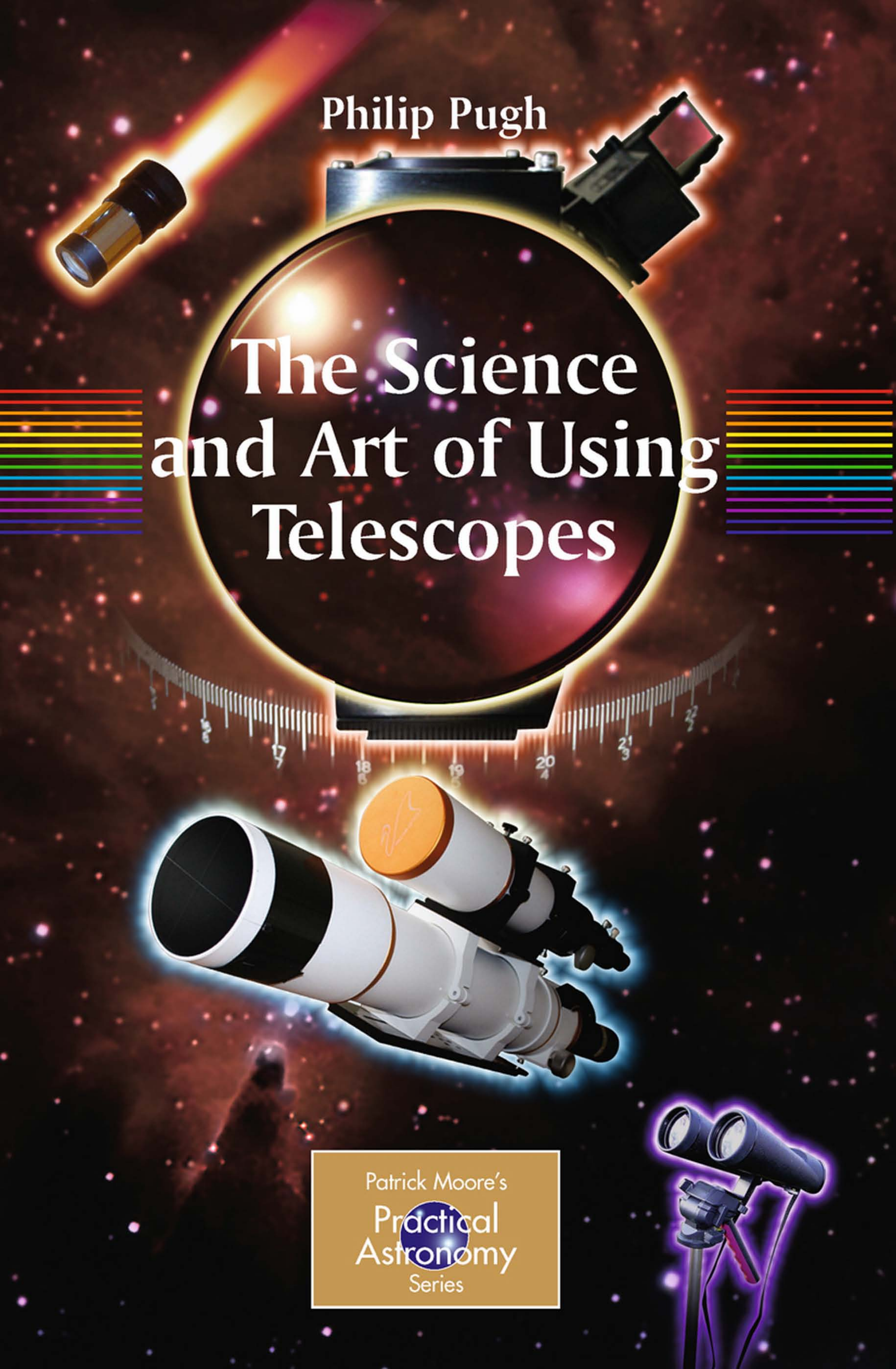
Philip Pugh

The Science and Art of Using Telescopes



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The Science and Art of Using Telescopes

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To my wife, Helga and daughter, Marcela,
who have given me lots of encouragement in
working on this book.

Preface

Astronomy seems to be good at grabbing the attention of the general public, whether it is from seeing the exciting pictures of the rovers Spirit and Opportunity on Mars, a solar eclipse, or a feeling of amazement while looking at the night sky on a particularly clear night. Indeed, some people are so inspired they rush out to buy their own equipment. Eventually, they may have seen enough of the Moon or brighter planets and to want to do more, but the question is, how?

This book addresses how you can move on from the beginner stage. Yes, it is true that many astronomy writers have lots of expensive equipment, and yet they tell you that you do not need to. This may appear (at first glance) as much of a mystery as the missing mass in the universe.

However, many astronomy writers are financially challenged, like the rest of us, and those who do spend money on expensive equipment do so because they wish to pursue some particular branch of the hobby. The short answer is to learn how to get the most from your existing equipment and seeing how your interest develops, rather than rushing out to buy the newest "next best thing." There is not any "one size fits all" advice when it comes to buying equipment, but this book will present some of the options available.

Having a few grand to spend wisely on equipment will help you get more enjoyment from the hobby, but sometimes a smaller purchase is all that is needed or even no purchase at all, just a fresh approach.

What Is in This Book

The Introduction discusses the overall use of equipment and introduces the types of instruments available in today's increasingly complex market. It also suggests a strategy to progress beyond the beginner stage and introduces the skills and equipment required to do so. The following chapters, from "Lunar Viewing" to "Beyond the Local Group," discuss the techniques and equipment needed for each subbranch of the hobby. The "Imaging" chapters discuss astrophotography using amateur equipment from the humble digital camera to CCDs and driven mounts.

The later chapters provide supplementary information to accompany the main chapters. "Usual Suspects List" describes some deep sky objects that can be viewed using modest equipment and "Planetary Data" gives some guidance on the sizes, orbits, and brightness of planets. Finally, the Glossary is deliberately large and comprehensive but is not intended to take the place of an astronomical dictionary or encyclopedia.

Philip Pugh

Acknowledgements

Many thanks to Anthony Glover for contributing the "Deep Sky Astro-Imaging" chapter. Thanks to his knowledge and expertise, I was able to complete the book in a way that the path from the beginner stage onwards is more clear.

Contents

CHAPTER ONE

Introduction

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Getting Past the "Beginner" Stage

Being a beginner itself is not a bad thing. Everything is new and exciting. Seeing the lunar craters for the first time or Saturn's rings fills you with awe and wonderment. Indeed, there is something to be said for staying a beginner for life and still enjoying it, just as some are content to remain on the bottom rung in careers or are content to go fishing without the urge to keep catching more or bigger fish.

Fortunately, though not all experienced astronomers have lost their sense of wonder, there is always something new to see or do if you are prepared to look for it and prepared to fail occasionally. As an example, teasing out some detail on a photograph of the Sun in calcium K light for the first time can feel as exciting as first seeing the Moon through a telescope. Another example is photographing Alpha Centauri, which is not visible from England. Although this star is known in science fiction lore as being our nearest star (technically it is the second nearest), not only it is a double star but it is also the one with the brightest secondary component in the sky.

Now imagine that you have bought one of those "beginner" telescopes. You have managed to see the Moon and you can see loads of dark features known as "seas" and craters. You have seen it in the evening sky and possibly just after it is full. You may have found Jupiter and seen its cloud belts and moons and, like Galileo before, you may have seen some of the moons moving around the planet by watching it on a few successive nights. You may have even split some of the better-known double stars, seen Saturn's rings, and maybe even the phases of Venus or possibly Mercury. You will have possibly seen Mars and wondered what all the fuss was about!

Perhaps you started off with a pair of binoculars. If you were lucky, they would have been suitable, but there are chances that they will not have been. Nevertheless, it is still probable that you will have still seen details on the lunar surface, although fewer craters than through a telescope. You may have seen the Pleiades (Seven Sisters) and discovered that there were 20, maybe 30 of them. You may have found other star clusters, such as the Hyades and Beehive to look at, and you may well have gazed along the Milky Way on a clear night.

If you were really fortunate, you will have experience in using both binoculars and a telescope before reading this book. You may have learned that some objects are shown better in binoculars, while others require a telescope. You may have even explored the limitations of both instruments and be thinking, "What now?"

You may already be aware that, for some situations, neither a telescope nor binoculars are actually required at all! You may have seen meteors or satellites in the night sky and may have learned that not all stars stay the same brightness. Do not think there is not room for research and discovery here, either. Only recently, Delta Scorpii was discovered to be a variable star by an amateur astronomer, and some have suspected another star (Beta Ceti) to be variable.

So Where Do You Go from Here?

Before you pawn your jewelry or remortgage your house, the answer is not necessarily to buy a large telescope. Back to the point made in the Preface, astronomy writers will sometimes tell you that you do not need a big telescope, while owning several themselves. Because of one's particular needs, which is explained in a later section, owning a large telescope is not always the answer, although "small" does not necessarily imply cheap. To decide whether a purchase is a good idea or may turn out to be a disappointment, you need to be realistic about what you can do. It is not just budget that is a deciding factor but where you live and what your interests are. For example, many people live in housing complexes where there are a lot of obstructions blocking the view. It then becomes impractical to use a large telescope on a frequent basis. Although many writers point out the advantages of viewing from a dark site, in many parts of the world physical safety of the astronomer and security of the equipment are a problem. It is best to observe from dark sites in a group, unless you have a particularly secure site. Many amateur astronomers like to think of themselves as good all-rounders, but in truth, most of us gravitate toward one branch more than others. Solar astronomy, for example, is becoming more popular lately, with more affordable equipment now available.

Specializing in Subbranches

Now, it would be nice to say that we are all multi-skilled with lots of knowledge of every branch of astronomy. It would also be nice if we could say that our specialization has been motivated purely by interest. In truth, many of us are driven by other factors. If you live in a big city and are restricted by budget, the nearest you are going to get to any galaxy is looking at a photograph. Even our nearest and dearest large galaxy, the Andromeda Galaxy (or M31 in Messier's Catalogue) is a hard object to locate from city sites. Indeed, it is said that, in city locations, visual astronomy is completely useless. Fortunately, this is not strictly true. Some, even most branches of visual astronomy, are impossible from city locations. Yet, the converse of that is that there must be some branches that are possible to pursue.

Fortunately, there are two very bright objects in the sky that can be viewed from anywhere. Indeed our own Sun is so bright (and dangerous to look at!), viewing that is a challenge in itself. The other one is the Moon. By sheer persistence and practice it can be viewed and even photographed under the most appalling conditions when most sane astronomers would not be seen dead outdoors. Fortunately, we do not all suffer from that particular branch of sanity, and if one wants to observe and there is anything out there to observe, and then observe one can.

In the chapters that follow we will start with the Moon, because it can be viewed so frequently and is tolerant of poor conditions and even broad daylight. It does present its own challenges. From a scientific viewpoint, amateur lunar viewing has little value, but it is always something that can be enjoyed.

The Sun is the favorite of many. In an English summer, there are about three weeks where there is no true darkness at all (longer in Scotland) and about seven weeks where it gets dark too late for anyone who needs their sleep. The Sun and Moon may be the only objects you can see except on weekends, unless Venus or the elusive Mercury is visible in the evening sky. The other really great thing about the Sun is that it is in a state of constant change, much more so than anything else we can observe from Earth. To get the best out of it, some investment is necessary. Be warned, however, that solar viewing can become seriously addictive and ruin your bank balance.

Although the Sun and Moon can be viewed under quite poor conditions, the next subbranch to be considered needs a moderately clear sky and, fortunately, little or no outlay in equipment. Where this author lives, in southwest England, the general viewing conditions are moderate. Compared with most parts of England, the weather is quite mild, but the downside is the risk of cloud and rain from across the Atlantic Ocean. I live in a small town, so the light pollution is medium. On a clear summer night, I can see the Milky Way without binoculars and stars down to 5th magnitude. This enables me not only to see the Sun and Moon but also to see the brighter planets and the easier deep sky objects using binoculars. This is quite typical of amateur observing conditions in the UK.

Such conditions allow naked-eye observation of variable stars and meteors. Meteors are, in themselves, easy to observe, but you need a certain amount of patience. On a clear night, you can normally see about 10 meteors per hour if you can cover the whole sky. As most of us can only see about a third of the sky at any one time, this drops to about 3. There is fortunately an alternative, and that is to watch during regularly occurring showers, where a larger number of meteors originate from a common source at the same time (known as the radiant). There are several types of variable star that can be regularly observed with no equipment whatsoever, but specialist variable observers also observe many more using binoculars. In this way, they are able to do useful scientific work, too, as professional astronomers do not have time to watch all of them. You may even discover a star that was not previously known to be variable, as happened with Delta Scorpii recently.

Following the planets by telescope does not require pristine viewing conditions, either. In fact, you can see some features using binoculars, the most notable being the four of Jupiter's moons discovered by Galileo (known as the Galilean Moons). However, planetary viewing past the beginner stage really requires a telescope and a "serious" one to really get the best out of it.

From an average suburban location, some deep sky observing is possible. The easiest objects are double stars, which are very tolerant of poor viewing conditions. The hardest are "faint fuzzies," such as galaxies and globular star clusters. Although comets are not related to either of these, visually (or photographically) the challenge is pretty similar. As an example, the Andromeda Galaxy (M31) has a magnitude of 3.7, so it should be fairly bright. As it is a relatively large object (one of the largest in the northern sky), the light is spread out over the area of 12 Suns or Moons as seen from Earth. The Andromeda Galaxy is not seen often without the aid of binoculars or a telescope. A similar challenge occurs with the Magellanic Clouds (a pair of satellite galaxies that can only be seen from south of the equator). Their magnitudes are 0.1 and 2.3, but they cannot be seen from a city location without using binoculars. They can be seen, however, from areas with little or no light pollution, such as parts of the Chilean coast.

Outside of the easier deep sky objects, you need a dark sky, good equipment, and a lot of luck.

Choosing a Telescope

OK, so you are starting out. The first question many beginners ask is, "Which telescope?" This is not always the best starting point. It assumes that one telescope will suit all of your observing needs and totally ignores the possibility of binoculars. Too many telescopes end up left to gather dust in garages or lofts and are frequently seen being advertised second-hand. You see very few pairs of binoculars on the second-hand market, as they are actually being used, maybe not always for astronomy but used nevertheless. Figure 1.1 shows the author's telescopes that are now in common use. On the left is a Skywatcher Startravel 80 with a Coronado Personal Solar Telescope (PST) piggy-backed on top. To the right is a Skywatcher 127 mm Maksutov–Cassegrain.

Fig. 1.1. The author's collection of telescopes.

There is no real simple answer, except to consider building up a range of equipment and consider the following type of questions:

- How much money is available now? Is there likely to be more in the future?
- How much time do you have available for observing? Are you likely to look on most clear nights for a few minutes at a time or are you likely to stay up all night once a month?
- What is your main interest in astronomy? Are you likely to want to specialize in one branch, such as binocular variable stars?
- Do you travel a lot for business or recreation? A lot of fun can be had observing while on business trips or holidays.
- Do you have any health problems that may affect observing? For example, frequent back problems may make using certain types and sizes of telescope difficult.
- Can you see anything from your home? Even if you can, you may still be unable to get a good view from one spot and may need to move equipment from one part of your property to another.

As a general rule, it is best to start off with some small binoculars, such as 8×30 (8× magnification and 30-mm aperture) and a small telescope (60 mm refractor or 76 mm reflector). A compact reflector is better if you intend to travel with it, while the refractor gives better images on most (but not all) objects.

It is also a good idea to watch the market, via magazines or the Internet. At the time of this writing, some seriously high quality small refractors were becoming available at moderate prices, and the trend in the United States and Europe is for prices to continue to go down over time.

Why the quotes? Is not the aim of every astronomer to buy a telescope and then, later on, to buy a "serious" telescope? The words questioned are "a" and "telescope." Many amateurs use binoculars for quick sessions grabbed during opportune moments and also own more than one telescope. It has been said that an astronomer is someone who owns a $500 telescope and spends most of his time using $30 binoculars. Although this may sound a bit of an exaggeration, many use binoculars about as much as all of their telescopes put together. Poor beginner telescopes can find their way to the attic very quickly; good ones will enjoy several years of use before being sidelined for something better, but a very well chosen one will be used alongside more serious ones at a later date.

If you are still unconvinced about the value of binoculars for astronomy, read the advertisements for used equipment in the magazines. You will see many large telescopes for sale, but very few binoculars. For those of us who have busy lives, they are the ultimate "good to go" instrument. Apart from the really big binoculars, they are light, do not need to be mounted, and require very little set-up. There are lots of objects that you can enjoy that do not take a lot of finding. Binoculars can also fit into hand luggage when traveling by airplane. A good choice is 15 × 70 binoculars. These are the largest size that large people can comfortably hold in their hands, although most people would tend to go for 60 mm binoculars for the same reason. In 2002, most models cost around $150, but similar models are now available at half the price. Under average cloudless viewing conditions, they can detect stars down to 10th magnitude and faint fuzzies, such as galaxies and globular clusters, down to magnitude 8.5. They have a field of view of 4°, although only the central 2° is totally free of distortion for a typical low-priced pair.

There is some advice in each section about which types of equipment are best for lunar, solar, planetary, and deep sky viewing. As a general rule, aperture and field of view are key to deep sky viewing, whereas optical quality and magnification are key to planetary viewing. Rules are to be broken, and there are some exceptions to this rule. For example, the Ring Nebula (M57) is one of the few deep sky objects in our galaxy that responds well to high magnification.

When choosing a telescope or binoculars, however expensive they are, there will always be limitations. Some of these will be climatic and location based, but others will be inherent in the equipment itself. For example, binoculars are great at sweeping the night sky for deep sky objects, but you will never, ever see any surface detail on Mars, although some people have seen detail on Jupiter with good quality 80 mm binoculars. Alternatively, no beginner telescope bought from a catalog or camera shop will show the full extent of the Andromeda Galaxy (M31) without the purchase of some additional accessories. By buying various accessories, you can improve the performance of your equipment to overcome some of its limitations and even those of the climate. If you are clever enough in your choice of equipment, you can even move accessories between telescopes.

Choosing Binoculars

Fig. 1.2. The author's binoculars.

Figure 1.2 shows the binoculars that I commonly use: Helios Stellar 15×70. Unlike telescopes, most binocular purchases are quite similar in idea. You do not buy binoculars to look at fine planetary detail. Although lazy or busy people use larger binoculars to check solar and lunar features when they cannot be bothered to get a telescope out, their main intended use is to perform a quick scan of deep sky objects. Larger ones can also be used to hunt for comets, and once a comet reaches a large apparent size (especially after it has grown a tail), it is far easier to find it and see the entire tail. When looking at binoculars, the main considerations are:

- Aperture: Larger binoculars gather more light. However, they also gather cost, and larger ones are too heavy to hold. This loses the advantage of quick set-up time, and you have to weigh the use of tripod-mounted binoculars against short tube refractors. Large adults can hold binoculars up to 70 mm in aperture, but for others it could be more or less. For comet discovery attempts, you really need to look at something with an aperture of at least 100 mm, although there is an alternative solution to that. The minimum sensible aperture is 25 mm, and binoculars with these can be purchased very cheaply.

- Magnification: Too little, and objects do not appear much bigger than with the unaided eye, too much and you have a reduced field of view (which makes binoculars no better than a telescope) and you cannot hand-hold them because any wobble is also magnified. A suggested maximum magnification is 15× for hand holding. The other key indicator is the *exit pupil*. This is the width of the light beam leaving the eyepiece and is derived by dividing the aperture by the magnification. It should be as close to your pupil width as possible. For example, 15 × 70 binoculars have an exit pupil of just under 5 mm, which is suitable for most of suburban viewing. Younger astronomers may have an exit pupil up to 8 mm at a dark site, but this is reduced with age and the amount of background light

- Optical quality: The best optical quality is achieved by using twin short tube apochromatic refractors, but not all of us are lottery winners. Most mid-aperture binoculars (50–70 mm) suffer from various types of defect. These are:

  - Chromatic aberration: The light of different wavelengths (colors) comes to focus at different points and so show false color fringes.

  - Astigmatism: Objects near the edge of the field of view appear distorted.

One feature of high-price binoculars is that they have interchangeable eyepieces. Sometimes they have barrel diameters that are particular to that of the binoculars, although some have barrel sizes common to those used in telescopes. That way they can be interchanged between equipment. They also have the advantage of having fewer defects and/or defects of smaller effect, due to the use of higher quality objective lenses and eyepieces. However, they may cost much more than regular quality binoculars, even 3 or more times as much. High quality 70 mm binoculars are of comparable price to a Coronado PST (solar telescope) or 127 mm Maksutov–Cassegrain. You will need to get a lot of use from them to justify such a purchase. Finally, there are various types of specialist binoculars, such as for solar viewing with built-in filters. Coronado did produce some hydrogen alpha binoculars; although these have been discontinued they may possibly be found on the second-hand market.

Although this negates the idea of quick set-up, binoculars can be more effective when used with a tripod. A simple camera tripod can be used, but these are very difficult to use when viewing objects near the zenith. Although not cheap, you can get specialist binocular mounts, while others can be mounted on an equatorial tripod. There are now some large binoculars available on the market up to 100 mm aperture, with retractable nebula filters. In fact, the market for affordable large binoculars is getting better all the time.

Some sort of binocular purchase is essential for just about all astronomers, and it is recommended that you get a pair before looking too deeply into telescopes. Small binoculars are also easier to use and produce better viewing than many beginner telescopes, which is where the next bit comes in.

Before leaving the subject of binoculars, we need to say that you might already own a pair. Perhaps as many as a quarter of UK households have a pair that may not be ideal or optimal for astronomical use but may have some benefit. If you have a pair in the attic, take them down and have a go. The 12 × 50 binoculars are a good size, but 8 × 30s and 8 × 35s are still a worthwhile purchase.

Beginner Telescopes

The simple answer to this one is do not buy a beginner telescope, although with some guidance it is possible to make a purchase without wasting money. Quite frankly, a lot of money is spent by well-meaning relatives on equipment for children that is, at best, unsuitable and, at worst, utterly useless. There are a lot of "toy" telescopes about. Many of them are incapable of showing Jupiter's brightest four moons, which is one of the minimum requirements for a telescope. So, yes, avoid toyshops that do not actually employ astronomers!

However, there are camera shops and even some large "megastore" supermarkets that stock telescopes. If you know what you're looking for, there are some good deals to be made, but please insist that they let you look *through* the telescope as well as at it. In the United States, many of these shops have at least one astronomer on the staff, and they are more likely to sell quality equipment than in England. A common type sold worldwide is the 60 mm refractor. The biggest downfall (apart from the inherent limitations of some 60 mm refractors) is that their eyepiece barrel diameter is not standard, so its supplied eyepieces cannot be used with any other telescope.

Your best bet of all is to buy equipment from a reputable retailer. These can be found in monthly magazines, which also contain equipment reviews. Although they have a tendency to review expensive specialist equipment, from time to time, they review beginner or budget equipment as well. Retailers are usually run by enthusiasts who will give you a realistic assessment of what you can see through it and what else you may need to buy to get the best out of it.

The specifics of buying equipment for adults and children are slightly different, but here is a set of guidelines on what you should look for:

- The wow factor: It must be capable of delivering something that impresses you. If you cannot see at least two equatorial cloud belts on Jupiter and at least two of its moons at any time, just say "Thanks but no thanks." Lunar craters and Saturn's rings are also a good test.

- Aperture: This should be a minimum of 60 mm for refractors and 76 mm for reflectors. Some experts would suggest more, but these sizes are large enough to satisfy the wow factor

- Finderscope: Just try finding an object without one. Even experienced observers struggle, so what chance has a beginner?

- Ease of use: If it takes a long time to set up and find things, it will end up in the attic quite quickly.

- Defects: One would expect some degree of chromatic aberration to be inevitable, but check for astigmatism or any other defect that distorts an object.

- Mount: This must be steady. The use of equatorial mounts is not recommended for beginners, although some patient adult beginners can learn to use them. GOTO mounts, which can help you find objects, are good. However, you need to spend some time setting up your telescope before you can use them, which includes polar alignment and recording guide stars. One with a manual override will allow you to pop out for a few minutes to photograph the Moon before bedtime. Also, for those on a limited budget, a GOTO mount adds a lot to the cost of a telescope. Better, perhaps, to spend the money on a telescope with larger aperture instead. However, GOTOs are particularly useful for deep sky enthusiasts and photographers.

Young people can be remarkably enthusiastic about astronomical viewing. Astronomers sometimes take their telescopes to schools and find that the students are very enthusiastic. However, when it comes to finding the objects themselves, they have as much patience as a deep sky enthusiast on the night of a full Moon. Apart from finding things yourself and telling them a thousand times not to knock the equipment, either binoculars or a telescope with a wide field of view on an alz-azimuth mount will be good. While an adult beginner would be thrilled about splitting a difficult double star such as Castor, a child would wonder what all the fuss is about. When buying for a child, budget is more of an issue, but adults, unless they are parents, may often have more cash at their disposal. A short tube refractor is a good starting point and is likely to be kept in use for a fair while longer.

In the next section, we will look at various types of telescopes and discuss their suitability for beginner and intermediate observers.

Wide Field Reflectors

These are among the cheapest telescopes on the market, and they have been advertised at around $30 when on offer but their normal retail price is usually a bit higher. Their aperture is either 76 mm, with a focal length of 300 mm (a focal ratio of f/4) or 114 mm aperture with a focal length of 450 mm (just under f/4). They are supplied on a cradle mount or some (like the Orion Starblast) come on a simple Dobsonian mount. They are not necessarily that good for planetary viewing but are certainly capable of delivering the minimum wow factors, listed above. Most of them use the standard 31.5 mm (1.25″) barrel diameter eyepieces, so these can be interchanged with other telescopes. Although marketed for beginners, they are often bought by more experienced observers as a quick get-up-and-go telescope, for travel or for deep sky viewing. The cradle mount may cause more experienced observers to wince, but it is a very convenient way for young people to locate and follow objects. Just do not let them outside unsupervised while the Sun is above the horizon. The wide field of view allows you to see large objects, such as the Andromeda Galaxy (M31) in their entirety. You do not use both eyes with one of these telescopes, but one advantage is that you can change the magnification by using different eyepieces and accessories, which you cannot do with most binoculars. This allows you to use the higher magnification required for lunar close-ups and planetary viewing. To get the most out of this type of telescope, you need to use eyepieces that cost considerably more than the telescope itself.

If you already own a short tube refractor and/or large binoculars, you may find that this type of telescope offers you nothing new. Otherwise, it is well worth looking at, or even through.

Small Aperture Achromatic Refractors

Some cynics would say that there should be a large warning sign around this section, or it should be labeled "how to waste your money in one easy step." Others say that, with care, one of these telescopes can keep you gainfully amused until you get something better.

First of all, many of the toy telescopes are not achromatic at all. They just have an objective lens made from a single piece of glass or even plastic (keeping the price down), but the optical quality is horrific. A true achromatic objective lens is made from two lenses of different types of glass (usually crown and flint). Although both of these types of glass have chromatic aberration, by using the correct configuration, their optical defects can actually cancel each other out – well, almost! To improve beyond that, you need an apochromatic objective lens or some sort of intermediate "semiapochromatic" objective. Further to previous moans, do not consider a budget refractor of less than 60-mm aperture either. If you look at the market, most of these telescopes are in apertures of 60 or 70 mm. An 80 mm refractor usually comes with a short tube, and these telescopes will be discussed in a section of their own. There are also many 90 mm refractors available. Perhaps they are too large to be considered small, but they are certainly not large, either. However, although the light gathering and resolution of a 90 mm achromatic refractor is noticeably better than a 60 mm model, the properties are essentially the same.

At the risk of repetition, one of the biggest drawbacks of this type of telescope is that many nonastronomical retail outlets sell it. As long as you can try it out before purchase or return it easily after purchase if it fails to deliver, you are okay. Many of the 60 and 70 mm refractors and some of 80 and 90 mm use the 24.5 mm (0.965″) eyepiece barrel diameter. This restricts the range of accessories that you can use. If it is likely to be your only telescope for a long time, this is fine, but if you think you may buy other, larger telescopes later on, one that uses the 31.5 mm (1.25″) eyepiece barrel diameter is better, even though you may have to pay a bit more money.

These telescopes usually come supplied on an alz-azimuth mount, although some are available on equatorial mounts and GOTO mounts. They usually have a focal ratio of between f/10 and f/15. As an example, a 60 mm Vanguard refractor has a focal length of 900 mm, giving a focal ratio of f/15. Using such long focal ratios reduces chromatic aberration (although just try using very high magnification and see what happens!) and allows high magnification for planetary viewing. In the time of William Herschel, many advanced astronomers used refractors with focal lengths in excess of 20 feet! However, the tube length makes that type of telescope impractical for air travel. Although these telescopes are not totally useless for deep sky viewing, due to the narrow field of view, they are not the most suitable except for splitting double stars. Like with most telescopes, buying additional eyepieces can enhance their performance. For example, Celestron makes SMA eyepieces of 25 mm and 10 mm focal length and the 25 mm one is very useful. The 10 mm one delivers under good conditions. The theoretical practical maximum magnification is twice the objective aperture in mm, so 120× for a 60 mm refractor and 140× for a 70 mm refractor. This can be increased if your telescope is of reasonable quality and being used under good conditions.

Despite the general cynicism surrounding this type of telescope, you can get a half-decent lunar and planetary telescope for a reasonable price.

Small Aperture Newtonian Reflectors

Apart from compact reflectors (which are covered in a later section), many astronomers prefer small aperture refractors to reflectors. "Small" usually refers to anything under 150 mm, which according to Patrick Moore is the minimum useful aperture for a reflector. This is not necessarily true for compact reflectors (covered later) or wide field reflectors, as they are easy to use. Traditional Newtonian reflectors can be quite useful for lunar and planetary viewing (and indeed many have enjoyed some of the views through them), but they are not as easy to use as small aperture refractors. The main disadvantages of Newtonian reflectors are:

- Effective aperture: The central obstruction of the secondary mirror and the "spider" supports block some of the light. This means that to get the same light-gathering power you need to increase the mirror size, resulting in a wider and heavier optical tube assembly than an equivalent refractor. Note, however, that in larger sizes, the size of the secondary mirror is less significant and the lighter weight of the mirror makes large reflectors lighter than refractors with the same light-gathering powers.

- The Newtonian design has the eyepiece at the top of the tube. This results in the viewing height being totally different for objects near the zenith and those near the horizon. This is also an issue with refractors, but it is not so bad.

- Maintenance issues: when in use, the mirror is exposed to the elements, and it needs to be recoated from time to time. Then there is the dreaded collimation, where the primary mirror needs to be positioned correctly, not to mention adjusting the position and inclination of the secondary mirror.

- Many budget reflectors use a spherical mirror, which introduces spherical aberration. This is not noticeable with the wide field reflectors but, like achromatic refractors, just notice the effect with high magnification. Fortunately, there are several available with parabolic mirrors, which do not have this problem. While many telescopes are advertised as such, if in doubt, it is best to ask.

Despite these limitations, it is possible to achieve nice views of planets and deep sky objects through these telescopes, and (possibly in common with binoculars and other telescope types) many improvements have been made in both quality and price over the last 2 years. There is at least one popular 130 mm Newtonian reflector with a parabolic mirror (the Skywatcher 130PM) that is very popular and has a good reputation.

Short Tube Refractors

These are sometimes known as wide field refractors or vista refractors, but their purpose is still the same. In fact, were it not for the cost implications (about 60% or more expensive than a 60 mm refractor), it is a good choice of starter telescope. To make matters even better, you will still want to keep the telescope, even if you later buy a more "serious" one later. The only telescope that you might want to replace it with later is an apochromatic refractor, which is described later.

Like all types of telescopes and binoculars, they have their limitations. Nevertheless, they have several advantages:

- They have a wide field of view, so they can accommodate objects of large apparent size, such as galaxies and comets.
- Their small physical size and weight makes them suitable for air travel.
- They are not particularly expensive.
- They are more versatile than binoculars, as you can use different eyepieces and accessories.

Most of these instruments are available with an aperture of 80 mm and have the standard 31.5 mm (1.25″) eyepiece barrel diameter. They also have a focal length of 400 mm. They are available from several different manufacturers and are usually supplied on a lightweight equatorial mount. They also have fittings to allow attachment to a camera tripod. This will not allow stable viewing at high magnification but will at least make the telescope portable by air. Even lightweight equatorial mounts and tripods can play havoc with your baggage allowance, so it is best to use a camera tripod. The maximum magnification that this setup permits is about 80× and the maximum on a steady mount is about 160×. Around this, chromatic aberration starts to kick in badly, in a way that it does not on longer focal length refractors.

The maximum effective field of view is about 4°, and this comes with a magnification of 12.5×. Although you can use certain eyepieces and accessories to push this down further, the problem becomes the exit pupil. A magnification of 12.5× gives an exit pupil of 6 mm, which is a bit on the high side for suburban skies. An increase in exit pupil can help with photography, though. It is good for photographing close conjunctions between objects, such as planets with stars.

This type of telescope is also available in apertures of 120 and 150 mm. These sizes gather more light (2.25 times and 3.7 times more than an 80 mm refractor). The maximum magnification also goes up to 240× and 300×, respectively, although you will need a steadier mount. However, as the focal ratio of f/5 is still maintained, the field of view decreases, so these sizes are not as popular as the 80 mm aperture.

Larger Aperture Newtonian Reflectors

Put bluntly, the 150 mm+ Newtonian reflector is the backbone of amateur astronomy in the northern hemisphere, but does it really justify its standing? In many ways, it does. For many years, larger aperture refractors were simply not available, at any price. In more recent years, there are some alternative types of reflectors available, which are described later. Some of the limitations of small aperture Newtonian reflectors are carried over to their larger cousins. The Dobsonian mount is a great innovation for simplicity and budget but just try observing an object near the horizon.

For many applications, particularly difficult "faint fuzzies," aperture is all-important. The Newtonian reflector (in its larger sizes) delivers more millimeters of aperture per buck than any type of telescope. Also, in the larger sizes, the percentage of light lost by the secondary mirror and spider is a lot less than the smaller reflectors. Aperture also delivers resolving power, which, on some occasions, will outscore the better optical quality of similarly priced compact reflectors. It is not rare to see 250 mm reflectors at star parties and maybe even larger ones. These will enable you to see faint objects, such as Pluto. The cheapest type of reflector is called a Dobsonian. Although not wanting to take anything away from its inventor, John Dobson, it is actually the mount that the name is referring to. The basic Newtonian design has not changed for over 300 years, although the materials used for its construction and optics certainly have. A Dobsonian reflector is one of the first recommended projects for amateur telescope makers. Indeed, the precision to which these telescopes are now manufactured would make Isaac Newton and even the Herschels green with envy.

Since monthly magazines became widely available a few years ago, the price of brand new Dobsonian reflectors has dropped by about 30%. Added to that, as many amateur astronomers catch aperture fever and are selling older telescopes to pay for an extra 50 mm of aperture, there are lots of second hand telescopes available. Many are quite small and best avoided, but, with few moving parts to go wrong, the main risk of buying a second hand Newtonian reflector is that the mirror needs recoating. Another idea is to replace a Dobsonian mount with an equatorial one, especially if you are going to perform long exposure photography. An equatorial mount, however, will add considerably to the weight of the telescope and take up a lot of room in a small property. As for carrying a large equatorially mounted reflector downstairs on a regular basis, forget it, unless you are an Olympic weightlifter. Many astronomers prefer to buy other types of telescopes instead, sacrificing aperture for portability.

This topic is not complete without mentioning truss Newtonians. These do not have a solid tube, so are lighter, and some models can even be disassembled and carried by air. The drawback is that they must be used from a perfectly dark sky, or they will let stray light ruin the view. A work-round is to use a plastic shroud around the tube assembly to block the light. An innovation that has hit the market in volume very recently, these can only get better and cheaper.

A variation on the Newtonian theme is the Maksutov–Newtonian. In terms of tube length, weight, etc., they are very similar to the classic Newtonian design. A spherical mirror is used and a corrector plate is added at the top of the tube assembly. This is a more accurate optical correction than the parabolic mirror. Also the corrector plate makes the assembly into almost a sealed unit, reducing the problems of exposing the mirror to the elements quite considerably and removing the need for frequent recoating of the primary mirror. In terms of optical quality, these instruments are great performers, way outscoring classical Newtonians of similar aperture but naturally out pricing them. The Intes Micro 7″ instrument is very impressive.

Larger Aperture Achromatic Refractors

These are commercially available in the size range of 100–150 mm. They are not normally advertised in sizes larger than this. The lack of a central obstruction makes the aperture 100% effective, unlike reflectors. However, one of the reasons very large instruments are always reflectors is that lenses are simply very heavy. Also, the very long tube lengths of larger refractors make them difficult to use. The largest refractor in the world is a "mere" 40″ (just over a meter) in diameter, while the largest reflectors are ten times that.

In terms of millimeters per buck, Newtonian reflectors outscore achromatic refractors, although the views of the planets and Moon are rather better. These types of refractors are of little use for deep sky viewing, given their long focal length and consequent narrow field of view. They are good for splitting close double stars, but chromatic aberration spoils the view. It is only recently that 150 mm refractors have become commercially available, and these require less maintenance than a Newtonian reflector of comparable effective aperture (about 200 mm). Their weight is a big minus, and there are other telescope types perhaps more worthy of consideration.

Clear Aperture Reflectors

These telescopes are a recent variation on the Newtonian theme, where the primary mirror is tilted at an angle and directs the light to the side of the tube, where it is passed to an eyepiece. This removes the need for a central obstruction, thus using the entire aperture of the primary mirror. These instruments are so cutting edge that reviews are rare and few people have seen them. At the time of writing, the only size available was 3.6″, so rather on the small side and appears to be rather expensive for what it is. It sounds like a good idea, but the jury has not even been selected, let alone gone out for a verdict!

Compact Reflectors

The best evidence for the effectiveness of this type of telescope is that many intermediate and advanced astronomers use them. Indeed there are several subtypes of compact reflector within this genre.

Now, the focus of this book is about using telescopes, rather than optical engineering, but some of the qualities of each subtype, such as the cost, quality, and use, can vary quite considerably. What they all have in common is that some sort of lens or corrector plate covers the top of the tube. This protects the optics from the elements, making the maintenance a lot easier than for the Newtonian reflectors. Most subtypes also allow long focal lengths to be used with a short physical length of tube. This makes them a lot lighter and easier to carry by airplane. In terms of millimeters per buck, they are more expensive than Newtonians, but their lighter weight allows you to use smaller and cheaper mounts.

The first type we come across is a catadioptric. This uses a special type of lens called a meniscus that helps to focus the light path and correct for spherical aberration (which it does to some extent) and a primary mirror reflects the light to just under the meniscus, where a secondary mirror reflects the light to the side of the tube where it can be viewed with an eyepiece. Note that no spider is used. These are commercially available in sizes of 76–150 mm and are slightly more expensive than Newtonian reflectors (although only 20–30% more). They are not generally available in larger sizes, where other subtypes of compact reflector take over.

The small Tasco compact reflector is extremely portable and certainly capable of delivering the minimum requirement for a beginner telescope. It has an aperture of 76 mm and focal length of 600 mm. It is also amazingly good at splitting double stars, despite its obvious limitations. Although the catalog advertises the maximum magnification as being 200×, it really only handles up to 60×. This is more than enough to show Jupiter's cloud belts and Saturn's rings, but during the 2003 opposition of Mars, it was very disappointing and a 60 mm refractor outscored it by a mile. Like many budget telescopes, its performance can be enhanced by the purchase of suitable eyepieces. There are problems with chromatic aberration, although these telescopes are better than many others of similar price in this way. This type of telescope (in its smaller sizes) has a similar type of use to binoculars and short tube refractors. In many ways, this genre of telescope makes a good budget starter telescope and will often continue to be used after the purchase of a larger telescope for a while. It is also extremely portable.

A revolution has occurred recently with Maksutov–Cassegrains. The basic design is far from new, but the mass amateur use certainly is. The primary mirror reflects the light to a secondary mirror on the corrector plate/meniscus, which consists of a coating. The light is reflected back through a hole in the primary mirror. Where it differs from a Maksutov–Newtonian is the hole in the primary mirror, rather than reflecting light to the side of the tube. This allows a much shorter tube to be used than with a Maksutov–Newtonian, which improves portability. In fact, the telescope weight and tube weight are light enough to allow it to be carried by people who suffer back trouble or are simply not very strong. Although the tube assembly is light enough for most models to be carried by air, the weight of the mount makes it less suitable. Quite why this arrangement produces results vastly superior to a Newtonian or achromatic refractor is somewhat of a mystery. What is in no doubt is that it definitely delivers excellent image quality.

It is now nice to see these excellent telescopes are now available in apertures from 80 to 200 mm, although from 200 mm upwards, the Schmidt-Cassegrain starts to take over. In head-to-head tests, the true apochromat is still better, although some of the chromatic aberration is more due to the low/medium cost eyepieces many use with it than to the telescope. Also, you must allow some loss of aperture for the central obstruction, so a 5″ Maksutov–Cassegrain will perform about the same as a 4″ apochromat. However, the Maksutov–Cassegrain is usually cheaper. Maksutov–Cassegrains are often sold on GOTO mounts, which increase the purchase price considerably. The Meade ETX range is the best-known example of this genre, although the smaller models in the Meade ETX range are actually compact refractors. Many choose to buy a larger aperture telescope without the wizardry for the same money, but this is up to you.

The Skywatcher Maksutov–Cassegrain of 127 mm aperture is really quite excellent. It gives great views of the lunar features and can tease out fine detail on Jupiter. For example, the cloud belts are no longer the straight lines that you see in beginner telescopes, but the edges become jagged and the regions in between the belts take on a shaded appearance. Though not intended as a deep sky telescope, this instrument shows great views of the planetary nebulae, including the Ring (M57) and Dumbbell (M27). Like most other telescopes, the supplied eyepieces are of limited use, and to get the best use, it is necessary to acquire a set of accessories. Without buying anything vastly expensive in proportion to the cost of the telescope, it is possible to achieve a magnification of 24× with a 1.7° field of view, which just gets in the main asterism of the Pleiades. At the other extreme, it is possible to use magnifications up to 500× for viewing bright Solar System objects. On an exceptional night, it is possible to use magnifications in excess of 700×, but this requires a driven mount. This telescope is also good for viewing and photographing double stars.

Now we come to the other type of telescope that dominates star parties – the Schmidt-Cassegrain. Again, the telescope uses a corrector plate, and the light path goes through a hole in the primary mirror using a convex secondary mirror. These telescopes were used extensively for professional astrophotography but have found their way into the amateur market. Meade and Celestron are the market leaders in this field, with a variety of telescopes available commercially with apertures from 200 to 400 mm. Do not be fooled by the term "compact" for the larger sizes, as they are quite heavy and often require two people to move and set up. Many models come with a fork mount that is computer controlled. As a result, they are not cheap, but they are of great use at star parties on a selection of Solar System and deep sky objects.

The final type of compact reflector is the Ritchey-Chreiten. Although the design was engineered in 1910, it is only recently that models have become available on the amateur market. This type of telescope uses hyperbolic primary and secondary mirrors with a corrector plate. The design eliminates all types of optical defect but comes at a price. Not only are these more expensive than Schmidt-Cassegrain telescopes of similar aperture but also the design requires a large secondary mirror, which increases the central obstruction and reduces the effective aperture. The excellent images seen in the monthly magazines bear testament to their quality. Very similar to these are the Meade Advanced Coma Free (ACF) telescopes, which are now sold in a variety of sizes.

Apochromatic Refractors

In terms of millimeters of aperture per buck, these are just about the worst of the lot. They are also quite heavy for their size, and it is no coincidence that the largest refractor in the world (just over 1 m in aperture) is a lot smaller than the largest reflector (10 m and rising). Their popularity is due to their undoubted quality. The emergence of the Maksutov–Cassegrain onto the amateur market offers a real threat, as they are almost as good as the apochromat (or APO) and are much cheaper. If you actually observe the amateur market, you will see that there is a huge price difference between models. This is not because the higher-priced models are a con, but it does mean that you have to be careful with what you are buying.

Before describing a "true APO," there is the slightly misleading term "semi-APO." First, there is the "semi-APO" filter, which merely removes color fringes when used with an achromatic refractor. The term "semi-APO" is sometimes used to describe high quality achromats. One interesting type to look for is one that carries the title "ED." This stands for "extra dispersion" and uses a special type of flint glass with better properties than that used in standard achromats. An enhancement to the "ED" idea is using some sort of oil in the space between the glasses. The commercial availability of these has mushroomed over the last year, and, indeed, even a small one has several advantages over an achromat.

A true APO actually consists of a lens made from three different types of glass, but, again, there is a lot of difference in the price and quality of these telescopes! When considering any purchase, consult a reputable retail distributor and seek independent advice over the Internet. Also ensure that what you buy carries the label "triplet". A "doublet APO" may well be good value for money and a good performer but is certainly not a true APO. Some brands to consider are Takashi and Televue, who have both produced quality APO refractors over a number of years. These certainly do not come cheap, but they have a long pedigree. Orion ED refractors do not make false claims to be true APOs but are, nevertheless, better than achromats.

There are not many large APOs made, and they have long delivery times. A common size is 60 mm, and many of these have a short focal length, suitable for deep sky viewing and imaging. Many of the excellent photographs of the Andromeda Galaxy (M31) are taken using such equipment. These telescopes are for the connoisseur, and leaving one in the attic should be made a criminal offence.

At the time of this writing, many players have entered the market, with several “ED”, “doublet APO” and “triplet APO” models available. The purchase of a suitable instrument of this genre is a good starting point for the financially advantaged amateur astronomer just starting out. It will continue to be used as a second or “grab and go” telescope long after larger models and been bought and lesser instruments relegated to the attic.

Although anyone who can realistically afford to buy an APO should give it serious consideration, any advantage over an ED requires you to use eyepieces and other accessories of similar quality to that of the telescope itself. If you are unable to spend about a further 50% in accessories in the foreseeable future, a good quality ED (of larger aperture for the same price) may be a better buy.

Specialist Telescopes

There are other types of telescope that do not fall into the above categories. Although many of these are the province of the professional, some have (fortunately) found their way into the amateur market. The most significant of all has been the narrowband solar telescope. This enables amateurs to view features on the Sun that could previously only be seen during a total solar eclipse or by professionals. The most significant change has been the introduction of the groundbreaking Personal Solar Telescope (PST) from Coronado, which has recently broken the $400/£400 affordability barrier. This allows only a narrow band of light around the hydrogen alpha wavelength to pass through. The telescope's features are described more fully in the "Solar Viewing" chapter. There is a large range of dedicated telescopes, ranging from the PST to the MaxScope 90. Although this type of viewing is more affordable, it is still far from cheap, with the entry-level PST costing a bit more than a 127 mm Maksutov–Cassegrain or 200 mm Newtonian reflector. Although Coronado is the market leader, especially at the budget end of the market, there are other players such as SolarScope and Thousand Oaks. New to the market (at the time of this writing) but with an impressive pedigree is Andy Lunt.

The other type of narrowband solar telescope is the calcium K one. This shows a different layer of the solar chromosphere containing ionized calcium. Its structures are not that different to the hydrogen alpha layer but are subtly different enough to make looking through a calcium K telescope worthwhile. The calcium K features are difficult to see visually but come out very well in photographs. Other telescopes that find their way into specialist amateur hands include the coronograph and spectrohelioscope. These can be difficult to track down.

The spectrohelioscope is an arrangement of lenses and mirrors that uses a primary mirror (flat) to track the Sun and reflect its light down a tube. It also contains a set of prisms, mirrors, and a diffraction grating to isolate a given light wavelength, such as hydrogen alpha or calcium K. Although it is more flexible than the Coronado solar telescopes, it has to be permanently mounted, because of its size and weight. It is not commonly available to buy but some amateur astronomers have made their own.

Coronographs use an occulting disc to block the central light source from the Sun to allow the fainter solar Corona to be seen. Although the principle may sound simple, it cannot be achieved by placing a disc in front of the objective; otherwise, most reflector types would operate as a coronagraph. Also, consider how the disc must be positioned exactly, or part of the bright solar disc would be visible. The Corona is as bright as the full Moon but cannot be seen against the (much brighter) solar photosphere.

Accessories

Fig. 1.3. Collection of accessories.

Figure 1.3 shows a sampling of accessories quite typical for an avid amateur astronomer, collected over several years. From left to right, the accessories are:

1. Skywatcher Long Eye Relief eyepieces (25 and 10 mm focal length)

2. Skywatcher Plossl eyepieces (6.3 and 32 mm focal length)

3. Coronado TM eyepiece of 12.5 mm focal length

4. Moonfish SWA eyepieces (20 and 15 mm focal length)

5. Moonfish 3× Barlow lens and Soligor 2× Barlow lens

6. Antares 2× focal reducer and Magni Max 1.6× image amplifier

7. Celestron moon filter and Astro Engineering variable polarizing filter

Bad accessories can make a reasonable telescope into a poor one. Good ones can turn a modest telescope into a half-decent one. Exceptional accessories cannot turn a bad telescope into a good one but can extend the use of a telescope way beyond its original intentions.

The first and most important accessory is the eyepiece. Most telescopes come supplied with eyepieces, but, unless you are very lucky, these eyepieces will not normally do anything to sell the telescope. It is almost inevitable that, to get the best out of a telescope, you need to buy a good set of accessories. If you are thinking of buying a second (or subsequent) telescope, it is possible that you will be able to use eyepieces supplied with your first. If you buy your second telescope from the same retail outlet as your first, you may well have the problem of owning duplicates. Some retailers are willing to supply alternate accessories and charge any difference in retail price.

Some brands of telescope use non standard eyepiece barrel sizes, but most sell them in three standard sizes:

- 0.965″ (24.5 mm): These are mostly for beginner telescopes but some older, larger telescopes, such as the Vixen Custom 80 use them.

- 1.25″ (31.5 mm): These are the most common and cover some beginner telescopes up to quite serious ones.

- 2″ (50.8 mm): These are mostly used with large Dobsonian reflectors and quality APO refractors.

In the barrel size of 0.965″, the common eyepiece types are orthoscopic. They are usually quite simple in design and not ineffective either. Their limitation is that their apparent field of view is only about 30°. Many planetary viewers swear by them, but they make objects very difficult to find. A useful type is the modified achromatic (or SMA). These have an apparent field of view of about 50° and give good images. They work well with many beginner telescopes. Although Plossl eyepieces are mostly used with the 1.25″ barrel size, some manufacturers supply them in the smaller size as well.

Most eyepiece types are available in the 1.25″ barrel size. The main types are:

- Plossl: These are good visually but not always that good for taking photographs, the exception being the Coronado CEMAX eyepieces. They have an apparent field of view of about 52° and are available in different qualities, from budget to deluxe. They are suitable for both planetary and deep sky viewing and are available in focal lengths from about 5 to 40 mm.

- Long Eye Relief (LER): These do exactly what their name suggests and are regarded as suitable for spectacle wearers. In general, they do not perform as well visually as Plossls but take better photographs. Like Plossls, they have an apparent field of view of about 50°.

- Super Wide Angle (SWA): Again, an apt name, as their apparent field of view is at least 70°. They are not quite as good visually as Plossls, but the difference is not that great. Photographically, they are better than LER eyepieces, and so are good all-round performers.

Moving on to the 2″ barrel size, most of the eyepiece types available in the 1.25″ barrel size are available here, but there is also the Nagler, which is the Rolls-Royce of eyepieces and almost as expensive. It has an apparent field of view of about 80° and subtypes known, imaginatively, as Type 1 to Type 6. They are very good indeed, but outside the budget of most amateurs. Even more amazing is the Ethos eyepiece, which has an apparent field of view of 100° and is more expensive than many telescopes.

There are also several types of zoom eyepieces available. Usually, their focal length range is from 7 to 21 mm or 8 to 24 mm. They allow you to find objects, then zoom in to get a closer look. They are also good at adjusting the telescope magnification/field of view combination to allow the whole solar or lunar disc to be seen at the highest magnification, filling the field of view. Unfortunately, even the good ones introduce a fair amount of chromatic aberration. The other problem is that adjusting the magnification usually requires a small adjustment to the focus. The good news is that there is one branch of astronomy where this is not a problem – narrowband solar viewing. Some brands also introduce a lot of internal reflections, but fortunately most people's eyes are not sensitive to them. It is amazing how some pieces of equipment come up trumps in most unexpected ways.

This brings us to the Moon filter, which serves its purpose in reducing the glare from the Moon when viewing the whole disc. Indeed, lunar viewing near the full Moon is not good for your eyes, although not as dangerous as solar viewing without protection. What may be a surprise is that it can also be used for solar viewing and getting better contrast when viewing the brighter planets, such as Venus and Jupiter. Like many filters, it simply screws into the eyepiece thread. It allows 18% of light to pass through but does not reduce the aperture. One term often used to describe such filters is "neutral density," as they do not allow or block nominated light wavelengths, just all light across the spectrum.

Also available is a variable polarizing filter. As well as blocking stray light, it can be adjusted to allow any amount of light between 1 and 40% to pass. This is particularly useful for lunar photography, as it can be adjusted to suit the conditions and aperture of the telescope being used. If you are doing close-up viewing or photography, you need to increase the amount of light getting through.

Another type of filter is the "minus violet," which is sometimes marketed as "semi-APO." This filter blocks color fringes caused by chromatic aberration in refractors and some types of reflectors. Remember also that some chromatic aberration is introduced by the eyepiece and Earth's atmosphere, especially for objects near the horizon. With an achromatic refractor there can be a doubt whether the polar ice cap of Mars was real or caused by the optics. However, these color fringes can be removed from digital photographs by processing.

There are also "light pollution" filters that block wavelengths caused by street lighting and are useful for deep sky viewing and photography. There are also various types of color filters, but these are not recommended for telescopes below 200 mm aperture. They have been known to bring out more detail on Mars and Jupiter, in particular, and author Larry Alvarez has successfully used green filters to tease out more detail for "white light" solar viewing. There are also broadband filters centered around a particular wavelength, used to show more detail in nebulae and galaxies. These block out a lot of light and need a large aperture telescope to get the best out of them. Examples include hydrogen alpha, hydrogen beta, and oxygen III.

This brings us to a word of warning. *DO NOT* use screw-in night time hydrogen alpha filters to view the Sun. Not only it is dangerous but it is quite useless anyway, as you need narrowband filters to view the solar disc. The one type of screw-in filter you can use is calcium K but it *MUST* be used in conjunction with a white light *FULL APERTURE* filter as well. You can get neutral density white light solar filters, which are very good, as long as you observe common sense and safety rules and the various types of narrowband hydrogen alpha and calcium K filters that are described in the "Solar Viewing" chapter.

Additional accessories include image amplifiers and focal reducers. Although telescopes should usually be bought with a primary use in mind, by the use of image amplifiers and focal reducers, their use can be somewhat extended. The most commonly known image amplifier is the Barlow lens. We all know about them, do we not? We had one with our beginner telescope that allowed us to use magnifications in excess of 500×. It is probably stating the obvious to say that there are good Barlow lenses and bad Barlow lenses. Here are some of the characteristics of a bad one:

- Introduces chromatic aberration over and above what the telescope/eyepiece/viewing conditions produced.

- Reduces the field of view by a lot more than the factor they increase the magnification (for example, it is OK for a 2× Barlow lens to reduce the field of view by 55% but not 70% or more).

- Is heavy enough to alter the balance of the telescope.

There are also variable Barlow lenses. These are not commonly used, and there is a tendency to be suspicious of them, expecting the same problems introduced by zoom eyepieces. Barlow lenses are not prohibitively expensive, and there is no reason why you cannot have two: one that increases the magnification by 2× and another 3×. The Astro Engineering 1.6× image amplifier screws into the eyepiece in the same way that a filter does. It is a recent innovation and a good one. It is always very satisfying when you buy something that does not cost a lot of money, yet really improves your viewing. This object is particularly useful with a Coronado PST when it amplifies the image with a 12 mm eyepiece to fill the whole field of view. It can also combine well with a 2× Barlow lens to give a combined magnification boost of 3.2× and a 3× Barlow lens to give a magnification boost of 4.8×. The latter is particularly useful for taking close-ups of lunar craters. This technique can also be used to tease more detail out of Jupiter, Mars, and Saturn. The downside is that it introduces some light loss when viewing/photographing faint objects, but "chaining" image amplifiers to obtain very high magnifications is normally used only on bright objects, anyway.

Just as there are times you would like more magnification, there are also times when you would like less. When are these times?

- When the viewing conditions of the day or night are not good, and it may be impossible to obtain a sharp image at high magnification

- When you wish to take a long exposure, unguided photograph and do not want too much movement

- When you would like a wider field of view to take in a large object, such as a star cluster.

There have been focal reducers available for Schmidt-Cassegrains for a long time, but these are dedicated to a particular model of telescope and are not for general use. They are wrongly described as f/6.3 focal reducers, when what they really do is reduce the focal length by 0.63 times. The Antares focal reducer has proved very useful in reducing the focal length by a factor of 2 and increasing the field of view by about 1.7 times. Although introducing another lens does introduce some extra light loss, it has been possible to view the entire Hyades star cluster, using a short focal length refractor and see the main asterism of the Pleiades in a Maksutov–Cassegrain with a focal length of 1,540 mm. Using this accessory with instruments that are already of short focal length can result in very wide exit pupils (in excess of 10 mm) and lose a lot of light visually, although it will not be an issue with some types of camera.

A final word of advice concerning both telescopes and accessories: Models on the market and purchase prices vary from country to country. The best value for the money at this time is to be found in the United States and so is the widest range of equipment.

Rules Are Meant to Be Broken

Let us start by introducing the one rule that you cannot possibly break: you must be extremely careful when viewing the Sun. With the possible exception of a full Moon and a large aperture telescope, the Sun is the only object that can permanently damage your eyes. See the "Solar Viewing" chapter for details.

The first rule that is often quoted is that you cannot use any eyepiece/image amplifier combination with a telescope that yields a magnification of more than twice the aperture in millimeters. This is true for some telescopes under some conditions but is not a universal rule by any means. A lot of experimentation in this area has found the following to be more accurate:

- This figure can be doubled for bright objects, such as the Sun, Moon, and brighter planets.
- If an object, especially a bright one is near the zenith, you can increase the magnification. Unfortunately, the converse is also true in that an object near the horizon may only take a magnification of somewhat less than the telescope aperture in millimeters.
- Some telescope types have a better optical design, the prime example being the apochromatic refractor.
- Longer focal length telescopes seem to tolerate higher magnifications than short focal length ones.

The main limiting factor of magnification using quality telescopes is a motor drive with certain mounts. Otherwise, it would be possible to obtain lunar close-ups in excess of four times the aperture in millimeters. Another strange finding is that using image amplifiers seems to give sharper images than using short focal length eyepieces, especially when using beginner telescopes. You should use as many combinations of your accessories as you can to compare results and find out which works best. A word of warning, though! While the results on the Sun, Moon, Jupiter, and Saturn are consistent and predictable, they will not be when you start viewing Mars.

The next issue concerns the Moon. Most experienced astronomers curse the full Moon. It drowns out everything else, it scatters moonlight off any thin clouds, and it is not particularly interesting anyway. If there is not anything else to see, why not just take a good look? It does not have the subtlety of the crescent or half Moon, but it has a charm of its own. Favorite features near the full Moon are the ray systems of craters such as Tycho, Copernicus, and Kepler. Tycho's rays stretch right across the lunar landscape and can be seen quite clearly in modest binoculars. The same goes for larger lava-filled craters and basins, such as Plato and Grimaldi. There is the issue of lunar glare, but sensible use of a Moon filter or variable polarizing filter can soon sort this out. The full Moon is also a good subject for digital photography and does not need long exposure times. The best results are had by keeping the exposure as short as possible. Although deep sky specialists are right in their complaints that faint fuzzies are drowned out by moonlight, the brighter planets, and double stars that can still be observed during a full Moon.

Unfortunately, the next rule breaker is one that hinders you, rather than helps you, but you have to be aware of it. Many telescope retailers publish limiting magnitudes for their instruments. This is not meant to mislead you in any way and is a good point of comparison for different telescopes and binoculars. The theory goes that someone with average eyesight should be able to see stars of magnitude 6.0 from a dark site under clear conditions. Unfortunately, few of us (especially those in Europe) have the luxury of a clear sky very often. Many do the majority of their observing from urban or suburban locations, mostly for reasons of convenience and safety. On an average, cloudless night, the limiting magnitude without optical aid is about 4.5 from suburban locations, and on an exceptionally clear night (of which you can expect between 12 and 15 per year, although 2008 was a notable exception) it reaches 5.5. It is usually worst in large cities.

So, if you have (say) a 60 mm refractor, with a limiting magnitude of 10.8, you just need to subtract the difference between the unaided eye visibility where you are and 6.0 to get the answer, right? This is not a bad guide, but it is not quite this simple. Unfortunately, you lose a bit more than you might think. As an example, when the unaided eye limiting magnitude is 5.5, you lose about 0.8 off the limiting magnitude of a 60 mm refractor, which is an additional 0.3 of a magnitude. The other things that limit magnitude are extinction (dimming of objects near the horizon due to Earth's atmosphere) and extended objects. A good example of extended objects are the Magellanic Clouds, which are satellite galaxies of our Milky Way. These are only visible from south of the equator. However, more often than not, they were invisible! The Large Magellanic Cloud has a magnitude of 0.0 (about the same as Vega), and the Small Magellanic Cloud has a magnitude of 2.3. As the brightness is spread out over a large area, they are difficult to see with the unaided eye from suburban skies, and they appear as a mere lightening of the background sky through binoculars. The nearest equivalent in the northern hemisphere is the Andromeda Galaxy (M31), which has a magnitude of 3.7, but its light is spread out over about 3 square degrees. It is a challenge and achievement to see it for the first time without telescope or binoculars. As a general rule of thumb, allow a further 2 magnitudes off the limiting magnitude for extended objects such as galaxies, comets, nebulae, and globular star clusters. As an example, do not try to find comets fainter than 8th magnitude with 70 mm binoculars.

We come to the question of aperture. Does size matter? The answer is "it depends." If you are hunting down faint comets or galaxies, then it most certainly does. Aperture also gives you the ability to resolve fine detail – that is, unless there is some sort of optical defect that distorts the fine detail. A lower resolution that is more accurate is better for lunar and planetary viewing but not necessarily for deep sky. The best choice is a large aperture apochromatic refractor but these come at a price – a high one, and not unlike that of a brand new small car. For a given budget, you may choose to sacrifice aperture for optical quality. The other big limiting factor is that optical quality tends to be poorer for lower focal ratios, so larger aperture usually results in longer focal lengths and subsequently narrower fields of view.

Too Cloudy to Go Out?

Some of us are lucky (or sensible) enough to live under clear skies. Most of us need to live in or near towns or cities to find work. Besides light pollution caused by street and house lighting in cities, there is also the question of cloud. Living in southwest England, it is an almost daily fact of life. The classic problem many of us encounter is the loss of many astronomical events, such as the total solar eclipse in Cornwall and parts of Devon in August 1999. You could see some of the partial phases a couple of hundred miles east of the track of totality, but it was a huge anticlimax for many of us in England. More recently, views of Comet McNaught were ruined by weather from the UK.

However, over as many 24 hour periods as not, it is possible to get some viewing in, even if it is routine monitoring of sunspots. It is amazing just how tolerant the brighter objects are of bad conditions. A Coronado PST does not work well in poor conditions, due to it's small aperture of 40mm. At night, viewing and even photographing the Moon is surprisingly easy in conditions that no sensible astronomer would consider going out in. The reason many of us like to look at Hubble Space Telescope images on the Internet and read Steven Hawking et al. about the state and fate of the universe is that it is something interesting to do when viewing is impossible. Undoubtedly the most interesting and exciting part of astronomy is to go out and look. There are nights, however, when general busyness stops astronomers from going out or causes them to truncate an observing session to a 10-min browse round with binoculars, but if there is something out there to be seen, then if you are determined enough, you will get out.

There are at least 12–15 really clear nights per year from most suburban locations. Provided it is at least 20° above the horizon, the summer Milky Way around Cygnus is visible without optical aid. Very exceptionally, the winter Milky Way around Perseus and Gemini can be seen. On such a night, the galaxies M81 and M82 in Ursa Major are visible with medium aperture binoculars, and they look like galaxies, too. Such faint fuzzies are the first objects to disappear when there is a hint of thin cloud or haze. Using large aperture instruments helps combat any adverse conditions to some extent, and a pair of medium aperture binoculars are a wise buy. After the faint fuzzies, the next objects to disappear from the night sky are fainter stars. This includes faint companions to bright stars, such as Sirius B (which is a tough object, anyway) and star clusters where individual members are faint, such as the Beehive (M44). Clusters that contain a mix of brighter and fainter stars, such as the Pleiades, lose their fainter members, and only the main asterism is visible under poor conditions. Double and triple stars where the components are quite bright (such as Castor) stay visible under poor conditions. Although some detail can be lost on the brighter planets in cloudy conditions, you can still have some pleasant surprises, and for Venus, the phase can actually become clearer, as the cloud can reduce the glare.

After a while, you will learn what can be detected, seen, or cannot be seen under given conditions (except when it comes to Mars!). While it is true that the Usual Suspects (see the appendix) can sometimes look better under clear conditions, some gems, such as M81 in its full glory have to be enjoyed while the chance is there. Indeed, part of the skill of amateur astronomy is making good use of clear conditions and getting some enjoyment out of poorer ones. It is a case of deciding how much time to devote to hunting down difficult objects and how much time you want to spend enjoying the easier objects at their very best.

Daytime Viewing

In any part of the world, half of the time will be spent with the Sun above the horizon and half below. Unless you are a full time amateur astronomers, you will spend a good proportion of your night time asleep. To make matters worse, in temperate latitudes, such as the United Kingdom and Canada, there will be a time of year when there is no true darkness at all. The way around this is to do some astronomy in the daytime. The obvious target is the Sun itself. Once a minor fill-in as something to look at during summer evenings, it has now become a main astronomical interest for many amateurs. You will find more details in the "Solar Viewing" chapter. Even without specialist equipment, it is still something that can be enjoyed and revisited on a daily basis without disturbing your sleep. The converse is that many people become so engrossed in solar viewing that they lose interest in the night sky.

Figures 1.4 and 1.5 show photographs of the Sun taken in "white light" and hydrogen alpha light.

