

## Chapter 2

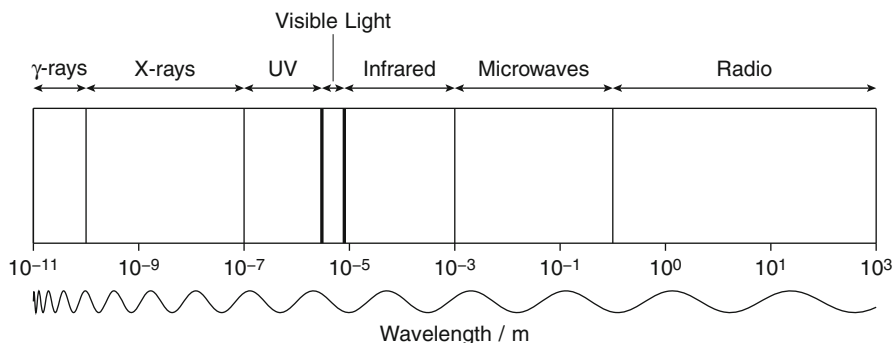
### Equipment for Observing the Sun

Let us begin this chapter by repeating the warning given at the start of the book. NEVER LOOK DIRECTLY AT THE SUN THROUGH ANY FORM OF OPTICAL EQUIPMENT, EVEN FOR AN INSTANT. A brief glimpse of the Sun through a telescope is enough to cause permanent eye damage, or even blindness. Even looking at the Sun with the naked eye for more than a second or two is not safe. Do not assume that it is safe to look at the Sun through a filter, no matter how dark the filter appears to be, because the danger of observing the Sun is caused less by its exceedingly bright light – though that would be enough to blind you if you looked at it for long enough – but by its *invisible* radiation.

#### The Sun's Radiation

So we can understand just why looking at the Sun without appropriate protection is dangerous, let us pause to examine the nature of the radiation emitted by our nearest star.

The visible light emitted by the Sun and other stars is just one of many forms of *electromagnetic radiation*, which is composed of electric and magnetic waves oscillating at 90° to each other. (Electromagnetic radiation also behaves as a stream of particles, but for the purposes of understanding the Sun's light as it affects the visual observer, it is better to think of it as waves.) Radio waves, infrared radiation, ultraviolet and X-rays are all forms of electromagnetic radiation. Different types of electromagnetic radiation are distinguished by their different wavelengths, which correspond to different energies.



**Fig. 2.1** The electromagnetic spectrum

The full range of wavelengths when plotted on a diagram is known as the *electromagnetic spectrum* (Fig. 2.1). The shorter the wavelength of electromagnetic radiation, the higher its energy and the greater its danger to humans and other living matter. Thus radiation with the shortest wavelengths and highest energies, X-rays and gamma rays, would quickly kill us if Earth's atmosphere were not opaque to them and blocked them out. Ultraviolet radiation is partially blocked by Earth's atmosphere, but some of the longer ultraviolet wavelengths – i.e., those closest to the visible part of the spectrum – reach Earth's surface. Exposure to ultraviolet light from the Sun can, of course, damage unprotected human skin (and pose a potentially serious health hazard). Most importantly for the solar observer, the atmosphere lets through more than enough ultraviolet to damage the eye, particularly if the Sun is looked at through a telescope.

Visible sunlight is a combination of the seven colors of the familiar rainbow: red, orange, yellow, green, blue, indigo and violet. This visible spectrum comprises a range of wavelengths between 700 nm (1 nanometer = 1 billionth of a meter, or  $1 \times 10^{-9}$  m) at the red end of the spectrum and 400 nm at the violet end and, as can be seen from Fig. 2.1, is just a tiny slice of the larger electromagnetic spectrum. Beyond the red end of the spectrum is the infrared. As with ultraviolet, the infrared wavelengths furthest from the visible part of the spectrum are blocked by the atmosphere, but those nearest to the visible – called the “near infrared” by astronomers – are transmitted and reach Earth's surface.

A great deal of the energy emitted by the solar surface is in the form of this invisible infrared radiation, which manifests itself as intense heat and presents the greatest danger of all to the eye. When a telescope is pointed at the Sun, the heat is focused behind the eyepiece and is easily enough to cause paper or clothes to smolder after a few seconds. When the eye is exposed to the Sun in this manner, the infrared radiation burns the retina (the light-sensitive area at the rear of the human eye), destroying the light receptors. A filter may block enough visible light, but it can still pass dangerous amounts of infrared, or ultraviolet, or both without you knowing it. More frighteningly, the retina is not sensitive to pain, and so you may

not be aware that your eye is being damaged while you are looking at the Sun. A retinal burn can also spread from a small hole in your vision to a large blind area over the ensuing weeks.

Fortunately, there are nowadays a number of safe ways in which to observe the Sun. Do not attempt solar observing until you have read and carefully considered the advice below. Your eyes are too precious for it to be worth taking risks.

## Telescopes for Solar Observing

The first question is, what sort of telescope is best suited to observing the Sun? The short answer is simply to use what you've got, as each of the main types of telescope used in amateur astronomy can be employed to some extent for solar observing. We will begin here by outlining the strengths and weaknesses of each type, and so enable you to decide what kinds of solar observing your existing telescope is best adapted to – or allow you to make an informed choice if you are contemplating buying a telescope for solar study. We will then discuss the safety precautions needed to observe the Sun with the various types of telescopes.

Unlike some other branches of astronomy, observing the Sun does not require a large telescope. While many targets in the night sky are difficult to observe because they emit too little light, this is not a problem with the Sun – indeed, the Sun has far too much light! Also, the Sun shows plenty of detail even in a very small telescope. Whereas details on planets or deep-sky objects often require a good-sized instrument to be seen, dramatic changes in sunspots and other solar features can be observed and recorded using just a 60 mm (2.4 in.) refractor, provided that it is equipped with appropriate eye protection.

