SOLAR OBSERVING

BY KIM HAY

The Sun, our closest star, is a wonderful Solar System object to observe with any type of telescope, if used SAFELY. Never look directly at the Sun, and always use a full-aperture solar filter. The solar filters that screw into the base of an eyepiece should be thrown out and never used. The telescope objective concentrates sunlight on such an eyepiece filter, making it very hot, leading to possible breakage, with a high risk of vision loss. The only safe filter is the kind that covers the full aperture of the telescope, at the front, allowing only 1/100000th of the sunlight through the telescope, thus lowering the heating effect and allowing you to view the Sun safely. Ensure that the filter material is specifically certified as suitable for solar observing.

The preferred solar filters are made of Thousand Oaks glass or Baader film. The Thousand Oaks glass gives the Sun a golden-orange colour. The Baader film gives the Sun a natural white look, which can provide good contrast if there is any glare on the Sun (see below). Other options include lightweight Mylar film (which gives a blue-white tint) and eyepiece projection. Projecting the image from the eyepiece onto white card-stock paper or a wall produces an image that can be safely shared with others.

For safety, the filter must be kept covered. Since your telescope and finder are aligned, look at the shadow of the telescope on the ground and move the telescope until you have the smallest shadow on the ground. The Sun should be in the eyepiece or close to it. Alternatively, make a small filter for your finder, if you want to use it.

For the amateur, there are alternatives for observing the Sun in various wavelength bands—the simplest method involves a wide spectrum of sunlight, using the solar filters described above. For the enthusiast, narrowband filters, such as the hydrogen-alpha (Hα) red filter (656.3 nm) or the calcium K-line (CaK) violet filter (393.4 nm), can be fitted to existing telescopes (but they also need a broadband pre-filter). Recently, dedicated solar telescopes with built-in narrowband filters have become affordable. An Hα filter shows solar prominences at the solar limb and possibly granulation on the disk. The CaK filter (especially in photographs) enhances granularity and flares.

A Herschel wedge (a type of prism used for white-light observing and photography) can be used, but with caution. Only 5% of the light is reflected to the eyepiece. The remaining 95% that is directed out the end of the diagonal is very intense and can burn. Herschel wedges should only be used with refractors or a telescope with an aperture stop to avoid the build-up of heat, which could damage internal components. The cover should only be taken off after the telescope has been set up. You will also need a neutral-density filter (optical density 3.0–4.0, 0.01%–0.001% transmittance). For enhanced viewing comfort, a filter (either green or polarizing) may help, depending on the sky conditions. A Herschel wedge should only be used by an experienced observer.

The Sun is best observed at high angular altitude, minimizing the optical effects of the unstable lower 100 m of atmosphere. Try to observe when the Sun is at least 25° above the horizon. Keep in mind that daytime atmospheric seeing conditions are usually very poor, so even a small telescope can be used without loss of detail. Another observing tip is to use a dark hood to cover your head and the eyepiece to block stray light, improving views of fine details.

Observing the morphology of prominences, filaments, flares, sunspots, and other solar phenomena is a great way to witness the dynamics of the Sun. These phenomena result from the strong magnetism within the Sun, which erupts to the surface. An active area can start with plage (white area) and faculae, turn into a pore, and then blossom into a small dark spot. As a pore grows into a sunspot (umbra), a grey area (penumbra) surrounds the sunspot. The umbra is cooler than the surrounding penumbra. Prominences are solar plasma ejections, some of which fall back to the Sun in the form of teardrops or loops against the Sun’s disk, prominences appear as dark filaments. In a turbulent-free atmosphere, look for white-light flares, which are flash-points produced from sudden discharges of energy. Flares can last from a few moments to several hours, but they are generally measured in minutes. There are also limb flares, flare kernels/hot cores, two-ribbon/two-strand flares, Hyder/impact flares, homologous flares, and Moreton waves, which are shock waves emanating from a white-light flare. An intense solar flare can eject charged particles, which may reach Earth, possibly exciting the upper atmosphere to create aurorae.