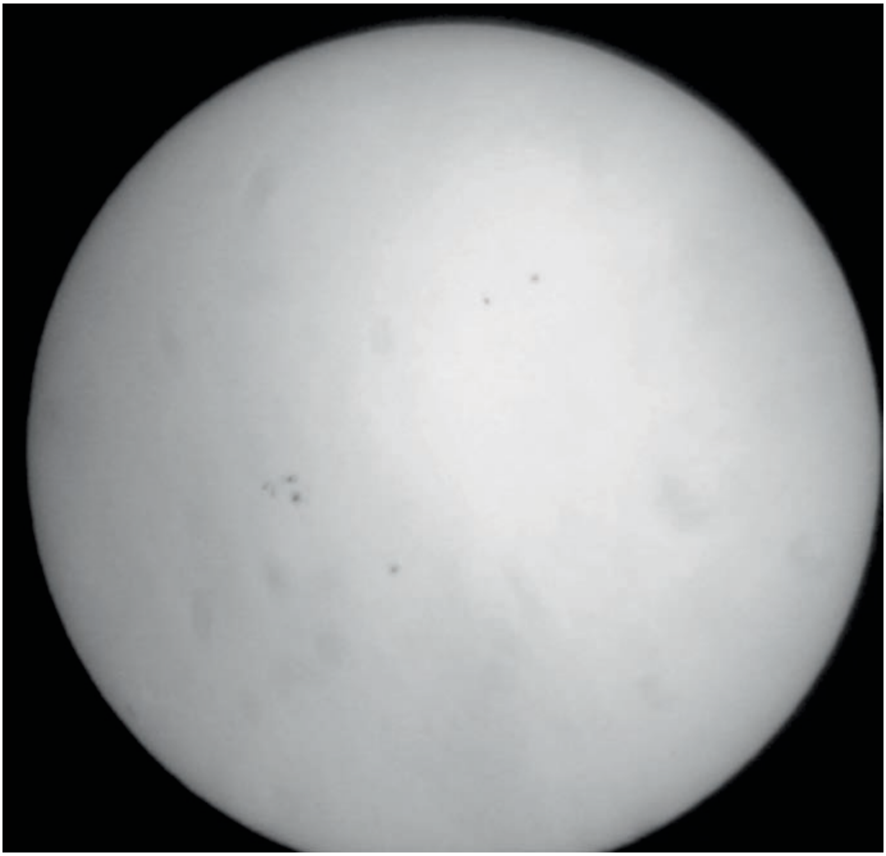

Fig. 1.4. "White light" photo of the Sun showing sunspots.

Fig. 1.5. Hydrogen alpha photo of the Sun.

The second object is the Moon. Unfortunately, small instruments with an aperture below 60 mm are ineffective during the day, but once that threshold is reached, many of the familiar features (such as Tycho's rays) become visible, and at around 100-mm aperture, there is very little difference in viewing during night or day. The disappointment is that photography is much harder and was the subject of a recent debate on a popular astronomy message board. Although it is possible to take good pictures, there is always some blue glare that cannot be removed completely by postprocessing. Figure 1.6 shows an example. Although the major lunar features can be seen clearly, the general effect is not as clear as night-time shots.

Fig. 1.6. The Moon in daylight.

The only other object that is readily viewable in daylight is Venus, which is a good astronomical challenge to be able to find before sunset or after sunrise. Just like cloudy conditions, daylight can often reduce the glare from the planet. It is not usually visible at midday, but could be viewable from the clearer skies in the southern hemisphere. If you try to find it using binoculars or a telescope during daylight, *BE VERY CAREFUL* not to look at the Sun. You should choose a viewing position where the Sun is behind an obstruction and the expected position of Venus is not. A GOTO telescope can be very useful in finding Venus even when it is not visible in a finderscope.

Similar techniques can be used to find Mercury, which is invisible without optical aid when the Sun is above the horizon. Jupiter can only very rarely be seen in daylight without the use of a telescope or binoculars, such as when it is near the Moon, but sighting by anyone with average eyesight would depend on its approximate position being known. Although Jupiter can often be seen at dawn or dusk, the best you are likely to see in even a good telescope is the equatorial cloud belts and the moons. The intricate jagged edges of the cloud belts and the subtle shading between the belts is simply not possible except in a dark sky. There are claims of people seeing Mars and some of the brighter stars during daylight, but this is anecdotal. Again, a lot of detail is lost during daylight and twilight, so it comes as a disappointment to many.

Recently, Comet McNaught has been seen during daylight with the unaided eye. In theory, some brighter meteors from the regular showers should be visible in daylight, but you need a lot of patience. Certainly, bright fireballs have been spotted by the general public during daylight, but this is a once-in-a lifetime experience for the lucky. To sum up, apart from the Sun, daylight viewing is more difficult than night viewing, but there are some nice surprises for those determined enough to try.

Digital Photography

Only ten years ago, the mere mention of astrophotography would bring up images of monetary symbols and four figure sums, not to mention having your own darkroom and an endless supply of film. The good news now is that astrophotography is open to just about everybody, and those with the time, expertise, and money are getting better and better pictures.

The easiest targets are the brightest ones: the Sun and Moon. You must take the same care when photographing the Sun as you do when viewing it, as you can cause a lot of damage to your equipment. Simple "point and click" photography using a digital camera can produce some quite amazing results, although a lot of the work is in postprocessing. For solar photography with narrowband filtering, such as hydrogen alpha, a monochrome camera is actually better.

Apart from obvious differences in cameras, such as number of pixels, each model of camera has different user features, such as "night mode" and manual/automatic settings and has different settings. Also the sensitivity to certain types of light differ vastly between models, and there are older cameras particularly sensitive to hydrogen alpha light. If you have more than one camera at home, it is a good idea to take photos with all cameras to reduce the risk of a bad session.

Domestic digital cameras have their limitations, and there is no way that you can consider taking the excellent photographs of faint deep sky objects seen in books and magazines. For these, you need to consider using more sophisticated equipment and techniques, but the key element is the mount. However, domestic digital cameras are great for "volume work": taking lots of images in a short space of time. Suitable targets (apart from the Sun and Moon) are:

- Brighter planets, such as Venus, Jupiter, Saturn, and Mars
- Double stars
- Positions of Jupiter's moons
- Constellations for cameras that support a "night" exposure of several seconds

Figure 1.7 shows an example of Mars, which is a tough object for photography with a digital camera. The contrast on the dark areas has been enhanced to improve the detail and the blue and red (!) components have been removed, with false color applied.

Fig. 1.7. Mars (photograph by Nick Howes).

Figure 1.8 shows Jupiter with three of its moons. To capture the moons, it is necessary to overexpose the planet. Pictures of Jupiter with its moons in magazines are usually made by superimposing another photograph of Jupiter over the overexposed disc.

Fig. 1.8. Jupiter showing moons.

Figure 1.9 shows Mizar (which is itself a double star), with Alcor near the top. Double stars are an interesting subject for this type of photography but are not particularly popular with magazine editors.

Fig. 1.9. Mizar with Alcor.

Figure 1.10 shows an example of Orion taken with 8 seconds exposure. It actually shows rather more stars than were visible with the unaided eye on the night in question and also shows the Orion Great Nebula (M42), although not in detail. What is striking is the color contrast of Betelguese at the top left corner of the main asterism.

Fig. 1.10. Orion.

CHAPTER TWO

Lunar Viewing

“We know all about the Moon, don’t we? People have set foot on it, and spacecraft have mapped anything larger than a pebble.”

“Why are you going to photograph the Moon? You can just look it up on the Internet and see a picture of it there.”

“I hate the Moon. It drowns out all the interesting deep sky objects, so I may as well stay indoors.”

All of these arguments have been put forward as reasons not to look at the Moon. You may even have some sympathy for some of the points. It is apparently true that the chances of a great amateur discovery happening because someone was looking at the Moon seem pretty much zero, but why do amateurs look into space at all? Are we all envious of research scientists? Is there anything actually wrong with just looking at the Moon, or anything else for that matter, and simply admiring the view?

Now here are some strong arguments in favor of looking at the Moon:

- When young (or not so young) people see the Moon through a telescope for the first time, it has the “wow” factor. That cannot be said for asteroids or galaxies through entry-level equipment. Figure 2.1 shows the Moon at first quarter, the time when most observers claim is the best.

- With the possible exception of the Sun through specialist equipment, there is far more detail on the lunar surface than you can see on any other object.

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore’s Practical Astronomy Series,
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Fig. 2.1. First quarter Moon.

- It can still be viewed and enjoyed under quite appalling conditions when there is not a single star visible in the night sky.

- It can be viewed in daytime.

- It is a great subject for photography and does not need any expensive equipment.

- A lot of experienced observers have developed their skills by viewing the Moon.

Rather than taking a lazy approach of just snapping the Moon through an ordinary digital camera, many observers like to draw the lunar features. For those with more artistic talent, this is a good idea. For those whose talents lie elsewhere, you can use photography to learn some of the major lunar features by taking photographs and comparing what you have captured to a map. You can then browse the Moon at a later date and recognize the features that you have learned.

One great advantage of lunar viewing is that the Moon is easy to find. It is large and bright and, at night, the surrounding sky lightens, so that you know you are in the lunar vicinity. It even gets to the point where you are finding the Moon subconsciously. If you try finding it during daylight, you realize how easy it is to find at night. Many regular astronomers know roughly how far the Moon is along its monthly cycle. However, after a few cloudy days and nights, one can lose track of where it is. Fortunately, many daily newspapers and websites give details of moonrise and moonset, and many calendars and diaries give the lunar phases.

Apart from transient lunar phenomena (TLPs), the Moon itself does not actually change. The last major change in the lunar landscape came about 115 million years ago when an asteroid impact created the crater Tycho. There is the chance that a new crater could be formed at any time, but the chance of it happening during any one individual's lifetime is pretty small. On the one hand, there have been odd rumors, but none has ever been substantiated. On the other hand, dust being scattered by the impact of smaller objects, although rare, does occur.

Although the lunar landscape remains more or less static, its appearance from Earth does not. The inclination of the lunar orbit of 5° to the ecliptic and its elliptical nature mean that the Moon never presents exactly the same face to us. Over a period of time, we can see 59% of the lunar features from Earth, although most of the far side can only be seen from spacecraft. The north/south and east/west variations are called *libration*.

The other interesting aspects of lunar viewing are associated with the close passage of the Moon with other objects in the sky. The Moon can obscure or occult both stars and planets. Many people have observed occultations of Jupiter, Saturn, and Regulus and have taken photographs and videos. With the unaided eye, a star usually disappears completely like a light being turned off, while a planet (being of finite apparent angular size) dims gradually. Some stars, however, do dim, and that is because they are close doubles (optical or true binary), and one star can become obscured while another remains clear of the lunar disc. Some specialists even follow *grazing occultations*, where a star catches the edge of the lunar disc, and it appears and disappears over the course of a few minutes while the star passes behind mountains. Some double stars have been discovered in this way.

The most exciting close passage of the Moon with another object is a solar eclipse. This is described in the "Solar Viewing" chapter of this book. The second most exciting is when the Moon passes through Earth's shadow, and we see a lunar eclipse. Exactly what we see depends on the atmospheric conditions at the time. We might see a bright, coppery red lunar disc, or the disc can appear very dark gray. Usually, it is possible to see some lunar features, even through the darkest shadow (or umbral shadow). The outer or (penumbral) shadow is lighter, and some features show up well thanks to the glare normally associated with a full Moon being obscured.

Lunar viewing can be enjoyed for its own sake, but it can also be used to develop skills that can be transferred to planetary viewing and photography. For example, you can learn how to find objects and center them into the field of view. Should the Moon be visible during an observing session, it is good to take at least a couple of shots of the entire lunar disc.

Choice of Equipment

It would be easy here to say that anything would enhance the view as seen by the unaided eye. Theoretically, on the one hand, it is possible to see lunar craters with the unaided eye, and there have been odd occasions when a large crater is on the terminator. Yet, it's certainly not a frequent occurrence. On the other hand, even a finderscope or very small pair of binoculars will certainly show the larger craters. If we go as far as a 60-mm refractor or 76-mm reflector, which are really the smallest telescopes of each kind that are really any use at all, the amount of detail is quite great. Many people have been simply amazed at their first view of the Moon through a telescope. Conventional wisdom suggests that a 60-mm refractor is only capable of delivering a useful magnification of 120×. Do not believe the catalogs that tell you that the magnification goes up to 500× or more. The real answer, at least for lunar viewing, is somewhat in between, at around 240×, but the use of higher quality eyepieces is essential to get the best view.

The Moon is tolerant of high magnifications because it is very bright and is, by far, the brightest object in the night sky. In fact, its very brightness can sometimes cause problems for the observer or photographer. To get around this, many observers use a neutral density filter or Moon filter. This usually allows about 18% of the light to get through without reducing the aperture or resolving power. If you are using a telescope with a standard 1.25 in. (31 mm) eyepiece fitting, the filter simply screws into the eyepiece thread. There are many brands of such a filter available, usually from $15 upwards. An alternative is a variable polarizing filter, which blocks between 60 and 99% of the light without reducing the aperture.

Now, the big question is what sort of telescope to use/buy for lunar viewing? Certainly, many entry-level telescopes give very striking views, but the photographic results are usually quite poor. Moving to an 80-mm refractor certainly resolves smaller lunar features, but many of these telescopes are of the "short tube" type and have a short focal length of about 400 mm. These telescopes are certainly good all-round astronomical performers but are not as tolerant of high magnification as 60-mm refractors are. A practical limit of 160× magnification seems to be about the limit.

Now you may have gotten the impression that lunar viewing is all about using high magnification. This is not strictly true, but the ability to use high magnification, at times, offers greater flexibility in visual and photographic use. For most lunar viewing sessions, it is best to start by viewing the whole lunar disc. This has the added advantage of being easier to find than trying to find a single lunar feature at high magnification. Most telescope/eyepiece combinations give the best results for this at about 70× magnification. Most common eyepiece types have an *apparent field of view* of 52°. This means that if you had an eyepiece capable of delivering 1× magnification with your telescope, you would see 52° of sky. To get the *actual field of view*, you need to divide the apparent field of view by the magnification. As an example, 70× magnification yields a field of view of about 44 arcminutes, or about 1.4 times the lunar diameter, which varies according to its distance from us. Any telescope/eyepiece combination that yields an actual field of view of less than 40 arcminutes, will require you to keep tracking the Moon frequently if you are using manual adjustment. In practice, this can be quite tricky, but how tricky depends on your choice of mount. Taking a photograph of the entire lunar disc is quite satisfying, and it can be done using afocal projection, which is the act of placing a camera near the telescope eyepiece and clicking. Many domestic digital cameras do not take the whole field of view, so you may need to increase your actual field of view to about 50 arcminutes (or even a degree if your mount is not steady).

There is one branch of lunar photography that actually requires low magnification and a wide field of view. This is where the Moon passes within a few degrees of another bright object, such as a planet or star. This is called a conjunction. Aldebaran, Regulus, and Antares all lay near the ecliptic (with Regulus being the closest) and the Moon is capable of passing close by. In the case of Aldebaran and Antares, it has to lie south of the ecliptic. This is where our old friend the 80 mm short tube refractor comes in. It has a focal length of 400 mm. If you use a 32-mm Plossl eyepiece, it delivers a magnification of 12.5× and field of view of about 4°. This can be verified by getting two objects known to be 4° apart to appear in the field of view at the same time – just! If objects are more than 4° apart, you need to use a focal reducer or just use a camera without a telescope. Apart from using better photographic equipment, one improvement is to use an apochromatic refractor (sometimes known as an “APO refractor”). Top of the range apochromatic refractors are very expensive but there are a lot of models priced lower that are not true APO refractors but are of better quality than achromatic refractors.

Although taking photographs at low magnification does not require so much precision, a solid mount is certainly an asset. The one disappointing aspect of this is that the lunar disc never shows much detail (although the results are better in an “APO refractor”). If the conjunction is close (say under a degree), it is possible to use higher magnification and at least catch a few craters. This technique can also be used for photographing conjunctions between planets or planets and stars. A short tube refractor of low aperture is not much use for day-to-day lunar viewing but does make a good all-round telescope, especially if it is apochromatic. Sometimes the optical zoom of the camera can be used to obtain suitable close-ups without the need to change eyepieces and refocus.

The advantage of using high magnification is that you can view or photograph areas of the Moon in more detail. You cannot see the entire lunar disc at high magnification, but you can certainly see detailed close-ups, such as the "seas" or maria. Using a 60-mm refractor it is possible to use magnifications of 240×. The things that limit the maximum magnification that can be used are:

- The mount: Most beginner telescopes do not come supplied with a solid mount and, indeed, some of the mounts are real horror stories. Alz-azimuth mounts are OK, but you need to keep following the Moon using horizontal and vertical adjustments.

- The telescope aperture: While the often-quoted rule of multiplying the aperture in millimeters by 2 is (after much experimentation) conservative for most set-ups, no telescope will take you much beyond twice that figure.

- The telescope's focal length and f-ratio: If you divide the focal length by the aperture, you get the f-ratio. If it is 5 or less, then you are pretty much limited to a maximum magnification of twice the aperture of the telescope in millimeters. For telescopes with a high f-ratio, such as over 10, you get better results.

- The telescope design: Apochromatic refractors are the best, followed by Maksutov–Cassegrains.

- The optical quality of your instrument and any eyepieces and accessories used.

The ideal choice of lunar telescope for routine viewing would be a 10-in. (250 mm) apochromatic refractor, which is expensive, heavy, and usually has a long waiting list. The good news is that, unlike with some branches of solar observing, you do not need to buy a telescope to look exclusively at the Moon. Any telescope that can be used for lunar viewing can also be used for viewing the brighter planets and "white light" solar viewing (although remember to check the chapter on solar viewing for safety advice). Such a telescope can also be used for deep sky viewing but will not be ideal or optimum for the purpose.

In theory, a medium quality apochromatic refractor (100 mm) or Maksutov–Cassegrain (125 mm) of moderate aperture should produce better results than a 200 mm reflector, although they are about the same price. The view through the eyepiece is much more pleasant, but this does not alter the fact that some excellent photographs have been taken through 200 and 250 mm Newtonians. The larger aperture of the Newtonian also makes it more suitable for most types of deep sky viewing.

A suitable example is the Skywatcher 127 mm Maksutov–Cassegrain, which has a focal length of 1,540 mm and which may vary slightly, as focus is achieved by movement of the primary mirror. As well as the reputed optical quality, which is as good as the hype, it is easy to set up and carry. An alternative is the Orion OMC140, but, unfortunately, is outside many people's budget.

Some eyepieces that are generally medium-priced (with and without image amplifiers) are:

- Moonfish Group SWA eyepieces of 70° apparent field of view and of 15 and 20 mm focal length
- Skywatcher Plossl eyepieces of 52° apparent field of view and of 6.3 and 32 mm focal length
- Coronado CEMAX eyepiece of 52° apparent field of view and of 12 mm focal length.

The eyepiece/magnification/field of view combinations (used with a telescope of 1,540 mm focal length) are as follows:

Eyepiece	Magnification	Field of view (arcminutes)
15 mm Moonfish SWA	103	40
20 mm Moonfish SWA	77	53
6.3 mm Skywatcher Plossl	244	12.5
32 mm Skywatcher Plossl	48	64
12 mm CEMAX	128	24

Example image amplifiers are:

- Magni Max 1.6× Image Amplifier
- Soligor 2× Barlow lens
- Moonfish Group 3× Barlow lens

These can be “chained together” to obtain a larger magnification boost, but the largest sensible option is using the Magni Max image amplifier in conjunction with the 3× Barlow lens to give a magnification boost of 4.8×. In theory, the field of view reduces by the same amount as the magnification boost, but there is an extra 10% loss of field of view. Also, having a lot of lenses in the light path loses light transmission but, in the particular case of the Moon, this is not a major problem.

Although keen amateur astronomers never tire of trying out new combinations of eyepieces and other accessories while viewing the Moon and other objects, one of the key features of the Moonfish Group 15-mm eyepiece is the ability to photograph the Moon at a relatively high magnification (103×) and get the whole lunar disc in. As often as not, it works and produces rather nice results. You will experience problems when the Moon is near perigee and its apparent size is larger. The 20 mm Moonfish Group eyepiece does the job instead and obtains a magnification of 77×, a bit less but still better than the 60× achievable with a Plossl. The entire lunar disc is visible with the 15-mm eyepiece, but there may be some loss of field of view with some types of digital camera.

Now that memory cards have come down in price, it is possible to take scores or even over 200 lunar photographs in a single session. The idea is to take some of the whole lunar disc, then increase the magnification until the image becomes too blurry. Some patient amateur astronomers take close-ups, then “stitch” them together digitally to obtain a high resolution full disc. However, the resulting image file is extremely large and takes ages to download from a Web site.

What is special about the Moonfish Group eyepieces is both quality and cost. It is an unfortunate fact and, some would say, a con of telescope sellers that eyepieces supplied with a telescope are of dubious quality. One needs to be open-minded and fair about this. Despite the impression you may get otherwise, most amateur astronomers are financially challenged but will forgo other things that ordinary people might consider essential to fund equipment purchases. However, in UK, there is a psychological price barrier of £500. Many consider anything that costs more than this over budget. If the manufacturers supplied 2 eyepieces costing about £250 each, the headline telescope price would be double. There are a few eyepieces about that cost a few hundred pounds that would, undoubtedly, get the very best out of a £500 telescope but would be disproportionately expensive compared to the cost of the telescope. The Moonfish Group eyepieces are not the cheapest you can get, but they have similar optical quality to mid-range Plossl eyepieces and a wider field of view. In various countries, Knight Owl and GSO are similar brands, and it is highly probable that they are manufactured at the same factory but sold under different brand names. Many of the Skywatcher range of telescopes are supplied with Skywatcher Long Eye Relief eyepieces. Although these are not bad and actually produce better photographic results than low price Plossl eyepieces, they do not perform as well visually. Indeed, the Moonfish Group eyepieces are almost as good as Plossls visually and as good as Long Eye Relief eyepieces photographically.

The purchase of a Maksutov–Cassegrain and accessories may prove very worthwhile. Many specialist lunar observers own the same or a similar instrument. Despite photographic evidence that suggests otherwise, the best instrument on any given budget is a Maksutov–Cassegrain. If you are fortunate or irresponsible enough to have an unrestricted budget, then a high quality APO refractor is best. The Moon through a 102 mm APO and is just simply amazing. Large aperture quality APO refractors can retail for about the same as a quality used car! One of the big advances in recent years is that there are now some quality larger aperture Maksutov–Cassegrains. For example, the Intes Micro range is quite extensive and goes up to 203 mm aperture, and the Orion OMC range currently includes models of 140 and 200 mm. One disadvantage of using a larger aperture is that the inherent design of these instruments produces a long focal length. This can result in you not being able to see or photograph the entire lunar disc in a single field of view, although this can be overcome by the use of a focal reducer. As well as moving to a higher aperture telescope, you can also improve your visual and photographic results by using higher quality eyepieces. An example list is given below:

- High-end Plossl
- Lanthanum
- Panoptic
- Radian
- Nagler (several types)

Many lunar observers recommend Orthoscopic eyepieces, but these have a much narrower apparent field of view. Nevertheless, they are not particularly expensive.

If you casually glance at the entire lunar disc at moderate magnification, there is no need to invest in a high quality mount. This changes, however, if you wish to view close-ups or perform any form of photography. Most beginner telescopes come supplied with alz-azimuth mounts, which require you to follow the Moon in both up/down and right directions. You need to follow it upwards until it reaches the meridian (that is, due south) and then follow it down. When it has not been risen for long or is close to setting, the up and down movements are quite noticeable.

It is when you move to a standard equatorial mount that you realize how bad the mounts supplied with beginner telescopes really are. There is a lot of "play" in the mounts, and a clumsy slight nudge will require you to find the Moon all over again. Nevertheless, you can use 240× magnification for lunar and planetary viewing with a Vanguard 60-mm refractor but need the patience to do it.

In modern times, a lot of Newtonian reflectors are available in the 114 mm (4.5 in.) size. These are supplied on an EQ1 mount, as are a lot of smaller telescopes, such as short tube refractors and smaller Maksutov-Cassegrains. If you read the equipment advertisements, you will see many mounts advertized as EQ1, EQ3/2, EQ5, or EQ6, with some variations. These are of a German design, so are often known as "German Equatorial Mounts," GEM for short. Most are manufactured in China and come supplied with lots of different telescopes from many manufacturers. Some come supplied with a right ascension motor drive to enable you to look through the eyepiece without having to follow the Moon manually.

The EQ1 mount is certainly not a precision one, but it does offer an advantage over a low quality alz-azimuth mount. It can be tricky to use at first and, strangely enough, the larger EQ3/2 mount is much easier to use, although harder to carry. The hardest part is when the telescope tube tangles with the slow motion controls of an EQ1. It offers enough stability to allow one to take photographs of the Sun through a Personal Solar Telescope (PST) at medium magnification. The motor drive is more of a convenience than an absolute necessity, as the EQ1 mount is not recommended for long-exposure photography. Fortunately, as the Moon is a very bright object, this is not a major issue.

Using an EQ3/2 mount and Maksutov–Cassegrain, it is possible to use magnification up to about 500× using manual controls. One can also take "point and click" photographs using a digital camera. As 500× is approaching the practical limit beyond which images get blurry and cannot resolve any further surface detail with this telescope, a motor drive is not essential for lunar viewing, but anyone interested in doing webcam imaging will find one helpful, even though many software packages allow for drift. The same also applies to more precise polar alignment. It is helpful, but lunar photography is far less exacting in its requirements than deep sky long exposure imaging. EQ3/2 mounts are also used with refractors in the 90–120 mm aperture range and Newtonians up to 200 mm aperture.

The heavier EQ5, EQ6, and HEQ5/HEQ6 mounts are normally used with refractors and Maksutov–Cassegrains of up to 180 mm, and Newtonians up to 250 mm. Anything larger than this can certainly be used for lunar viewing and photography, but their use has been left for a later chapter.

For deep sky viewing, gathering enough light can be a problem, while with the Moon, it is more the opposite. Reducing the aperture does reduce the amount of light gathered, but it also reduces the resolution. Neutral density Moon filters can reduce the glare without reducing the aperture. For example, the Celestron Moon filter, blocks 82% of the light. An Orion variable polarizing filter blocks from 60 to 99% of the light, and it can be adjusted for the lunar phases. When viewing or photographing close-ups, it is not necessary to use a filter and, indeed, it can actually harm the view.

What to See

There is a saying that you will never see more detail on any other astronomical object than you can see on the Moon. Although there is one possible exception if you use specialist equipment, this is certainly true of anything in the night sky. Most obvious, even with the unaided eye, are the maria or "seas." We now know that they do not contain water, but we did not when we first saw them. We also know the composition of the Moon quite well now, although there is still some doubt as to exactly how it formed. The most popular modern theory is that it formed when a Mars-sized object collided with Earth before it solidified. Certainly, this theory explains what we can see.

Maria

The maria were formed by ancient lava flows created when the Moon was young, between 3,700 million and 3,900 million years ago. Some say that they form a pattern that looks like a man's face (known as "The Man in the Moon") while others visualize the pattern as a girl reading a book. They can be seen clearly at any time of the lunar cycle, but you can see all of them at full Moon. An individual mare is best seen when it is close to where the dark side of the Moon meets the sunlit side (known as the *terminator*). The larger, more prominent, ones can even be seen on the dark side of the Moon when it is a thin crescent. Although their surfaces are smoother than the brighter parts of the Moon, there are still some craters and other features inside them, but you need some sort of optical aid to see them.

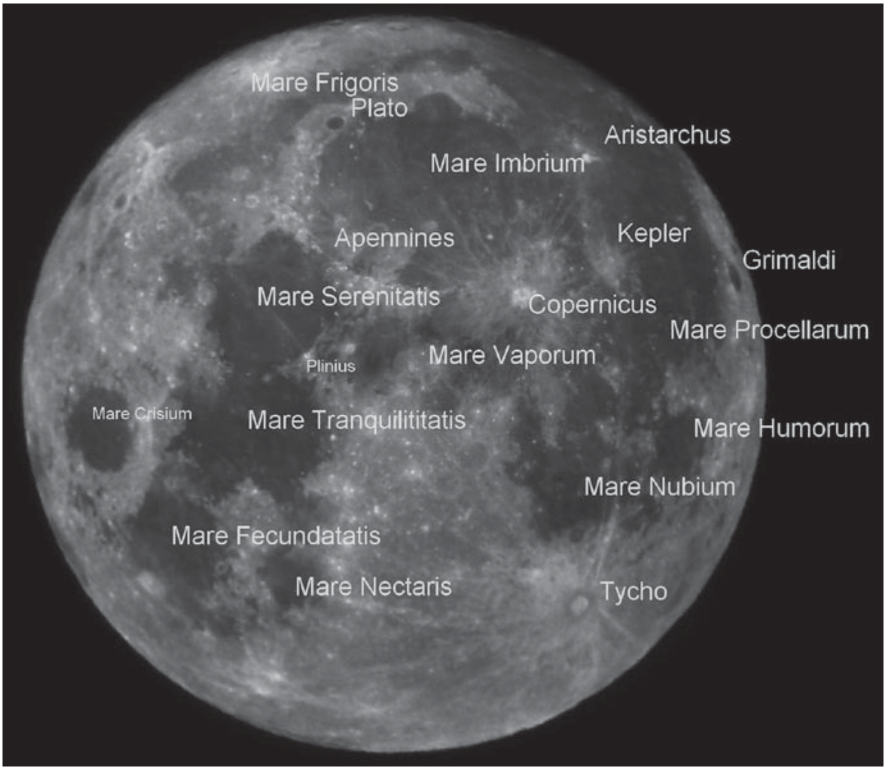


Fig. 2.2. Map of the Moon showing the maria.

Figure 2.2 shows a photograph of the full Moon annotated with the maria and some of the major features. In maps they are usually shown with their Latin names, but this section lists an English translation for convenience. Note that the above map was made using an image captured with a Maksutov–Cassegrain telescope, so appears as if seen in binoculars or a terrestrial telescope reflected in a mirror. If you use a Newtonian reflector or astronomical refractor, the image will appear upside down. The table below lists the main maria:

In general, any object more than 90° east or west is not visible, but liberation may cause it to be visible on certain days. Similarly, objects of longitude slightly less than 90° may become invisible on some days.

Figures 2.3 and 2.4 show some of the lunar seas:

Name	English translation	Lunar latitude	Lunar longitude	Major axis diameter (km)
Mare Crisium	Sea of crises	17.0N	59.1E	418
Mare Fecunditatis	Sea of fecunditity	7.8S	51.3E	909
Mare Frigoris	Sea of cold	56.0N	1.4E	1596
Mare Humorum	Sea of moisture	24.4S	38.6W	389
Mare Imbrium	Sea of showers	32.8N	15.6W	1,123
Mare Nectaris	Sea of nectar	15.2S	35.5E	333
Mare Nubium	Sea of clouds	21.3S	16.6W	715
Oceanus Procellarum	Ocean of storms	18.4N	57.4W	2,568
Mare Serenitatis	Sea of serenity	28.0N	17.5E	707
Mare Tranquillitatis	Sea of tranquility	8.5N	31.4E	873
Mare Vaporum	Sea of vapors	13.3N	3.6E	245

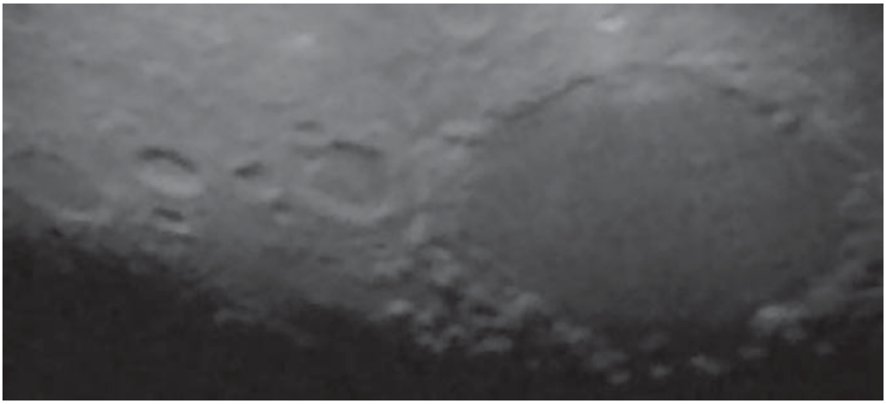


Fig. 2.3. Mare Crisium.

Fig. 2.4. Mare Serenitatis.

Craters

Moving even to small binoculars enables you to see the craters. These are now known to have been caused by impacts, most of which occurred more than 3,800 million years ago, but some, such as Tycho, are known to be more recent, about 115 million years ago. Within 3–4 days of a full Moon, Tycho is very prominent with its rays stretching for hundreds of miles across the lunar surface. These were caused by ejecta or small rocks blasted out by the impact. These ray systems can also be seen surrounding other newer craters such as Copernicus and Kepler. In the case of other craters, the ejecta have been eroded over hundreds of millions of years by the solar wind. Larger binoculars in the 70-mm aperture range show several tens of craters under the right conditions, the largest being Clavius, which is near to Tycho. Clavius is most prominent when the Moon is 8–10 days past new, but it fades as it becomes more fully illuminated, whereas Tycho becomes more prominent because of the ray system. Most of the older craters, such as Clavius, are most prominent when just on the sunlit side of the terminator.

Most craters are circular in shape but may appear elliptical if the object causing the crater impacted the Moon at a near-horizontal angle. Also

Name	Lunar latitude	Lunar longitude	Major axis diameter (km)
Abel	34.5S	87.3E	122
Albategnius	11.7S	4.3E	114
Alphonsus	13.7S	3.2W	108
Amundsen	84.3S	85.6E	101
Babbage	59.7N	57.1W	143
Bailly	66.5S	69.1W	287
Balmer	20.3S	69.8E	138
Barnard	29.5S	85.6E	105
Blancanus	63.8S	21.4W	117
Boussingault	70.2S	54.6E	142
Brianchon	75.0N	86.2W	134
Casatus	72.8S	29.5W	108
Catharina	18.1S	23.4E	104
Clavius	58.8S	14.1W	245
Cleomedes	27.7N	56.0E	125
Copernicus	9.7N	20.1W	107
Darwin	20.2S	69.5W	120
De La Rue	59.1N	52.3E	134
Demonax	77.9S	60.8E	128
Deslandres	33.1S	4.8W	256
Drygalski	79.3S	84.9W	149
Eddington	21.3N	72.2W	118
Einstein	16.3N	88.7W	198
Endymion	53.9N	57.0E	123
Fra Mauro	6.1S	17.0W	101
Fracastorius	21.5S	33.2E	112
Furnerius	36.0S	60.6E	135
Gärtner	59.1N	34.6E	115
Gassendi	17.6S	40.1W	101
Gauss	35.7N	79.0E	177
Gilbert	3.2S	76.0E	112
Goldschmidt	73.2N	3.8W	113
Grimaldi	5.5S	68.3W	172
Hausen	65.0S	88.1W	167
Hecataeus	21.8S	79.4E	167
Hedin	2.0N	76.5W	150
Hermite	86.0N	89.9W	104
Hevelius	2.2N	67.6W	115
Hipparchus	5.1S	5.2E	138

(*continued*)

(continued)

Name	Lunar latitude	Lunar longitude	Major axis diameter (km)
Hommel	54.7S	33.8E	126
Humboldt	27.0S	80.9E	189
J. Herschel	62.0N	42.0W	165
Janssen	45.4S	40.3E	199
Kästner	6.8S	78.5E	108
Klaproth	69.8S	26.0W	119
Lagrange	32.3S	72.8W	225
Lamarck	22.9S	69.8W	100
Lamont	4.4N	23.7E	106
Langrenus	8.9S	61.1E	127
Le Gentil	74.6S	75.7W	128
Letronne	10.8S	42.5W	116
Longomontanus	49.6S	21.8W	157
Lyot	49.8S	84.5E	132
Maginus	50.5S	6.3W	194
Maurolycus	42.0S	14.0E	114
Mee	43.7S	35.3W	126
Messala	39.2N	60.5E	125
Meton	73.6N	18.8E	130
Moretus	70.6S	5.8W	111
Neper	8.5N	84.6E	137
Orontius	40.6S	4.6W	105
Pascal	74.6N	70.3W	115
Petavius	25.1S	60.4E	188
Phillips	26.6S	75.3E	122
Phocylides	52.7S	57.0W	121
Piazzi	36.6S	67.9W	134
Pitatus	29.9S	13.5W	106
Plato	51.6N	9.4W	109
Ptolemaeus	9.3S	1.9W	164
Purbach	25.5S	2.3W	115
Pythagoras	63.5N	63.0W	142
Rayleigh	29.3N	89.6E	114
Regiomontanus	28.3S	1.0W	108
Repsold	51.3N	78.6W	109
Riccioli	3.3S	74.6W	139
Riemann	38.9N	86.8E	163
Russell	26.5N	75.4W	103
Scheiner	60.5S	27.5W	110
Schickard	44.3S	55.3W	206

Name	Lunar latitude	Lunar longitude	Major axis diameter (km)
Schiller	51.9S	39.0W	180
Scott	82.1S	48.5E	103
South	58.0N	50.8W	104
Stöfler	41.1S	6.0E	126
Struve	22.4N	77.1W	164
Theophilus	11.4S	26.4E	110
Tycho	43.4S	11.1W	102
Vendelinus	16.4S	61.6E	131
Volta	53.9N	84.4W	123
W. Bond	65.4N	4.5W	156
Walter (Walther)	33.1S	1.0E	128
Wilhelm	43.4S	20.4W	106
Xenophanes	57.5N	82.0W	125

craters near the lunar limbs can appear elliptical as their horizontal dimensions are foreshortened. Larger craters may also have smaller craters inside them or even straddling their boundaries. Other craters, such as Plato and Grimaldi, have dark floors as they were formed by impacts that occurred while the Moon was still volcanically active. These can be seen around the time of the full Moon. Listing the whole set of named craters is not really necessary, as there are plenty of lunar guide books and maps available. However, here is a list of craters that are 100 km or more in diameter along their major axis:

The first time that you see a list of craters of 100 km or larger in size, the first question that you ask is where are they all? First, any crater that is more than 60° latitude north or south from the lunar equator will appear a lot smaller. Similarly, any crater more than 60° east or west will also appear much smaller. Many craters that are in the "corners" of northeast, southeast, northwest, and southwest will appear smaller in both directions. Try drawing circles on a football and rotate it, and you will see how it works. The same also applies to sunspots. The other issue is that some parts of the Moon (particularly the south) are so full of craters that it is difficult to say which is which, without a map. Craters without rays or lava-filled floors are sometimes difficult to spot unless they are near the terminator. Clavius (for example) is hard to see at a full Moon. It is only when you are able to see (and preferably photograph) the Moon on a few successive nights and identify each crater individually that you can fully appreciate it.

Figures 2.5–2.8 show close-ups of some lunar craters:

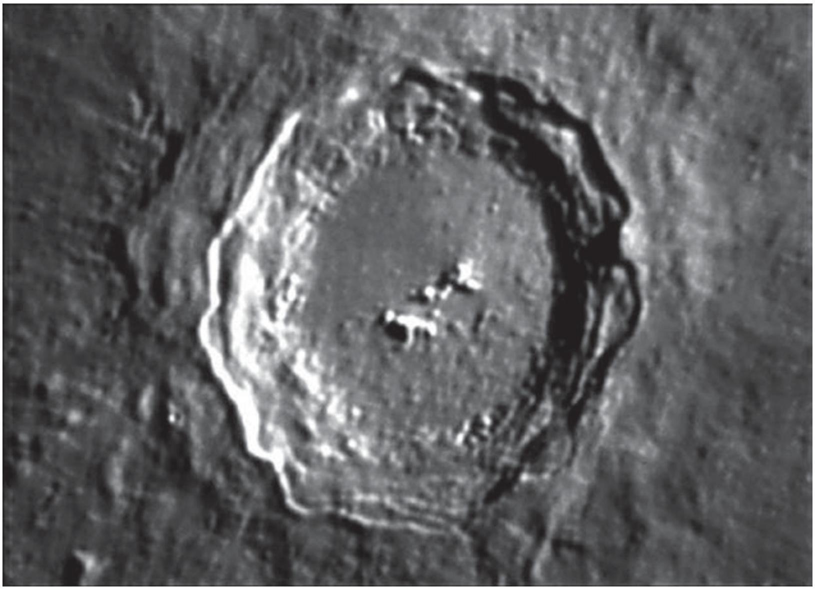


Fig. 2.5. Copernicus by Nick Howes.

Fig. 2.6. Gassendi by Nick Howes.

Fig. 2.7. Plato.

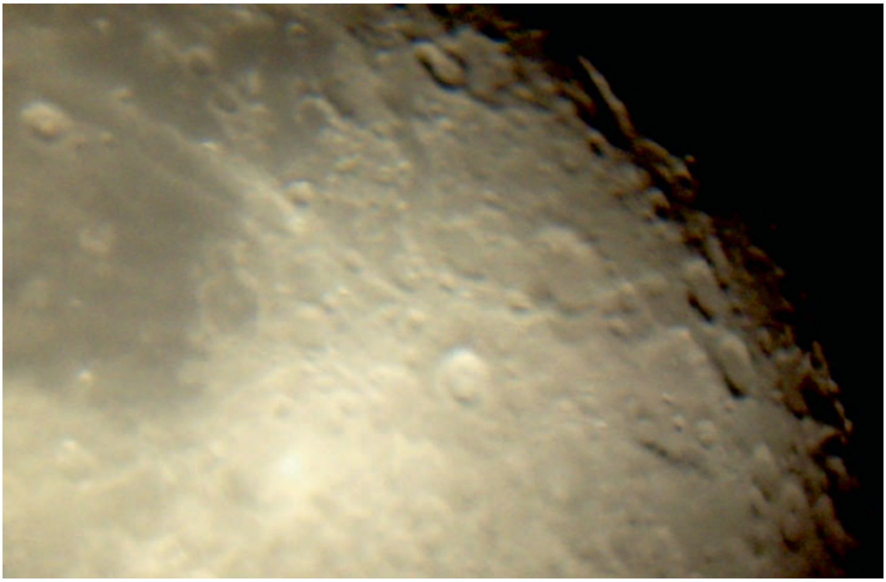


Fig. 2.8. Tycho.

Name	Lunar latitude	Lunar longitude	Major axis diameter (km)
Montes Apenninus	18.9N	3.7W	401
Montes Caucasus	38.4N	10.0E	445
Montes Cordillera	17.5S	81.6W	574
Montes Haemus	19.9N	9.2E	560
Montes Jura	47.1N	34.0W	422
Montes Rook	20.6S	82.5W	791

Mountains

Through medium-sized binoculars, the mountain range that is most obvious is the Appenines, which encircles Mare Imbrium on the south side and can often be seen in the same close-up view as the crater Copernicus. The other mountain range is the Montes Alpes (Alps), which are to the north, and Plato lies within them. Many craters have central peaks within them, and there are also a few mountain ranges that are larger but not so obvious, as they are smaller or nearer the lunar limb.

For reference, below is a list of mountain ranges that extend 400 km or more. This actually excludes the Alps, which are “only” 281 km in length.

Figures 2.9 and 2.10 show the lunar mountains.

Fig. 2.9. Appennines.

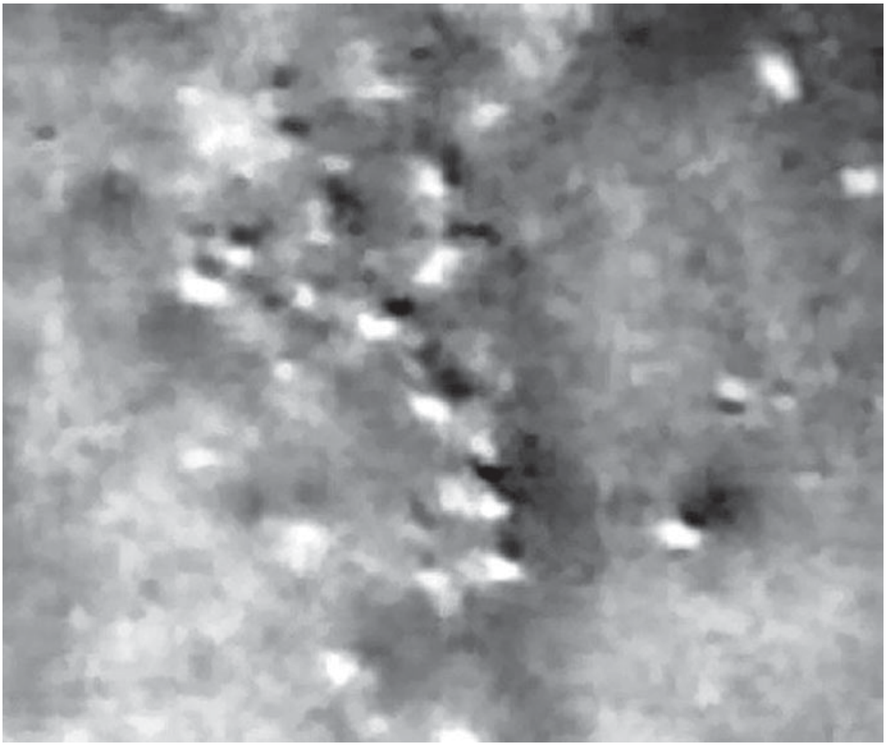


Fig. 2.10. Lunar Alps.

Rilles

Rilles are long, narrow depressions in the lunar surface. Although their exact origin is not well understood, they are believed to have been caused by collapsed lava flows and fault lines when the Moon was volcanically and tectonically active. They have been unchanged for thousands of millions of years.

Rilles are not normally seen in binoculars or by casual viewers using modest telescopes but usually require an instrument in excess of 100-mm aperture and high magnification (200× and over).

How to Get the Best from Lunar Viewing

We now revisit the original question of whether the Moon is a nuisance, the major interest in the sky, or just one of many objects that can be seen and enjoyed. For those readers wishing to gain a deeper knowledge of the Moon, there is a list of books and resources at the end of this chapter.

For those who do regard the Moon as a nuisance, why not actually go out and observe the Moon, instead of staying indoors? You can enjoy other peoples' favorite subbranches of the hobby. There are many nights when not a single star is visible, nor even any of the brighter planets, but detailed observations of the Moon are possible. Also, while it is true that first quarter is the best time to observe the Moon, it is not the only time. Indeed, neither Clavius nor Tycho (two well-known and liked craters) are visible at first quarter. Do not reject the full Moon out of hand, either. There are plenty of things to observe and enjoy at the full Moon.

Many people take pleasure from sketching the Moon. Do not expect, though, to emulate the sketches made by maestros such as Peter Grego; there is no way most of us can do anything like that. However, by sketching the Moon, you can learn or improve on your observing skills, which can later be transferred to the planets and other objects. Using Peter's sketches as an example, they are remarkably similar to photographs of the same objects.

Where sketches or other recording of observations are a real help is when learning your way around the features. The practicalities are that, during the hours of darkness, it is difficult to view the Moon and a map at the same time. Fortunately, there are two things that are a great help. Although the Moon is a lot harder to photograph in daylight, almost as much detail is visible through medium aperture telescopes as at night, so it is easy to view the Moon and read the map quite easily. Using a telescope during the day results in many puzzled looks from onlookers, although neighbors will become accustomed to such antics over the years and may stop and look through your telescopes.

The other thing that really helps is digital photography. Now, not everybody wants to get involved with the technical complexities of long exposure deep sky photography, but the Moon is the easiest subject for point and click photography. In fact, many lunar photographs were taken with a simple domestic digital camera. You do, however, need postprocessing to really get the best picture possible. You may well have a good telescope and reasonable quality eyepieces, but when using a camera it is almost inevitable that blue fringes will appear. There are often red fringes too, but these are usually not as pronounced as the blue ones. Although some may be introduced by the optical system, many are introduced by the camera itself. The answer is simply to use a tool such as Paintshop Pro or Photoshop to remove the fringes and restore the color balance of the photograph. A lot can be done with postprocessing of photographs, something that was not possible in the predigital days.

Many astronomers like to be able to "master" the Moon, or at least learn the names of the obvious features visible through binoculars or a small telescope. Apart from viewing the Moon during daylight with an atlas, another idea is to photograph the Moon and compare the resulting photographs to the atlas. If you are able to take several photos when the Moon is at a different phase, you can see how the views of various features change and how some become visible and invisible. With practice, it is possible to see libration changes through binoculars and even take photographs.

A suitable long-term observing project is to view and photograph the "what to see" objects that are listed earlier in this chapter. The prevailing conditions do not always permit high magnification close-ups of individual objects, but it is possible to photograph around 10–30% of the lunar surface at a time using magnifications in the 180–300× range. A good subject is the southern craters when the Moon is about 9 days past new, and Clavius and Tycho can be identified among a large number of other craters. This can be done under poor conditions, such as when there is simply nothing else to see in the night sky.

For Further Reading

Thanks to the Internet, there are now many pages of information readily available to you. There are quite a few maps of the Moon, produced by annotating photographs. As an example, there is a map of the Moon on this author's Web site showing the maria and some of the craters with ray systems. Figure 2.2, earlier in this chapter, was derived from that. There is also a lunar features page showing the approximate location of some of the major features and several links to other sites that allow you to look up the rising and setting times of the Moon.

For traditionalists, several observing guides have been written over the years by experienced observers such as Sir Patrick Moore and Peter Grego. Apart from a decent lunar atlas, obtained via a book store or the Internet, the following books are available from Springer:

- How to Photograph the Moon and Planets with Your Digital Camera; Buick, T., ISBN 978-1-85233-990-6, 2006, Softcover

- Astronomical Sketching: A Step-by-Step Introduction; Handy, R., Robbins, S. (et al.), ISBN 978-0-387-26240-6, 2007, Softcover

- Lunar and Planetary Webcam User's Guide; Mobberley, M., ISBN 978-1-84628-197-6, 2006, Softcover

- Observing the Moon; Wlasuk, P.T., ISBN 978-1-85233-193-1, 2000, Hardcover

Solar Viewing

Once the safety implications of viewing the Sun are digested, understood, and committed to memory, it is as easy to view and photograph as the Moon. Of all the branches of amateur astronomy in recent years, it is the one that has advanced the most. Indeed, it is a personal favorite of many amateurs, partly because of its newness/novelty value but also because the Sun is the most changeable of all the naturally occurring objects in the sky.

Few astronomers specifically set out to become a solar observer. It is the lack of ability to do night time observing from temperate latitudes in summer that inspired people to take an interest, although some of the excellent photographs taken are inspirational, too.

As far as stars go, the Sun is not particularly exciting. Its official designation is a yellow dwarf. Yet it actually outshines most stars in the galaxy and known universe, as the smaller, fainter red and orange dwarves are more numerous. Although there are fewer more massive, brighter, and larger stars than the Sun, the maximum size is thought to be about 120–150 solar masses and several thousand times brighter. However, conflicting new theories place different upper limits of stellar mass, and many of the heavyweights have recently been observed to be part of multiple star systems. Also, the Sun is relatively constant in its output, unlike the many types of variable stars visible in the night sky. Recent research seems to suggest that the Sun can have short-term brightness variations of about 1% and that the Sun has continued to get brighter and hotter and will continue to do so. There is also reason to suspect that longer term climate

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series,
DOI 10.1007/978-0-387-76470-2_3,

fluctuations on Earth may be caused by the Sun. There has certainly been a warming in some places since the 1950s.

From the amateur viewpoint, the most exciting event is a total solar eclipse. Unfortunately, total solar eclipses do not occur frequently, and the viewing of them can be ruined by bad weather. As an example, the total solar eclipse viewed from Cornwall, England, in 1999 was ruined by bad weather nationwide. Many people travel to view a total solar eclipse but, although weather is more reliable in some countries other than England, it is not guaranteed. Also, the path of the eclipse often crosses the sea or regions that are difficult to reach, for various reasons. There is also the unfortunate possibility of disruption to travel plans.

A total solar eclipse is caused when the lunar disc completely covers the solar disc, as seen from Earth. By a stroke of luck, the apparent angular size of about 30 arcmin (or half a degree) of the Sun and Moon are about the same, although both can vary according to their relative distances from Earth. When the Moon is closest to us (perigee) and the Sun is furthest from us (aphelion), a total eclipse has the widest path across the Earth (about a hundred miles), and in the middle of the path, the eclipse can last for about 7 min. Outside the path of totality, a partial solar eclipse (see the example in Fig. 3.1) can be seen for several hundred miles north and south.

Fig. 3.1. Partial eclipse (photo by Nick Howes).

When the Moon is furthest from us (apogee) and the Sun is nearest (perihelion), the result is an annular solar eclipse where a ring of solar light is seen surrounding the Moon. Although this is not as spectacular as a total solar eclipse, it is interesting and aesthetically pleasing to the eye, nevertheless. Figure 3.2 shows an example.

Fig. 3.2. Annular eclipse (photo by Nick Howes).

During a total solar eclipse, the most noticeable feature is the *solar corona*. This is the inner solar atmosphere, and it stretches tens of millions of miles into space. Its appearance is very striking, and it can vary from one eclipse to another, not just because of viewing conditions but also due to changes in the corona itself during the solar cycle. Instruments capable of showing the corona other than at a total solar eclipse are too expensive for most amateurs. Prominences can also sometimes be seen during a total solar eclipse using suitable amateur equipment. If the relative apparent diameters of the Moon and Sun and the alignment are right, it is possible to see a red band of light surrounding the solar disc (or at least part of it). This is called the *chromosphere* (literally color sphere), and, like prominences, it can be viewed using amateur equipment.

Partial solar eclipses are more common and can even occur when totality misses Earth completely. This is still interesting to view and, indeed, many working and studying days are interrupted by a partial solar eclipse. Using a hydrogen alpha or calcium K telescope (covered later in this chapter) is the best way to enjoy it, but a lot of pleasure can be had from various white light techniques. This enjoyment can also be enhanced by the use of various drawings and photographs.

Another set of related events involve eclipses, although their results are not obvious for most of the general public. The inner planets, Mercury and Venus, sometimes pass between Earth and the Sun, and their silhouette can be seen crossing the solar disc. The general term used to describe this event is a *transit*, and there are those who insist that a total solar eclipse is also a transit, as the literal meaning of eclipse is to pass into a shadow. If there are sunspots present, they can appear much larger in apparent size than either planet. However, dark sunspots may appear, though the planetary silhouettes are much darker.

These transits can last for several hours, the exact duration being determined by:

- The distance between Earth and the Sun
- The distance between the planet and Earth
- The distance between the planet and the Sun
- The inclination of the planet to the ecliptic
- Where you are on Earth at the time

The transit of an inferior planet across the solar disc occurs when the planet is at the place in its orbit where it crosses the ecliptic. These points are called *nodes* or *orbital nodes*, and the term is also used for the point where the lunar orbit crosses the ecliptic. As the orbits of Mercury, Venus, and the Moon are inclined to the ecliptic, there is not a solar eclipse in every new Moon, and neither is there a lunar eclipse in every full Moon. Similarly, there is not a transit of either Mercury or Venus every inferior conjunction.

The orbital nodes of Mercury are at the points on the ecliptic where the Sun's apparent path in the sky is encountered on May 8 and November 10. If Mercury reaches the precise point on either of those dates, a maximum duration transit will occur. However, as the solar disc is of finite size (about 30 arcmin or half a degree), it may occur up to 3 days before or after those dates. November transits occur at intervals of 7, 13, or 33 years, whereas May transits can only occur at intervals of 13 or 33 years. This is due to the increased orbital speed of Mercury during May. Each century, there are either 13 or 14 transits of Mercury.

As Venus is further from the Sun, transits are less frequent. The orbital nodes of Venus are at the points on the ecliptic where the Sun's apparent path in the sky is encountered in early June or early December. Transits recur at intervals of 8 years, then 121.5 years, 8 years (again), then 105.5 years. Figure 3.3 shows a transit of Venus.

Fig. 3.3. Transit of Venus (photo by Nick Howes).

Spring transits (May and June from the northern hemisphere) are naturally a lot easier to observe than autumn transits, because of the elevation of the Sun above the horizon and the likelihood of the Sun being visible during the increased hours of daylight. From some locations, only a part of the transit may be visible, because of the local sunrise and sunset times.

Transits of the inferior planets were used to make early estimates of the planets' sizes, those of the Sun and Earth, and the Earth–Sun distance. Estimates were made by measuring and timing the transits from at least two locations. The first recorded instance of this method being used was in 1639 by Jeremiah Horrocks near Preston in Lancashire and his friend, William Crabtree, from Salford in Manchester. The two used solar projection.

One thing that Jeremiah Horrocks recorded and has never been explained is the *black drop effect*. When the silhouette of Venus leaves the solar limb and reaches the main part of the solar disc, it still seems to be somehow connected to the solar limb. Once this was thought to be due to the atmosphere of Venus, but the same phenomenon has also been observed on Mercury, which has no appreciable atmosphere. It has also been linked to the optics used, but again, the same phenomenon has also been noted in hydrogen alpha telescopes as well. Perhaps it is due to Earth's or the Sun's atmosphere. Further observation may solve the mystery. Recent observations, including live TV broadcasts, have confirmed its authenticity.

In the early days of solar observation, it was thought that there might be a small planet whose orbit was inside that of Mercury. The object even had the name Vulcan, which is familiar to followers of Star Trek. It was thought that any planet closer to the Sun than Mercury would be difficult or impossible to see unless it transited across the solar disc. Indeed, many astronomers spent a lot of time searching fruitlessly for it. There had been rumors of objects seen transiting the Sun but these were suspected to be caused by optical effects. There is the theoretical possibility of a near Earth asteroid transiting the solar disc but its small apparent angular size would make it very difficult to spot.

By comparison to these events, it would seem that day-to-day monitoring of the Sun would be seriously mundane by comparison. Although that may be true of white light observations at or near solar minimum, it is not always or even often the case. Most days there is some sunspot activity, and, at times, the solar disc can appear like a currant pudding. As described later in this chapter, it is not necessary to spend a lot of time or money to watch the Sun. As well as monitoring the solar disc for solar activity personally, you can always "cheat" and look at the SOHO pictures to see if there is anything interesting going on.

At the time of writing (December 2008), solar minimum had theoretically passed but seemed to be longer and deeper than previous minima. There had been many consecutive days, even weeks since late 2005, when the solar disc had been blank in white light. A sunspot group, visible as a single large sunspot in binoculars, was visible during November, and December 2006 saw two smaller sunspots appear. Near solar maximum, hardly a day goes by without some visible sunspot activity. There appears to be an 11-year cycle between successive maxima and minima, but the solar cycle is actually 22 years. At each solar minimum, the Sun's magnetic field reverses polarity. In fact, evidence suggests that Earth's magnetic field has been known to reverse every few tens of thousands of years.

Now, one of the objectives of this book was simply to describe observational techniques without getting bogged down in scientific explanation. Mentioning visible solar features without reference to the solar magnetic field is a bit like a carriage without a horse. Everything from sunspots observed and photographed in white light to the solar Corona are caused by magnetism. Not only do sunspots follow the 11-(22) year solar cycle but so does the corona and everything else. Knowing the solar cycle should give us some idea on the best time to view the Sun, except it does not always. It is still an exciting activity even around a solar minimum.

At the time of writing, the 400th anniversary of the (known) first occurrence of the use of a telescope to view the Sun was less than 2 years away. Some solar maxima are more pronounced than others, and many solar minima still exhibit a lot of activity. Some periods have thrown up surprises. During the Maunder minimum of the seventeenth century, no sunspots were seen for several years. Unfortunately, the equipment available to professionals and even amateurs today was not available then, so we do not know what the Sun would have looked like in hydrogen alpha or calcium K light. Future generations can look forward to seeing records of sunspots and other phenomena dating back hundreds, thousands, or even millions of years. It would be interesting to see whether the Maunder minimum will repeat, and, if so, whether it will be regular. It would also be interesting to see whether the 11/22 year solar cycle will change as the Sun evolves.

Strictly speaking, aurorae are neither astronomical nor solar but meteorological. Neither indeed, do they have anything to do with telescopic observation! That does not mean that we do not have the right to observe or enjoy them. These phenomena are caused by the solar wind encountering Earth's magnetic field. They are frequently visible from regions close to Earth's magnetic poles, which incidentally are a few hundred miles from the geographical poles. As a consequence, the northern United States are more favored than northern Europe, with Canada and Scandanivia favored even more. Very few people live anywhere near the south magnetic pole.

If the solar wind is particularly strong or the corona releases a large amount of material in the right direction (known as a *coronal mass ejection*, or *CME* for short), the aurorae are pushed further from the magnetic poles and have, exceptionally, been seen in southern Europe. In 2003, some displays were visible in southern England, and a few other times there seemed to be a lightening of the sky that could not easily be explained by cloud or light pollution. They are most common a year before and after solar maximum, and there is also a biannual peak at the spring and fall equinoxes when the solar equator is tilted toward Earth.

The Sun is also guilty of causing other meteorological phenomena, such as noctilucent clouds, parahelia (sun dogs) and, most well-known of all, rainbows.

Solar observing is today one of the most pleasurable branches of astronomy. Today's younger astronomers should see even more advances in their lifetime. Like in many cases, the costs for the technology are decreasing, thus opening up the field to more people.

Choice of Equipment

It would be easy to launch into a monologue about hydrogen alpha viewing, but this is not the only way to enjoy the Sun. Indeed, hydrogen alpha viewing can be highly addictive, but it can burn a seriously large hole in your pocket. Let us start, then, with using your existing equipment to view the Sun in white light. Just in case you have not read the warnings before, here they are again:

- Do not use any equipment for solar viewing unless it has been specifically recommended and approved by the manufacturer.
- Make sure that you do not use anything for visual study that is for photographic use only.
- Test any equipment before use by visual inspection for scratches and tears. Approach a solar limb gradually.
- Finderscopes also need protection.
- Do not view the Sun through a telescope or binoculars using an eclipse viewer intended only for use with the unaided eye.
- For white light viewing, use full aperture filters and not eyepiece filters, which are simply not safe.
- Do not be tempted not to use filters if it is cloudy or if the Sun is very near the horizon. It is not as safe as it looks.

It is safe to view the Sun, PROVIDED that you follow sensible rules. Many people have been observing the Sun for years, without any problems.

By reputation, the safest method of solar viewing is projection. Projection can be achieved using binoculars mounted on a tripod, but the result is rarely satisfying. A small refractor is the best telescope for this purpose and the worst is a Newtonian reflector, as damage to the telescope can result. The red flag with solar projection is that you must remember to shield any finderscope. To get the best results, it is recommended that you project the solar image at an angle to the Sun, for example, using a star diagonal. This makes the image stand out against any glare from the Sun itself. Some experienced users of the method suggest using an aperture stop to reduce the risk of glare or damage to the equipment. With an object such as the

Sun, you do not need a large aperture to capture light, as for deep sky viewing, but aperture does help you resolve smaller details.

Solar projection certainly helps you to monitor sunspot numbers, sizes, and patterns, and is particularly useful for showing the solar image to an assembled group. As a technique, it requires little or no outlay, although many people like to purchase a projection screen. Indeed, there is a device called a SolarScope that uses a projection system suitable for mass viewing. This is a rather confusing name, as there is also a company called SolarScope that makes hydrogen alpha telescopes.

Solar projection is not the best method for white light viewing. There is little doubt that a lot of image detail gets lost in the projection method, so the challenge is to reduce the light transmission without reducing the aperture. The answer is to use filters that let only a small percentage of the light through them. For photographic use 0.1% of the light is okay, especially if you plan to use a calcium K filter (see later). Indeed, the view through these filters may appear good for visual viewing, but do not try it! The amount of harmful radiation in ultraviolet and infrared wavelengths may damage your eyesight. The filters that let only 0.01% of the light through are the best for visual use.

The great thing about this type of filter is that it allows you to see far more detail on the solar surface than you can ever hope to see using solar projection. You can see smaller sunspots than you could with solar projection, and the larger ones show umbral/penumbral shading. In addition to the central dark areas (or umbra) (in reality about 70–80% "black"), you can also see lighter areas (the penumbra). You can also see the phenomenon of limb darkening, where the Sun is darker near the edges than it is in the center. This has been seen using solar projection but is more noticeable using filters. Other features can be seen in white light, but do not expect to see them on a daily basis. Also, some white light filters show more detail than others.

There are several options for using white light filters, as follows:

- Dedicated instruments: These have filters built in and do not need any set-up time at all. Everything is ready-made, and there is few if any safety problems, apart from the odd scratch if you are not careful. Several manufacturers produce these, and they can be quite good. The problem is that these instruments cannot be used for any other type of viewing or photography and can be quite expensive.

- Ready-made filters: These are made in various sizes and are designed to fit over the objective of your telescope or binoculars. If you intend to use a lot of your instruments for solar viewing, this can get quite expensive, and not every telescope has an exact fit. You also need white light filters for any finderscopes. Evidence suggests that they can be better than making your own, showing more solar detail, but the results are inconclusive.

- Making your own: This is the cheapest method, as you just need to buy the filter material in sheets and use cardboard, paper glue, and tape to finish the article. You can also use unused corners of the sheet to make filters for your finderscope. Phil Harrington described this in *Astronomy* magazine in 2001. They can fall off if you are not careful, but this and the above option allow you to remove the filter and use the instrument for night time or other solar use.

If you are financially challenged, you can make your own white light filters. Even if you do hydrogen alpha viewing, "white light" viewing still shows sunspots a lot more clearly (Fig. 3.4).

Fig. 3.4. A pair of 15×70 binoculars fitted with white light filters.

A lot of astronomy is done using binoculars. Some may be quite large compared with bird watching equipment. Medium to large binoculars of about 70 mm aperture require minimal setup time and are very transportable. It can be quite difficult to get enough time during the day to make detailed solar observations, especially in winter in temperate latitudes. A "bin scan" of the Sun will show if there is any activity in white light. Exceptionally, it is possible to see a large active region resolve into smaller sunspots and umbral/penumbral shading but, as often as not, it is only possible to see a group appear as a single large sunspot. You can do a quick sketch of the sunspots on view and at a later time (as soon as possible) do a computer-based drawing of the sunspots using a drawing package. You can also sketch the sunspots on an A4 sheet of paper, and then scan them into your computer.

This method is far more effective than theory/guesswork would suggest. Even in summer, many days have clouds. Despite this, it is possible to see sunspots in unbelievably bad conditions. If cloud or mist blocks the Sun, do not give up as long as you can see a disc with clear edges. Do not, however, be tempted to dispense with the filters, as invisible ultraviolet and infrared radiation can ruin your eyesight without you having a clue it is going on. It is pretty much impossible to take photographs while a cloud is moving quickly across the solar disc, but you can keep watching for breaks and note down the positions and appearance of sunspots as the whole disc or parts of it clear. Under these conditions, hydrogen alpha viewing is much more difficult and requires better conditions than those required for white light.

