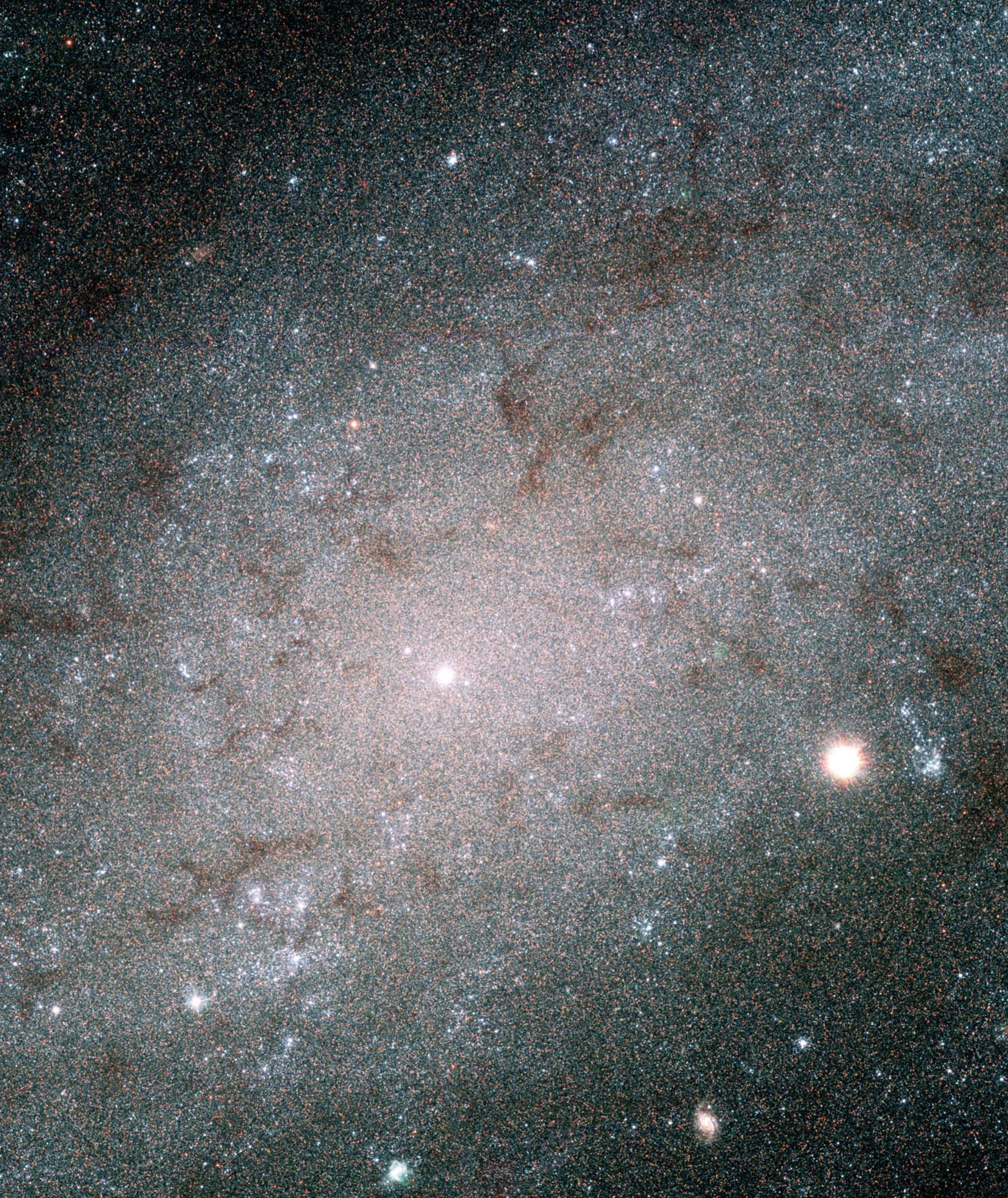
A gravitational lens can even act as a kind of 'natural telescope'. In 2004, Hubble was able to detect the most distant galaxy in the known Universe, using the magnification from just such a 'gravitational lens' in space.



European Space Agency, NASA, J.-P. Kneib (Observatoire Midi-Pyrénées) and R. Ellis (Caltech)

The most distant galaxies

Close-up of the large galaxy cluster Abell 2218 (also seen on the preceding pages) showing how this cluster acts as one of nature's most powerful 'gravitational telescopes', amplifying and stretching the images of all galaxies lying behind the cluster core (seen as red, orange and blue arcs). Such natural gravitational 'telescopes' allow astronomers to see extremely distant and faint objects that would otherwise not be seen. A new galaxy (split into two images marked with an ellipse and a circle) was detected in this image. The extremely faint galaxy is so far away that its visible light has been stretched into infrared wavelengths, making the observations particularly difficult. The galaxy has set a new record in being the most distant known galaxy in the Universe so far. Located an estimated 13 billion light-years away (redshift around 7), the object is being viewed at a time only 750 million years after the Big Bang, when the Universe was barely 5 percent of its current age. In this image the distant galaxy appears as multiple 'images', an arc (left) and a dot (right), as its light is forced along different paths through the cluster's complex clumps of mass (the yellow galaxies) where the magnification is quite large. The colours of the differently lensed galaxies in the image depend on their distances and galaxy types. The orange arc is, for instance, an elliptical galaxy at moderate redshift (around 0.7) and the blue arcs are star-forming galaxies at intermediate redshift (between 1 and 2.5).



8

BIRTH AND DEATH OF THE UNIVERSE

Stars in NGC 300

Myriads of stars embedded in the heart of the nearby galaxy NGC 300 can be singled out like grains of sand on a beach in this Hubble image. The telescope's exquisite resolution enables it to see the stars as individual points of light, despite the fact that the galaxy is millions of light-years away. NGC 300 is a spiral galaxy similar to our own Milky Way galaxy. It is a member of a nearby group of galaxies known as the Sculptor group, named after the southern constellation where the group can be found. The distance to NGC 300 is 6.5 million light-years, making it one of the Milky Way's closer neighbours. At this distance, only the brightest stars can be picked out from ground-based images.

NASA, ESA, and The Hubble Heritage Team (AURA/STScI)

Telescopes are time machines. Light takes time to cross the vastness of space, so looking further away means looking back in time. This produces the mind-wrenching idea that Hubble can spend a few hours looking at galaxies as they were in the early history of the Universe. It can then be re-pointed to look during the next few hours at old stars in a nearby galaxy that were formed billions of years ago – at the very same time as the young galaxies it had just been observing were emitting their light. Hubble is being used to sample different historical epochs. By observing nearby Cepheid variable stars and distant supernovae it is mapping the large-scale properties and long term history of the Universe to determine its ultimate fate.

Who hasn't thought about what it would be like to travel in time?

Light may travel through a vacuum at the highest speed anything can ever reach, but it is still a finite speed. This means that it takes a while for rays of light to travel between two points in space.

The speed of light through space is about 300,000 kilometres per second. 300,000 kilometres is nearly the distance from the Earth to the Moon. So it takes light just over a second to travel from the Moon to the Earth. When we look at the Moon we see it as it was just over a second ago. Who hasn't thought about what it would be like to travel in time?

The finite speed of light enables us to do the next best thing by allowing us to look back in time. When looking out into space, we just need to wait for the light from distant places to reach us, and it shows us how things were when the light began its journey.

Powerful instruments, like Hubble, have made it possible to look farther out and farther back than ever before. What cosmologists are seeing is simply astounding.

In the 1920s, astronomer Edwin Hubble discovered that most galaxies appear to be moving away from us at a rate proportional to their distance. The farther away a galaxy is, the faster it appears to be moving away from us. This is due to the expansion of the Universe.

That expansion began in a titanic explosion, called the Big Bang, many billions of years ago. The rate of expansion holds the key to estimating the age and size of the Universe. This rate is called the Hubble constant.

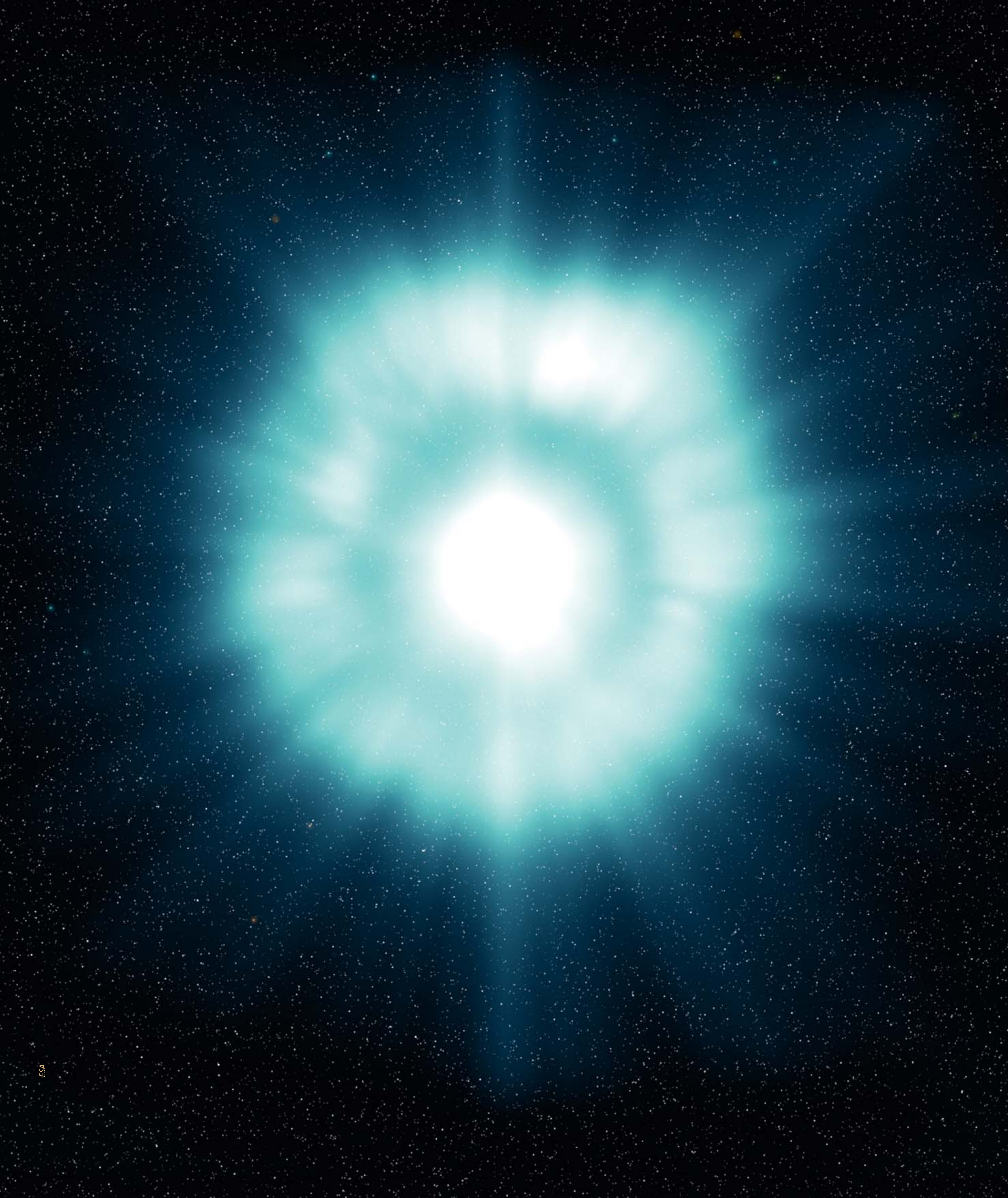
The age and size of the Universe can be estimated by 'running the expansion backwards' — until everything is compressed into that infinitely small point of energy from which the Universe was generated.