Counting sunspots and groups is another interesting activity. For consistency, observing should be done at the same time each day. Start at the limb of the Sun, because this is where you will notice plage and faculae. Then sweep across the disk in a grid pattern to look for disturbances or sunspots. These can be in either hemisphere and at any latitude, depending on the progression of the sunspot cycle. The relative sunspot number (also Wolf number or Zurich number) is \( R = 10g + s \), where \( g \) is the number of groups (including groups of one) and \( s \) is the number of individual spots (including those in groups). Individuals may submit their observations to the Solar Section of the American Association of Variable Star Observers (AAVSO, see below) who compile monthly averages from all observers. To help locate the latitude and longitude of a sunspot, and to find instructions and a template (called the Stonyhurst disk) to place over your sketch or image, see the Web links below. See also the EPHEMERIS FOR THE SUN on p. 185, which lists the orientation of the Sun (\( P \),...
Solar activity can be mapped as an exercise, using disk templates (Stonyhurst, Porter, or grid) and solar orientation elements (see BAA Solar Section and Atmospheric Optics Web sites, below).

The Sun takes 25 to 29 days to make a full rotation, with an average of 27 days. The Carrington rotation number, invented by Richard Carrington, counts the number of rotations of the Sun since 1855. The Solar Section of the Association of Lunar & Planetary Observers (ALPO) uses Carrington rotation numbers for the study and archiving of solar morphology and prominence activity. For an updated Carrington list, visit www.alpo-astronomy.org/solarblog. ALPO accepts sketches and photographs (in all wavelengths) on the Sun Forms available from their Internet site. (For instructions on astronomical sketching see ASTRONOMICAL SKETCHING, p. 88; for a primer on astrophotography, see DIGITAL ASTROPHOTOGRAPHY, p. 91.)

A wide range of digital cameras and Webcams, combined with various filters, can produce phenomenal images of the Sun. Numerous computer programs allow the combination of multiple images to create an enhanced image or video. Libraries, online chat rooms, and email lists provide a wealth of information on solar photography. The best way to learn is to read and ask questions of experienced solar imagers.

A Solar cycle takes 9–14 years (11 years on average) to complete, and we are currently at the peak of Cycle 24 (Solar Max). However, sunspot counts show Cycle 24 to be very weak, with two mini-peaks, perhaps the weakest on record (see science.nasa.gov/science-news/science-at-nasa/2014/10jun_solarminmax). On 2012 Jul. 23, the Sun unleashed a very strong coronal mass ejection, as strong as the 1855 Carrington Event. This shows that we are not experiencing a Maunder Minimum (which had been suggested). With the waning of the Solar Max, there is still a high probability of some spectacular solar activity and space weather in 2015. If you do not have the proper equipment to observe the Sun, you can always visit the Solar and Heliospheric Observatory (SOHO) Internet site (see below) and see daily images of the Sun. The following Handbook sections contain related information: FILTERS (p. 64), SOLAR ACTIVITY (p. 189), and VIEWING A SOLAR ECLIPSE—A WARNING (p. 147).

References
ALPO Solar Activity Handbook, ALPO Solar Section

Web sites for Solar Observing and Astrophysics
www.aavso.org/solar (AAVSO)
www.alpo-astronomy.org/solar (ALPO)
www.atopics.co.uk/tltsun.htm (Atmospheric Optics Tilting Sun)
www.oneminuteastronomer.com/999/choose-solar-filter (choosing solar filters)
www.petermeadows.com/html/stonyhurst.html (Stonyhurst disks and instructions)
www.britastro.org/~solar (BAA Solar Section: Stonyhurst, Porter, and Grid disks)
sdo.gsfc.nasa.gov (NASA Solar Dynamics Observatory)
sdo.nasa.gov/Solar (Solar and Heliospheric Observatory)
swpc.noaa.gov (NOAA Space Weather Prediction Center)
radiojove.gsfc.nasa.gov (NASA Solar and Planetary Radio Astronomy for Schools)
www.solarham.net (solar page by amateur radio station VE3EN)

The 10.7-cm solar radio flux, averaged monthly (see p. 192). This index, which originates in the low solar corona overlying active regions, is a more global index of magnetic activity than sunspot number. The 10–13 year solar activity cycle is clearly visible. The shorter-term spikes are shorter episodes of activity as active regions and clusters of regions form, evolve, and decay. There is some level of activity even during solar minima.

