CHAPTER 2

IDENTIFYING SOLAR FEATURES

For the serious amateur astronomer, observing the Sun is all about measuring, counting, or recording solar features that evolve on a continuous basis. Observations tend to split into two distinct areas of study called statistical and morphological. Statistical efforts are tabulated by an observer following various solar metrics like the daily sunspot number, prominence frequency, or the noting of sunspot group classifications. Morphology is documenting the changing appearance of a feature. Solar morphology is inclusive of photos/drawings that depict features and their positions on the Sun or perhaps a series of images showing the eruption of a prominence, even an individual snapshot of an active region.

To conduct these studies adequately it is necessary to be familiar with solar features. Features of the Sun are some of the most dynamic found in the solar system, each having certain defining features. Beginning first with the photosphere and moving outward through the chromosphere to the corona, let's see what the Sun has to offer.

Photosphere

The lowest layer of the solar atmosphere is the photosphere. It is observable in the solar continuum, more commonly called *white light*, via direct (objective filter/Herschel wedge) or indirect (solar projection) methods. Interestingly, due to opacity, the photosphere appears to give a solid surface to the gaseous globe of the Sun. Evidence of convection from the region below is provided by the granules best visible near the center of the solar disc. Magnetic fields make their presence known by inhibiting convection, thereby developing faculae and dark sunspots (Fig. 2.1).

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Astronomer's Pocket Field Guide, DOI 10.1007/978-1-4614-8015-0_2,

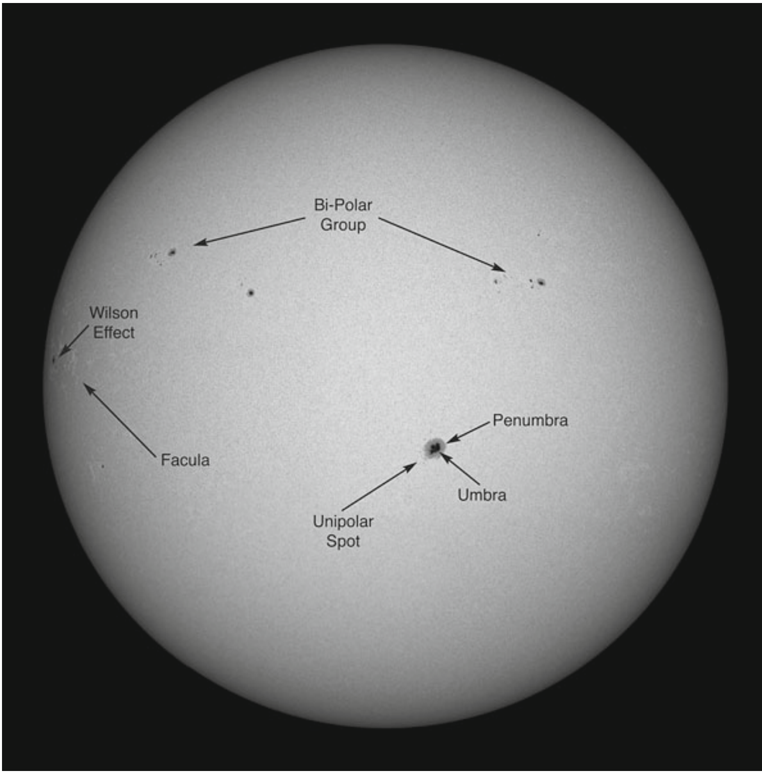

Fig. 2.1 Solar photosphere in white light from 6 April 2013. The tiny symmetrical spot on the east (*left limb*) is exhibiting the Wilson effect (Illustration courtesy of Alexandra Hart)

Naked Eye Sunspots

The existence of blemishes on the Sun has been known for several thousand years thanks to the interpretations of ancient Chinese astronomers. Observations were made by looking unwittingly at the Sun with the naked eye during occurrences of thin clouds, fog, or when atmospheric extinction happened to be heavy at sunrise or sunset. Consequently, the Chinese were able to achieve these first sunspot sightings. Of course today we know their techniques to be a very risky and dangerous business. We must not attempt to duplicate their observations without the proper filtration protecting us from the Sun's harmful effects.

To view sunspots with the naked eye safely, a white light objective filter of visual density 5.0 is used. A circular filter works famously if it is large enough to envelop your face, for which 125 mm diameter is usually sufficient. Cup your hands around the edge of the mounting cell to limit ambient light from reaching your eyes, hold it before your face and take a deep look at the Sun. The visibility of a borderline spot can be improved by rocking your head from side-to-side. A few alternative approaches are to use the specially made mylar type "solar eclipse glasses" (*not* sun-glasses worn at the beach) or a large piece of shade #14 or darker welder's glass. The glass is safe for naked eye sunspot watching since it removes IR and UV light, while the #14 shade darkens the solar intensity sufficiently. Welder's glass, depending on its make-up may tint the Sun green; a telescopic objective filter will as a rule give the Sun a hue of white, blue or orange.

For sunspots to be visible several criteria must be met. The size of the spot is important. For instance, in bright sunlight the pupil of the eye contracts to about 1.5 mm. Dawes Limit (116/aperture in mm = resolution in arc second) tells us that a spot for discernment with the typical unaided eye must subtend an angle of about 77 arc sec. Other factors affecting visibility include: seeing conditions, the position of the Sun, and the inherent resolution of the observer's eyes.

Poor seeing can deform and reduce the contrast of a spot making it increasingly difficult to detect. The altitude of the Sun plays a role because the light from a low placed Sun has more layers of turbulent air to transverse. The general rule of thumb is that the greater altitude at which you find the Sun, the better.

Individual acuity (the capacity to make out fine detail) plays another big role in identifying naked eye sunspots. Think about legendary observers like Edward E. Barnard or S. W. Burnham and the acuteness demonstrated in their astronomical discoveries. An individual's ability to distinguish subtle differences in contrast and grasp optimum resolution with their eyes may ultimately be the influential factors for seeing a naked eye sunspot.

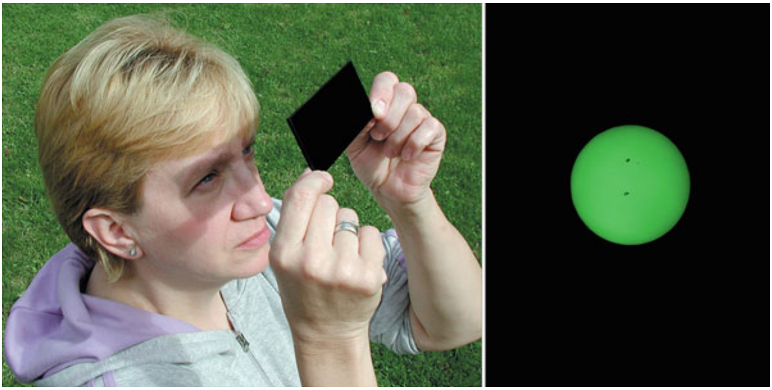

Fig. 2.2 Viewing naked eye sunspots

While of little scientific value, naked eye observations are a test of your eyesight and a sidebar to conventional solar observing. It is a fun activity that adds a "remember when moment" to a spectacular sunspot.