The lack of appearance on sunspots through a binocular scan does not usually encourage you to try with a larger aperture instrument. In fact, it is highly discouraging. However, if you see a large sunspot group or two, you should try a larger aperture view. There are those who say that aperture is not that important for solar viewing, as the Sun emits a large amount of light. While the higher magnification afforded by small telescopes shows more detail than with binoculars, there is little doubt that a medium aperture instrument, such as a 127 mm Maksutov–Cassegrain is an extremely good instrument for white light solar viewing. Indeed it is possible to take some nice photographs on some good days that reveal sunspot details way beyond the capabilities of most people's drawing abilities.

If you have not tried white light solar viewing, give it a go. There are some limitations, which we will come to in a minute, but if you fail to be gripped by it, at least you will have something to do while waiting for sunset or the Moon to be visible. Although there are other features that you can sometimes see in white light, most of the time, viewing is restricted to sunspots, especially with low aperture and/or low magnification. Sunspots rotate in approximately 29 days, as seen from Earth and, like lunar craters, can be difficult to spot when they are near the solar limb. Indeed, read the lunar viewing chapter and see the bit about circles on a football, as the same applies. In practice, sunspots can be seen clearly through modest equipment about a third of the time. The rest of the time, they are either on the far side of the Sun, as seen from Earth, or they are too close to either limb.

Some sunspots survive long enough to be seen from one rotation to another, but this is not very common. If you monitor the Sun every hour, you will see the sunspots rotate. This is not real rotation around the solar globe but is actually caused by our Earth's rotation. Real rotation is rarely noticeable over periods less than 12 hours. To monitor sunspot rotation, it is best to view the Sun as close to the same time of day as possible, otherwise any rotational effects will be compounded by terrestrial rotation. You will notice that the sunspots appear to rotate more rapidly when they are near the center of the solar disc, but just try drawing spots on a football again. Also, they will apparently change shape as they move from one limb to another (east to west).

Notice that we are talking about sunspot rotation, but sunspots themselves change shape and are created. The majority of sunspots that appear seem to have rotated from the far side. This is because of the spherical nature of the Sun and because amateurs tend to pay more attention to the east side of the Sun, so any sunspots that emerge near the western limb get missed. A truer picture is often obtained when you look at the Sun through a higher quality instrument.

It is generally true that sunspot patterns are best viewed in white light. Unless you are very lucky, you do not see much else, and the sunspots do not change or rotate much during periods of less than 12 hours. During the English or Canadian summer, it is possible to observe the Sun in white light when you first get up and again before sunset.

The best instrument to buy specifically for solar white light viewing is a large aperture apochromatic refractor. Chromatic aberration is as annoying for solar viewers as lunar ones. If you cannot afford one of those, a Maksutov–Cassegrain is almost as good and can be used for lunar and planetary viewing as well.

If the weather outside is a bit uncomfortable, you can always cheat! There are several Web sites that show the latest solar images. An example is the Big Bear Solar Observatory, whose Web site is http://www.bbso.njit.edu/.

This brings us to the question of equipment for solar hydrogen alpha viewing. Unfortunately, there is often little or no debate because many astronomers are restricted to entry-level. Even those able to afford thousands of dollars on a telescope may feel more inclined to spend it on an instrument that is not restricted to a single object. For white light viewing, home-made filters were the cheapest. However, making your own filters is not a job even for gifted amateurs. Ironically enough, purpose-made instruments are the cheapest route to entry-level. At the time of writing, the cheapest options were a Coronado Personal Solar Telescope (PST), costing about $400 in the

United States, and the Lunt LS35, which was slightly cheaper. For most amateurs, that represents quite a considerable outlay. Andy Lunt is the son of the founders of Coronado. At the time of writing, he was a new entrant to the market, but his telescopes had great specifications at relatively low prices.

Before helping you to choose hydrogen alpha viewing equipment, we will examine what the principle is, without getting too scientific. Some of you may be familiar with Moon filters and may have used color filters for general astronomical use. Indeed, there are even hydrogen alpha filters that are used for night time viewing. So the answer is quite simple: you use a "white light" filter to reduce the light transmission without reducing the aperture, and then apply a night time hydrogen alpha filter. Easy? Well no! Night time hydrogen alpha filters are broadband filters. Although broadband is good news for Internet users, it is bad news for solar viewing. What is needed for hydrogen alpha viewing is narrowband filters. These only permit a small range of wavelengths around the hydrogen alpha wavelength to pass. This range is usually measured in Angstrom units, where an Angstrom is a meter divided by itself ten times or a tenth of a nanometer.

Now, the exact figures depend on the optical quality of the equipment being used, but as a general rule, any hydrogen alpha filter with a bandpass of more than 1.5 Angstrom units (abbreviated to A) will not show any more solar detail than will white light. At 1.5 A, some prominences will be visible, and some of these filters are marketed as "prominence filters." At 1 A, some surface detail becomes visible, and at 0.7 A more detail can be seen/photographed, although the prominence features may be dimmed. The 0.5 A is about as good as it gets, but some amateurs have managed to achieve even better detail with a bandpass of 0.2 A.

The next most important factor after bandpass and optical quality is aperture. As for any other type of viewing, it is aperture that determines the amount of light collected and the resolution of fine detail. Beware of one issue, though. Many systems reduce the effective aperture, so if you are thinking of buying any equipment, make sure you know what the effective aperture is and not just the diameter of the objective lens. In some examples, the aperture is deliberately reduced to increase the focal ratio. In other cases, it is a limitation introduced to make the production costs cheaper.

As separate filter systems are much cheaper for white light viewing, it must therefore follow that they must also be cheaper for hydrogen alpha viewing. Well, no! It may well be true at the top end of the range but not at the bottom end, where the entry-level instrument was a Coronado Personal Solar Telescope (PST). The launch price was $499, but it was retailing at around $400 in August 2008. At that price it was the only means of hydrogen alpha viewing available to many amateur astronomers for many years. The next cheapest option appeared to be some separate filter units at around $600. As listed under the Further Reading section of this book, material is available to appraise the commercial solar hydrogen alpha market. However, Andy Lunt had introduced the LS35, which had 35 mm of aperture and which fully uses that aperture and does not "beam down" the aperture of the objective onto a small etalon. It also has a lower bandpass of 0.75 A than the PST. In the United States, it retailed at slightly less than the Coronado PST. In theory, it has a better specification than the PST, but at the time of this writing, no results from a head-to-head trial were available.

To cut a long story short, the PST is an excellent instrument, although its size and effective aperture (30 mm) may appear off-putting to amateur astronomers who have been led to believe that aperture is king. Apart from its narrow aperture, it also has a small focusing range, making use of some eyepieces and Barlow lenses impossible. It can show a lot of detail, but the small aperture does mean it is not tolerant of hazy conditions. It is also very portable. If it is the only solar hydrogen alpha telescope you ever buy, you will not feel it is a waste of money, nor will you regret it if you later buy a bigger telescope, keeping this one for travel. The Lunt LS35 is even more portable, being of smaller size. Whichever entry-level narrowband solar telescope you buy (and who knows if there may be even more entrants to the market?), it is worth keeping, as it will be very good for nipping out to catch gaps in the cloud and for travel.

Figure 3.5 shows the Coronado PST. It is light enough to work well with a camera tripod, although for photographic use, an equatorial mounted

Fig. 3.5. The Coronado PST.

tripod is better. Nevertheless, the set-up works well for air travel. The eyepiece shown is the Coronado CEMAX 12 mm, which has been designed specifically for hydrogen alpha viewing. It also makes a good all-around eyepiece and is suitable for general night-time use. It works well with a Soligor 2× Barlow lens or 1.6× Magni Max Image Amplifier. Unfortunately, it does not work with both at the same.

The CEMAX 12 mm eyepiece outscores medium priced Plossl eyepieces and certainly any budget ones. It is available in longer focal lengths, although these are not particularly useful with the PST. Moonfish Group SWA eyepieces work well with the PST, as do Revelation Plossls. Zoom eyepieces, although not always good for night time viewing, as they introduce chromatic aberration, work well with the PST or any other hydrogen alpha telescope or viewing system.

Now the $64,000 question, or perhaps more accurately the $3,000 question is that if you have a budget above entry level, which telescope(s) and/or filters should you buy. Many experienced solar observers will shout bandpass, although it is not quite so simple. Bandpass may be more significant if you live in regions blessed with clear skies and little haze, but most parts of Europe are not so lucky. Conventional wisdom suggests that any bandpass greater than 1 A is a waste of time for hydrogen alpha viewing. In any case, just about all options in the $3,000 price bracket have a bandpass of 0.7 A or lower. Once a bandpass of less than 1 A is achieved, aperture is usually more significant than a lower bandpass.

Below $3,000, dedicated telescopes appear to win the battle of quality against price. Coronado, in particular, has several interesting models less than this price, particularly the MaxScope 60 and MaxScope 70. The MaxScope 60 has a smaller aperture (60 mm) and lower bandpass (0.7 A), while the MaxScope 70 has a larger aperture and wider bandpass (0.8 A). People who have used both say that "either of them will knock your socks off." For the full range of Coronado products, see the For Further Reading section of this book. At the time of this writing, Andy Lunt (son of David Lunt, founder of Coronado) had entered the market with dedicated telescopes and filters, which were much cheaper than either Coronado or Solarscope but, to date, no head-to-head comparisons had been written.

Whether you purchase a Coronado or other telescope, one of your options is to add a second filter at a later date to achieve double stacking. This reduces the bandpass, usually by a factor of 30%. For example, double stacking a Coronado MaxScope 60 reduces the bandpass to 0.5 A. This certainly shows more surface detail but can obscure prominences, especially under poor light conditions or with a low aperture. One of the reasons it is best to go for aperture before bandpass is that bandpass can be added at a later date. Coronados have their own secondary filters (and it is necessary to follow their recommended practices), but non-Coronado filters have also been added. Note, however, that you should contact the manufacturer before adding a second filter. If carried out inappropriately, the bandpass may be reduced by only about 10%. Most Coronado instruments need to be sent back to the manufacturer for double stacking.

Coronado and SolarScope, for example, produce full aperture filters and dedicated telescopes. Certainly, in the budget range, they seem the best option, but there are also filters that can be placed in the terminal light path (near the eyepiece) of the telescope. There are several of these types available, and they provide a cheaper and more flexible option than dedicated telescopes or full aperture filters. Marcello Lugli has designed some called CromixSun that can be used to produce a range of bandpass options and can be used for double stacking other equipment. The advantage of such filters is that they can be used with more than one telescope, so it can be used by those who travel the world.

The top end dedicated hydrogen alpha telescopes are superb instruments but cost as much money as a reasonable used car, around the $12,000 mark. The photographs taken through them are simply superb and can be seen on the Coronado Web site and others. It is certainly a cheaper option to buy filters for the terminal light path, such as CromixSun and use them with a larger aperture telescope. Unfortunately, most people are too financially challenged to consider this option at present. Indeed, many amateur astronomers would be hard pressed to find $12,000 for an instrument that can only be used on one object.

In fact, observing the Sun in hydrogen alpha light is not the last word in amateur solar astronomy. It is possible to use calcium K equipment instead, although the range of equipment on the market so far is not as great as for hydrogen alpha. Coronado has brought out a calcium K version of the PST, known as the PST CaK. Although the design of the PST CaK is very similar to the regular PST, the bandpass is 2.2 A, as opposed to 1.0 A. Calcium K viewing and photography transmits only a small amount of solar light, and it is possible to use a bandpass as wide as 8 A. The Baader Planetarium filter is an example and is much cheaper than the PST CaK, which costs the same as its hydrogen alpha cousin.

The calcium K wavelength is much nearer the near ultraviolet, so it is difficult for many people to see any details through a telescope. Indeed, ability to see the details (or lack of them) is reputedly age-related. As a general rule, calcium K reveals more surface detail, but hydrogen alpha reveals more in the way of prominences. An interesting photographic technique is to combine photographs taken in hydrogen alpha light and calcium K within a few minutes of each other.

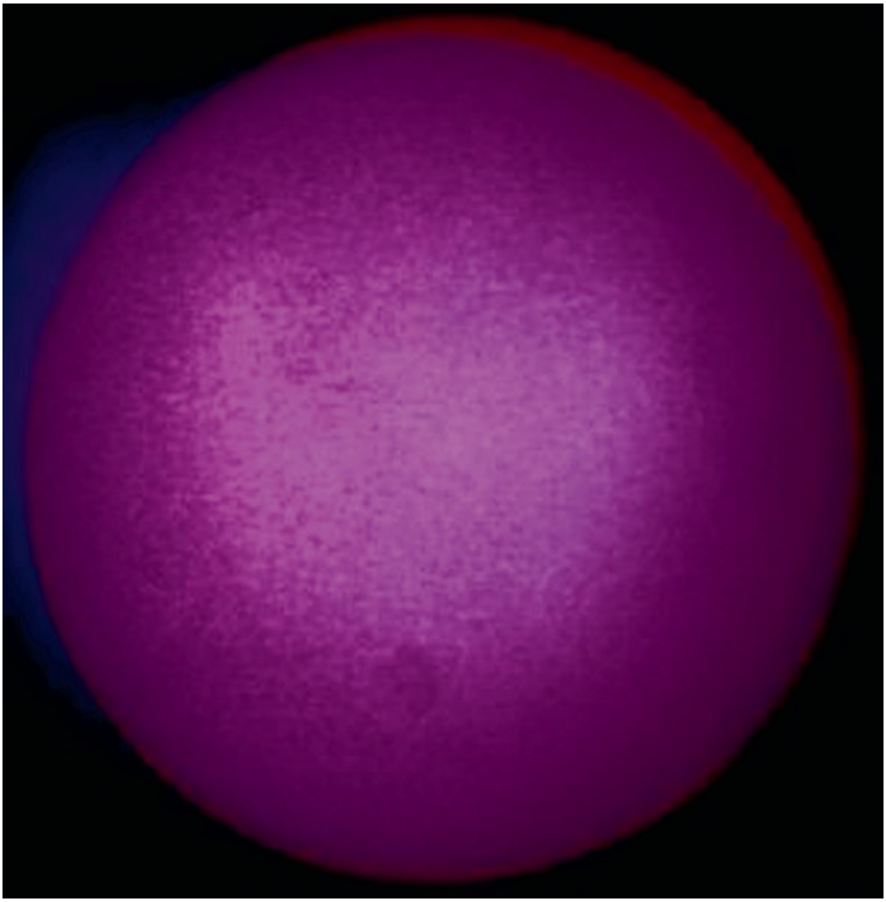


Fig. 3.6. Composite photograph of the Sun taken on Oct 7, 2006, combining hydrogen alpha and calcium K light.

Figure 3.6 is an example of a photo taken using the calcium K and hydrogen alpha versions of the PST and gives a good representation of what the Sun looks like on a quiet day. A lot of the trick of calcium K is learning how to tweak the photographs (see the imaging chapter for this).

To sum up, yes, you can enjoy viewing the Sun in white light, but the addition of hydrogen alpha and possibly calcium K to your armory certainly improves your enjoyment. Indeed, it has been said that many solar addicts even start to lose interest in the night sky.

What to See

There is little doubt that hydrogen alpha and calcium K viewing greatly enhances the amount that you can see on the Sun. That does not alter the fact that you can still enjoy white light viewing, and solar addicts should remember that it is worth checking the Sun without the narrowband filters as well. Any sunspots of reasonable size are visible in binoculars, but some of the larger ones can even be seen in finderscopes. When no sunspots are visible (typically near a solar minimum), you can still see limb darkening. In this the limb or edge of the Sun appears darker as light from the photosphere (layer of the Sun visible in white light) passes through a thicker layer of the solar atmosphere, as is found in the center of the solar disc. It is a similar effect to the dimming of objects near the horizon as viewed from Earth. If you can see limb darkening in white light, then the viewing conditions are probably quite decent. If you are unable to see sunspots but can see limb darkening, it suggests that there may be some sunspots smaller than the resolution limit of your instrument, but you are not missing anything "big." Binoculars with an aperture of about 70 mm are ideal for this purpose. You can sometimes even see umbral/penumbral shading.

Increasing the aperture of the telescope used for white light solar viewing and the magnification to match allows more detail to be resolved. It is more likely you will see the bright regions of the solar disc, although these are better in hydrogen alpha or calcium K light. Under ideal conditions they are visible in an 80 mm refractor. You can sometimes see them in a larger telescope, such as a 127 mm Maksutov–Cassegrain surrounding sunspots. Sometimes sunspots can be prominent in white light but almost invisible when viewed in narrowband instruments. Very large instruments can show sunspots showing the penumbra as lines, rather than a smooth surface and can show the many irregularities in their shapes.

Sometimes it is possible to see the granularity on the solar disc in white light. The solar surface is not actually smooth and is certainly not static. It has "bubbles" of gas that carry heat from the solar interior before releasing the heat and sinking back toward the solar center, where it is reheated. Imagine a school science project showing how an immersion heater works. However, it requires a good day and a good quality instrument to see this effect. Conventional wisdom suggests a minimum magnification of 300× to see it, and observational evidence confirms this.

The Holy Grail of white light viewing is to catch a solar flare. There have been few recorded instances of the event where it is so bright as to be seen without narrowband instruments. Indeed, it is said that if you spend an entire lifetime viewing the solar disc in white light, you will be lucky to see even one flare.

Apart from the fact that some sunspots lose their intensity due to narrowband filtering, it is a more interesting way to view the Sun. What you are actually seeing is a layer of the solar chromosphere, which is the layer of the Sun above the photosphere but below the corona. This layer is sometimes seen during total solar eclipses. The light wavelengths most used for narrowband filtering are hydrogen alpha and calcium K, which correspond to specific light emissions from hydrogen and calcium wavelengths, respectively. The calcium K emissions are weaker and come from a lower layer of the chromosphere than hydrogen alpha. If we were orbiting an older star (Population II), the calcium K emissions would not be present. They are only present in second and subsequent generations of stars, with significant amounts of heavier elements.

The most obvious features in hydrogen alpha light are the prominences. These look like flames but are actually caused by solar magnetic fields where the chromosphere meets the corona. They are a nice sight and can be seen in hydrogen alpha light with a bandpass as wide as 1.5 A. When prominences are silhouetted against the chromosphere, they appear as filaments. When you see them for the first time, they look like hairs that you failed to clean from the optics. Just move the telescope a little bit and see if the "hairs" move with it. The filaments move across the solar disc and change shape in the same way that sunspots do but can change in a matter of hours. Prominences can change over minutes and even change shape in "real time," although this is not a common occurrence.

There are many pictures of prominences taken with CaK 70 solar telescopes. These telescopes are like the MaxScope 70s, except that they show the Sun in calcium K light. Like the PST CaK, the CaK 70 has a bandpass of 2.2 A.

Like solar hydrogen alpha viewing, there is now competition at the budget end of the market. For example, there are now some screw-in filters, such as the Baader Planetarium. The Lunt device is a star diagonal that retailed for about $600 in the United States and is suitable for using with telescopes with an aperture up to 80 mm, while the PST CaK is about the same price.

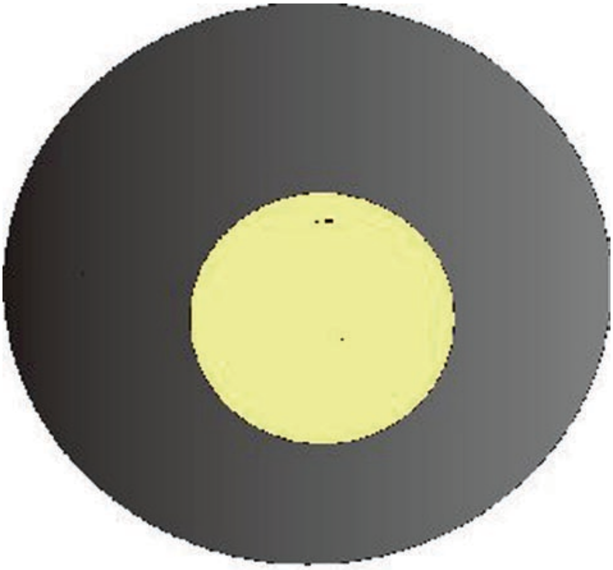
Although faculae can be seen in white light, as can granularity, they are much clearer in hydrogen alpha light and even better in calcium K light. It is not necessary to wait for clear conditions and use high magnification, although if you have a filter with a bandpass of 2 A or thereabouts and a large aperture, the conditions should be rather good. You can also see bright regions of the solar disc called plages, which are extremely bright and up to 1.5 million degrees Celsius. Very bright plages are known as flares and are often followed by coronal mass ejections, resulting in aurorae being visible in temperate zones.

Getting the Best from Solar Viewing

Frequency is the key to solar observation. Even in white light, the Sun changes its appearance more rapidly than most other celestial objects. Daily observations are recommended, except that during a solar minimum, you may go weeks without seeing a sunspot, so you might cut down to twice weekly and be confident that you are not missing much. The challenge in temperate and higher latitudes is that during winter, seeing the Sun can be quite difficult. Many go to work or school before sunrise and return after sunset. For that reason, some sort of quick binocular scan will enable you to do a simple recording of sunspot patterns. If you are able to take a reasonable lunch break, you may be able to take photographs through a telescope, as binoculars are less suitable for this purpose. One idea is to make a sketch of the sunspots to later produce drawings on the computer using a consistent blank, perhaps one made with an overexposed hydrogen alpha view or just a yellow circle on a shaded black background. Examples of these are shown in Fig. 3.7–3.11.

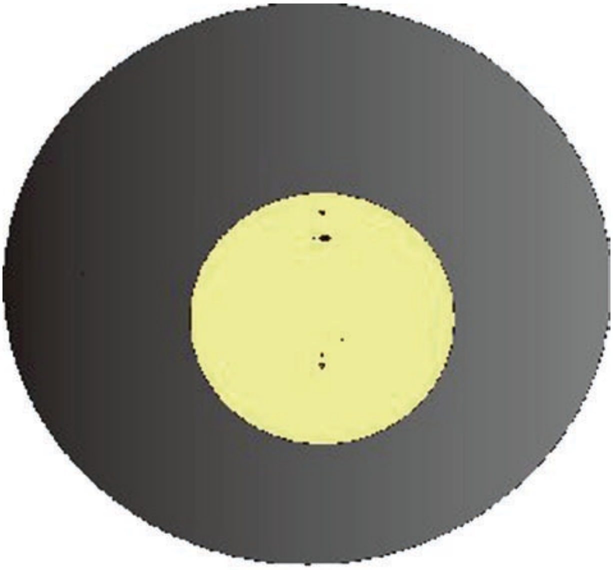
Sometimes, drawing is much better than photography. Thin, uneven cloud can ruin an otherwise great shot, and fast moving clouds can make photography just about impossible. One can often spend much time waiting for a gap to appear in clouds, so as to catch the Sun. Sunspots can certainly be seen under incredibly bad conditions in white light. You can even see them through thin haze, but if the outline of the solar limb is not sharp, you will not see them. Using this method also allows one to monitor the Sun while traveling.

Figures 3.7–3.11 show drawings of the Sun changing over 5 days, not long after solar maximum.



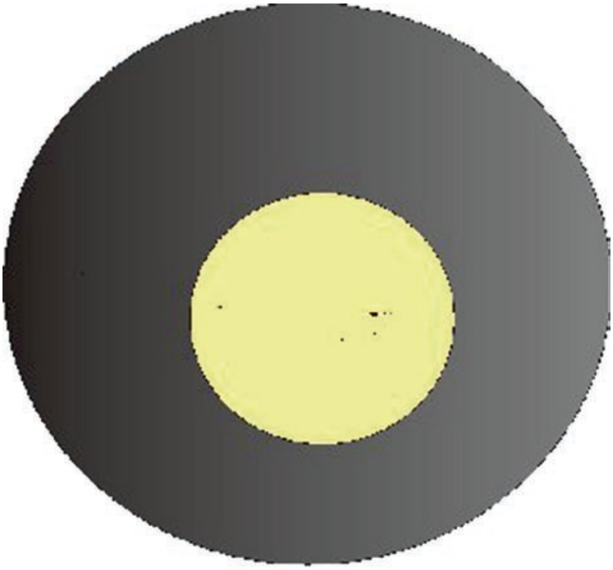
Sep 10 2002 07:30 GMT

Fig. 3.7. Sunspot sequence 1.



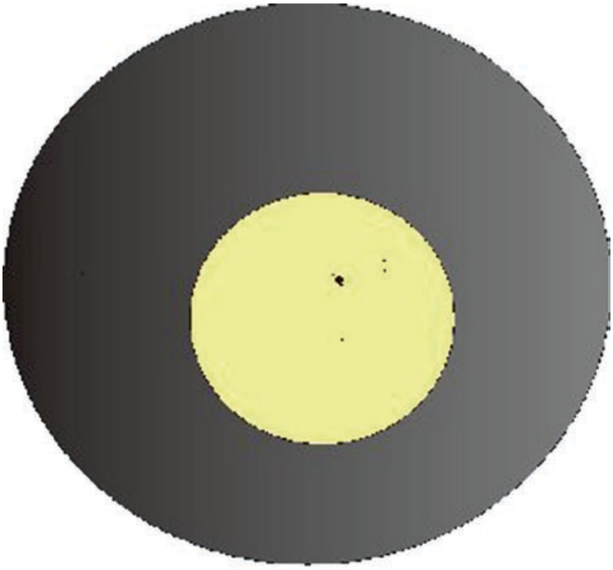
Sep 11 2002 07:25 GMT

Fig. 3.8. Sunspot sequence 2.



Sep 12 2002 18:15 GMT

Fig. 3.9. Sunspot sequence 3.



Sep 13 2002 12:30 GMT

Fig. 3.10. Sunspot sequence 4.

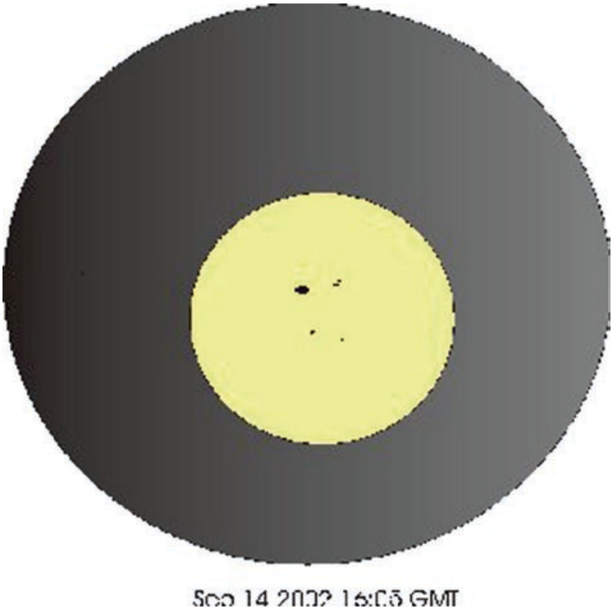


Fig. 3.11. Sunspot sequence 5.

By maintaining a consistent blank, at least over the course of a year, each drawing will have the same dimensions (Fig. 3.12). You can even use the previous day's drawing by moving the sunspots and making any changes of shape and emergence of new spots. The best shade to use is 80% black, with adjustments made for any penumbral shading or lighter spots. The reason for not using 100% black becomes apparent if you see a transit of Mercury or Venus. Example drawings are shown in the Observations section of this author's Web site:

http://philippugh.fortunecity.com/

You can also make animations of the sunspot movements using these drawings and *Animation Shop Pro* or a similar tool.

If you have the time, regular monitoring of the Sun in white light can be rewarding, although not near a solar minimum. If you have a larger aperture instrument, you can see patterns in the sunspots themselves. Although drawings are good for monitoring the number, size, and position of sunspots, they do not always record the sometimes complex structure of spots at low magnification. The best instrument you can use is an APO refractor, but, like lunar viewing, a Maksutov–Cassegrain is almost as good and a lot cheaper. With the distraction of hydrogen alpha viewing,

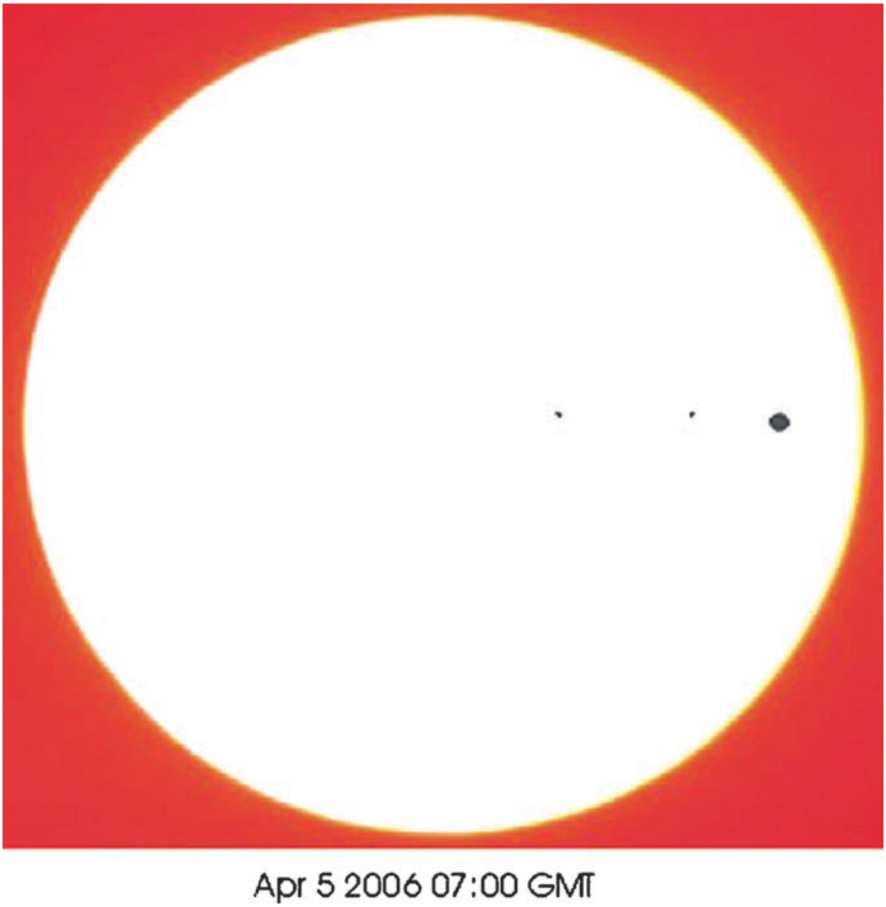


Fig. 3.12. Sunspot drawing using a newer blank.

many keen solar observers have gotten a bit lazy with white light viewing and photography.

Although white light viewing and photography can be very rewarding, narrowband viewing of the Sun is almost essential to get the very best out of your sessions. The first and most obvious choice is hydrogen alpha, as this is the most prominent wavelength generated in the solar photosphere. Unfortunately, it is an expensive branch of astronomy, and you need at least $400 before even thinking of starting, unless you can get a good deal somewhere. The entry level price will buy you a reasonable Maksutov–Cassegrain or 200 mm Dobsonian reflector.

The biggest problem with using the Coronado PST is finding time to use it when weather allows and time to postprocess the images. Most of our daylight hours are spent at work or study, although the long summer evenings in England and Canada are useful for solar viewing and more enjoyable than bemoaning the lack of darkness for deep sky viewing. The PST's portability is a huge asset when traveling, and business travelers can spend as much time abroad as at home.

Calcium K viewing and photography is a more realistic extension to solar viewing. It gives another dimension to solar viewing. As for what can be achieved using quite modest equipment, read the chapter on imaging. The cheapest option seems to be a separate filter with a bandpass of about 8 A, but you must use a white light filter as well. The thickness of the filter could be less than that used for white light viewing, as calcium K lets very little visible light through, even compared with hydrogen alpha. However, the calcium K version of the PST is more effective and produces more detail. In fact, Andy Lunt had a filter with a bandpass of 2.4 A available for $599 (at the time of this writing) that can be used with telescopes up to 80 mm aperture, but no feedback on how effective it is was available, nor how it compared with the PST Cak.

For Further Reading

Books

The following books are available from Springer-Verlag:

- *Aurora: Observing and Recording Nature's Spectacular Light Show* by Neil Bone. Explains how to predict and view auroral displays.

- *Solar Observing Techniques* by Chris Kitchin. Discusses how to view the Sun in more detail than covered here and emphasizes the safety aspects of solar viewing.

- *How to Observe the Sun Safely* by Lee Macdonald.

- *The Sun in Eclipse* by Michael Maunder and Patrick Moore.

- *Transit*: *When Planets Cross the Sun* by Michael Maunder and Patrick Moore.

- *Observing the Sun with Coronado Telescopes* by Philip Pugh, with contributions by many heavyweights in amateur solar observing. Gives the lowdown on Coronado equipment and an insight into some of the competing equipment. This is a special favorite of mine!

The Internet

This author's Web site contains a diary of observations, with white light drawings and hydrogen alpha photographs. It also contains links to many other Web sites.

The Coronado Web site contains a good picture gallery, as well as descriptions of their telescopes and filters.

Many magazine Web sites and gallery pages have photographs of the Sun taken through various instruments.

CHAPTER FOUR

Planetary Viewing

Planets are not as forgiving of modest equipment and poor conditions as the Sun and Moon but, nevertheless, can still provide some interesting viewing. The planets are not as obvious to find as the Sun or Moon and, unlike the stars, move. Fortunately, they move in predictable patterns in relation to the Sun, Moon, and stars.

An appendix called *Planetary Data* contains details of each planet.

For the Sun and Moon, the observational environment is not that important. Although it is true that pollution and weather are so bad in a few parts of the world as to make even the Sun and Moon invisible, it is not true for the majority of locations. For planets, visibility and the presence of obstructions, such as trees and buildings, are more critical. Again, though most people are lucky enough to be able to see large parts of the sky from their home or that of a friend or relative, some are so closed in by obstructions that they need to find somewhere else to view from. If you have any choice in the matter, if you can choose where you live, look for somewhere with an unobstructed view to the south (north if in the Southern Hemisphere) and as clear an eastern and western horizon as possible.

One of the key steps to finding planets is knowing your way around the zodiac. Only the brighter constellations of Taurus, Gemini, Leo, and Virgo are obvious for average suburban skies. Aries can be found with a bit of practice and so can the part of Scorpius that is visible from England and Canada. Although there are some bright stars visible from England in Sagittarius, there is not a recognizable pattern. You can sometimes

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series,
DOI 10.1007/978-0-387-76470-2_4,

recognize the pattern in Pisces from suburban skies, but any planet known to be in Pisces can be found by looking south of the Square of Pegasus.

Now, a word of warning here! If an astronomy magazine says that a planet is in Pisces or anywhere else for that matter, believe it. If a horoscope section of a magazine or newspaper says that a planet is in Pisces, it could actually be found in Aquarius or Cetus. The problem is that the original zodiac was drawn up over 2,000 years ago, and Earth's axis has shifted somewhat since then. With a bit of practice and a good star atlas, it is possible to translate horoscope positions to real ones, but it is actually much easier to use a planetarium program on a computer or look up the real positions in an astronomy magazine.

Fig. 4.1. The eclipsed Moon and Saturn among the stars of Leo.

Figure 4.1 shows an example of the Moon and Saturn in Leo. Saturn is the bright "star" to the right.

The pattern of Cancer is difficult to see from anywhere in the world. On the odd lucky day, the Beehive star cluster may be seen with the unaided eye, but it is really very faint. To find Cancer (or anything in it) look southeast from Gemini. If Gemini and Leo are both visible, it is on an imaginary line between Pollux and Regulus. Similarly, Libra is all but invisible from suburban skies in the Northern Hemisphere, but it is southeast of Virgo and lies on an imaginary line between Spica and Antares. The few bright stars east of Antares are in Sagittarius, but also note that many planets (and the Moon) will actually pass somewhat north of Scorpius and Sagittarius through the faint constellation of Ophiuchus. Capricorn and Aquarius have also largely escaped many eyes. However, you know where they should be, because they lie between Sagittarius and Pegasus progressively further northeast.

After a while, you will hopefully get familiar with the layout of the zodiac from your home or other places you observe from. If you travel north to Scotland or Northern Canada, Antares becomes invisible, and anything in Scorpius, Sagittarius, or Ophiuchus simply skims the horizon and may be hidden from view by any obstruction. If you travel south to Europe or the United States, the constellations of the zodiac appear higher in the sky, although their orientation remains the same. If you travel south in summer and look at the night sky, you will be amazed at how large Scorpius appears. When you get to the equator, you will see the familiar constellations lying on their side, and from the Southern Hemisphere they are upside down.

One rather interesting fact is that nearly all places that you are likely to visit in the Southern Hemisphere are all around 35° south. This includes Adelaide, Perth, Sydney, and Melbourne in Australia; Cape Town, Johannesburg, and Pretoria in South Africa, Buenos Aries in Argentina and Santiago in Chile. New Zealand is only slightly further south.

Some people seem to have an uncanny ability to navigate around the night sky worldwide, even if they easily get lost driving in unfamiliar territory. It is well worth becoming comfortable with the zodiac, or to use its proper technical term, *ecliptic*. Not only does it help you find the planets but can also act as a good reference point for some deep sky objects, which are discussed later on. There are not any shortcuts, so the best advice is get out there, practice, and watch the planets move against the background stars and familiar landmarks on the horizon.

The key to successful planetary observation is location. Although this book is mostly about observational topics, there is some information about orbital mechanics in order to explain how the planets appear to move across the sky. This book also introduces some terminology, as you will need it when you look up the planetary positions in the monthly magazines and Web sites.

In a nutshell, Venus is the easiest planet to find, as it is bright enough that it should not be confused with anything else, although it is not impossible to confuse it with Jupiter! Jupiter is also very bright and outshines any star in the night sky, including Sirius. Mars can vary from being very bright, even outshining Jupiter, to about the same brightness as Castor near conjunction. Because of its color, it can be confused with Antares or Aldebaran. Saturn should not be confused with any of the bright stars around the ecliptic, as it never gets fainter than any of them. Uranus and Neptune are relatively faint, and you will need a star chart to distinguish them from many stars of similar brightness. Like Mars, Mercury can vary quite considerably in brightness and can be confused with stars such as Regulus and Spica.

We have seen in the chapter on lunar viewing that the Moon can pass close to any of the planets and even occult them. One interesting event is when planets pass very close to each other in the sky or close to stars. This author was pleased to view Mercury passing close to Spica while away on business in Belize. As per Murphy's Law, I only had binoculars and no camera. Fortunately, in June 2005, I was able to witness a close conjunction between Mercury and Venus and this time I did get a few photographs.

Fig. 4.2. Conjunction between Venus and Mercury.

Figure 4.2 shows the conjunction between Venus and Mercury taken with a 127 mm Maksutov-Cassegrain using afocal projection with a Sony Cybershot P72 digital camera (3.1 megapixels) and a 15 mm Moonfish Group SWA eyepiece.

The Inferior Planets

The inferior planets are so named because their orbits lie within that of Earth, not because they are telescopically inferior to Jupiter and Saturn. Although the latter is true, Mercury and Venus have some interest of their own. What they have in common is the way that they move in the sky relative to the Sun and background stars.

They are never actually visible when they are at 100% phase, since they are too close to the Sun at that time for observation. They are on the opposite site of the Sun from the Earth and are said to be in *superior conjunction*. In practice, they usually pass slightly above or below the Sun, as their orbits are inclined to the ecliptic. As an inferior planet travels faster around the Sun than Earth does, it moves away from superior conjunction. It moves eastward relative to the Sun in the sky. Its phase decreases, but its apparent angular size increases as it gets closer to Earth.

When the planet reaches right angles between the Sun and Earth, it shows a phase of about 50% and is as far eastwards as it gets. It is said to be at *maximum eastern elongation*. It is at this time that it is easiest to find, as it is visible in the evening. The best maximum eastern elongations are when they occur around spring equinox and when the planet is at or near its maximum distance from the Sun. However, although spring equinox is best, any time between December and May is favorable from the Northern Hemisphere and from June to November in the Southern Hemisphere. This is due to the angle of the ecliptic to the horizon.

As the planet passes maximum eastern elongation, it swings in between the Sun and Earth. Its apparent size increases, while its phase decreases. However, the brightness change is remarkably different for both planets. Venus brightens, whereas Mercury fades. This is due to the relative distances of the planets to Earth. When an inferior planet lies between the Sun and Earth, it is said to be at *inferior conjunction*. If it lies exactly between them you can see its shadow cross the solar disc. This is called a *transit*. These events are described in the chapter on solar viewing. Usually, the planet will pass above or below the Sun and will not be visible. Under very rare circumstances Venus can be seen at inferior conjunction, when it passes sufficiently north of the Sun to be seen from the Northern Hemisphere or sufficiently south of the Sun to be seen from the Southern Hemisphere. This is not true of Mercury, as it is much fainter than Venus.

After inferior conjunction, an inferior planet passes into the morning sky to reach *maximum western elongation*, when it forms a right angle between the Sun and Earth on the other side. Here it is best if this happens at the autumn equinox or, failing that, sometime between July and December from the Northern Hemisphere or between January and June from the Southern Hemisphere. As it occurs during morning it is not seen by as many people as a maximum eastern elongation. It then moves around again to superior conjunction.

The time taken for a planet to move from one superior conjunction to another is called the *synodic period*. This is 97 days for Mercury and 584 days for Venus. The same term is also used for superior planets, except that they only have one conjunction with the Sun, as they cannot pass between Earth and the Sun.

Superior Planets

These are so called because their orbit lies outside that of Earth. They also take longer than a year to orbit the Sun. Unlike the inferior planets, their motion is not restricted to a few degrees each side of the Sun but can appear exactly opposite the Sun in the sky, rising at sunset and setting at sunrise. This is called *opposition* and is within a few days of the planet's closest approach to Earth. This is the most favorable viewing time, as the planet will be at its largest apparent angular size, and its features will be most visible. If opposition occurs in winter, the planet will be reasonably high in the sky by mid-evening, which is convenient for amateur astronomers who work, study, have daytime family commitments. It is best placed at midnight, but still well above most of the atmospheric interference by about 9 o'clock. If the opposition occurs on or near the summer solstice (June 21 in the Northern Hemisphere) at temperate or higher latitudes, there are several disadvantages:

- It is not visible at all until 9 o'clock and not in a darkish sky until 10 o'clock

- It never gets particularly high in the sky and from high latitudes is affected by atmospheric interference

- In countries with daylight saving, it is highest in the sky (best placed for observation) at 1 a.m. local time

This means that decent observing is usually restricted to weekends, unless you are one of these lucky people who do not need to sleep much.

When a planet is exactly on the opposite side of the Sun as the Earth is, it is said to be in *conjunction*. Unlike the inferior planets, there is only one type of conjunction for the superior planets. As most planets have an orbit inclined a few degrees to that of Earth's a superior planet will usually pass up to 8° above or below the Sun. However, unlike Venus, none of the superior planets is bright enough to be visible at conjunction and can only be seen using electronic finding equipment during daylight. Even then they are not particularly interesting to look at in most amateur telescopes.

As the Earth moves faster around the Sun than a superior planet, it emerges from conjunction into the morning twilight. In the case of Neptune this takes about a month, as its orbit around the Sun is very slow (169 years). In the case of Mars, its orbital period is less than 2 years, so Mars's motion keeps it closer to the Sun in the sky for much longer, so it can take up to 3 months. Planets emerge from conjunction more quickly in the summer and autumn, because of the angle of the ecliptic with the horizon.

After conjunction, a planet is visible just before sunrise. To see it you need to be up rather earlier than you might otherwise be for work or study. As both the planet and the Earth move around the Sun, the Sun appears to move more quickly along the ecliptic than the planet. The planet's angular separation from the Sun increases, so it rises earlier in the morning and its apparent diameter and brightness both increase. When it reaches a right angle between the Sun and the Earth, it is called *quadrature*. At quadrature, a planet exhibits a change of phase, similar to an inferior planet but only noticeable in amateur telescopes in Mars, as the other superior planets are too far away.

At quadrature, a planet would normally rise about 6 hours before the Sun, although the exact figure is dependent on the angle between the ecliptic and horizon at the time. If a planet's quadrature coincides with a last quarter Moon, the two objects will appear close together in the sky and the Moon may even pass in front of the planet. This is called *occultation*.

As the planet moves from quadrature to opposition, it grows in apparent angular size and brightness. It also grows in phase, but this is only noticeable in Mars. It also rises earlier in the morning, eventually before midnight. It is just as it approaches opposition that it exhibits a strange phenomenon called *retrograde motion*. Normally, most of the time, the superior planets move across the sky from right to left, in the same direction as the Sun. Just before opposition, they change direction and move from left to right. This caused some confusion among astronomers until as recently as the fifteenth century. As they believed that everything circled Earth, they had to invent *epicycles*, which were paths around which planets moved in addition to their orbit. We know today that Earth moves around the Sun, and this effect is caused by Earth "overtaking" planets on the inside, causing them to appear to reverse direction for a while before continuing their eastwards (left to right) motion.

However, this only tells the story in two dimensions. Were all superior planets neatly aligned with their orbits parallel to the ecliptic, they would progress along the ecliptic, slow down, then reverse direction along the ecliptic. As all planets have orbits aligned a few degrees to the ecliptic, what you actually see is a *retrograde loop*. Whether the planet loops up or down is dependent on whether it is above or below the ecliptic at the time.

As a planet is about to enter a retrograde loop, its motion relative to the background stars slows down quite noticeably and appears to stop for a few days before reversing. This is called a *stationary point*. In monthly magazines and annual lists of events in books, this is normally recorded as, for example, “Mars stationary.” Once a superior planet has passed its stationary point and approaches opposition, the difference in rising times is more noticeable, and it is worth looking out for a little earlier each night. Remember, too, that while in a retrograde loop, a superior planet is much closer to Earth than usual, so it is worth making more effort to see it. After opposition, it continues its retrograde loop until, eventually, it resumes its eastwards motion. Again, it will slow down just beforehand and appear to stop for a while. This is also called a stationary point, but, surprisingly enough, it does not have a different name to the one before opposition. Similarly, the planet progresses to a point where it forms a right angle between the Sun and Earth, called quadrature. Again, it does not have a different name to the quadrature before opposition. At this point, if it coincides with a first quarter Moon, the two objects will be close together and the Moon may occult the planet. After quadrature, the planet recedes from Earth, shrinking in apparent angular size and fading. It appears to move closer to the Sun in the sky, although in reality, the Sun is moving eastwards faster than the planet. Soon it becomes too close to the Sun to see in the evening twilight, then reaches conjunction with the Sun which starts the whole cycle all over again.

Choice of Equipment

Some observations can be made with binoculars, but for anything reasonably advanced, you need a telescope. On the one hand, if you are restricted by budget, this does not mean that you have to forget about viewing the planets altogether. On the other hand, if you are able to afford something a bit more substantial and choose carefully, you will be able to get more enjoyment than you can from beginner telescopes. Most of what writers say about equipment in general (and especially lunar viewing in particular) applies to planetary viewing. Yet, if you wish to buy a telescope specifically or mainly for planetary use, your choice is different from if you were more interested in deep sky viewing. First, you will normally be using much higher magnifications than you would use for star clusters or galaxies. Most planetary observing starts at 30× magnification, and 200× is quite commonly used. You will need a telescope with a long focal length (900 mm plus). You will need some *good* quality short focal length eyepieces and a Barlow lens. Some types of telescopes, such as the apochromatic refractor or Maksutov–Cassegrain, support the use of very high magnifications for their aperture. Also, evidence suggests that using a Barlow lens with a long focal length eyepiece usually gives a clearer image than a short focal length eyepiece. When looking at the brighter planets, do not be afraid to try using very high magnification, but remember it has its limits. Venus in a 60 mm refractor at 600× magnification looks more like a comet!

Many budget telescopes have an upper limit of about 250× magnification on very bright objects. Better quality telescopes are also limited by the speed at which objects travel through the field of view. Precise polar alignment and motor drives are needed for anything much above 300× magnification. Short focal length telescopes are not ideal for planetary use. They can be used for reasons of portability, as they will fit in hand luggage on an airplane and are more suitable for planetary viewing than the eyes alone. For example, you can only achieve a maximum magnification of about 60× with a 76 mm Catadioptric and about 160× magnification with a 80 mm short tube refractor (Skywatcher Startravel 80). Actual values will vary according to the model of telescope used. However, as most people are only able to take a camera tripod with them on business trips and holiday without incurring excess baggage charges, the maximum practical magnification is about 100×. If you are forced to use such telescopes for reasons of budget or portability, you will have to accept some limitations.

For a general description of telescopes suitable for planetary viewing and the relationships between telescope focal length, eyepiece focal length, magnification and field of view, please refer to the "Choice of Equipment" section in the chapter on lunar viewing. The same principles apply to planetary viewing, and this chapter concentrates on use of equipment specific to viewing planets.

The big difference between planetary and lunar viewing is that planets have a much smaller apparent angular size. Venus can just exceed an arcminute in size near inferior conjunction, which makes it about 1/30 of the apparent angular size of the Moon or the Sun. If you do a bit of math, like we did in the chapter on lunar viewing, it suggests that we can use magnifications in excess of 3,000× and still fit the Venusian disc into the field of view! However, there are many optical and practical limitations of using such high magnifications. Even with a good quality telescope, there is an upper limit of 4× the aperture in millimeters (convention wisdom says 2× but you can bend this rule for bright objects) and you need good polar alignment and tracking for anything much above 300× magnification.

Conventional wisdom suggests that Orthoscopic eyepieces are best for planetary viewing. They have an apparent field of view of only 30°, but this is not considered a major drawback, given the small apparent angular size of the planets. However, unless you have a GOTO telescope, you may find the narrow field of view makes planets difficult to find. Furthermore, to see the major moons of Jupiter and Saturn you sometimes need something approaching a degree field of view to see them all at the same time. If someone gives you a free Orthoscopic eyepiece (one comes supplied with the Coronado PST) do not refuse it, nor the offer of trying one out before you buy it. They are simply not the recommended first choice of many observers.

For good all-around eyepieces, the Moonfish Group SWA eyepieces are recommended. Indeed, there is little to add from the chapter on lunar viewing when it comes to eyepieces and image amplifiers in general. The only surprise is that you can actually use a Moon filter for viewing Venus and sometimes Jupiter, because of the amount of glare. Some people recommend color filters with larger aperture instruments when you use photographic postprocessing on planetary photographs. The best light/dark contrast in green light is when you separate the channels using RGB, although this may be more of a feature of many models of digital camera.

If you have not yet bought your first telescope, you should strongly consider a short tube refractor such as the Skywatcher Startravel 80. However, if you are not beset by budgetary restrictions, you should consider the apochromatic or extra dispersion equivalents. Although achromatic refractors have their limitations for planetary viewing, they are certainly far from useless and can be effective with higher magnification if it is on a good mount. If your budget can stretch to around $350, you can buy an extra dispersion refractor of the same aperture, and you can probably whack the magnification up over 300×. Indeed, even an 80 mm extra dispersion or apochromatic refractor may well be all the telescope you will ever need for planetary viewing, especially if you can afford the quality eyepieces needed to get the best out of it. A good all-around alternative is a 90 mm Maksutov–Cassegrain. The Meade ETX 90 is a good example but is relatively expensive, as it has powerful GOTO capabilities. These are handy but not really necessary for finding the brighter planets. You can add the better quality eyepieces later, and for the meantime you can use the supplied ones or got for quality budget eyepieces, such as the Moonfish Group SWA and Revelation Plossls.

To compare the performance of a Maksutov–Cassegrain with an apochromatic refractor, you have to allow for some light loss due to the central obstruction of the Maksutov–Cassegrain. A 90 mm Maksutov–Cassegrain has about the same effective aperture as a 75 mm apochromatic refractor. You can make similar comparisons between Newtonian reflectors, and achromatic refractors. As points of comparison:

- Maksutov–Cassegrains are more expensive than Newtonian reflectors, and achromatic refractors of equivalent effective aperture but are cheaper than apochromatic refractors.

- Apochromatic refractors have just about zero chromatic aberration, but that of a Maksutov–Cassegrain is very small. At least you are able to see the ice caps of Mars without confusing them with optical effects.

- Maksutov–Cassegrains usually have a longer focal length, making them better for planetary viewing but making their all-around use less effective. However, there is a simple work around for this. For the revelation, see the chapter on viewing deep sky objects.

- Newtonian reflectors have the least light loss due to the central obstruction, and they are the instrument of choice for many observers.

So you may have to consider an alternative. Perhaps a well-meaning friend or relative has bought you a 60 mm refractor for a birthday or for Christmas from a catalog or camera shop. I myself bought a 60 mm refractor from a camera shop and, for about 8 years, it was my main telescope. I was able to see plenty of lunar detail, but I was lucky that it also showed some planetary detail. I was able to see the phases of Mercury and Venus with it, Jupiter's moons and two or three equatorial cloud belts, Saturn's rings and Titan (but no planetary surface detail) and some surface markings on Mars when it was near opposition. I also bought a 76 mm catadioptric, which shows all of the above except for any detail on Mars, as it is incapable of delivering a magnification in excess of 60×. In fact, it came out of retirement recently during the baggage restrictions on the airlines when I was unprepared to risk my Skywatcher Startravel 80 being confiscated. Both telescopes cost me less than £100.

Most beginner telescopes have a 0.965″ (24 mm) fitting, whereas more serious telescopes have a 1.25″ (31.5 mm) fitting or 2″ (51.8 mm) fitting. This means that certain eyepieces cannot be used with newer telescopes. If you do not have the immediate budget to upgrade from a beginner telescope to another one, there is an alternative. In the United States, Plossl eyepieces are available with the 0.965″" fitting, but these are not available in the UK. Instead, modified achromatic eyepieces (or SMA) are available, which can give better views than the eyepieces supplied with the telescopes. The views of the planets are much better (clearer and brighter) and a longer focal length eyepiece is more suitable for deep sky viewing.

Mercury

There are no specific recommendations regarding Mercury, which do not apply in general to planetary viewing. The biggest challenge is safely finding it, which gets harder the further you are from the equator. If it is near a brighter object, such as the Moon or Venus, it is easier to find in twilight. The best thing is to catch it when it is high enough in the sky to avoid too much extinction but not too early into twilight as to be impossible to find. With most amateur instruments, you are only ever likely to see the phase. As it is estimated that less than 1% of the world's population have ever seen it, finding it at all is an achievement. But be careful if you are looking to avoid looking into the Sun!

Venus

Although the brightness of Venus makes it easy to find and something to look at on nights when you would be otherwise unable to see anything, it can be a handicap. All but the best quality optics have some imperfections, and the two that come up most are glare and chromatic aberration. There are four ways to cure glare, and you can even try all four together:

- Moon filter – this reduces the total amount of light and improves contrast. An alternative is a variable polarizing filter.

- Sunglasses, especially Polaroid – these reduce any stray light being reflected or refracted at an unfavorable angle

- Viewing in twilight or daylight

- Aperture mask (cardboard mask that fits over the objective and has 2–4 large holes in it) This is better than using a small telescope because it reduces light gathering capability but increases resolution slightly

These also work on Jupiter. By reputation color filters block out too much light with telescopes under 200 mm aperture. Chromatic aberration can be corrected by buying another eyepiece or another telescope, although there are some filters available to reduce it, often misleadingly called "semi-APO." Although they provide a more pleasing image to the eye or camera, they are removing color fringes, rather than bringing them to focus.

What to See

Mercury

Fig. 4.3. Mercury photographed at 169× magnification, showing its phase.

Your first view of Mercury will probably be disappointing, especially if you have seen the Moon, Jupiter, or Saturn, all of which can look rather impressive. People who like finding difficult faint galaxies for the challenge will enjoy Mercury. Several prominent astronomers have simply never seen it. It is never an easy object. Most of what was described earlier about learning your way around the ecliptic does not apply to Mercury. It is very rare to see it against a stellar background, and you are lucky do so from temperate latitudes within a lifetime. It is at its brightest around superior conjunction, but it is then too close to the Sun. It is visible at maximum eastern or western elongation, but then it is fainter. If it is near inferior conjunction, it is both close to the Sun and faint.

The balance between being bright enough and far enough away from the Sun to see usually occurs about 5 days before maximum eastern elongation, or 5 days after maximum western elongation. If you are very lucky you will see a bright "star" close to the horizon about an hour before or after sunset. If the sky is anything less than as clear as it gets, you will be unable to find it. You might be able to find it with binoculars first, then return to look at it with a telescope.

A telescope will show some phases. At/near maximum elongation, it will show a 50% phase. Although this has been seen in binoculars, it is not really clear at much less than 50× magnification. You will not see it against a dark background, and if the phase is less than 30% or above 70% it will be too close to the Sun to find. There have been some claims of "albedo" features visible in amateur telescopes – parts of the planet lighter/darker than others. Do not expect to see anything except the phase with a telescope with less than 250 mm aperture. Figure 4.3 shows Mercury through a Maksutov–Cassegrain, showing its phase.

On the one hand, if you can see Mercury nearly every day or every other day around the time of maximum eastern elongation around April, you may notice its movement against the horizon and its phase change happening very rapidly. On the other hand, because of lack of favorable elongations, it is easy to go the best part of a year without seeing it.

Venus

Venus is a lot easier to see than Mercury but still lacks the visual impact of the Moon, Jupiter, or Saturn. As it is physically larger and more reflective than Mercury, it is much easier to see, even near superior conjunction. In fact, near superior conjunction it is at magnitude –3.9, and at maximum brightness a couple of weeks either side of inferior conjunction it reaches up to –4.6. This is not a particularly large variation, compared with other planets, and it happens because the brightening effect of it getting closer to Earth is almost canceled out by the reduction in phase. What does vary considerably is the apparent angular size. At inferior conjunction it is about an arcminute across, whereas it is only about 9 arcseconds across at superior conjunction. This six times difference in apparent angular size at closest and furthest approach is matched only by Mars.

Although you can see the phases of Venus in binoculars, especially near inferior conjunction, measuring the phase accurately simply does not work. Low magnification is simply unable to resolve the phase accurately, and it always appears smaller in a telescope. This is particularly noticeable when you use binoculars to view deep sky objects; take a look at Venus, then return with a telescope. The effect has been proved to be real photographically. At maximum elongation, you need to be thinking of about 50× magnification to see the 50% phase accurately, and it takes about 200× magnification to distinguish a 90% disc from a 100% disc near superior conjunction. When viewing Venus, a larger telescope, such as a Maksutov–Cassegrain, does not give you a huge advantage over (say) a 60 mm refractor, but it allows you to estimate the phase percentage to a greater degree of accuracy.

Fig. 4.4. Venus photographed at 77× magnification.

Fig. 4.5. Venus photographed at 231× magnification.

Figures 4.4 and 4.5 show Venus photographed with a Maksutov–Cassegrain at 77× and 231× magnification, respectively. Apart from Fig. 4.5 suggesting some cloud features visible in near ultraviolet light, it definitely suggests a smaller apparent phase than Fig. 4.4.

Under very fortunate circumstances, Venus can actually be seen at or near inferior conjunction if it passes 5° north of the Sun. If it passes 5° south of the Sun, it is visible in the Southern Hemisphere. Many have seen it about a week before inferior conjunction from England. Some people have claimed to have seen the crescent shape with the unaided eye at the time. Through even modest binoculars at this time, the crescent shape is unmistakable, and you may well notice two things. First, the crescent shape can be slightly different from the Moon, as the sunlight reaches some of the "dark" parts of the planet via the atmosphere. This is a bit like how twilight on Earth would look like from the Moon. Sometimes, also, the dark part looks a bit like earthshine on the Moon. This is called the *ashen light*. This is not caused by reflected earthlight, as Venus is always at least 100 times further away than the Moon. Instead, it is caused by sunlight being scattered by the Venusian atmosphere. Unlike the Moon, Mercury and Mars but like Jupiter and Saturn, you cannot actually see the surface of Venus. If it had had either a transparent atmosphere or none at all, watching Venus would have been a lot more interesting than it is. All you can see are the cloud tops, the phase shape, and the ashen light. The clouds are usually bright yellow/white, and sometimes people with eyes sensitive to ultraviolet light can see faint markings. They certainly show up in photographs.

Another effect caused by the Venusian atmosphere is the *Shroter effect*. Venus, theoretically, shows a half phase when it forms a right angle between the Sun and the Earth at maximum eastern or western elongation. In practice, it usually occurs when the predicted phase should be about 47%. Maximum eastern elongation occurs about 2 months before inferior conjunction, and maximum western elongation occurs about 2 months after. Although visibility is affected in a similar manner to Mercury, Venus is much brighter and further from the Sun. This means that Venus is always visible at maximum eastern or western elongation, even if it is not favorable. When it is near superior or inferior conjunction, it becomes difficult if not unfavorable. It is not recommended to make a specific trip abroad to see Venus, when it is invisible from England, but it is worth taking something to view it with when traveling to a more southerly location.

If maximum eastern elongation occurs at or around March (or September from the Southern Hemisphere), Venus can actually be seen in the afternoon before sunset. It helps to scan the sky with binoculars first, taking care not to look at the Sun! To follow it over successive days, stand in the same place and locate it against certain local landmarks. Good examples are trees, chimneys, and telegraph poles. Similarly, Venus can be seen in the morning after sunrise if maximum western elongation occurs at or around September (or March from the Southern Hemisphere). Finding Venus in daylight without optical aid is a suitable challenge for people who like to find difficult objects.

When near superior conjunction, Venus makes almost agonizingly slow progress in its position relative to the Sun and Earth, and there is no reason to check it more often than once a month, as the phase change is very slow. It is really best to pay attention when it is between maximum eastern and western elongation, where its phase is changing rapidly and there is a chance of seeing its atmospheric effects.

Mars

Fig. 4.6. Mars (photograph by Nick Howes).

If you measure the time Mars takes to go from one opposition to the next or one conjunction to the next, it is 784 days (about 2 years and 2 months). Since Mars is a lot closer than the other superior planets and consequently orbits the Sun more quickly, its synodic period is much longer. Of all the planets Mars has stirred the imagination the most with legends of intelligent beings that built canals and are likely to invade us! Maybe the redness of the planet and its association with the Roman god of war suggest that any inhabitants are more likely to be hostile than not. Although modern science would suggest that any life on Mars is likely to be extremely primitive, we are still excited at the prospect of finding life or even evidence that it may have existed at some time in the past (Fig. 4.6).

Yet for most of the time Mars takes to complete its journey around the sky, it is an unexciting object. At conjunction, it is less than 4 arcseconds in diameter and appears as a star-like point of light in binoculars. To be able to recognize, it as a planet and not a star, you need about 150× magnification, the actual figure being dependent on things like visibility, the aperture of your telescope, and the quality of your eyesight. You will notice that this book uses such qualifying statements because observing Mars is not an exact science. Of all the planets, any statement anyone might say about what you can see on Mars is least likely to be true. Anything said or written is for guidance only and not to be taken as a hard fact. There are so many times things have either worked or not worked while viewing Mars that the best rule to follow is that there are no rules. It does not mean, however, that there are not any patterns that we can learn from and use as a starting point.

You can probably guess that if, for most of the time, Mars is an unexciting object that means that for some of the time it must be exciting. Unlike Venus, it is never exciting in binoculars. It can appear as a disc, rather than a star-like point source of light, but you can never see any detail on its surface. It simply appears as a bland orange-red disc with no features, even at a favorable opposition. Earth has a slightly elliptical orbit, but that of Mars is even more so. Mars is closest to the Sun (about 128 million miles) in late August and furthest (about 160 million miles) in February. If an opposition occurs in late August, Mars can reach a magnitude of about –2.9 and an apparent angular size of 25 arcseconds. However, a February opposition produces an apparent angular size of less than 14 arcseconds. It is this and how high Mars gets above the horizon that determine what you are able to see and what you need to see it.

When Mars is in conjunction with the Sun, its disc is so small that no amateur equipment will see any detail on its surface, and even the Hubble Space Telescope photographs are unimpressive. If you look at it, all you will see is a disc, and you will probably need at least a 100 mm aperture telescope to see that. As it approaches quadrature, its phase shrinks to about 87%. Through a 60 mm refractor, it appears “a bit funny,” while through a Maksutov–Cassegrain it shows up like a gibbous Moon, although you normally need at least 120× magnification to see the phase clearly.

At quadrature, Mars only has a maximum apparent angular size of 8 arcseconds. It has been written more than once that amateur telescopes are unable to see any detail on the planet when the apparent angular size is less than 10 arcseconds. Where this “adds up” scientifically is that a 60 mm refractor has a “Dawes Limit” of 2 arcseconds. This is the minimum possible resolution that can be achieved with the telescope under perfect conditions. The term is normally used in relation to double stars but also applies to resolving objects on the surface of an object such as a planet or moon. A 127 mm telescope has a Dawes limit of just under an arcsecond. In theory, increasing the aperture to, say, 250 mm, would result in a Dawes limit of half an arcsecond. In practice, the properties of Earth’s atmosphere result in a resolution of less than an arcsecond being all but unachievable with amateur telescopes. So if Mars is 10 arcsec across, you can see ten dots across, or about 86 separate color "cells" with a 127 mm telescope.

Once Mars gets just close enough to appear as anything other than a red disc, you will see some green regions, although they sometimes appear gray. Exactly how soon before opposition you can see them depends on several factors, but steady seeing, high elevation, and a telescope over 100 mm aperture all help. Quite understandably, these green regions were thought to be vegetation, especially as they have been seen to change shape in professional telescopes. Unfortunately, they are simply areas of rock and dust that appear a different color from the usual orange/red. At first, you may only see one or two green/gray regions, but as Mars approaches opposition, they may resolve into four or five. Also, the polar ice caps may appear. They appear rather different as the southern ice cap actually consists of "dry ice" – frozen carbon dioxide – and is more or less a permanent feature with sharp boundaries. It may be seen to shrink and grow with the seasons. The northern ice cap is mostly water ice and is less distinct, appearing more as a diffuse lightening of the surrounding area, rather than a sharp feature like the southern one. Either ice cap may be tilted away from Earth at any one time. Unfortunately, chromatic aberration can make the ice caps appear in error.

If you follow the features by looking at them at about the same time every day, they will change slightly. Mars takes about an extra half hour to rotate than Earth, so it presents a slightly different face to us each day. Dust clouds obscure some features, or even sometimes the whole planet. This can be rather irritating, and it is easy to think that something is wrong with the seeing conditions or even your telescope.