The top ranked scientific justification for building Hubble was to determine the size and age of the Universe. The quest to determine the Hubble constant precisely was headed by the Key Project team, a group of astronomers who used Hubble to look for remote, accurate 'milepost markers', a special class of stars called Cepheid variables.

Cepheids have very stable and predictable brightness variations. The period of these variations depends strictly on the physical properties of the star, which can be used to determine their distance very effectively. For this reason these stars are known as 'standard candles'. The Cepheids have been used as reliable stepping-stones to make distance measurements to supernovae, which are much brighter than Cepheids and so can be seen at far greater distances.

Due to its high resolution, Hubble has measured the light from supernova explosions more accurately than any other instrument. From the ground an image of a supernova usually blends in with the image of its host galaxy. Hubble can clearly distinguish the light from the two sources.

The Big Bang – The origin of our Universe (artist's impression)
This event created the time and the space within which the Universe has evolved over the remaining 14 billion years to form the Universe we see around us today.



ESA


Jeffrey Newman (Univ. of California at Berkeley) and NASA/ESA

Cepheids as standard candles

Several groups of astronomers have used Hubble to observe a special type of variable star called a Cepheid. The brightness of a Cepheid varies in a very stable and predictable manner that depends on the physical properties of the star such as mass and absolute brightness. This means that astronomers, just by measuring the variation in the light from these stars, can effectively determine their distance. For this reason, cosmologists call Cepheids 'standard candles'. The magnificent spiral galaxy NGC 4603, seen here, is one of the most distant galaxies in which Cepheids have been observed with Hubble.

Cosmologists have called this nightmare scenario, the Big Rip

Cepheids and supernovae have given a measure for the scale of the Universe. Today we know the age of the Universe to a much higher precision than ever before: around 14 billion years.

With Hubble the rate of expansion of the Universe, known to astronomers as the “Hubble Constant”, was determined. After eight years of Cepheid observations, this work was concluded by finding that the apparent speed of recession in all directions increases by 70 km/second for every 3.26 million light-years you look further out into space.

For many years astronomers have discussed whether the expansion of the Universe would stop in some distant future, making the Universe collapse in a fiery "Big Crunch", or whether it would continue to expand ever more slowly. Combined observations of distant supernovae with Hubble and most of the world’s top-class telescopes were used to measure distances to remote supernovae. And it looks like the expansion of our Universe is nowhere near slowing down. Instead, it seems to be speeding up.

When Hubble was used to measure how the expansion of the Universe has changed with time, it turned out, quite surprisingly, that during the first half of cosmic history, the expansion rate was actually slowing down. Then, a mysterious force, a sort of ‘anti-gravity’ made the Universe ‘hit the accelerator’ starting the acceleration we see today.

This suggests an extraordinary fate for the Universe because it implies that the anti-gravity force is getting stronger all the time. If this continues, it will eventually overwhelm all gravity and catapult the Universe into a super fast acceleration that will shred everything into its constituent atoms. Cosmologists have called this nightmare scenario, the Big Rip.

NASA, ESA, A.V. Filippenko (University of California, Berkeley), P. Challis (Harvard-Smithsonian Center for Astrophysics), et al.

Zooming in on a supernova explosion

The explosion of a massive star blazes with the light of 200 million Suns. The supernova – seen in the upper right corner – is so bright in this image that it easily could be mistaken for a foreground star in our Milky Way Galaxy. And yet, this supernova, called SN 2004dj, resides far beyond our galaxy. Its home is in the outskirts of NGC 2403, a galaxy located 11 million light-years from Earth. Although the supernova is far from Earth, it is the closest stellar explosion discovered in more than a decade. Hubble’s sharp vision means that it can see supernovae that are difficult to study with other telescopes. A supernova image from the ground usually blends with the image of its host galaxy. Hubble can distinguish the light from the two sources and thus measure the supernova itself directly.

9 LOOKING TO THE END OF TIME

The first deep fields

Hubble Deep Field North and South gave astronomers a peephole into the ancient Universe for the first time, and have caused a revolution in modern astronomy.

Some of the objects viewed on the images were so dim that seeing them would be as difficult as discerning a flashlight on the Moon from Earth.

By taking the first very long, high-resolution images of the sky, Hubble created a new branch of astronomy: the direct study of galaxies in the young Universe. These long-exposure 'deep field' observations are being examined by many astronomers throughout the world and are stimulating follow-up observations with the largest ground-based telescopes to create a comprehensive picture of the assembly and subsequent evolution of galaxies throughout the history of the Universe.

Robert Williams and the Hubble Deep Field Team (STScI) and NASA/ESA

Pointing the world's most sophisticated telescope at the same piece of sky for ten days in a row may sound a bit strange

We are collecting exclusive news from deep space. Just as geologists dig deeper underground to find ever more ancient fossils, bearing witness to ever more remote epochs, so astronomers 'excavate' deeper and deeper towards the beginning of time, by looking for light coming from fainter, and thus more distant, objects.

Hubble started a new era we could call 'astroarcheology' and it began over Christmas, 1995. Pointing the world's most sophisticated telescope at the same piece of sky for ten days in a row may sound a bit strange. And this was what many astronomers thought when they tried it for the first time at the end of 1995. Deep field observations are very long exposures pointing at a particular region of the sky. They aim to reveal faint objects by collecting as much light as possible over a long period of time. The 'deeper' an observation goes, the fainter the objects that become visible are. Objects in the sky can either look faint because their intrinsic brightness is low, or because their distance is great.

When this experiment was first proposed, nobody really knew if this would lead to any interesting scientific results. But when they examined the first image astronomers were astonished! More than 3000 galaxies could be counted in this small field.

The thousands of galaxies observed in the first Deep Field were at various stages of evolution and were strung out along a corridor billions of light-years long. This allowed the study of the evolution of these objects through time, glimpsing different galaxies at different stages of their lives.

The observed region of sky in Ursa Major, the Plough, was carefully selected to be as empty as possible so that Hubble would look far beyond the stars of our own Milky Way and out past nearby galaxies.

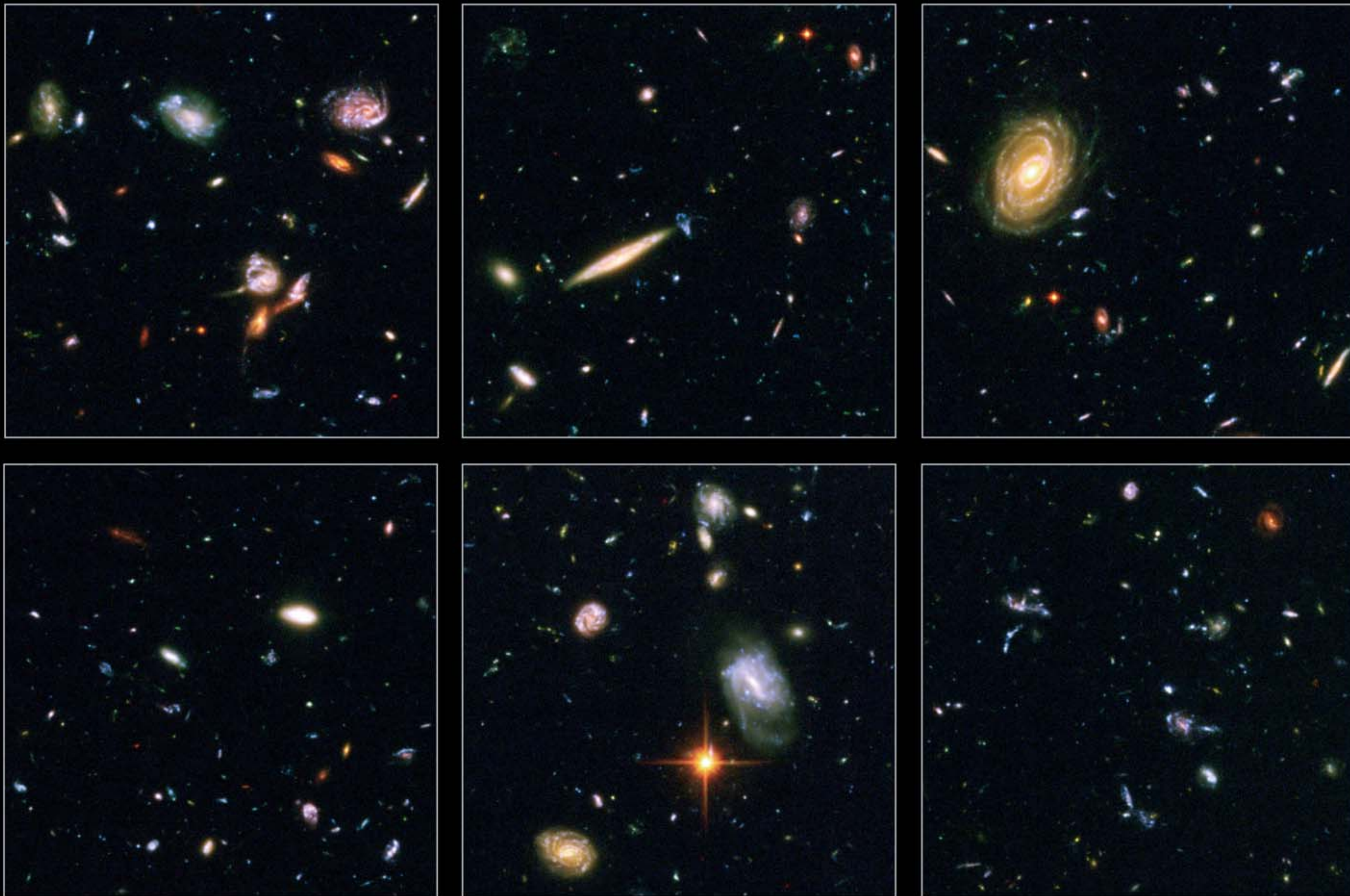
Hubble Ultra Deep Field close-up

These close-up snapshots of galaxies reveal the drama of galactic life and were plucked from a harvest of nearly 10,000 galaxies in the Ultra Deep Field. Almost every panel is littered with oddball-shaped galaxies that are the results of close encounters with other galactic neighbours.