Figure 2.2 pictures a solar observer glimpsing several sunspots through a piece of #14 welder's glass. On the right side we see what the observer sees, a filtered view of the solar disc and in this case two tiny black umbrae.

Limb Darkening

Your first telescopic view of the Sun will present the globe as a unique three-dimensional orb. The central region of the Sun looks brighter than the outside edges. This is an interesting effect known as limb darkening.

Limb darkening is a visual perception caused by our ability to view slightly deeper into the center region of the Sun, where it is definitely hotter and therefore brighter. The regions nearer the limb appear progressively darker because they are seen at an increasing angle, where the cumulative amount of gas has acquired greater opacity, permitting only the upper photospheric layers to be discerned. These upper layers have a temperature near 5,000 K, the deeper view at the Sun's mid-region closer to 6,000 K.

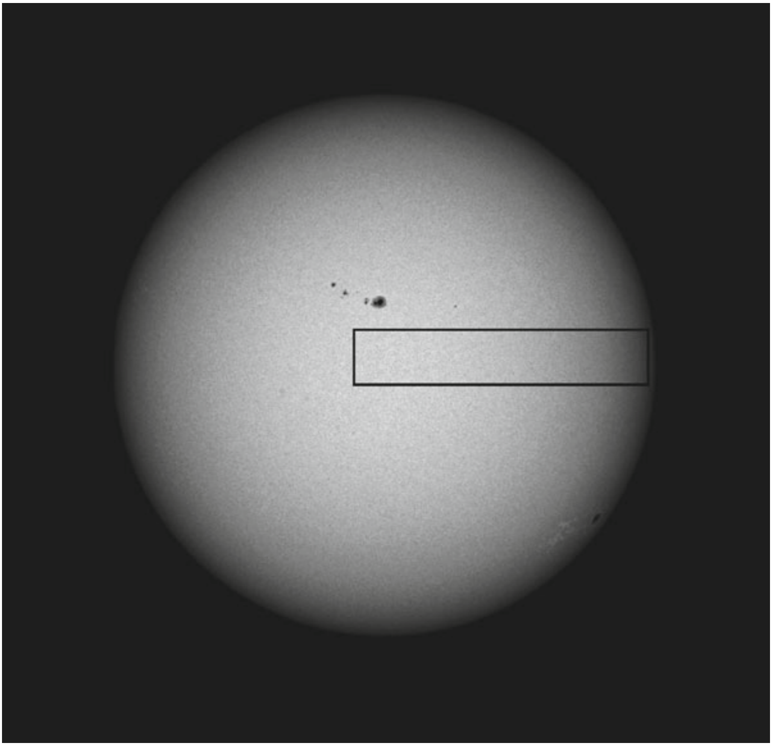

Fig. 2.3 Limb darkening on the white light Sun evident by the difference of density within the box. Notice how the center is brighter than the limb region

If our eyes were infrared sensitive, darkening would be essentially invisible. In ultraviolet light the darkening is still noticeable. However, limb brightening, a reversal of limb darkening, takes place at the far ultraviolet wavelengths.

Photometric studies by an observer at various points from the Sun's center to the limb, and at a variety of wavelengths, might provide some interesting data pointing out the differences in photospheric opacity. This experiment can be accomplished by positioning a photometer to measure filtered light near the western edge of the Sun and then allowing diurnal drift to scan the disc producing a brightness profile. A graph of the photometer's output will provide a clear picture of the limb darkening process (Fig. 2.3).

Solar Activity Cycle

If you study the Sun long enough (several decades) it becomes apparent that it experiences periods of increased and decreased activity. During several years the photosphere will be constantly churning with literally dozens of sunspots, while other times hardly anything is seen for weeks on end. Similarly during these periods the chromosphere can be ablaze or rather quiet. The time having the greater amount of activity is called the solar maximum, or solar-max for short. Likewise when little or no activity is occurring we call that the solar minimum. The stretch between a max to minimum and back to a max works out to be anywhere between 8 and 14 years, the average working out to around 11.1 years. Hence, this period is called the 11-year solar activity cycle.

The German amateur astronomer and pharmacist, Samuel Heinrich Schwabe, discovered the solar cycle in the early to mid-1800s. Schwabe had developed a clever plan for locating a suspected planetoid thought to orbit between the Sun and Mercury. In essence the strategy was to be on the lookout for the mysterious planet crossing the face of the solar disc. At the heart of the plan was the necessity to maintain records of all intervening sunspots, so they could be eliminated as questionable quarry. After some time he found no planet, but he did discover a periodicity to the appearance of sunspots. Schwabe thought the cycle to have a length of about 10 years, but additional observations refined the interval to the current values.

Every new cycle is given a serial number distinguishing it from each successive solar cycle. Solar astronomers established that cycle number one would begin in the year 1755 and end about 1766. Thereafter, each following cycle has been well tracked, providing useful information on the activity of the Sun throughout recent history.

New solar cycles begin with sunspots forming in high solar latitudes, near to the polar regions. As a cycle progresses, the amount and frequency of sunspots increase, then slowly as time passes newer spots will appear closer to the solar equator. When graphing the heliographic latitude of sunspots against time, a unique pattern known as a butterfly diagram becomes evident, see Fig. 2.4. To reach the activity crest an average of 4.8 years transpires.

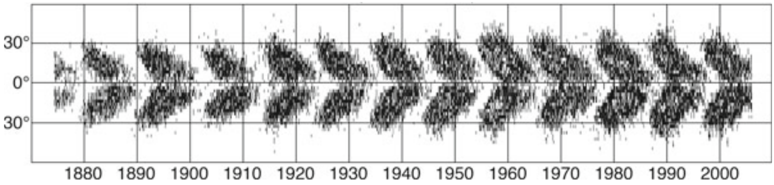

Fig. 2.4 Butterfly diagram (Courtesy of D. Hathaway/NASA)

During solar maximum the Sun acquires a daily sunspot count in excess of 200 on some days with several groups producing solar flares of various intensities. In the chromosphere prominences are frequently visible about the solar limb and across the disc. Solar minimum is gradually attained after an additional 6.2 years of slowly declining activity. The prediction of a cycle's strength and duration is a difficult task for solar astronomers. Many of the facets that play into a typical solar activity cycle are yet to be understood.

It's worth noting that bi-polar sunspots have positive and negative polarities whose magnetic alignment is determined by the hemisphere in which they appear. If the leading spot of a bi-polar group is of positive polarity then the following spot will be negative. This will be true for all sunspot groups of that hemisphere. Oddly, all bi-polar groups in the other hemisphere will be aligned with a reversal of that polarity, the leading spot becoming negative and the following positive.

Even more unusual is the phenomenon that takes place when a new solar cycle begins. A complete reversal of the magnetic field of the Sun happens, so that each hemisphere's sunspots have a polarity opposite that of the previous cycle. Some solar astronomers use this "field reversal" as the telling point to assess when a new solar cycle has begun.