Three basic types of telescopes are used by amateur astronomers: the refractor, which uses lenses to focus the light; the reflector, which uses mirrors; and the catadioptric, a generic name which covers two different designs combining lenses and mirrors to form an image at the eyepiece.

### *The Refractor*

The refractor (Fig. 2.2) is in many ways the best type of telescope for observing the Sun. Perhaps partly because of the recent advent of affordable solar filters and the consequent increase in the popularity of solar observing, recent years have seen a great number of new refractors appear on the amateur astronomy market, at all price ranges. All modern refractors use an object glass composed of at least two pieces of glass, in order to eliminate “chromatic aberration” – fringes of bright color around the image caused by the glass splitting up light into its spectrum of colors.

The most common type of modern refractor lens is known as an “achromatic” lens. This type of lens, although greatly reducing the amount of false color, does not eliminate it entirely, and a number of other lens designs have been produced,



**Fig. 2.2** The author's 80 mm (3.1 in.) refracting telescope on a German equatorial mount with electronic slow motion controls. A home-made balsa wood projection box is attached to the eyepiece end of the telescope for safe viewing of the Sun's image

using exotic types of glass and sometimes involving three or four glass elements (Fig. 2.3). Telescopes using these special lenses are known as “apochromatic” refractors, and they give excellent images almost entirely free from false color. They have the advantage of having shorter tubes than achromatic refractors of the same aperture, and this is especially useful in refractors of more than 100 mm aperture, because it makes them more compact and portable. Whereas achromatic refractors generally have focal lengths of between 10 and 15 times their apertures – that is to say, they have focal ratios (abbreviated  $f$ /ratios) of between  $f/10$  and  $f/15$  – an apochromat can have an  $f$ /ratio of  $f/8$  or even shorter.

Apochromats can be very expensive, particularly in larger sizes, but in recent years some refractors with apochromatic or semi-apochromatic lenses have appeared at more reasonable prices. In apertures smaller than 100 mm an ordinary achromatic



**Fig. 2.3** The author's 60 mm (2.4 in.) f/5.9 Takahashi apochromatic refractor. Its short tube makes it extremely compact and portable

refractor is adequate for all-around solar observing, provided it has an  $f$ /ratio of  $f/11$  or longer; as in small telescopes false color does not hugely degrade the image. Apochromats come into their own in high-resolution imaging of the Sun with webcams or webcam-type cameras designed for high-resolution imaging, because chromatic aberration becomes a serious problem at the very large image scales used in this type of imaging. Do not buy a simple achromatic refractor with a focal ratio shorter than  $f/10$  if you have a serious interest in solar observing. These short-focus refractors are designed for visual deep-sky and comet observing at low powers and are not suitable for the rather higher magnifications employed in observing the Sun, because they have far worse optical aberrations than their longer  $f$ /ratio cousins.

A small achromatic refractor, with an object glass of between 60 and 100 mm and a focal ratio of between  $f/10$  and  $f/15$  has a number of distinct advantages for the amateur solar observer. Firstly, such a telescope is relatively cheap to buy, the prices of 60 mm refractors starting at as little as \$100. The second main advantage of a small telescope such as this is portability. Ideally, a telescope used for serious solar observing should be permanently set up in an observatory. However, for it to be worth building an observatory, a site that has access to most of the sky and where objects low on the horizon can be observed is required. Most of us do not have a suitable site, let alone the money to construct a good-quality building. Even if you are lucky enough to have an observatory, the Sun might not always be accessible when you want to observe it. The Sun's position in the sky varies greatly with the time of day and the time of year. For example, it may still be behind the rooftops in the southeastern sky when you want to have a quick look at the Sun on a winter's morning before going to work, or it could be equally inaccessible on summer evenings, when the Sun is low in the northwest.

For reasons we will discuss in Chap. 3, there are a lot of advantages in observing the Sun when it is between  $15^\circ$  and  $40^\circ$  above the horizon, and so it is a good idea to have a telescope that is compact and light enough to be carried to a spot where the Sun can be seen. Unlike a larger telescope, a small instrument can be carried in one or two pieces and can be used at very short notice – an essential requirement if you live in a cloudy climate, where every minute of clear sky is precious.

Another advantage of a small refractor is that it does not collect much solar heat. This is of great importance if you are using the telescope to project the Sun's image onto a screen and you are not employing a filter over the telescope's front aperture. When focused inside the telescope, the Sun's rays generate a great amount of heat, which can cause turbulence in the air inside the tube and so cause the solar image to flicker and blur. Even more importantly, the concentrated heat inside a medium- or large-sized telescope can be enough to damage your telescope's internal components – particularly if, as with some modern telescopes, the tube contains parts made of plastic. Reflectors and catadioptric telescopes both have components close to the focus and so are very susceptible to heat damage. Even refractors can collect dangerous amounts of heat, and some of the cheaper modern refractors have plastic drawtubes and other internal parts. Heat damage caused by projecting an unfiltered image could damage the warranty in some telescopes. But by following the precautions described below in the section on eyepieces for solar observing you should be able to avoid heat problems. Small refractors also allow you to easily attach your own accessories for projecting the Sun's image, as will be described below.

Another (albeit expensive) accessory that you might want to attach to your telescope, either now or in the future, is an H-alpha filter for observing prominences and other features in the solar chromosphere. This is another argument in favor of a refractor, because most H-alpha filters are designed to work on refractors, and many adapters are available that enable these filters to be mounted on reflectors.