Deep Fields

Deep fields result from lengthy observations of a particular region of the sky. They are intended to reveal faint objects by collecting their light for an appropriately long time. The 'deeper' the observation (i.e. the longer the exposure time), the fainter the objects that become visible are. Astronomical objects can either look faint because their natural brightness is feeble, or because they are very distant.

In making a 'deep field' observation, the telescope is not simply pointed in exactly the same direction with the shutter open for days or weeks. It will actually take many separate observations with the telescope moved a very small amount between each. This is called 'dithering' and, when the dithered exposures are combined, the resulting image is free from many of the small defects that would appear in a single pointing. By taking many exposures, it is also possible to identify and remove nearly all of the 'false stars' created when the many energetic particles found in space collide with the detector and leave trails of exposed pixels.



NASA, ESA, and S. Beckwith (STScI) and the HUDF Team

After the first deep field, another long exposure was taken in the southern sky. Together the Hubble Deep Field North and South gave astronomers peepholes into the early Universe for the first time.

The Hubble Deep Fields have caused a real revolution in modern astronomy. After the first Deep Field was observed, almost all of the most powerful ground- and space-based telescopes were pointed at this same area for long periods. Some of the most interesting results in astronomy emerged from this fruitful synergy between instruments of different sizes, in different environments and with sensitivity to different wavelengths.

They gave us the first clear picture of the rate of star formation throughout the Universe. It showed that star formation peaked during the first half of the Universe's life. At that time, over ten times more stars were forming than today. This was also the epoch when quasars were hundreds of times more common than they are now.

Once they had begun to discover the most distant Universe ever seen, Hubble astronomers tried to push their observations even farther back in time. In 2003 and 2004, Hubble performed its deepest exposure ever: the Hubble Ultra Deep Field. It is a 28 day-long exposure, going much deeper than the earlier Hubble Deep Fields North and South.

NASA, ESA, and S. Beckwith (STScI) and the HUDF Team

The Hubble Ultra Deep Field from 2004 represents the deepest portrait of the visible Universe yet achieved by mankind. It reveals the first galaxies to emerge from the 'dark ages', the time shortly after the big bang when the first stars reheated the cold, dim Universe. Some may be the most remote ever seen, existing when the Universe was just 400 million years old.

Perhaps Hubble's greatest legacy has been to open our eyes to the incredible beauty of nature – not only 'out there' in the depths of cosmos, but also everywhere around us in our daily lives...

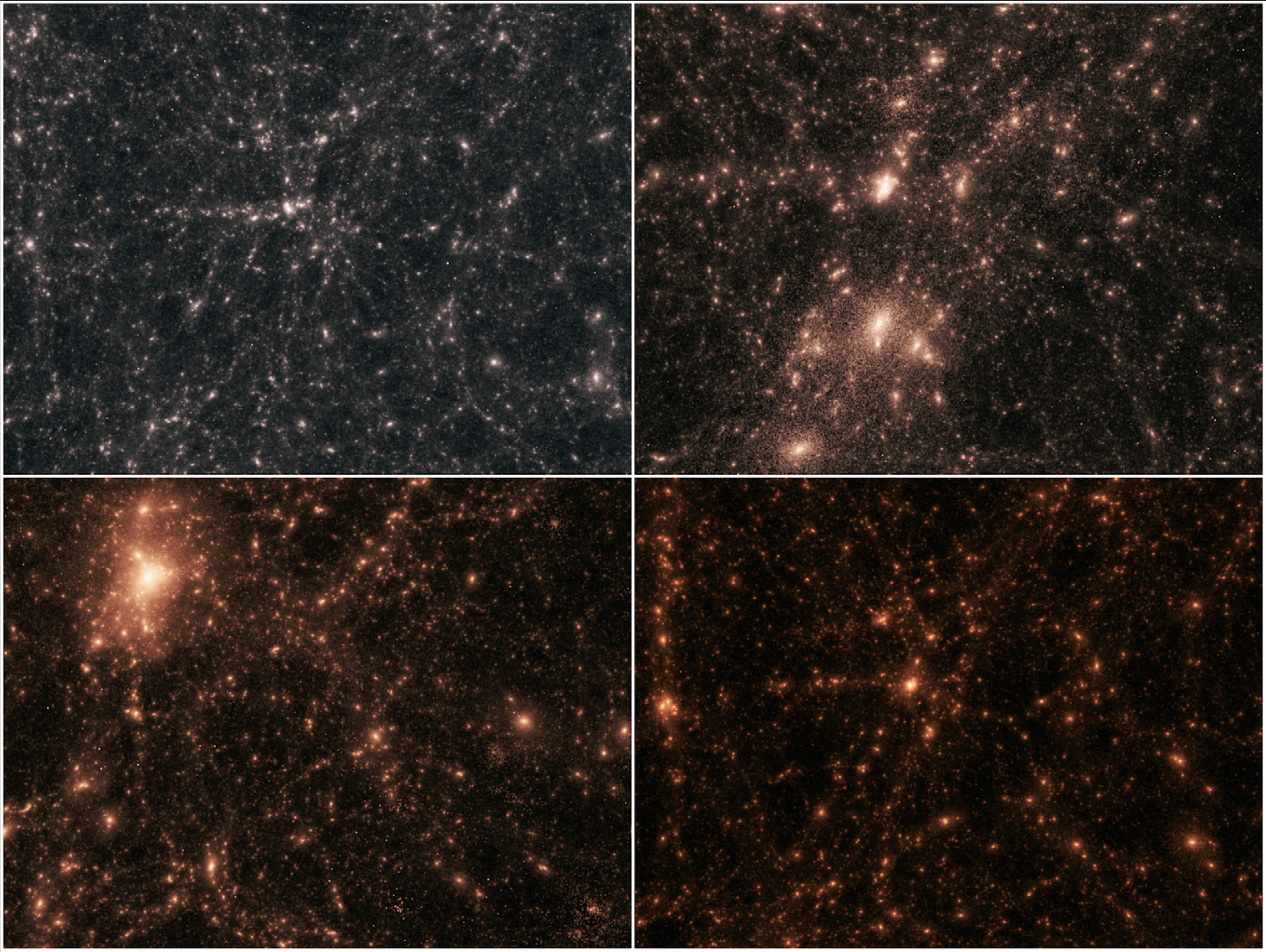
The Hubble Ultra Deep Field reveals the first galaxies to emerge from the so-called "dark ages" – the time shortly after the Big Bang when the first stars reheated the cold, dark Universe. Just after the Big Bang, in the newborn fast-expanding Univers – before the era of the stars and galaxies – the distribution of matter was fairly smooth. As time went on, the king of all forces – gravity – started acting. Slowly, but steadily.

Under the influence of gravity from the mysterious dark matter, small clumps of normal matter started to coalesce in regions where the density was slightly higher than average. With no stars to light up space, the Universe was in its dark age. Where the density of the clumps became higher, even more matter was attracted, and a competition between the expansion of space and gravity took place. Where gravity won, regions stopped expanding, and started to collapse in on themselves. The first stars and galaxies were born. Where the matter density was highest – at the intersections between the large web-like structures of matter – the largest structures we know were formed: clusters of galaxies.

The Deep Field images are studded with a wide range of galaxies of various sizes, shapes, and colours. Astronomers will spend years studying the myriad shapes and colours of the galaxies in this image to understand how they formed and have evolved since the Big Bang.

In vibrant contrast to the image's rich harvest of classic spiral and elliptical galaxies, there is also a zoo of oddball galaxies littering the field. Some look like toothpicks; others like links on a bracelet. A few appear to be interacting with each other. Their strange shapes are a far cry from the majestic spiral and elliptical galaxies we see around us today. These oddball galaxies chronicle a period when the Universe was more chaotic, when order and structure were just beginning to emerge and galaxies were being assembled from smaller pieces.

One of the great things about Hubble is that there are many instruments onboard that can make different observations at the same time. The Hubble Ultra Deep Field is actually two separate images taken by two instruments: Hubble's ACS camera and the NICMOS instrument. NICMOS can see even farther than the ACS. It detects infrared light, and so it is able to reveal the farthest galaxies ever seen because the expanding Universe has stretched and weakened the light from these objects so much that, they are now only visible at infrared wavelengths.