In order for the magnetic polarities to return to their previous state, two solar cycles will have had to occur. The reversal and return of the Sun's magnetic field to its original state is called the magnetic cycle and averages 22 years.

Amateur observers with a preference for sunspot counting or positional recording of spots and groups can use their data to construct their own

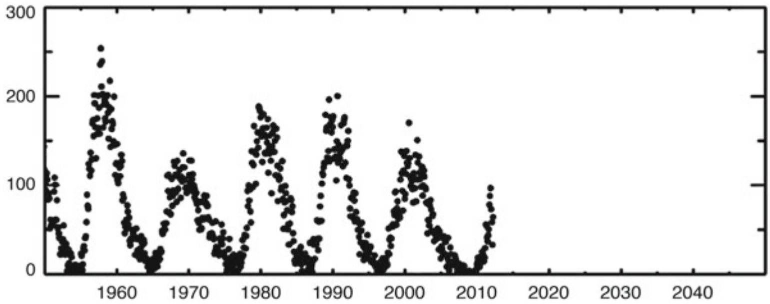

Fig. 2.5 Solar activity cycle plotted through the years (Courtesy of D. Hathaway/NASA)

butterfly diagram or activity cycle graph (see Fig. 2.5), detailing the yearly progress of Sun activity. These visual presentations correspond to the real solar waning and waxing experienced at the telescope.

Granulation

Granulation is a low contrast, high resolution feature, which covers the entire photosphere of the Sun. Described variably as rice grains, rice pudding, kernels of corn, multi-sided polygons, or other geometric patterns, perhaps the most intriguing description is that of an "orange peel". Take a large, thick skinned orange, hold it at arms length and slowly rotate it on your fingertips, and you will have an exaggerated representation of how the feature appears on the Sun. A low-resolution view almost always will show granulation as having a rounded appearance.

Granulation is composed of very small (approximately 1–5 arc sec) elements, each called a granule. The surface of the Sun finds itself covered with approximately 2–3 million granules at any given moment. This feature is less visible near the limbs; attribute that to foreshortening because of its depth within the photosphere. However, granulation does become markedly easier to spot near the middle of the Sun's disc. There is a definite lack of uniformity to the brightness of granules. Some appear dull and others by comparison somewhat brighter. Figure 2.6 by solar photographer Art Whipple illustrates this characteristic well.

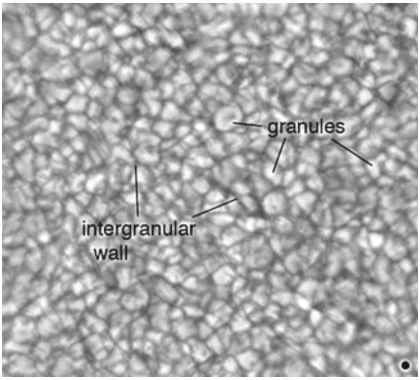

Fig. 2.6 Granulation near the center of the Sun's disc. Individual granules and the intervening intergranular walls are *marked*. The *small black dot* in the *lower right corner* is 1 arc sec in diameter (Image courtesy of Art Whipple)

A granule is the top of the column of gas (plasma), rising from deep within the convection zone. The plasma ascends to the solar surface subsequently to release its energy. Brighter granules have more stored energy than the duller counterparts. After releasing the energy, the plasma cools, becomes darker and flows back into the solar interior along what is called the intergranular wall. This wall or lane forms a boundary separating granules; the wall defines each granule's unique shape. The lifetime of the typical granule is 5–10 min, greater with the larger specimens. A change in shape is visible after only a minute or two of observation; large granules often form out of the fragments left behind by the breakup of previous large granules. Smaller granules tend to fade away. All in all, the majority of granules perish by either splitting apart or disintegrating. A few will disappear by merging with neighboring granules.

A noteworthy observation is that granules located near the penumbra of a sunspot will have a compressed diameter as compared to their outlying neighbors, the result of a sunspot's magnetic influence.

Granulation is difficult at best to observe. The short life span combined with a necessity of excellent seeing conditions make studies for the typical solar observer a challenge. During a time of superb seeing, visual observations will be enhanced by following these recommendations: look near the center of the solar disc, use a supplementary green (i.e. Wratten #58) filter or broadband interference filter transmitting near 540 nm, consider that higher magnifications (75× or more) may be required to resolve individual granules, and lastly apply extreme patience and expect only fleeting glimpses unless the seeing is abnormally good. The successful granule observer will possess sensitivity to a mild shift in shape, size, and brightness during the short lifetime of the feature.

Photographic methods are by far the preferred means of serious granulation studies. Video recording captures the infrequent instants of fine seeing, and then later the photographer can pluck the sharpest images from the video. These superior samples are then assembled into a series of images depicting the feature's evolution or used for the creation of a time-lapse movie showing the changing morphology.

Supergranulation is a large-scale pattern found in the photosphere of organized cellular structure. Each structure contains hundreds of individual granules with a supercell diameter of roughly 30,000 km and a lifetime from several hours to about a day. The observable side of the Sun shows something like 2,500 of these supergranulation cells. The feature is virtually invisible to the white light observer; however it can be detected in Ca-K and H-alpha light. The chromospheric network overlies this feature.

Faculae

Decidedly easier to observe than granulation, even in less than ideal conditions, are the wispy, cloud-like faculae (singular is *facula*). Facula means a bright point or small torch; the vast majorities of examples however are not at all point-like, but rather are venous streaks, having a brightness slightly greater than the surrounding photosphere. Faculae tend to surround sunspots, developing a length parallel to solar rotation and having a width of several heliographic degrees or more.

To understand the cause of faculae, it is helpful to comprehend that sunspots are the result of strong magnetic flux stifling convection from below the photosphere. Facular regions, too, are the result of magnetic fields active in the photosphere, but while sunspots arise where a strong field is present, a magnetically weaker field produces faculae.

One characteristic of stifled convection is an apparent depression given the encompassing solar surface. An obvious example of this depression is visible when a symmetrically shaped sunspot approaches the solar limb. The spot gradually assumes a cavity-like appearance, the so-called Wilson effect. In reality the Wilson effect is the result of magnetically influenced gas becoming more tenuous or transparent, thus permitting an observer an opportunity to see a bit deeper into the photosphere. This is what produces the illusion of a saucer-shaped depression. The weaker magnetic fields associated with faculae likewise produce a fissure effect resulting in light emerging through the "sidewalls" of the depression. Scattered light from this sidewall leakage causes the faculae to be brighter and nearly 100 K warmer than the surrounding photosphere.

All sunspot groups are linked to faculae, but not all faculae have attending sunspots. Faculae are a precursor to developing sunspots and can experience a life lasting up to several rotations of the Sun. It is therefore quite possible to observe "orphaned" facular regions, particularly if the facula has developed outside the sunspot zone of ±35° solar latitude. The zone for faculae development is wider than the sunspot zone, extending to about ±50° heliographic latitude.