If you are considering buying a telescope specifically for solar observing, avoid very cheap models of the kind that are found in camera stores or at the bottom end of telescope manufacturers' price lists. Such telescopes very often have plastic parts and so can be damaged by solar heat. These telescopes are often bundled with "Go To" systems that find stars and other objects in the night sky at the touch of a few buttons, but are completely unnecessary for locating the Sun. More generally, whatever kind of telescope you buy, it is best to invest in an instrument with a respected brand name, rather than any of the cheap imitations, called "clones," that have appeared in recent years. Clones are very tempting, because they appear to offer the same telescope as the brand name for significantly less money, but they sometimes contain plastic parts, and features such as metalwork, gears and slow motion controls are often inferior to the "real thing." It is better to buy, say, a brand-name 80 mm refractor than a 100 mm clone.



## *The Reflector*

When we use the term “reflector” in amateur astronomy, this most commonly means the Newtonian reflector, after its inventor, Isaac Newton. Reflectors have often been described as the best all-around telescopes for the amateur astronomer, and with good reason. Of the three main types of telescopes, the Newtonian is the cheapest per unit aperture. Partly because Newtonian telescopes are cheaper, they tend to be sold in larger apertures than refractors. A 114 mm Newtonian is usually the smallest size commercially available, and the 150 mm size has long been popular with the average amateur astronomer. A good 150 mm Newtonian can often outperform a smaller but more expensive refractor in picking up faint star clusters and galaxies and can give very satisfactory results on the Sun, too.

However reflectors, especially in the larger sizes, are less convenient than refractors for visual solar observing, for several reasons. The larger size of a reflector makes it less portable, and the large aperture is of no advantage in solar observing. Although in theory a larger telescope should resolve more fine detail on the Sun than a smaller instrument, the atmospheric turbulence caused by the Sun heating the ground during the day rarely permits this. In an average climate, most of the time you will do well to resolve details as small as 1 arc sec (") across – the resolution limit of a 100 mm telescope. (1 arc sec = 60 arc min (60') =  $\frac{1}{3,600}$  of a degree, or approximately  $\frac{1}{1,800}$  of the angular diameter of the Sun or Moon.) In fact, if you use the projection method, the large aperture can be a danger, due to the concentrated heat inside the tube, making the telescope effectively a solar furnace. The secondary mirror, or “flat,” in a reflector is especially susceptible to overheating, since it lies quite close to the focus. Even if the heat inside the tube is not great, it can still be enough for the secondary and its mount to generate a small current of warm air, spoiling the solar image. These tube currents are worsened by the fact that a Newtonian has an open tube, which allows the warm air to mix with the cooler air outside, causing further instability.

You can overcome the heat problem by covering the front of the telescope with a cardboard mask that has a small hole cut in it. For a 150 mm reflector, the hole should be about 60 mm in diameter, and it should be positioned away from the center of the tube, so that the secondary mirror or its support vanes do not block the light path. Such an “off-axis mask” greatly reduces the amount of heat in the tube but still allows plenty of detail to be seen on the Sun.

Beware of the aperture stop fitted to the tube caps of some very cheap, small reflectors. These are often “on-axis” – i.e., removing a secondary cap from the main cap leaves a small hole in the center. This is fine in a refractor, which has no central obstruction, but in a reflector the secondary mirror takes up most of the small aperture left by the central hole, greatly reducing the contrast of the image and the amount of light coming through and rendering the instrument almost useless. If you are using a 150 mm telescope at full aperture, or a larger reflector even with an off-axis

mask, you must use a filter in front of the telescope, as such large apertures generate too much heat inside the tube for safety.

Although Newtonians are of little advantage in ordinary visual observing, they can be very useful for imaging the Sun at very high resolution using webcams or purpose-built astronomical video cameras based on the webcam principle. Because webcams can capture fleeting moments when the atmosphere is steady, they sometimes allow the large aperture of a reflector to be exploited to its full advantage. Webcam imaging of the Sun is discussed in more detail in Chap. 8.

## *Catadioptric Telescopes*

Since they first appeared on the amateur telescope market in the 1970s, catadioptric telescopes have become very popular with amateur astronomers. Two designs of catadioptric telescope are readily available: the Schmidt-Cassegrain telescope (commonly abbreviated to SCT) and the Maksutov. Both designs work on the same general principle: the light passes through a specially designed corrector lens at the front of the tube before the main mirror reflects it onto a much smaller convex mirror set just inside the corrector lens. The convex mirror then reflects the light back down the tube through a hole in the main mirror, and the image is focused and viewed at the bottom of the tube, as in a refractor. The main physical difference between the two designs is the shape of the corrector lens.

Because they reflect the light twice along the length of the tube, SCTs and Maksutov telescopes fold up a long focal length into a short tube, and so they are very compact and lightweight. This makes them very portable and also easy to mount rigidly. The latter quality means that SCTs and Maksutovs are well-suited to astronomical imaging and many of them are marketed for this purpose as well as visual observing. Telescopes of this type designed for serious imaging of the night sky are available in apertures of 200 mm and above, but catadioptrics designed for visual observing and short-exposure photography are also available in smaller apertures. Widely advertised models of these small telescopes include the Meade ETX range of Maksutovs (available in apertures from 90 mm up to 125 mm – see Fig. 2.4), the exquisite and expensive 90 mm Maksutov made by Questar and various Schmidt-Cassegrain and Maksutov instruments offered by Celestron.

All catadioptric telescopes can be used for solar observing, but they *must* be used with a filter. These telescopes contain some delicate internal components, and the Sun's heat could easily damage them if they were used for projection. In any case, the mountings of these telescopes would make it difficult to attach projection apparatus to them. Fortunately, many front-aperture filters are available to fit specific models of SCT and Maksutov telescopes. These instruments are also especially suitable for solar photography and webcam imaging, as they were designed with astronomical imaging in mind, and many adapters and attachments are available for them.