John Dubinsky

The evolution of large-scale structure

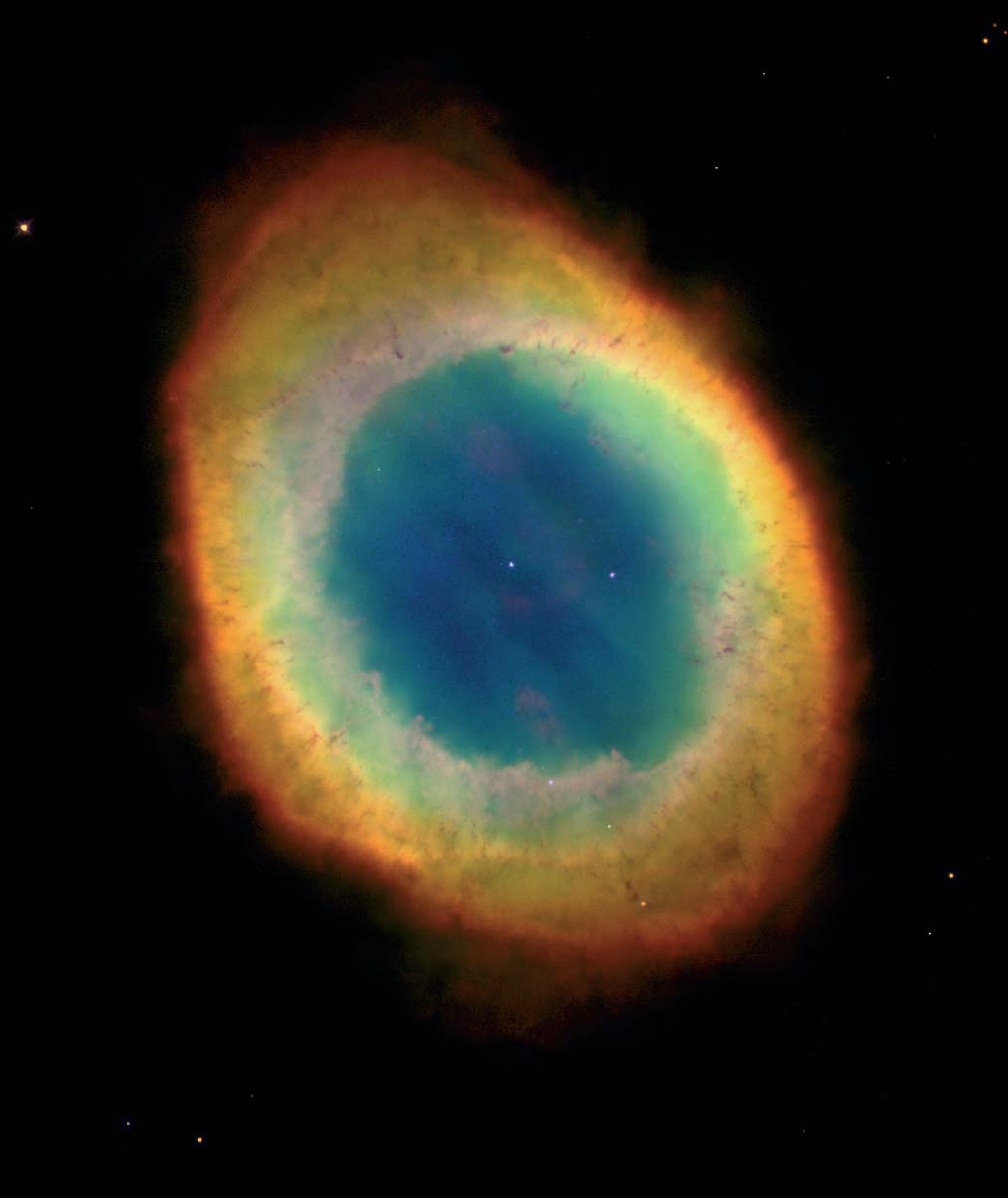
These four frames show a sequence of computer simulations of the evolution of the large-scale distribution of matter, both luminous and dark, as gravity inexorably shapes the Universe.

The Hubble Ultra Deep Field is likely to remain the deepest image of the Universe for the next decade or so, until an ESA Ariane rocket launches the James Webb Space Telescope in 2011.

Up until today, during the first 15 years of its life, Hubble has orbited the Earth 80,000 times. This is nearly 4 billion kilometres or more than 25 times the distance from the Earth to the Sun. Hubble has taken more than 700,000 exposures of the Universe and created a visual heritage that has shaped the way humanity looks at the Universe today.

But perhaps Hubble's greatest legacy has been to open our eyes to the incredible beauty of nature – not only 'out there' in the depths of cosmos, but also everywhere around us in our daily lives.

And it's nowhere finished yet...



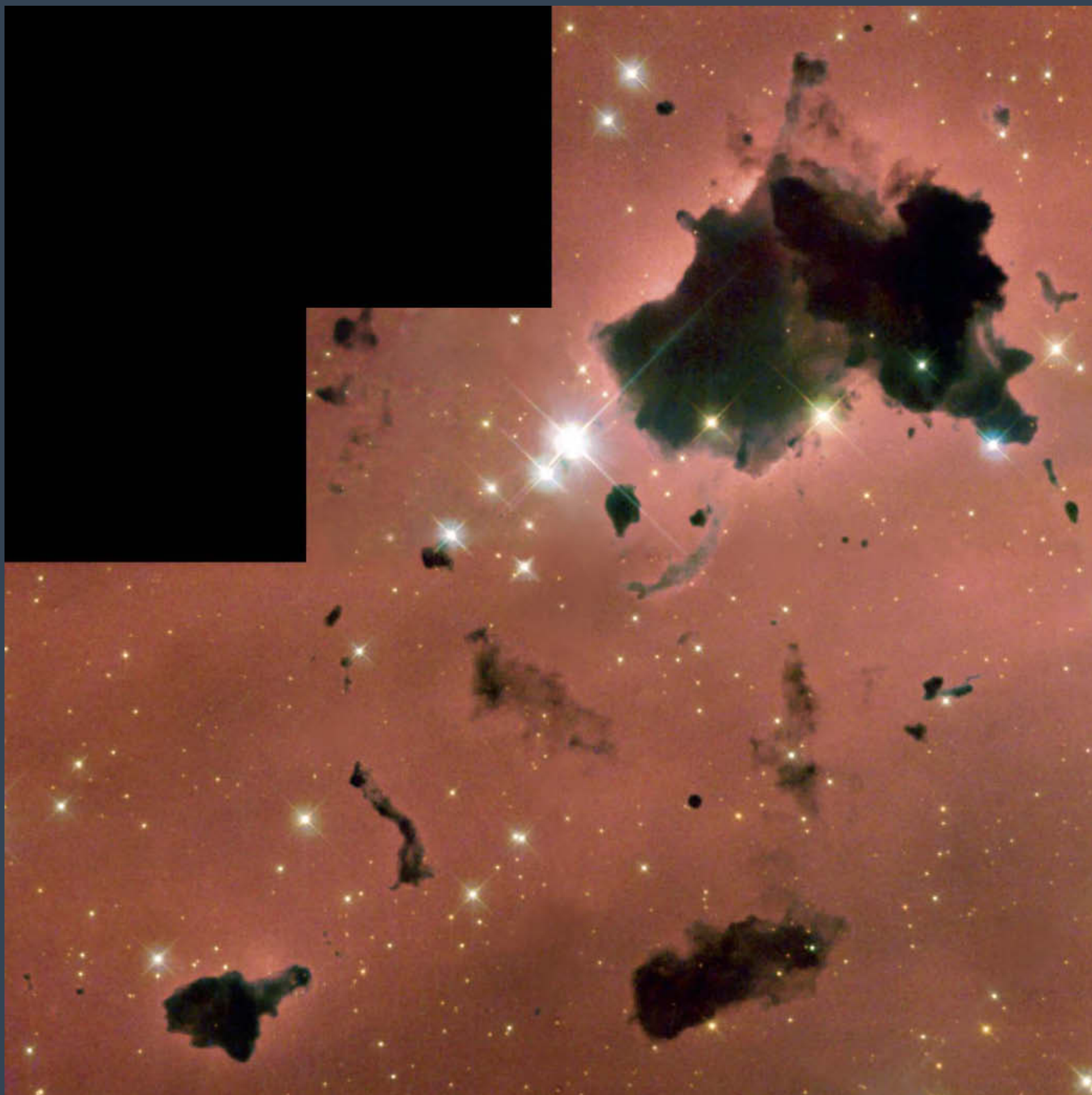
10 HUBBLE GALLERY

The Ring Nebula

The sharpest view yet of the most famous of all planetary nebulae: the Ring Nebula (M57). In this image the telescope has looked down a barrel of gas cast off by a dying star thousands of years ago. This photo reveals elongated dark clumps of material embedded in the gas at the edge of the nebula; the dying central star is floating in a blue haze of hot gas. The nebula is about a light-year in diameter and is located some 2,000 light-years from Earth in the direction of the constellation Lyra.

Hubble Heritage Team (AURA/STScI/NASA) and ESA

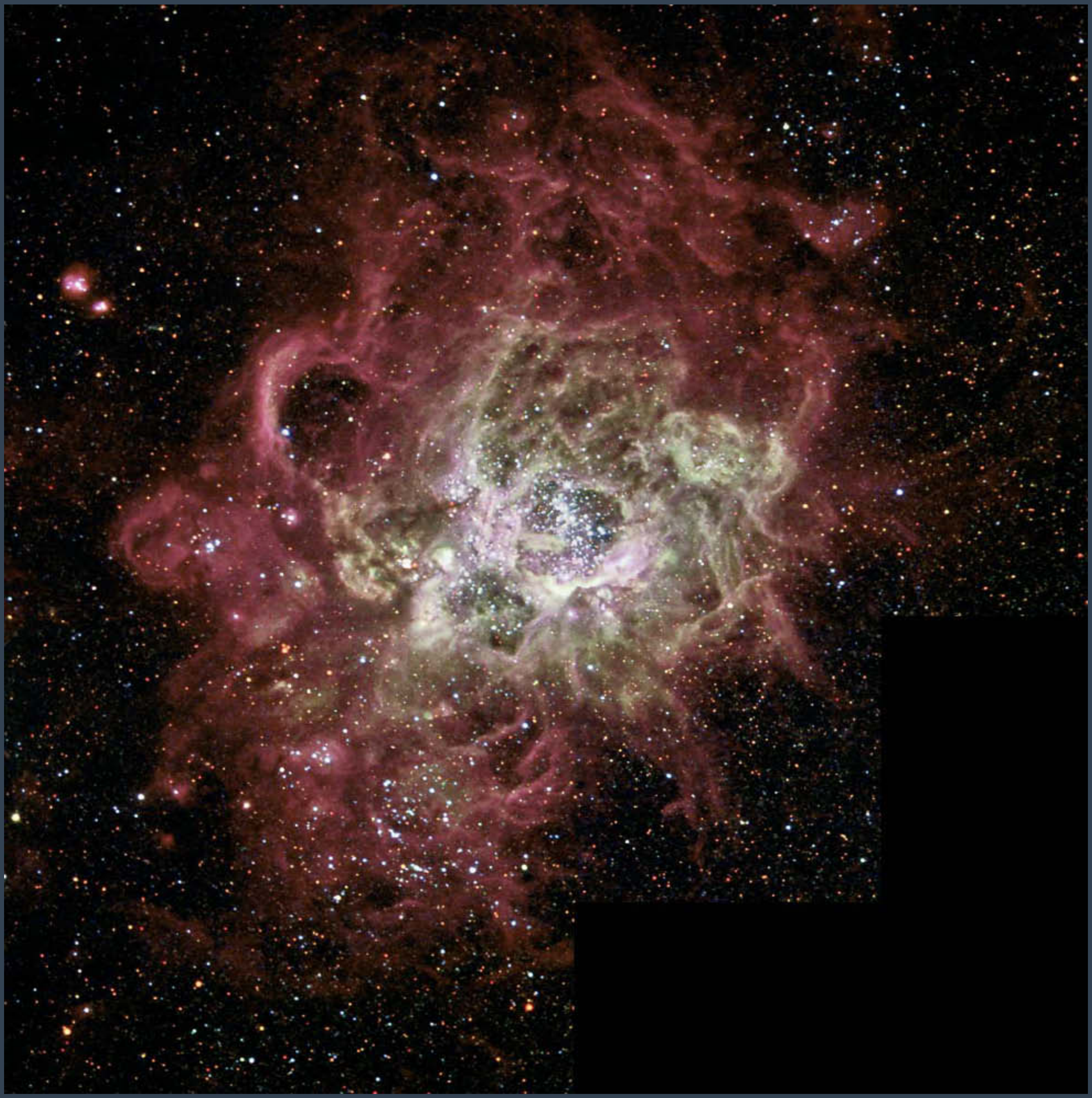
Since the launch of Hubble 15 years ago, the public has been treated to striking images of jewel-like star clusters, colourful star-forming regions and colliding galaxies. However, the data from Hubble itself are greyscale and have to be manually processed and combined, filter by filter, to create the colourful and detailed images. This is done using software such as Photoshop and the ESA/ESO/NASA Photoshop FITS Liberator. On the following pages we present some more of these iconic images.