When faculae occur outside the sunspot zone and expressly near the polar regions of the Sun (±60° to 90°), they are known as polar faculae. Polar faculae differ from ordinary faculae in area and lifetime. Small granular sized points or elongated flakes, polar faculae last from only minutes to a day or two at most. During the minimum of an 11-year solar cycle, polar faculae are seen more frequently. Observing the smaller area of polar faculae necessitates a telescopic aperture of 100–125 mm, used during moments of fine seeing conditions.

Solar projection is not the best method of observing this feature. The low contrast of a facula makes it difficult to spot on a projection screen. Direct observation is the preferred method of viewing both faculae and polar faculae. A mylar type objective filter transmitting in the blue region of the spectrum is ideal. Not having that accessory, try using the Baader AstroSolar™ Safety Film coupled with a light green (Wratten #56) or light blue (Wratten #80B) eyepiece filter. The supplementary filter boosts contrast of the facula, making it easier to distinguish. Photography is enhanced with even deeper green filters such as the Wratten #58 or a Wratten #61, and for locating faculae furthest from the Sun's limb try a Wratten #47 (deep blue) (Fig. 2.7).

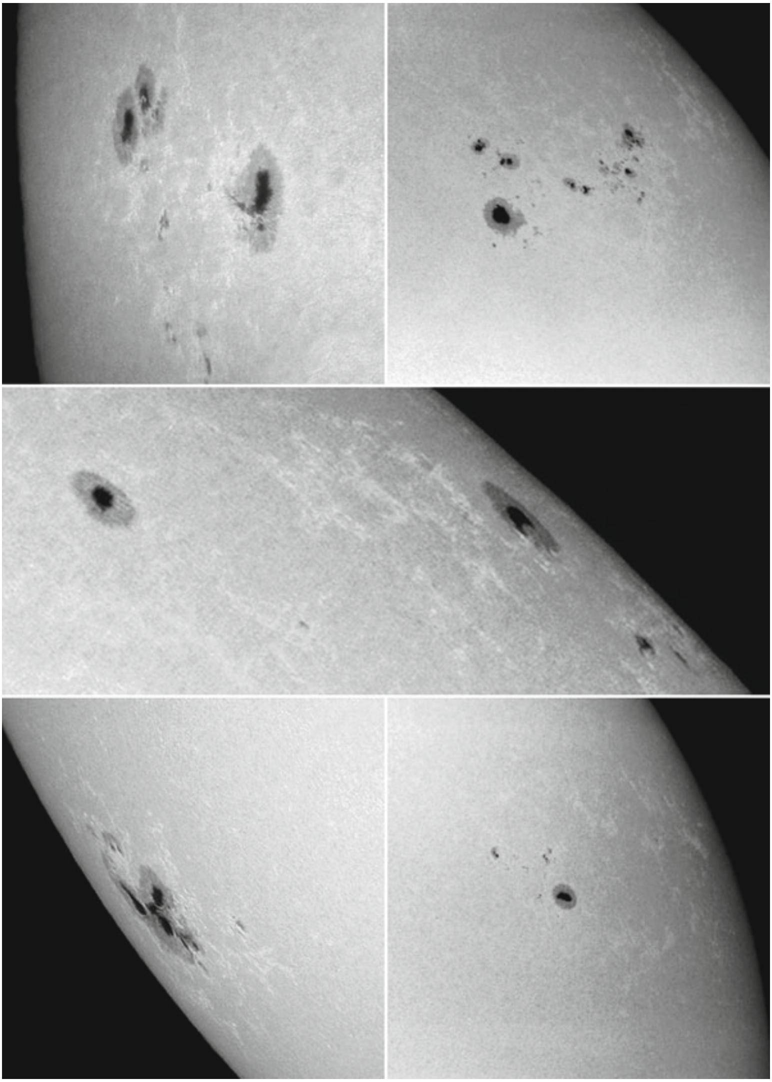

Fig. 2.7 Examples of faculae appearing near the solar limb and associated with sunspots. Faculae are wispy, cloudlike features, slightly brighter than the photosphere

Bright Points

Appearing between granules at the intergranular wall and sometimes on the very edges of granules are the so-called bright points. These miniscule features (average size 0.25 arc sec) result from intensive but small flux tubes (300 km) poking through the photosphere that allows an inspection of the solar interior. The name is quite descriptive of the visual appearance of the feature, bright point-like dots randomly located on the darker lanes between granules.

A group of bright points, forming a string or chain upon the intergranular wall, are known as *filigree*, observable in the solar continuum but more frequently at the G-band (430.5 nm) or in H-alpha. In the literature, bright points are often referred to as G-band bright points because of the increased contrast given them at that wavelength.

Pores and Voids

At times the intergranular wall may appear duskier than normal, or a granule may look darker than surrounding granules, or even missing; this is customary because of a natural variation in brightness with granules. Identifying brightness differences between granulation and other solar features called pores and voids can be a challenge. There is also an art to distinguishing a pore from a sunspot, because any sunspot lacking a penumbra may possibly be a pore.

Consider the following characteristics when separating pores from sunspots. Pores are defined as tiny features with a diameter usually between 1 and 5 arc sec, averaging about 2.5 arc sec. For the most part pores are symmetrical in shape. They are darker and bolder than granular material though not as dark as the umbra of a well-developed sunspot. The intensity of most pores is 0.2–0.4 of the surrounding photosphere. The intensity of the photosphere is given a numerical value of 1.0 and is commonly allocated the term, I_{phot}.

Size has a direct relationship to longevity, and longevity a relationship to a pore developing into a sunspot. Large pores may last for several hours, while smaller examples can form and then dissolve in a few minutes. Pores with a size greater than 5 arc sec have the best chance to grow into a sunspot.

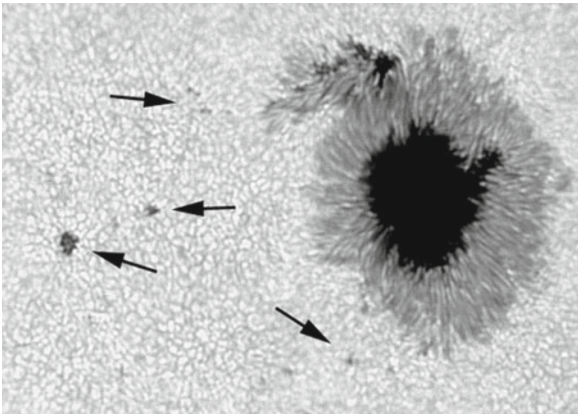

Fig. 2.8 Two features sometimes difficult to tell apart, dark granules and pores, accompany the larger sunspot on the *right*. Dark-appearing granular material is *arrowed right* while several pores are *arrowed left* (Courtesy of Eric Roel)

While many times found near existing sunspots, pores can also be located in isolated faculae. Like sunspots, the formation of pores is the result of magnetic flux tubes extending upward through the solar interior and restricting convection.

The void is not a pore; it is a circumstance where granulation is actually found to be missing. Again these are dark areas about 1–5 arc sec, with intensity near 0.7 I_{phot}. While the typical pore is round, a void may have an irregular shape, which can in a few minutes change brightness as it begins to fill with a granule (Fig. 2.8).