**Fig. 2.4** A Meade ETX 90 mm (3.5 in.) Maksutov telescope equipped with a glass aperture filter. Note that the finderscope has been removed. This is an important safety precaution, because the Sun is just as dangerous to look at through the finderscope as the main telescope, and careless people, particularly children, could look through it by accident

## Telescope Mountings

Just as important as the telescope itself is the mount that supports it and moves it to track the apparent motion of the Sun. A telescope on an inadequate mount is very frustrating to use, as the image constantly dances about when the telescope is adjusted or focused. Even wind or passing traffic can cause annoying vibrations in a telescope that is on too flimsy a mount. Many very cheap, small telescopes sold in department stores and smaller shops are on very poor-quality mountings, and these telescopes – which are often optically inferior anyway – should be avoided. Even some more expensive telescopes of high optical quality come with inadequate mountings, which is why some serious observers re-mount their telescopes on more expensive, heavy-duty mounts.

Mountings for both amateur and professional telescopes are of two basic types – *alt-azimuth* and *equatorial*. The simplest is the alt-azimuth, in which the telescope moves around horizontally (azimuth) and up and down vertically (altitude). An equatorial mounting is effectively an alt-azimuth mounting that has been tipped over so that the azimuth axis points towards the celestial pole.

Alt-azimuth mountings for small refractors are on tripods, and the telescope is carried on either a small fork or a pan-and-tilt head similar to that on a camera tripod. Alt-azimuth reflectors are usually on “Dobsonian” mountings,

a form of alt-azimuth mount that runs on Teflon bearings and has a low center of gravity, giving a very stable mount with smooth motions for a reflecting telescope's relatively bulky tube. Equatorial refractors and Newtonians normally employ the "German" equatorial mount design (see Fig. 2.2). One disadvantage of the German equatorial is that it requires a counterweight to balance the telescope, thus adding to the weight of the overall setup. Catadioptric telescopes also sometimes have German equatorial mounts, but more usually they are on "fork" mountings, an equatorial design suitable only for telescopes with short tubes but which dispenses with the counterweight, making such telescopes even more portable.

An alt-azimuth mount is the cheapest option, and for a refractor or Newtonian owner it is also the most portable. General solar viewing, sunspot counting and even basic drawings and photography can be done with a telescope on a good alt-azimuth mount. As you become more experienced, however, you may wish to upgrade to an equatorial mount. The main disadvantage with an alt-azimuth mount is that in order to keep the Sun centered in the field of view you need to move the telescope in two directions – altitude and azimuth – using two slow motions, which is tedious and compromises accuracy if you are recording sunspot positions or doing detailed sunspot counts. An equatorial mount allows the Sun to be tracked with only one motion.

Best of all is an equatorial mount with a motor drive to keep the Sun in the field of view. Also, an equatorial mount that is properly aligned with the pole enables the orientation of the Sun's image to remain the same throughout the period in which it is observed – an essential feature for serious sunspot counting and drawing the Sun's disc to determine the positions of sunspots. With an alt-azimuth mount you need to adjust the orientation every few minutes to ensure accurate results. Electronic slow motions are a very useful accessory for a motor drive, as they allow you to scan the Sun at high magnification and make fine adjustments to the tracking.

Some modern telescopes have alt-azimuth mounts with motorized tracking, the positional adjustments being made by the instrument's internal computer. However, although these mounts keep the Sun conveniently in the field of view, they do not correct for the changing orientation of the image, and so you still need to adjust the image to keep it aligned. In any case, computer-controlled alt-azimuth mounts are generally sold with "Go To" systems, which, as we noted above, are not necessary for finding the Sun.

Whatever type of telescope mount you choose, make sure it is steady enough. A good test of a mount's stability is to give the telescope tripod a sharp knock and time how long the vibrations in the image take to die out when a high magnification is being used. If the vibrations take longer than a few seconds to settle down, you may wish to consider upgrading to a better-quality mount. Similarly, check that the slow motions – manual or electronic – turn smoothly in all directions.



**Fig. 2.5** Projecting the Sun's image onto paper for safe solar viewing. A card has been fitted over the eyepiece end of the telescope to shade the image from direct sunlight

## Viewing the Sun's Image

### *Solar Projection*

Solar projection is traditionally the most popular method of viewing the Sun's image. Reduced to its basics, projection consists of holding a simple white screen, such as a sheet of white paper, 30 cm or more behind the eyepiece of the telescope and focusing the telescope so that a sharp image of the Sun is formed on the paper. The image on the paper is formed in a similar manner to that produced on a digital sensor by a camera lens.

In the opinion of many, projection remains much the best method for observing the Sun with a refractor. It is less convenient with a reflector, however, because a projection screen attached to the side of the telescope tube is ungainly and can cause problems with the telescope's balance. Projection is totally unsuitable for Maksutov or Schmidt-Cassegrain telescopes; if you have one of these instruments, you need to use a filter over the telescope aperture, as described below.

As an experiment, you can project the Sun's image quite simply by holding a sheet of A4-sized white paper between 30 and 50 cm behind the eyepiece of your telescope (Fig. 2.5). Shade the image from the ambient sunlight by fitting a sheet

of paper around the telescope tube. A low-power eyepiece will project an image of the Sun several centimeters across – easily large enough to show the principal sunspots visible on the disc. Eyepieces of higher magnification will show more detail in the sunspots but give a fainter image. Moving the paper further behind the eyepiece also gives a larger but fainter image.

Some small refractors, and occasionally Newtonians, come with a ready-made solar projection screen. This usually takes the form of a small sheet of white-painted metal attached to a long stalk, the other end of which is clamped to the eyepiece end of the telescope. This setup will also show the main sunspots. However, while commercial screens such as this and the simple method above are fine for experimentation or casual viewing, they are not adequate for serious observing. The main reason is lack of contrast. Even with a sunshade, the daylight makes the image much fainter than it should be and can all but wash out delicate solar details. Also, you cannot make accurate observations with a hand-held or commercial projection screen.