If you are very lucky, some of the green or gray regions may appear as straight or curved lines, rather than the usual triangular or elliptical areas. Although these do not appear in pictures taken from space, with the exception of one deep valley, they certainly appear on several drawings made using larger telescopes at the turn of the century. They have been seen in a 127 mm Maksutov–Cassegrain on several favorable occasions. It was believed that they had been constructed by intelligent beings to transport water around the planet. This led to them being known as "canals" and spawned decades of popular science fiction.

It is worth noting that most sightings of the "canals" were made using good quality amateur telescopes within a month of the most favorable opposition since telescopes were invented. Both ice caps were visible, although the northern one became less distinct after opposition. Most viewings were best at 240× magnification, although on a few occasions, it was possible to obtain more detail at 300 or 480× magnification. Sometimes, it was only possible to get a reasonable image at 60× magnification, and for others one could use a 120 or 150× but not 240×. At the lower magnifications, the green/gray areas tended to merge together, and it was normally necessary to use at least 100× magnification to see either ice cap.

At the 2001 opposition, Mars was at an unfavorable declination from England, and this author used a 60 mm refractor . However, I did have some modified achromatic eyepieces, as mentioned before.

It was only possible to resolve one or two darker regions at a time, and it was not possible to see any ice caps. As Mars was a lot nearer the horizon, sinking to 27° south soon after opposition, it was only possible to use 96× magnification and that anything lower revealed no detail at all. Sometimes it was possible to use 192× or 240× magnification, and the darker regions showed a bit more shape.

Although I had always intended to try the refractor out at the 2003 opposition, I was actually forced to use it (instead of the Maksutov) by back trouble. I first tried the 76 mm catadioptric at 30 and 60× magnification. The image was very blurred, and although some darker regions were visible, the view was less encouraging than the 60 mm refractor at the 2001 opposition. Using 32× magnification with the refractor just to find Mars, it was surprising to see that some of the tiny disc was darker than the rest. Excitingly, the dark areas were noticeably clearer at 96× magnification. At 240× magnification, the view was not much worse than with the Maksutov–Cassegrain, and on several viewings the southern ice cap appeared! This was a great result for a telescope costing under £100 new, although £60 worth of eyepieces did not do any harm.

To sum up, there is no need to stay indoors or ignore Mars if you only have modest equipment. Especially near a favorable opposition, even a 60 mm refractor will show the dark areas and might just show an ice cap. A larger telescope will show more detail and support a higher magnification, and an apochromatic refractor or Maksutov–Cassegrain will give considerable improvement over a standard model.

The final point concerns the moons of Mars, Phobos, and Deimos. Occasionally, several faint star-like objects are visible near Mars, and Phobos is well within the range of a telescope of 100 mm aperture. The problem is that Mars is so much brighter than they are that it drowns them out. You need absolutely clear seeing and need to get Mars just out of the field of view (difficult) or use an occulting bar (specialized).

Jupiter

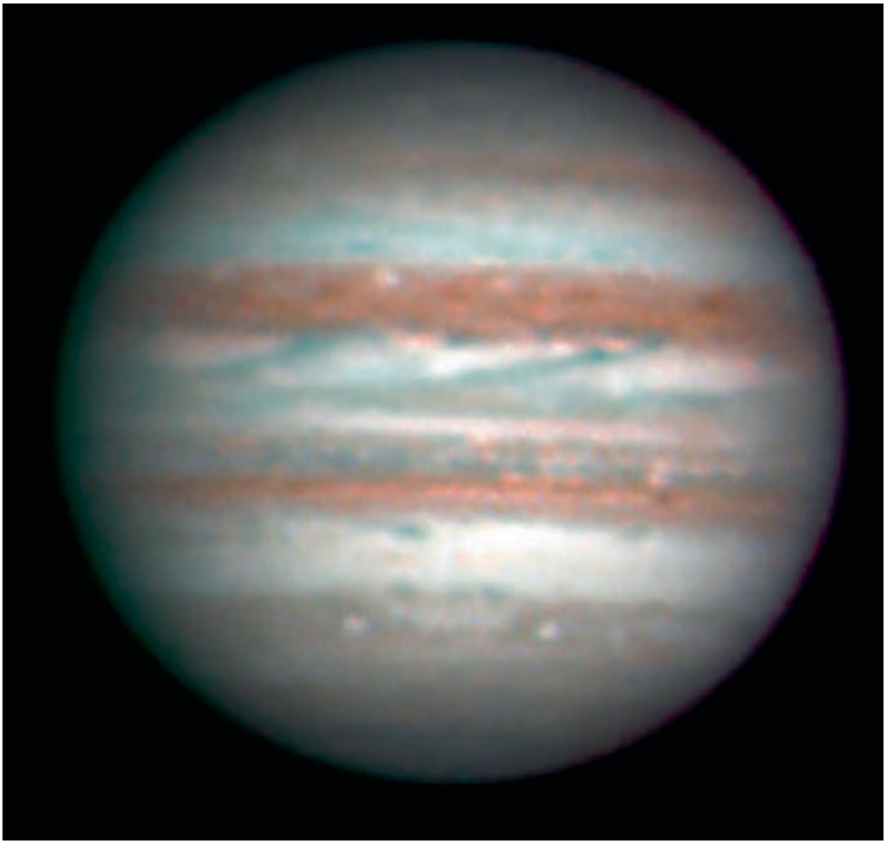


Fig. 4.7. Jupiter.

The planets described so far and indeed the remainder (with one exception) spend all or most of their time either being invisible or a disappointment. Jupiter has a little bit of something for everyone. Although when Mars or Venus are close to Earth or Mercury is visible at all, people will make all sorts of sacrifices to see them, including missing favorite television programs or nights down at the local bar. Not so for Jupiter. It gets taken for granted until such time as it starts to sink into the evening twilight and becomes more difficult, and we have our annual regrets at not paying it enough attention (Fig. 4.7).

Jupiter provides some easy, meaningful viewing on nights when nothing else is worth looking at, and it provides a few challenges for those who are achievement-driven, like those who like hunting down galaxies with small binoculars. It is invisible around the time of conjunction and for about a month on either side. The exact period of invisibility is dependent on the angle the ecliptic makes with the horizon, just as for other planets. When it is near conjunction, it has a magnitude of –1.8 and an apparent angular size of about 32 arcseconds. That it is so large and bright despite being around 600 million miles away at conjunction is due to its enormous actual size. Its volume is equivalent to about 1,300 Earths. At that distance from the Sun, it takes 12 years to make a complete circuit. When finding it, this rate of motion translates to moving about one constellation along the ecliptic every opposition. Each opposition is about 1 year and 1 month after the previous one (synodic period). Even at its faintest, Jupiter is noticeably brighter than Sirius. The only other object it can possibly be confused with is Venus, but, with practice, you will learn to notice just how much brighter Venus is. One of the Jupiter's challenges is seeing it in daylight.

At opposition, Jupiter is about –2.7 in magnitude and 48 arcseconds in apparent angular size. This increase in brightness and apparent angular size does not significantly improve the view. Indeed, like Venus, sunglasses will reduce the glare. Unlike Mars, there is not a great deal of difference between favorable and unfavorable oppositions, and you would not notice it in an amateur telescope. What is significantly different is the brightness of the moons. If you start off with modest binoculars you can certainly see the two brightest, Ganymede and Callisto, and people have seen Ganymede with the unaided eye! So there is the first challenge. It is a lot easier when Jupiter is near opposition, when its magnitude reaches 4.3. It is only its closeness to Jupiter that makes it difficult. Callisto is actually easier, at least some of the time, as its orbit takes it further away from Jupiter. Io is a tough one. It is so close to the planet that it only takes about 2 days to orbit. The other moon visible in amateur equipment is Europa, which is the faintest of the four. Jupiter has many more moons, but the rest are too faint for amateur telescopes.

It can be quite difficult to see all four in binoculars at the same time. They frequently pass behind or in front of Jupiter or are so close that their distance cannot be resolved. It is difficult to see all the four in 20 × 50 mm binoculars. A pair of 15 x70 mm binoculars give much better results and also show the flattening effect of Jupiter's rapid rotation, appearing elliptical instead of circular. This is the limit of what can be seen by hand-held binoculars on Jupiter. One thing you can do is to draw the positions of the moons, then draw them again a few hours later. In winter you can do this before dinner and again before bedtime. You can also do it mid-evening and early the next morning before you go to work or school.

Fortunately, you do not need anything much bigger to see detail on the surface. Just about any telescope, or even some types of large binoculars, with 30× magnification or higher, will show the two main cloud belts. Exceptionally, it is possible at 24×, but 30× is more normal. The rest of the planet appears a uniform dull yellow. With modest equipment, say 80 mm aperture or under, you can sometimes see what appears to be a third band.

On nights of very good seeing at high magnification (150× and higher) and if it just happens to be near the center of the planet as seen from Earth, you can see the Great Red Spot. This is a storm that has been raging since before the telescope was invented. Over the years, its color has faded to the same reddish brown of the equatorial belt, so it just appears as a bulge in a belt. It is quite easy to do a computer-based drawing, or do a sketch and scan it in.

Here you can see the moons changing positions, and sometimes the relative thickness of the equatorial belts may change. Once you increase the magnification to 60× or higher, the moons have a "pearl-like" appearance, showing tiny discs, and no longer appear star-like. This can be difficult to convey in these types of drawings. After a while, you can even learn to tell which moon is which. Ganymede is the brightest, Callisto is almost as bright and can be confused with Ganymede, but if one seems a few Jupiter diameters away, it has to be Callisto, as no other moons can be that far away. Io and Europa are closer in brightness than Ganymede and Callisto, with Io being the brighter. Again, it is the distance from Jupiter which often gives away the difference, as Io is very close and Europa can be rather further away.

So with a small telescope you can follow the dance of the moons and even learn which is which; you can see the main cloud belts; and, once in a while, see the Great Red Spot. This is quite enough to keep you interested for a few years. It will also interest people who have never seen a planet through a telescope before.

Now there are some interesting claims about what can be seen through a 90 mm Maksutov–Cassegrain. Several owners have claimed to see both the moons and their shadows cross the planet. It is certainly possible to see this on several occasions with a 127 mm Maksutov–Cassegrain. This author has been privileged to see Jupiter in various telescopes up to and including 20 inches. The best view was in a 4-inch apochromatic refractor. The next best was in a Maksutov–Cassegrain. With these telescopes you start to get a sense of what Jupiter is all about. No longer do cloud belts appear as straight lines; they have jagged edges, and the areas in between become shaded rather than a uniform background color. On a good night they even show patterns. Jupiter does not appear as detailed as it does in the Hubble Space Telescope or space probe pictures, but you start to get a sense that you are not far away. Large reflectors also give some very nice views, but it seems that apochromatic refractors and Maksutov–Cassegrains have a clear edge. To record Jupiter properly you need either better drawing skills or the ability to take guided exposures with a camera.

Under poor conditions, the equatorial belts can still be seen with a small telescope, but they become difficult, even with a slightly larger one, in twilight. To see Jupiter in its full glory, you really need a dark sky and for it to be clear of the horizon. Also, you need a magnification of at least 150×.

Saturn

Fig. 4.8. Saturn.

Saturn for many is a personal favorite. The really distinguishing feature is the ring system. Although other planets have rings, it is only Saturn that reveals them in amateur equipment. It is debatable as to what is the lowest specification equipment in which you can see them. A pair of 7 × 30 binoculars show that Saturn is not quite round. In 15 × 70 binoculars they are somewhat clearer. We now know, thanks to telescopes, that the "teapot handles" on either side of Saturn are rings. Galileo noticed them but was unable to recognize them for what they were (Fig. 4.8).

Once you get to about 30× magnification on even a modest telescope, you can see the gaps between the rings and the planet, showing what they are. Unfortunately, unlike Jupiter, a modest telescope does not show any detail on the planet's "surface." If you are lucky, you may see Titan, Saturn's largest moon, which is about an 8th magnitude, well within the range of 70 mm binoculars.

Saturn's appearance does not vary much between conjunction and opposition, its range of apparent angular size being between 16 and 19 arcseconds. Its brightness varies by little more than half a magnitude from conjunction to opposition. What also affects Saturn's magnitude are its rings. Saturn is at its dimmest when they are edge-on and brightest (maximum –0.5) when they are 27° open. They open and close over a cycle of its orbit, which is 29 years. Even compared with Jupiter, Saturn crawls around the ecliptic, taking about 2½ years to cross each constellation. Once you have found it once, you do not need a lot of effort to find it again. It is noticeably brighter than any stars close to the ecliptic.

Although no planetary detail can be seen with small telescopes, the rings look impressive enough. They impress many beginners worldwide. On good nights, the "Cassini Division" is visible, which is not really a gap at all but simply a part of the ring made of darker material.

What Saturn also has in common with Jupiter is that a larger telescope, especially an apochromatic refractor, will bring out the detail. Not only cloud belts but shading in between are brought out. Saturn's features are not as prominent as Jupiter's and require high magnification and a sharp eye. Quality telescopes also bring out other features, such as the shadow of the rings on the planet and the shadow of the planet on the rings. These are best seen around quadrature. Also, subtle shading can sometimes be seen on the rings themselves.

Although an apochromatic refractor or Maksutov-Cassegrain is better for bringing out detail on the planet, pound for pound a large reflector is better for seeing the moons. A Maksutov–Cassegrain shows up to four, but a 200 mm Newtonian reflector that costs about the same money shows up to seven! This just demonstrates that a single telescope is not the answer. The most curious moon is Iapetus, which has a 2-magnitude difference in brightness between eastern and western elongation. To find out which moon is where, you need to use a planetarium program. Jupiter's moons are well within the range of even a small telescope, but Saturn's can be affected by any degradation of viewing conditions or twilight. They are an interesting challenge to which few pay enough attention. The usual excuse is that the rings are too much of a distraction.

The Outermost Planets

After Jupiter and Saturn, the outermost planets are somewhat of a letdown. The nearest and brightest is Uranus, which is about 5.7× magnitude and just over 3 arcseconds apparent angular size. At the time of writing and for a couple of decades afterwards, it was too far south to be seen without optical aid from northern temperate latitudes, except from the best dark sites on the clearest nights. You will need a detailed star chart to find it, and you should follow the monthly magazines and wait until it is somewhere near something brighter and well known, such as another planet.

It takes 84 years to orbit the Sun, so unless you see it for the first time at a very young age, you will not see it complete its path around the zodiac in your lifetime. No amateur telescope and very few Earth-based telescopes can see any detail on Uranus. At high magnification (150× and higher) you can tell that it is a disc and therefore not a star. The only satisfaction is to say that you have found it and crossed it off your list of things to see before you die.

Now this applies even more to Neptune. Although it is almost identical in size to Uranus, it is even further away and has an apparent angular size slightly larger than Jupiter's moons. At a magnitude of about 7.8 it needs binoculars to see it at all and, at the time of writing, was even worse positioned for observation from the Northern Hemisphere than Uranus. Recently it passed close to Mars, so it was easier to find than normal. It takes 164 years to orbit the Sun, so it has not even completed an orbit since discovery. It needs even higher magnification (200×) to see a disc than Uranus.

Although both Uranus and Neptune have moons, they require quite substantial amateur telescopes to see them. Examples are Fig. 4.9, which shows Uranus, and Fig. 4.10, which shows Neptune and Triton.

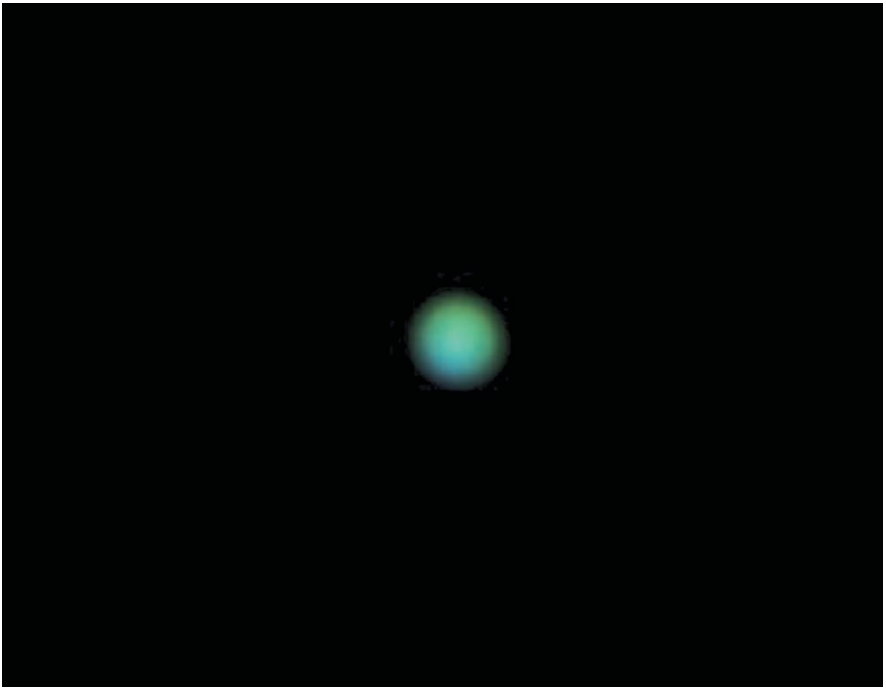


Fig. 4.9. Uranus (photograph by Nick Howes).

Fig. 4.10. Neptune and Triton (photograph by Nick Howes).

How to Get the Most from Planetary Viewing

The easy answer is to point you at the equivalent section of the chapter on lunar viewing, as a lot of it is similar. Many of the rewards and challenges are, indeed, similar, as you can use lunar filters to view Venus and sometimes Jupiter as well. One well-known saying is that you can see more detail on the Moon with the unaided eye than you can on a planet with an amateur telescope. As planetary viewing and photography is more demanding, equipment needs to have larger aperture and high optical quality.

Within the limitations of your equipment and what you can reasonably afford to add to it, it is best to plan your viewing in advance. Monthly magazines are a good source of knowing where the planets are so that you have a reasonable chance of a good result. Jupiter and Saturn are not as affected by Earth/planet distance as are the inner planets, but they are greatly affected by declination and subsequent elevation above the horizon. Viewing prospects for Jupiter from the Northern Hemisphere are not good for the next 3–4 years (at the time of this writing), and Saturn has about one more year in the celestial Northern Hemisphere. Mars spends most of the time outside the range of amateur telescopes, and you really need to be on the ball to see it around opposition. Mercury can be found, but its main disadvantage is that any cloud can obscure it or render it too faint, unlike Venus, which can be seen in the most appalling conditions.

For Further Reading

The following relevant books are available from Springer:

- *How to Photograph the Moon and Planets with Your Digital Camera* by Tony Buick.
- *Transit When Planets Cross the Sun* by Sir Patrick Moore and Michael Maunder.
- *Lunar and Planetary Webcam User's Guide* by Martin Mobberley.

CHAPTER FIVE

Viewing Other Solar System Objects

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-0-387-76470-2_5,

Meteors

To view meteors, you need patience, although clear skies, luck, and a calendar can also be of great help. Although meteors have been noticed since prehistoric times, it has only been relatively recently that we have discovered their true nature. Most meteors are caused by cometary debris, although some of the larger ones originate from asteroids. Figure 5.1 shows an example against the stellar background.

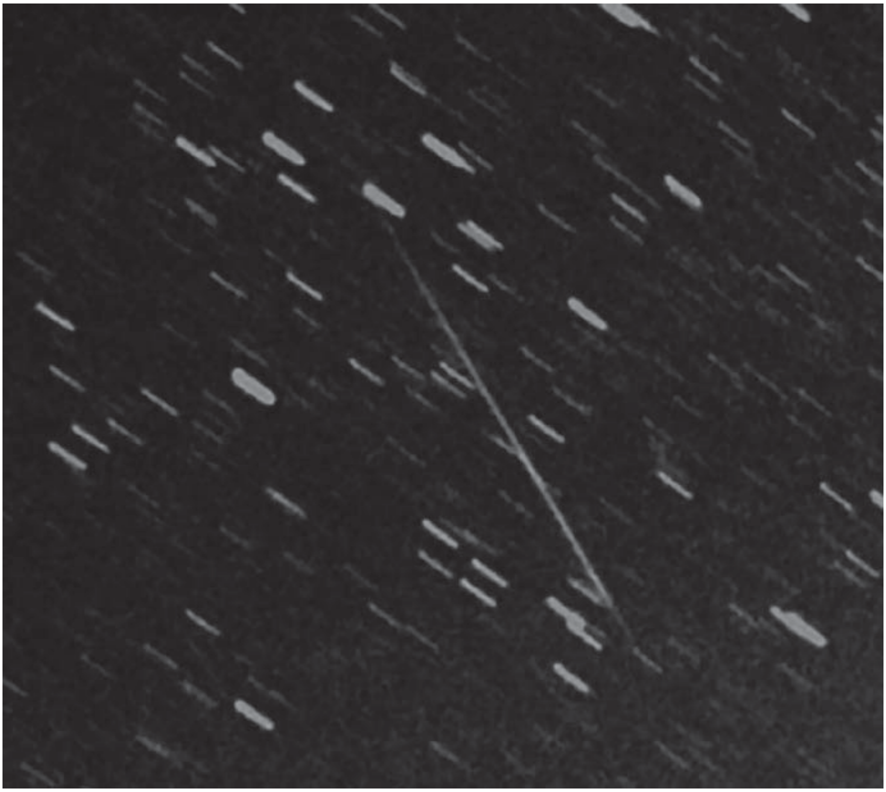


Fig. 5.1. Meteor (photograph by Nick Howes).

Many of the meteors people have seen were discovered by pure chance, such as during observing sessions of the night sky or while walking after dark. Indeed, should you happen to stare at the night sky for about an hour, on average you should see three meteors. The average background, or *sporadic*, rate for meteors is ten per hour, but, as we can normally see only about a third of the sky at a time, an individual observer will pick up three. Even though there is no guarantee of success, on some nights it is possible to see ten in a given hour. It is just down to luck and patience.

Sporadic meteors are caused by small debris spread around the Solar System. The general term for the objects that cause meteors is *meteoroids*. Most of this debris was left by long extinct comets, but some of it is caused by collisions between asteroids and even planets. Such debris is much larger in size than cometary debris and can, in extreme circumstances, be large enough to survive being burnt up in Earth's atmosphere and land on the ground. Objects that reach Earth's surface are called *meteorites*, and their collection is a sub-branch of astronomy. Rocks originating from the Moon, Mercury, Mars, and Venus have been identified.

Visually, the meteors resulting from the entry of large objects can be spectacular and have even been seen in daylight. Objects as large as small asteroids have been known to reach the Earth's surface, causing large crater formation and massive damage to the environment. Indeed, the potential danger to life was the main driving force behind many asteroid search programs.

Very bright meteors caused by asteroidal debris are often seen by the non-astronomical general public. The chances of an individual astronomer seeing one, though, are remote, even if that astronomer can maintain a lifelong 24 hour watch. That is because the location will vary. The best chance of detecting a rare fireball is by looking at the "fish eye" all sky cameras and playing the replay at a fast rate. This method can also detect ordinary sporadic meteors as well. Most sporadic meteors are caused by cometary debris, and, though not exceptional, they are often bright enough to be seen clearly.

So far, it seems that meteor observing is a branch of astronomy that is best left alone. Although it is certainly true that lunar and solar observing require a lot less patience, if you wish to cross off seeing a meteor as something you want to do before you die or lose your eyesight, there are easier ways of seeing one than just waiting around for sporadic meteors.

Meteor Showers

Fortunately, there are several major meteor showers each year and a few minor ones. They occur when a meteoroid stream meets Earth. Meteoroid streams usually follow the orbit of a periodic comet, or indeed one that has broken up or expired. One meteoroid stream follows the orbit of the asteroid Phaethon, which may well be an expired comet, with its volatile materials having been exhausted and left a rocky core. Like the comets themselves, the orbits of the meteoroid streams can be perturbed by the gravity of planets. This can bring the streams to an orbit that intersects Earth or moves them away.

So if we wish to see a meteor or multiple meteors, do we just wait for the predicted time for the meteoroid stream to reach us and sit back and watch? Unfortunately, no! Apart from the possibility of cloud, especially if you live somewhere that gets lots of rain, there is the possibility that the peak of the shower will occur during daylight in whatever part of the world that you live. Indeed, according to Murphy's Law, if you move to another country, the best show will occur in the country that you have just emigrated from! Then there is the sheer unpredictability of the meteor showers themselves.

Conventional wisdom tells us that meteoroid streams spread out over a few hundred miles in width and the meteoroids are spread around the orbit. There should be a few meteors at the start of the shower, a lot more at mid-shower, and it then should tail off. Showers can last about 2–3 weeks. What happens in reality is that the meteoroid streams are usually most dense around the time that the comet crosses Earth's orbit. In fact, as most comets have orbits somewhat inclined to the ecliptic, the chance of a collision with us is reduced. Also meteoroid streams are depleted during close encounters with Earth and other planets, and their orbits may vary slightly. The end result is that you can look up the time of the peak activity and stare at a quiet patch of sky for hours on end!

Observing Recommendations

To start with, be prepared that meteor observing is potentially a great challenge, but its unpredictability is part of the interest. For a first attempt to observe a shower, it is best to watch one of the more reliable ones. There have been many occasions where astronomers have stared at a quiet space of sky for half an hour. Yes, according to Murphy's Law, there would be a storm of 1,000 meteors per hour after the viewer goes indoors.

One way around the boredom caused by staring at an area of sky is to observe in groups. Many astronomical societies organize meteor storm watches, the most popular meteor storm being the Perseids during August, when the warm weather in the Northern Hemisphere makes the whole experience rather pleasant. Just in case of zero or low activity, societies usually bring telescopes and binoculars as well. To see meteors, though, you do not need anything apart from your own eyes, and using any optical aid will more likely harm than enhance your view.

Apart from relying on other members to organize events, the monthly magazines will give details of upcoming meteor showers and the time of the predicted peak. It is no use relying on data from the previous year, as leap year adjustments and variations in the meteoroid stream can render such data inaccurate. In theory, you can do a Web search. It is optimistic to start looking for occasional meteors at the start of a predicted shower, but glancing in that general direction while out observing other things can often bring rewards. If you notice an early meteor, dedicate a quarter of an hour for a second one. It is not usually until 2 or 3 days before the peak that it is worth dedicating half-hour slots, unless you see more than one in a quarter-hour period.

The most prominent meteor showers are the Perseids, which peak between August 11 and 13 and the Geminids around December 14. Although the highest known rates are for the Leonids, around November 17, these are not expected to reach storm levels again until the 2030s. Outside of exceptional activity every 33 years, normal annual activity is quite low.

The part of the sky where the meteors seem to originate is called the *radiant*. In practice, meteors actually start about 5 or 10° from the radiant, and then continue in a direction straight away from it. This is why conventional wisdom suggests that you should not look straight at the radiant but away from it. This technique is OK when observing in groups, since a group member can shout the name of their sector when a meteor appears. Fortunately, some meteors leave persistent trails, so the other members have time to glance in the right direction. Although watching for sporadic meteors with people of limited conversational skills is not recommended, a common method is to have 4 members of a team facing each point of the compass. For team observing, there is often a nominated recorder who writes down the details of the meteors observed, and he or she will swap with another team member after a certain period, such as a half hour. When observing alone, try to focus on the relevant part of the sky, as it is easy to get distracted.

The Scientific Bit

Although most people who observe meteors are recreational astronomers, rather than wannabee research scientists, there is always the chance that a casual observer or even someone who has set out to observe a known or suspected shower may turn up with something unexpected. If you do, you should send an e-mail to the BAA Meteor Section, or post your findings on an amateur message board. This will help researchers refine their models of the orbits and distribution of meteoroid streams.

There are several ways of recording activity. Using a camcorder to record a shower is a good idea that many have used successfully. Some observers have used long exposure photography with a wide-angle camera lens, and other use a tape recorder to shout out the direction and brightness of meteors. It is through accurate recording that we can gain better understanding of the orbital mechanics of meteoroid streams and avoid those long nights of staring at quiet parts of the sky and going to bed tired and disappointed.

One way those of us who regularly watch the night sky can contribute is to watch for new showers that can be caused by perturbation of existing meteoroid streams or the visit of a new comet to the inner Solar System.

For Further Reading

The following book, published by Springer, contains at least some information about meteors:

- *Observing Meteors, Comets, Supernovae and other transient Phenomena* by Neil Bone

Simply using an Internet search engine on the word "meteor" will reveal a wealth of information. The International Meteor Organization has a Web site that details all of the showers, major and minor, in an annual calendar. Most monthly magazines also give details of upcoming showers.

Comets

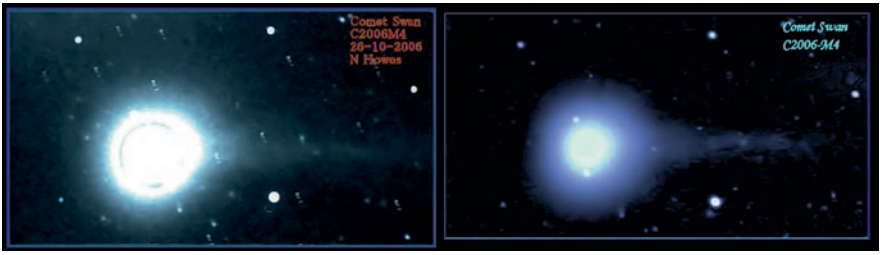


Fig. 5.2. Comet 2006 Swan M4 (photograph by Nick Howes, October 2006).

At the time of writing (first draft in 2006), we were very fortunate to have a bright comet in the night sky. It is shown in Fig. 5.2. Although it was not as spectacular as the bright comets of the 1990s, nevertheless it was not the sort of thing that happens every day of the week. Its brightness would suggest that it could have been visible to the unaided eye from a dark enough sky.

When you mention comets to the general public, they normally think of Hyukutake or Hale-Bopp. When Hyukutake first appeared, many of us thought it was very unlikely that we would see another comet like it in our lifetime. The next year, Hale-Bopp came.

Any sort of naked eye comet is quite rare. If you count 2006 Swan M4 (shown in Fig. 5.2), there have been two visible without optical aid since, the other being Ikeya-Zhang, which was just about visible from a suburban location. Figure 5.3 shows it.

When comets are visible to the unaided eye, they are easy objects. In the case of Hyukutake and Hale-Bopp, the comet tails were over 10° long, so the best view of the whole comet was to be had without telescope or binoculars. Optical instruments could be used to view the coma in a bit more detail. For more modest comets, such as 2006 Swan M4, some sort of optical aid is essential to see anything at all. Indeed, even in 15 × 70 binoculars (considered large by many amateur astronomers), it was very difficult to detect a tail. For observing comets of between 4th and 7th magnitude, binoculars are the instrument of choice. Comets are usually large objects, so the viewing techniques and restrictions make them similar to “faint fuzzies” such as galaxies and globular clusters.

As a comet’s brightness is usually spread out over an area, in the same way that a galaxy’s or globular cluster’s light is, it needs to be about 5th magnitude to be visible to the unaided eye from a dark site and clear

Fig. 5.3. Comet 2006 Ikeya-Zhang (photograph by Brian Woosnam).

conditions, whereas a star's light is concentrated in a single point, so that it can be seen to about 6th magnitude from a suitable location. Unlike galaxies and globular clusters, a comet's brightness varies. When out beyond the orbit of Mars, a comet is faint. Even the brighter comets, such as Halley's, are only a few miles across, and they are not very reflective. When near the Sun, the material sublimates and forms a reflective shroud of dust and gas known as the *coma*, which causes the comet to brighten several times. The other factor that causes a comet to brighten is its distance from Earth. In fact, statistically, there are many more comets that are not visible to amateur equipment (even advanced amateur equipment) than actually are, and many experts would claim that this is a gross understatement.

So the question becomes, "How do you find a comet that is not visible to the unaided eye?" Or even, "How do you know the comet is there in the first place?"

What Comets Are There?

Many people of a certain age will bemoan the "good old days" when you could run without getting short of breath, but there are some advantages to modern life, apart from solar hydrogen alpha telescopes and digital photography. In times gone by, the only way of knowing what was there was the printed word, which was very good at telling you which comets might be visible during a given month, especially the periodic ones that returned at regular intervals, such as Halley's Comet and Encke's Comet. Unfortunately, most periodic comets are faint. Encke's Comet can reach 6th magnitude every few years, and it is visible through binoculars under favorable conditions. Halley's Comet is the brightest but will not return to the inner Solar System until 2064. The problem is that a comet can be discovered and fade from the range of amateur instruments before the next month's magazine hits the stands.

The best place to find what comets are visible is the British Astronomical Association (BAA)'s Comet Web site. This tells you what is there, where it is, and how bright it is. For some of the brighter comets, the Web site provides finder charts or links to other sites. It is best to check the site at least once per week. Although most of the new discoveries are too faint for most amateurs to detect with their instruments, it is best to follow their progress until they reach 8th magnitude or brighter and then observe at any opportunity.

To be quite frank, an 8th magnitude comet seen through 70 mm binoculars is not too impressive. Neither are most 8th magnitude galaxies or globular clusters either. Most of the time, you will see a faint blur where you think the comet should be. It is a bit "seen that, got the T-shirt," and on to the next one. Using smaller aperture instruments is even more difficult and needs clear skies from a dark site.

Comets are capable of throwing up the odd surprise. In late 2007, Comet Holmes was beyond the reach of all but the largest amateur telescopes, but it shed a lot of material and brightened by about a million times. It was even possible to take photographs using a domestic digital camera. It is always worth taking a look, just in case.

Remember, though, that most of the time, there are no comets brighter than 10th magnitude, and you need to refer to later chapters for tips on how to view such faint objects (Fig. 5.4).

Discovering New Comets

Most of us are content to look at the night and/or daytime sky without making any great scientific breakthrough – or are we? Just as there is a chance that someone might catch a record fish by pure chance, there is the possibility that a new amateur with his or her first pair of binoculars might just discover a new comet. Having said that, just as record or large fish

Fig. 5.4. Comet Holmes (photograph by Nick Howes).

are now more likely to be caught by people specializing in that branch of fishing, it is now more likely that new comets will be discovered by design rather than accident, as was the case many years ago.

Hereby is a cautionary tale, and, indeed, demonstrates why Charles Messier is more famous for his catalog (or list) of noncomets than he is for the cometary discoveries he made. As is a habit of mine, I was scanning the sky around Lyra and Draco with my binoculars one day and saw a bright comet-like object. Fortunately, I did not make an idiot of myself by contacting the BAA Comet Section but checked my star atlas and found that my "comet" was none other than the globular star cluster M92! It was not the first time I had ever seen M92, but that part of the sky was unusually clear that night, so it appeared almost a magnitude brighter than I had seen it before.

Now had I not found it in the star atlas, I would have checked the BAA Comet Section Web site to see if its position and description matched any known comets. The next step would be to contact other astronomers to independently confirm its presence and then to stake a claim.

Should you wish to get your name in lights and discover a comet, there are three main ways of going about it:

- Sweeping the sky with binoculars in likely places
- Photographing parts of the sky at close intervals to check for anything that has moved
- Checking the SOHO Web site for signs of sun-grazing comets

When it comes to hunting for comets, it is good news and bad news. The good news is that in the last 20–30 years, there have been a great number of advances in equipment and techniques. The bad news is that there are a lot more people hunting for comets, and a lot are found not by comet hunters but by sky surveys designed to find near-Earth asteroids. The late, great George Alcock discovered several comets visually, using nothing more than a pair of binoculars. Although it is possible to emulate this feat, it is becoming statistically less likely.

Your first instinct when hunting for a new comet would be to scan along the ecliptic in a dark sky. Wrong! This is precisely where the various near-Earth asteroid programs hunt. Anything brighter than about 18th magnitude (and a good deal of fainter objects) will be swept up in no time. Although it is possible that the odd object might slip through the net, the odds are not in your favor.

Apart from the inherent difficulty in finding anything along the plane of the Milky Way, it is also pretty much covered by nova patrollers, who scan this part of the sky.

The ecliptic (or let us say most of it) is ruled out because of the number of professional and amateur asteroid hunters who are already hunting there. Also most comets in that region are short-period, ones whose orbits are in a similar plane to the planets, and most of them will already be known. This leaves the polar regions, which are not covered that well, except by other comet hunters. For those of you who enjoy or have enjoyed more competitive pursuits, astronomy (in the main), is not competitive, but when it comes to finding new objects, you have to view other hunters as competition. Indeed, if you are really determined to get your name in lights, one option is to move to the Southern Hemisphere, where the skies are generally clearer and there is a lot less people looking in the same place.

Long period comets can approach Earth from any direction, although it is more likely that they are within 30° of the ecliptic. In a dark sky, most comets are around 15th magnitude or fainter at the time of discovery, so a 60 mm refractor will just not do the job. Visually, you will need to be looking at least at a 300 mm telescope, but if you have a good mount you can photograph an area of sky. Modern digital photographic techniques allow you to take long exposure photographs to 15th or 16th magnitude. You just photograph the same area of sky a day or two later and check for anything that has moved or was not there before. There are devices called blink comparators that can help you do this automatically. It was one of the forerunners of this technique that was used by Clyde Tombaugh to discover Pluto in 1930. At the time of discovery, most comets will not show any coma or tail and will appear as an asteroid or nova. It is only their orbit that is likely to reveal their true nature.

Fortunately, there is one part of the sky neglected by professional asteroid hunters, and that is the area of sky within 15° of the Sun. Those of you who like to see Mercury will be well-acquainted with the problems of viewing this part of sky, especially from temperate latitudes, such as England and Canada. Apart from moving to a tropical location with little or no cloud, we can rely on some seasonal help. In spring, the ecliptic is well-inclined to the horizon in the evening, and in fall (autumn) it is well-inclined in the morning. These are good times to look for comets (and asteroids) by sweeping with binoculars or taking photographs.

Many comets, especially smaller ones, can slip through the net of professional and amateur search programs because they do not brighten until they are near the Sun. This method of comet hunting has proved productive, even in recent years. The best recent discovery was Comet Bradfield in 2004. Many missed it visually (due to bad weather) but saw it on the SOHO images, during its closest approach to the Sun, which brings us onto the next topic on cometary viewing and discovery.

Now, it could be argued that this topic is against the spirit of the book, which is about using amateur equipment, but it is included because of its relevance to cometary viewing. Judging from the BAA Comet Section Web site, there must be people who are watching for comets on it 24/7, as the same names seem to crop up every time.

The home page of the SOHO Web site is http://sohowww.nascom.nasa.gov/. If you explore the site, you will see the solar image through various instruments, but the ones relevant to cometary viewing are LASCO C2 and LASCO C3. LASCO stands for Large Angle Spectrometric Coronograph. C2 shows the inner corona up to 8.4 million kilometers (5.25 million miles) from the Sun or about 5° field of view. C3 shows 45 million kilometers (29 million miles), or about 16° field of view. Comets have been discovered in both the C2 and C3 images. Comets that reach C2 and avoid detection in C3 are usually very small ones that only become visible when very near the Sun.

The type of comet that is discovered close to the Sun is usually referred to as a *sungrazer*. Indeed, many of them meet a fiery end by falling into the Sun. Most of these comets belong to two groups of comets known as the Kreutz Group and the Meyer Group and are believed to be fragments of much larger comets that have broken up by being pulled apart by the gravity of the Sun or a planet. Indeed, there is much speculation about how small comets can actually get, and some scientists believe that Earth is being bombarded constantly by house-sized comets. Small comets are only likely to be discovered away from the near-solar neighborhood if they pass very close to Earth and then will probably be classified (wrongly) as asteroids due to the lack of obvious cometary features. Could a comet be discovered by transiting the Sun? It is possible but statistically extremely unlikely. A tail would not show up at all, and only a very large comet would have a silhouette that would show up and such a comet would be discovered long before it transited the Sun.

For Further Reading

The following books, published by Springer, contain at least some information about comets:

- *The New Amateur Astronomer* by Martin Mobberley
- *Observing Meteors, Comets, Supernovae and other transient Phenomena* by Neil Bone

Simply using an Internet search engine on the word "comet" will reveal a wealth of detail that will take more than a single human lifetime to read. The one site that is worth checking at least twice per week is the BAA Comet Section Web site.

Dwarf Planets

Fig. 5.5. Pluto (photograph by Nick Howes).

The category of dwarf planet is a new one at the time of this writing (fall/autumn 2006). There is a possibility that it may be removed or redefined before you read this book. The discovery of Eris in the Kuiper Belt caused the controversy. Traditionally, Pluto was regarded as the ninth planet. It is shown in Fig. 5.5, and its position is near the bottom left of the picture shown by the two horizontal lines. On discovery, it was believed to be the size of Earth but was later downgraded to 3,600 miles (slightly larger than Ganymede) Observations in the late 1970s revealed it to be even smaller than the Moon. Since 1992, we have known that Pluto is not alone in that part of the Solar System, and the discovery of several large objects in the Kuiper Belt, almost as large as Pluto, brought its status into question. The recent discovery of Eris, which is slightly larger than Pluto, finally relegated Pluto to the new category of dwarf planet.

Although the new category of dwarf planet is confusing to amateur astronomers, and speculation continues about undiscovered objects in the Kuiper Belt that may render Mercury, Mars, and even Venus and Earth as ex-planets, observationally there is little doubt as whether astronomers should go about viewing them.

The first dwarf planet and easiest to view is Ceres. It lies in the main Asteroid Belt between Mars and Jupiter and can reach a maximum magnitude of 6.9 at opposition. This place it on the edge of unaided eye visibility by a sharp-eyed observer from a very dark sky, preferably from a high altitude. Ordinary human beings have to resort to binoculars. Although some people normally use quite powerful binoculars by amateur standards, it is bright enough to be seen through quite small ones, such as a 8 × 25, from suburban skies.

Ceres has been known since 1801, and its orbit is well known; thus, its position can be predicted accurately. As a result, the monthly magazines publish finder charts when it is near opposition, which is the best time to look for it.

Visually, however, Ceres is incapable of stirring the imagination. It never shows more than a point of light, hence William Herschel's description as "asteroid" or star-like. Unlike Jupiter's Galilean moons or Titan, it never shows a disc in amateur instruments and does not show surface features particularly well even in advanced professional ones. It is an object to tick off the list of things to do and get the T-shirt, rather than something to be enjoyed for its aesthetic beauty.

For the record, Ceres is about 600 miles in diameter and is thought to be composed of a rocky core, covered by ice.

The problem with both Pluto and Eris is their extreme distance from us. Were either of them at the same distance as Mars, they would be visible to the unaided eye and would show a disc in small amateur instruments, possibly showing some surface features in larger instruments. However, their extreme distance means that Pluto is about 14th magnitude and Eris is about 19th. Pluto has been seen in high quality refractors of 150 mm aperture, but Eris will require something right at the top of the amateur range to see visually. Most amateurs prefer to image them using long-exposure photography instead. As well as needing large instruments and/or sophisticated photographic techniques to detect them, there are several background stars that can be confused with Pluto and Eris, so very accurate finder charts are essential and not regularly published in monthly magazines. If you wish to see either of them, you should take the chance soon, as they will recede from us and get even fainter.

Ceres has been recorded as it occulted stars, although this is not a frequent occurrence. Both Pluto and Eris are capable of it, but their apparent angular size makes it much more unlikely.

The chance of even the professional discovery of a new dwarf planet in the main Asteroid Belt is extremely remote. Amateur discoveries in the Kuiper Belt are certainly possible, but with the number and accuracy of the professional search programs discovery of a new comet is far more likely.

Main Belt Asteroids

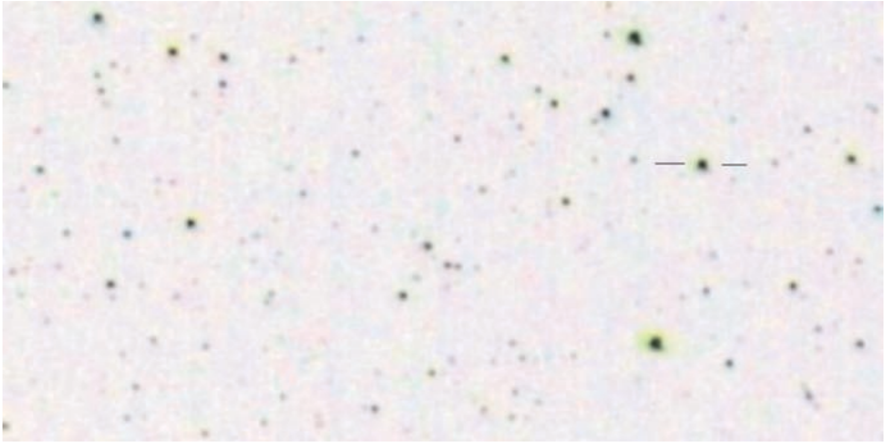


Fig. 5.6. Vesta seen against the star background (photograph by Nick Howes, October 2006).

Even brighter than Ceres, Vesta is the brightest object in the main Asteroid Belt. Because of its brightness of up to magnitude 5.2 near opposition, Vesta has been seen on several occasions with the unaided eye, although most people need binoculars to see it from suburban skies and at less favorable oppositions. Its small apparent angular size makes it impossible to show any surface detail or even a disc in amateur telescopes, and, like Ceres, it is an object to cross off the list of things to see rather than admire. Near opposition, most monthly magazines show the position of Vesta and the brighter main belt asteroids, such as Pallas, Juno, and Hygiea. Figure 5.6 shows Vesta against the stellar background. The two horizontal lines identify it.

The other main belt asteroids are smaller and fainter and can be very irregularly shaped – not that their shape can be determined by amateur instruments. All of those visible in mid-range amateur instruments have well-defined orbits, although they can be perturbed by the gravity of Mars or Jupiter, or even other asteroids. Also in the main asteroid belt are comets. This is really where the difference between dwarf planet, asteroid, and comet gets hard. Any object that has a surface made of volatile material, such as ice and frozen hydrocarbons, will form a coma and tail when close enough to the Sun. An object that is made entirely of these materials will eventually disintegrate completely, whereas one with a rocky core will continue to exist but be regarded as an expired comet. The rocky core will simply continue to appear and behave like an asteroid.

Although the main Asteroid Belt appears to consist mainly of objects that were created between the orbits of Mars and Jupiter, it has also been joined by Kuiper Belt objects that have drifted into the inner Solar System.

An amateur discovery of a faint asteroid is possible, but the professional search programs render this very improbable. Amateur discovery of a change in the orbit of an asteroid is more likely.

Near Earth Asteroids

Some would say that the study of these objects is the most important branch of science, as it may determine the fate of the human race. Large objects have been known to strike Earth during its history, and, as Earth becomes more heavily populated, the chance of major loss of life increases. A major impact at sea is probably worse, as the tsunami it would create and could wipe out many millions of people.

The official definition of a near-Earth asteroid is one that comes within 0.3 astronomical units (AU) of Earth's orbit. There are some large asteroids that are known to cross our path, but their orbital mechanics are well-known, and any danger would have been apparent by now.

Viewing an asteroid that passes close to us is quite different to viewing a main belt asteroid or Kuiper Belt object. There are some known ones that have their details published in the monthly magazines whenever they get close enough to be visible in amateur telescopes, but many can be discovered and be out of range before they get to press. The exception was NY40, which reached 9th magnitude and moved very fast (over a degree per hour) across the night sky around Cygnus.

It is the rapid motion across the sky that differentiates these objects from any others and what gives them their unique appeal. To get the best from this type of object, you should use a small tripod-mounted instrument (such as binoculars) with a wide field of view. Since many of these objects are rather faint, you will need good photographic equipment to record one. Probably the best result would be a guided exposure where the asteroid appears as a trail. It would certainly be possible for an amateur to discover one, but it is more likely to be by accident than design, either while viewing another object over a period or hunting for comets, novae, or other objects. Although there is no definite record of a near-Earth asteroid crossing the Sun, there have been apparent sightings of unknown objects transiting the solar disc. These led to the myths about Vulcan, a planet inside the orbit of Mercury, but, despite many searches and mechanical modeling, nothing has ever been found. The passage of a near-Earth asteroid (unknown in the days that these sightings were reported) would certainly be a plausible explanation.

Kuiper Belt Objects

Like the main Asteroid Belt, the Kuiper Belt is believed to be home to many objects from very small up to over 2,000 km. Indeed, there is even speculation that even larger objects may exist. As even the larger objects usually require a telescope with an aperture of at least 250 mm, the chances of an amateur discovery are somewhat remote. It is safe to say that anything smaller than a dwarf planet in that region (around the orbit of Neptune and beyond) would need a professional instrument to detect.

Other Objects

Having exhausted comets, dwarf planets, asteroids, in the main Asteroid Belt, and near-Earth asteroids, we should have covered everything. For most amateur observing, we just about have, but there are various pieces of debris from around the orbit of Mercury right out to where nobody knows. There have certainly been asteroids or comets (although at that distance it would be hard to know which) discovered between the orbits of Jupiter and Neptune. Some of the moons of the planets are thought to be captured asteroids and comets, rather than created along with the planet, as we believe our Moon to be. Indeed, a moon has been discovered recently orbiting Saturn at a distance of 13 million miles. The Kuiper Belt is thought to extend to about 50 astronomical units (AU) from the Sun, and the Oort Cloud (if it really exists) can be anything up to a light year away. However, anything that far away in the right direction would certainly be influenced by nearby stars, and even something as large as a brown dwarf would be difficult to detect in amateur instruments, assuming you knew where to look. There is certainly speculation that there is something out there in an eccentric orbit that disrupts the inner Solar System every 26–30 million years, which causes mass extinctions of life on Earth. Some think it is some sort of invisible "nemesis" object, such as a brown dwarf or even a stellar mass black hole. Alternative theories are related to the Solar System passing through spiral arms of our galaxy during its orbit and interactions with dark matter of an (as yet) unknown form. What we do know is that there are lots of discoveries still to be made about our Solar System.

CHAPTER SIX

Simple Deep Sky Viewing

You step outside your back door in the heart of the countryside. You can see the Milky Way stretch from horizon to horizon. The Andromeda Galaxy and the Beehive are clearly visible even without binoculars.

Then you wake up. You are living in the middle of a small town. A street light mars the view, and the assorted orange glows from a couple of nearby towns and housing estates do not do anything to help the situation, either. Should you give up astronomy for good and do something else?

No, not at all! Many experienced amateur astronomers only go out on the clearest of nights, but they are missing something. Maybe some astronomers have a bias toward the Solar System, which is influenced by the conditions under which many of us do most of our viewing, such as in the suburbs of a small town. There are several interesting objects that can be enjoyed under bad viewing conditions from bad sites, with modest equipment, although good viewing sites, clear skies, and good quality equipment is not seen as a disadvantage.

You may have heard the term deep sky, which refers to anything outside our Solar System. In many ways it is a good description, because even the nearest star is over a thousand times further away than the Edgeworth-Kuiper Belt, which is generally considered to be the boundary of the known Solar System, with the possible exception of the Oort Cloud. Yet it can conjure up pictures of giant reflectors at dark sites. This gives the impression that deep sky observing is simply too difficult for all but the most expert astronomers, and anyone with less than 20 years' experience,

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a telescope smaller than half a meter across, and no regular access to a dark site should skip this chapter and restrict themselves to the beginners' stuff in the Solar System. No! All you need is a pair of small binoculars (8 × 30) and a suburban sky, where the faintest star you can see with the unaided eye is magnitude 4. The Pleiades (or Seven Sisters) are even known to many non-astronomers. These small binoculars will show about 25 stars on an average night. The nearby (but not so well known) Hyades star cluster is brighter with its stars more spread out and can be enjoyed even on poor nights. There are several other star clusters that show up well, too.

Just about all objects are best seen when they are well above the horizon, due south in the Northern Hemisphere and due north in the Southern Hemisphere. This is called transit, and timing your viewing to coincide with the transit of an object (where possible) will improve your viewing of it. This can often mean arranging your viewing when most sane people are fast asleep. Light pollution and thin cloud is worse for objects near the horizon.

If you point a telescope at most stars, the result is disappointing. We can only see stars because they are extremely bright, but they are so far away that their apparent angular size is (much) smaller than the resolution limit of amateur telescopes. Only a few are within the resolution limits of the largest professional telescopes. However, if you look closely at some stars you may notice that they become two or more, when they only appear as a single star to the unaided eye. Many can be seen with binoculars, but those with bright components and close separations require larger telescopes and high magnification. Some double/multiple stars are a simple illusion caused by a line of sight effect, but many are true binary systems where the stars are physically close together. The most famous example is Mizar and Alcor in the Plough. This is a line of sight effect, but Mizar is actually a true binary star in its own right and can be split with a 60 mm telescope.

Double stars and star clusters such as the Pleiades (known as open clusters) are tolerant of poor conditions and modest equipment. However, there is another group of objects known informally as faint fuzzies. These are usually large, with their light spread out, and include the following:

- Galaxies
- Globular clusters (dense star clusters which look like galaxies in modest instruments)
- Planetary nebulae (remains of Sun-like stars)
- Nebulae

Going back to the first paragraph, faint fuzzies are the objects that are difficult with modest equipment from town centers. Indeed there is only one galaxy and one nebula visible under such conditions from the UK and Canada, and all globular clusters and planetary nebulae are too faint. When you go through the list of objects in the Usual Suspects appendix, you may notice that some faint fuzzies are included and others are omitted. For example, the Ring Nebula in Lyra is fainter than many galaxies in the Virgo Cluster but is easier to see because it can be nearly overhead in late summer from England and Canada but the Virgo Cluster galaxies barely reach halfway up the sky. Some objects of southern declination, such as the open cluster M41 in Canis Major are visible from England but are much easier from locations in the Southern Hemisphere. Similarly, the Ring Nebula is a very difficult object from Australia.

In general, the best thing to decide on whether something is visible or not is to see what you can see with the unaided eye. Most of the stars that appear on the constellation charts are 4th magnitude or brighter, so if you can see most of the major constellations, it is a clear night. If you can make out the outlines of Pisces, Ursa Minor, Draco, Cancer, Capricorn, or Aquarius, you are onto a sure good thing. Stars near the zenith are usually more easily seen than ones near the horizon, usually by a factor of 1.5–2 magnitudes, but when it is clear, it is more like a single magnitude. So what you can see is dependent on how high up it is as well as the viewing conditions. Faint fuzzies are usually harder by a factor of 2 magnitudes, as their light is spread out over a larger area. For example, the Andromeda Galaxy (M31) is magnitude 3.7, but, because it is large, you will see it when you can see a star of magnitude 5.7 at a similar elevation from the horizon.

For the next bit we have to do a little mathematics, but it is not rocket science. Having done a rough guess as to how faint an object you can see with the unaided eye, you:

1. Take the aperture of your instrument (telescope or binoculars) in millimeters and divide by 6 (Example: for 12×60 binoculars this gives 10.)

2. Multiply the number you get by itself. (Example: $10 \times 10 = 100$.) This means that you can see objects this much fainter with your instrument (Example: 100).

3. Take the approximate logarithm to base 2.512 (more of this later!) (Example: 5.)

4. Add this number to the faintest star (or faint fuzzy) you can see with the unaided eye at this elevation and this gives you the limiting magnitude.

(Example: You have seen a star near the zenith that you know to be of magnitude 5.2. Using your binoculars, you should be able to see a star in the same area of magnitude 10.2 or a faint fuzzy of magnitude 8.2.)

OK, so this has condensed a book-worth of mathematics into four paragraphs. The magnitude scale is logarithmic, so an object of magnitude 1.0 is 100 times brighter than magnitude 6.0 and 10,000 times brighter than an object of magnitude 11.0. For smaller steps, you can approximate 2.512 to 2.5, so a star of magnitude 1.0 is 2.5 times brighter than one of magnitude 2.0, 6.25 times brighter than one of magnitude 3.0, 15.6 times brighter than a star of magnitude 4.0, and 39 times brighter than a star of magnitude 5.0.

The idea of dividing the instrument aperture by 6 is based on the assumption that an adult pupil is 6-mm wide under night time suburban viewing conditions, and you square it because the light-gathering power is related to the area of the objective lens (or mirror) and not its diameter.

This should give you a rough guide, but you may find that other factors come into play, such as the quality of your instrument, the central obstruction on reflectors, and errors in approximations. Furthermore, there is a world of difference between seeing a faint fuzzy and actually being able to see its structure. For example, on a good night you can see the galaxies M65 and M66 in Leo, using 70 mm binoculars. Although these are slightly fainter than many of the galaxies in Virgo, they are higher in the sky during spring. Yet, they are indistinguishable from a comet or globular cluster unless you see them through a larger instrument.

Many amateur astronomers specialize in faint galaxies, but without a dark viewing site free of light pollution, an exceptionally clear night, and a large telescope, they are best left to star parties in dark places with a variety of instruments to see them through. There are more than enough easier deep sky objects to keep you entertained. Refer to the Usual Suspects list in the appendix of this book for details.

With the exception of the Andromeda Galaxy, all of the Usual Suspects are in our own galaxy and contain a cross-section of the different types of object. Before considering each type of object and some individual objects in detail, it is worth revisiting the night sky with the unaided eye. As a beginner, you have probably learned how to find the Plough. You know how to use it to find Polaris, the Pole Star, Leo, and Arcturus in Bootes. You have found Cassiopeia on the other side of Polaris to the Plough, not exactly opposite, and you have seen the Square of Pegasus below it. You may also have used Orion to find Taurus, Gemini, Canis Major, and Canis Minor. But then, just how good are your navigation skills? Even if you cannot see the shape of Vulpecula (the Fox) in the summer sky, would you be able to aim a pair of binoculars where it is? Can you trace the path of the Milky Way on summer and autumn evenings? It is surprisingly easy, once you have found Cygnus and Aquila. Yet the winter Milky Way is much fainter and is normally only visible from very dark sites, while the summer Milky Way is often visible from suburban locations. Knowing your way around is an important way to learn how to find things. Of course, you can buy a "GOTO" telescope, where you just key in object identities, but then you lose the spontaneity of simply browsing the night sky with the unaided eye or binoculars.

Catalogs

Most of the brighter objects in the night sky, such as the Pleiades, have names. Some, like the Hyades, only have a name, but many have catalog numbers, too. The most well known catalog is the Messier one. It was compiled by Charles Messier and his colleague, Pierre Mechain, in the early days of telescopic observation, and his idea was not to compile a list of things to look at but a list of things to avoid while searching for comets. There are few references to him ever finding any comets (he found about 11), but his catalog has cemented his place in history. It is a good place to start finding things to look at. He used a 6″" Newtonian reflector in French skies rather clearer than those in many parts of the world today. Some of the more southerly objects are difficult from the United Kingdom and northern United States (one is actually impossible), whereas the more northerly ones are impossible from 35° south, which is where most large centers of population in the Southern Hemisphere are. A challenge that some deep sky observers enjoy is the Messier Marathon. The objective is to see all of the Messier objects in a single night. It must be done from around 45° north of the equator, and the best time to do it is around the time of the last new Moon in March. Real purists claim that you have to do it without using any electronic controls!

As a general rule, the Messier Catalog contains all of the bright deep sky objects. There are some that he missed and others that he simply never saw, as they are only visible in the Southern Hemisphere. The fainter objects in the catalog are rather difficult from suburban locations and need a telescope or binoculars with at least 100-mm aperture and a dark sky. Messier objects are known by “M” and a number, so the Pleiades are also known as “M45.” The faintest object in the catalog is M76, a planetary nebula in Perseus, known as the Little Dumbbell. It is a challenge to see at all and is best seen in late autumn when it is near the zenith. It has a magnitude of 10.1, and it is amazing that it was discovered with quite small instruments. Blink and you miss it.

The second most commonly used catalog is the New General Catalog. Although it contains some brighter objects that Charles Messier missed, it contains a lot of much fainter objects that require telescopes at the larger end of the amateur range. Objects in this catalog are known as NGC and a number. For example, the North America Nebula is known as NGC7000. It does not have a Messier number. Apart from those objects that are obviously bright ones that Messier did not list, you can get a smug sense of satisfaction when you find an object in the New General Catalog that is not in the Messier Catalog. In many star atlases, objects are shown with their NGC number but with the "NGC" letters omitted. If you get into conversation with a group of deep sky specialists, always refer to objects by their NGC number and not the Messier number, or they will think you are a beginner or Solar System specialist.

The other lists you come across are:

- Barnard's list of dark nebulae, identified by "B" and a number.

- International Catalog of galaxies and nebulae not in the New General Catalog, identified by "IC" and a number.

- Patrick Moore's list of objects, identified by "Caldwell" and a number. He could not use "M" for Messier/Mechain, so he used his mother's maiden name instead.

- Melotte's list of star clusters, identified by "Melotte" or "Mel" and a number.

- Abell's list of galaxy clusters, identified by "Abell" and a number.

With two exceptions on Melotte's list and one object without a name, everything described in this book is either in the Messier Catalog or New General Catalog.

Choice of Equipment

In the chapters on the Solar System, we sung the praises of apochromatic refractors and Maksutov–Cassegrains. These can be used for deep sky observation, but they are not the best choice. A 127 mm Maksutov–Cassegrain is a precision instrument, but for the same money you could buy a 200 mm Newtonian reflector on an equatorial mount, and for a little bit more money you could buy a 250 mm Newtonian reflector on a Dobsonian mount. This would give you 2½–4 times more light-gathering power, respectively. This is more useful for deep sky observing than for precision.

The other option concerns the use of "GOTO" telescopes. There is nothing wrong with them as such. The issue is that you have to pay for the wizardry, so if you are on a restricted budget, you get less telescope for the same money. Where they have an advantage is that you can find faint objects very quickly. It can be quite tiresome to spend half an hour finding a faint globular cluster, only to discover that you can see no more detail than you can in binoculars.

Now this brings us to the final general point. Even if you own a small telescope, get a pair of binoculars, however modest. And consider the possibility of buying more than one pair. One pair should be capable of being hand-held, which has a limit of 70 mm for large adults but lower for many people. A lot of deep sky objects are large enough that high magnification is a hindrance. If you come into serious money, 80 mm and larger binoculars are even better, but you must mount them, using a tripod or specialist binocular mount. Again, a "vista" refractor may not allow you to use both eyes, but it does allow you to swap eyepieces to allow a range of different magnifications and fields of view.

What to See

Double Stars

These may not be the most exciting objects visible in amateur instruments, but the great thing is that they are among the most reliable. Most people think that they are the province of telescopes and that none can be seen through small binoculars. Wrong! There are three easy double stars that are circumpolar from the Northern Hemisphere and a fourth one that can be seen through large binoculars. Refer to the Usual Suspects appendix in this book for details.

Apart from that, well yes, you do need a telescope, but not necessarily a fuel-injected, turbo-charged model. One that you can buy in a camera store will split enough double/multiple stars to keep you occupied all night. At the top end of the scale, a large telescope can split closer double stars and those where the components are bright. With one exception, all of these double stars can be split in 60 mm refractors (or 76 mm reflectors).

Figure 6.1 shows Castor as taken through a Maksutov–Cassegrain. Castor is well known, as it lies in Gemini, near the ecliptic. Although being a well-known double star, it is also difficult and sometimes frustrating to

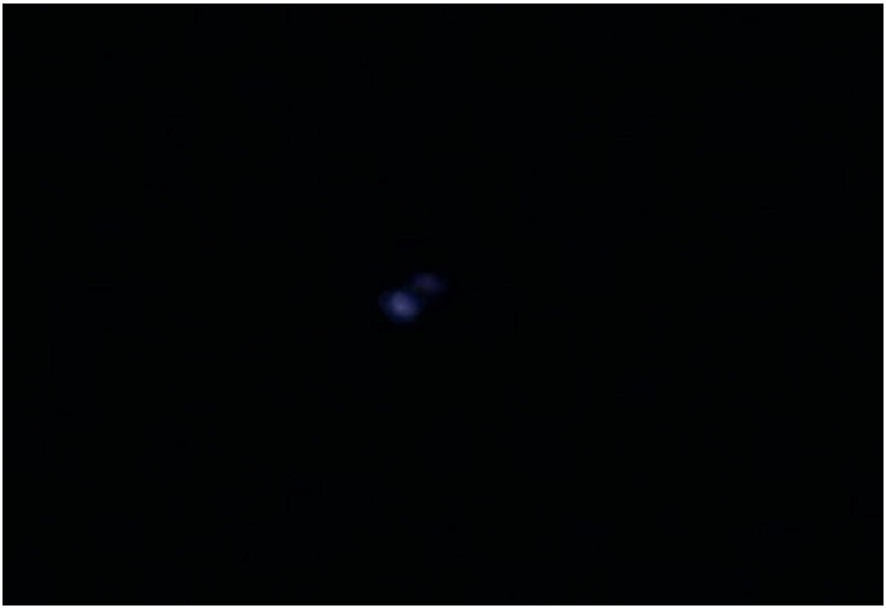


Fig. 6.1. Castor.

split and even harder to photograph. Of all the double stars listed here, it is the most difficult. The brightness of each component and its close separation (2.5 arcsec) makes it a target for those who prefer challenges to relaxation.

Castor is almost circumpolar from northern parts of the UK and Canada but is best placed around January for mid evening viewing.

You can just about manage to get the "peanut" effect in a 60 mm refractor and 76 mm reflector. What is needed is an 80 mm refractor and 80× magnification to get a clean split, and it can sometimes be tough even in a 127 mm Maksutov–Cassegrain. A high magnification, usually 120× plus, is recommended to get a clean split under most conditions.

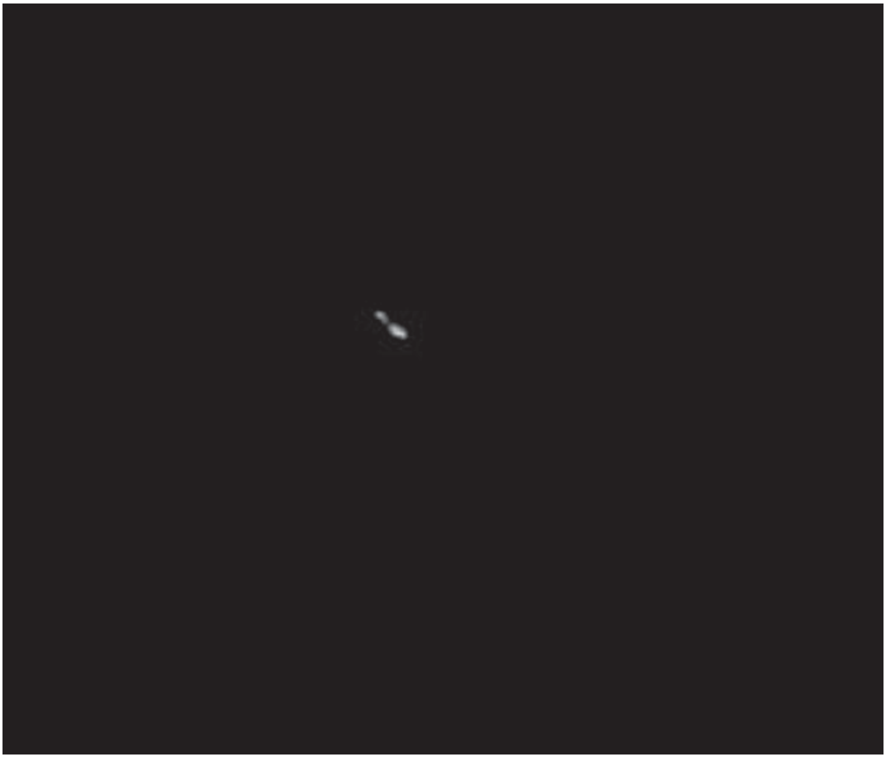


Fig. 6.2. Alpha Centauri.