Sunspots

Revealed several thousand years ago by Chinese astronomers, a sunspot is still the most observed feature of the white light Sun. The first impression of many new observers is that a hole or crater has blemished the near perfect appearing photosphere. Repeated observations indicate that these blemishes go through a development process that includes several fascinating phases.

Sunspots are birthed through a generally repeatable pattern in white light that follows this basic scheme. Bright faculae will develop about 7–14 days before a sunspot appears. A number of pores will begin to cultivate within the facular region. The majority of these will be granular sized, ultimately to decay and disappear, however some pores will become larger and darker, becoming as dark as an average sunspot's umbra. This is called an umbra spot, a point where development is sometimes arrested and decay occurs in a short time. The umbra spot can continue to experience growth and a rough appearing penumbra likely will appear. This penumbra could become intricate, harboring islands of dark umbrae containing slightly brighter umbral dots within their interior. Now we have a fully developed sunspot, most likely accompanied by similar shaped features, each experiencing its own evolutionary cycle.

Sunspot structure is often the focus of the amateur solar observer. Whether the interest is in the changing appearance of a feature (morphology), or in maintaining an index of solar activity (sunspot counting), observing sunspots and their associated phenomena provide an excellent opportunity for increasing your understanding of how the Sun works (Fig. 2.9).

Umbrae

Umbra (the plural form is umbrae) is the darker central region of a sunspot. To the eye an umbra appears dark only because it is in contrast against the surrounding, brighter photosphere. In reality the brightness of a typical umbra is in excess of any star in the night sky.

Detailed examination of an umbra reveals that the interior is not the flat charcoal colored smudge it presents. Rather an umbra is made up of shadowy granules, tiny bright points, and material with intensity somewhere between the dark granules and bright points called umbral dots.

Average intensity in the umbra interior is on the order of about 0.1 of I_{phot}. Variables affecting the brightness of any umbra include the seeing conditions, light scattering and the resulting loss of contrast, as well as the chosen wavelength of observation. A direct relationship exists between brightness and temperature of an umbra, therefore the temperature of an

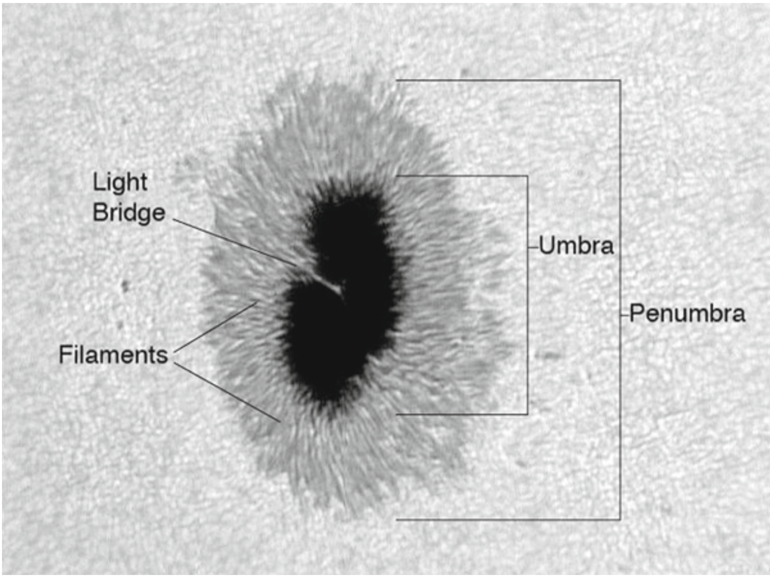

Fig. 2.9 The general anatomy of a fully developed sunspot includes, as seen in this photo by Eric Roel, *a dark interior* called the umbra and a surrounding donut of *lighter gray*, the penumbra. *Thread-like filaments* compose the penumbra and a small light bridge is just beginning its trek to divide the umbra into two segments

umbra can be calculated from the Stefan-Boltzmann law: $I/I_{phot} = (T_e/(T_e)_{phot})^4$. Based on a given photospheric temperature, $(T_e)_{phot}$, of 5,780 K and an I_{phot} of 1.0, the typical umbra computes a temperature near 3,300 K.

There can also be a variation in the umbral color. At first glance the umbra may give an impression of black or a very dark gray. Examine the umbra closer with a filtration system neutral in its spectral transmission (i.e. Herschel wedge or Baader Astrosolar film) and subtle shades of color may become evident. Black and shades of gray may graduate into a dusky deep reddish-brown hue. The stronger the magnetic field of the sunspot, the darker an umbra appears. Past observations have revealed that umbrae appear darker during sunspot maximum than at the sunspot minimum (Fig. 2.10).

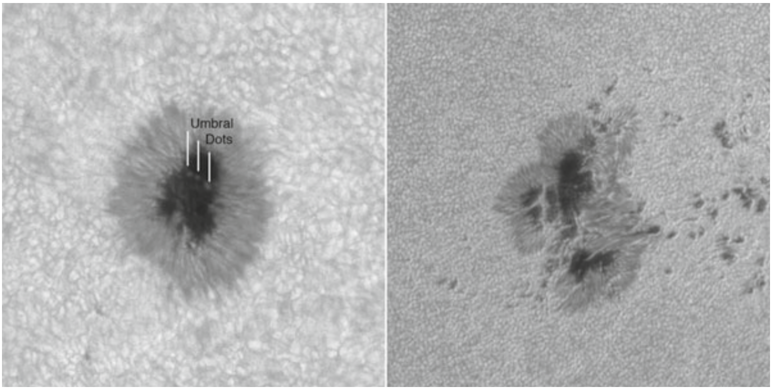

Fig. 2.10 The *left-hand image* obtained with a 14-in. aperture f/4.6 Newtonian telescope illustrates fine interior details of an umbra. Several streaks are visible and at the foot of the *three markers* are umbral dots. Art Whipple is the imager. *To the right* is another high-resolution photo depicting the appearance of numerous umbral dots visible near the photo's center (Courtesy of Eric Roel)

Umbral dots (UD) are round features with a diameter about 0.2–0.5 arc sec and intensities on the order of 0.1 I_{phot}. Slightly brighter and therefore hotter than the surrounding umbra, UDs resemble clumps of granular material located within the umbra. The classification of an umbral dot is determined by its umbral location, central or peripheral. A peripheral UD is located near the surrounding penumbra; a central UD is positioned nearer the middle of the hosting umbra. Peripheral dots have a habit of gradual movement toward the central region of the umbra where they are apt to remain stationary features. Umbral dots are conjectured to be the result of minimally active convection within the umbra. UDs are difficult to observe and like most low contrast solar forms necessitate excellent seeing conditions and an instrument capable of resolving their diminutive size.