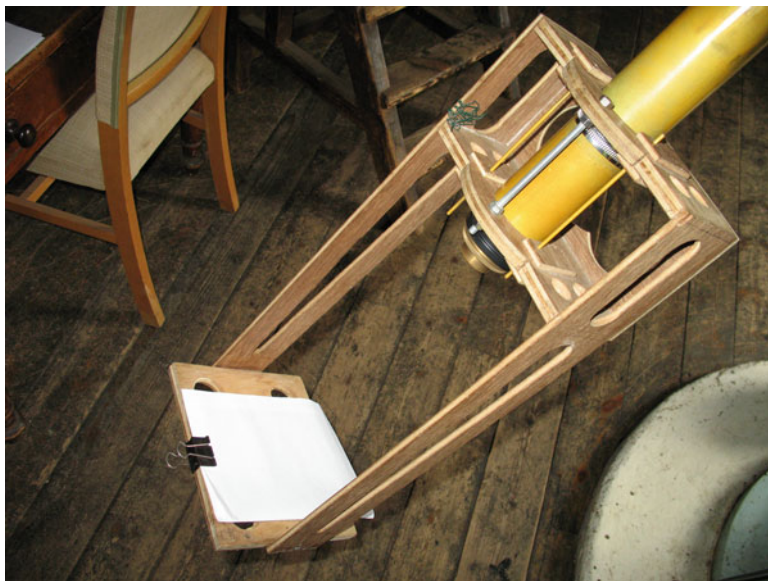
Fortunately, it is possible to shade the Sun's image very effectively using a box that holds the screen to the telescope while keeping out most of the daylight. Projection boxes are not available commercially, but it is quite easy to make one yourself. The entire box is covered, except for one side, all or part of which is kept open to allow the Sun's image to be seen. Attaching the box to the telescope leaves both your hands free to make notes, drawings and adjustments. The telescope eyepiece protrudes into the box through a hole in the eyepiece end of the box just big enough to fit over the eyepiece or drawtube and projects the image onto a white screen at the far end of the box.

In order not to upset the balance of the telescope tube, you need to make the box from a very light material. Balsa wood is excellent, as it is light but strong and can easily be cut and manipulated using ordinary hand tools. You can obtain balsa wood from toy shops, model shops or suppliers to the packaging industry. How you build your box is up to you, as amateurs have achieved excellent results with many different designs (Fig. 2.6). The author built his own projection box (Fig. 2.7) using balsa wood, and the details of its construction are described in Appendix A.

A few amateurs, particularly those with observatories or who do their observing from indoors, mount their projection screens entirely separate from the telescope, on a tripod or other support. This is not a recommended practice for accurate work, as even if the telescope has a motor drive the Sun is always moving relative to the screen. However, observing from indoors out of an open window has much to be said for it, as your surroundings are generally darker, and so the image contrast is increased still further. It is only possible in the warmer months, though, as in winter the mixture of warm and cold air causes severe air currents that ruin the image.

You may ask why, when a number of solar filters have been available commercially for years and have been tried and tested to be safe, the old-fashioned projection method is still recommended. The reason is that projection has several distinct advantages over filters. The first is that it is very safe. Filters can be damaged, and even small scratches or pinholes in their delicate metallic coatings can allow dangerous radiation to pass through. It is also possible for filters to be blown off the telescope by gusts of wind or fall off if not properly secured – with disastrous





**Fig. 2.6** A solar projection screen, designed by Roderick Willstrop of Cambridge University, attached to the 200 mm (8-in.) Thorrowgood refractor at the Institute of Astronomy in Cambridge, England. Here the screen is made from a light framework of plywood – heavier than balsa wood – attached to a large and heavy telescope



**Fig. 2.7** A balsa wood projection box made by the author and attached to an 80 mm (3.1-in.) refractor

consequences for the observer's eyesight. Projection is also much the cheapest method of viewing the Sun. The projection box described in Appendix A cost less than \$10 to build, whereas some filters for the same size of telescope cost more than ten times this amount. Thirdly, projection allows the Sun to be observed by more than one person at the same time – a unique advantage over any other astronomical object, where people have to take turns at the eyepiece and the focus has to be adjusted each time, or else have to be content with an electronic reproduction of the image on a computer screen. This makes projection ideal for teaching purposes and group viewing at astronomy clubs. Finally, for the serious solar observer, a projected image makes it much easier to plot the positions of sunspots and to make accurate counts of sunspot numbers.

Although the projection method described above is generally “very safe,” one word of warning is due. When you use the projection method, the sunlight coming through the eyepiece is totally unfiltered, and it is only too easy for uninformed people, especially children, to look through the eyepiece by accident. Projection also presents a minor fire hazard in that you can easily singe hair, clothes or personal items if they are placed too close to the eyepiece. A projection box is a helpful safety device, as it can prevent someone's eye from getting near to the eyepiece, but the best precaution when using the projection method – as with any other way of observing the Sun – is to *never* to leave a telescope unattended in the sunshine.

As far as the serious solar observer is concerned, the main problem with projection is the Sun's heat. Because the telescope is unshielded, heat builds up inside the telescope tube when the instrument is pointed at the Sun. In particular, the eyepiece, because it lies near the telescope's prime focus, can become very hot, and so great care must be taken when choosing eyepieces for solar projection. The advice of experienced solar observers for many years has been never to use any eyepieces except the very simple types such as the Huygens and the Ramsden, and avoid altogether the more complex types, such as Orthoscopes and Plössl. The reason is that the more complex eyepieces contain several lens elements bonded together with optical cement. The intense solar heat can melt the cement and so damage these eyepieces. Huygens and Ramsden eyepieces each contain just two completely separate lenses, with no cement, and so they can withstand prolonged exposure to the Sun.