NASA/ESA and The Hubble Heritage Team (STScI/AURA)

Thackeray's Globules in IC 2944

Strangely glowing dark clouds float serenely in this remarkable and beautiful image taken with the Hubble's WFPC2. These dense, opaque dust clouds – known as 'globules' – are silhouetted against nearby bright stars in the busy star-forming region, IC 2944. Astronomer A.D. Thackeray first spied the globules in IC 2944 in 1950. Globules like these have been known since Dutch-American astronomer Bart Bok first drew attention to such objects in 1947.

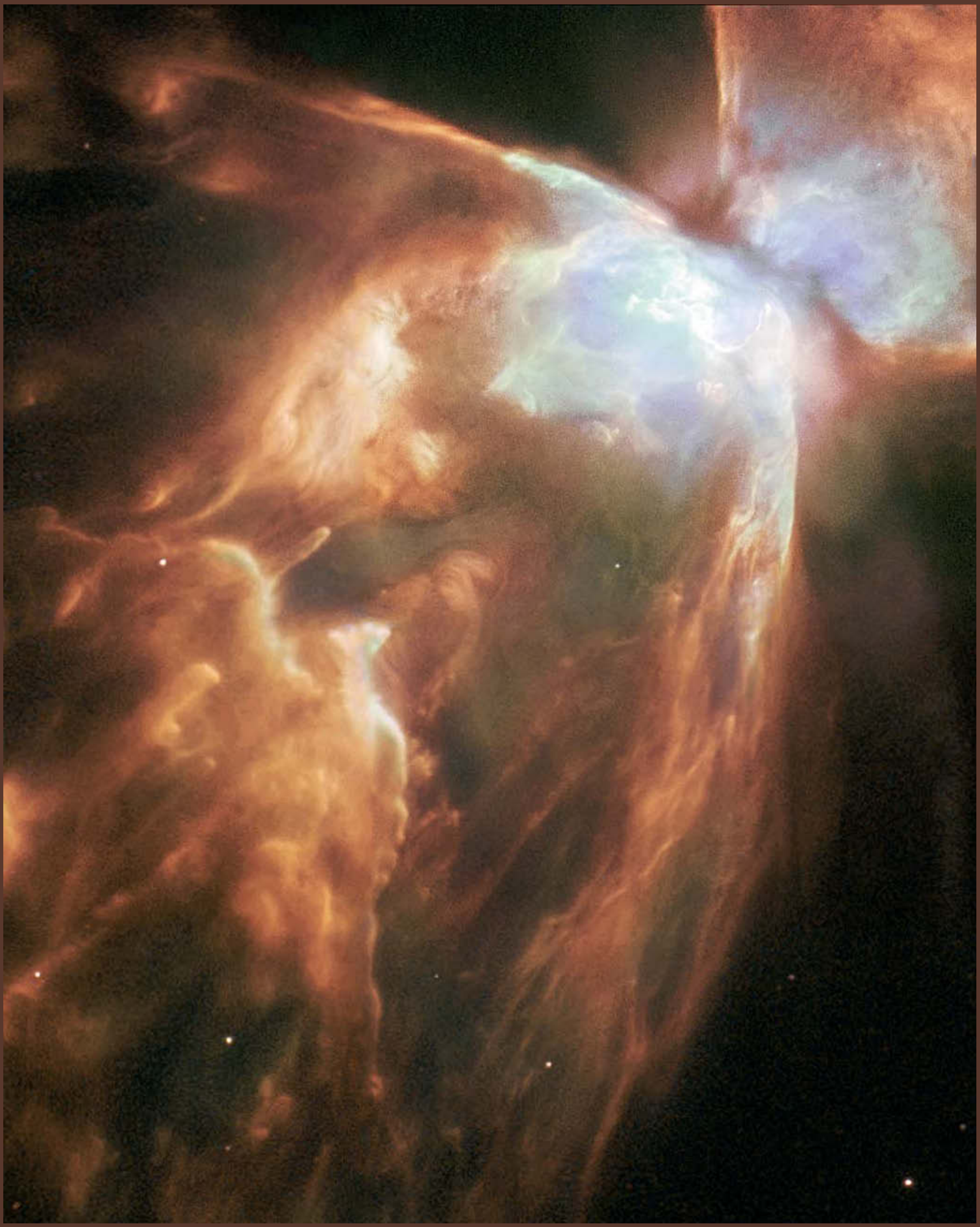


NASA/ESA and The Hubble Heritage Team (AURA/STScI)

Star-forming region in Messier 33

NGC 604 provides Hubble astronomers with a nearby example of a giant star-birth region. Such regions are small-scale versions of more distant "starburst" galaxies, which undergo an extremely high rate of star formation. Starbursts are believed to have been common in the early universe, when the star-formation rate was much higher. Supernovae exploding in these galaxies created the first chemical elements heavier than hydrogen and helium.

ESA/NASA and Albert Zijlstra



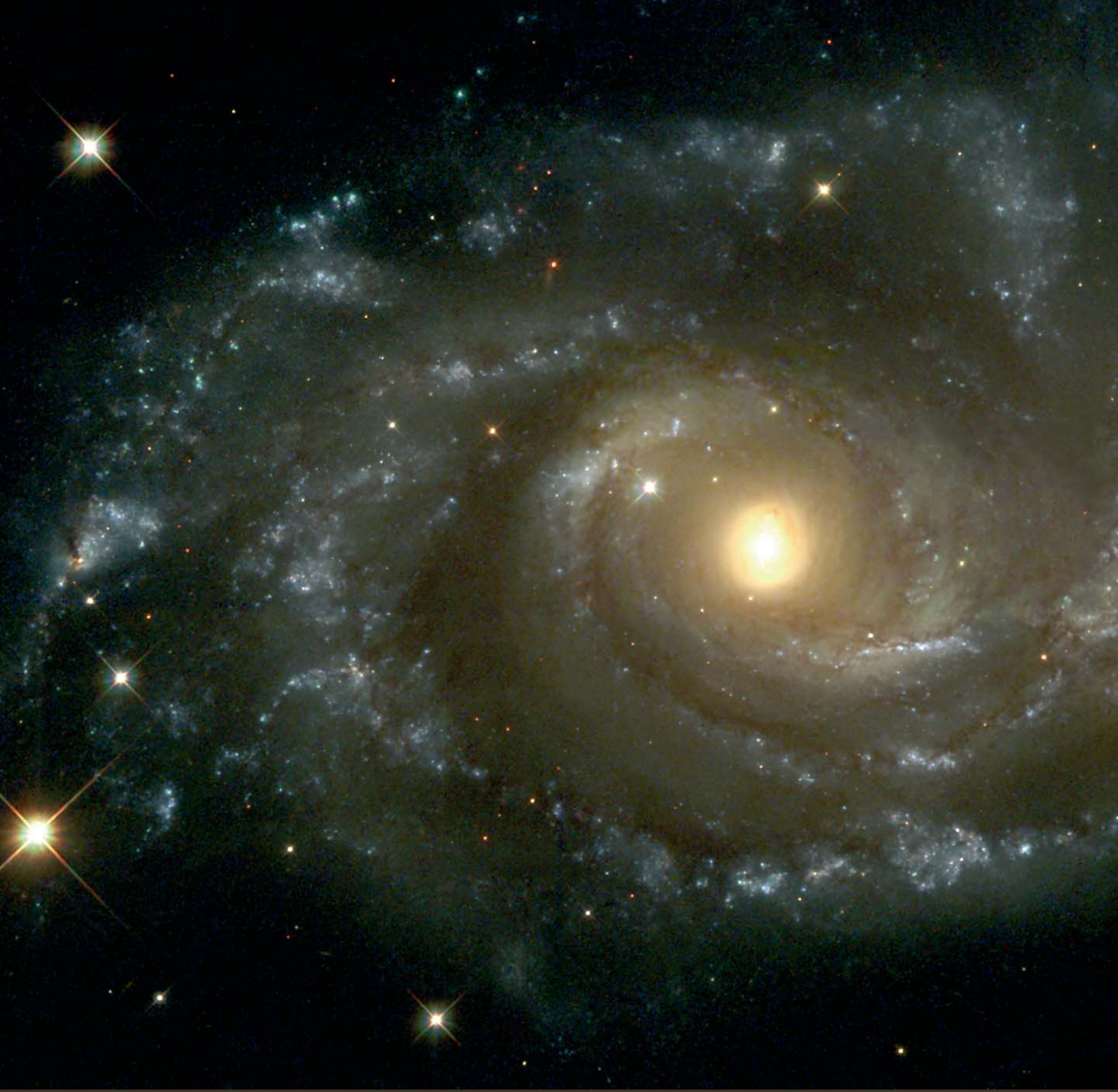
Demise in ice and fire

The Bug Nebula, NGC 6302, is one of the brightest and most extreme planetary nebulae known. At its centre lies a super-hot, dying star smothered in a blanket of hailstones. This Hubble image reveals fresh detail in the wings of this cosmic butterfly.