The amateur astronomer desiring to study such sunspot phenomena can apply a couple different photographic techniques. The first utilizes deep exposures of the umbra to reveal detail frequently missed by the visual observer. Another technique, the creation of an isophote map of an active region illustrates sectors of equal density that translate into various

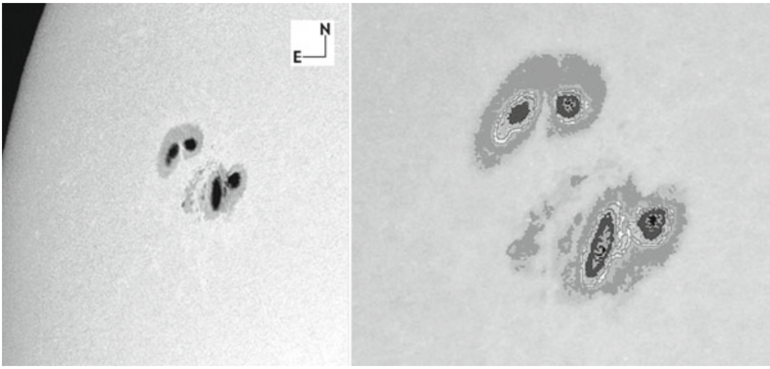

Fig. 2.11 Isophote map created using NIH-image software. In this map the conventional photo *on the left* had density slices extracted and recombined to form the image *on the right* showing areas of similar density. The leading umbras of each bi-polar group contain the core or region of greatest density and therefore the coolest temperature

regions of differing temperature. An isophote map also indicates the point of coolest temperature (greatest magnetic strength) in the umbra, a zone identified as the sunspot's core.

Briefly let's touch on how these methods are accomplished. A deep exposure is attempted by first masking out the photosphere and the surrounding penumbra and permitting only the light from the umbra to reach the detector. Give several times the standard exposure to reveal the granular nature of an umbral interior. Excellent seeing conditions are of course necessary for the success of this technique. An isophote map is easily created with readily available software applied to medium through high definition digital images. Recommended software includes the *NIH-Image* (Macintosh version) or *ImageJ* (Windows PC version), both available as freeware.

The basic procedure is to create numerous individual images representing "slices" of photographic density from the original photograph, colorize each slice, and then recombine the slices, forming a descriptive layered map. Features easily picked out from a map include: regions of similar temperature, the sunspot core, inner and outer bright rings, as well as weaker light bridges. Details on creating an isophote map of a sunspot can be found in the Springer book, *The Sun and How to Observe It* (Fig. 2.11).

Penumbrae

Sunspot penumbra has been likened to a halo, at lower resolution seen as a lighter gray outer region surrounding the darker umbra. Rudimentary penumbra often forms from the intergranular material adjoining newly developed umbra. Any spot possessing a large umbra will have developed a penumbra which evolves structures of dark penumbral filaments that radiate about the umbra like fine threads, 0.2–0.3 arc sec in width. These threads are magnetic in nature and have a similarity to granules in their convective characteristics. Between the dark threads are brighter comet-shaped regions called penumbral grains. Superb seeing conditions and an instrument capable of resolving better than 1 arc sec are required to distinguish penumbral filaments and grains.

Penumbral grains are found to move outward, away from the umbra with speeds of 0.5–2.0 km/s^{-1}. This movement is called the Evershed effect, discovered in 1909 by John Evershed, as he observed a Doppler shift in the spectral lines of sunspots. Penumbral filaments possess a horizontal alignment following the sunspot's magnetic field lines, which emerge vertically from the umbra and then become inclined at an angle of 25°–30° to the photosphere near the outside edge of the penumbra.

A mature sunspot will usually have a penumbra that is symmetrical in shape. Less often seen is an irregular penumbra, which has been mutated by complex magnetic fields. An irregular penumbra will inundate the sunspot group with filaments of varying widths throughout. Independent islands of penumbrae may appear separated from the umbra. This condition is somewhat infrequent and rarely lasts longer than a day.

Within highly developed penumbra may be found islands of dark umbral material that are only a bit larger than pores. Regions of material as bright as or brighter than the photosphere may also be found. These dark and bright regions are known to undergo rapid changes, and ought to be observed closely. Occasionally, a bright region may become elongated and fade, transforming itself into filaments or growing larger into what is known as a light bridge (Fig. 2.12).

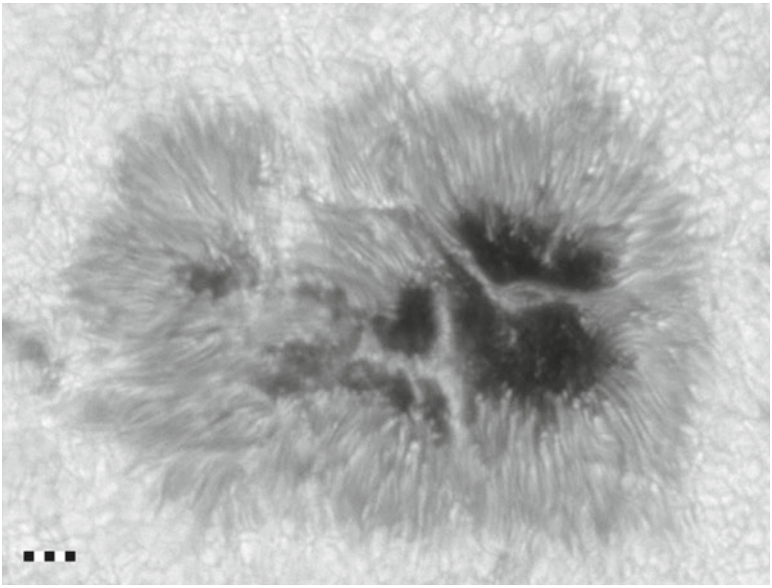

Fig. 2.12 High Definition solar photography. Notice the dark central lane of the oval structure in the light bridge that divides the larger umbral region. Umbral dots and small-scale granulation in the more developed light bridges are visible. In the penumbra the *dark radial threads* are filaments and the *white "comet-shaped"* features are penumbral grains. The *squares* in the *lower left corner* represent a scale of 1 arc sec (Photograph courtesy of Art Whipple)

Light Bridges

A light bridge is loosely defined as any material brighter than an umbra that also divides the umbra, sometimes even dividing the penumbra. The perception is frequently given that the photosphere has started to flow into the sunspot, somewhat like a river coursing a new path. Three varieties of light bridges may be categorized: the penumbral island, the streamer, and the familiar classical light bridge. Over time a light bridge can transition from one category to another, making it difficult to classify. A sunspot group may contain an assortment of light bridges at any one time.

Older, mature sunspots often contain a well-developed, thickly proportioned light bridge (LB), the typical classical variety. In some venues this bridge is referred to as a photospheric light bridge because of its structural similarities to nearby photospheric granules. It is important to note that granules surrounding sunspots are smaller than those found in the quiet photosphere. Likewise the photospheric LB is made up of similarly sized compacted granules. The photospheric LB is often brighter than the photosphere, with a lifetime of 1–14 or more days.