Nowadays, however, this advice requires serious qualification. Huygens and Ramsden eyepieces are becoming difficult to get hold of lately, and those that are available are often made of plastic, which will quickly melt when exposed to the Sun. This author personally uses Orthoscopic and Plössl eyepieces for all solar work with the 80 mm refractor, because they give much better images than the simpler types. But do take the precaution of observing the Sun when it is less than 40° above the horizon, when its radiation is much less intense than at higher altitudes. For reasons described in the next chapter, it is never a good idea to observe the Sun when it is high in the sky anyway. Also, cover the telescope's object glass to let the interior of the tube cool after half an hour of continuous solar observation. Provided the above precautions are taken, Orthoscopic or other cemented eyepieces are quite suitable for solar projection with 80 mm or smaller refractors. If you use



a reflector or a larger refractor, though, you need to reduce the telescope aperture to 80 mm or smaller, using an aperture mask described above.

Do not use “exotic” wide-field eyepieces, such as the Ultra Wide Angle, Nagler or Ethos varieties, for solar projection. These eyepieces were designed for deep-sky observing, and their wide fields are not necessary for solar work. They would also cost a lot of money to replace if they were damaged by the Sun's heat.

If you use a refractor to project the Sun's image using a relatively high power (as you may need to do when making detailed observations of sunspots), you may notice a small amount of chromatic aberration in the image, which gives sunspots a purplish appearance and can sometimes make it difficult to get a good focus. This can be corrected, to some extent, with a filter such as the “Fringe Killer” filter sold by Baader Planetarium, which is designed specifically to reduce chromatic aberration. This screws into the front of an eyepiece like a lunar or planetary filter, though it is *not* a solar filter as such – it does not block any significant solar radiation and must be used either with the projection method or in addition to a proper solar filter (see below). As when using eyepieces for solar projection, the filter should only be used when the Sun is at a relatively low altitude, to avoid overheating. This author has used a Fringe Killer for several years on a 9 mm Orthoscopic eyepiece, which gives 101× with an 80 mm refractor, and it does greatly improve the image at higher magnifications. As well as removing a lot of the false color from sunspots and the limb of the Sun, it also enhances the contrast of faculae and especially the solar granulation. At only around \$50, it greatly improves a solar image without the need to invest in an expensive apochromatic refractor.

Projection works excellently with refractors, and while it is not so convenient with reflectors, it is usually possible to rig up some sort of projection arrangement with this type of telescope as well. You may have to be ingenious and attach some heavy object, such as a small can or bag filled with nails, to the bottom end of the tube to balance out the weight of the projection box. But if you have a Maksutov or Schmidt-Cassegrain telescope, or wish to do solar imaging, you have to employ a different method.

## ***Solar Filters***

The subject of filters is not easy, as many filters are not safe for solar viewing. One of the most dangerous types of filter is that designed to screw into the eyepiece. These eyepiece filters take the form of a piece of dark glass encased in a metal ring and are often marked “SUN.” They sometimes accompany the very cheap, small refractors sold in stores and are another reason for avoiding these telescopes. These filters are dangerous partly because they pass unsafe levels of radiation, but also because their proximity to the telescope's focus can cause them to crack without warning, instantly enabling the Sun's heat and light to pass unchecked through to the eye. Fortunately, these filters are less common than they used to be. Never be tempted to use one, and never use *any* filter at the eyepiece end of the telescope.

Only filters mounted at the *front* of the telescope are safe, because they are not subjected to the focused heat inside the telescope and only receive the normal daytime solar heat. Such filters are known as *aperture filters*. However, not all aperture filters are safe or suitable for solar observing through a telescope. In particular, never use home-made filters. They may *appear* to reduce the Sun's light and give an image faint enough not to dazzle your eyes, but they let through far too much invisible radiation and so damage your eyes before you realize it. Examples of dangerous home-made filters include sunglasses, polarizing and Neutral Density photographic filters, CDs, CD-ROMS, DVDs, computer floppy disks and food wrappers, including those with a silvery appearance that appear to reflect the Sun's light.

Some older sources recommend using black-and-white photographic film as a solar filter. The film is unraveled and exposed to normal daylight before being fully developed, making it turn as black as possible. The silver halide crystals in the film cut out the infrared radiation. However, this is not a good idea for the modern solar observer, as film might still not block enough infrared for use with a telescope. Also, not all black-and-white films contain silver halide nowadays, and in any case, film is becoming ever harder to obtain in the age of digital photography. This advice was intended in the past for those observing a solar eclipse with the naked eye. The optical quality of photographic film is also not nearly good enough for the telescopic observer. Even with the naked eye, the Sun has a noticeable "fuzz" around it when viewed through this type of filter. Color film of any type should NEVER be used as a solar filter, for naked eye or telescopic observing. Although it absorbs visible light well, it is nearly transparent to infrared radiation.

Another traditional filter, again intended for naked-eye viewing but worth mentioning here, is smoked glass – a piece of glass coated in soot by holding it over a candle flame. This is very risky because it is easy to coat the glass in too thin a layer of soot, and it is very difficult to get an even layer. There is therefore the risk that the amount of filtration might not be enough. The soot layer is also very easy to smudge and damage. In any case, with so many good filters available on the market nowadays, there is no need for the modern amateur to resort to such a primitive device.

The only truly safe solar filters are filters made specifically for solar observing through a telescope. These fall into three basic types. A popular and inexpensive type is a sheet of polyester film, often known by the trade name Mylar, coated with a thin layer of aluminum. Mylar is available from astronomical suppliers either in mounts designed to fit a particular make and model of telescope or as a sheet from which the amateur can cut a portion to place in a home-made mount. Never confuse silver food wrappers or "space blankets" with Mylar filters – they are not produced to optical standards and let through far too much infrared radiation. Some of these materials are not even Mylar but just ordinary plastic coated with silver paint. Before buying Mylar – or, indeed, any solar filter – check with an experienced amateur that it is safe and of good quality.