NASA/ESA and The Hubble Heritage Team (STScI/AURA), George Herbig and Theodore Simon

Ghostly Reflections in the Pleiades

Hubble has caught the eerie, wispy tendrils of a dark interstellar cloud being destroyed by the passage of one of the brightest stars in the Pleiades star cluster. Viewed indirectly, like seeing a flashlight beam shining off the wall of a cave, the star is reflecting light from the surface of pitch black clouds of cold gas laced with dust. These are called reflection nebulae.



Grazing Encounter Between two Spiral Galaxies

In the direction of the constellation Canis Major, two spiral galaxies pass by each other like majestic ships in the night. The near-collision has been caught in images taken by Hubble's WFPC2.

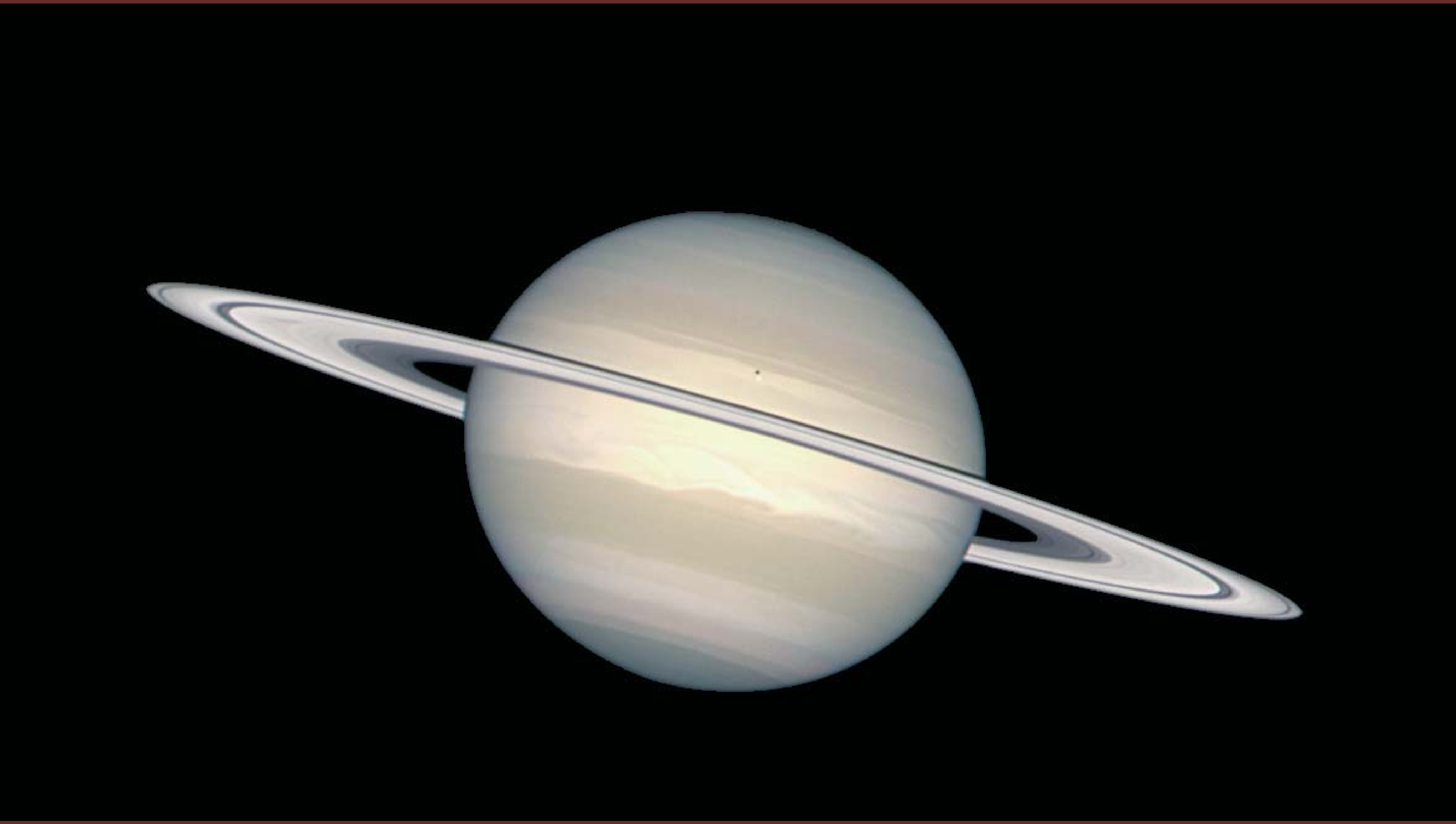

NASA/ESA and The Hubble Heritage Team (STScI)

ESA & Garrelt Mellema (Leiden University, the Netherlands)

The Red Spider Nebula in Sagittarius

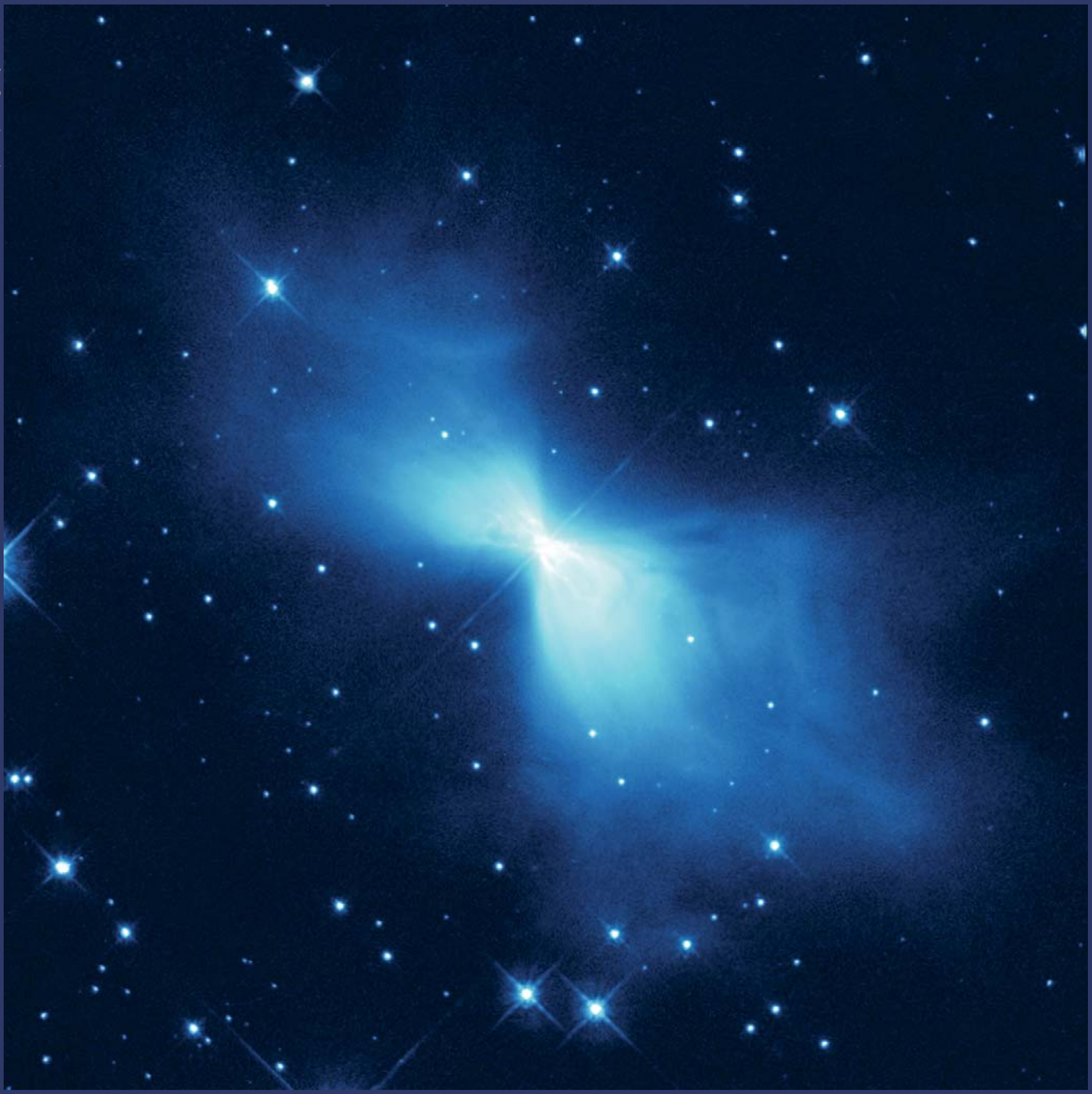
Hubble observations have revealed huge waves sculpted in the Red Spider Nebula. This warm and windy planetary nebula harbours one of the hottest stars in the Universe and its powerful stellar winds generate waves 100 billion kilometres high.

Hubble Heritage Team (AURA/STScI/NASA) and ESA



Saturn in Natural Colours

Hubble has provided images of Saturn in many colours, from black-and-white, to orange, to blue, green, and red. But in this picture, image processing specialists have worked to provide a crisp, extremely accurate view of Saturn, which highlights the planet's pastel colors. Bands of subtle colour – yellows, browns, greys – distinguish differences in the clouds over Saturn, the second largest planet in the solar system.