Younger sunspots many times develop a light bridge that is thin, streaky, and intense. They are known to mature into a semi-complex network that resembles a "lightning strike." This is the so-called streamer. Angularly a streamer is a narrow 1–5 arc sec in width. Like the classical LB, a streamer also has a granular nature, though the grains are somewhat narrower than photospheric granules. Some granules may appear elongated and bright, reminding the observer of a penumbral filament. At other times a streamer appears to be composed of dots, similar to but brighter than an umbral dot. Streamers have an erratic lifetime of several hours to several days.

Penumbral islands are located in the penumbra of a sunspot. This is an independent area of material (also granular in nature) that is brighter than the surrounding penumbra. Appearance of the feature can deviate from an irregular patch to a streak of any size and shape. Penumbral islands are known to last for several hours to several days.

Granular structure is a common thread between all classes of light bridges. Figure 2.12 captures this characteristic well. In the late nineteenth century the astronomer Janssen was the first to note the granular structure of light bridges (Fig. 2.13).

There is no strict "rule-of-thumb" for light bridge development because a LB may well begin to grow, and then at any stage of growth become quiet and possibly reverse its course. However, there is a guideline to the development of the classical photospheric light bridge that follows this basic outline. In a sunspot lacking a light bridge, bright penumbral filaments will begin to enter the umbra, many times from opposing sides of the umbra. Individual granules will begin to separate from the filaments crossing the inner umbra, forming a streamer and completing the connection of the opposing sides of penumbra. As the LB connection grows, remaining bits

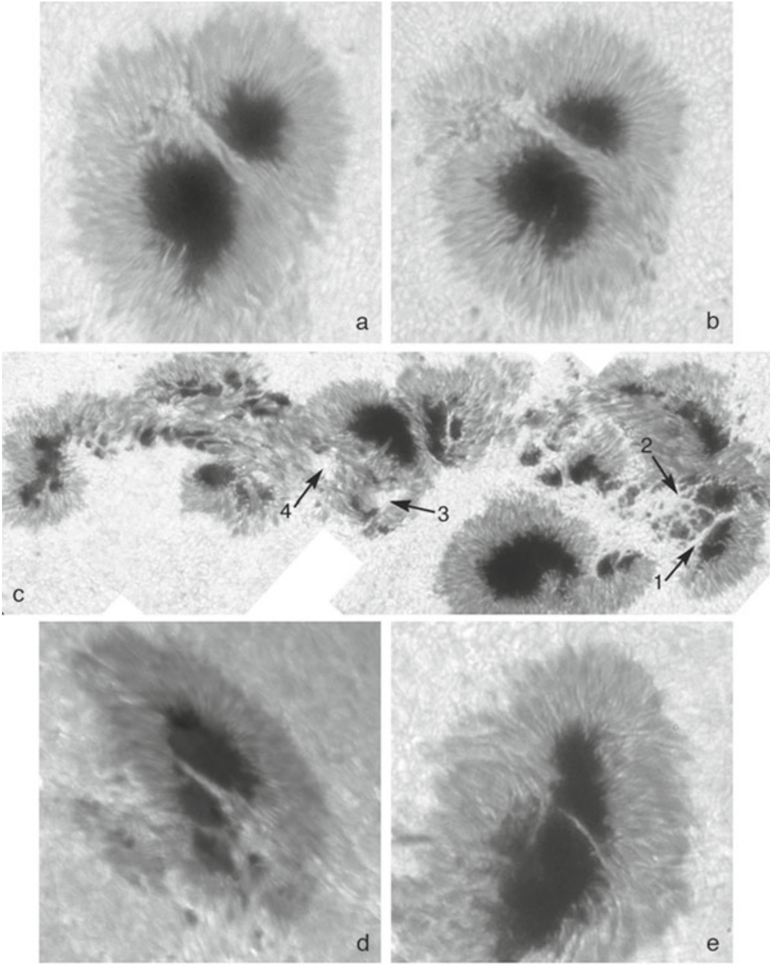

Fig. 2.13 Classic light bridge development over a 24-h period is visible in photos **a**/**b** of active region 11,289 from the 10th and 11th September 2011. Notice how the penumbra filaments appear to have grown a "finger" across the umbra. The granular nature of the light bridge is obvious in the original photo within the *left area* of the LB. The *middle photo*, AR9393 from 28 March 2001, contains examples of all three types of light bridges. Beginning from the *right*, **c1** is a classic photospheric LB, streamers can be found at several locations, but prominently are visible at **c2**. Penumbral islands are at **c3** and **c4**, near the center of the photo. The example on the *lower left*, AR11109 from 2 October 2010, has a streamer midway in the umbra developing into a classic light bridge. The umbra of AR10110 supports a dividing thin streamer on 21 September 2002 (All photos courtesy of Art Whipple)

of filament or umbral material continue to decay leaving behind a classic light bridge dividing the sunspot umbra.

Studying the development of a light bridge can be a relaxing activity. Several days can pass before the bridge has completely divided an umbra. A light bridge at times is born with a new sunspot, and can stay throughout its lifetime.

All light bridges display a wide range in intensity or brightness. Some can be so weak that they are practically invisible, only showing up best in digitally enhanced photographs, while other examples are somewhat brighter than the surrounding photosphere. Viewed near the solar limb a light bridge is time and again particularly intense, outshining any nearby faculae.

Use of a Wratten #21, #23, or #25 red filter will darken the umbral area of a sunspot causing an increase in the contrast of light bridges. Any of these filters are also helpful for discerning details in the structure of penumbrae, such as knots and streaks (Fig. 2.14).

Bright Rings

The inner and outer bright rings of a sunspot are a misnomer; the rings are not bright in the sense that they greatly outshine other features. Rather the rings when detectable, and all sunspots have rings, are only ever so slightly brighter than their immediate surroundings.

The inner bright ring is situated between the outer umbra and the inner penumbra, a thin region occupied by the comet-like heads of the penumbral grains (see Fig. 2.12). The inner bright ring is surely an increase in intensity found in the penumbra, extremely difficult to perceive, but traceable photometrically.

Beyond the penumbra of a sunspot in the immediate vicinity of the photosphere is found the outer bright ring. Having an intensity of approximately 1.0–1.1 I_{phot} the outer bright ring generally is less thick than the sunspot's penumbra. The outer ring is brightest near the penumbra and decreases