If you are south of the Tropic of Cancer, you can see Alpha Centauri. Figure 6.2 was taken with a more modest telescope: a Skywatcher Startravel 80 from Campinas, Brazil. The stars have also been split using a 76 mm reflector from Argentina and Chile.

Like planets, double stars need magnification, especially if they are close (or have a small separation). This is normally expressed in terms of arcseconds.

Anything with a separation of 10 arcsec can usually be split with a 60 mm refractor under average to poor conditions. You can get down to about 4 arcsec on a good night. The only restrictions are that faint companions can be difficult to see, especially if the brighter star (or primary) is bright. Examples of these are Regulus and Rigel, both of which have 7th magnitude companions (or secondaries) that are often drowned out by the light of the primary. Moonlight may also drown out faint secondary stars but will not affect brighter secondaries or the separation that can be seen.

If you catch a double star on the limit of splitting, it appears rather like a peanut in shape. The stars can be seen individually but appear to be touching.

Double stars are also good targets for astrophotography, which is a field that is much neglected. The Usual Suspects appendix in this book contains a list of easy objects that can be seen using modest binoculars. The table below lists some of the other multiple stars that can be seen using small to medium telescopes:

Multiple star	Right ascension (h/min)	Declination (deg/min)	Separation (arcsec)	Component magnitudes
Castor	7/34.6	+31/53	2.5	1.9, 2.9
Algeiba (Beta Leonis)	10/8.4	+19/51	4.3	2.2, 3.5
Alpha Centauri	14/39.6	–60/50	19.7	0.0, 1.2
Mizar	13/23.9	+56/22	14.4	2.3, 4.0
Gamma Arietis	01/53.5	+19/18	7.8	4.8, 4.8
Gamma Andromedae	02/03.9	+42/20	9.8	2.3, 4.8
Eta Bootis	14/45.0	+27/04	2.8	2.5, 4.9
Alpha Canis Venacti	12/56.0	+38/19	19.4	2.9, 5.5
Zeta Orionis	05/40.8	–01/57	2.4	1.9, 4.0
Alpha Librae	14/50.9	–16/02	231	2.8, 5.2
Gamma Virginis	12/41.7	–01/27	3.0	3.5, 3.5
Beta Scorpii	16/05.4	–19/48	13.6	2.6, 4.9
Theta Serpens	18/56.2	+04/12	22.3	4.5, 4.5

(*continued*)

(continued)

Multiple star	Right ascension (h/min)	Declination (deg/min)	Separation (arcsec)	Component magnitudes
Alpha Capricornii	20/18.1	–12/33	377.7	3.6, 4.2. This is quite a complex system consisting of about 7 stars
Gamma Delphinius	20/46.7	+16/07	9.6	4.5, 5.5
Beta Tucanae	00/31.5	–62/58	27.1	4.4, 4.8
Gamma Velae	08/09.5	–47/20	41.2	1.9, 4.2. This is another multiple star system with 5 members
Alpha Crucis	12/26.6	–63/06	4.4	1.4, 1.9
Alpha Scorpii	16/29.4	–26/26	2.7	1.2, 5.4
Delta Apusii	16/20.3	–78/42	102.9	4.7, 5.1

Star Clusters

Strictly speaking there are many star clusters visible in the night sky that we do not recognize as such. The technical term for these clusters is *association*. In fact, clusters are such a recent area of research that not all associations and their members have been identified. It has been known for some time that five stars of the Plough share a common motion, and in 100,000 years' time, the familiar Plough will have changed shape quite considerably. What has been discovered recently is that several other stars visible in the night sky also belong to this group (the Ursa Major Moving Group) and others (such as Sirius) are suspected to be members.

The general term for star clusters where the members are clearly separated from each other is *open cluster*. The apparent separation of individual members from each other is determined mainly by their distance from us. For example, the Hyades, Melotte 20 and Melotte 111 (see Usual Suspects) are examples of star clusters, whose members are separated by several degrees of sky, whereas the Wild Duck Cluster (M11) in Scutum has members so close that they cannot be separated by binoculars. Its shape (which gave it its name) shows that it is not a globular cluster. Most open clusters are found in the plane of the Milky Way or nearby. Using the Hyades as an example, the greatest challenge is getting the whole cluster in the field of view. It is even a struggle for 15×70 binoculars. However, some of the fainter open clusters require a large aperture to combat their low brightness (usually due to distance).

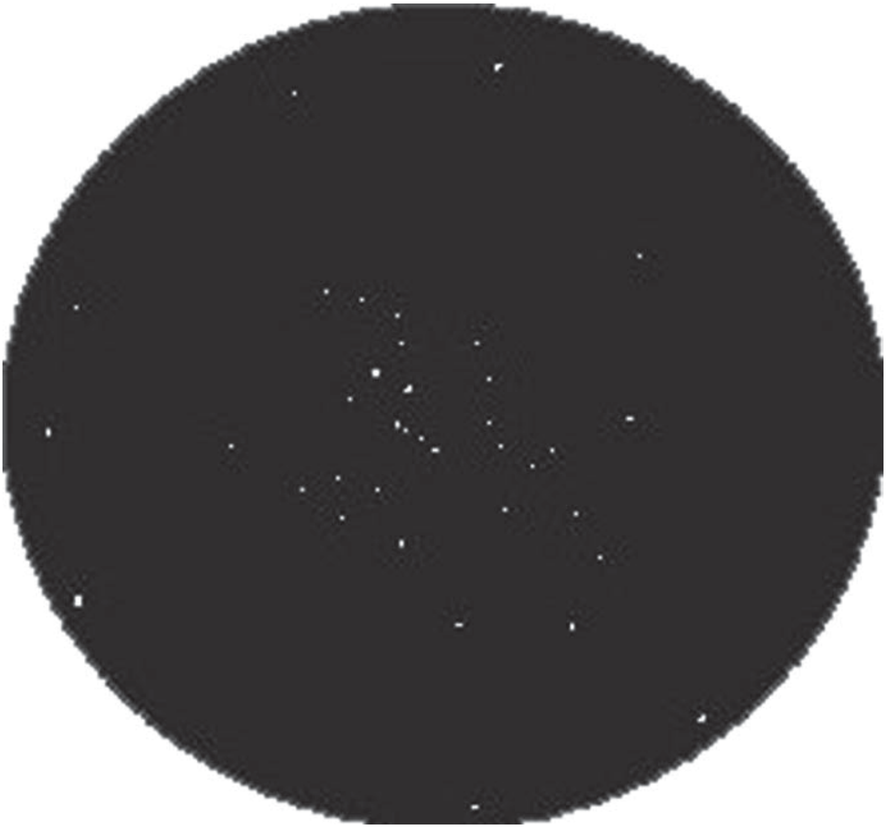


Fig. 6.3. Beehive.

One popular star cluster is the Beehive (M44), which is listed under Usual Suspects. Before starting to do astrophotography, this author made a drawing of it (Fig. 6.3) using binoculars over several nights.

The following table gives a list of open clusters that are not included in the Usual Suspects but can be seen under good conditions with a 100 mm instrument. Anything more than about 25° south of the celestial equator is a challenge for observers in the Northern Hemisphere and anything more than 35° will not be visible at all.

Figure 6.4 shows another example of an open star cluster: M52.

Name	Declination (deg/min)	RA (h/min)	Magnitude	Size (arcmin)
M7	–34/49	17/53.9	3.3	80
M34	+42/47	02/42.0	5.2	35
M35	+24/20	06/08.9	5.1	28
M36	+34/08	05/36.1	6.0	12
M37	+32/33	05/52.4	5.6	24
M38	+35/50	05/28.7	6.4	21
M39	+48/26	21/32.2	4.6	32
M41	–20/44	06/46.0	4.5	38
M47	–14/30	07/36.6	4.4	30
NGC2516	–60/52	07/58.3	3.8	30
NGC4755	–60/20	12/53.6	4.2	10
IC2391	–53/04	08/40.2	2.5	50
IC2602	–64/24	10/43.2	1.9	60

Fig. 6.4. M52 (Image by Nick Howes).

Globular Clusters

Fig. 6.5. M13 (Image by Nick Howes).

As a general rule, these are more difficult to see than open clusters. None of them is particularly close to us. As their light is spread over an area, they count as “faint fuzzies.” For observation it means that you will not be able to see them as easily as stars of the same magnitude. To modest equipment, such as small binoculars, they do not look any different from elliptical galaxies. Larger telescopes are capable of resolving some of the outer individual stars. From a scientific point of view, they are interesting, as they are scattered around the Milky Way halo (or outer regions) but are not as pleasant to look at as open clusters. None of them is particularly nearby in stellar terms. In the Southern Hemisphere, the brightest is Omega Centauri (once thought to be a star!) and in the Northern Hemisphere, it is M13 in Hercules, shown in Fig. 6.5. You can pick up a few in binoculars, but most of them need a clear night. M13 is very difficult in 20 × 50 binoculars but is much easier in larger binoculars. It shows up quite nicely in a 127 mm Maksutov–Cassegrain at low magnification but is not easy to find without a GOTO mount or finderscope. Another example is M15, which is visible in binoculars on a good night. M15 is shown in Fig. 6.6.

Fig. 6.6. M15 (Image by Nick Howes).

Nebulae

The original name "nebula" means cloud, and, in terms of how they appear, the name is rather apt. There are several types of nebulae, but all have one thing in common: they are faint fuzzies. However, many are huge, not just in real terms but also in apparent size. In fact, they are among the largest objects in the night sky. Most of them are large areas of hydrogen, helium, and other elements that are denser than the interstellar medium. Many are in the process of becoming more dense and forming into stars. Some, with stars embedded within them, shine from the radiation emitted by one or more stars. These are called *emission nebulae*. Others reflect the light from one or more nearby stars and are called *reflection nebulae*. In small instruments, it is difficult to tell which are which, without reading a book.

Fig. 6.7. M42, or Orion Great Nebula (Image by Nick Howes).

The most spectacular example of a nebula is the Orion Great Nebula (M42), which is on the Usual Suspects list and shown in Fig. 6.7. If there are no stars within a nebula and no nearby bright stars to reflect the light, the nebula appears black, as it is silhouetted against the stellar background (or in some cases) emission or reflection nebulae. Some are even visible to the unaided eye as "gaps" in the Milky Way. These can sometimes be seen in galaxies outside the Milky Way with larger amateur telescopes and have the rather imaginative name of *dark nebulae*. The best known one is the Horsehead Nebula (RA 05 h 41.0 min; Dec –02 deg 24 min) in Orion. Unfortunately, this nebula is not visible in modest instruments. The Coal Sack (RA 12 h 53 min; Dec –63 deg) in the Southern Cross would be better known were it not so far south and is even obvious in 20 × 50 binoculars.

Fig. 6.8. Horsehead Nebula (Image by Nick Howes).

It is significant that none of the other two types of nebula make our Usual Suspects list. Quite simply, neither supernova remnants nor planetary nebulae are bright enough, as no examples are close enough to us to be brighter than 8th magnitude. The only supernova remnant visible to modest amateur equipment is the Crab Nebula (RA 05 h 34.5 min; Dec 22 deg 01 min) (M1) in Taurus and, frankly, it is a disappointment. Although professional telescopes show its intricate structure, most amateur instruments will not tell you it is not (for example) a galaxy. Planetary nebulae are more encouraging in that quite small telescopes show what they are, as opposed to "there is a fuzzy patch where my star atlas tells me where the object is."

Fig. 6.9. Dumbbell (Image by Nick Howes).

The basic structure of the Ring Nebula (RA 18 h 53.6 min; Dec 33 deg 02 min) (M57) is visible in an 80 mm refractor. It is the most well-known object of this genre, mostly because it is the easiest to find. The Dumbbell Nebula (RA 19 h 59.6 min; Dec +22 deg 43 min) (M27) is actually brighter but, as it is among some rather faint stars, it is much harder to find. The Ring Nebula is one of the few deep sky objects that benefits from using higher magnification, and a 127 mm Maksutov–Cassegrain starts to show what the fuss is all about. Fuzzy patches are visible where other planetary nebulae are reported to be, but the Ring and Dumbbell (shown in Fig. 6.9) are the best examples to enjoy.

Other examples of nebulae are the following:

- Cone Nebula (Fig. 6.10)
- Pacman Nebula (Fig. 6.11)
- California Nebula (Fig. 6.12)

Fig. 6.10. Cone Nebula (Image by Nick Howes).

- Crescent Nebula (Fig. 6.13)
- Bubble Nebula (Fig. 6.14)
- Rosette Nebula (Fig. 6.15)
- Tadpole Nebula (Fig. 6.16)
- Veil Nebula (Fig. 6.17)

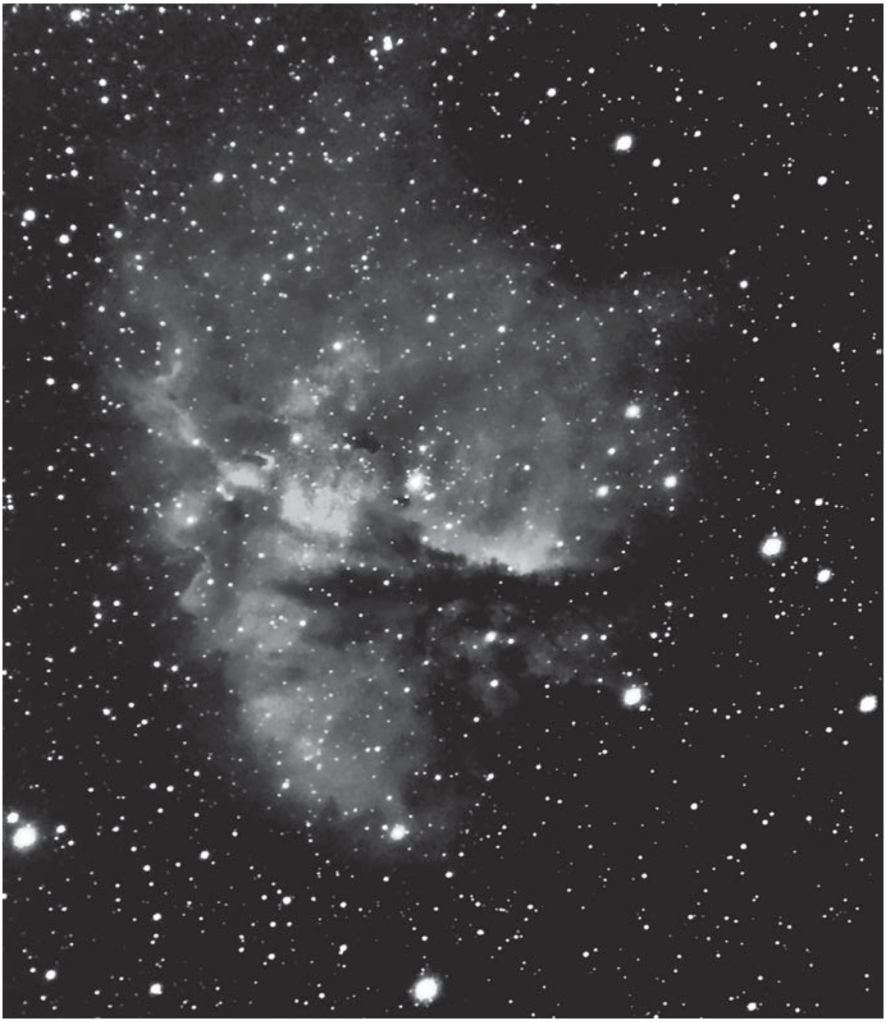


Fig. 6.11. Pacman Nebula (Image by Nick Howes).

Fig. 6.12. California Nebula (Image by Nick Howes).

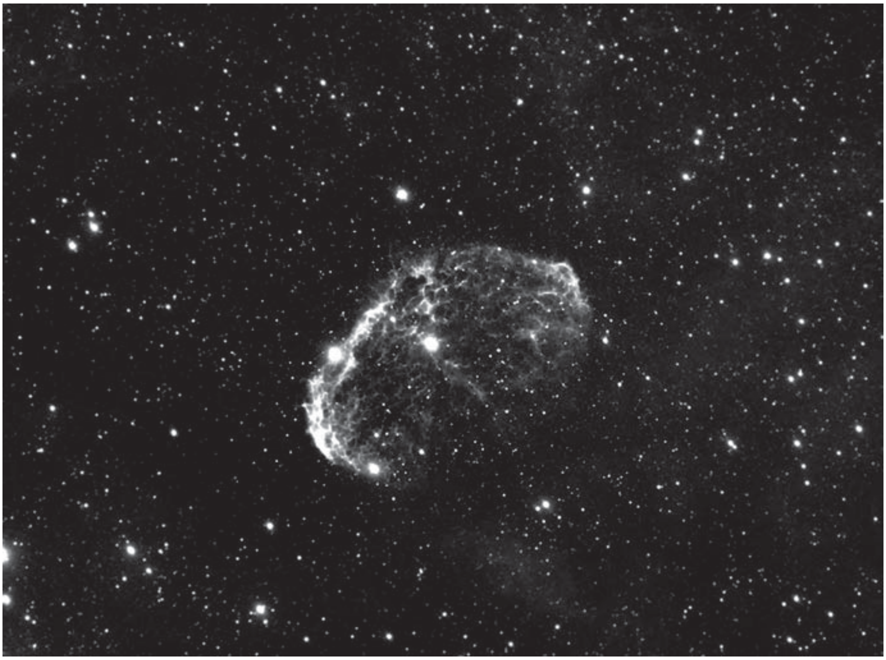


Fig. 6.13. Crescent Nebula (Image by Nick Howes).

Fig. 6.14. Bubble Nebula (Image by Nick Howes).

Fig. 6.15. Rosette Nebula (Image by Nick Howes).

Fig. 6.16. Tadpole Nebula (Image by Nick Howes).

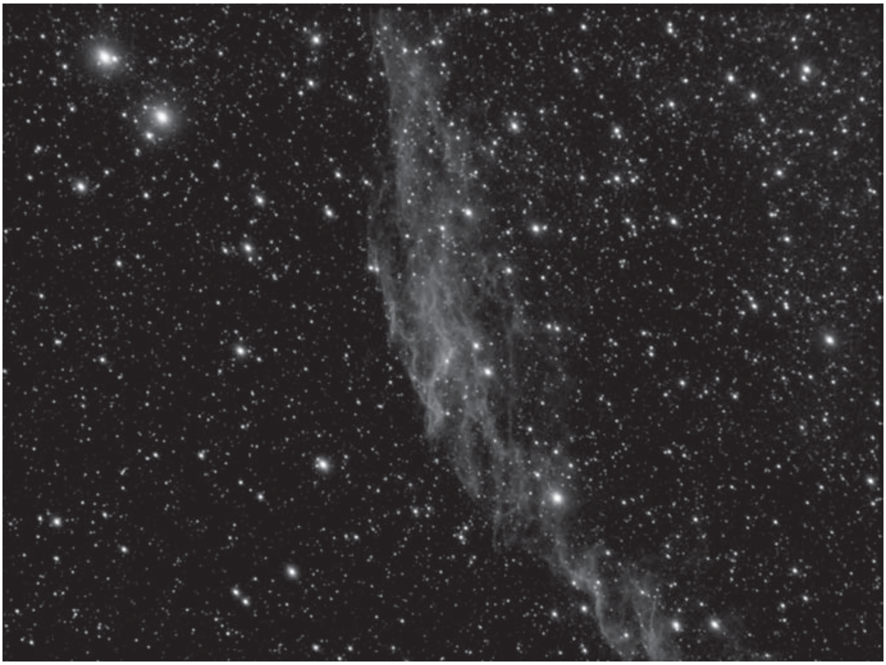


Fig. 6.17. Veil Nebula (Image by Nick Howes).

Galaxies

This is really more the subject of the next chapter. Only a few galaxies appear as more than faint blobs where a galaxy is supposed to be. The brightest galaxy is the Large Magellanic Cloud (LMC), but this can never be seen very far north of the equator. As its brightness is spread out over a wide area, it needs a dark site to see it. From suburban skies in the Southern Hemisphere, it appears just as a lightening of the sky as you scan your binoculars around where it is supposed to be. The Small Magellanic Cloud (SMC) is smaller and even further south, and there is almost certainly fewer sightings of it north of the equator than Mercury or even the tooth fairy. These galaxies are actually small satellite galaxies of our own Milky Way and appear to be parts of it that have broken off, although in reality the opposite is happening. Well known to science fiction fans, the Andromeda Galaxy (M31) is almost as difficult from the Southern Hemisphere but is circumpolar from the Northern Hemisphere. Exceptionally, it is visible without optical aid from suburban locations. It has a large apparent size, so can be difficult to see in large instruments, because of problems with the field of view. The best way to see it is to use a long focal length eyepiece and/or focal reducer, especially when using telescopes of long focal length. There are claims of the nearby Pinwheel (M33) being seen with the unaided eye but, although the claim are genuine, it is difficult to see with 70 mm binoculars (it is not listed in the Usual Suspects). The Pinwheel is shown in Fig. 6.18. On a clear night, it can be an amazing sight in instruments of 100 mm aperture or larger.

Fig. 6.18. Pinwheel Galaxy, or M33 (Image by Nick Howes).

If anything, M81 in Ursa Major is easier and some structure is visible through 70 mm binoculars on a few occasions when the sky is exceptionally clear. NGC253 is theoretically visible from UK skies, but its southern declination makes it more difficult than the fainter M65 and M66 in Leo. It should be worth trying from the southern United States. The final galaxy on the list is NGC5128, better known as Centaurus A. This galaxy is known to professional astronomers as a strong radio source. As M31 is the only galaxy on this list that is a Usual Suspect, it is also included it in this table:

Name	RA (h/min)	Dec (deg/min)	Magnitude
LMC	5/23.6	–69/45	0.1
SMC	0/52.7	–72/50	2.3
M31	0/42.7	+41/16	3.7
M33	1/33.9	+30/39	5.7
M81	9/55.6	+69/04	6.9
NGC253	0/47.6	–25/17	7.1
NGC5128	13/25.5	–43/01	7.0

There are actually more than seven galaxies that you can see with modest instruments. There are accounts of people who track down galaxies in the (relatively) nearby Virgo Cluster with 10 × 50 binoculars. Experienced observers with good eyesight and clear skies can do quite remarkable things. Most peoples' experiences with the Virgo Cluster are that under average conditions it can be difficult to distinguish a galactic nucleus from a star. Also, M65 in M66 in Leo can be difficult to distinguish from nebulae or any other faint fuzzy without a star atlas. Although these galaxies are the same brightness as those in the Virgo Cluster, their more northern declination makes them easier targets. If you cannot see them on any combination of night and equipment, it is better to leave the Virgo Cluster well alone. Similarly, if M81 is well placed and you cannot see that, then it is simply not a good night for galaxy viewing.

How to Get the Best from Simple Deep Sky Viewing

First of all, congratulations on getting to this part of the chapter. Many would have already given up and reread the Solar System bits instead. Alternatively, others may be planning to take early retirement, splash their lump sum on a large Dobsonian, and head for the uncharted wilds.

Although both of these reactions are extreme, we have to be realistic about what can be achieved from the suburban and urban locations that most of us live in. If you spend some time learning how to determine what you can see and cannot see under given conditions and instruments, you will find it is a lot more predictable than Mars. It is nice to learn a few tricks, such as picking some "barometer" objects that you can use to judge the conditions. A good one many people use is if you can see the stars that form the pattern of Ursa Minor. We have already mentioned M65 and M66. If you can see M31 (the SMC if you are south of the equator) without optical aid, drop what you are doing and just observe. If you can see anything fainter than M81 or Centaurus A without optical aid, maybe its time to restrict your alcoholic intake!

Browsing around the Usual Suspects with binoculars may not sound "advanced" or "expert" to many, but it is often the only pleasure that can be had from the night sky when the conditions are poor and there are no planets around. You could also use the time to split a few double stars. On a good night, try to enjoy the Usual Suspects, perhaps noticing something about one of them that you had not noticed before (such as the dust lanes in M31), then try for some of the more challenging objects listed in this chapter. If you are not rushed to get back in, try for something that you have never seen before. If you have read the chapter, gone outside, and enjoyed what you have seen and done, it is time to read the next chapter.

For Further Reading

The following titles are available from Springer:

- *Observing and Measuring Visual Double Stars* by Bob Argyle
- *Deep Sky Observing The Astronomical Tourist* by Steve R. Coe
- *Visual Astronomy in the Suburbs A Guide to Spectacular Viewing* by Antony Cooke
- *Visual Astronomy Under Dark Skies A New Approach to Observing Deep Space* by Antony Cooke
- *The Practical Astronomer's Deep-sky Companion* by Jess K. Gilmour
- *Field Guide to the Deep Sky Objects* by Mike Inglis
- *Astronomy of the Milky Way The Observer's Guide to the Southern/Northern Sky* Parts 1 and 2 hardcover set by Mike Inglis (also available as two separate volumes)
- *Light Pollution Responses and Remedies* by Bob Mizon
- *The Urban Astronomer's Guide A Walking Tour of the Cosmos for City Sky Watchers* by Rod Mollise
- *The Deep-Sky Observer's Year A Guide to Observing Deep-Sky Objects Throughout the Year* by Grant Privett and Paul Parsons

CHAPTER SEVEN

Beyond the Local Group

For the purposes of definition, the Local Group (of galaxies) includes the following:

- The Andromeda Galaxy (M31)
- Its satellite galaxies (M32 and M110)
- The Magellanic Clouds
- The Pinwheel (M33)

There are also some dwarf elliptical galaxies that are not readily visible to amateur telescopes.

As a general rule, anything outside of this area becomes progressively more difficult because of the sheer distance. Although there have been some exceptional claims of galaxies outside of the Local Group being visible to the unaided eye, it is certainly not something to expect and, indeed, on many days it is impossible to see anything outside the Local Group in large binoculars. The term "aperture fever" is often used to describe the type of equipment used for viewing beyond the Local Group, and it is a fair assessment.

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-0-387-76470-2_7,

Choice of Equipment

Unlike Solar System viewing or simple deep sky viewing, there now becomes a significant difference in visual use and photography. The latter is covered in the next chapter. There is also a significant difference in equipment that is good for Solar System viewing that may not be so good for viewing faint galaxies. Indeed, it may even be necessary to consider a separate purchase.

Although binoculars are great for the Usual Suspects and some of the more slightly difficult objects, they have serious limitations when it comes to objects outside our Local Group. With a few exceptions, we are looking at 8th magnitude objects and fainter. An example of a difficult "pot" outside the Local Group with 70 mm binoculars is to see the spiral structure of M81 in Ursa Major. However, this is far from a usual occurrence, and, in typical suburban conditions, you are lucky to see a fuzzy patch where M81 happens to be according to the maps.

Having eliminated the choice between visual and photographic equipment, there now comes another choice: Do you go for something that helps you find the objects or something that will give a better view when you find it (or should that be "if you find it!?")? On a limited budget, the best choice is for a telescope that will show the object at its best, although many might not agree on a freezing cold night when the lure of a few easy views and photos followed by a nice cup of coffee is hard to resist.

Although the price is coming down all the time, a 90 mm Meade ETX that has all the gadgetry to find things electronically costs about the same as an 8″ Dobsonian mounted Newtonian reflector. Assuming that we are all on a limited budget, we have to decide what is best. The Meade ETX is acclaimed as an excellent portable "GOTO" telescope. It is also good optically. However, many users have expressed doubts as to its tracking capabilities for long exposure photography. The problem is that, however good it is, the aperture is still only 90 mm. There is also a counter argument that if you know your way around the sky that you can find most of the objects visible in it without the gadgetry. Certainly, many anecdotal experiences with short tube refractors would lend some weight to this argument. Where the GOTO telescopes really come into their own is when they are 8″ and bigger, not to mention rather expensive. The views of M65 and M66 in Leo through an 8″ Meade LX10 (a Schmidt-Cassegrain) are quite remarkable (giving the "wow" factor, as views of the Whirlpool (M51)). These are particularly popular at star parties.

Looking at aperture per buck, the best solution is a "Dobsonian," which is really a short name for a Newtonian reflector on a Dobsonian mount. These do not enable you to track objects manually or otherwise.

Your best bet when using these instruments is to use wide angle eyepieces of a long focal length. However, there are also some ways to make objects easier to find. As you will have gathered by now, even the financially challenged have a habit of acquiring things that help them, a personal example being a 9 × 50 finderscope. Its value was demonstrated publicly when a fellow club member was having trouble finding M31 with a Skywatcher 127 mm Maksutov–Cassegrain. We put my finderscope on and found not just M31 but also M33 quite quickly. The view of M33 through the finderscope was remarkable in itself. The 127 mm Maksutov–Cassegrains are great for lunar and planetary viewing but not so for deep sky. A suitable work-around is to use an Antares screw-in 0.5× focal reducer to obtain a wider field of view. The field of view increases by 1.7 times and not the hoped for doubling, but it is still a very useful accessory. Using a suitable eyepiece, it is possible to achieve a magnification of about 30× and field of view of about 1.5°.

The final idea seems both sound and cost-effective. Not only can you find “computerized Dobsonians” on the market but you can also buy separate electronic finders that you can use to find objects.

Although this equipment description is aimed at galaxies beyond our Local Group, it can also be used for some of the more difficult objects in our own galaxy.

What to See

Despite all the great discoveries of galaxies dating back to near the dawn of time, such as those in the Hubble Deep Field, it is more realistic to think in terms of 120–150 million light years, as far as amateur observation in concerned. Even then, this requires instruments at the very top end of the amateur scale and, despite this, we are able to see only about a tenth of the observable universe. The Local Group has a boundary of about 3 million light years from us, while the next set of galaxies appear to be around the 10–15 million light year mark. Depending on where you live, the next target outside the Local Group is M81, or Centaurus A, and M81 is only marginally brighter. There have been sightings of M81 without optical aid, making it the furthest object ever spotted, but, with a magnitude of 6.9, it requires an exceptionally clear sky. Quite often, it does not even show up in 70 mm binoculars.

To see M81 it is best to live north of the Tropic of Cancer, as it has a declination of just over 69°. On a night where it is visible (but only just) you can just see the nucleus, giving the false impression that it is an elliptical galaxy. On a better night (or with a higher aperture instrument), the spiral arms appear as a blur, and a further improvement in equipment or conditions reveals that the spiral arms are separate entities from each other. However, the blue open star clusters will normally be visible only in long exposure photographs (Fig. 7.1).

Fig. 7.1. M81, *top left*, and M82 (photograph by Nick Howes).

Nearby is M82, somewhat fainter at magnitude 8.4. It is an irregular galaxy whose strange shape can usually be made out. It is highly probable that M81 and M82 have interacted with each other in the relative recent past (last few hundreds of thousands of years).

By contrast, Centaurus A is just over 43° south in declination, which means that you need to be south of the Tropic of Cancer to get a decent view. This explains why Charles Messier did not include it in his catalog. It is officially classed as a peculiar galaxy, and good quality photographs show a spherically shaped elliptical galaxy with (what appears to be) a dust lane in silhouette. It is likely that the dust lane is the result of a recent galaxy merger. Centaurus A is known to be very active in radio wavelengths.

A rather significant "miss" by Charles Messier is the Sculptor Galaxy (NGC253). At just over 25° south in declination, it is not seen at its best from Paris, but with a magnitude of 7.1 it is only marginally fainter than Centaurus A and M81 and brighter than many of the globular star clusters discovered by Messier and Mechain further south. It is a spiral galaxy some 10 million light years away.

At a similar brightness to M82 but slightly further away at about 14.5 million light years is M94, the Cat's Eye Galaxy in Canes Venacti. This galaxy has a declination of about 41° north and is a spiral galaxy, although modest instruments will just show the nucleus. Its bright inner region gives the impression of an elliptical galaxy in small instruments, but larger apertures will reveal the outer spiral regions (Fig. 7.2).

Fig. 7.2. M94 Cats Eye Galaxy (photograph by Nick Howes).

Once we get past the 15 million light year mark, nothing is brighter than 8th magnitude. Although there are many dwarf galaxies, particularly dwarf elliptical galaxies, these are not readily visible to amateur instruments. However, there are many large galaxies that can be seen in binoculars on a good night. One such example is the Whirlpool Galaxy, (M51).

Although at 47° north in declination, it is circumpolar from northern Europe and parts of the United States and is best seen in spring when its elevation is at its greatest. M51 is interacting with its neighbor, NGC5195 and is somewhere between 20 and 37 million light years away, depending on whose estimates you believe. In fact, most published estimates to distances to objects outside our galaxy can easily be 15% off, and there is always a possibility that some discovery will reveal the distances to be much nearer or further than we currently think. At magnitude 8.4, M51 is one of the brighter galaxies outside our Local Group. It is visible in 70 mm binoculars but looks superb in a 200 mm Schmidt-Cassegrain (Fig. 7.3).

Fig. 7.3. M51, the Whirlpool Galaxy (Image by Nick Howes).

Another group of galaxies around 35 million light years away is the Leo Triplet. The members of this group are M65, M66, and NGC3628. Many would (maybe harshly?) put NGC3628 down as a "Messier Miss," as more difficult objects have found their way into the Messier Catalog than this one. All three objects are spiral galaxies. M66 is the brightest of the three and is visible with M65 in 70 mm binoculars but just as faint fuzzy patches. Nevertheless, they are a pleasant sight, showing their spiral nature in 200 mm aperture instruments.

Moving 60 million light years away, we come to the Virgo Supercluster. This is the largest group of galaxies anywhere near us and contains around 2,000 members, although only about 16 are readily visible in amateur instruments. Despite the huge distance compared with members of our Local Group, the largest members are visible, as they are physically large and bright and contain more stars and other matter than the Milky Way or Andromeda Galaxy (M31). The dominant member appears to be the giant elliptical galaxy M87, which appears to be at the center of the cluster. Its extent, including outer regions, is over half a million light years, and it has a mass of about 2.7 million million solar masses. The Virgo Supercluster appears to be pulling our own Local Group toward it, and it is possible that we could merge with it in hundreds of billions of years' time. Compared with the Leo Triplet, the Virgo Supercluster is somewhat more difficult to see, because of a greater southerly declination. The other problem is identifying which faint fuzzies are which.

Much beyond the Virgo Supercluster, we are really looking at instruments in the 250 mm plus class and bigger. However, as the aperture increases, so does the number of galaxies that may be seen. Most good star atlases will have details of many suitable targets for viewing or imaging (Fig. 7.4).

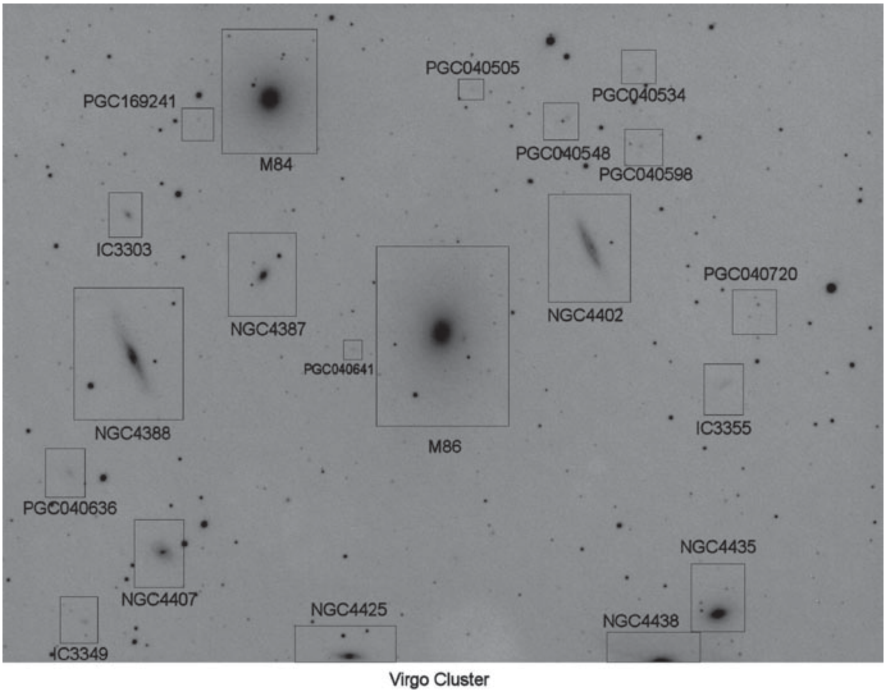


Fig. 7.4. Virgo Supercluster (Image by Nick Howes).

Tips and Tricks

This may scare you off, but first a touch of realism – observing anything beyond the Local Group (of galaxies) is inherently difficult. Indeed, it is really quite tempting to limit one's deep sky viewing to the easier members of the Messier Catalog or do to a quick binocular tour of the Usual Suspects before bedtime. This is especially true when there is any hint of cloud around or a bright Moon is high. On a rare really clear night, though, you should try to "bag" at least one object that you have never seen before or try to get a new angle on a more familiar object. An example of this is the dust lanes in M31.

It is also worth doing some tests to see if it is really worth bothering at all (on any one particular night). For example, if you can see a faint smudge where M81 should be in your chosen instrument, it is worth trying something more ambitious. If you can see any galactic structure, even better! Other tests are binocular scans of the Pleiades (M45), Beehive (M44), Melotte 20, and Melotte 111. During spring, check out M65 and M66. If you cannot see them, there is no point in attempting the Virgo Supercluster.

Assuming that you have not decided to abandon deep sky viewing and stick to the Moon, you now must decide what is worth seeing. Anything with an elevation of less than 30° suffers significant extinction, so any extended object fainter than magnitude 8.0 is simply not going to be visible to any but the largest binoculars on most nights and therefore invisible in a large finderscope as well. If what you are looking for is near some celestial landmark, you stand more chance. Although it is an object in our own galaxy, the Ring (M57) is more easily found than its larger and brighter neighbor, the Dumbbell (M27) because it is between two bright stars. Now, an extended object may be visible in a telescope but, in less than good conditions, what you see may be limited to a faint smudge where the object is known to be, hardly a good reward.

Even on a good night, it is best not to get too ambitious, unless you have GOTO technology. Aim for a good look at one or two objects, rather than trying to rush through a complex observing program before bedtime. Find the object and increase the magnification to obtain a higher contrast with the surrounding sky. With apertures in excess of 200 mm, light pollution filters that block emissions from streetlights can be quite handy.

At the time of writing, many expert deep sky photographers were producing excellent photographs using narrowband filters in wavelengths such as hydrogen alpha, hydrogen beta, and oxygen III. Note that the bandpass of such instruments are much wider than solar filters of the same type and note, ESPECIALLY, that they are totally unsuitable and DANGEROUS for solar viewing, if used as the only filter. Conversely, the bandpass of solar filters is so narrow that they do not let in anywhere near enough light to make night time objects visible.

Although these filters are of more use for objects within our own galaxy, such as M42, there is room for experimentation on some of the brighter galaxies, if you have the time and patience.

The final tip is to travel to a dark site with others. Star parties are a good time to do this, when there is safety in numbers.

For Further Reading

The following titles are available from Springer:

- *The Observer's Sky Atlas* by E. Karkoschka
- *Deep Sky Observing The Astronomical Tourist* by Steve R. Coe
- *Visual Astronomy in the Suburbs A Guide to Spectacular Viewing* by Antony Cooke
- *Visual Astronomy Under Dark Skies A New Approach to Observing Deep Space* by Antony Cooke
- *The Practical Astronomer's Deep-sky Companion* by Jess K. Gilmour
- *Field Guide to the Deep Sky Objects* by Mike Inglis
- *Astronomy of the Milky Way The Observer's Guide to the Southern/Northern Sky* Parts 1 and 2 hardcover set by Mike Inglis (also available as two separate volumes)
- *Galaxies and How to Observe Them* by Wolfgang Steinicke and Richard Jakie,
- *The Herschel Objects and How to Observe Them* by James Mullaney

CHAPTER EIGHT

Simple Digital Photography

As you look through the pictures in the monthly magazines, it is easy to admire the many wonderful amateur images of distant galaxies yet also feel a sense of defeat at not being able to do anything as good. On the one hand, it is true that you need a lot of time and equipment to do these, although Anthony Glover in the final chapter shows that it might be more feasible than you think.

On the other hand, you can try the simple approach instead, at least at first. It may not be possible to be able to produce deep sky images of near-professional quality, but you can produce some pleasing photographs using very simple (and inexpensive) equipment. All you need is to find an object visually, place a digital camera at the eyepiece, and then click.

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series,
DOI 10.1007/978-0-387-76470-2_8,

Fig. 8.1. The Moon.

Figure 8.1 shows a photograph of the Moon. Visually, there is nothing remarkable about it, and there are plenty more photographs of the Moon in magazines and on the Web that are better. The only remarkable thing about it is that it was taken using a pair of 15 × 70 binoculars and 3.2 megapixel digital camera. It proves that it is possible to take decent pictures using relatively modest equipment, with a little bit of skill and processing. The Moon itself is a very suitable target for this type of photography and a good one to master before moving on to more difficult objects. Binoculars are not the instrument of choice for photography, and most of us use larger telescopes instead. The photographs in the chapter on lunar viewing (apart from those taken by Nick Howes) used this telescope and domestic digital cameras, the Sony Cybershot P72 (3.2 megapixels) and a Samsung Digimax (10.1 megapixels). The main reason why astronomers do not always use larger equipment is for reasons of travel and portability. Even a small refractor can be quite heavy to carry in hand luggage.

Although this may sound like stating the obvious, it is a good idea to learn your way around the controls of your digital camera. The key ones to look for are brightness control, exposure time, and optical zoom (ignore digital zoom, as this is done separately). Exactly what you do is dependent on the camera and object being "snapped," which we will come to later. Optical zoom is a lot more useful than it may seem and saves a lot of fiddling about with eyepiece changes. Although you can adjust the number of pixels used to allow more space on the camera's memory, it is best to use the "fine" option for astronomical objects. It is also worth mentioning that it is a good idea to take lots of shots, in case they do not all come out, and try lots of eyepiece/accessory combinations, although after a while you will get more of an idea of what works and what does not, and it is not always the same as what you can do visually. One relatively inexpensive addition is a memory card, which will allow you to take hundreds of shots in a single session.

Apart from budget and simplicity, another advantage to this approach is that you can take lots of shots in a short space of time and then process them later. It is a fact that there is hardly a single photograph in the magazines or Web sites that has not been processed. This can be done later, after loading your photographs onto a computer. There are several computer programs available commercially to do this, most notably Paintshop Pro and Adobe Photoshop. Using Paintshop Pro as an example, the main functions are the following:

- Split channel to obtain red, green, and blue components separately. (Sometimes CMYK – cyan, magenta, yellow, black – works better instead, as can HSL – hue, saturation, lightness.)

- Histogram to adjust brightness and noise on each channel (or the whole image).

- Clarify and sharpen to bring out small details.

- Adjust brightness/contrast.

- Combine channel to reconstitute the picture from its components.

- Adjust red/green/blue to obtain the final color.

The exact processing you can perform is dependent largely on the object in question. We will discuss the specifics later.

Choice of Equipment

It is tempting to be cynical here and say that one would not use a digital camera through choice. Indeed, as we are talking about the budget end of the market, it is often a case not so much of choosing equipment as adapting existing equipment for use. A high percentage of people own digital cameras, and many of them were bought for taking holiday snaps. This does not make them unsuitable for astronomical use but could make them somewhat limited. In spite of many peoples' results, there is a great picture of Jupiter's Great Red Spot that was taken with a cell telephone camera. It is a good idea to keep an eye on the market constantly, even if funds are limited. Things are changing very quickly, and it is likely that many new innovations are being made, even as you read this section. It is likely that you will want to buy a new digital camera for other uses sometime, and these are the sorts of features you need to look for if your new camera is to double up as an astronomical camera:

- High "ISO rating": This figure was used for films but is still used to measure camera sensitivity to light. At the time of writing ISO 1600 was common and ISO 3200 was just coming in. Big numbers are great news, as they mean you can capture fainter objects with shorter exposure time. Note, however, that you also capture a lot of noise.

- Optical zoom: This is great for taking lunar, solar, and planetary close-ups without having to fiddle with eyepiece changes. However, much over 5× is not very effective, even though many cameras support higher magnifications.

- Exposure control: This will never be as good as a digital SLR camera, but (at the time of this writing, of course!), there were many digital cameras with "night mode" that allowed an exposure of 8 s, enough to make a huge difference to what one can do.

- Image stabilization: New feature that allows for "wobble" but introduces a lot of noise.

Early impressions led many to believe that it was necessary to use large telescopes for photography, and this was quite true with the early generation of digital cameras. However, Fig. 8.1 shows that it is no longer the case, and that it is possible to take quality photographs with much smaller instruments. Nevertheless, there are some things you can use/buy that will improve your use:

- Eyepieces: Refer to the Introduction chapter for information on eyepiece types. Long eye relief (LER) eyepieces are particularly suitable for this, but the Coronado CEMAX eyepiece is a good all-rounder, even on nonsolar objects.

- Mounting bracket: This steadies the camera to avoid shake. Although it is no longer made, the PHO47 was a good example, holding the camera to the eyepiece using two adjustable rods. It is shown in Fig. 8.2.

Fig. 8.2. PH047 (photograph by Nick Howes).

Lunar Photography

A lot of lunar photographs shown in magazines are taken using a 127 mm Maksutov, although improvements in techniques have allowed astronomers to take more reasonable pictures with smaller telescopes and even binoculars. The recommended approach is to try to get a shot or two of the entire lunar disc, and then take various close-ups. This can involve fiddling with various eyepiece and accessory combinations. This was before the optical zoom facilities on newer cameras did the job instead and usually produced clearer photographs. This usually entails at most one eyepiece change. Apart from getting the magnification/field of view combination right and using optical zoom to fit the lunar disc to the field of view, the most important part is the postprocessing.

For full disc shots, it is best to use a low light sensitivity, but this is not necessary for the close-ups.

Let us start with an unprocessed lunar image (see Fig. 8.3).

Fig. 8.3. Raw lunar image.

The next step is to use the Crop function to get rid of any excess dark edging. As this is quite a trivial process, there is little point in showing it. You may notice, though, that you may see some blue edging, which is more pronounced in achromatic refractors and spherical reflectors. Visually, this can be avoided by using "minus violet" filters, sometimes marketed (pretentiously) as "semi-APO" filters. What we do next is split the lunar photograph into red, green, and blue constituents (Split Channel in Paintshop Pro). Depending on the camera, normally the best channel is the green one, and, unlike other objects, you do not normally need to recombine them but it is shown here for the sake of illustration and completeness.

Using the example above, Figs. 8.4–8.6 show the red, green, and blue components.

Fig. 8.4. Red Moon.

Fig. 8.5. Green Moon.

Fig. 8.6. Blue Moon.

Using the blue component as an example, a Histogram component of 0.8 was applied twice to get rid of the “fuzz.” This could have been achieved with a single component of 0.64. It is better to use smaller steps and reapplication, rather than applying a large adjustment and then using the Undo function. Note that this is no “magic” number, as it will vary according to the telescope and the camera and the individual quality of the image. Figure 8.7 shows this.

Fig. 8.7. Blue Moon after Histogram adjustment.

This is as good, if not better, than many photographs on the net. It is your personal choice whether you take a high volume of shots and apply minimum processing or you just aim for one "killer" shot per session and spend ages perfecting it. By many standards, the Moon shot shown would not undergo further processing. However, for the purposes of illustration, a Histogram adjustment of 0.8 was applied to the red component three times and the green component once. They were then recombined to produce the shot in Fig. 8.8.

Fig. 8.8. Recombined lunar image.

Again, this looks rather good and, in this example, the final version is only marginally better. The final coup de grace is using the Clarify function (but use the highest figure and apply it several times if there is substantial camera shake) and/or the Sharpen function and finally the Salt and Pepper filter that removes the "graininess" of the image. Practice may not make 100% perfect, but if you are hitting the low to mid 90s after a year, you are doing well (Fig. 8.9).

Fig. 8.9. Final lunar image.

Solar Photography

The Sun had been very quiet (at the time of this writing), and there had not been a sunspot for several weeks, so few "white light" shots were shown in the magazines or gallery Web sites. Indeed, even hydrogen alpha viewing and photography had been difficult with the lack of features. Hopefully, by the time this book makes it to bookstore shelves, we should be seeing a more active Sun than the one we are seeing now. Remember that, although you do not go blind by photographing the Sun without filters, you can cause damage to your equipment, so refer to the chapter on solar viewing.

Larry Alvarez, who was one of the cowriters for *Enjoying the Sun with Coronado Telescopes and Filters,* uses green filters for white light viewing, and there is a lot to be said for isolating the green channel of a digital shot. It is useful to eliminate the blue channel in the same way for lunar photographs to get rid of the fringes.

When it comes to hydrogen alpha, the best word comes from Nick Howes' chapter of the same book and, indeed, many solar photographers are indebted to Nick for the improved quality of their own photographs. Few are as thorough as Nick and or have his patience in squeezing the last pip out of an image. In 2008, he produced some simply amazing images using the Solarscope range, and he is getting better all of the time.

It is when we use color digital cameras for light of one wavelength that we realize that they are not really the best tools for the job. The bad news is that there are not many good monochrome cameras in camera stores, but the good news is that we can get around this by using postprocessing. This example was taken on November 9, 2007, as shown in Fig. 8.10.

Fig. 8.10. Raw solar image.

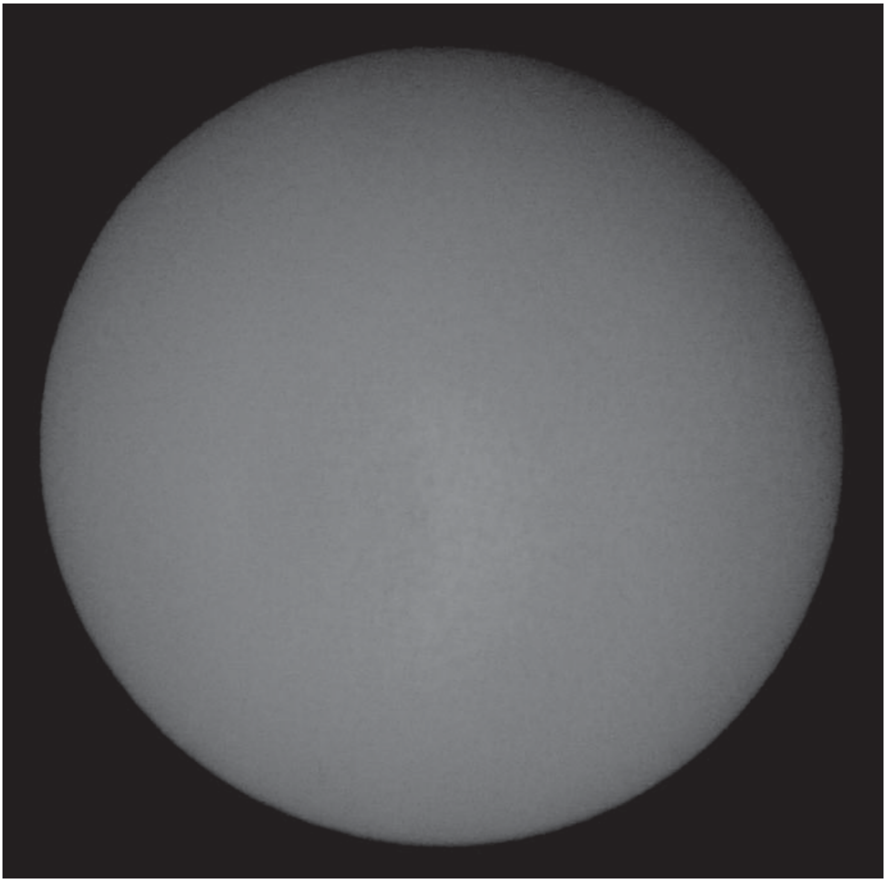


Fig. 8.11. Green solar image.

The red channel usually shows the prominences. The blue and green channels show the surface detail, but either the blue or green channel may appear completely blank, depending on the camera and, sometimes, the shot. In the example above, the blue channel was blank and the green channel came up needing no Histogram adjustment. Figure 8.11 shows the green Sun.

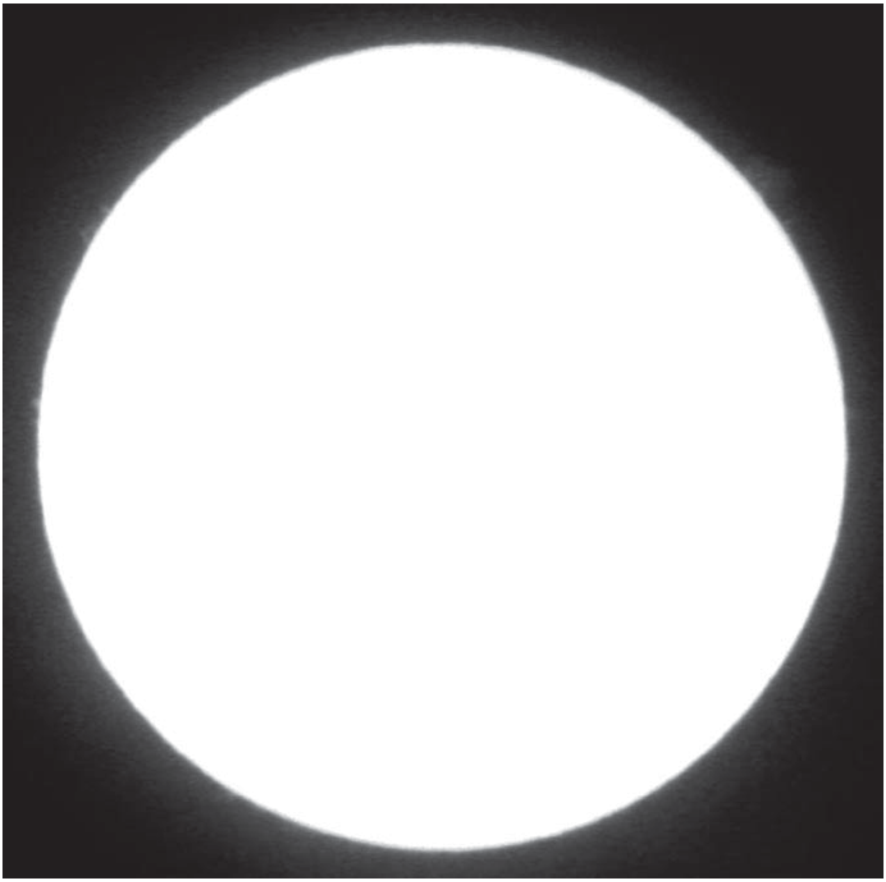


Fig. 8.12. Red solar image.

The idea of the Histogram function on the red channel is to remove the haze but preserve the prominences. In this example (Fig. 8.12), a Histogram adjustment of 0.36 was used.

Figure 8.13 shows the final image but, quite frankly, it is less than perfect. The color shows up nicely, and using the green channel as the blue input, it loses a lot of prominence detail.

Fig. 8.13. Final solar image.

In fact, it is often preferable to keep the red and blue/green channels separate, rather than trying to show them on the same shot. It needs the detail shown in both to give a true solar picture. It seems that there is some sort of "industry standard" to color the final image in a fiery yellow or orange, but the pinkish red of the composite image above looks nice, too. A mustardy yellow made up of 100% red and 50% green is quite nice and can show a lot of contrast, but a false color blue, as a "fake" calcium K shot, can be done. Sometimes trying to color the image does more harm than good, in which case, it is best to leave it as a gray monochrome.

Now calcium K photography is very similar, except that most details come out as blue. A nice shot can be made by combining the hydrogen alpha and calcium K images. Like lunar photography, you can experiment with features such as Sharpen and Clarify.

Planetary Photography

It is tempting to go through lots of examples for all the different planets, but, honestly, they are not that different from solar and lunar photography. With the exception of Venus, it is not easy to overexpose planetary images. Indeed, the Add function is often used to increase the brightness of an image while postprocessing.

Starting with Mercury, there is a big surprise. At the time of this writing, there were very few amateur photos of Mercury taken through telescopes. Most Internet search engines show only images taken from spacecraft, so it needs a lot of detective work to track down amateur shots.

Next out from the Sun is Venus, and as cameras are sensitive to ultraviolet light, it is possible to obtain images of cloud features when Venus is close to Earth. Apart from wariness about overexposure, it is not that different from taking pictures of the Sun and Moon.

Mars is tougher, but potentially one of the most rewarding planets. It is possible to get some very good photographs, but its small disc, even at opposition, means that you need higher magnification, increasing the risk of a bad image due to camera shake. It is better to check Mars out visually first before attempting a photograph. Most Martian detail comes out in red and the contrasting detail in green.

Many good photographs of Jupiter have been taken from Europe and North America, but the southerly declination of the last 2–3 years has ruined the view due to extinction. The best recent views and photographs have been from around the Tropic of Capricorn. You can usually snap the two main equatorial belts, and sometimes you can record shading between the belts. It is normally necessary to overexpose the planetary disc to record the moons in a photograph. Northern observers are expecting to revisit Jupiter seriously in a couple of years. Most surface detail comes out best in green.

Surface detail is also hard to come by on Saturn but not impossible with a digital camera. The rings, however, add further interest to the planet. Snapping any of its moons is difficult with a digital camera (most non-SLRs are limited to 8-s exposures, which may just catch Titan on a good night). Uranus and Neptune are too far away to capture any planetary detail through a small telescope or digital camera, and Pluto and Eris are just too faint to capture at all, unless you use an SLR and/or large aperture telescope. It is possible to snap some of the brighter objects in the main Asteroid Belt, such as Ceres and Vesta when close to maximum brightness.

Constellation Photography

Sometimes life throws up some pleasant surprises. If your digital camera has some sort of night mode or ability to take photographs with exposures of a few seconds, this is worth a try. The only prerequisite is that you need to keep the camera steady for the duration of the exposure. For digital SLR cameras (beyond the scope of this section), you will need a driven mount and accurate guiding. Although you can take constellation photographs using a camera tripod, you can obtain more accurate pointing using a piggy back technique.

Figures 8.14 and 8.15 give examples of such shots. Postprocessing consists of using the Add function until the constellation stars (and if you are lucky some background ones as well) become visible, then use the Histogram function to reduce the fuzziness in the background. You may then need to add the result to itself again and reapply the Histogram function until you get a result.

Fig. 8.14. Orion.

Fig. 8.15. Leo with Saturn and the Moon.

Double Star Photography

For some strange reason, this is a branch of astronomy that is much neglected by the monthly magazines yet is an excellent subject for digital photography. The techniques are similar to those for constellations, except that you take the image through a telescope, and you do not normally need long exposures (only for fainter stars). The double stars in the Usual Suspect List are a good place to start, and many of the photographs are included in that section. Double stars with a close separation and big difference in brightness are the hardest, while widely separated double stars of nearly equal magnitude are much easier. Figure 6.1 shows Castor (separation 4 arcsec), and Fig. 6.2 shows Alpha Centauri, which has a wide separation of 20 arcsec.

The Final Word (Or Is It?)

For “proper” deep sky work, you can forget about digital cameras, except for SLRs, and then there is CCDs and driven mounts. So it would seem that we can skip straight to the next chapter and forget the rest. Yet, simple domestic digital cameras still have a lot of untapped potential. Although it will not print well and is hardly a great breakthrough, it is possible to capture the faint signature of the Orion Great Nebula, (M42), through binoculars. Figure 8.16 shows a photograph of the Pleiades (M45) through a Startravel 80.

Fig. 8.16. The Pleiades.

On its own, this is not a remarkable photograph, but it was the first successful attempt to capture the main asterism of this open star cluster. The potential for what one might be able to achieve using undriven mounts and low magnification is rather exciting. For example, parts of the Hyades can be captured through a telescope. The trouble is that there will always be new cameras and techniques. Looking at the advances in computers since the early 1970s, one day we could be talking about gigapixels and not even needing a telescope. So no matter what time an author decides to stop writing about the subject, there will always be something new barely weeks afterwards. If it is not some groundbreaking technique, it will be a newer, cheaper camera with greater sensitivity and pixel size. We live in interesting times, indeed.

CHAPTER NINE

Deep Sky Astro-Imaging

Anthony Glover

The aim of this section of the book is to provide an overview that the novice-to-intermediate astro-imager will find useful in getting started and making progress in taking pictures of deep sky objects.

Deep sky astro-imaging is a fascinating and hugely rewarding hobby. From your own back garden, you can quickly produce detailed images of those faint and fuzzy objects one peers at through the telescope eyepiece. In almost no time at all you can get results that will have you grinning from ear to ear! Mind you, frustration can come in equal measure, and we cannot casually gloss over the difficulties faced in trying to produce an image we are proud of.

We all have to start somewhere, and one can guarantee 100% that every amateur out there had quite humble beginnings, no matter how spectacular their images are today. This chapter will hopefully allow you to establish solid foundations.

Astro-imaging is something of an art and a science. It is a science in that you can undertake a systematic study of each part of the overall process in an attempt to understand (and hopefully control) as many aspects as possible. It can be something of an art form in that the final result, the image that you see on your computer screen, is the result of your subjective interpretation and presentation of the data.

P. Pugh, *The Science and Art of Using Telescopes*, Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-0-387-76470-2_9, © Springer Science + Business Media, LLC 2009

Do be aware that this is not intended as a statement telling you which equipment or software, etc., you should buy. That part of the process has to be decided by every individual as to what suits him or her best. On the one hand, reference to certain products is unavoidable and occurs for various reasons, mostly to illustrate techniques that have been used of which we have anecdotal hands-on experience. On the other hand, a certain product might be so widely used by the astro-imaging community that it simply cannot be left out!

In considering the information in this chapter, various terms are introduced, sound guidelines are conveyed, and a range of results you can achieve with amateur equipment from your own back garden are demonstrated. A single chapter in a book is no place to be exhaustive about this area of astronomy; however, you will find plenty here to keep you going.

Getting Started

Well, what equipment do you need?

The response is not as straightforward as you might like! You could ask ten experienced astro-imagers this question and get twice as many answers. Every time the reply will begin, "Well, that depends……."

Whether you are a complete beginner, or if you find yourself at an intermediate level, you are toward one end of a steep learning curve. Your allies in the navigation of this curve are understanding and hands-on experience.

Before we get going, we will make a straightforward comparison. Imagine taking a photograph in poor light. If we do not use a flash, the picture will be dim and blurred. It is dim because not enough light reaches the chip/film. It is blurred because the shutter stays open for a longer time to catch every bit of light possible. If the camera is not rock steady, this blurring will happen even if the shutter is open for only fractions of a second.

As a result, any movement by us, no matter how slight, blurs the picture. If we try to zoom in on an object, any slight tremor in our hand is exaggerated by the magnification, causing more blurring. Zooming in means that we are collecting light from a smaller area and so less light is available. Low light levels also make it difficult to achieve good focus.

In astro-imaging we are trying to take pictures of objects that are typically so dim, they are invisible to the unaided eye. We use our telescope as a version of the camera lens to collect light that has been traveling for thousands or millions of years. Our aim is to bring as many of these scarce photons as possible to precise focus on the electronic chip of our camera. Magnification is typically greater than the average photo, and we require individual exposures to be of 5, 10, 15, or even 30+ min duration. Things are complicated further, for Earth's rotation in one direction creates an apparent movement of our target in the other.

We need long exposures to collect faint details. We will use software to then "stack" these exposures as a means to smooth out the noise and other artifacts in the image so that we may process and present our image as well as possible. To overcome these hurdles we need an understanding of the integration of ourselves and our equipment into each part of the imaging process.

So when starting out it is strongly recommended that you make things easy for yourself. It is much easier to get good exposures with short focal length telescopes, and if you have collected reasonable data you can explore more options with processing. Your progress will be swifter and more satisfying if you start with reasonable goals that you can then build on once achieved. You will automatically develop a better understanding of the basic principles. This is essential as you take on more demanding targets.

Take care to understand these principles. Think about what you are doing and why. Probably the most important bit of advice is to be patient. This is a challenging requirement, as our instinctive enthusiasm goes against patience!

For the purposes of this chapter, the discussion is restricted to digital imaging rather than film. Dedicated "astro-imaging" cameras are now quite accessible to the amateur astronomer and have many advantages. One obvious example of digital is immediate image display. You can quickly identify focus problems, tracking issues, etc., and investigate/tweak them as needed.

Let us start with equipment.

The choices for equipment are many and wide ranging. Choice is good. However, it can also complicate matters and render decision making tricky.

There are three essential items of equipment:

- Telescope
- Camera
- Mount

The Telescope

Almost any telescope can be used for astro-imaging. It is the design, quality, and "know-how" that dictate how well your telescope might perform. If you already have a telescope and motorized mount, then you should try them before racing out and buying a new one.

The most commonly used telescopes for deep sky images tend to be refractors, Newtonian reflectors, or "folded" reflectors such as the Schmidt-Cassegrain, (SCT), design. Details of these designs can be found in the introductory chapter of this book. All can be used to very good effect. All have "pros and cons." Maksutov–Cassegrains can also be used, but their longer focal lengths can make things a bit too demanding for the inexperienced.

With any telescope, as for camera lenses, we talk about aperture, focal length, and focal ratio. A relationship exists between all three factors, and each plays a critical role in astro-imaging.

The relationship is described as follows

$$\text{Focal ratio} = \text{Focal length} / \text{Aperture}$$

Aperture

The light-gathering ability of a telescope is determined by the surface area of the objective.

Compare an 80 mm aperture refractor with a 100 mm version. In terms of diameter, the 80 mm objective is 80% the size of the 100 mm. However, when we look at the ratio in terms of surface area, the 80 mm telescope only gives 64% the light-gathering area of the 100 mm version! The 20% difference in diameter makes for a significant percentage difference in light-gathering ability.