European Space Agency and NASA

The Boomerang Nebula

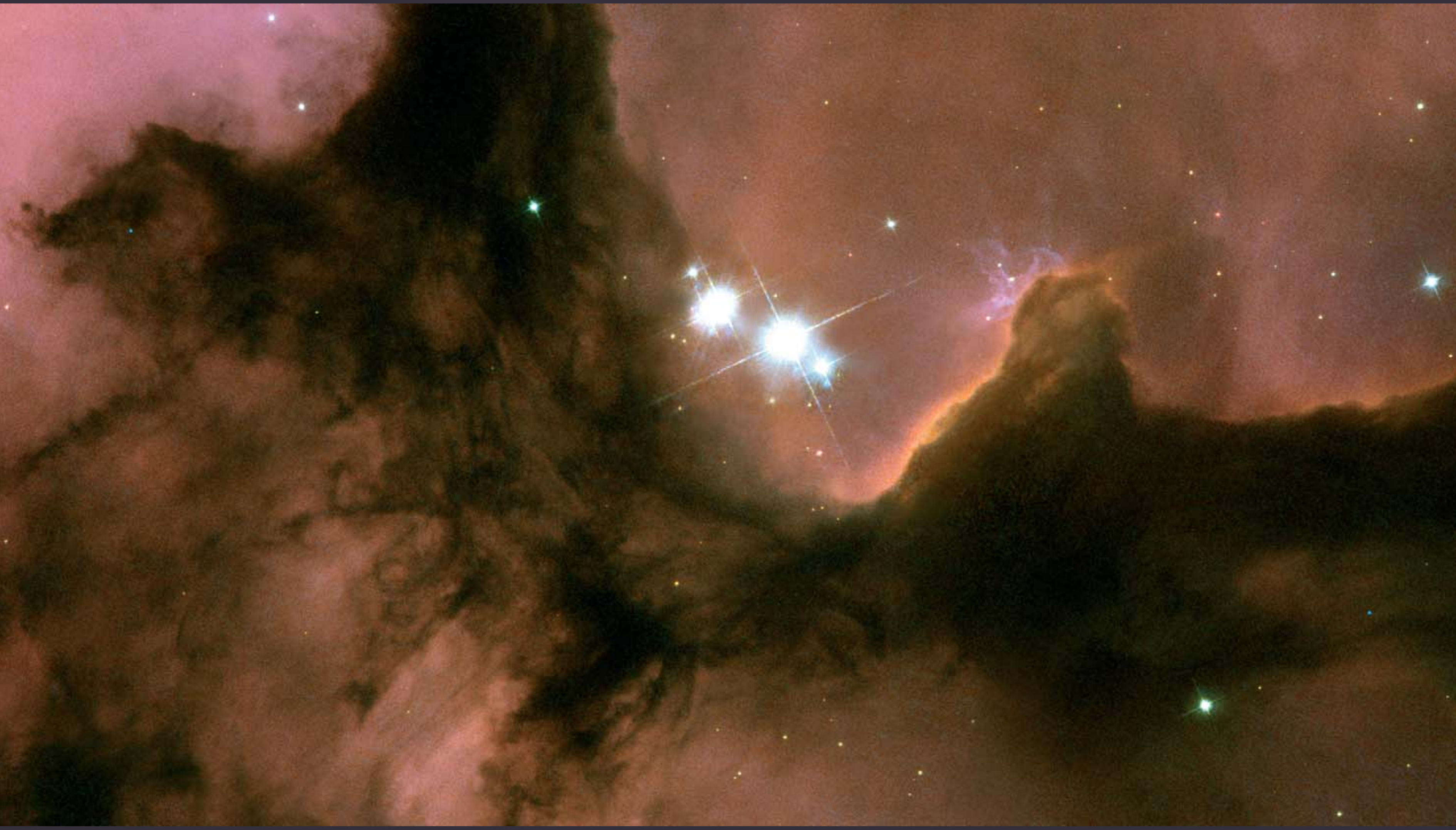
The Boomerang Nebula is a young planetary nebula and the coldest object found in the Universe so far. This is yet another example of how Hubble's sharp eye reveals surprising details in celestial objects. The Nebula is one of the Universe's peculiar places. In 1995, using the 15-metre Swedish ESO Submillimetre Telescope in Chile, astronomers revealed that it is the coldest place in the Universe found so far. With a temperature of -272°C, it is only 1 degree warmer than absolute zero (the lowest limit for all temperatures). Even the -270°C background glow from the Big Bang is warmer than this nebula. It is the only object found so far that has a temperature lower than the background radiation. This Hubble image was taken in 1998. It shows faint arcs and ghostly filaments embedded within the diffuse gas of the nebula's smooth 'bow tie' lobes. The diffuse bow-tie shape of this nebula makes it quite different from other observed planetary nebulae, which normally have lobes that look more like 'bubbles' blown in the gas. However, the Boomerang Nebula is so young that it may not have had time to develop these structures. Why planetary nebulae have so many different shapes is still a mystery.

The Hubble Heritage Team (AURA/STScI/NASA) and ESA

A swarm of ancient stars

This stellar swarm is M80 (NGC 6093), one of the densest of the about 150 known globular star clusters in the Milky Way galaxy. Located about 28,000 light-years from Earth, M80 contains hundreds of thousands of stars, all held together by their mutual gravitational attraction. Globular clusters are particularly useful for studying stellar evolution, since all of the stars in the cluster have the same age but cover a range of stellar masses. Every star visible in this image is either more highly evolved than, or in a few rare cases more massive than, our own Sun. Especially obvious are the bright red giants, which are stars similar to the Sun in mass that are nearing the ends of their lives.

NASA, ESA, and The Hubble Heritage Team (AURA/STScI)



The Heart of the Trifid Nebula

Three huge intersecting dark lanes of interstellar dust make the Trifid Nebula one of the most recognizable and striking star birth regions in the night sky. The dust, silhouetted against glowing gas and illuminated by starlight, cradles the bright stars at the heart of the Trifid Nebula. This nebula, also known as Messier 20 and NGC 6514, lies within our own Milky Way Galaxy about 9,000 light-years from Earth, in the constellation Sagittarius.

NASA/ESA and the Hubble Heritage Team (AURA/STScI)/HEIC

Star formation in the Large Magellanic Cloud

Hubble captures the iridescent tapestry of star birth in a neighbouring galaxy in this panoramic view of glowing gas, dark dust clouds, and young, hot stars. The star-forming region, catalogued as N11B lies in the Large Magellanic Cloud (LMC), is located only 160,000 light-years from Earth. With its high resolution, the telescope is able to view details of star formation in the LMC as easily as ground-based telescopes are able to observe stellar formation within our own Milky Way galaxy.

The Helix Nebula

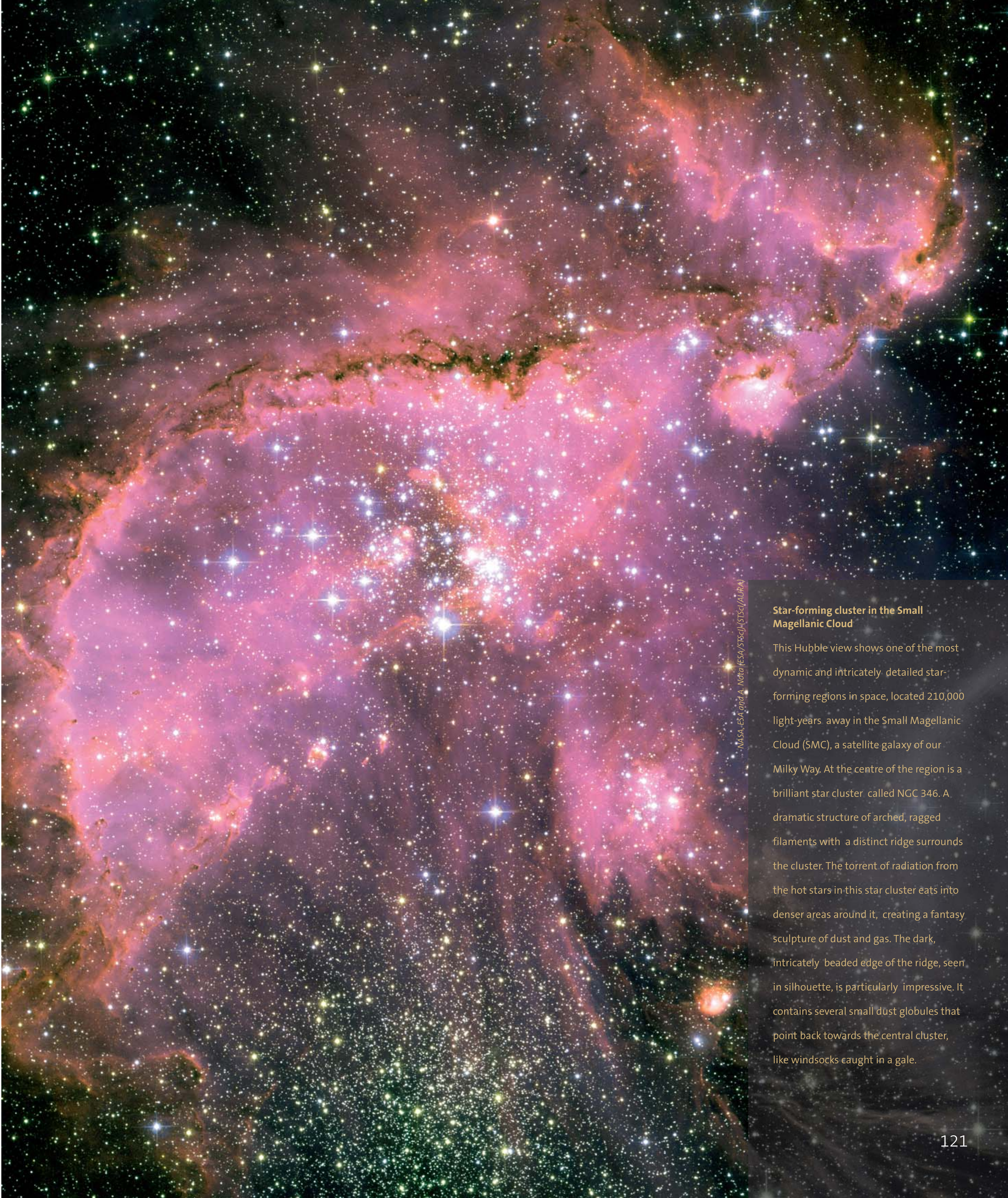
The image of the Helix Nebula shows a fine web of filamentary "bicycle-spoke" features embedded in the colourful red and blue gas ring, which is one of the nearest planetary nebulae to Earth. The tentacles formed when a hot "stellar wind" of gas plowed into colder shells of dust and gas ejected previously by the doomed star.

NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO).