When you take delivery of the filter, hold it up to the light and see if there are any scratches or pinholes that let the light through. If it has any such defects, do not



**Fig. 2.8** Aperture filter made from Baader AstroSolar Safety Film in a home-made mount, fitted to an 80 mm refractor

use it, as they can let through dangerous radiation. Check with the supplier that the Mylar is coated on both sides; this offers extra protection against scratches or pin-holes. When you receive a mounted Mylar filter, you may be surprised that the material is slightly loose and wrinkly in its mount, but this has no effect on its optical performance. In fact, if you choose to mount the Mylar yourself, never pull it taut, as this can damage the surface.

When properly mounted up and attached to the front of the telescope, some Mylar filters give a solar image with a strong blue tint. This is because aluminum passes blue light more efficiently than red. It also scatters light slightly, making the sky background look very faintly blue. Both these effects can be reduced somewhat by threading a light yellow filter (also available from astronomical suppliers) into the eyepiece, *in addition to* the Mylar mounted over the aperture. Such “secondary filtering” gives the Sun a more realistic color and can also increase the sharpness and contrast of the image.

In the late 1990s, Baader Planetarium introduced a variation on Mylar known as AstroSolar Safety Film (Fig. 2.8). In outward appearance it resembles Mylar, but the manufacturer claims that the material has undergone special treatment and that its radiation transmittance has been precisely measured. It certainly gives images far superior to conventional Mylar filters. The blue color is hardly noticeable at all – indeed, the Sun looks almost white – and the sky background is almost totally black. The solar image is very crisp, and sunspots show up in beautiful detail. The Baader material is such an improvement over traditional Mylar that it now dominates the market for Mylar-type filters. Some companies supply mounted

filters made from AstroSolar, while the material is also available in rolls or A4-sized sheets with instructions on how to make your own mount. AstroSolar is very reasonably priced, and buying the material unmounted is even better value for money, as you can share the cost of sheets or rolls with other interested members of your local astronomy club, and you have the option of making up a new filter from the remainder of the sheet if your first one gets damaged. Be sure, however, to follow the manufacturer's instructions for safely mounting the material. Even with a Baader filter, a light yellow filter will give the Sun a warmer hue and enhance the contrast of the solar image still further. The No. 8 light yellow filter is useful in this regard. Secondary filters such as this are especially useful in solar photography. Indeed, AstroSolar is also available coated to a lighter density for photographic use, but this is not safe for visual observing. Solar photography with filters is discussed in Chap. 7.

Another solar filter that looks like Mylar but isn't is the R-G Solar Film supplied by Thousand Oaks Optical. This is similarly priced to Baader AstroSolar and is also available either mounted or unmounted. It gives the Sun a yellow-orange tint, much like glass solar filters (see below), so a secondary filter is not necessary.

If buying a sheet of Mylar-type material, note that its optical quality can sometimes vary from place to place on the sheet. It is not uncommon that in one part of a sheet, the solar image is excellent, while in another part of the same sheet it is so fuzzy and distorted as to be unusable, even with the naked eye. It is a good idea to check a sheet of Mylar by looking through it at the Sun or another bright object with the naked eye in order to ensure that you select a sound part of it before mounting it up. Also, the quality of Mylar-type filters degrades enormously if they are left exposed to air over long periods. A small, sealable plastic bag gives excellent, airtight protection. The filter inside its plastic bag can then be stored in an airtight plastic box of the sort intended for storing foods, in order to protect the somewhat delicate cardboard and plastic structure from knocks and scratches.

A cheaper alternative to Mylar is black polymer, which, although it looks like ordinary plastic, is designed for solar observing and blocks the harmful radiation. It gives the Sun an orange tint. Black polymer is somewhat more durable than Mylar, and so is very useful if you travel a lot with your telescope or are going somewhere to see a solar eclipse. Its chief disadvantage is that its optical quality is not as high as that of Mylar or glass solar filters, so it does not stand up as well to high magnifications in a telescope. Black polymer does, however, make an excellent filter for observing the Sun or solar eclipses with the naked eye (see below).

More expensive are the glass solar filters supplied by several astronomical instrument makers. These consist of a disc of glass polished on both sides to optical quality and coated on one side with a layer of stainless steel (sometimes known as "Inconel"), chromium or an alloy. Most glass filters come in mounts made for a specific telescope (Fig. 2.9). They are sometimes available in unmounted format, but the small saving in price is not worthwhile, because glass filters are more difficult to mount securely than Mylar filters. Again, if you purchase such a filter, you should check it carefully for defects.



**Fig. 2.9** A glass aperture filter mounted to fit the Meade ETX 90 mm (3.5 in.) Maksutov telescope pictured in Fig. 2.4

Unlike Mylar, glass filters give a solar image colored yellow or orange, due to the different transmission characteristics of the coating, and so there is no need to use a secondary yellow filter. The sky background is very dark, and sunspots show up with excellent contrast. Glass photographic filters are also available, but again these are not suitable for visual observing. Glass filters are more durable than Mylar-type filters. Although they can cost up to ten times as much as Mylar filters, it may be worth considering purchasing a glass filter if you use a catadioptric telescope and so have to use a filter all the time. Glass filters do still need to be stored carefully – use the stiff cardboard box it came in to protect your filter from impact and either the plastic sleeve it was originally wrapped in or a sealable plastic bag to keep it from exposure to the air.

Once again, always check out a solar filter carefully before using it. Sometimes even aperture filters advertised as being suitable for solar observing turn out to be unsafe. A classic case happened in the UK during the early 1990s, when advertisements for solar filters appeared in a British astronomy magazine. The filters were found to be pieces of colored plastic and totally transparent to infrared radiation. One experienced solar observer dramatically demonstrated this at an astronomy meeting by pointing a television remote-control unit through the filter and switching on the TV! Enough of the radiation from the unit's infrared beam was getting through the filter to the TV. Only buy filters from reputable, established astronomical suppliers and even then get an experienced observer to check your filter before using it.