Certainly, aperture is important, but in photography it cannot be dealt with in isolation.

Focal Length

Focal length is the distance from the point where light is first collected by the mirror or lens to the point at which it is brought into focus. A longer focal length will yield a higher magnification.

Take a look at Fig. 9.1 and the two pictures of M57, the Ring Nebula. On the left, M57 is imaged at 2,000 mm focal length; the version on the right is at 770 mm focal length. Note how each image varies depending on the focal length of the telescope. Working at 2,000 mm focal length on an F10 SCT gives the highest resolution and the narrowest field of view (FOV). The wider field of view was taken through a 110 mm refractor operating at F7, a focal length of 770 mm.

The longer focal length version is the more demanding image to get just right. The greater magnification will show tracking errors more readily, and image quality can suffer, depending on the quality of the seeing, etc.

Fig. 9.1. A demonstration of the effect of focal length on image size.

Shorter focal length telescopes have greater resistance to the effects of poor seeing and tracking errors.

A narrower field of view means gathering light from a smaller area of the sky, and so our picture will be dimmer for a given exposure duration. Our targets are inherently dim, and so we have to work harder (take longer exposures) to get the same brightness. There is a larger window of opportunity for tracking errors, seeing, etc., to spoil the image.

Focal Ratio

Now this is the important one! Focal ratio is a major factor when choosing a telescope for astro-imaging.

Focal ratio is determined by aperture and focal length. A typical SCT of 200 mm aperture and 2,000 mm focal length is classed as *f*/10.

The relationship is governed by the equation below:

$$\text{Focal ratio}\left(\text{or f / x}\right)=\frac{\text{Focal length}}{\text{Aperture}}=\frac{2{,}000\,\text{mm}}{200\,\text{mm}}=\text{f / 10}$$

Rearrange the equation, and you can see that a refractor of 80 mm aperture and a focal ratio of f/6 must have a focal length of 480 mm. A *lower* "*f* number" describes a "faster" focal ratio. Conversely, a *higher* "*f* number" is "slower." A faster focal ratio will require shorter exposure times to achieve a brighter image, and in this respect focal ratio is more important than aperture. The actual nature of the relationship means that an *f*/10 telescope will require four times as long to achieve the same image brightness as an *f*/5 telescope.

Although a bit of a simplification, an easy way to think of this relationship is as follows. First off, "square" each f number. The *f*/5 and *f*/10 become 25 and 100, respectively. Then divide 100 by 25 to give us the answer 4. This tells us rather neatly how many times longer you need to expose through the *f*/10 telescope to get an equally bright image for a given exposure. It also works the other way around. Divide 25 by 100, and you can say that the *f*/5 telescope needs only a quarter of the exposure time that the *f*/10 version does.

A very important difference between these two telescopes is that the *f*/5 version will provide a wider field of view, (see Fig. 9.1). Consequently, you will often see the terms "fast" and "wide field" used in conjunction when describing a telescope.

Interestingly, if you had a 100 mm *f*/5 telescope and a 200 mm *f*/5 telescope, you would achieve an equally bright image for the same exposure length, despite the difference in aperture. This is dictated by the focal ratio.

Similar focal ratios will produce the same image brightness for a given exposure despite a difference in aperture. The larger aperture of the 200 mm telescope requires a longer focal length to achieve an *f*/5 focal ratio than the 100 mm aperture telescope. This longer focal length means a greater degree of magnification (a narrower field of view) and so light is collected from a smaller area of sky. This is why the *f*/5, 200 mm telescope, having twice the aperture, does not give images that are twice as bright as the *f*/5 100 mm telescope for the same exposure time.

A longer focal length and greater magnification will reveal issues such as tracking errors more readily and so place greater demands on your mount. Also consider that the greater weight and size of a 200 mm aperture telescope will ask more of your mount's performance than a 100 mm telescope.

All of the above does not mean that a faster focal ratio telescope is better than a slower focal ratio telescope. Deep sky targets will vary in brightness and size, and different targets may require different focal lengths and different focal ratios. What is fact is that faster focal ratios will require shorter exposure times and the shorter focal lengths, often associated with faster focal ratios, place less demands on a mount's tracking ability.

Hopefully a picture is starting to emerge – a good starting point in making the task more manageable is a fast focal ratio telescope of small physical dimensions. A focal length in the region of 400–800 mm is a good starting place. An example of such a telescope would be a little 80 mm refractor at *f*/6 or *f*/7. Notable telescopes in this range are those by Orion, Skywatcher, and William Optics. All three offer good color correction, good build quality, and at a reasonable price too. A refractor generally does not have "collimation issues" and allows plenty of focus travel. Do not be put off by a telescope "only" having an aperture of 80–100 mm. Many of the images in this chapter were captured by an aperture in this range.

Of course, this does not mean that no other telescope is suitable. A 200 mm aperture Newtonian operating at *f*/5 has great attributes. The fast focal ratio and large aperture means that it can out perform the little refractor, giving nice bright images with a decent field of view for many astronomical objects. Such a telescope is considerably larger than an 80 mm refractor and requires a lot more care when attempting to image. Figure 9.2 shows a 250 mm, *f*/5 Newtonian reflector with an

Fig. 9.2. 80 mm *f*/7 refractor piggybacked onto a 250 mm *f*/5 Newtonian reflector.

80 mm refractor piggybacked on top. Several images in this book were captured with this set up.

SCTs come in a range of apertures. Quite common are the *f*/10, 200 mm or 250 mm aperture versions by companies such as Meade and Celestron. Indeed many amateur astronomers started with such a telescope. Trying to image at 2,000 mm focal length as a beginner is very difficult, though you can get focal reducers to bring the focal ratio down to a more manageable *f*/3.3 or *f*/6.3 for example. These do make for very versatile telescopes for both viewing and imaging.

The reflecting telescopes (Newtonians, SCTs) do need to be well collimated to give the best results. Refractors are largely factory collimated and require no user collimation unless this has been incorporated into the design.

Another important consideration is the focuser. Is it up to the job of holding a range of accessories absolutely true to the optical axis? Does it have a fine focus control? Can you add an electric focuser to give even finer control, or to even to automate the process? If the focuser is not perfect, can you upgrade or change it at a later date?

These are important considerations. The camera has to be held steady and true. You need to be able to exert predictable fine control. In general, companies are more than aware of the increasing popularity of astro-imaging and do take all of these factors into consideration.

The Camera

What Is a CCD?

At the heart of our dedicated astro-imaging camerais the CCD, a charge-coupled device. Essentially, this is a chip composed of "pixels." Each pixel is a capacitor capable of storing a negative electric charge. As a photon lands on an individual pixel, an electron is generated and stored as a negative electric charge. The total negative electric charge is related to the amount of light hitting that pixel. When each pixel is "read" the resultant brightness on the computer screen is determined by the number of photons registered by each pixel.

Many dedicated astro-imaging cameras are available. Major producers are Starlight Xpress, Santa Barbara Instrument Group (SBIG), and Finger Lakes Instruments, (FLI). SBIG cameras come with excellent software packages that can be used for image acquisition, guiding, and image processing.

Recent and very successful newcomers to cooled long exposure dedicated astro-cameras are Artemis, Atik, and QHY.

Digital SLRs have become more and more popular. With their wide availability and reasonable prices, it has been easier for more people to try astro-imaging with pre-existing equipment. DSLRs use a different technology to capture the digital image – the CMOS chip.

DSLRs have inherent disadvantages, such as the inability to cool the chip. This is overcome somewhat by using dark frames. (More on dark frames later.) The large sensor size and dedicated software has allowed many spectacular images to be produced. DSLRs are covered later in the book.

Cooling

Most dedicated astro-imaging cameras are cooled, many versions to 30°C or more below the ambient temperature. Cooling dramatically reduces "noise" in our images.

We do not like noise. A full explanation of noise requires more time and detail than we have here – but try to think of it as anything other than the photons (signal) you are trying to capture as a valid part of your image. Noise is an inherent part of our image and appears in many ways.

Our CCD chips are very sensitive to electromagnetic radiation. The light we see with our eyes is a narrow portion of the electromagnetic spectrum, and our CCD will register and faithfully display radiation within and beyond the visible range. Noise comes from many sources – heat, stray light creeping into the system, or random cosmic rays. Noise is even introduced by the camera electronics in the process of reading the CCD chip itself.

Our goal is improving the ratio between signal and noise. As you increase exposure length, both noise and signal increase. However, signal will increase at a greater rate than noise. The longer the exposure the better the signal-to-noise ratio. A good signal-to-noise ratio will produce a smoother image that will stand up to more processing to reveal or enhance the detail. A poor signal-to-noise ratio will create a grainy image that will tolerate very little processing before it becomes unacceptable.

Fig. 9.3. Thirty-second exposure of M34.

Fig. 9.4. One-min exposure of M34.

Fig. 9.5. Five-min exposure of M34.

Figures 9.3– 9.5 show 30 s, 1, and 5-min exposures of the open star cluster M34. You can observe a reduction in noise with increasing exposure time. Furthermore, the longer exposure has collected more photons from the dimmest areas, and several stars are resolved that simply cannot be seen in the shorter images. The better signal-to-noise ratio in a longer exposure will allow more assertive processing to be carried out on a typical deep sky object.

8 Bit or 16 Bit?

Dedicated astronomical cameras can be "8 bit" or "16 bit." This relates to the total number of brightness levels between a pixel being completely black (empty/no charge) and completely white (full).

An 8-bit camera has 2^8 steps between black and white. In other words, 2 multiplied by itself 8 times, or 256. A 16-bit camera has over 65,000 steps between black and white and can thus show greater brightness range in your image. This is desired as many deep sky objects have extreme brightness variations within them. An 8-bit camera offers a distinct limitation compared with 16-bit when processing slight differences in brightness levels in an astronomical image.

Quantum Efficiency

"Quantum efficiency" can be thought of as the sensitivity of the chip to particular wavelengths of light. A "QE" of 65% means that for every 100 photons landing on that pixel, approximately 65 will be registered and stored as a negative charge. Approximately 35% will not be registered at all. QE values will vary for different wavelengths of light in the same chip.

In more general terms, the "spectral sensitivity" of a camera is the quantum efficiency across the whole spectrum. Figure 9.6 shows the spectral sensitivity for a Kodak CCD. The visible spectrum boundaries (marked in red) are approximately in the range of 400–700 nm. It can be appreciated that the chip sensitivity extends beyond the visible spectrum.

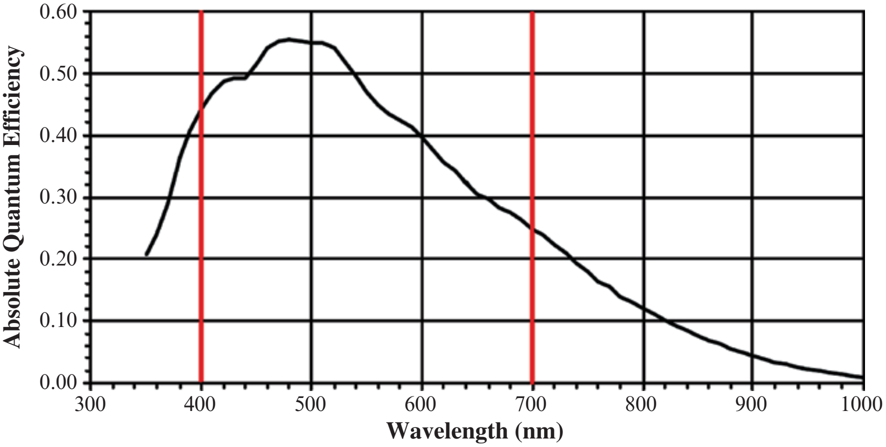


Fig. 9.6. Spectral sensitivity of a typical CCD.

ABG or NABG

Antiblooming gate or nonantiblooming gate? Particularly bright regions of your target can easily saturate pixels during long exposures and "spill" vertically into surrounding pixels – a phenomenon known as blooming. Look at Fig. 9.7. The light from the brightest star has saturated the pixels. Consequently, charge has spilled into adjacent pixels. An ABG camera prevents blooming but at a cost of lower sensitivity.

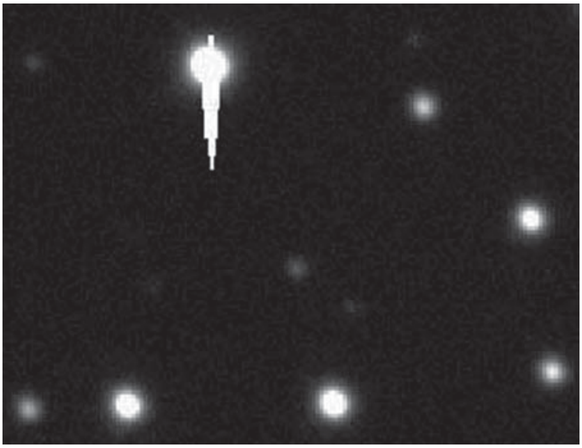


Fig. 9.7. An example of blooming.

Blooming can be repaired at the processing stage but can be time consuming. NABG cameras can be used for valid studies in astrometry and photometry.

Binning

Binning is a useful facility. In Fig. 9.8 each square represents a pixel on a CCD chip. It is possible to group four adjacent pixels together in a square to create one larger pixel. This is known as "2 × 2 binning" and creates a pixel that has four times the area of the original pixel. As a result we get increased sensitivity but at the cost of decreased resolution.

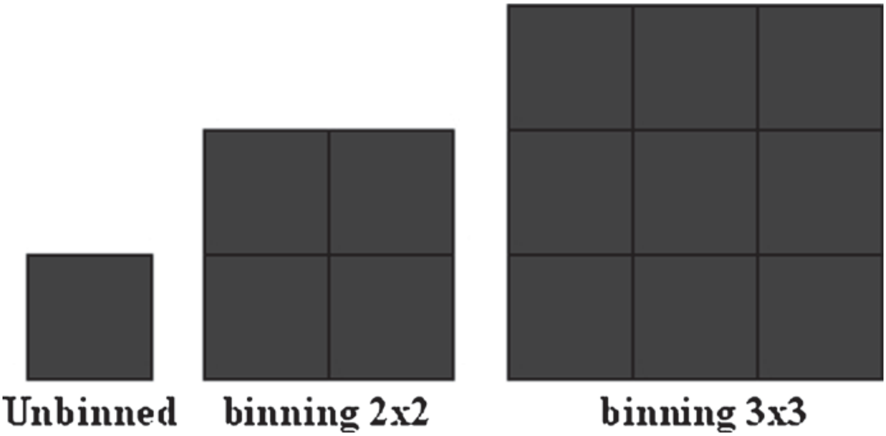


Fig. 9.8. Binning.

Where you see the term 1×1 binning, understand it to mean that no binning has been implemented. Taking an image "un-binned" allows you to get the highest resolution possible from your camera.

Figure 9.9 demonstrates these factors in an enlarged and cropped portion of the Cone Nebula. In the 2×2 binned version the image is brighter, even though exposure times were the same. The 2×2 binned image is smaller and when enlarged to the same size as the unbinned version you can see that resolution has suffered.

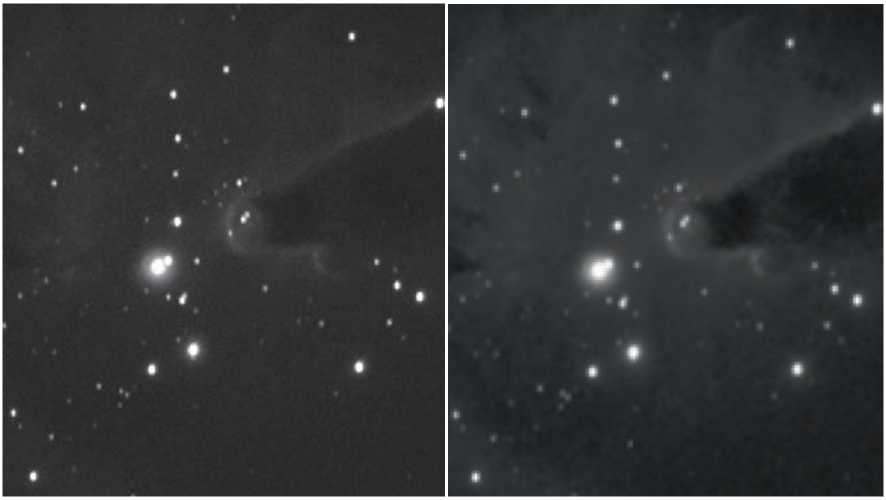


Fig. 9.9. Unbinned and 2×2 binned images.

You can also bin 3×3, (combines 9 pixels) and 4×4 binning, (16 pixels). Because of the faster download times and increased sensitivity, this facility is useful when trying to locate a faint object on a CCD chip, or when framing a target.

Binning at different values will change your image scale. Image scale refers to the amount of sky covered by each individual pixel and is determined by the focal length of our telescope and the size of the pixels. Longer focal lengths or smaller pixels give a higher resolution. Higher resolution images are impacted more by the quality of your mount's tracking and/or seeing. Binning pixels will help get acceptable results when conditions do not permit higher resolution.

You need to match the image scale to the conditions and your equipment. When the seeing is poor or if your mount is not tracking accurately, then do not try to image at 1 arcsec per pixel. When starting off you should try for a telescope/camera combination that allows you to get an image scale of around 2 arcsec per pixel.

As a quick reminder, an arcsecond is a measurement of an area of sky. The apparent size of celestial objects, such as galaxies and nebulae, are measured in terms of arcseconds, arcminutes, and degrees. If you draw a straight line from any point in the sky, continue it through the zenith, right around the celestial sphere, and back to where you started – you have just described 360° of sky.

Each degree can be divided into smaller units. There are 60 arcmin in one degree. Each arcminute itself can be further subdivided into 60 arcsec. A fist at arms' length is around 10°, and the full Moon is around half a degree (or 30 arcmin). The Ring Nebula, (M57), weighs in at approximately 1 × 1.5 arcmin.

1 degree = 60 arcmin

1 arcmin = 60 arcsec

1 degree = 3,600 arcsec

The individual pixel dimensions of a CCD are measured in microns. A Starlight Xpress SXV H9 camera has 6.45 × 6.45 micron pixels. An SBIG ST2000XM has 7.4 × 7.4 micron pixels.

As already stated, focal length and pixel size dictate image scale. To work out the image scale for a particular combination you can use the following equation:

$$\frac{205 \times (\text{Pixel size in microns})}{\text{Telescope focal length in mm}}$$

Referring back to Fig. 9.1, the respective images scales are 0.7 arcsec/pixel and 2.75 arcsec/pixel.

Color or Monochrome

Our raw, unprocessed image is monochrome and will be displayed on the computer screen as a range of brightness values between black and white – a grayscale image.

We construct a color image by software combining individual exposures through red, green, and blue (RGB) broadband filters. Each filtered image will appear as a monochromatic grayscale image where detail and brightness levels correspond to the amount of red, green, or blue light in our target. It is the software combining of these RGB exposures that gives a true color image.

Some cameras are known as "one shot color." In these cameras a "Bayer Matrix" overlies the CCD. In effect, each pixel has a small filter covering it, red, green, or blue (alternatively, cyan, magenta, and yellow).

Using this type of camera means that every individual exposure has color data locked up within it. The raw image still appears as a grayscale image on your computer screen. Appropriate software is used to decode it into separate grayscale images, each carrying information for color channels. Further processing is required to recombine and present a color image.

"One shot color" offers advantages in that you can collect all of your information in shorter time and without requiring a set of filters and filter wheel to hold them. On the downside they have reduced sensitivity over an unfiltered monochrome camera, and you have less flexibility when it comes to selecting how you want to filter your images. Another consideration is that color information is normally lost when you use "binning."

Light pollution can make achieving a quality final image more difficult to attain that an image captured through individual RGB filters.

Many superb images are produced with one shot color camera, as a quick Internet search will testify.

The Mount

Although third on the list the mount, is arguably the most important. Without a decent mount you cannot properly support the telescope, camera and all the required accessories. Accurate tracking is also essential to achieve long exposures. The top end kit (as for cameras and telescopes) can be very expensive. However, a decent mount can still be had for a reasonable price.

Do not retire your current mount straightaway! If it is motorized, get online and see what other people have achieved with the same mount. See what "tuning" has been carried out. A little bit of effort may help you get the most out of your mount. At the very least, you will gain valuable knowledge in understanding the workings and limitations of mounts.

Take care with tinkering and only carry out what you are confident to do. It is no one's aim to damage equipment or invalidate warranties. Having offered that little proviso, I have to say that my greatest learning experience was taking apart a Losmandy G11.

A telescope mount has two axes of rotation positioned at right angles to each other. In a simple "alt-azimuth," mount (altitude and azimuth) the telescope moves up and down, left and right on a level base (see Fig. 9.10).

Fig. 9.10. Alt-azimuth mounted SCT.

On a German equatorial mount (GEM), one axis is aligned to the axis about which Earth rotates – polar alignment. Set up this way the simple up and down movements are translated into movements in right ascension (RA) and declination (Dec). Again, the axes are orientated at right angles to each other (see Fig. 9.11).

Fig. 9.11. Losmandy G11 Equatorial Mount.

In long exposure astro-imaging, it is essential that every star, every wisp of nebula, every last detail can maintain a precise position on the CCD chip. Any deviation detracts from the image quality. Because of quality of build, components, and machining, higher end mounts have fewer tracking issues.

Through gears, the motor is connected to a worm that drives the worm wheel and thus allows the mount to track the sky. Figure 9.12 shows the setup on a Losmandy G11. Worn gears, excessive backlash, debris in the bearings, a worm wheel that is out of round, etc., all contribute to poor tracking.

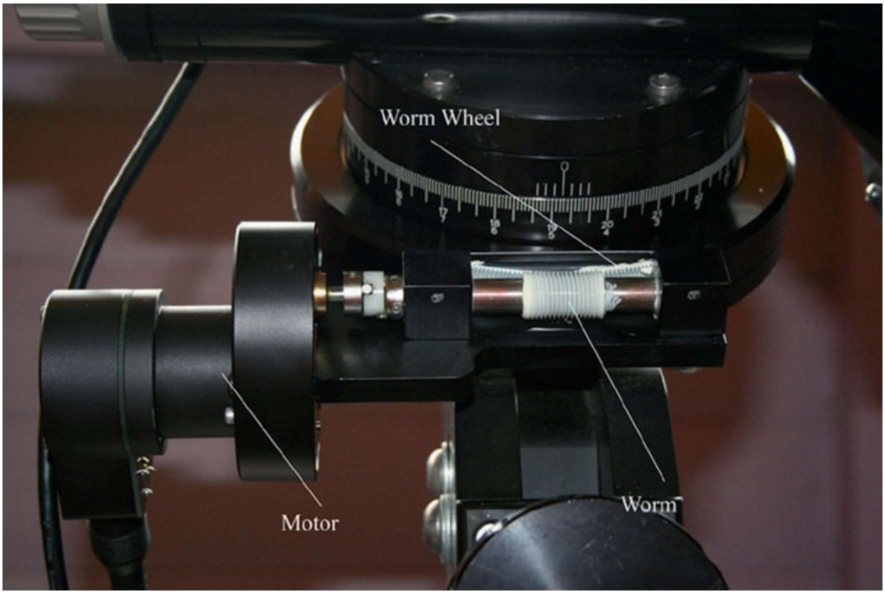


Fig. 9.12. Motor, worm gear, and worm wheel in a Losmandy G11 Equatorial Mount.

You need to identify and reduce backlash. Backlash in this situation can be described as the degree of movement between the worm and worm gear before they actively engage. For the purposes of tracking or guiding reducing backlash is important to maintain accuracy. The worm and worm gear need to be set closely but without binding. If they are set too closely then the mount can seize up and damage may occur. There needs to be a small amount of freedom for smooth operation.

Some GOTO mounts have the capacity to compensate for backlash via settings in the hand controller.

Balance is critical. Making sure that balance is achieved in both RA and Dec is essential. Proper balance will allow the motors to do their job to the best of their ability without suffering any damage due to excess loading. Tracking accuracy is likely to suffer due to incorrect balance. Always balance the telescope with all imaging accessories attached. If your mount is particularly sensitive to balance then you should consider balancing it with respect to the area of the sky that the night's target resides in.

Having said this, it is often a common practice to offset the balance slightly to the east. As your mount tracks in RA, it is constantly moving the telescope from the east to the west. A bias in weight to the east means that the gears are actively engaged, and the mount is more likely to track constantly than have spells when backlash is being taken up.

It is also very useful to tie all of your cables together and route them back to a single point on the mount. Doing this reduces the influence that they have on changing balance during the course of an evening. Finally – *always remember* – tighten clutches after balancing!

Errors in tracking accuracy can be referred to as "Periodic" or "Random" (nonperiodic). Periodic errors (PE), as the name suggests, recur at the same point in the worm rotation. The time taken for a complete revolution of the worm will vary between different types of mounts.

On the celestial sphere, each object has coordinates in RA and Dec. As Earth rotates and the sky appears to move, the telescope must move in RA at precisely the right rate to counter the apparent shift caused by Earth's rotation. Perfect polar alignment would mean that tracking needs to take place in RA only to keep an object centered with no corrections needed in Dec. In real life we do need to introduce corrective changes in both RA and Dec to keep our tracking accurate.

A typical alt-azimuth mount is a long way from being polar aligned! When imaging on an alt-azimuth platform, a phenomenon known as field rotation can quickly appear in our images. On an alt-azimuth mount, the motor drives create movement that is "across and up" rather than tracking in one direction, as it would in an EQ mounting, (the direction that stars appears to move). The end result is that as exposure time increases the field of view appears to rotate. Consequently, star trailing is seen first at the edge of the field of view. This places a limit on our exposure times. The longer the focal length the quicker this effect will intrude.

In astro-imaging, we align images prior to stacking them. Field rotation makes for problems with aligning images due to trailing at the periphery of the image. This can result in heavy cropping to present a decent image.

Figures 9.13–9.16 show four individual pictures of a portion of the western part of the Veil Nebula – NGC6960. This image was taken with an Atik 16iC CCD through a Fastar equipped Celestron Nexstar8 GPS mounted in alt-azimuth and is composed of individual 35 s subframes.

Fig. 9.13. Single image with field rotation (image by Helen Usher).

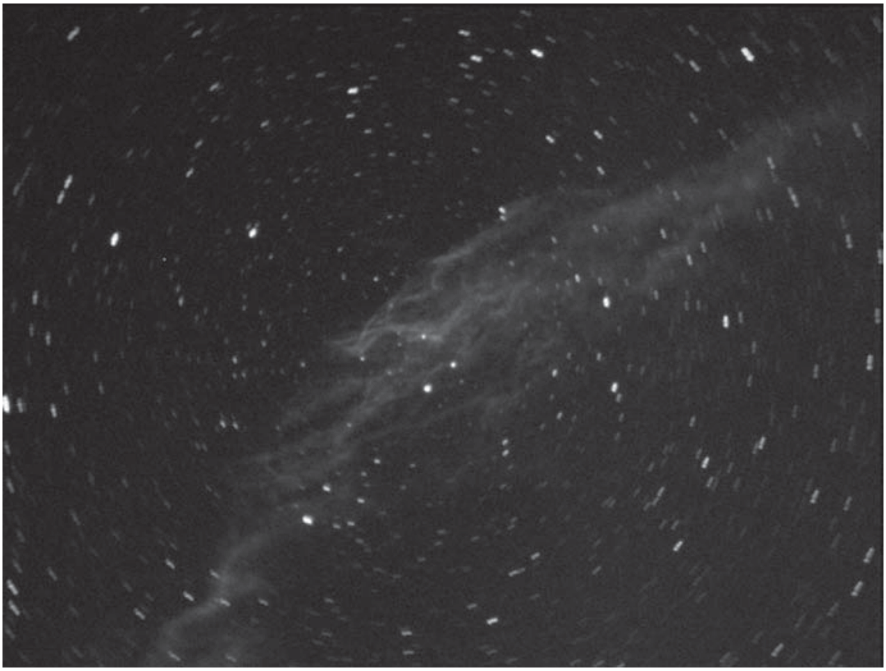


Fig. 9.14. Single image with reduced exposure to avoid field rotation (image by Helen Usher).

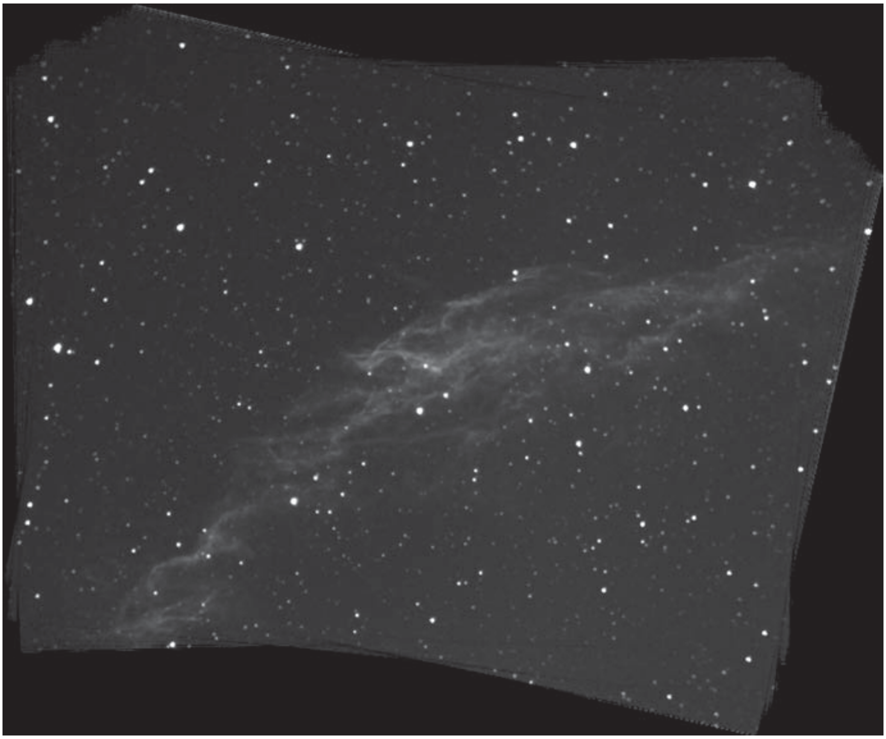


Fig. 9.15. Stacked images with no obvious field rotation (image by Helen Usher).

Fig. 9.16. Final image with crop (image by Helen Usher).

Figure 9.13 is of two exposures stacked without taking account of field rotation; you can start to see the effects toward the periphery. Figure 9.14 is six exposures stacked in the same way, thus making the field rotation rather more obvious. Notice how it spoils the nebula detail. Figure 9.15 is the result of stacking individual exposures in Deep Sky Stacker to take account of field rotation, and in this image the degree of frame overlap is quite obvious. Finally Fig. 9.16 highlights the cropping required to present an acceptable image.

An alt-azimuth mounting does not prevent you from taking images of deep sky objects, as the individual pictures in Figs. 9.17– 9.19 demonstrate.

Fig. 9.17. Image taken through an alt-azimuth-mounted Celestron GPS8 Nexstar SCT (image by Roger Warner).

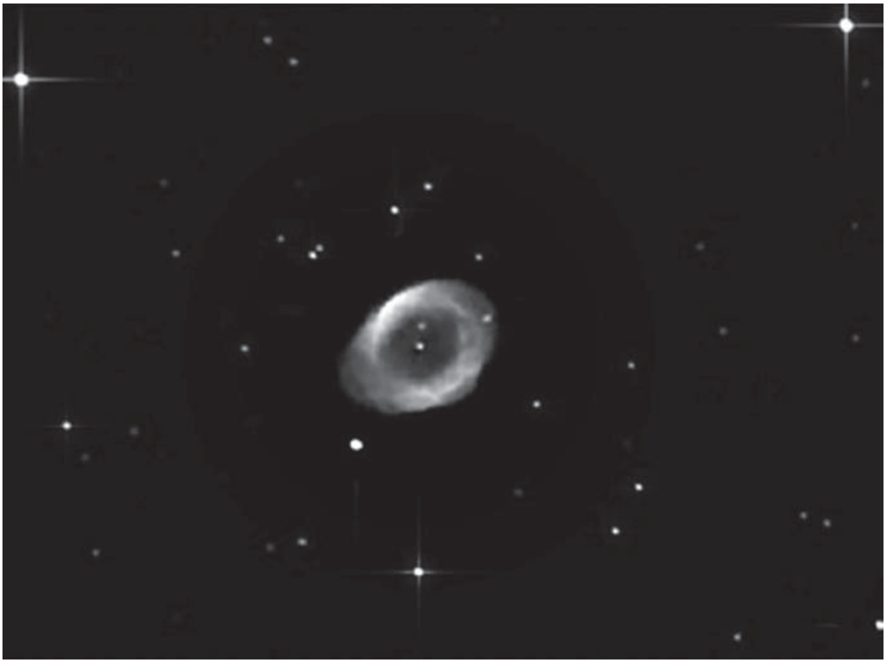


Fig. 9.18. Image taken through an alt-azimuth-mounted Celestron GPS8 Nexstar SCT (image by Roger Warner).

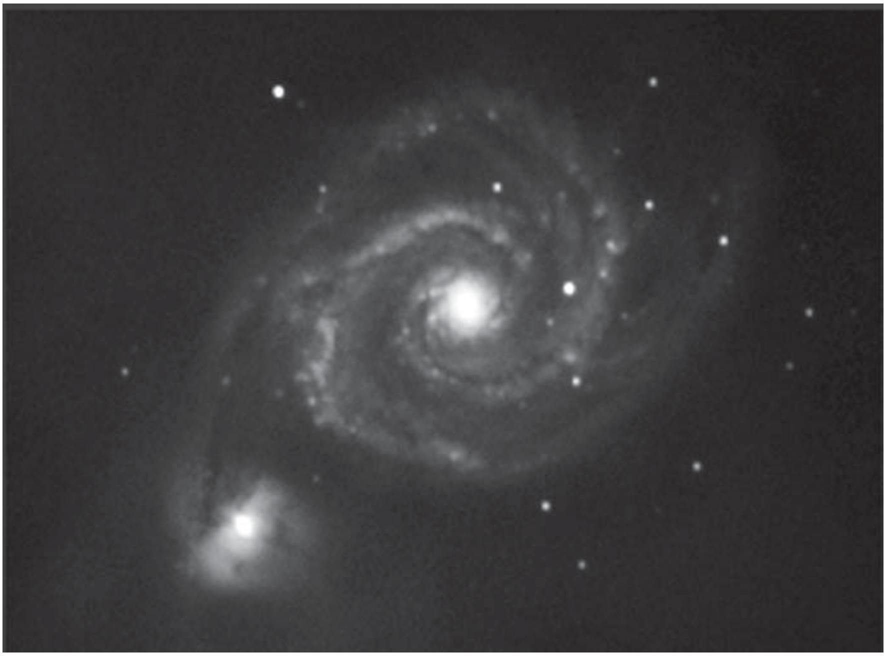


Fig. 9.19. Image taken through an alt-azimuth mounted Celestron NS8 (image by Helen Usher).

Figures 9.17 and 9.18 were taken through an alt-azimuth mounted Celestron GPS8 Nexstar SCT, using an Atik 2HS camera. The subexposures were 45 s.

Figure 9.19 was taken through an alt-azimuth-mounted Celestron NS8, using an Atik 16ic camera. There were sixty 20 s exposures with 2 × 2 binning.

It is possible to use a commercially available "wedge" to mount the telescope so that one axis is then polar aligned, such as in Fig. 9.20. Polar alignment is a precise procedure, and the quality of the wedge can have a big impact on the ease of alignment.

Fig. 9.20. Wedge-mounted SCT.

In addition, if using a fork-mounted SCT, you may find that there are regions in the sky that you cannot access with the camera fitted. This is due to inadequate clearance for your camera and accessories when the optical tube assembly (OTA) is pointed directly up the axis of the fork arms. One big advantage of fork arms, or any driven alt-azimuth mounting, is that there is no need to carry out a meridian flip as you do for GEMs.

On a GEM, field rotation can still occur to a small degree if polar alignment is poor. It reduces the closer you are to perfect polar alignment.

GEMs are capable imaging platforms, but a distinction must be made between the load carrying capacity for visual and imaging. Imaging will often necessitate a greater net weight than visual astronomy because of guide scopes, cameras, accessories, etc. It is also a lot more exacting of the mount's abilities than for visual. Hence, if a mount is listed as having a 20-pound load capacity for visual, take it for granted that it will be less for imaging.

One downside of GEMs is that they can only track so far across the meridian before part of the telescope or camera wants to bump against the tripod! To continue tracking you need to perform a meridian flip. This is inconvenient, as your target will not have the same orientation on your imaging chip after the flip. Also, it is quite normal to have a less accurate GOTO after a meridian flip. One big advantage of fork arms, or any driven alt-azimuth mounting, is that there is no need to carry out a meridian flip. You can track happily right across the meridian.

Decent, affordable GEMs are available, and good examples are those such as the Skywatcher EQ5 pro, EQ6 pro, and the Orion Atlas. They have a decent load capacity, accept auto-guiding inputs, and in general allow quite lengthy subexposures to be achieved across a wide range of focal lengths. They also have "GOTO," which is a real bonus for locating those very faint objects that are not easily visible in the eyepiece. These mounts are pretty good for mass produced mounts. They are also superb mounts for visual astronomy.

Losmandy makes a reasonable mount in the form of the G8, but it has only a moderate load capacity. A much more capable version is the Losmandy G11. Coupled with the Gemini GOTO system, the G11 is very good indeed for an upper end "budget" mount. It is well engineered but can require a bit of "tweaking" to get the best out of it. Unguided exposures at longer focal lengths can be troublesome on some mounts because of tracking errors. However, you will find that auto-guiding can compensate for this very well. Celestron also offers a version of this mount.

Moving up in quality and performance, companies such as Astro Physics, Takahasi, and Software Bisque manufacture excellent mounts. However, considering the typical cost, they are not mounts for a beginner!

No matter how expensive the mount, there will always be some degree of periodic or random error. Whether it reveals itself in the image is the key issue. In reality, for most affordable "beginner" mounts, these errors will become more and more obvious as we increase our exposure times or increase focal length. We compensate for this through "auto-guiding."

Unfortunately, the periodic and random error in some mounts might be too large to be successfully guided out. This may result in being restricted to certain exposure lengths or focal lengths. It might even require the purchase of a new mount.

Auto-Guiding

In days gone by, the patient photographer would sit at the eyepiece and meticulously correct any deviation of a selected star from a predetermined point in the field of view. It only made sense to automate this process!

Fig. 9.21. Guided exposure.

Fig. 9.22. Unguided exposure.

Auto-guiding permits longer exposures, which in turn makes for deeper and smoother images. Figures 9.21 and 9.22 demonstrate the difference in tracking between guided and unguided exposures. In the unguided image you can clearly see the stars are not round. In this case, this is a result of periodic and random errors. In the guided image, appropriate corrections have been sent to the mount , and errors have been compensated for before they detract from the image. But, your mount must be able to accept auto-guiding inputs.

In auto-guiding, a second camera monitors a preselected star. This camera takes regular images that are downloaded to the computer. Software then assesses any movement of our star, (more accurately than we can!), and sends signals to the mount motors to correct the mount positioning in RA and Dec. These signals may instruct the mount to momentarily increase the tracking speed to allow the mount catch up with the guide star. Alternately, the tracking rate may slow to allow the star to catch up, so to speak. Considering this, you can appreciate how important it is to minimize issues such as backlash.

A higher quality mount should require less guide corrections. Furthermore, as guide corrections are sent, a better mount will implement the corrections more accurately. Guide errors being detected and corrections being issued can prove wasted effort if a correction is not implemented effectively by the mount. Too much backlash or overcompensation due to improper balance can mean that guide corrections are ineffective or overly enthusiastic. No matter how good or bad your mount, taking care to set it up correctly is critical for good imaging and good guiding.

A common method is to "piggyback" a small guide scope on top of your main imaging telescope and fit a second camera to the guide scope. Good telescopes for this method are small, fast focal ratio refractors.

Both telescopes must be rigidly connected so that there is no opportunity for any differential movement between either telescope. Nor can there be any differential movement between any part of either assembly that might impact upon the integrity of the optical path, e. g., focuser slop, mirror shift. Guiding software will move the telescope mounting with the aim of maintaining the guide star in its original location. If mirror slip or focuser slop occurs, then the two optical paths may no longer be coincident, and although guide corrections will still occur, they will no longer be correct with respect to the imaging scope.

The Starlight Xpress SXV guide camera and Starlight Xpress Lodestar are commercially available cameras designed specifically for auto-guiding, though the SXV guide camera will only work with Starlight Xpress cameras. Many people have great success using webcams, which are often modified to allow longer exposures, giving a wider choice of guide stars. A good guide camera will be lightweight and have a reasonably sized chip with high sensitivity and low noise.

Many SBIG cameras have a separate guide chip situated alongside the main imaging chip. An "add on" external guide camera for SBIG cameras is also available.

Software applications such as Maxim DL, CCDSoft, and AstroArt do a very good job with the guiding process. Other programs such as PHD guiding and Guidedog are standalone programs and do work very well. PHD (Push Here Dummy!) guiding in particular comes highly recommended; http://www.stark-labs.com/phdguiding.html.

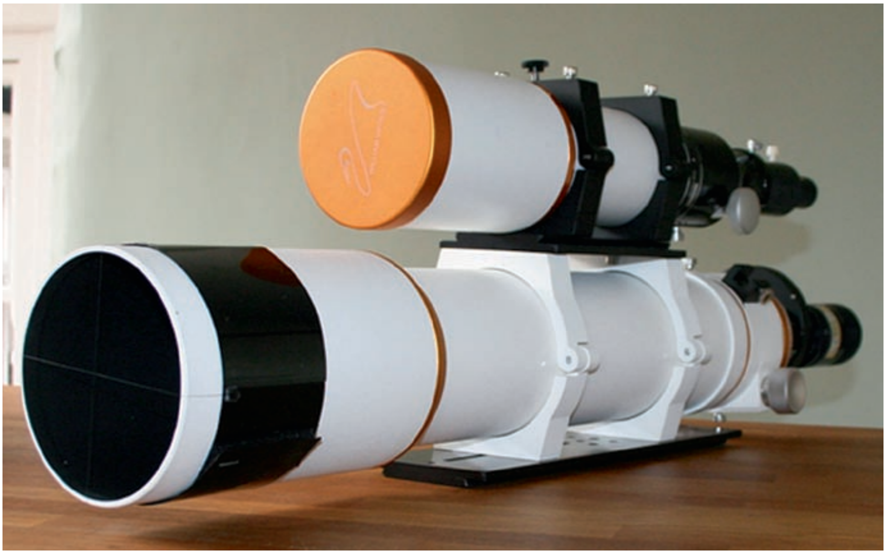


Fig. 9.23. Rigid piggyback mounting.

The guide scope is typically mounted on top of the imaging telescope in a set of adjustable guide rings, as shown in Fig. 9.23. Depending on various factors, a suitable guide star may not be immediately visible, and so the capacity to adjust the guide scope in the guide rings can be valuable. However, given a sensitive guide camera or a "fast" guide scope or a star-rich field, normal tube rings will often suffice, see Fig. 9.24.

Fig. 9.24. Adjustment piggyback mounting.

As mentioned earlier, SBIG cameras can be supplied with two integral chips. One as a main imaging chip and the other as an auto-guiding chip. There are several advantages to this setup. You only need one telescope, and you drastically reduce issues of differential flexure associated with the piggyback set up.

A downside of the two chip camera is that the only guide stars you can use are those that are present within the field of view of your imaging telescope. If there are no suitable guide stars in that area then guiding can be problematic. This is particularly true if you are imaging at a long focal length or through narrowband filters, which will cut the intensity of starlight reaching the chip (more on narrowband later).

Regardless of method, you will often have a tangle of wires issuing from the eyepiece end of your telescope. It is a good idea to tie these all together and route them via a central point somewhere on your mount. These cables hanging loosely off the end will affect balance as your telescope changes position during the course of the evening.

Mount Calibration

It is a very good idea to perform a software-assisted calibration of your mount. Software instructs your mount to undertake a set of movements in RA and Dec. After each movement, an image is recorded. Star movements and subsequent location are analyzed to refine guide corrections. In a sense, the software attempts to learn some of your setup characteristics, and models guide corrections on that basis. This is a very useful tool and will help achieve successful guiding.

Calibration routines are available in the main astronomical imaging programs such as Maxim DL, CCDSoft, and AstroArt.

Taking Your Image

A dedicated astronomical camera typically comes with at least a basic software package that is good enough to get you started. Follow the instructions that come with your camera to get communication between the computer and camera. It is a good idea to practice in daylight. Do bear in mind that this set up is very sensitive to light and so use the shortest exposures when practicing in daylight. Another useful approach is to step down the aperture of your telescope or camera lens so that less light can enter. Once you are happy with the basics have a go at night time.

Focusing

We want perfect focus, since focus accuracy has a huge impact on the quality of our images. Do not rush this part of your evening's work. You should try to avoid wasting a precious night of clear skies and several hours of effort, only to achieve a substandard set of results because of poor focus.

There are two main ways to achieve good focus, software assisted and with physical aids. The physical aids are the quickest and easiest to come to grips with if you are a beginner.

The first step is getting a rough focus. If you are a long way from good focus you will see nothing! To start off, center a star in your eyepiece (preferably a star near your target for the evening). Using high magnification helps to ensure that the star is as central as possible in the telescope's optical axis. Carefully remove the eyepiece and insert your camera. Always make sure that thumbscrews supporting expensive equipment, such as cameras, are securely fastened. It is very likely that the position of your telescope focuser will be different for your camera and your eyepiece, and so when you insert your camera you will almost certainly not be in focus.

Changing the binning level from 1×1 will reduce download times. Try 4×4, set the exposure for a second or two, and instruct the camera Focusings running, rack the focuser in or out until you can see the star (or stars) appear. The star may be obvious from the start, or it might be a large diffuse region of light. As you approach focus this light becomes more and more concentrated in a smaller area, and often you fainter stars become visible. In an out of focus telescope with a secondary mirror, such as a Newtonian or an SCT, the star will appear as a doughnut of light with a dark central portion – see Fig. 9.25.

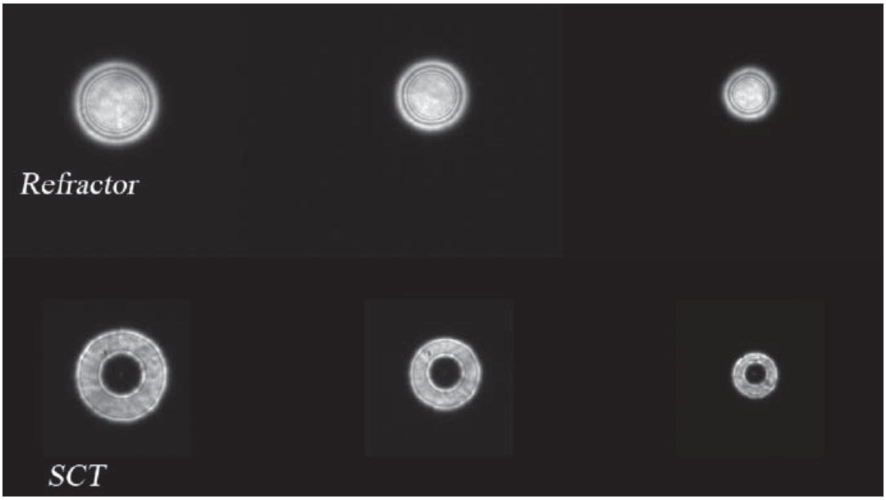


Fig. 9.25. Refractor and SCT views of stars approaching focus.

With focus “almost there,” it is a good idea to recenter the star in the middle of the camera image. When focussing an SCT it is the primary mirror that moves and so you can see the star start to wander off the CCD chip. Re-centering the star is often required.

When you feel the star image is as small as you can get, change the binning to 1 × 1 for the maximum resolution. As a consequence, the download time will increase. To try and minimize this inconvenience, the capture software will often allow you to select a smaller region of your image (a subframe) and download just that portion. Simply select a region encompassing the star. The smaller area of the subframe means quicker downloads.

The closer to focus you are the smaller the adjustments you should make. Make sure that any vibration you have caused in adjusting the focuser has settled before you take the image. Again, capture software comes in handy in that you can set a delay between successive images. This delay should be long enough to allow vibrations to settle.

Once rough focus has been achieved you can try the following options.

Focusing Mask

This is a mask that you fit over the front of your telescope, commonly referred to as a Hartmann mask. A quick Internet search will give you precise details. The following Web address allows you to make a template for your particular telescope.

http://billyard.servehttp.com/Hartmann.html

Cut a disk out of cardboard to fit over the front of your telescope and then cut out two or three holes. The only light that can enter should be through the holes you have cut. Make them the same size and equidistant from each other. They can be circular or triangular – see Fig. 9.26. The black tags are to allow easy placement and removal.

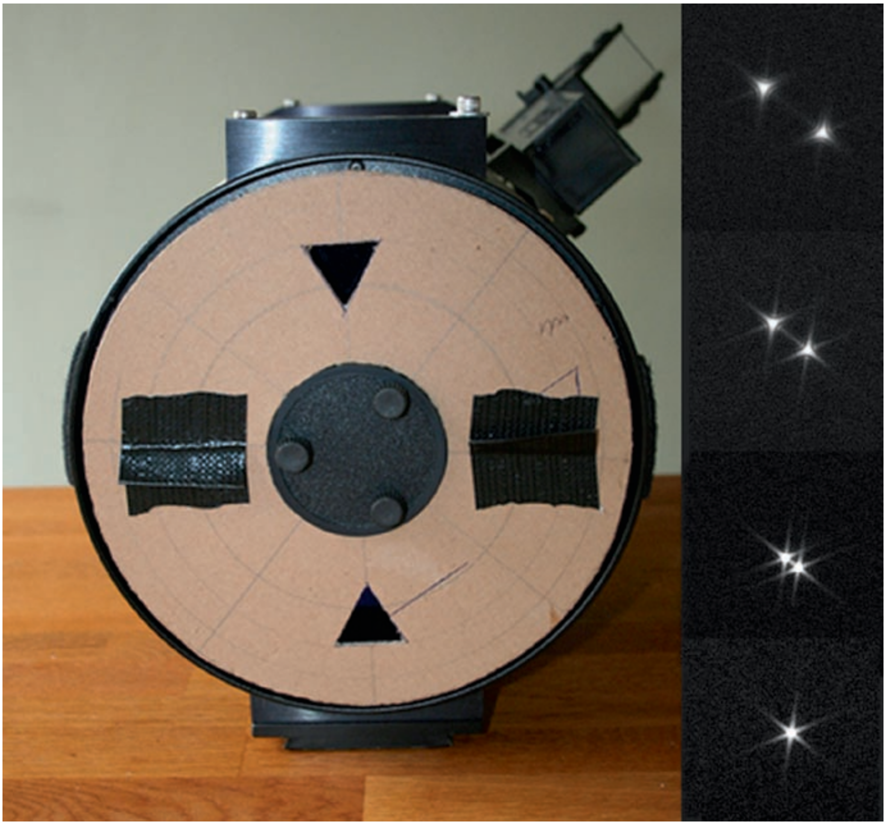


Fig. 9.26. Hartmann mask fitted to an 8"″ SCT.

When the star is out of focus you will see two or three images of that star, depending on how many holes you have cut. As focus is approached the stars merge into one. Focus is achieved at this point.

It is handy to use triangles rather than circles for two reasons: neat edges are easier to achieve than circles; they also generate diffraction spikes.

When you finally start your imaging session, *always remember to take the mask off*. You will almost certainly forget at least once! If you do not, then pat yourself on the back.

Since the writing of this book a very effective version of the focusing mask has been developed by an amateur astronomy the design of which has been made freely available on the Internet. The Bahtinov Mask is commercially available but with a bit of care it can be made at home. An internet search will quickly track down intstructions.

Diffraction Spikes

If you are the owner of a Newtonian telescope, you will be familiar with the diffraction spikes seen on bright stars when you are in focus. This effect is caused when light entering the telescope is diffracted by the spider vanes that support the secondary mirror.

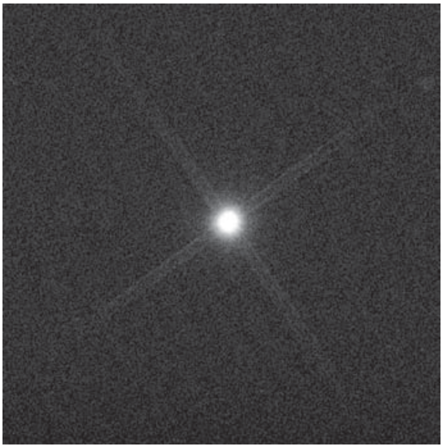


Fig. 9.27. Star out of focus.

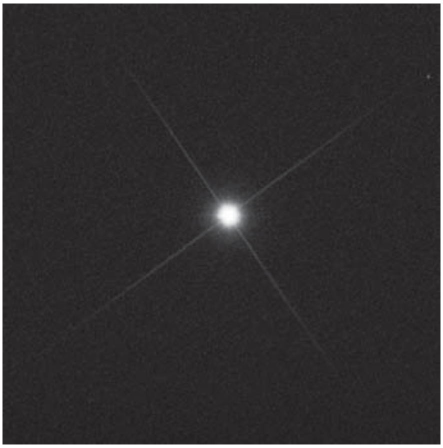


Fig. 9.28. Star approaching focus.

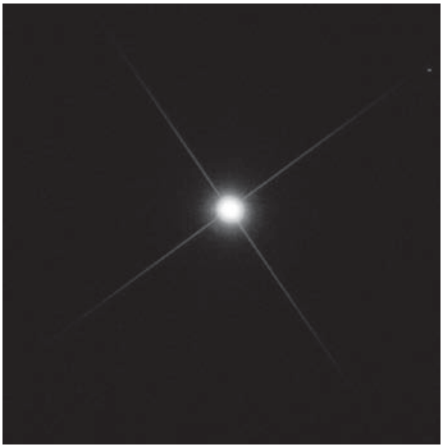


Fig. 9.29. Star in focus.

Center a bright star near your target on your CCD chip and adjust focus until the diffraction spikes are as sharp as you can get them – see Figs. 9.27–9.29. Notice how the faint star becomes visible and well defined as focus is reached.

If you are using a refractor, you can get the same effect by making a set of cross hairs. Make a collar in cardboard, an inch or two wide, which will fit snugly over the front of your telescope. Using string, cotton thread, or fishing line affix two lengths across this collar at right angles to each other. The angle is not tremendously important. As long as the string is taut across the front of the OTA, then you will get diffraction spikes on bright stars when in focus. If the strings are at right angles then the diffraction spikes can lend something of an esthetic component to your image. Of course, this depends on personal preference.

When focus is reached, you may see very dim stars appear. As you pass beyond good focus, these stars disappear again as their faint light is not focused tightly. Dimmer stars appearing is a good visual indicator of correct focus.

Once you have got the focus right, it is handy to note the focuser position for future reference and as a time saving. Many focusers now come with a graduated scale. Setting the camera to this at the start of an imaging session will not give precise focus but can save you a bit of time. If your focus draw tube does not have a scale make a physical aid. For example, cutting a piece of lollipop stick to match the degree the focuser drawtube is extended works pretty well.

Another handy method is to find an eyepiece that is parfocal, or at least close to it. Use of a parfocalizing ring may help refine this.

Software-Assisted Focusing

The major image acquisition programs will have some form of focus assist. A common and useful method is full width half maximum (FWHM).

As you carry out rough focus you will see the star becoming smaller and smaller as focus is approached. We want the smallest, tightest star possible, and by using FWHM we can reduce guesswork that is inevitable through using our judgment alone.

If we could measure precisely from the exact center of the star to a well-defined outer edge, then we could judge properly when the star is smallest, (coincident with best focus). Unfortunately, the effects of our optics and the scintillations of the atmosphere on the starlight mean that we cannot easily identify a discrete outer margin to the star. Added to that, these factors constantly cause the apparent diameter of the star to vary.

FWHM is a software-generated assessment of the width of the star. It measures the pixel values corresponding to the star. These values are highest in the center, where most of the light has been focused, and taper off toward the edge. A bell-shaped curve such as that in Fig. 9.30 carries the brightness profile for a typical star. Taking the maximum pixel value, dividing

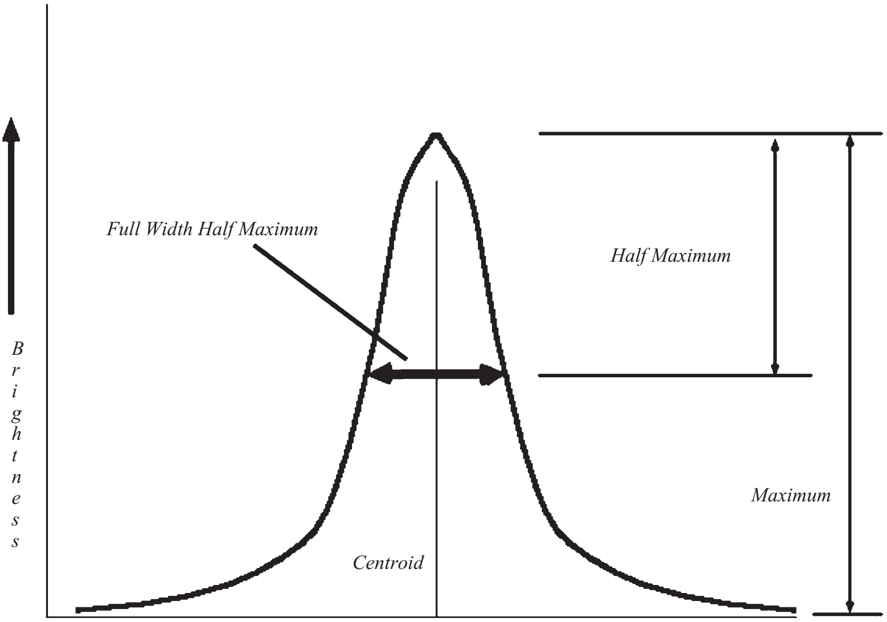


Fig. 9.30. Full width half maximum.

it in half, and measuring the distance these pixels are from the center, gives a method of measuring star width, and so determines when best focus is reached. The lowest FWHM value will be coincident with best focus.

It can be helpful to note the highest pixel value when focusing, as well as the smallest FWHM measurement. The higher the pixel value the better focused light will be. Note that these values may fluctuate from exposure to exposure due to factors such as seeing, so be prepared to take an average.

The reliance of this method on pixel values is why it is important not to use too bright a star. If the pixels become saturated then measurements will be inaccurate. The peak of the FWHM graph will become flattened if the star is saturated.

Filters

Fig. 9.31. M27 taken without filters.

You can certainly elect to use no filters and still manage excellent results. Figure 9.31 shows M27, the Dumbbell Nebula. This image was taken without the use of any filters and represents a stack of ten 5-min images taken through a 110 mm apochromatic refractor from a rather light polluted back garden.

Without a filter we are collecting the maximum amount of photons. This is desirable as our targets are often dim, and our ultimate goal is a good signal-to-noise ratio.

It can be disadvantageous for several reasons. CCDs are sensitive to light that we cannot see. Consider that the majority of telescopes are constructed for visual use and so may not take account of regions of the spectrum such as infrared (IR). If IR light is not brought into focus at the same point as the visible spectrum then the stars will appear bloated on the computer screen. Using an IR blocking filter can reduce this effect and at the same time allow light in the visible spectrum to pass with minimal attenuation.

Light pollution is another area where filters can be of use. Light pollution has several peaks in the visible spectrum and so will add erroneous data to your individual subexposures. This can often be seen in your final image, and the degree of influence depends on how bad your local light pollution is. A light pollution reduction filter (LPR) will selectively block the wavelengths of light commonly associated with light pollution. This benefit is offset by the reduction in the strength of signal you collect and so reduces your signal-to-noise ratio.

If you use a one-shot color CCD, it is wise to research which filters permit the most natural color rendition for that particular camera.

Light pollution will often introduce a gradient into your image. A gradient is simply a difference in the average background pixel values across your image but importantly is not part of the signal you are trying to collect. Light pollution is not equally intense across the sky and will diminish the further it is from the source. Even on something as small as your CCD chip, a difference in the background values from one side to the other can and do result.

A minus violet filter is useful for less well corrected refractor optics where the blue end of the spectrum is not brought into focus at the same point as the rest of the visible spectrum. This can reduce or avoid star bloating as described for the IR end of the spectrum.

Color Imaging

We can use RGB or CMY broadband filters to produce individual exposures that record relative strength of the signal in that region of the spectrum. With appropriate combining, we can create a color image. RGB is the most widely used technique.

Filtering out a large swathe of the spectrum does reduce the signal-to-noise ratio, and so we require long exposures to boost the signal-to-noise ratio and produce a decent image. This can be time consuming and is often interrupted by poor weather and/or limited hours of darkness.

A technique known as LRGB imaging (luminance, red, green, blue) can overcome some of the associated problems. A higher quality (good signal-to-noise ratio) luminance frame is combined with lower quality RGB (binned 2×2, shorter exposures) images to produce a high quality final color image.

The human eye/brain combination works in a particular fashion. Fine detail is resolved in the full spectrum monochrome luminance frame. The RGB frames provide hue and saturation. The RGB signal-to-noise ratio needs to be just as good as the luminance to avoid introducing noise. The eye does not resolve fine detail in the color RGB component as well as it does for the luminance frame. Consequently, we can bin our RGB frames 2×2 to maintain a good signal to noise ratio with shorter exposures and minimal loss of resolution in the final combined LRGB image. Binning 2×2 reduces exposure time by a factor of 4. A good signal-to-noise ratio in the RGB frames is essential to achieve good color saturation with minimal introduction of noise.

You can of course still aim for high quality RGB frames to get the best possible image if time and conditions permit.

LRGB filter sets are available from various manufacturers. An important aspect is that they are all parfocal. As light passes through the filter, the focus point of the light can be changed. It is important for each filter to do this equally to avoid the need for refocusing after every filter change.

The Luminance (L) filter is typically a clear filter that allows all wavelengths through. Having this filter in place helps maintain that parfocal aspect and remove the need to refocus between filter changes.

LRGB filter sets can also be "IR blocked," thus avoiding the need for a separate IR filter to be in the imaging train. If your telescope focuses IR light as well as other portions of the visible spectrum, then you may not need any IR blocking and therefore be able to benefit from a higher signal-to-noise ratio.

Figure 9.32 demonstrates the transmission curves for the Astrodon Type E LRGB filter set.

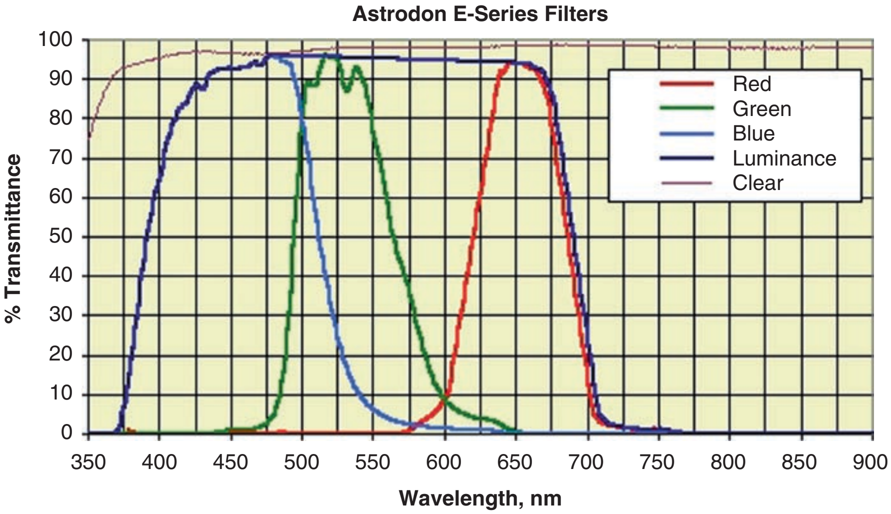


Fig. 9.32. Astrodon E series filter transmission curves.

Narrowband Filters

Certain targets such as nebulae can emit light in very specific wavelengths such as hydrogen alpha (H alpha), H beta, doubly ionized oxygen, (OIII), and SII (ionized sulfur). A filter that allows only a very narrow portion of the spectrum to pass is referred to as a narrowband filter. Figure 9.33 shows the Astrodon narrowband filter transmission curves for Ha, OIII, and SII.

These are very good as they attenuate significantly the effects of light pollution. They also allow good contrast between your target and a dark sky background. However, because they only let through a small portion of the spectrum you often need longer exposures to get a good signal-to-noise ratio and have very limited use on targets such as galaxies.

There are plenty of bright nebulae emitting in H alpha wavelengths to justify investing in such a filter. OIII is also a very good choice as a second narrowband filter.

A wide range of filters are available, and popular brands are Astronomik, Lumicon, Baader, and SBIG Custom Scientific.

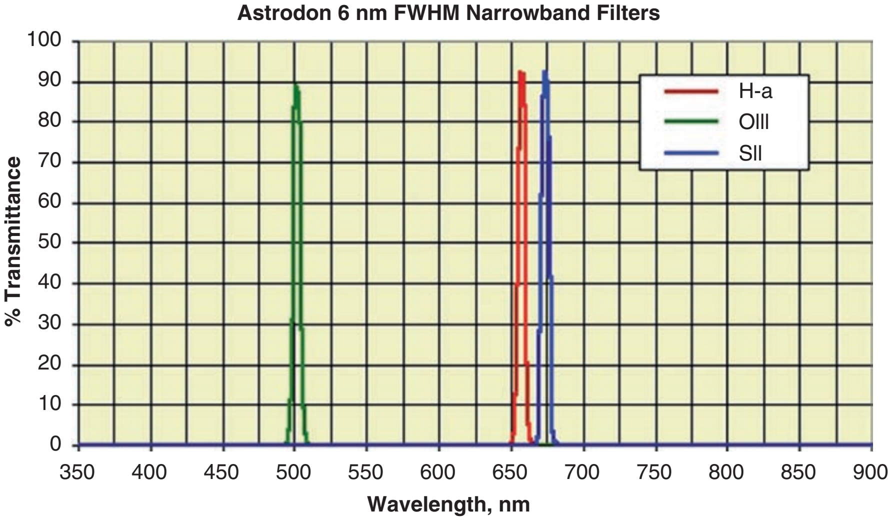


Fig. 9.33. Astrodon narrowband filter transmission curves.