Solar activity is fundamentally a magnetic phenomenon. Deep below the photosphere, differential rotation and convection cause the solar material to move in a complex manner. The density of this material is high enough for its movement to drag the magnetic fields along with it. This generates electric currents, which in turn produce magnetic fields. The result is a complex system of subphotospheric “magnetic flux ropes.” The penetration of sections of these flux ropes through the photosphere and into the chromosphere and corona gives rise to the many observed forms of solar activity. Above the photosphere the situation is strikingly different: the density is much lower, and the magnetic fields trap and confine the ionized gas of the solar atmosphere, supporting loops and filaments, and forming the diverse menagerie of photospheric, chromospheric, and coronal structures with which we are familiar, such as sunspots, active regions, complexes of activity, and systems of loops. Changing emissions in the X-ray and ultraviolet wavelengths, and at radio wavelengths, are due to the changing amount of trapped plasma and the strengths of the magnetic fields containing them. The Sun’s total energy output is also affected by magnetic activity, fortunately only slightly.

The organization of the subphotospheric magnetic fields gives rise to a consistent pattern in the magnetic configuration of active regions. Each region is magnetically bipolar, with the bipolar arranged east–west on the disk. All bipoles lying in the same hemisphere are arranged with the same magnetic polarity leading (facing in the

The numbering system for solar activity cycles was started by Rudolph Wolf, who arbitrarily designated the activity maximum of 1750 as that of Cycle 1.
direction in which the region appears to move as it is carried across the disk by solar rotation—westward in the observer's sky. In the other hemisphere, the leading and following magnetic polarities are reversed.

 Exceptions do occur. Regions are sometimes formed that have a magnetic orientation perpendicular to or even the reverse of the norm for that hemisphere. Such regions usually try to move into the conventional orientation but are impeded by the magnetic linkages formed with their surroundings. These regions tend to produce flares as potential energy builds up in their magnetic structures and is subsequently released catastrophically.

The "conventional" magnetic configurations for active regions reverse on alternate activity cycles. For example, during Cycle 22, active regions in the northern solar hemisphere were oriented with their "negative" (i.e. south-seeking) magnetic polarity ends leading and "positive" (north-seeking) ends following, with the reverse situation in the southern hemisphere. In Cycle 23, this arrangement was reversed. Cycle 24 re-establishes the pattern of Cycle 22. A magnetic activity cycle, which is probably a more realistic description of the rhythms of solar activity, is equal to two of Wolf's activity cycles and takes about 22 years to complete.

Active regions are not isolated phenomena; they occur in complexes, comprising several active regions at various stages of development, together with the network of elements remaining from decayed regions. This localization of activity gives rise to a rotational modulation of the 10.7-cm radio emission as the active regions rotate across the disk and disappear around the east limb. To smooth out this modulation in long-term studies of solar activity, the data are averaged over solar rotations rather than by month. Active regions can persist for one or more solar rotations and the complexes for a dozen or so.

The large-scale organization of solar magnetic activity is also apparent in the spatial distribution of active regions during the solar cycle. The first activity of the new cycle is marked by the formation of active regions at high latitudes. As activity builds toward the maximum of the cycle, the number of active regions increases, and they tend to form at lower latitudes. As the activity wanes toward the next minimum, the number of regions decreases, but the average latitude continues to decrease until the last activity of the cycle is located near the equator. Then, as the new cycle starts, new active regions form at high latitudes.

The formation of a new active region begins with the emergence of magnetic loops through the photosphere and into the overlying chromosphere and corona. This is heralded by the appearance of small pores, about 1000 km across, which coalesce and spread into a patch of magnetic flux that may exceed 50,000 km in length. The average magnetic-field strength in such patches is of the order of 0.1T (100 gauss). The emergence of these magnetic fields modifies the spatial and density structure of the chromosphere, giving rise to enhanced emission in the calcium and magnesium II K spectral lines. These bright patches (called plage), which stand out prominently in filtergrams, are the most conspicuous aspect of active regions. In some areas of the new active region, magnetic field strengths reach or exceed 0.1 T. These magnetic fields are strong enough to impede the transfer of energy from within the Sun, leading to these patches being cooler (3000 K) compared with the surrounding photosphere, which has a temperature of about 6000 K. Although actually quite hot and shining quite brightly, in contrast with their hotter surroundings, these flux concentrations appear as dark spots: sunspots. As a region grows, one or more large spots form at the leading end, and a scattering of smaller ones form at the trailing end. Sunspots are a prominent feature of active regions and are the aspect of solar activity that has been longest known.