**Fig. 2.10** A Herschel wedge or Sun diagonal made by Lunt Solar Systems

### *Other Observing Methods*

Before the advent of safe aperture filters, there were two alternatives to solar projection. The first was the *Herschel wedge*, sometimes called a *Sun diagonal*. This resembles an ordinary star diagonal as supplied with refracting and catadioptric telescopes and takes the form of a prism whose housing has a hole at the rear (Fig. 2.10). The prism reflects a small percentage of the Sun's light up to the eyepiece while the rest of the light passes through the prism and out of the hole at the back. These devices are not recommended for visual observing, as the amount of radiation passed, including visible light, is still dangerously high, and it is still necessary to use a dark secondary filter to dim the Sun's image enough for it to be comfortable to look at. It is also very easy to burn yourself with the unchecked solar heat emerging from the back of the prism.

In recent years, however, the Herschel wedge has made something of a comeback among more advanced observers imaging the Sun with webcams. The spectacular resolution of these cameras tests aperture filters to their limits, exposing the tiniest optical flaws, and so the resolution of the images is sometimes compromised. The high optical quality of the prism in a Herschel wedge allows a good telescope to perform to its theoretical resolution limit, given good enough sky conditions. Also, the very bright image transmitted by a Herschel wedge allows a very short exposure to be used. Using a Herschel wedge with a webcam poses no danger to the eyesight, because the image is focused on a computer



screen. These devices work best with apochromatic refractors, because they transmit the full range of visible wavelengths (unlike aperture filters, which transmit a more restricted range), and so chromatic aberration would show up more with an achromatic telescope. This characteristic is actually an advantage, because it shows the Sun in its natural color and gives no tint to the image.

Because the Sun's radiation is coming into the telescope unfiltered, you need to take the same precautions against heat build-up as you would when projecting the image. For the same reason, Herschel wedges must never be used with catadioptric telescopes or any telescopes with plastic parts inside. Herschel wedges are definitely a tool for the advanced solar imager, something underlined by their high price and the fact that they are usually sold to fit a 50.8 mm drawtube, a size often found on high-end apochromatic refractors.

Another alternative is the dedicated solar telescope. Several designs for these have been tried, although the best-known is an ordinary Newtonian reflector with an non-aluminized mirror. This design works in the same way as the Herschel wedge, the mirror reflecting a small amount of light back to the eyepiece and passing most of it out of the back of the tube. Such a telescope still requires a secondary filter at the eyepiece and, unless an aluminized mirror were substituted for the unsilvered one, it could not be used for anything but solar observing.

Many astronomy books recommend using a welder's glass as a solar filter. Provided that it is of a shade number 14 or higher (i.e., denser), a welder's glass is indeed safe for viewing the Sun with the naked eye, as these devices are designed for preventing harmful radiation from reaching the eye. It is not recommended as a telescopic filter, however, as its infrared blockage may still not be enough for the far greater power of a telescope. Also, it is not made to the highest optical standards and so would not provide as sharp a view as a conventional solar filter. Additionally, a welder's glass turns the Sun a lurid shade of green.

## ***Observing the Sun with the Naked Eye and Binoculars***

For observing the Sun's larger spots you do not even need a telescope. Very large sunspot groups can sometimes be seen with the naked eye – always provided that it is protected by a safe solar filter as described above. A welder's glass of the appropriate shade number is also suitable as a naked-eye solar filter. Black polymer filters (Fig. 2.11, left) are excellent for naked-eye solar observing, but they must be made specifically for solar observing. Also suitable are eclipse glasses (Fig. 2.11, right), which are intended for observing solar eclipses but can be used for observing naked-eye sunspots at any time.

Never be tempted to examine the Sun through mist or when it is low in the sky – you can never be sure that enough radiation is being blocked out. When you see a large sunspot using your telescope it is interesting to see if it is visible with the protected naked eye, and, as we shall discuss in Chap. 5, some amateurs carry out systematic counts of naked-eye sunspots.



**Fig. 2.11** A naked-eye solar viewer made from black polymer (*left*) and a pair of Mylar eclipse glasses (*right*)

A safe way of observing the Sun without filters or optical aid is the “pinhole camera” method. Simply make a small hole no more than 5 mm across in a large piece of cardboard and hold a sheet of white paper 1 or 2 m behind it. This is, effectively, solar projection without a telescope. It is best done indoors, where you can close curtains around the pinhole and increase the contrast of the image. The very poor resolution of this method allows only the largest sunspots to be seen, but it is a traditional, and safe, way of observing the partial phases of a solar eclipse. Remember not to look through the pinhole, or let others do so.

Many astronomy books recommend using a pair of binoculars if you cannot afford a good-quality telescope. This is sound advice and it applies to the Sun as well. The chief disadvantage with binoculars is their relatively low magnification, which allows only the larger spots to be observed well. Binoculars are especially suited to projecting the Sun indoors: simply mount them on a camera tripod and let them throw an image of the Sun on to a white screen mounted 1 or 2 m away. Cover the lenses of one side of the binoculars, or you will end up with two images of the Sun. As with “pinhole camera” solar viewing, closing the curtains around the binoculars will darken the room and so increase the contrast of the projected image. If you are observing outdoors, shade the image from ambient light using cardboard as described above, in the section on solar projection. Be careful not to let the unfiltered sunlight coming through the binoculars get into your eye, and always keep children or uninformed people under supervision. Also, do not leave binoculars pointed at the Sun for too long, as the concentrated solar heat inside the

instrument may damage the cement holding the prisms in place. You can also use binoculars with a pair of Mylar-type filters, provided that you mount the filters safely as described above. Some companies supply such filters in pairs mounted to fit larger binoculars. If you have smaller binoculars you will need to buy a sheet of solar filter material and make your own mounts.

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