Image Acquisition and Processing

You will probably end up using a variety of software packages. There are many applications available, and they do vary. As your experience grows you will find that you prefer certain programs to perform specific tasks. Some programs are quite expensive, some are free!

SBIG cameras come with a very comprehensive suite of software that will let you do most things associated with image acquisition and image processing.

Examples of general acquisition and processing packages are Maxim DL, CCDSoft, and AstroArt.

AIP4WIN (Astronomical Image Processing for Windows) is a great program for processing your astronomical images. It comes with a very comprehensive book that explains processing in great depth and will answer just about every "how" or "why" one could think of.

Many people use Adobe Photoshop to do a lot of their postacquisition processing. Photoshop is a powerful tool, and the latest editions have the capacity to carry out many functions on 16-bit image files. You can download a very useful 30-day trial. Various similar programs are available. Photoshop Elements is a scaled down version but cheaper. GIMP is a popular free program that is also very capable. Another excellent and free program is Pixinsight, which is a very useful tool for removing gradients and the effects of light pollution.

When using Photoshop, a highly recommended add on is "Noel's Actions." Noel has written a set of excellent plugins that greatly facilitate the processing of astronomical images within Photoshop. Find information here: http://actions.home.att.net/Astronomy_Tools.html

IRIS is a very capable and recommended program. It offers a full range of processing options and is free! http://www.astrosurf.com/buil/us/iris/iris.htm

Image Acquisition

Image acquisition software allows you to instruct your camera to take and download an exposure onto your computer. Most CCDs are packaged with some form of acquisition program. The image itself is downloaded from your camera as a FITS file. FITS (Flexible Image Transfer System) is a format developed by astronomers to share astronomical image data in a standardized form.

Programs like AstroArt, Maxim DL, and CCDSoft allow you to set up routines to capture all of your images. For example, if you want to take 12 subexposures of 5 min each, you simply input the details and get on with other stuff while the computer takes over for the next hour.

These programs will also communicate with your mount, motorized filter wheels, and focusers.

The best advice is to read and familiarize yourself with the particular program you have. They generally come with user manuals either in paper or electronic form as well as comprehensive tutorials.

Image Processing

The simplest way of creating an astro-image is to take a single unfiltered luminance frame. Depending on the target you can get a decent end result. However, combining multiple longer exposures allows you to significantly improve matters.

Figure 9.34 is an image of the Jellyfish Nebula, a portion of the supernova remnant IC 433. Figure 9.35 shows the same image but consists of eleven 10-min exposures that have been stacked. Noise is dramatically reduced, and finer details appear in processing.

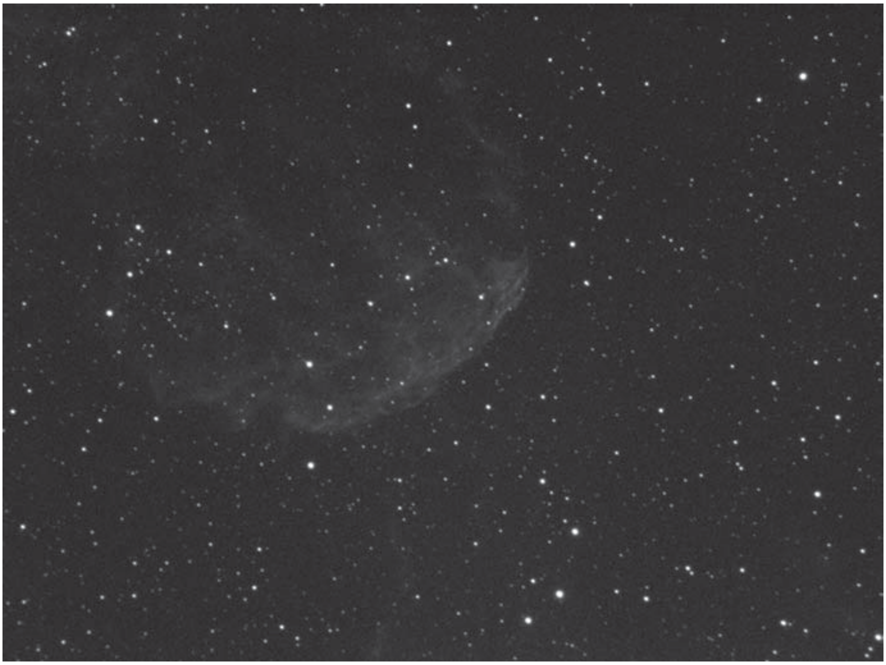


Fig. 9.34. Single 10-min exposure of Jellyfish Nebula.

Fig. 9.35. Stacked exposures of 11 × 10 min.

Before combining your images you need to make sure that all the images are properly aligned. The main software packages make this a breeze, offering excellent automatic processes or giving full manual control. For the sake of simplicity, use the method that automatically matches star position.

It is a good idea to open and carefully inspect all the images prior to starting. Discarding images due to star trailing or other errors is an unfortunate but necessary stage in the process. Poor subs can detract from the final image quality. Once aligned, we can stack the images to create a master frame.

A few typical choices when combining images are:

- "Sum" – simply adds all pixel values.

- "Average" – this adds the value of every pixel and then divides it by the total number of images.

- "Median" – this method takes the middle pixel values and so reduces the impact of pixel values at the extremes, for example, hot pixels and dead pixels. This method is not as accurate as average if the data is good.

- “Sigma Clip” – attempts to get the best out of average and median combines. It does this by only rejecting pixels if they fall a set number of standard deviations away from the mean.

Prior to creating your master frames you can further improve your basic subframes by carrying out image reduction.

Image Reduction/Calibration

Image reduction is the process of applying "Dark Frames" and "Flat Frames" to your basic image (the light frame) in an attempt to improve the overall image quality by removing hot pixels, reducing noise, vignetting, and shadows cast by dust motes. Again, software comes to the rescue as a lot of what follows can be automated.

Dark Frame

A dark frame is an image taken with the camera shutter closed (or with the lens cap over the front of your telescope) to prevent light entering. A dark frame records the system noise – the noise that is inherent in each of your exposures. Taking a record of this noise allows you to remove it from your light frame and create a smoother, less noisy end result. Figure 9.36 is a typical dark frame from a Starlight Xpress SXV H9 camera.

Fig. 9.36 SXV H9 min dark frame at an ambient temp of 15 degrees centigrade.

Dark frames should be of the same duration as your main exposures. They should ideally be taken at around the same time as your light frames to ensure that the chip temperature is as similar as possible. SBIG cameras allow you to specify a chip temperature – a useful feature. Starlight Xpress cameras have very little inherent noise and a lot of images in this chapter have been taken without the use of dark frames. Notice that this does not say without the "need" for dark frames. A dark frame would reduce image noise as well as remove the hot pixels.

As for your light frames, it is better to take several dark frames and combine them either by "averaging" or "median combining" to create the "master dark." It is advisable to take at least three darks if you wish to median combine. As per the common theme – the more the merrier, as no two dark frames will be identical, and combining several helps smooth out the noise.

The combined dark frames are applied to each of your light frames before the light frames are combined. Using our software we subtract the dark frame from the light frame.

Flat Frame

Vigneting, dust particles (dust motes), and internal reflections introduce gradients and shadows and ensure that our CCD chip is not evenly illuminated. Recording flat frames allows us to correct for these problems.

A flat frame is an image of an *evenly illuminated* surface. This can be of the twilight sky before the stars become visible on the CCD chip. A brighter sky can be used if a white t-shirt is securely affixed to the front of your telescope. The t-shirt diffuses the light further and helps avoid any subtle gradients that might present in the early twilight sky.

Any flat, white surface that is evenly illuminated can also do the job well.

Alternatively, you can make a light box. Essentially this is a box that fits snugly over the front of your telescope. The interior should be a uniform white, preferably matt to reduce reflections. The end furthest from the telescope aperture should have some form of light source that evenly illuminates the interior of the box. White light LEDs that run off a 9v battery is a popular set up. They can even travel with you to a dark site if you image away from home.

Figure 9.37 is a typical flat frame.

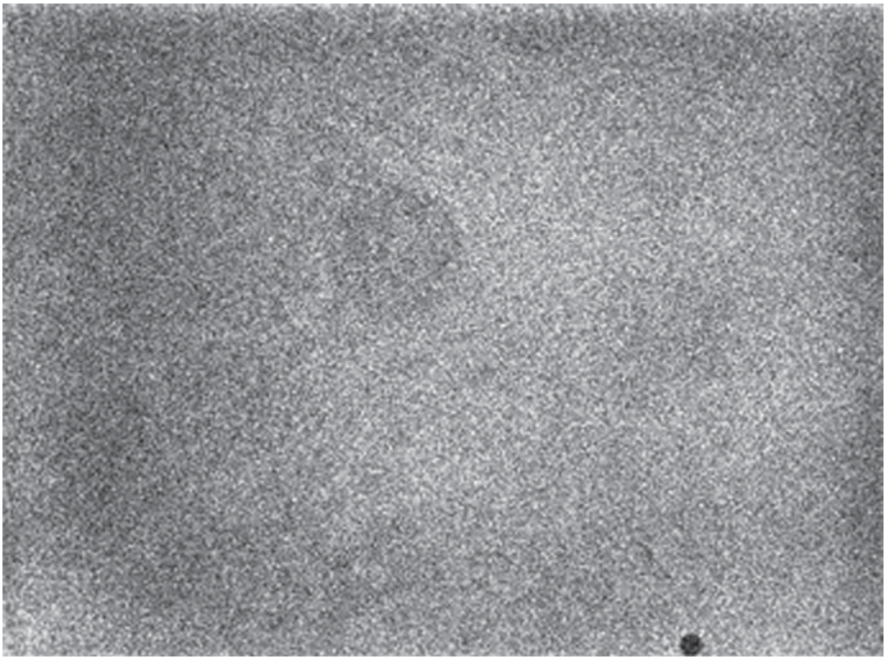


Fig. 9.37. Flat frame.

The aim is to record the pattern of illumination that is specific to your camera, filter, and telescope combination – your optical system.

It is very important not to rotate the camera or adjust focus between the taking of the light and flat frames, as this will introduce problems rather than remove them.

Additionally, as it is very specific to your particular optical system, a flat frame needs to be taken for, and applied to, every filter you have used for that image. So, if you have taken an LRGB image, then you need a corresponding flat frame for each L, R, G, and B filter.

Although a flat frame will tidy up dust motes, it is not the solution if the problem is too pronounced. Therefore, take care to keep your system as clean and dust free as possible.

Flat frames require much shorter exposures than your light or dark frames, usually no more than a few seconds duration. Each CCD chip will require a different exposure length to get the optimum pixel values so that the flat frame is effective but does not overcorrect. The average pixel value of your flat frame must be around a third of the saturation level of your camera. The saturation value will vary from camera to camera and is affected by factors such as the camera being ABG or NABG. To work out the saturation value you need to divide the full well capacity of the CCD chip by the "gain" in the analog to digital converter. This information should be available from the manufacturer of your camera.

Again, combine several flat frames to get a "master flat" with the smoothest data before applying them to your dark subtracted light frames.

Flat Darks

Your flat frames will have inherent noise, and you must minimize introducing that to your light frame. The solution is to take several "flat dark" frames and combine them to form a "master flat dark." Once again, cover the telescope or close the shutter and take several dark frames of the same duration as your flat frames. Subtract these from your flat frame before you apply the flat frame to your dark subtracted light frame.

Figures 9.38 and 9.39 clearly demonstrate the difference that calibration can make. Beyond the fact that Fig. 9.39 has been properly calibrated, both images were processed identically. Vigneting and shadows from dust motes lurk in the image data and lie in wait, ready to spoil the image as processing progresses. Good calibration permits a better job when it comes to processing.

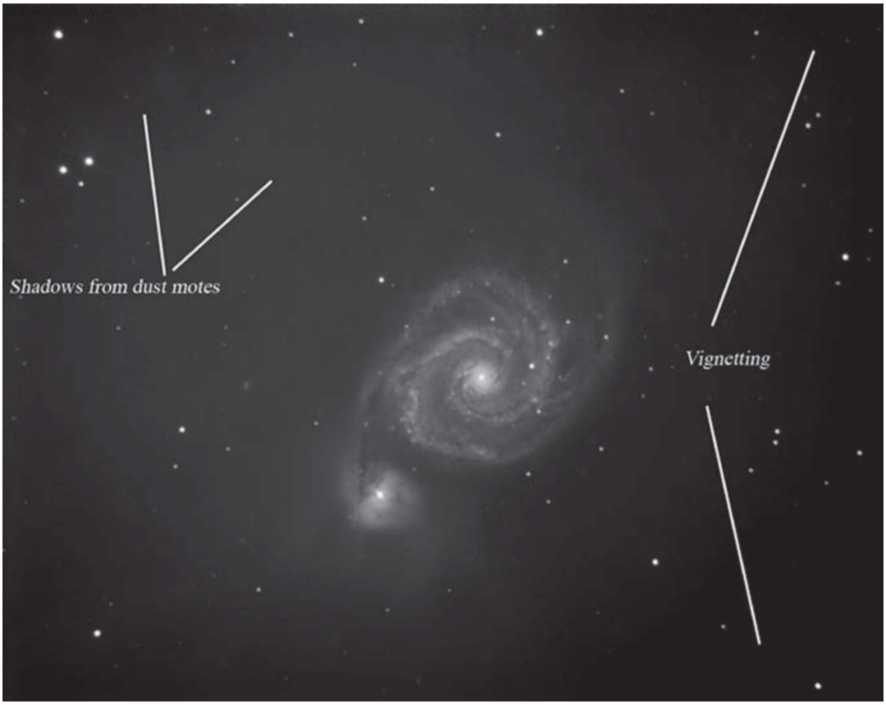


Fig. 9.38. M51 with calibration (Image by Mike Deegan).

Fig. 9.39. M51 without calibration (Image by Mike Deegan).

Order

It is easy to get a bit muddled when surrounded by all of these images. Approach this with a plan, and you will get on fine. Name and save each image in a manner that allows you to quickly identify what it is. It is certainly worth the effort of reading up on how your individual software package allows you to automate this process.

Each light frame should be "reduced" or "calibrated" before the individual light frames are combined.

First subtract the master dark frame. Then divide this by the master flat (that has already had the master flat dark subtracted).

Your final image should be saved as a 16-bit FITS file. That way any processing "errors" you might inflict do not mark the end of the world!

If you are going to export this calibrated light frame from your capture software to another program for processing, you need to decide the format you are going to use. The ideal of course is to be able to transfer it as a FITS file, but unfortunately, mainstream image editing programs do not support FITS files. If you are using Photoshop, then it is essential to acquire a plug-in that allows you to load and process FITS files. A popular one is that found on the European Space Agency Web site: http://www.spacetelescope.org/projects/fits_liberator/. FITS liberator includes some stretching tools that people occasionally find useful.

Another version can be found on Eddie Trimarchi's Web site, http://astroshed.com/fitsplug/fitsplug.htm. This will handle color images unlike the FITS liberator.

Otherwise save it as a TIFF file to minimize data loss and maintain the image as 16-bit. Applying a "stretch" (see below) to the image before saving the image as TIFF minimizes data loss.

Image Processing

Just as important as acquiring good data, processing really brings out the detail hidden within the astro-image.

One of the main steps in processing is to "stretch" the image. The typical computer monitor will display a range of pixel brightness values between 0 and 256. Therefore, the monitor cannot readily display all the brightness levels that our image contain, and so we need to select which pixel values to display. Figures 9.40 and 9.41 show "unstretched" and "stretched" versions of the Horsehead and Flame Nebulae. Both are, of course, the same image, the only difference being that one has been "stretched" – a process that took about a minute.

Fig. 9.40. Unstretched image of the Horsehead and Flame nebulae.

Fig. 9.41. Stretched image of the Horsehead and Flame nebulae.

Any digital image has a range of pixel values. The lower values will be darker on our computer screen and the higher values, brighter. In every image, there will be a certain number of pixels that shares the same value. It is possible to plot a graph of brightness values against the number of pixels with specific values. This graph is known as the histogram.

Figure 9.42 is an imaginary CCD chip that has been used to take an image of a star. This CCD chip is 7 pixels square, and each pixel can have a value from 0 to 3

0 = black, 1 = dark grey, 2 = light grey and 3 = white.

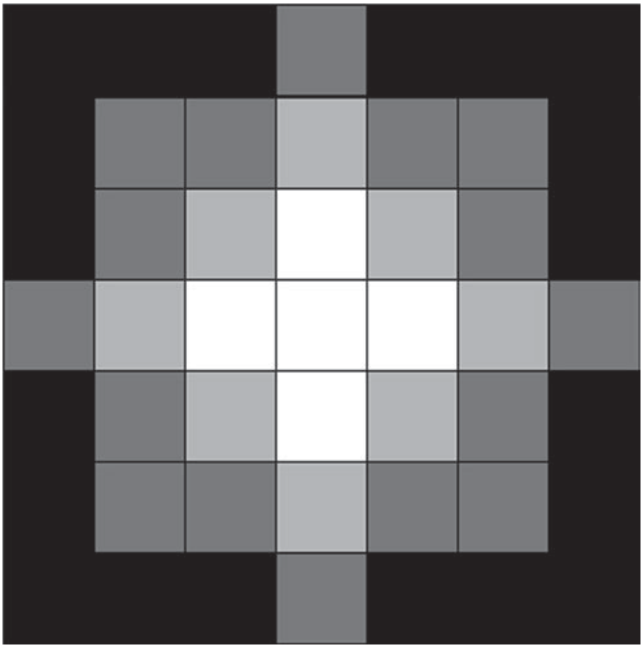


Fig. 9.42. Exposure of a bright star on an imaginary CCD.

Figure 9.43 is the associated histogram for this particular image.

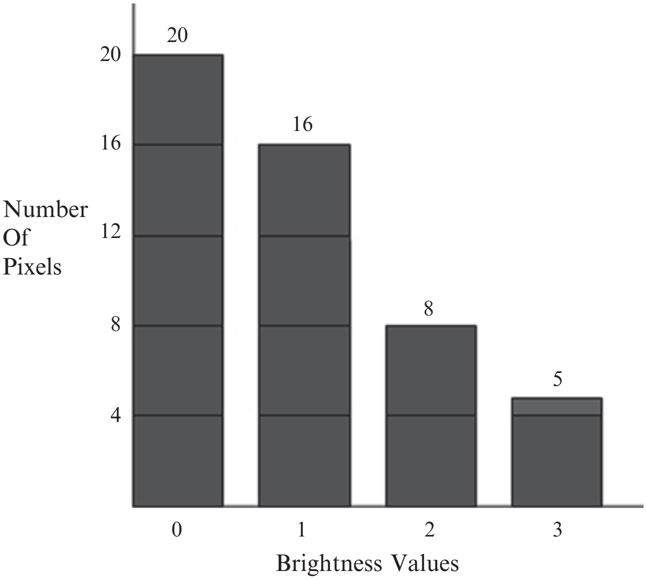


Fig. 9.43. Histogram of brightness values for the CCD chip in Figure 9.42.

Our example is rather simplistic, and in reality a CCD chip will commonly have in excess of a million pixels (and significantly more brightness levels than our example).

When we examine a histogram we refer to the black and white points. The black point is the pixel value below which every pixel will be rendered black on our computer screen. The white point is the pixel value above which every pixel will be rendered white. When we stretch an image, we are selecting the values above and below which a pixel will be seen as white or black.

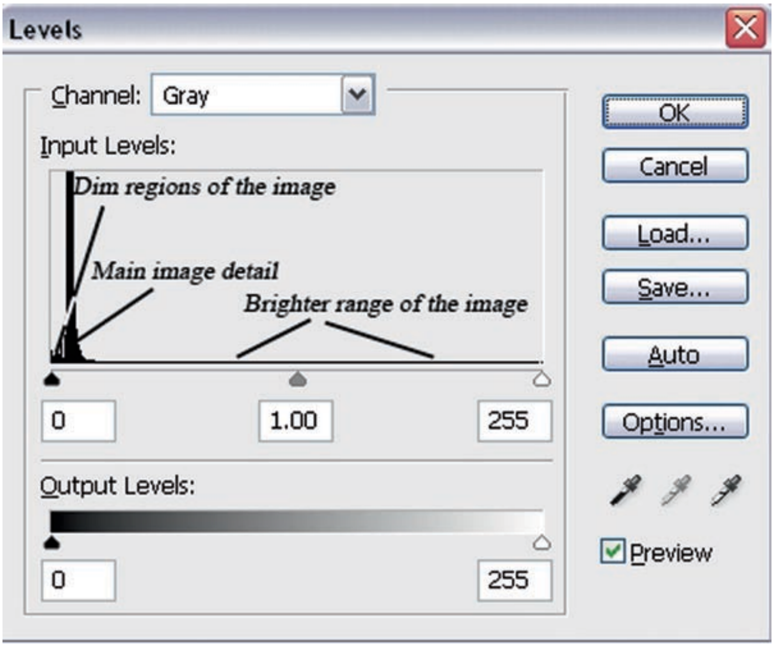
In various image processing programs such as Photoshop, we can decide which brightness levels to select using "Levels" and "Curves." Many photo editing software packages have this property. Photoshop Elements does not come with Curves, though a plug-in is available. Levels, on the one hand, is a linear stretch in that each pixel in the image is modified in the same proportion. Curves, on the other hand, is a nonlinear stretch and will affect different pixels to different extents, depending on the shape of the curve applied.

With these two tools you can do a lot of the processing required to present your image data in the best light. Always duplicate your image and carry out processing on the copy. If things do not go as desired then your original data will not be ruined. A gradual process of repeated adjustment with curves and levels form a large part of your basic processing.

Let us look back at Figs. 9.40 and 9.41 and consider the steps between the two. This is a very general overview to convey the main principles. In addition, the steps at times have been exaggerated to convey the information in the format of a book. In practice you will quickly appreciate the subtle changes that are typical of these adjustments.

The screen grabs are from Photoshop, simply because this is a very popular program for processing astronomical images.

Take a closer look at a typical histogram and try to appreciate the various landmarks. Figure 9.44 is the histogram as it first appears for our Horsehead and Flame nebulae. It does not look like much to begin with. The most obvious thing is the main peak. This area carries information relating to the most substantial part of the image, such as a galaxy or nebula. The peak seems very narrow, as the predominant brightness values in our image fall within a certain range. To the left of the main peak, there may be some small regions visible. These reflect the background of the image and include light pollution, sky glow, dark borders following alignment, etc. To the far right are pixels relating to the brighter portions of the image, such as the stars.



Levels

Channel: Gray

Input Levels: 0 1.00 255

Output Levels: 0 255

☑ Preview

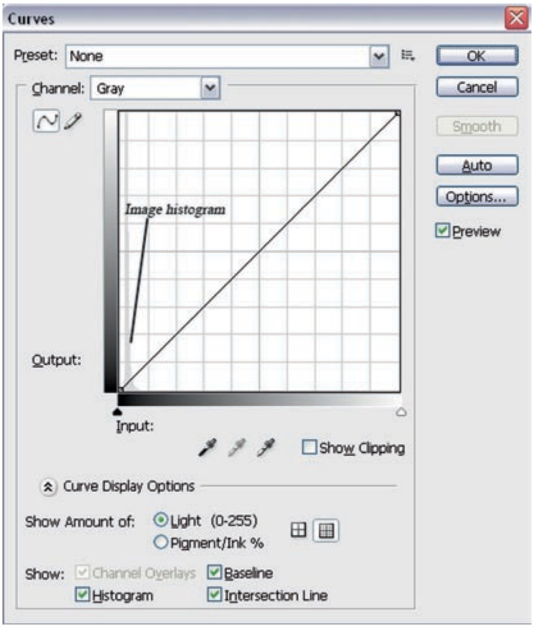
Fig. 9.44. Histogram for the image in Fig. 9.38..

These areas to the left and right may not obviously carry much information. However, they do! This is a consequence of trying to squeeze information for over a million pixels into a simple graphical representation.

It is our job to select which pixel values we wish to identify, and we do this using levels and curves. Although I deal with each separately here, in practice they must go hand in hand, and typically an adjustment in curves is followed by an adjustment in levels. Before applying any of the following to an image of your own, you need to read right through to appreciate how levels and curves work together.

To begin, we carry out a "stretch" using curves. In Photoshop, access the curves function via "Image/Adjustments/Curves." A handy shortcut is pressing "m" while holding down the "Ctrl" key. Figure 9.46 shows the Curves window for the basic image in Fig 9.45. The straight diagonal line represents the brightness levels in the image, with the lower left representing the dim portions of the image and the upper right the brighter portions.

Fig. 9.45. Initial image.



Curves

Preset: None

Channel: Gray

☐ Show Clipping

Show Amount of: ● Light (0-255) ○ Pigment/Ink %

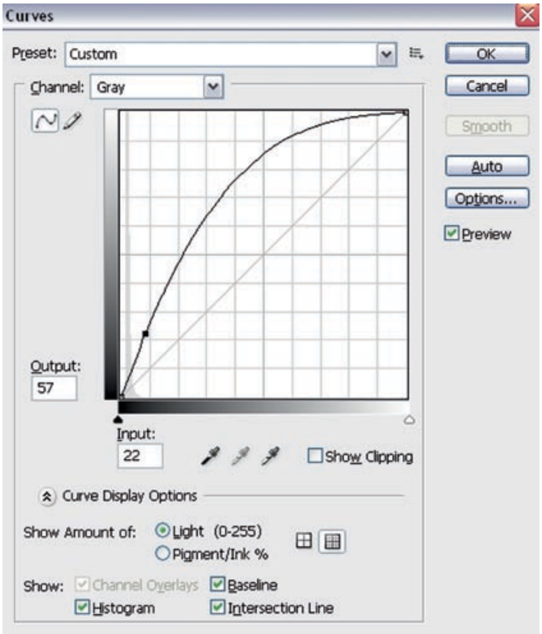
Show: ☑ Channel Overlays ☑ Baseline ☑ Histogram ☑ Intersection Line

☑ Preview

Fig. 9.46. Curves window for initial image in Fig 9.45.

By left clicking and holding the mouse button down, we can select a point on the curve and drag it to a new position. The adjustment of the curve will affect the pixels in a nonlinear fashion. Figure 9.48 shows the first curves adjustment for this image. The biggest change is affecting the dimmer pixels, and we can start to see details emerging in the intermediate image in Fig. 9.47. The whole image has brightened, including the background. We do not wish to emphasize the background too much, and this shall be dealt with through levels a little later.

Fig. 9.47. First curve applied.



Preset: Custom

Channel: Gray

Output: 57

Input: 22

☐ Show Clipping

☑ Preview

Show Amount of: ● Light (0-255) ○ Pigment/Ink %

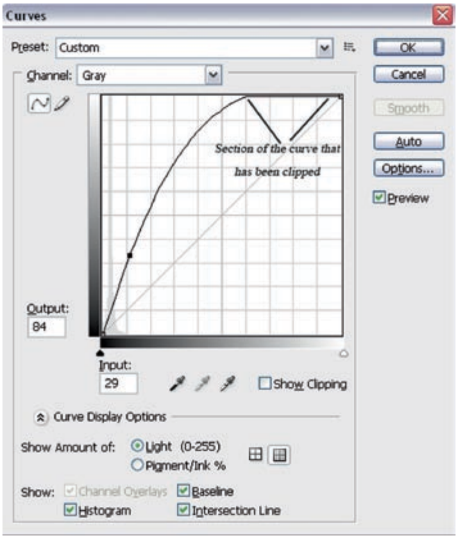
Show: ☑ Channel Overlays ☑ Baseline ☑ Histogram ☑ Intersection Line

Fig. 9.48. Intermediate curve applied.

These examples demonstrate rather strong curves, which are appropriate at the beginning of the process. As you progress in the processing of an image, it is advisable to use gentler and gentler stretches in curves.

Figure 9.50 shows a curve that has been overdone and has clipped the image. (Note where the curve is striking the top right hand side of the box.) Clipping refers to losing image data at the bright or dim extremes, and looking at the associated image you can see that all the detail in the brighter areas have been lost. What has happened is that the value above which all pixels will be rendered white has been set too low. You will need to be more careful. You can avoid this problem by adding a second point to the curve. Simply left click at a second point further up the curve and drag it down so that you no longer have clipping of the white point – see Fig. 9.51. While starting off, try to keep the overall shape of the curve smooth when using multipoint adjustments.

Fig. 9.49. Overzealous application of curves resulting in clipping of image data.



Preset: Custom

Channel: Gray

Output: 84

Input: 29

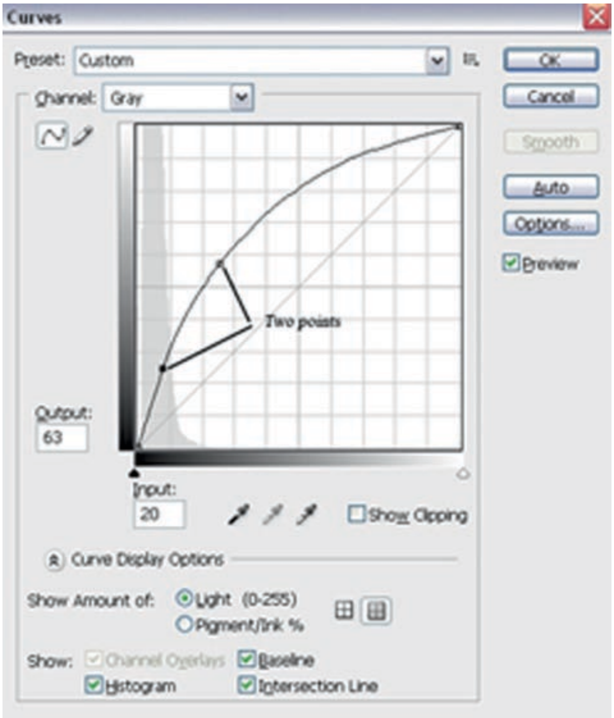
☐ Show Clipping

☑ Preview

Show Amount of: ● Light (0-255) ○ Pigment/Ink %

Show: ☑ Channel Overlays ☑ Baseline ☑ Histogram ☑ Intersection Line

Fig. 9.50. Overzealous application of curves resulting in clipping of image data.



Preset: Custom

Channel: Gray

Output: 63

Input: 20

☐ Show Clipping

Show Amount of: ● Light (0-255)
○ Pigment/Ink %

Show: ☑ Channel Overlays ☑ Baseline
☑ Histogram ☑ Intersection Line

☑ Preview

Fig. 9.51. Use of two points on the curve, allowing greater control in data manipulation.

Each curves adjustment is typically followed by a levels adjustment. One of the simplest adjustments you can make in levels is to raise the black point – i.e., you are setting the values below which all pixels are rendered black. By doing this you are eliminating details that do not contribute to your image. In practice, this is very straightforward, but getting it just right can be quite tricky. A lot of your targets will be very faint or at least have very faint extremes that may not be much brighter than the sky background or local light pollution. Therefore, it is very easy to overdo it and clip detail that you would rather keep. Again, we turn to our part processed version of the Horsehead and Flame nebulae.

Following a curves adjustment, we have brightened both the interesting part of the image (the nebulosity, etc.) as well as the sky background. The brightening of the sky background starts to reveal noise in the image and also diminishes image contrast.

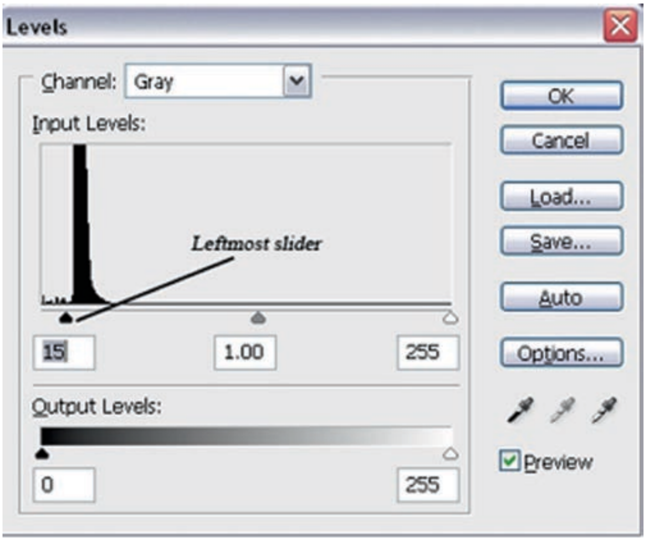
Access the levels function via Image/Adjustments/Levels or the shortcut "Ctrl and l."

With levels you can carefully raise the black point so as to select out the detail you wish to present in your final image. Raising the black point effectively increases the pixel brightness value below which all pixels will be rendered black.

In the Levels window you will find three triangles immediately below the histogram. On the left we have a black triangle, in the middle a gray triangle, and on the right a white triangle. These are sliders with which you can adjust the image in a linear fashion. To begin with the process is simplified through just using the black slider to adjust the black point of the image. An example of this can be seen in Figs. 9.52–9.54.

Fig. 9.52. Image before levels adjustment.

Fig. 9.53. Image after levels adjustment.



Levels

Channel: Gray

Input Levels: 15 1.00 255

Output Levels: 0 255

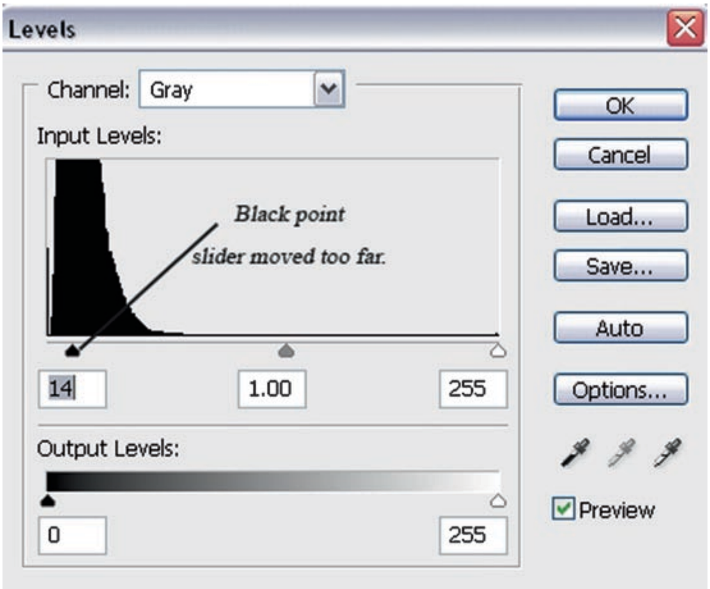
☑ Preview

Fig. 9.54. Adjustment required through moving the black point slider to just before the main histogram peak.

It is important to raise the black slider to just before the main histogram peak. If you move it too far clipping of the black point will occur and image data will be lost. Figures 9.55–9.57 demonstrate the loss of the dimmer detail we wish to retain if a heavy hand is used to raise the black point.

Fig. 9.55. The processed image prior to black point clipping.

Fig. 9.56. Processed image clipped by too great a black point adjustment.



Levels

Channel: Gray

Input Levels: 14 1.00 255

Output Levels: 0 255

☑ Preview

Fig. 9.57. Processed image clipped by too great a black point adjustment.

Each pixel value in the image has a location on the diagonal line in curves. If you open the Curves window and the hover the cursor over any point in the image and left click you will see a box appear over the corresponding point on the diagonal line in curves. Hover over dim and bright areas of the image while holding down the left mouse button, and you will see how the location of the box on the diagonal line changes. By being aware of this and using multiple points in the Curves adjustment you can be more selective about which pixels you wish to display more prominently.

Through several gentle iterations of levels and curves you can tease out the detail without clipping.

After a certain point, further levels and curves adjustment will only serve to clip the data you want to keep. In addition, noise will quickly become objectionable. If you have not yet managed to incorporate flat frames into your image calibration you will begin to see problems such as vigneting and dust motes appearing.

Try and familiarize yourself with these aspects and get a feel for what retains a natural appearance and what looks too processed – every image will be different.

Other Basic Processing Functions

If your processing software allows it, then you can select certain areas of your image to process. You can do this directly by hand with a selection tool such as a "Lasso." Simply use a tool such as this to select a particular portion of your image and apply processing steps to just that area. Remember to be conservative with your changes, as you do not want a stark contrast between the processed and unprocessed areas. If you can "feather" the boundary between the two areas, then do so to make the transition easier on the eye.

Another selection tool that might be available in your image editing software is "color range." You can select areas of the image depending on the pixel values. So, for example, imagine that after the levels and curves process the noise in the dim background areas has become objectionable that you could select this region with the "Color Range" tool or equivalent, feather the selection boundary, and carry out a mild "Blur." Blurring smoothes out the image detail in the selected area and can reduce the appearance of noise. Alternatively, you can select the brighter areas in the same way and apply gentle sharpening to enhance detail that has a better signal-to-noise ratio.

These are the basic and commonly used tools in processing. It is at this point that all your best efforts at collecting premium data come to fruition. If you have poor data to start off with (poor focus or tracking), you have already compromised the final result. If you have decent or very good data, then you can produce a very fine image.

Each image editing suite will have different capabilities and its own particular way of applying each function. The keys things are the following:

1. Before even opening your image editing software, make sure that you have the best data you can – collimation, balance, tracking, focus, etc.
2. Do not effect permanent changes to your raw image data – process a copy.
3. Do not overdo it! Keep it subtle and avoid clipping, and keep an eye on that histogram.
4. Keep your image data at 16 bit for as long as you can.

Color

There are many variations in the method of LRGB combining to form a color image, and only time, practice, and experience will help you decide what suits a particular set of data best. A lot of reading on the subject and Web-based research of other people's experiences will be required.

Each of the previously mentioned astrophotography programs will perform LRGB combining for you. This section describes the main principles involved. There is considerable variation between programs, and as such it is essential to read the tutorials accompanying your particular software.

Each of the LRGB frames should be calibrated. If the RGB images were binned 2 × 2, then they should be resized to match the luminance frame. Before combining, each of the LRGB in the images should be aligned. This is done most easily in your astro-imaging software package, as it will account for any rotation.

At this stage the images can be combined in a program such as Maxim DL, AIP4WIN, AstroArt, Photoshop, etc.

It is quite likely that the background pixel values of the RGB channels will differ. Combining without considering this will create a color cast in the background of the color image. Maxim DL has a "Background Equalize Function" and AIP4WIN has an "Automatic Color" option. Check what options your software offers. In programs such as Photoshop you may need to assess background pixel values in each color channel and raise the black point as appropriate for each channel so that the background is correct.

If you are a Photoshop user the very useful suite of "actions" by Noel Carboni is something of a must. Among many other functions these actions will help carry out an RGB combine.

Digital SLR Cameras

Digital SLRs excel at their primary function of everyday photography and consequently many people own one. They are pretty versatile in terms of astro-imaging in that they can be used with everyday camera lenses, or the camera body itself can be attached to the telescope. They also offer a large sensor. For the astro-imager that large sensor means that larger deep sky objects, such as the Andromeda Galaxy or the Californian Nebula could finally be captured in their entirety without resorting to time-consuming mosaics and other measures. These factors have made DSLRs quite popular among astro-imagers.

Nikon and Canon seem to be the main brands being put to use. Canon appears to be the most popular. Canon produced the 20 Da, a DSLR geared toward the astro-imager. However, its advantages for astro-imaging were a little outweighed by the cost, and it was the Rebel XTi or 300d and 350d that really hit home with astro-imagers.

However, more and more large format astro-imaging specific CCDs are becoming available from the usual companies as well other manufacturers, such as Artemis and QHY. Only time will tell how things progress in this respect.

There are other points to consider. DSLRs have a restricted spectral sensitivity, as their primary use is everyday photography. Manufacturers have placed an IR cut off filter in front of the CMOS detector. Without this measure the color balance of everyday photos would not be right. For astro-imagers, this IR blocker means a reduced sensitivity toward the red, H alpha containing portion of the spectrum. This has an impact on how well many nebulae can be captured.

It is possible to remove the IR cut off filter (warranty warning!) and regain that red sensitivity. If you do this you can still achieve correct day-time colors, but only if you set a custom white balance. Unfortunately, the ability to use the auto-focus is lost.

There is also the issue of noise. The chips are not cooled, and so hot pixels and noise in the image are problems, meaning that dark frames are essential. In addition, the CMOS chip is not as sensitive as a CCD.

DSLRs tend to be in the 10- to 12-bit range, with less tonal depth than a dedicated 16-bit CCD. The more recent versions are 14 bit, and certainly the gap is narrowing.

With a DSLR you can typically change the ISO setting and thus the sensitivity. The higher the number (for example 1,600 as opposed to 200) means greater sensitivity but at the expense of a noisier image. Experimentation will decide what setting suits your target, location, skies, telescope, etc.

There are two freeware programs that many astro-imagers are successfully using to process their DSLR acquired astro-images: Deep Sky Stacker by Luc Coiffier can be downloaded from http://deepskystacker.free.fr/english/index.html. IRIS by Christian Buil can be downloaded from http://www.astrosurf.com/buil/us/iris/iris.htm.

Deep Sky Stacker can align your images and calibrate them with dark and flat frames. It can also assign a quality score to your images and stack only the best 80%, for example.

Where Deep Sky Stacker offers just a few processing options IRIS offers a full range of processing options, making it comparable to programs such as Maxim DL or Photoshop. IRIS is a bit more “hands on” in that it is command line driven. This takes some time to get to know and get used to. However, it is free and it is very well regarded.

Either program is a very good way to manage the calibration, alignment, and stacking of your deep sky images.

There are a couple of aspects of astro-imaging unique to using a DSLR camera for astro-imaging.

When you press the shutter button the mirror flips up to allow light to hit the sensor. This will cause vibration and potentially introduce blurring at the start of your image! If you have a mirror lock up facility then make sure that it is enabled. Once enabled, the first press of the button flips the mirror up. On the second press, and after vibrations have settled, the shutter opens, and the exposure begins. Using a remote shutter release minimizes vibrations imparted by your finger depressing the button. Alternatively, you can simply cover the telescope aperture by holding something dark over it for a few seconds after you have pressed the button. In that way you prevent any light entering until after the vibrations have dissipated.

Second, DSLRs are typically powered by battery. Make sure that you have a fully charged battery and even a spare to keep you going! It is worth noting that these can be powered by dedicated power supplies.

Another point is that you must set the camera to record in RAW format. RAW simply means unprocessed. The standard setting sees the image data converted to JPEG format, resulting in compression and loss of data. Certainly in the Canon range of cameras when you set it to RAW, the image is saved in both RAW and JPEG, using up precious room on your memory card. Make sure you have enough room or an extra card!

Focusing can be a little challenging. Given a bright enough star the diffraction spike method works very well. A Ronchi grating supplied by Stellar Technologies works very well in getting focus, and the Web site is well worth a look:

http://www.stellar-international.com/

The previously mentioned Hartmann and Bahtinov masks are very useful.

Webcam Imaging

Webcams can capture brighter deep sky objects but are limited in their ability to do so. Modifications are necessary to allow longer exposures so as to capture anything other than the brighter deep sky objects. As per the recurring theme, longer exposures without cooling make for a poor signal-to-noise ratio.

Another limitation is the small chip size, which offers an inherently small field of view.

Where they do stand head and shoulders above the crowd, though, is in planetary or lunar imaging. Certain webcams are more popular than others, with the now discontinued Philips Toucam Pro being an initial and subsequent long-term favorite. A quick Internet search will reveal which of the latest incarnations are being put to good use. At the time of writing DMK versions with Firewire connections are popular and producing excellent results. Major benefits of the humble webcam are that they are relatively inexpensive and the AVI file format used is a common one. Furthermore, given that your targets are the Moon and bright planets, it is possible to get a high signal-to-noise ratio with short exposures and an uncooled chip.

General requirements are as follows:

1. High speed connection – USB 1.1, USB 2, or Firewire

2. More sensitive CCD chip rather than CMOS

3. Removable integral lens assemble

The faster the connection the more frames per second you can acquire. In planetary imaging you are working at long focal lengths to get a high magnification. This can exaggerate problems such as seeing/atmospheric turbulence. Periods of poor seeing are interspersed with moments of good seeing, and the higher the frame rate, the more likely you are to capture images at a time of good seeing. Also, a planet such as Jupiter will rotate during an imaging session, and it does not take long (depending on your image scale) until surface features have moved enough to reduce image clarity. This can be as short as 2–3 min for Jupiter. Mars can also be quite harsh in this respect, though Saturn is a bit kinder given its lack of large scale surface features.

The lens assembly should be removable and allow the ability to fit an adapter to connect it to your telescope. This will also give you the option of fitting a filter such as an IR blocker.

It is possible to "rechip" webcams, removing the standard CCD or CMOS chip and putting in its place a monochrome CCD chip. This gives greater sensitivity. However, this is at the cost of needing to image through RGB filters to assemble a color image. This section concentrates on the use of the color chip that is integral to standard webcams.

To begin with, avoid the use of Barlow lenses/image mates/eyepiece projection, etc. Keep it simple. A small chip and high magnification can make finding and focusing on a planet quite a challenge.

When starting out try to stick with the software that comes with the webcam to capture your AVIs, as it is often simpler to use. Other astronomy specific software is readily available on the Internet and a fine example is K3CCD tools (http://www.pk3.org/Astro).

Make sure that your computer and webcam are communicating well. Disable any sound capture in the software, and set the capture format to full frame for best quality. Make sure that you have plenty of room on your hard disk, as you can quickly capture AVIs of thousands of frames that will take up a lot of your computer's physical memory. The frame rate of capture will depend on your PCs capabilities and the camera/connection type you have. If you go for too high a frame rate, there might be some data compression as your computer tries to keep up.

For focusing, you can refer back to the previous section on focusing for more detail to flesh out the quick summary below.

Locate a bright star close to your target. Failing that, a lunar crater can be used. The planet itself (or even one of its moons) can also suffice in good conditions. Center the star in a high power eyepiece and then swap the eyepiece for your webcam and start the capture process. Hopefully, you will have something on your screen. Do remember that being a long way from focus can make the light so diffuse that you may not easily tell that you are pointing at a star at all! Racking the focuser in and out will hopefully bring the star to approximate focus and confirm that you are pointing in the right direction. If this is not the case then replace your eyepiece and confirm that you are still pointing at the star. Having a well aligned finder can be invaluable.

Another reason for seeing nothing on your screen could have to do with the capture software settings. Adjusting the gain and brightness setting to near maximum will help tell if the star is centered on the chip. Disable any auto exposure setting as the webcam is, of course, designed for daytime use. Once you have clearly identified and focused the star return the gain and brightness to original settings, and be prepared to experiment with these settings.

Getting the star as small as possible or the image as crisp as you can is the aim. If you have a bright star then you can use a Hartmann mask or diffraction spikes as well as software-assisted focusing such as FWHM.

At the end of the focusing procedure, try and make a parfocal eyepiece for future use.

Once you have focused you can point the telescope at the planetary target and begin image capture in earnest.

Once you are more familiar with the basics you can start to increase the focal length by using a telescope with a longer native focal length. Alternatively, use of Barlow lenses, "image mates," and eyepiece projection can permit a larger image.

Be content to let your images start off on the dim side. If you begin too bright, then this is only going to be exaggerated in later image stacking and spoil your results.

Processing Your Planetary Images

Using a program such as Registax this task becomes very straightforward. Registax is the creation of Cor Berrevoets and has the added bonus of being freeware! Details can be found at http://www.astronomie.be/registax/.

Figure 9.58 shows good and poor quality individual frames from an AVI and the final result of a stack of several hundred individual frames.

Fig. 9.58. Frames of Saturn from a stack of several hundred individual frames (image by Mike Deegan).

The general idea with a program such as Registax is to select the good quality individual frames from your AVI, coregister, and stack them before final processing in Registax.

Figure 9.59 provides another example of what can be achieved with an unmodified Philips Toucam web camera.

Fig. 9.59. Double transit. June 2005, 8"″ SCT, un-modded Toucam (image by Ed Sampson).

The following workflow is courtesy of amateur astronomer and astro-imager Mike Deegan. It applies to version 3, though version 4 is due for release in the near future. The numbered descriptions match those superimposed on the screen grabs. (You will notice Mike Deegan's name attached to a few of the deep sky images at the end of this chapter.)

Basic Planetary Processing with Registax3

1. Check color in the USE box.

2. Set pixel area to 1024 in the processing box and pick a good frame from the AVI using the “Frame” slider at the bottom to move from frame to frame. (Once you have clicked on the slider you can also use the left/right arrows to move from frame to frame.)

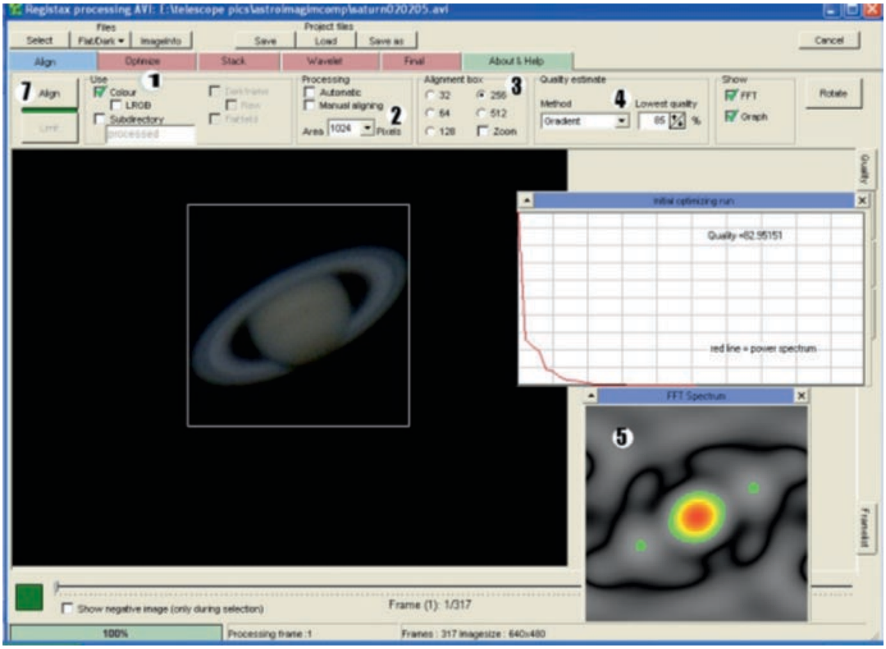
3. Select an alignment box size to cover the planet (in this case a box size of 256 was used). Cover the planet with this box using the mouse (left click to set the box position).

4. Set method to gradient and lowest quality to 85%.

5. FFT spectrum is left automatic.

6. All other settings are left default.

7. Press the align button. After the program has finished aligning the frames the initial optimizing run window will show the frames to be processed, (green line). If you want to use the best possible frame for alignment you can open the frame list tab and select the first frame in this list. This frame is the best quality frame in the AVI; use this frame to repeat steps 3–7.



Registax processing AVI: E:\telescope pics\astroimagincomp\saturn020205.avi

Area 1024 Pixels

Method Gradient

Lowest quality 85 %

Quality =82.95151

red line = power spectrum

Frame (1): 1/317

100%

Processing frame :1

Frames : 317 imagesize : 640x480

Fig. 9.60. Steps 1–7 of basic planetary image processing.

8. At this point, the number of frames to be processed can be increased or reduced by moving the slider at the bottom. Moving it to the left reduces the number of frames to be processed, to the right increases this number.

9. As you move the slider you will notice the individual frames will be shown in the image window. This is useful in being able to select the percent of frames that still show good detail.

10. When you are happy with the selection of frames to be further processed, press the "limit" button.

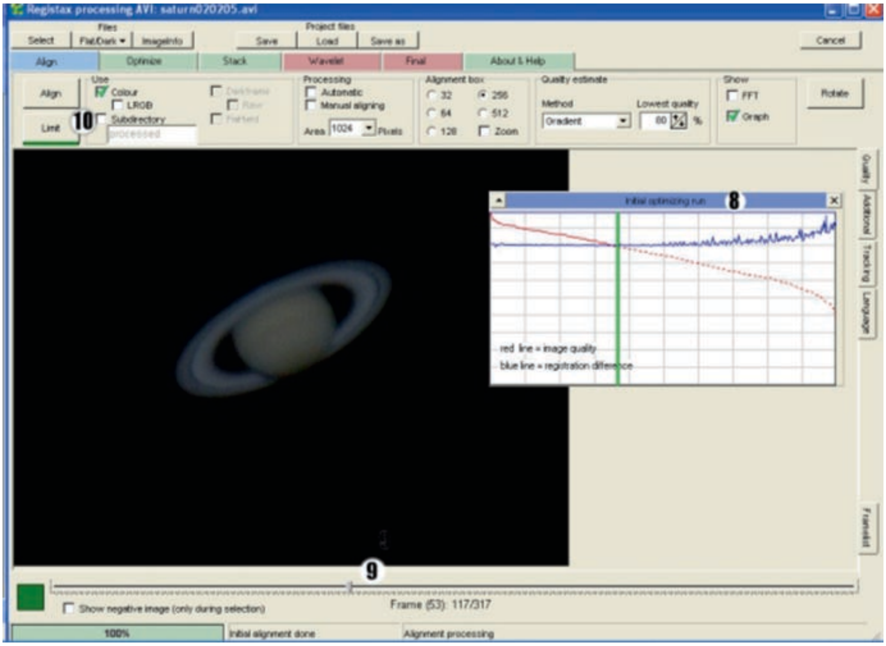


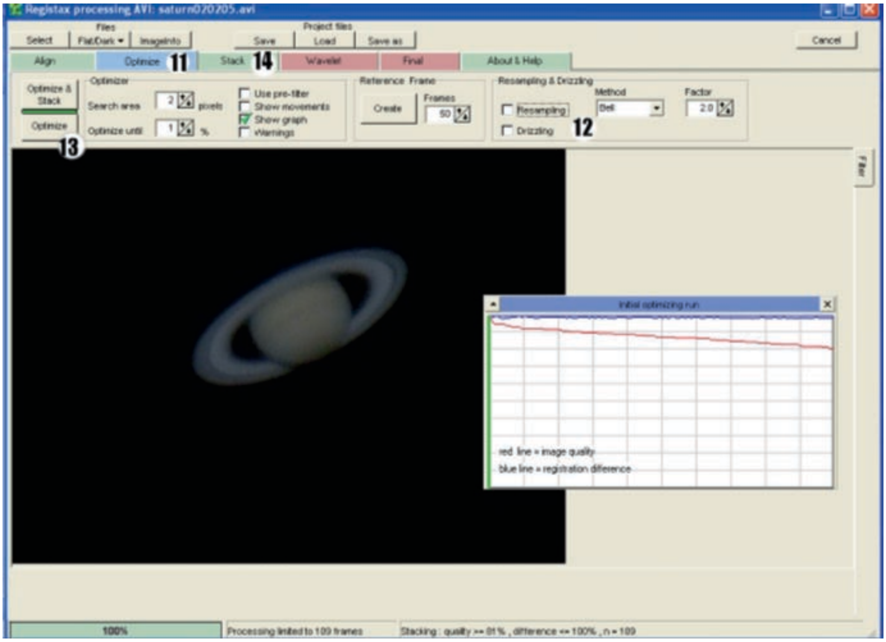
Fig. 9.61. Steps 8–10 of basic planetary image processing.

11. The program will then move you on to the Optimize section. Here you can create a reference frame to be used to optimize, though for the purposes of this basic introduction this will be omitted. (You can try it once you are familiar with the rest of the processes described here.)

12. You can also resample your image to a new size by selecting “resampling” or “drizzling” and setting the factor to your required size (for example, 2.0 = 2×).

13. Next press the “optimize” button.

14. Once the frames have been optimized move to the next section “stack.”



Search area 2 pixels

Optimize until 1 %

☐ Use pre-filter
☐ Show movements
☑ Show graph
☐ Warnings

Frames 50

Method Bell

Factor 2.0

red line = image quality
blue line = registration difference

Processing limited to 109 frames

Stacking : quality >= 81% , difference <= 100% , n = 109

Fig. 9.62. Steps 11–14 of basic planetary image processing.

15. In the stack section open the "frame list" and uncheck any frames you consider to be of a less than desirable quality. As you click on a frame number you will be shown that frame in the main image window, and you can use the arrow keys to move from frame to frame.

16. You can also use the "Stack graph" to fine tune the frames to be used in the final stack. The "quality cut-off" bar at the bottom of the stack graph window basically increases the lowest quality percentage as you move it from right to left. The "difference cut-off" will remove frames with a specified registration difference from the original frame used to do the alignment.

17. The settings recommended in the optional box are "histo stretch" and "intensity balance." These help to brighten the final image.

18. When you are happy with the frames to be used in the final image, press "stack."

19. When stacking is complete Registax will move to the "wavelet" section.

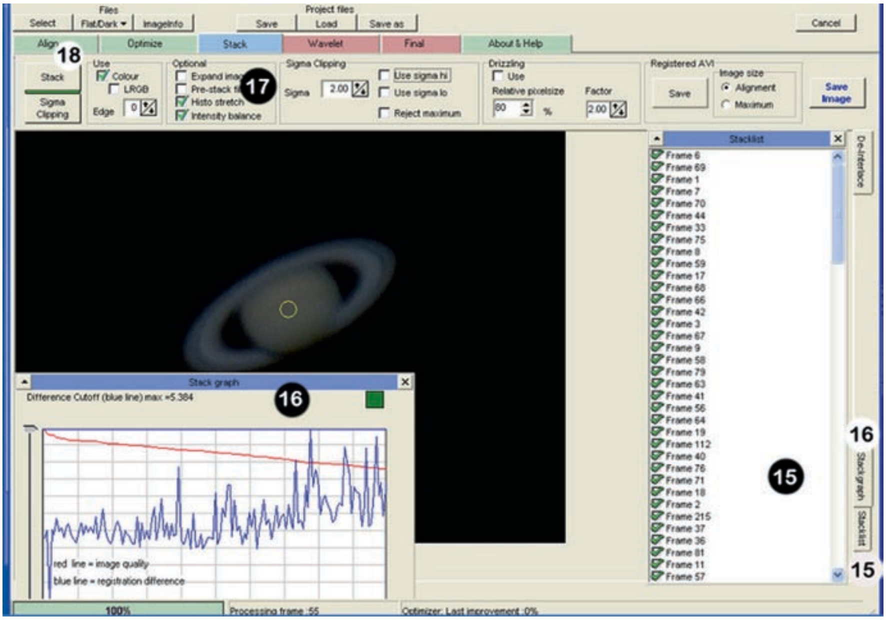
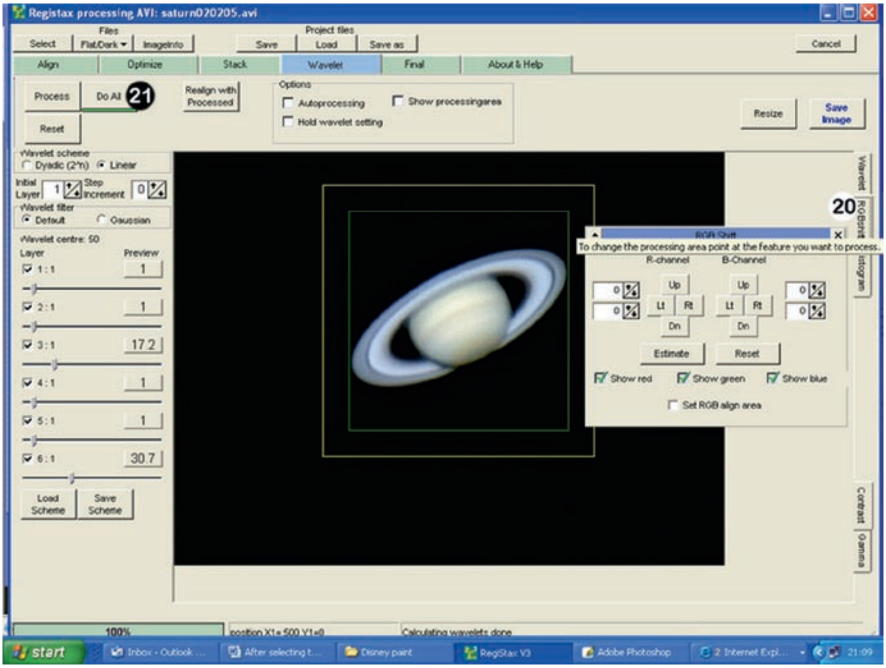


Fig. 9.63. Steps 15–19 of basic planetary image processing.

20. First thing that needs to be done here is to open the RGB shift window and press "estimate." This will realign the RGB elements of the color image.

21. Then it is time for you to you play with the wavelets and other adjusters (contrast, histogram, etc.) until you get the basic image you are happy with to be processed with other programs such as Paintshop Pro. It is recommended to use wavelet 3 and 6, but it is a matter of taste.



Wavelet scheme: ☐ Dyadic (2^n) ● Linear

Initial Layer 1, Step increment 0

Wavelet filter: ● Default ○ Gaussian

Wavelet centre: 50

☑ 1:1 — 1
☑ 2:1 — 1
☑ 3:1 — 17.2
☑ 4:1 — 1
☑ 5:1 — 1
☑ 6:1 — 30.7

To change the processing area point at the feature you want to process.

☑ Show red ☑ Show green ☑ Show blue ☐ Set RGB align area

position X1= 500 Y1=0

Calculating wavelets done

Fig. 9.64. Steps 20–21 of basic planetary image processing.

Conclusion

Hopefully, the contents of this chapter have been helpful in enabling the reader to become better acquainted with astro-imaging. It is a big subject, and a lot of reading in and around the subject is required. "Hands on" experience is critical, and you will learn as much through your mistakes as you do in those evenings where everything works perfectly.

Be methodical, and you will make better progress in a shorter time. You will not need reminding that clear nights can be few and far between, and you need to make the most of them. Therefore, set yourself a minimum acceptable quality standard for focus, tracking, etc. This will be lower to start as you need some results to practice your processing on. But as ability increases, so will the quality cut off, and you will mark steady improvement. Do keep your early efforts and date them clearly. You will be surprised and pleased at the progress. Finally, sign yourself up to one of the numerous Internet-based forums that discuss and share astro-imaging know how. Popular examples are CloudyNights (http://www.cloudynights.com), StargazersLounge (http://www.stargazerslounge.com), and UKastroimaging forum (http://www.ukastroimaging.co.uk).

This chapter concludes by presenting a few images that are achievable by amateurs in backyards with modest equipment. The contributors are relative newcomers to the hobby, and their day jobs have absolutely nothing to do with astronomy or computers. They image from backyards with severe light pollution or local obstructions to the horizon. The point here is that they do not necessarily possess any technical, academic, or environmental advantage over most people. They have just applied themselves to learning and practice. With time, patience, and experience many readers could expect to achieve similar results to those which follow (Figs. 9.65–9.75).

Some Images

Images depicted in Figs. 9.65–9.67 were acquired in my rather light polluted back yard, and they demonstrate the value of narrowband filters to enable one to get a satisfactory image, despite heavy light pollution. However, heavy light pollution does not prevent you taking reasonable shots of regular deep sky objects such as the Andromeda Galaxy in Fig. 9.68 or the globular cluster M13 in Fig. 9.69.

NGC 2024 and B33: The Flame and Horsehead Nebula

Fig. 9.65. The Flame and Horsehead nebulae.

The Horsehead nebula is a very faint object that one might see from a dark site and a large telescope. For a small refractor equipped with a camera, it is a superb and willing target with a lot of emission at Hydrogen Alpha wavelengths. The bright star is Alnitak (lower left star in Orion's Belt). A 16-bit CCD camera and careful processing are needed to prevent the glare from Alnitak spoiling the image. If you are working at a longer focal length or have a smaller sensor in your camera, then the Horsehead nebula by itself makes a great target offering lots of contrast for a striking image.

Camera: Starlight Xpress SXV H9 and SXV guide camera
Telescope: William Optics 80-mm refractor
Mount: Losmandy G11
Image Data: Luminance 6 × 5 min Haun-binned
RGB 5 × 10 min unbinned

NGC 2174: The Monkey Nebula

Fig. 9.66. NGC2174, the Monkey Nebula.

Camera: Starlight Xpress SXV H9 and SXV guide camera
Telescope: William Optics 80-mm refractor
Mount: Losmandy G11
Image Data: Luminance 20 × 10 min Ha unbinned

Another object that lends itself to imaging with narrowband filters such as Ha and OIII. A pleasing image is readily attained though numerous and lengthy subframes that are required to keep the background smooth and contrast high.

NGC 6992: The Veil Nebula

Fig. 9.67. NGC 6992, the Veil Nebula.

Camera: Starlight Xpress SXV H9 and SXV guide camera
Telescope: William Optics 80-mm refractor
Mount: Losmandy G11
Image Data: Ha filter 11 × 10 min unbinned
SII filter 9 × 10 min unbinned

Another example of the detail can be captured through a telescope measuring just 80-mm aperture. Ha and SII filtered images were assigned to the red and blue channels, and this information was used to create a synthetic green.

M31: The Andromeda Galaxy

Fig. 9.68. M31, the Andromeda galaxy.

Camera: SBIG ST4000XCM one shot colour camera self guided.
Telescope: William Optics 80-mm refractor with Televue 0.8 focal reducer
Mount: Losmandy G11
Image Data: 10 × 5 min exposures unbinned

This camera was briefly on loan to me, and despite an almost full moon, I was able to capture this image of one of our neighboring galaxies. The moon makes deep sky imaging a challenge but not impossible.

M13: The Hercules Cluster

Fig. 9.69. M13, the great cluster in Hercules.

Camera:	Starlight Xpress SXV H9 and SXV guide camera
Telescope:	William Optics 80-mm refractor
Mount:	Losmandy G11
Image Data:	LRGB 5 × 2 mins per filter unbinned

M13 is another favorite target. It is bright enough to be easily located and allows the beginner to take a decent image with modest equipment. It is also a common target for the experienced and advanced imagers wish test their skills at reproducing good star colour and resolving the countless stars.

My first contributor is Mike Deegan of Swindon, UK. Mike is a resourceful astronomer, and Fig. 9.70 shows his set up in action. When this picture was taken, he was acquiring the data for his M51 image shown in Fig. 9.71. His guide rings are home made from a cut off from an aluminium pipe and his dew shield (set at a jaunty angle!) is a camping mat. The mount is an HEQ6 with a retrofitted module that accepts guiding inputs. The main imaging scope is a 10 Skywatcher with a piggybacked 80-mm refractor (Skywatcher 80ED). Guiding is carried out with a webcam and PHD guiding. Mike's imaging camera is a secondhand Starlight Xpress Hx916 monochrome CCD. Despite his obviously light polluted locality, Mike has managed to produce some excellent results. He started imaging the moon with a webcam in 2004. In 2006 he saw his first exposure of greater than 15 s. It is thanks to Mike that we have the excellent primer on planetary imaging.