The growth of the new active region continues through repeated episodes of magnetic flux emergence. In general, the size is directly proportional to the total magnetic flux in the region. Growth stops when the emergence of new magnetic flux ceases. Soon after, the region starts to decay. This proceeds partly by the resubmergence of magnetic flux and partly by fragmentation. The spots disappear, and eventually, all that remains is a large area of magnetic flux arranged in a network pattern, blending in slowly with the remains of other decayed active regions.

Repeated episodes of magnetic-flux emergence, together with motions of the footpoints, which are the photospheric anchors of magnetic loops, lead to the magnetic field overactive regions becoming complex and tangled and storing enormous amounts of energy. The relaxation of these fields is an important aspect of the evolution and dissipation of active regions. In some cases, this can occur nonostrophically; otherwise, stresses increase until various plasma instabilities allow rapid relaxation and reconnection of the magnetic fields and a rapid release of the stored energy. These energy releases are known as flares.

The Solar Wind and Aurora

The solar atmosphere is not stable. It is constantly flowing outward as a stream of particles and magnetic fields—the solar wind. The flow is strongest where the magnetic loops are very large and impose the least drag on the outwardly flowing particles. Because of their lower coronal densities, these regions produce a lower flux of X-rays and appear in X-ray images as dark patches, known as "coronal holes." The solar wind is not homogeneous or steady; its speed, density, and direction can change according to the positions of coronal holes and the nature of current solar activity.

The solar wind profoundly changes Earth's magnetic field. The wind pressure pushes the field out of its dipole shape into a long teardrop. The magnetic geometry in the tail of the drop makes it the site of many plasma instabilities. The flow of the solar wind over the boundary of Earth's magnetic field (the magnetopause) excites many types of waves, which move along Earth's magnetic field lines and which can be detected on the ground at high magnetic latitudes. Increases in the density or velocity of the solar wind change the pressure equilibrium between the solar wind and the magnetosphere, producing fluctuations in the strength and direction of the magnetic field lines at ground level. If the fluctuations are strong enough, the events are referred to as magnetic storms and substorms. These can disrupt any human activity that involves connected metal networks covering large geographical areas, especially at high magnetic latitudes.

Complex interactions between the solar wind and Earth's magnetic field lead to an accumulation of trapped particles in the magnetosphere. During magnetic storms, instabilities and waves excited in the magnetosphere by the solar wind accelerate some of the trapped particles downward along Earth's magnetic field into increasingly dense atmosphere, where they collide with the atmospheric constituents, exciting them with sufficient energy to produce light. These displays are called auroras, or the northern and southern lights: aurora borealis and aurora australis, respectively.

Views from space show that aurora fall in a rough circle (the auroral oval), centred around the magnetic pole, that is, in a definite band of magnetic latitudes. As activity increases, the auroral oval expands, covering lower and lower magnetic latitudes. It also becomes increasingly distorted. During the period of very high activity in March 1989, auroral displays were seen as far south as the Caribbean.

Aurora occur in many forms and can be steady, moving, or rapidly pulsating, depending upon the nature of the particle streams causing them. Aurora can appear green or red, although if they are faint, the eye cannot respond in colour and they appear grey. The greenish colour is due to spectral lines from oxygen (558 nm) and a range of lines from nitrogen covering the band 391 nm to 470 nm. Under highly disturbed conditions, red spectral-line emissions at 630 nm and 663 nm and in a series
The above sketches illustrate standard auroral forms. This simplified classification was devised for visual observers during the International Geophysical Year over five decades ago (1957–58). Although there is a great variety in auroral patterns, the sketches emphasize fundamental features and minimize variations that depend on the location of the observer. The light of the aurora is emitted by the upper fringes of Earth's atmosphere (heights of 100 to 400 km) as it is bombarded by electrons of the solar wind (solar wind protons contribute a smaller amount of energy). The modification of the trajectories of these particles by Earth's magnetic field restricts activity to high latitudes, producing the "aurora borealis" in the Northern Hemisphere and the "aurora australis" in the Southern Hemisphere. The wavelengths of four atmospheric molecular and atomic emission lines that can contribute strongly to auroral light are included in the list on p. 32. Whether aurorae appear coloured depends on their luminance—light that is too faint will not activate colour vision and appears grey. When the luminance is sufficiently great, the relative contributions of blue, green, and red emission lines can result in a variety of auroral hues.