Hubble Heritage Team (AURA/STScI/NASA) and ESA

Multiple generations of stars in the Tarantula Nebula

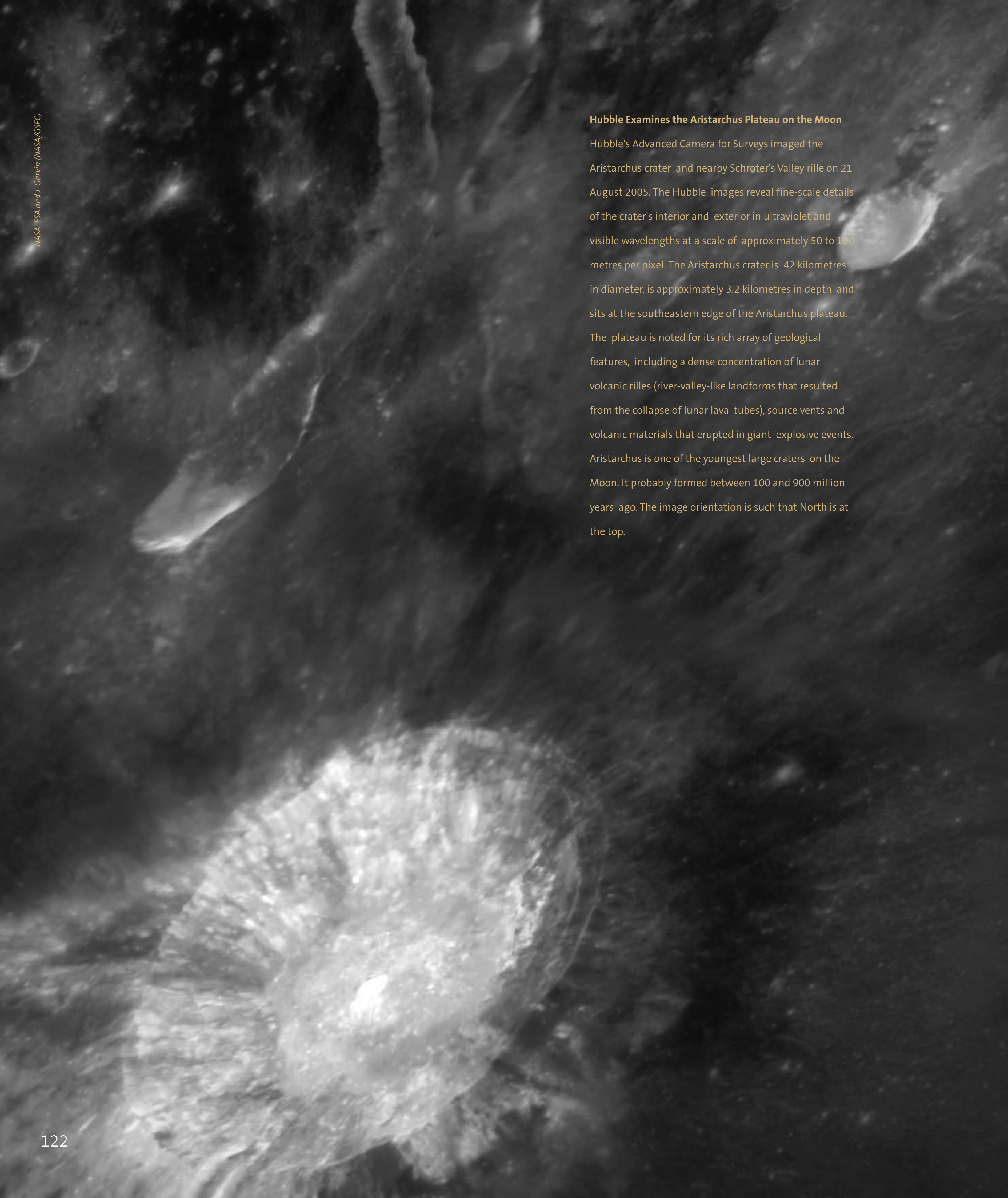
Hodge 301, seen in the lower right hand corner of this image, lives inside the Tarantula Nebula in our galactic neighbour, the Large Magellanic Cloud. Many of the stars in Hodge 301 are so old that they have exploded as supernovae. These exploded stars are blasting material out into the surrounding region. This high speed ejecta are plowing into the surrounding Tarantula Nebula, shocking and compressing the gas into a multitude of sheets and filaments, seen in the upper left portion of the picture.



NASA, ESA and A. Nota (ESA/STScI) (STScI/AURA)

Star-forming cluster in the Small Magellanic Cloud

This Hubble view shows one of the most dynamic and intricately detailed star-forming regions in space, located 210,000 light-years away in the Small Magellanic Cloud (SMC), a satellite galaxy of our Milky Way. At the centre of the region is a brilliant star cluster called NGC 346. A dramatic structure of arched, ragged filaments with a distinct ridge surrounds the cluster. The torrent of radiation from the hot stars in this star cluster eats into denser areas around it, creating a fantasy sculpture of dust and gas. The dark, intricately beaded edge of the ridge, seen in silhouette, is particularly impressive. It contains several small dust globules that point back towards the central cluster, like windsocks caught in a gale.



NASA, ESA and J. Garvin (NASA/GSFC)

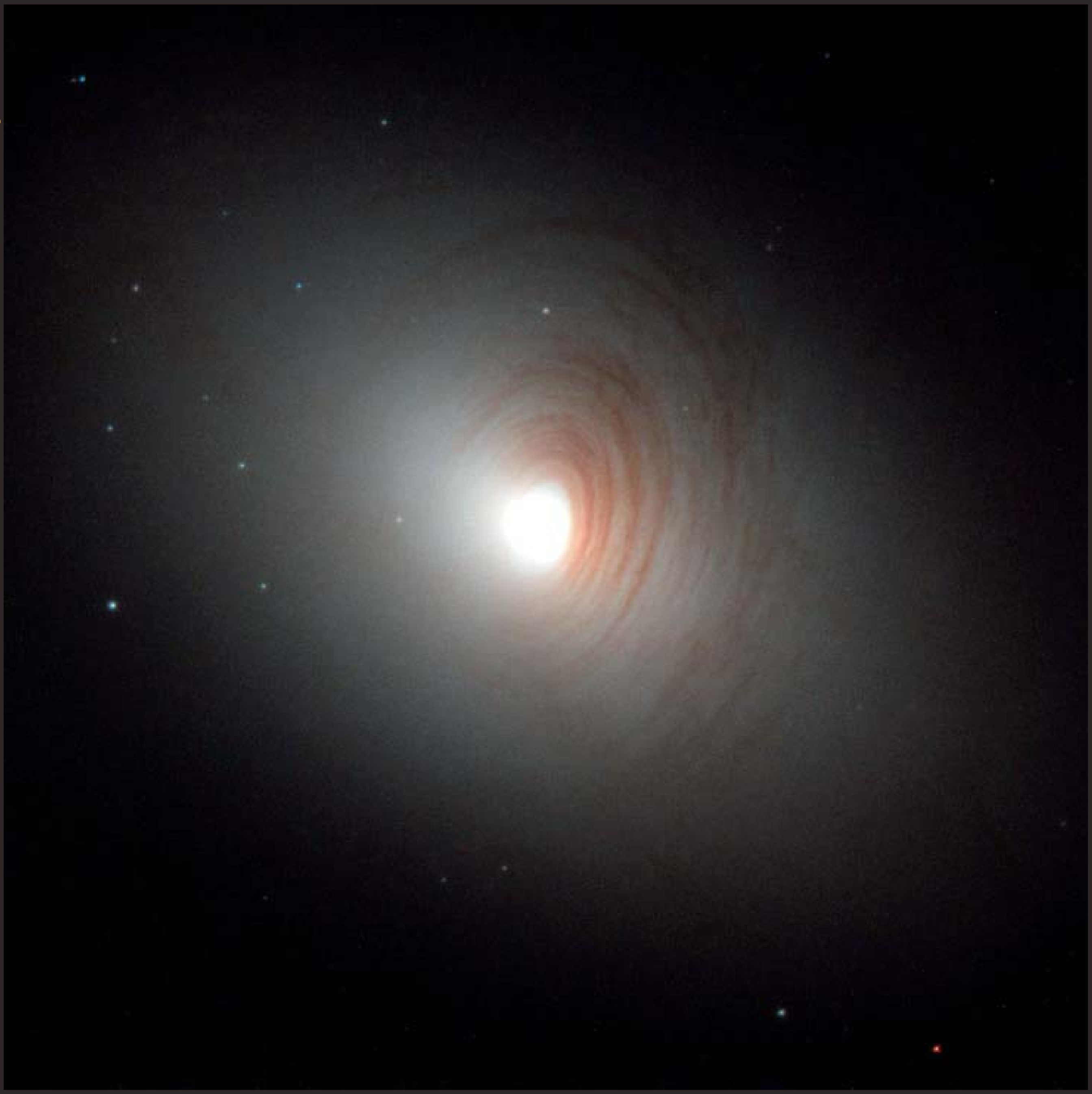
Hubble Examines the Aristarchus Plateau on the Moon

Hubble's Advanced Camera for Surveys imaged the Aristarchus crater and nearby Schroter's Valley rille on 21 August 2005. The Hubble images reveal fine-scale details of the crater's interior and exterior in ultraviolet and visible wavelengths at a scale of approximately 50 to 100 metres per pixel. The Aristarchus crater is 42 kilometres in diameter, is approximately 3.2 kilometres in depth and sits at the southeastern edge of the Aristarchus plateau. The plateau is noted for its rich array of geological features, including a dense concentration of lunar volcanic rilles (river-valley-like landforms that resulted from the collapse of lunar lava tubes), source vents and volcanic materials that erupted in giant explosive events. Aristarchus is one of the youngest large craters on the Moon. It probably formed between 100 and 900 million years ago. The image orientation is such that North is at the top.

NASA and The Hubble Heritage Team (STScI/AURA)

The Spirograph Nebula

Glowing like a multi-faceted jewel, the planetary nebula IC 418 lies about 2,000 light-years from Earth in the direction of the constellation Lepus. This Hubble image is shown in a false-color representation, based on Wide Field Planetary Camera 2 exposures taken in February and September 1999 through filters that isolate light from various chemical elements. The remarkable textures seen in the nebula are newly revealed by the telescope, and their origin is still uncertain.



NASA and The Hubble Heritage Team (STScI/AURA)

The Dust-wrapped Galaxy NGC 2787

Galaxy-hugging arms of dark dust encircle the bright nucleus of galaxy NGC 2787 in this Hubble image created by the Hubble Heritage Team. In astronomer Edwin Hubble's galaxy classification scheme, NGC 2787 is classified as an SB0, a barred lenticular galaxy. These lens- shaped galaxies show little or no evidence of the grand spiral arms that occur in their more photogenic cousins. By peering at the centre, astronomers are able to search for clues about the process of galaxy formation including the role of galaxy collisions and central black holes.