If you want to see more of Mike's work, you can visit his website at http://www.freewebs.com/mikesastroimaging/index.htm

Fig. 9.70. The handle of the Plough bathed in light pollution.

M51: The Whirlpool Galaxy

Fig. 9.71. M51: The Whirlpool Galaxy – image by Mike Deegan.

Camera: Starlight Xpress Hx916 CCD
Telescope: 10 Skywatcher Newtonian
Mount: Skywatcher HEQ6
Image Data: Luminance 88 × 5 min unbinned
RGB 10 × 5 min per channel binned 2 × 2
Ha filter 9 × 5 min binned 2 × 2

An astro-imagers favourite! In producing this image, Mike took a total of 107 subframes.

NGC4216: An Edge on Spiral Galaxy in the Virgo Cluster

Fig. 9.72. NGC 4216: edge on Spiral galaxy in the Virgo Cluster – image by Mike Deegan.

Camera:	Starlight Xpress Hx916
Telescope:	Skywatcher 10″ Newtonian
Mount:	Skywatcher HEQ6
Image Data:	Luminance 40 × 5 min unbinned RGB 9 × 2.5 min binned 2 × 2

A member of the Virgo galaxy cluster is located from our perspective between the constellations of Virgo and Coma Berenices. With a brightness of 11th magnitude, it is accompanied in this image by NGC4222 and NGC4206, which are around 13th to 14th magnitude.

NGC 2244: The Rosette Nebula

Fig. 9.73. NGC 2244: The Rosette nebula – courtesy of Mike Deegan.

Camera: Starlight Xpress Hx916
Telescope: Skywatcher 80ED/SLR lens
Mount: Skywatcher HEQ6
Image Data: Luminance 15 × 10 min Ha filter 80ED
Luminance 5 × 10 min Ha filter SLR camera lens

This image is notable due to the fact that Mike captured a significant portion with a $30 SLR lens. It serves to demonstrate that a budget of thousands is certainly helpful, but not essential to get great images. The SLR lens was fitted to the Starlight Xpress Hx916 and used to capture the widefield portion of the image. The core was imaged through the Skywatcher ED80. The two images were merged to give this final result.

Martin Bradley has been imaging deep sky objects since February 2006 and was kind enough to allow me to include a few of his images in the book to demonstrate what the beginner can aspire to. Martin has a website (http://www.astropixels.co.uk/) hosting further examples of his achievements in imaging and is recommended as an excellent source of useful information on processing techniques.

IC 1396 – The Elephant Trunk Nebula

Fig. 9.74. IC1396: The elephant Trunk Nebula – image by Martin Bradley.

Camera: Starlight Xpress SXV H9 guided with SXV guide camera
Telescope: William Optics FLT110 apochromatic refractor
Mount: Takahashi EM200
Image Data: Ha 12 × 15 min unbinned
OIII 12 × 15 min unbinned

Martin mapped the Ha data to the red channel and the OIII data to the blue channel. He then created a synthetic green channel with the Red and Blue channels to create this beautiful final result. The synthetic green was manufactured using the previously mentioned "Noel's Actions."

M33: The Pinwheel/Triangulum Galaxy

Fig. 9.75. M33: The Pinwheel Galaxy – image by Martin Bradley.

Camera: Starlight Xpress SXV H9 guided with SXV guide camera
Telescope: Skywatcher 80ED with 0.67 focal reducer
Mount: Takahashi EM200
Image Data: Luminance Astronomik CLS filter 80 × 2 mins unbinned
RGB 40/40/56 seconds × 60 binned 2 × 2

A member of the local group of galaxies, M33 is a beautiful but challenging target for astro-imaging. The faint spiral arms make it very difficult to do this object justice. It can be viewed through naked eye from a suitable dark site, and is one of the most distant objects that can be viewed without optical aid.

Usual Suspects List

The following is a list of deep sky objects that can be seen by inexperienced amateurs using modest equipment under average conditions. Of course, what can be seen is a bit open to interpretation. This list contains objects that are verified as being visible to 20 × 50 binoculars from a suburban sky in southern England. From southern Europe and the United States, there are some objects that would be difficult to see. However, an experienced observer would be able to tick the list off armed with good skies and a quality pair of 30 mm binoculars. Some of them may also be visible in small telescopes, but their large apparent angular size means that a telescope only shows a small part of them. If you use larger binoculars (say 60 mm or larger) most of the time, you should be able to see objects on this list under more difficult conditions and see a few more difficult objects under better conditions.

16/17 Draconi

Facts at a Glance

Object Type	Double star
Declination	+52 deg 18 min
Right ascension	19 h 46.4 min
Magnitude	Components of 5.4 and 5.5, and 17 has a fainter companion of magnitude 6.4
Separation	90.3 arcsec and 3.4 arcsec

Description

16 and 17 Draconi form a double star system, well within the range of most binoculars. In an 80 mm refractor or larger, 17 Draconi shows a fainter companion of magnitude 6.4.

Fig. 1. 16/17 Draconi.

This system is circumpolar from the UK and most of Canada but is best placed for evening viewing in late summer. It can be difficult to photograph without timed exposure, as the components are quite faint.

Albireo (Beta Cygni)

Facts at a Glance

Object type	Double star
Declination	+27 deg 58 min
Right ascension	19 h 30.7 min
Magnitude	Combined 3.1 with 3rd and 5th magnitude components
Separation	34 arcsec

Description

After the Mizar/Alcor pairing in the Plough, Albireo is probably the most famous double star in the Northern Hemisphere. It is often a "hit" at star parties and something to impress the neighbors with if they see you out with a telescope. The color contrast between the two stars makes it stand out as one of the most beautiful objects of its type. Being at the head of Cygnus, it is easy to find with the naked eye or in a binocular sweep, but it can get irritatingly difficult though a telescope if your finderscope is not precisely aligned.

Unlike Mizar and Alcor, it is a true binary star. It can sometimes be split in binoculars as small as 25 mm. Just about any telescope will be able to split it, and this is one of the few objects that is not improved by a larger telescope. The two stars have been resolved (but not the space between them, giving the "peanut effect") with 8 × 21 binoculars.

The stars' components have been reported as various colors. The primary often appears orange in many binoculars and the secondary blue, although the secondary component has been reported as green. Most photographs show the primary as yellow/orange and the secondary as blue. It is the color contrast that makes this double star a popular and well known object.

Seen under the most appallingly bad conditions, such as thin cloud, light-polluted skies, and twilight and is an easy object to show at star parties when little or nothing else is visible.

Fig. 2. Albireo by Nick Howes.

Alcor/Mizar (60 Ursae Majoris/ Zeta Ursae Majoris)

Facts at a Glance

Object type	Double star
Declination	+54 deg 56 min
Right ascension	13 h 23.9 min
Magnitude	Alcor is magnitude 4.0, Mizar has components of 2.3 and 4.0, with a combined magnitude of 2.1
Separation	Alcor and Mizar are separated by 708.7 arcsec (nearly 12 arcmin), and Mizar's components are separated by 14.4 arcsec

Description

This is the most famous double star in the sky and was featured in the film "Deep Impact." The Plough (in the UK) or Big Dipper (US) is well known even to people who do not follow astronomy. Alcor and Mizar are far enough apart that they can be split without binoculars on a good night, but, as often as not, a small pair of binoculars is needed to bring Alcor out of Mizar's glare.

A telescope is needed to split Mizar into its two components and only a small telescope, with medium magnification (around 40× but sometimes less), will do it. This is a nice trick to get things going at star parties where the seeing is poor and there are not many planets about.

It has been reported as being split with 80 mm binoculars.

Fig. 3. Mizar and Alcor.

Andromeda Galaxy (M31)

Facts at a Glance

Object type	Galaxy (Spiral)
Declination	+41 deg 16 min
Right ascension	00 h 42.7 min
Magnitude	3.1
Apparent angular size	3 × 1 deg

Description

The Andromeda Galaxy (M31) has inspired a lot of science fiction. Its photographs have decorated the covers of several books. Despite its extreme distance (over 2 million light years), it can be seen as a small fuzzy patch with the naked eye from a suitably dark site. On a really good night, it can be truly breathtaking through suitable instruments. Most nights, it falls rather short of that, as it is easily affected by thin cloud, moonlight, and light pollution, yet is still worth seeing as long as there are stars in the sky.

Despite its incredible distance, it is actually the largest natural object in the northern sky, being about six times larger than the apparent size of the Sun and the Moon.

Through small binoculars, Andromeda appears as a large fuzzy patch, somewhat larger than the full Moon. Larger binoculars (60 mm plus) show its full extent of 3° width on a good night and actually show some of its structure of a nucleus and subtle shading in the outlying regions.

Its large apparent size can cause problems when using a telescope. You can get the whole galaxy in using an 80 mm short tube refractor, which can deliver a 4° field of view at low magnification. This is about as good as you can get if you want to see the whole galaxy in one look. The picture shows the type of view you might expect on a good night. The only way to improve on this is very large tripod-mounted binoculars of 100 mm plus aperture.

Moving up to a larger telescope (125 mm plus) will allow you to see the nucleus in more detail, although its best to keep the magnification low. You can also pick up the companion galaxies M110 and M32.

Fig. 4. Andromeda Galaxy (photograph by Brian Woosnam).

Beehive

Facts at a Glance

Object type	Open star cluster
Declination	+19 deg 59 min
Right ascension	8 h 40.1 min
Magnitude	Combined magnitude of about 4
Apparent angular size	2 deg

Description

This is a star cluster similar in nature to the Pleiades and Hyades but is further away and much fainter. It is theoretically visible to the naked eye but needs a dark sky and pristine conditions. Most astronomers have only ever seen it in binoculars, although quite small ones will show it clearly. Its name is certainly a good description.

These stars are easiest to find when both Pollux (Beta Geminorum) and Regulus (Alpha Leonis) are both above the horizon, as it is about halfway between the two stars.

From the United Kingdom and Canada, the Beehive can be seen from about midnight in November to just after darkness in July.

Coathanger

Facts at a Glance

Object type	Asterism
Declination	+20 deg 11 min
Right ascension	19 h 25.4 min
Magnitude	Combined magnitude of about 4
Apparent angular size	1 deg

Description

This is an asterism in the constellation of Vulpecula. It looks just like a coathanger, hence its name. It is a pattern of 5th and 6th magnitude stars and is also in a rich part of the Milky Way, so the general view is rather good. It was once thought to be a true star cluster, but most of its stars are at various distances, so are not physically related.

From the United Kingdom and Canada, the Coathanger can be seen from about midnight in May to just after darkness in December.

Delta Lyrae

Facts at a Glance

Object type	Double star
Declination	+36 deg 58 min; +36 deg 54 min
Right ascension	18 h 53.7 min; 18 h 54.5 min
Magnitude	5.6 and 4.5 magnitude components, each with fainter companions of 9.3 and 11.2, respectively
Separation	About 4 arcmin and 174.6 and 86.2 arcsec for the fainter companions

Description

Delta Lyrae is an easy double star, well within the range of even the most modest binoculars. The only problem you might get is that the fainter companion might not be visible where transparency is poor.

It is almost circumpolar from many places in the UK and Canada but is best placed for evening viewing in late summer.

The fainter companions are well separated, too but will need at least a 60 or 80 mm aperture to see on a good night. It is a good target for star parties, as beginners can see it on an average night.

Fig. 5. Delta Lyrae.

Epsilon Lyrae

Facts at a Glance

Object type	Double star
Declination	+39 deg 40 min
Right ascension	18 h 44.3 min
Magnitude	5.0 and 5.2 magnitude components, each with companions of 6.1 and 5.5, respectively
Separation	207.7 arcsec and 2.6 and 2.3 arcsec for the fainter companions

Description

Epsilon Lyrae is an easy double star, well within the range of even the most modest binoculars. In a medium to large telescope, each component is also shown to be double, but the separation is quite close and does not photograph easily.

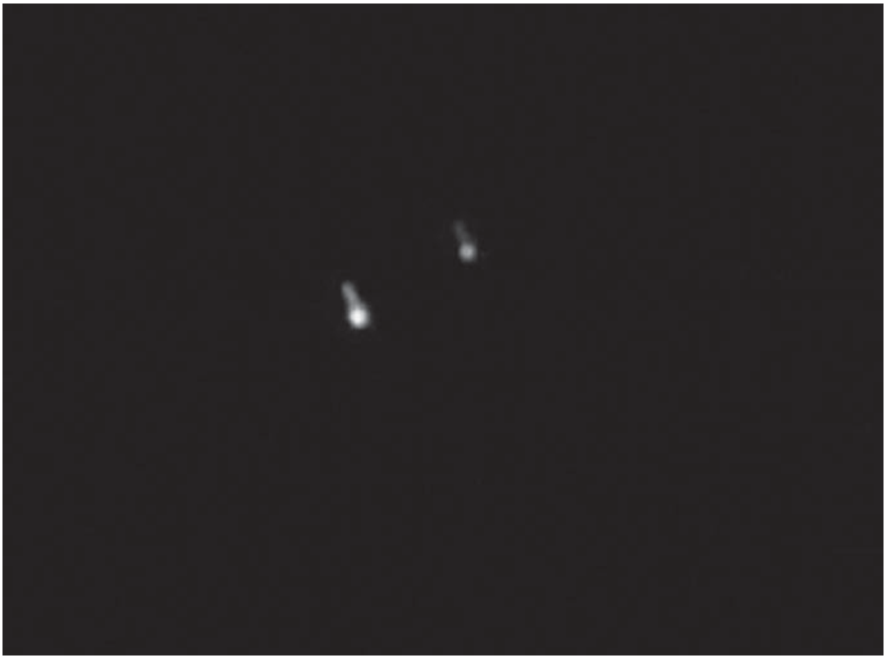


Fig. 6. Epsilon Lyrae.

It is circumpolar from most places in the UK and Canada but is best placed for evening viewing in late summer.

It is possible to see all four components in an 80 mm telescope with high magnification on an exceptional night but 100–120 mm is more realistic.

Hyades

Facts at a Glance

Object type	Open star cluster
Declination	+16 deg 0 min
Right ascension	4 h 27.0 min
Magnitude	The main stars are between 2nd and 3rd magnitude
Apparent angular size	Over 5 deg

Description

This is an easy object to find but can be difficult to view the whole cluster in the same field of view. It is a star cluster of much larger apparent size than the Pleiades. It can be seen with the unaided eye as the "V" of Taurus and apparently contains Aldebaran (which is really a foreground star). Since it is about 5° across, it is a challenge for binoculars with high magnification and narrow field of view. It contains about 200 stars, of which about 25–30 should be visible under normal conditions.

It is one of the last deep sky objects to remain visible when conditions deteriorate, because of its brightness and large separation of members.

The Hyades are visible from midnight in September until just after sunset in early May and are best placed around midnight in early December.

Kemble's Cascade

Facts at a Glance

Object type	Asterism
Declination	+62 deg 20 min
Right ascension	4 h 7 min
Magnitude	The main stars are around 8th magnitude
Apparent angular size	3 deg

Description

This is the most difficult of the Usual Suspects, as its host constellation (Camelopardalis) is difficult to find, with its brightest star being 4th magnitude. However, once you have practiced finding it, it is a string of stars of just over 2.5° in length. It will tolerate slightly hazy conditions, but if conditions deteriorate too much, an aperture larger than 50 mm will be required. Like the Coathanger, it is an asterism and not a true star cluster. It does not make it any less nice to look at, though, and this is about observational astronomy after all. Although it may have been known for a long time, it was not popularized until the 1970s by Father Lucien Kemble.

Kemble's Cascade is circumpolar from the United States and Europe.

Melotte 111

Facts at a Glance

Object type	Star cluster
Declination	+26 deg 0 min
Right ascension	12 h 25 min
Magnitude	Most stars are about 4th to 6th magnitude
Apparent angular size	Over 7°

Description

This is a star cluster similar in nature to the Pleiades and Hyades but is closer, brighter, and has a larger apparent size. Some of its stars are visible to the unaided eye, but it needs binoculars to reveal its true potential. There is also some background nebulosity and larger telescopes will also show that many of the "stars" visible to binoculars as small fuzzy patches are really background galaxies.

It is found by scanning north east from Leo's hind quarters.

Melotte 111 can be seen from about midnight in December to just after darkness in July from most major northern hemisphere locations.

Melotte 20

Facts at a Glance

Object type	Star cluster
Declination	+49 deg 0 min
Right ascension	3 h 22 min
Magnitude	The brightest star is Alpha Persei at 1.8; the integrated magnitude of the cluster is 1.2
Apparent angular size	3 deg

Description

This is not usually described in many books but is an impressive object, nevertheless. It can be used to test the clarity of the sky, and there are too many stars to count in ideal conditions. Like the Hyades, it can be seen under quite appalling conditions, when most sensible amateur astronomers will be indoors.

It is visible almost all year round from the United Kingdom and most parts of Canada if you have a clear northern horizon. June is the worst month.

North America Nebula

Facts at a Glance

Object type	Nebula
Declination	+44 deg 20 min
Right ascension	20 h 58.8 min
Magnitude	4
Apparent angular size	2 deg

Description

This is a nebula that covers about 4 square degrees of sky and is found by aiming a pair of binoculars at Deneb (Alpha Cygni) and panning west about 2°. It is possible to spot with the naked eye on a very good night, and it looks like North America in shape. It also has lots of foreground stars in the Milky Way. It is also known as NGC7000. Amazingly, it has only been discovered quite recently, although it is the second easiest nebula to see, after the Orion Great Nebula.

The North America Nebula is circumpolar from the United Kingdom and most parts of Canada but is too low for practical observation during the evenings of January and February.

Nu Draconi

Facts at a Glance

Object type	Double star
Declination	+55 deg 11 min
Right ascension	17 h 32.2 min
Magnitude	Equal magnitude components of 4.9
Separation	61.9 arcsec

Description

Nu Draconi is an easy double star, well within the range of most binoculars. It is circumpolar from the UK and most of Canada but is best placed for evening viewing in late summer.

It can be difficult to photograph this double without timed exposure, as the components are quite faint.

Fig. 7. Nu Draconi.

Orion Great Nebula

Facts at a Glance

Object type	Nebula
Declination	–5 deg 27 min
Right ascension	5 h 35.4 min
Magnitude	4.0
Apparent angular size	85 × 40 arcsec

Description

This nebula is one of the great star-forming regions of our galaxy. You will have probably seen many pictures of it in books and magazines. However, it is not so spectacular in modest binoculars. Like many objects, it is theoretically visible to the unaided eye but needs a dark site. If you have seen the North America Nebula, the Orion Great Nebula is smaller and brighter. It also has four stars embedded within it known as the Trapezium, which are not always visible to 50 mm binoculars and some nice surrounding stars, giving the appearance of a cluster. It also has a smaller nebula (M43) close to it, which is actually part of the same star-forming region.

You can find it by going to the left side of Orion's belt and scanning south.

The Orion Great Nebula can be seen from about midnight in October to just after darkness in May. There is also a photograph in the chapter on simple deep sky viewing.

Fig. 8. Orion Great Nebula (photograph by Nick Howes).

Pleiades (Seven Sisters)

Facts at a Glance

Object type	Open star cluster
Declination	+24 deg 7 min
Right ascension	3 h 47.0 min
Magnitude	Brightest star is 2.7
Apparent angular size	2–3 deg

Description

This is about the easiest object to find. It is visible as a hazy patch from a typical backyard site under average viewing conditions but is actually a star cluster. You can find it by following the left side of Perseus down toward Aldebaran. Even small binoculars resolve it into stars, although this is also possible with the unaided eye from a dark site. There is one claim of 19 stars with the unaided eye and 103 with a big pair of binoculars. Expect to see about 40 with average binoculars/conditions.

The Pleiades extends for about 2–3°, although professional instruments suggest that outlying, fainter members extend to about 5. You should also see a "string" of stars curving from top to bottom. There are six noticeably brighter stars, with a 7th around 6th magnitude (hence the alias "Seven Sisters"). More powerful instruments and photography have shown a hint of nebulosity. Nebulosity has been seen in instruments of 125 mm aperture. The brighter stars can be captured in constellation photographs.

The Pleiades are visible from midnight in late August until just after sunset in early May and are best placed around midnight in early December.

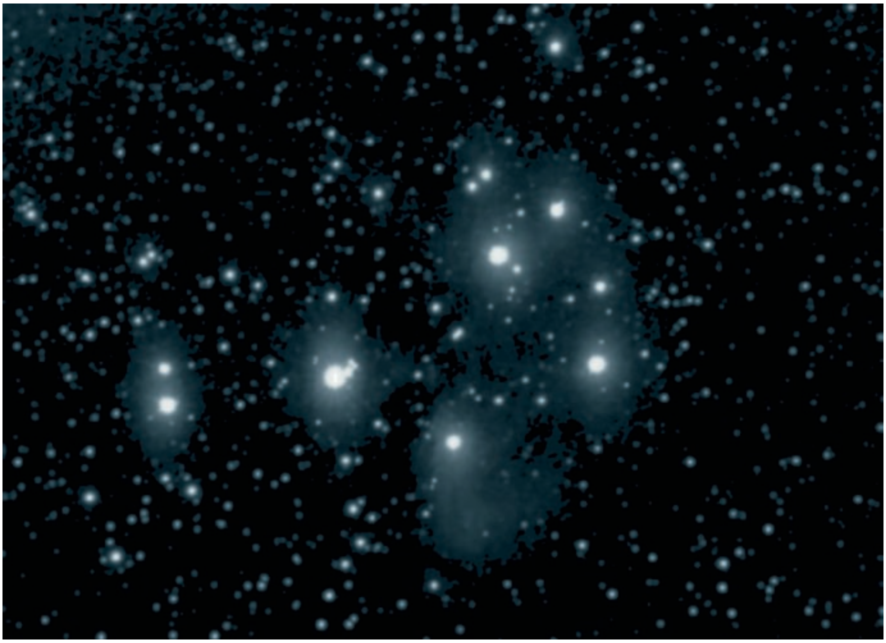


Fig. 9. Pleaides (photograph by Nick Howes).

Glossary

This section contains a description of some of the technical terms used in this book.

Accessory
This is a general term used for anything that can be added to a telescope that will enable it to be used visually or photographically or change its behavior in some way. These include eyepieces, image amplifiers, and focal reducers. There are all sorts of filters (q.v.) as well. There are also accessories used to improve the performance of a telescope when used for photographic use.

Achromat
See achromatic refractor (q.v.).

Achromatic refractor
This is the normal type of refractor on sale in stores. It uses an objective lens made of two types of glass (crown and flint) to reduce chromatic aberration inherent in telescope lenses.

Active region
This is a general term used by the research community to denote a region of the Sun containing active sunspots and associated features. Each active region has a serial number and is denoted ARxxxx, where xxxx is the serial number.

Actual field of view
This is the diameter of the area of sky that you can see through a telescope or binoculars and is measured in degrees and/or arcminutes. It is obtained by dividing the *apparent field of view* (q.v.) of an eyepiece by the magnification.

Afocal adaptor
Afocal photography is also known as "eyepiece projection" and is the act of taking a photograph through a telescope using an eyepiece. An adaptor allows the camera to be held near the eyepiece to reduce camera shake.

Afocal coupling
This is the act of taking photographs through a telescope eyepiece.

Afocal photography
See *afocal coupling*.

Afocal projection
See *afocal coupling*.

Albireo
This is a double star in the constellation of Cygnus, which is a true binary system. Its separation is wide enough to be resolved in modest binoculars. It is well known because of its orange/blue-green color contrast.

Alcor
This star forms part of a wide optical double star with Mizar (q.v.) in the Big Dipper (or Plough), which is part of Ursa Major.

Aldebaran
This is the brightest star in the constellation of Taurus and is a distinct red/orange color. There is some debate whether it is variable or not.

Alpha Centauri
This is a double star system in the constellation of Centaurus. As it is near the south celestial pole, it cannot be seen from the UK, United States, or Europe. Its components can be split in a small telescope. The larger of the two is very similar to the Sun but slightly bigger and brighter, and the smaller of the two is slightly smaller and fainter. There is a third member of the system, Proxima Centauri (q.v.), which is actually the true nearest star to us apart from the Sun.

Andromeda
This is a constellation in the Northern Hemisphere, which is home to the famous Andromeda galaxy (q.v.).

Andromeda galaxy
This galaxy is well known in science fiction. It is the nearest large galaxy to our own Milky Way and is the largest natural object visible in the sky from the Northern Hemisphere. It can be seen with the unaided eye on a good night from a dark location but normally needs binoculars.

Angstrom/angstrom unit
This is a very small unit of measurement used to measure the wavelengths of light and other very small distances. It is a meter divided by 10 ten times and is a tenth of a nanometer. It is abbreviated as A and is often quoted in relation to solar astronomy.

Annular solar eclipse
A solar eclipse that would be total, except that the relative distances of the Sun and the Moon mean that the lunar disc is not quite large enough to cover the solar disc, so a ring or annulus around the Moon is seen.

Antiblooming gate

This is a feature of an advanced camera that inhibits saturated pixels from spilling over into neighboring ones.

Antares

This is a name given to a red giant star in the constellation of Scorpius (Scorpio). It is also used as the brand name of a series of accessories (q.v.).

APO/apochromat

See apochromatic refractor (q.v.).

Apochromatic refractor

This is an improvement on the achromatic refractor (q.v.). It uses three types of glass to just about eliminate chromatic aberration entirely. Care must be taken to ensure that a telescope marketed as apochromatic is not extra dispersion (ED) or semiapochromatic (although these types of refractor are still better than an achromat). Also, there are several types of apochromatic telescope, so you need to be careful before you buy, especially if the manufacturer does not have an established track record.

Apparent field of view

This is a measure of the width of the field of view of an eyepiece. It is the theoretical field of view that would be obtained if you were able to use a magnification of 1×. To get the "real" or *actual field of view* (q.v.) for a given telescope/eyepiece combination, you need to divide the apparent field of view by the magnification. Although most eyepiece types have an apparent field of view of 52°, this can vary.

Association

This is a group of stars that share a common motion around the galactic center and, consequently, around our night sky but are too far dispersed to recognize as a true star cluster. An example is the Ursa Major Moving Group (q.v.).

Astigmatism

This is a type of defect in optical equipment where objects near the edge of the field of view become distorted. It is most common in binoculars.

Ashen light

This is an effect seen on Venus where the dark side is lit by light scattered through the Venusian atmosphere.

Asterism

This is a name given to a pattern of stars that is part of a constellation, rather than being a constellation in its own right. The most famous asterism is the Big Dipper or Plough.

Attenuation

This is the reduction in the strength of a signal while passing through a medium or process.

Asteroid

Just like until recently thought we knew what a planet was, we are now in doubt as to what constitutes an asteroid. Well, the short answer is that it is not big enough to be a dwarf planet, so that means that Vesta is still an asteroid, while Ceres is not. Oh, yes, to fully complete the picture, if an "asteroid" is in orbit around a planet or a dwarf planet, then it is really a moon.

Auto-guiding

This is a technique used in long exposure photography. It uses a second camera to track an object and sends signals to the mount to keep it aligned with the target object. Usually, the object tracked is a nearby bright star, known as the guide star. Auto-guiding helps correct tracking errors, such a periodic error (q.v.).

AVI

This is also known by its full name of audio visual interleave. It is a commonly used file format for capturing video format and is often used as the output from webcams.

Baader filter

This is a type of "white light" filter that reduces the amount of light reaching the eye used for solar astronomy. Filters can be bought ready made, or the material can be purchased in the form of sheets, which can then be made into filters. Note that different thicknesses can be used for visual and photographic applications.

Bandpass

When using a filter, light slightly longer or shorter than the required wavelength is allowed to pass through. The range of wavelengths allowed is known as the *bandpass* and is measured in angstrom units. A narrow bandpass is required for solar astronomy. Wider bandpasses are used for night time astronomy.

Bayer filter mosaic

A Bayer filter mosaic is a color filter array (CFA) for arranging RGB color filters on a square grid of photosensors. The term derives from the name of its inventor, Bryce Bayer of Eastman Kodak, and refers to a particular arrangement of color filters used in most single-chip digital cameras.

Bryce Bayer's patent called the green photosensors *luminance-sensitive elements* and the red and blue ones *chrominance-sensitive elements*.

He used twice as many green elements as red or blue to mimic the human eye's greater resolving power with green light. These elements are referred to as samples and after interpolation become pixels.

The raw output of Bayer-filter cameras is referred to as a *Bayer Pattern* image. Since each pixel is filtered to record only one of the three colors, two-thirds of the color data is missing from each. A demosaicing algorithm is used to interpolate a set of complete red, green, and blue values for each point, to make an RGB image. Many different algorithms exist.

Beehive

This is a star cluster (q.v.) found in the constellation of Cancer. It is an easy target for small binoculars, and as such is one of the Usual Suspects (q.v.).

Big Dipper

This is not a true constellation as such but is the most prominent pattern of stars (or asterism) within the constellation of Ursa Major (q.v.). It is known as the Plough in the United Kingdom.

Binary system

This is a pair of stars that orbit around a common center of gravity.

Binning

This is the process of combining neighboring pixels into a single one. A 2×2 binning combines four pixels into one; a 3×3 binning combines nine pixels into one, and so on. It is normally used when images are faint or taken under poor conditions. It can also counter the effects of blooming.

BK-7

Type of glass used for the construction of achromatic lenses and binocular prisms.

Black drop effect

This is a phenomena seen when an inferior planet transits the Sun and its silhouette appears to remain attached to the solar limb for a while.

Blocking filter

Secondary filter placed in a light path of a solar telescope to reduce the amount of light reaching the eyepiece.

Blooming

This is an undesired side effect when a digital camera pixel is overexposed and light "spills" onto surrounding pixels.

Broadband

Name used to describe a filter that allows a large *bandpass* (q.v.). Broadband filters are unsuitable for solar hydrogen alpha or calcium K viewing.

Brocchi's Cluster
This is an alternative name for the Coathanger (q.v.).

Brown dwarf
This is an object that is composed of the same material as stars but is too small for the nuclear fusion of hydrogen into helium to begin. From an amateur perspective, they are of little interest, as you cannot see them, except through very large telescopes.

CaK/calcium K
This is an emission line in the Sun from the layer about 2,000 km above the solar surface that is associated with ionized calcium. It is sensitive to magnetic fields and has a wavelength of 3,934 angstrom units and is toward the blue/violet end of the spectrum. Not all people are sensitive to it.

Camelopardalis
This is a faint far northern constellation said to represent a giraffe. It is home to Kemble's Cascade (q.v.).

California nebula
This is a nebula in Perseus. Although its integrated magnitude is quite bright, it is hard to see because its brightness is spread out over a large area.

Canals
These are features apparently seen on the surface of Mars that once suggested that they were built by intelligent beings to transport water around the planet.

Cancer
This is a constellation on the ecliptic and forms part of the zodiac. As well as being a temporary home to many solar system objects, it also contains the Beehive, one of many astronomers' favorite star clusters.

Catalog
There are several of these, which are lists of deep sky objects. The most famous is the Messier Catalog, drawn up by Charles Messier and his colleague, Pierre Mechain.

CCD/Charge coupled device
This is one of the two main types of image sensors used in digital cameras. When a picture is taken, the CCD is struck by light coming through the camera's lens. Each of the thousands or millions of tiny pixels that make up the CCD converts this light into electrons. The number of electrons, usually described as the pixel's accumulated charge, is measured, and then converted to a digital value.

Cell structure

The solar "surface" appears smooth in "white light" views using small instruments, but, in reality, it consists of "bubbles" or cells of hot gas, mostly hydrogen. This structure is visible in hydrogen alpha light, calcium K light, or sometimes in "white light" at high magnification.

Centaurus

This is a constellation (q.v.) of which only a small part can be seen from the United Kingdom, United States, and Europe. It contains a lot of interesting objects, most of them too far south to see.

Cetus

This is a large constellation that borders onto the zodiac. The Moon and most planets can pass through it at some time. It is home to Mira (q.v.), alias Omicron Ceti.

Charles Messier

Charles Messier was a comet hunter in France during the 1800s. However, he is better known for his "catalog" of deep sky objects that can potentially be confused with comets. His catalog is actually a useful list of interesting objects that are worth looking at.

Chromatic aberration

This is an undesirable property of many telescopes and accessories that causes light of different wavelengths to come to different focal points and cause color fringes in the image. This is not a problem with narrowband solar viewing, as the light is all of the same wavelength (monochrome light, see below).

Chromosphere

This is a layer of the Sun where the photosphere (layer of the Sun visible in "white light") meets the solar corona. It is where the hydrogen alpha and calcium K emission lines originate.

CMOS

CMOS is an abbreviation of complementary metal oxide semiconductor. Pronounced see-moss, CMOS is a widely used type of semiconductor. CMOS semiconductors use both NMOS (negative polarity) and PMOS (positive polarity) circuits. Since only one of the circuit types is on at any given time, CMOS chips require less power than chips using just one type of transistor. This makes them particularly attractive for use in battery-powered devices, such as portable computers.

Coal Sack

This is a dark nebula in the Southern Cross.

Coathanger
This is an asterism in the constellation of Vulpecula.

Collimation
This is the act of aligning the primary mirror of a reflector so that objects appear at a sharp focus.

Collinder
This is a name given to a list of deep sky objects, known as a catalog, in the same way that Messier's list of objects is known as a catalog.

Collinder 39
This is an alternative name for Melotte 20 (q.v.).

Collinder 399
This is an alternative name for the Coathanger (q.v.).

Coma
This is the part of a comet that forms when it comes near the Sun, usually within the orbit of Mars, and causes it to brighten and (hopefully) become visible to amateur instruments. It is also the name for a type of optical distortion.

Comet
Well, we all know what a comet is, don't we? Fortunately, for most amateur observers, the distinction is pretty clear-cut. However, from a scientific point of view, a comet differs from an asteroid (or dwarf planet) in physical composition. Many objects in the outer Solar System (probably the huge majority) are comets, and there is speculation that Pluto is a giant comet.

CONR
Color optimized nonraw. Mode that allows webcameras which have outputs that include image processing to be disabled.

Convection zone
This is the part of the solar interior where energy produced from nuclear reactions in the core are carried to the upper solar layers and, eventually, to the surface, where it shows up as electromagnetic radiation, including visible light.

Constellation
Pattern of stars that was believed by people in the past to represent some object, animate or not. Every star is regarded as part of one of the many constellations. The convention is still used today, as it helps astronomers find their way around the sky.

Core
The core is the central part of the Sun or other star, where nuclear reactions are converting hydrogen into helium, with an associated release of energy.

Corona
The solar corona is the part of the solar atmosphere that surrounds the Sun and is normally only visible at a total solar eclipse.

Coronal mass ejection
This is a stream of charged particles that are ejected from the solar corona into the Solar System. When they meet Earth and other planets with atmospheres, auroras are seen, sometimes at temperate latitudes, although more usually in polar regions only.

Coronograph
This is a special type of telescope that blocks the main light from the Sun, so that the corona can be viewed.

Corrector plate
This is a glass plate used over the tube of a reflector to eliminate the effects of spherical aberration (q.v.).

Cosmic rays
Cosmic rays are high-speed atomic particles that originate from various sources in space. They are about 90% protons, 9% helium nuclei, and 1% electrons. Some have known origins, such as the Sun, but the origin of most are unknown. They interfere with astronomical photography, especially long exposure.

Crab Nebula
This is the brightest example of a supernova remnant (q.v.) and is found in Taurus but is not an easy object, appearing as a faint fuzzy patch to modest instruments on a good night. It is also the first object on the Messier list.

Cygnus
This constellation is thought to represent the pattern of a swan, although its alternative description of the Northern Cross is perhaps more apt. It is home to many interesting objects, and the Milky Way passes through it, making it a nice place to just casually browse through binoculars.

Dark frame
This is a photograph taken with a digital camera with an obstruction placed over it. It captures any “hot pixels,” i.e., pixels that show light even

when no picture is being taken. This dark frame can then be subtracted from a photograph of an object to reduce the noise.

Dark nebula

Perhaps one of the more obvious terms in the glossary, one would suspect. Appearance-wise they neither emit nor reflect light but have a similar composition to emission nebulae (q.v.) and reflection nebulae (q.v.).

Dawes limit

This is the theoretical resolution limit for a telescope. It is normally calculated by dividing the aperture in millmeters into 116 to get the answer in arcseconds. As an example, a 114 mm Newtonian reflector has a Dawes limit of just over an arcsecond. In practice the Dawes limit is rarely reached. To get anywhere near it, you need a clear sky, perfect optics, and a magnification of at least twice the telescope's aperture in millimeters. Yes, and a lucky charm is helpful as well!

Dedicated solar telescope

A dedicated solar telescope is one that has been designed exclusively for narrowband viewing and photography, predominantly hydrogen alpha and calcium K. At the budget end of the market, dedicated telescopes are usually cheaper than separate filter systems, but the balance swings the other way at the top end of the market.

Delta Lyrae

This is a double star in the constellation of Lyra.

Diffraction spikes

This is where the appearance of a star is changed by lines appearing to emanate from it. These lines are caused by the "spider" supporting the secondary mirror in a Newtonian reflector.

Double stacking

The act of adding another filter to further reduce the bandpass of a telescope or filter used for narrowband solar viewing.

Double star/double star system

This is a pair of stars, orbiting around a common center of gravity. If the stars are very unequal in mass, the smaller (secondary) component of the system will appear to orbit around the larger (primary) component, as the center of gravity lies inside the body of the primary component. This is often referred to as a *binary system*. Another type of double star is the *optical double*, where the stars are not physically related but happen to lie along the same line of sight, as seen from Earth.

Draco
This is a far northern constellation that is home to a couple of bright double stars and a planetary nebula.

Dumbbell
This is the brightest example of a planetary nebula (q.v.) and can sometimes be seen in quite modest instruments.

Dwarf planet
This is a recently introduced class of object that does not qualify as a planet but is too big to be an asteroid. Although the precise definition is beyond most astronomers and probably is not that important anyway, there are only four of them: Ceres, Makemake, Pluto, and Eris.

Earthshine
This is an effect caused by light from the Earth reflecting on the dark side of the Moon and causing it to be lit enough to see some of the lunar features.

Ecliptic
This is the path around the background sky that the Sun traces out as a result of the Earth's orbit.

ED
See extra dispersion (q.v.).

Elongation
This is the apparent distance of an object from the Sun as seen from Earth and is measured in degrees. Any object less than about 15° elongation from the Sun cannot be viewed in a dark sky. Furthermore, the angle between the object and the Sun at sunset (and, hence, its elevation above the horizon) may require an elongation of more than 30° to see it clearly. Elongation is of particular interest to viewers of the inferior planets (q.v.).

Emission nebula
This has a similar composition to a dark nebula (q.v.) or reflection nebula (q.v.) but has started to condense to form stars and young stars embedded within the nebula are emitting radiation that causes the nebula to glow.

Encke's comet
This is a periodic comet that orbits the Sun every 3.3 years and during a favourable return can be visible to amateur instruments.

Energy rejection filter

Broadband filter used to block infrared and ultra-violet light, with the intention of preventing damage to equipment or human eyesight. It is usually associated with narrowband solar viewing.

Epicycle

This is a concept invented in mediaeval times to explain retrograde motion (q.v.). It was believed that planets not only rotated around the Earth but also around a central point that caused them to reverse motion.

Epsilon Lyrae

This is a double star in the constellation of Lyra, which can be split using binoculars. Each component is also a double star in its own right but needs a reasonable telescope and good conditions to split. It is, therefore, known as the "Double Double."

Eris

Eris is the object that caused all the controversy about dwarf planets. It was discovered in the Kuiper Belt and found to be larger than Pluto, which was previously classified as a planet. All we need now is for someone to discover something in the Kuiper Belt that is larger than Mercury and then the fun really begins!

Etalon

Narrowband filter used to allow only light very close to a specific wavelength to pass through. Typically used for hydrogen alpha light and calcium K light viewing. Also known as *Fabry-Perot etalon*.

Extra dispersion

An extra dispersion lens is an improvement on the achromatic objective lens theme where it uses extra dispersion flint glass to improve the performance.

Exit pupil

This is the width of the light beam leaving the telescope or binocular eyepiece. It is derived by dividing the aperture by the magnification. If it matches the aperture of the observer's pupil, the results are good and objects appear bright. If it exceeds it, there is some light loss and the object appears dimmer. Young observers may have a pupil as wide as 8 mm in complete darkness but this reduces to around 5–6 mm for middle-aged observers at suburban locations. Looking at bright lights can seriously reduce your pupil width.

Extinction

This is nothing to do with the end of the human race but the dimming effect caused when an object is near the horizon. As it has to pass through more of Earth's atmosphere, more of its light is absorbed, so it is much dimmer when it meets the eye, binoculars, or telescope.

Fabry-Perot Etalon

See *Etalon*, above.

Facula

Brighter region of the solar surface usually associated with a sunspot region.

Faculae

This is the plural of *facula*, above.

Field rotation

If you have an alt-azimuth mount and take long exposure photographs. It can also occur using equatorial mounts that are not properly polar-aligned.

Filter

Device used to allow light of only certain wavelengths to pass through. There are full aperture filters (q.v.) and those placed at the eyepiece end of a telescope. They can be broadband (q.v.) and narrowband (q.v.).

Fireball

Like many astronomical terms, there isn't a precise definition of a fireball but it is generally understood to be an exceptionally bright meteor. If you assume anything as bright as or brighter than Venus is a fireball, you are unlikely to mislead anyone.

Flame Nebula

This is a bright nebula in Orion in its belt region.

Flare

This is an exceptionally bright region of the Sun, which is often a precursor to a *coronal mass ejection* (see above).

Flat frame

This is picture of a white background and is used to capture any unevenness in the light captured in a photograph. When a picture of an astronomical object is taken, the unevenness can be removed by dividing by the flat frame. To be most accurate, a dark frame (q.v.) should be subtracted from the flat frame.

Focal reducer
This is the exact opposite of an image amplifier (q.v.).

Full aperture filter
A full aperture filter is a filter that is placed at the objective end of the telescope to reduce the light coming in. Narrowband full aperture filters are the most effective means of solar viewing but can be expensive in the larger sizes. Baader filters for white light viewing reduce the amount of light but do not restrict the wavelengths of light coming through. The other type is energy rejection filters (q.v.).

Full width half maximum
As focus needs to be very precise for imaging, software packages are used. Full width half maximum is one such method employed by these programs.

Galilean moons
These are the moons of Jupiter discovered by Galileo. They are Ganymede, Callisto, Europa, and Io.

GEM
This is an abbreviation for German Equatorial Mount (q.v.).

Geminids
This is a meteor shower that peaks in mid-December.

German equatorial mount
This is a commonly used design of an equatorial mount that includes coarse and fine controls used to find and track objects. Despite the name, most of them are made in China.

Ghosting
A side effect of some types of eyepiece design where a faint secondary image of an object is also produced.

Globular cluster
This is a star cluster whose members are concentrated in a small area. To the unaided eye or small instruments, they are hard to distinguish from small galaxies but a larger instrument may resolve outer members into individual stars.

Granularity
Granularity is the property of the solar surface (Photosphere) and Chromosphere to appear like grains. This is caused by the presence of pockets of hydrogen emanating from lower levels of the Sun.

Great Red Spot
This is an atmospheric feature on Jupiter that has been around since before the invention of the telescope.

Hale-Bopp
This was a bright comet that was visible in 1997.

Halley's comet
This is a periodic comet that returns to the inner solar system about every 77 years.

Halo
A halo is the outer reaches of a galaxy, which are usually faint and often contain globular clusters (q.v.).

Hartman mask
This is a mask placed over a telescope objective to act as an aid to focussing.

H alpha/hydrogen alpha
This is an emission line in the Sun from a layer about 1,700 km above the solar surface that is associated with neutral hydrogen. It has a wavelength of 6563 Angstrom units and is toward the red end of the spectrum.

Horsehead nebula
This is a dark nebula in Orion.

Hyades
This is a star cluster in the constellation of Taurus.

Hyukutake
This was a bright comet that was visible in 1996.

Ikeya-Zhang
This was a comet once visible to the unaided eye during 2004.

Image amplifier
This is a general term for a telescope accessory, which boosts the magnification of any given eyepiece. The most common type is the Barlow lens.

Inferior conjunction
This is the point in the path of an inferior planet around the Sun, as seen from Earth, where it is between the Sun and Earth. As both inferior planets (Mercury and Venus) have orbits inclined to the ecliptic, they will usually pass above or below the Sun, as seen from Earth. Both planets are capable of crossing the solar disc on rare occasions and this event is known as a transit (q.v.).

Inferior planet

This is a general term, which refers to a planet whose orbit is wholly contained within the Earth's orbit. Mercury and Venus are the inferior planets.

Inner solar system

This is a term that is often used but has no official definition. It is best thought of as the part of the solar system where comets form noticeable tails and is around the orbit of Mars.

Interface layer

The interface layer is where the Radiative Zone meets the Convection Zone in the solar interior and energy and matter and exchanged between the two zones. It is a relatively narrow layer.

Interstellar medium

The interstellar medium is the space between stars, believed mainly to consist of hydrogen and traces of other elements and to be less dense than any vacuum produced in a laboratory on Earth.

Interstellar space

This is the space between stars containing the interstellar medium (q.v.).

Jupiter

This is the largest planet in the solar system and a suitable target for small telescopes.

K3CCD

This is a computer program used to assist with image capture and stacking.

Kellner

This is a type of eyepiece, not commonly used but supplied with the Coronado PST.

Kreutz group

This is a group of sungrazer comets believed to be fragments of a large comet that broke up under the gravity of the Sun or a planet.

Kuiper belt

This is a disc outside the orbit of Neptune made of icy and rocky bodies including Pluto and Eris. Most short period comets originate from there.

Large angle spectrometric coronograph

This is an instrument on the SOHO spacecraft that is used to view the solar Corona. As a side issue, it is used by amateur astronomers to view and discover comets.

Large Magellanic Cloud
See Magellanic Cloud (q.v.).

LASCO
See large angle spectrometric coronograph (q.v.).

Leonids
This is a meteor shower that peaks just after mid-November and produces storm levels every 33 years.

Libration
This is the north/south and east/west "rocking" of the face of the Moon toward us caused by its orbit's elliptical nature and inclination to the ecliptic.

Long eye relief (LER)
Type of eyepiece where the image can be viewed a further distance than other designs. They are particularly useful for spectacle wearers and are suited to photography.

LRGB
This is the act of taking separate photographs of an object in monochrome (or luminance), red, green, and blue then combining them using software packages to achieve a final image.

Luminance
"Luminance layering" is a technique that has been developed independently by Dr. Kunihiko Okano and Robert Dalby. It allows astroimagers to overcome the "tricolor" hurdle. When used with RGB filters it is referred to as "Luminance Layering" or "LRGB" technique (the "L" referring to "luminance"). The technique can be used with other color filters such as CMY (cyan, magenta, yellow) filters or with film images with comparable success. The basic premise of luminance layering is that by combining an unfiltered high resolution and high S/N greyscale image with the weaker color data we can "buy back" the signal and detail lost in our filtered RGB exposures. The end result potentially should be a more aesthetically pleasing high contrast color image.

Lux value
This is the amount of visible light per square meter incident on a surface. 1 lux = 1 lumen/square meter = 0.093 foot-candles.

Lyra
This is a northern constellation thought to represent the pattern of a lyre (a type of musical instrument). Despite its small size, it is home to many interesting objects and the Milky Way passes though it.

M

The letter "M" itself is usually followed by a number, indicating that it is an object in the Messier Catalogue. Many of the Usual Suspects are in the catalogue.

Magellanic clouds

These are satellite galaxies of the Milky Way that can only be seen south of the equator. They appear as detached portions of the Milky Way. They are named after Magellan, their discoverer.

Magnetic field (solar)

The solar magnetic field is believed to be the main cause of all the interesting features that we see on the Sun, whether in white light or using narrowband filters.

Main sequence

This is the part of a star's life cycle where it is converting hydrogen into helium, just where the Sun is right now!

Mars

This is one of the smaller planets, which can get quite close to the Earth and show interesting features. It stirs the imagination because of rumours/hopes of life and science fiction but any life is likely to be very primitive.

Maksutov–Cassegrain

Type of reflecting telescope designed to reduce chromatic aberration and produce high quality images.

Mare

This is the singular of maria (q.v.).

Maria

This is Latin for "seas" as these dark lunar features were once thought to contain water, like the seas on Earth. We now know that they are ancient lava flows that occurred when the Moon was still volcanically active.

Maunder minimum

Period in the seventeenth century when sunspot activity was exceptionally low and was associated with low temperatures on Earth.

Melotte 111

This is a star cluster in the constellation of Coma Berenices.

Melotte 20

This is a star cluster in the constellation of Perseus, around its brightest star, Alpha Persei.

Mercury

Now Pluto has been downgraded to a mere dwarf planet, and Mercury is now the smallest planet.

Messier

See Charles Messier (q.v.).

Meteor

The strict definition of a meteor is the visual image formed by an object burning up in Earth's atmosphere.

Meteorite

This is a meteoroid (q.v.) that has not fully burned up in Earth's atmosphere and reached the Earth's surface. These nearly always originate from asteroidal debris but can sometimes be rocks knocked off the surface of the Moon and planets.

Meteoroid

This is a general term for asteroidal or cometary debris that can burn up in Earth's atmosphere and cause a meteor to be seen.

Meteoroid stream

This is a stream of cometary debris spread along the orbit of a periodic comet that may still exist or have expired.

Meteor shower

A shower is a group of meteors that come at the same time and usually result from the gradual break-up of a comet and dispersion of its debris in a stream.

Meteor storm

This is another one of these terms that do not have a precise definition. It is generally understood to be a time during a meteor shower when the rate of meteors becomes exceptionally high. A storm typically lasts for minutes, rather than hours. The exact definition of "exceptional" is open to debate but a rate of 1,000 meteors per hour sustained over a minimum of 5 min is as good as any.

Meyer group

This is a group of sungrazer comets believed to be fragments of a large comet that broke up under the gravity of the Sun or a planet.

Milky way

This is a band of many thousands of stars that form a cloudy or milky band around the sky. It has been known for some time that it is our own galaxy.

Minus violet filter

This is a filter that blocks the far end of the visible light spectrum. It is used because many telescopes, especially short focal length achromatic refractors do not bring wavelength of this light to the same focus as other wavelengths, such as red and green. They are sometimes called "semi-APO" filters as a marketing ploy.

Mira

This is a red giant star in the constellation of Cetus, so is also known as Omicron Ceti. It gives its name to a class of semiregular variable star (Mira-type variable). What is astonishing about Mira and similar stars is their extreme magnitude/brightness range.

Mizar

This is a star in the Big Dipper (or Plough) that forms a wide optical double star with Alcor (q.v.). It is also a binary system in its own right and can by split in a small telescope.

Monochrome light

Light that is of the same wavelength. The term "monochrome" as used for "black and white" television is in fact used incorrectly. Hydrogen alpha and calcium K are examples of monochrome light.

Nagler

This is a type of eyepiece only available to the financially gifted or irresponsible but is very, very good or maybe even better than that!

Nanometer

This is a billionth of a meter and, like the Angstrom unit, is also used to measure very small distances, such as light wavelengths. It is commonly abbreviated to "nm." There are ten Angstrom units in a nanometer.

Narrowband

Term used to describe filters with a low bandpass, which only allow light very close to a specific wavelength to pass through.

Nebula

This is a large "cloud" consisting mainly of hydrogen but also some heavier elements.

Neptune

Now that Pluto is now a mere dwarf planet, Neptune is now the furthest known planet from the Sun.

Newton's rings

The term sounds like something scientific and desirable but is the opposite, being an interference pattern that can appear when taking photographs.

Neutral density

This is a type of filter that blocks light of all wavelengths equally, reducing the light transmission but not the resolution.

Node

See orbital node (q.v.).

North America Nebula

This is a large nebula in the constellation of Cygnus.

Northern Cross

This is an alternative name for Cygnus (q.v.).

Nova

This is literally "new star" but it is really a white dwarf star that has captured some material from a nearby companion and heated it to cause a runaway nuclear reaction that causes it to brighten several hundred or thousand times.

Occulting bar

This is a specialized piece of equipment used to block the light from a bright object, so that surrounding fainter objects can be seen.

Omega Centauri

This is the brightest globular cluster (q.v.) in the night sky but is difficult to see from anywhere in the Northern Hemisphere and impossible from the UK and Canada.

Omicron Ceti

See Mira (q.v.).

Oort cloud

This is an area of space beyond the Kuiper Belt (q.v.) where there is a sphere of comets surrounding the Sun at about a light year in radius. At the moment, there is no conclusive proof that it exists.

Open cluster

This is a star cluster where most of the members can be separated clearly with or without optical aid but are close enough together to make it obvious that they are physically associated. Examples include the Hyades, Pleiades, and Beehive.

Ophiuchus

This constellation is on the ecliptic but is not part of the Zodiac, as known to astrologers.

Opposition

This is an event when a solar system object is opposite the Sun in the sky, when the Earth is directly between the object and the Sun. It is usually the best time to observe an object.

Optical double

This is a pair of stars that appear to form a binary system (q.v.) but simply appear close in the sky because of a line of sight effect.

Orbital node

An orbital node is where the orbit of a planet, moon, or other object crosses the path of the ecliptic (q.v.). As the orbits of every body in the solar system are somewhat inclined to the ecliptic, each orbit has two nodes.

Orion

This constellation is quite well known to non-astronomers. Part of it lies near the ecliptic, so can be a temporary home for the Moon and the planets.

Outer solar system

Like "inner solar system" (q.v.) this is a term that is often used but lacks a precise definition. A common use is that it begins just outside the orbit of Neptune but nobody is quite sure where it finishes, the Oort Cloud (q.v.) being the best current guess.

Parfocal

This is where a set of accessories have the same focussing position in a telescope, so can be easily interchanged without adjusting the focus.

Phaethon

This is an asteroid that may be a comet that has lost its volatile material and no longer be capable of growing a coma or tail.

Periodic comet

This is a comet that returns to the inner solar system at regular known intervals.

Periodic error

This is a property of a mount, even a good one, where there are inconsistencies in tracking introduced by the gears. There are several means of correcting it known as "periodic error correction."

Perseids

This is a meteor shower coming from the direction of Perseus, with the peak occurring between Aug 11th and 13th.

Perseus

This is a northern constellation said to represent a hero. It is home to many interesting objects.

Photon

This is a particle of light. By collecting photons from an astronomical object, we can form an image that we can look at or photograph.

Photosphere

This is a layer of the solar "surface," visible in "white light".

Pixelated/pixelation

This is an output with large, coarse-looking pixels. Using too high a resolution (pixels smaller than the output device can produce) increases the file size and slows the printing of the image; furthermore, the device will be unable to reproduce the extra detail provided by the higher resolution image.

Plage

This is an exceptionally bright area of the solar surface.

Planet

Knowing what a planet is should be simple enough but these days it is not, as nobody can agree! If it is too big, it is a brown dwarf and if it is a bit too small it is a dwarf planet and if it is much too small, it is an asteroid. Confused? I expect so! In any case, it may be large enough to qualify as a planet but if it orbits another planet then it is classed as a moon. Some people claim that our own moon has reasonable claims to be a planet.

Planetary nebula

This is a type of object formed when a star of comparable mass to the Sun finishes its red giant phase and sheds its outer layers.

Pleiades

Star cluster in the constellation of Taurus, also known as the Seven Sisters.

Plossl

Commonly used type of eyepiece, suitable for visual use.

Plough

See Big Dipper (q.v.). The Plough is the name in the United Kingdom.

Pluto

Well we all know what Pluto is, don't we? Er, actually, no! It is no longer recognized as a planet because it no longer follows the rules by which "planet" is now defined. It is not an asteroid either, so is now known as a "dwarf planet." But a "dwarf human" is still a human, even though he or she is a dwarf but then a "dwarf planet" is no longer considered a planet. If you feel confused, you have every right to be!

Population I/II/III

These terms refer to the relative ages of stars, with Population I (which includes the Sun) being the youngest.

Postprocessing

This is the act of improving digital images following capture using a tool such as Paintshop Pro, Photoshop, or similar. There are several techniques available for general photography but solar imaging often requires specialized use. For a detailed description, see the *Imaging* chapter.

Primary component

For the purposes of visual or photographic astronomy, the primary component is the more luminous of the two components in a binary system. For the purposes of celestial mechanics, the primary component is the more massive.

Primary mirror

This is a mirror used to collect light in a reflector, which performs the same task as an objective lens in a refractor.

Prominence

This is a flame-like solar structure, which appears on the limb of the solar disc.

Proxima Centauri

This is the nearest star to us apart from the Sun. However, as it is very small and faint, it is invisible without binoculars or a telescope. It forms a triple star system with the two main components of Alpha Centauri (q.v.).

Pugh effect

This is a humorous attempt by myself to name the effect of seeing Venus through binoculars or low magnification. The apparent phase appears larger than it should be, as the magnification is insufficient to resolve the Venusian disc. Despite the humor and the name, the effect is real and shows in photographs.

Quadrature

This is the point in an object's orbit where it forms a right angle between the Earth, itself and the Sun. For a superior planet, it will have an elongation of 90° from the Sun.

Quantum efficiency

This is the percentage of light that is recorded by a camera of the light that reaches it.

Radiant

This is the part of the sky from which a meteor shower appears to originate.

Radiative zone

This is the part of the solar interior just outside the Core, where energy radiates to the higher levels/zones of the Sun.

Red giant

This is a type of star characterized by its red color and extreme size. Most stars become red giants at some stage in their lives and the Sun itself will become a red giant one day. It happens when a star's hydrogen in its core runs out and it starts converting helium in its core into carbon and heavier elements. Its outer layers swell and become extremely thin.

Reflection nebula

This has a similar composition to a dark nebula (q.v.) but there happens to be a nearby star or few that light the nebula up to make it visible.

Retrograde motion

This is the apparent motion across the sky of a superior planet or other object outside the Earth's orbit as it approaches opposition. It is caused by the Earth overtaking the planet on the inside. During this time, the planet appears to move backwards across the sky.

RGB

Literally "red, green, and blue." In photographic terms, a color image is composed of red, green, and blue components and the amount of red, green and blue in a camera pixel determines the shade of color that is reproduced. Digital photography post processing (q.v.) manipulates the red, green, and blue outputs.

Rille

Rilles are long, narrow depressions in the lunar surface. Although their exact origin is not well understood, they are believed to be caused by collapsed lava flows and fault lines when the Moon was volcanically and tectonically active.

Ring Nebula

The Ring (as it is often referred to by its shortened name by those in the know) is the most well-known planetary nebula, as it is the easiest to find (although not the brightest). It is also known as M57.

Satellite galaxy

This is a small galaxy that orbits a larger one. For example, the Magellanic Clouds (q.v.) orbit the Milky Way and M110 and M32 orbit the Andromeda Galaxy (M31).

Saturation

Saturation is the result of over-exposing a pixel of a digital camera. One possible result is blooming (q.v.).

Saturn

Saturn is the second largest planet in our solar system and has the most impressive ring system.

Scorpio

This is a popular name for Scorpius (q.v.).

Scorpius

This is a constellation in the southern part of the sky crossed by the Sun during late autumn. Apart from the ecliptic passing through it, it is also well known for its brightest star, Antares (q.v.). It is also close to the central part of the Milky Way.

Secondary component

For the purposes of visual or photographic astronomy, the secondary component is the less luminous of the two components in a binary system. For the purposes of celestial mechanics, the secondary component is the least massive.

Secondary mirror

This is a mirror used in most types of reflector to reflect the light from the primary mirror (q.v.) to the terminal light path, so that an object can be viewed through an eyepiece.

Semiapochromatic

This is a term to be wary of. It can mean anything from a high quality achromatic refractor to some thing quite close to a true apochromatic one. Consult independent advice before buying. If it uses the term "ED" or "extra dispersion" (q.v.) it is quite good and you know what you are getting, although a true apochromat is rather better.

Seven Sisters

See Pleiades (q.v.).

Shroter effect

This is where the apparent phase of Venus appears larger than theoretical models predict, because of light scattering through the Venusian atmosphere from the sunlit side to the dark side.

Signal to noise ratio

This is the ratio of the signal (actual light captured by a camera) to the noise (light that is introduced by the camera and/or imaging process).

Small Magellanic Cloud
See Magellanic Cloud (q.v.).

SOHO
This stands for Solar and Heliospheric Observatory. It is a spacecraft that takes images of the Sun and its surrounding area. Its images can be viewed on the Internet.

Solar projection
Technique used to use a telescope to project the Sun's image onto a card or screen so that sunspots and other white light features can be seen. Not used much now, due to the presence of filters that allows you to see and photograph the Sun directly.

Solar system
Now we all know what the solar system is, so why is it in the Glossary? In truth, we all accept that planets and Kuiper Belt objects (for example) are part of the solar system but nobody really knows exactly where it ends and interstellar space begins. Some would draw the boundary where the solar wind meets the interstellar medium and others would say it is the Oort Cloud. Fortunately, as nothing is visible to amateur instruments at this distance, it is not our problem!

Solar wind
This is a stream of charged particles originating from the Sun and reaching the outer limits of the solar system.

Southern Cross
This is a constellation near the celestial south pole that contains many interesting objects, despite its small size.

Spectral sensitivity
This is the quantum efficiency (q.v.) of a camera across the whole visible light spectrum.

Spectroheliosocope
This is a special type of telescope that can be used to view solar light from different wavelengths to enable features to be seen.

Spicules
These are small "spikes" at the edge of the solar disc that can be seen in hydrogen alpha light. They are usually seen in the larger apertures.

Spider
This is a support for the secondary mirror in a Newtonian reflector (q.v.).

Spherical aberration

This is an optical defect introduced by the use of a primary mirror with a spherical shape. It can be corrected by various means, such as a corrector plate or using a parabolic mirror instead.

Sporadic meteor

This is a meteor that occurs at random and is not part of any recognized shower.

Star

We all know what a star is, or do we? For the purposes of amateur astronomy, it does not really make a difference. At the smallest end, the boundary between a star and a brown dwarf (the next smallest object) is a bit blurred, as is the boundary between a brown dwarf and planet.

Star atlas

This is a book or Website used to locate stars and other deep sky objects.

Star cluster

Group of stars that are bound by gravity and appear close together in the sky as seen from Earth.

Stationary point

This is a point in a planet's orbit where its motion changes from normal to retrograde or vice-versa.

Sungrazer

This is a type of comet that passes very close to the Sun.

Sunspot

Sunspots are darker regions of the solar Photosphere that are about 1,800° cooler then the rest of the Photosphere. They are caused by solar magnetic fields.

Superior conjunction

This is an event where an inferior planet (Mercury or Venus) is on the opposite side of the Sun to the Earth.

Superior planet

This is a planet whose orbit is entirely outside that of the Earth. Superior planets are Mars, Jupiter, Saturn, Uranus, and Neptune, although there is speculation that other planets are waiting to be discovered in the outer reaches of the solar system.

Super wide angle

This is a type of eyepiece with an increased apparent field of view of 70° or more.

Surface brightness

This is a term that relates to the brightness of "faint fuzzies" (q.v.) being spread out over a large area and being, therefore, much more difficult to see than a star or planet of the same magnitude.

Sweet spot/sweet band

Areas in the view through a hydrogen alpha telescope that show more detail than the rest of the view.

Sydonic period

This is the time taken for a planet to reach the same position relative to the Sun in its journey around the sky. It is related to the orbital mechanics of the planet and the Earth. To allow for discrepancies in the orbits of the planet and the Earth, its precise definition is the time between successive superior conjunctions of the planet. Note that superior planets can only have a superior conjunction, while inferior planets may have both inferior conjunctions and superior conjunctions. Mercury has the shortest sydonic period of 97 days and Mars the longest period of 780 days.

Tachocline

This is another name for the interface layer (q.v.) in the solar interior.

Taurus

This is a constellation apparently representing a bull that is on the ecliptic and is therefore part of the Zodiac.

Terminal light path filters

These are placed at the eyepiece end of a telescope. Although, in general, they are not as effective as full aperture filters (q.v.) for narrowband solar viewing, they provide a cheaper alternative for larger aperture use. They can also be used to lower the bandpass of full aperture filters, especially budget ones with a bandpass of 1.5 Angstrom units.

Titan

This is the largest moon of Saturn and can be seen in binoculars under good conditions.

Transient lunar phenomena

These are events where the lunar surface appears to change for a brief period, such as a lightening or darkening of parts of the lunar landscape. Once thought to be the result of deficiencies in the telescope's optics, they have been photographed and are known to be genuine. Their cause, however, still remains a mystery.

Transition region

This is part of the solar interior.

Triple star system
A group of three stars that are gravitationally bound to each other.

Uranus
This is one of the outer planets but is not an easy object for amateur astronomers.

Ursa Major
This is a constellation circumpolar from the United Kingdom, Canada, and many parts of Europe and the United States. It is home to the Big Dipper or Plough asterism.

Ursa Major moving group
This is the best-known example of an association, where a group of stars share a common motion across the night sky over thousands and millions of years. Five members of this group share a common motion and several stars across the night sky belong to the group or are suspected. One possible member is Sirius.

Usual Suspects
This is a nickname given to a group of easy deep sky objects that can be seen by inexperienced observers using modest equipment. Many astronomers have their own list. The main qualification to make my list is that it has to be visible from an astronomer's home with 50 mm binoculars under average conditions.

Venus
This planet is the closest in size to Earth but is extremely hot. It is the brightest natural object in the sky after the Sun and the Moon.

Vulcan
Vulcan is the name of a planet once believed to orbit the Sun closer than Mercury.

Vulpecula
This is a small northern constellation bordering on Cygnus (amongst others). It is home to the Coathanger (q.v.) and Dumbbell (M27).

Webcam
Abbreviated form of "web camera," which gives a high quality, low cost means of astrophotography.

White light
This is a general term for the collection of light emitted by the Sun in visible wavelengths.

Yellow dwarf

This is a type of star, of which the Sun is the closest example. The term "dwarf" is a bit of a misnomer because there are more stars smaller than the Sun than larger.

Zodiac

This literally means "circle of animals." It is the set of constellations (q.v.) on the ecliptic (q.v.). However, there is a lot of confusion because the zodiac as used by astrologers is about 2000 years out of date! This is one reason most astronomers are cynical about astrology. The true zodiac contains Ophiuchus and the planets and the Moon can wander into Cetus and Orion as well. Tell an astrologer than you were born when the Sun was in Ophiuchus, Uranus was in Cetus, and Neptune was in Orion. They will be unable to answer!

Index