of bands between 650 nm and 680 nm can also be seen. The green emissions are produced at a height of about 110 km; the red, 630-nm and 636-nm emissions, due to atomic oxygen, originate at heights between 200 km and 400 km; the 650-nm to 680-nm emissions are produced at about 90 km.

The Impact and Measurement of Solar Activity

We find evidence of the profound effects of solar activity upon Earth extending as far back in time as we have been able to look. The rhythm of the solar activity cycle is reflected in cores from ocean beds, ice cores, and sediments from lakes that dry up in summer. It is also apparent in the growth rates of trees (determined from the study of tree rings) in recently living timber, wood from medieval buildings, and fossilized trees.

Solar activity can dramatically affect our lives. Magnetic storms due to solar activity induce currents in communications and power-transmission systems having long-distance wires, disrupting their operation for hours. The power blackouts in Québec and Scandinavia produced by a large flare on 1989 Mar. 10 are a particularly outstanding example. Railway signalling systems might also be affected. Increased X-ray emissions from flares cause enhanced ionization of Earth's atmosphere at D-region heights (about 90 km), producing blackouts of shortwave communications.

Solar activity heats the upper atmosphere, causing it to expand further into space, increasing the drag experienced by artificial satellites in low orbits. It is ironic that the lifetime of the Solar Max satellite was dramatically shortened in this way. Above the atmosphere, satellites have no protection from high-energy particle fluxes produced by the Sun. Their electronic systems can be damaged, leading to catastrophic failures in some cases, as occurred with two Anik communications satellites in January 1994.

The oldest index of solar activity is the sunspot number. A number of techniques, many empirical, have been developed to combine observations from various observatories and observers to form the International Sunspot Number. This is a rather poor index; however, it has given us a database extending back to at least the 17th century.

Probably the best available index of solar activity, at least covering the last six decades or so, is the 10.7-cm flux, or $F_{10.7}$. This index is an objective measurement of the integrated emission at the 10.7-cm wavelength (a frequency of 2.8 GHz) from all sources present on the solar disk. It has been measured daily by the National Research Council of Canada for over 65 years and is now used worldwide as a primary index of solar activity. In 2003, the program became a joint one with the Canadian Space Agency. $F_{10.7}$ is expressed in solar flux units ($1 \text{ sfu} = 10^{-22} \text{ W} \cdot \text{m}^{-2} \cdot \text{Hz}^{-1}$). The 10.7-cm flux has the great advantage that it can be measured in all weather conditions and requires no human involvement or "interpretation." When quiet, the Sun produces a $F_{10.7}$ value of 64 sfu, due to free-free thermal emission from the quiet solar corona. Also, $F_{10.7}$ can be used as an objective proxy for other activity-related quantities. The strength of the radio emission constituting $F_{10.7}$ is modulated by the annual variation in the distance between Earth and Sun. When considering solar-driven phenomena at the Earth and in near-Earth space, this is not important, so the "Observed" value of the flux may be applicable. On the other hand, when considering solar activity, this modulation has to be removed from the data. In such instances, the "Adjusted" flux, which is scaled to an Earth–Sun distance of 1 au, should be used.

We are a long way from understanding the nature and the extent of the effects solar activity has upon Earth. Some correlations, like that between the length of miniskirts and solar activity, are probably spurious; others might not be. As we exploit our environment more fully, we become increasingly sensitive to things that might affect it, even slightly.

(See pp. 16, 64, 147, and 186 for safe methods of observing the Sun.)