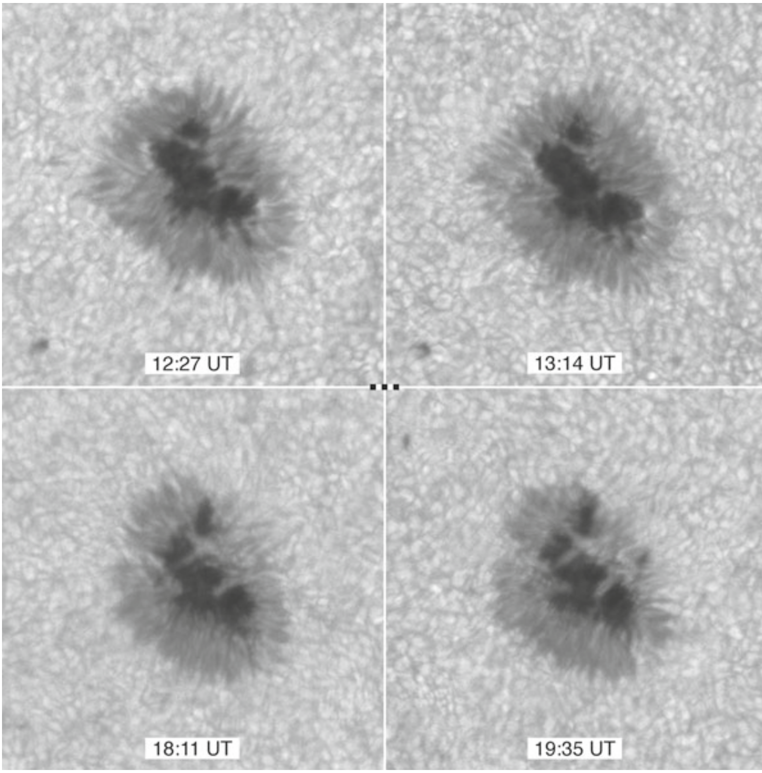

Fig. 2.14 Light bridge development over a 7-h period on 31 August 2011 is visible in these four photos. Fingers are growing from both sides of AR11279's penumbra, soon to connect after the 19:35 UT photo. Each *square* at the *center* represents 1 arc sec (All photos courtesy of Art Whipple)

with distance from the sunspot. This feature is best visible in blue or violet light, and rarely is noticeable in orange or red. Productive studies have been also performed in monochromatic Ca-K light. Rings *may* be more difficult to observe near the limb owing to the presence of the yet brighter faculae. Bright rings typically assume the shape of the host sunspot and can be only partial ill-defined rings, or entirely closed.

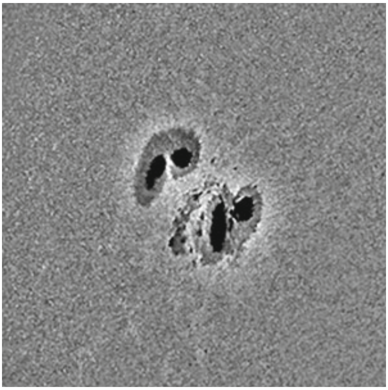

Fig. 2.15 The image from Fig. 2.11 has been digitally enhanced to show the outer bright rings surrounding each bi-polar sunspot

Bright rings seem to have a strong relationship to energy transport within the sunspot. Below the surface, convection is stifled by the sunspot's magnetic field, it is conjectured that part of this energy is distributed to the areas occupied by the rings, resulting in their increased brightness and temperature (approximately 75 K warmer than the quiet photosphere) (Fig. 2.15).

Wilson Effect

Alexander Wilson in the year 1769 discovered an interesting property of symmetrically shaped sunspots. When one of these spots approaches the solar limb the width of the penumbra, relative to the umbra, on the side facing the center of the Sun seems to become narrower than on the side facing the limb. This property, known as the Wilson effect, is perceptible with a round sunspot, but not so much with an asymmetrically shaped spot, which may show a completely opposite effect.

Observing the Wilson effect is best accomplished as the sunspot is nearing the west limb, although a reverse occurrence can be observed on the eastern limb. Several days before rotating out of sight, a spot will begin to appear narrower due to foreshortening. As the penumbra and umbra both become thinner, the umbra will seem to move closer and closer to the penumbral side nearest the Sun's center. A point will be reached where the trailing edge of the umbra indeed will touch the edge of the trailing penumbra; this is denoted as the "contact state". Continued solar rotation causes the umbra to narrow further and eventually disappear.

Wilson's conclusion to the cause of this effect was that sunspots are cavities in the Sun's surface with differing depths. The modern theories are not so far from Wilson's thoughts. The Sun is a gaseous body with the outer layers being of less and less density. Therefore various parts of a sunspot have differing transparencies, meaning that their light originates at differing heights within the photosphere. The quiet photosphere has the least amount of transparency, a sunspot penumbra a bit more transparency, and an umbra the greatest amount of transparency. The greater the transparency, the deeper into the Sun the light originates. A diagram drawn showing equal optical depth of the photosphere, penumbra, and umbra gives an appearance likened to Wilson's cavity theory.

The contact state can be difficult to observe visually owning to normally less than ideal seeing conditions. Of course the larger the sunspot, the easier the Wilson effect is to see. A Wratten #21 or #25 filter is useful to darken the umbra and increase the contrast between umbra and penumbra (Fig. 2.16).

Sunspot Group Classification

Observe the Sun even momentarily, and you'll discover that a sunspot is not necessarily a solitary feature. A sunspot tends to develop a network of faculae, pores, and numerous other spots. These features, all magnetically associated, form a cluster called a sunspot group.

Groups typically, but *not always* are located outside 10° of heliographic latitude or longitude from other groups. This is known as the "10° rule" and is used by some amateur astronomers classifying groups in order to distinguish one from another. Occasionally, two clearly established groups may form within 10° of each another, and the rule has to be bent to

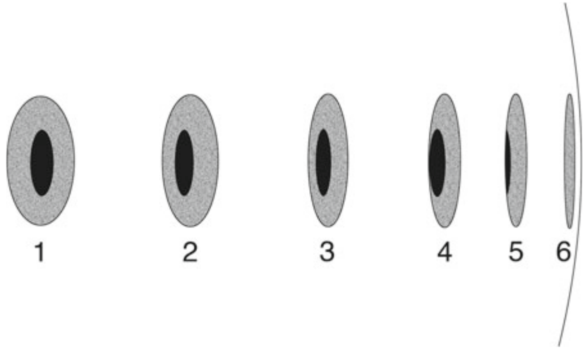

Fig. 2.16 The Wilson effect near the Sun's west limb. *Position 1* represents a spot some distance from the limb. As the spot gradually approaches the limb, the penumbra and umbra become narrower. The side of the penumbra facing the center of the disc will have less of a width than the side facing the limb. In *position 4* the umbra and penumbra eventually meet, this event is called the *contact state*. As the Sun continues to rotate, the umbra finally disappears from sight as the penumbra narrows further

accommodate the situation. Most times it will be obvious if several groups are clustered together, though on occasion making a distinction can be an art only mastered through experience.

Earlier in this chapter it was noted that sunspots go through classically repeatable life cycle patterns. A group develops through an observed blueprint that follows this course. In white light several pores may form a tight cluster confined within 10° of solar heliographic area. The pores will darken, becoming umbral spots (don't confuse them with umbral dots) sometimes gathered into two individual concentrations; this is classed a **bi-polar** sunspot group. After a short time, each concentration will develop a small sunspot. The two spots are identified as leading and following, the leading spot being the more westerly. Spot growth often terminates at this point with the dissolving of the newborn spots inside a few days. Should a group be particularly stable and continue to evolve, a penumbra will develop about the leader spot, and shortly thereafter around the other spots. The two sunspots will now begin to separate from each other by at least 3° in solar longitude, while rotating relative to the Sun's equator in an east–west direction. The leading (westerly) spot will have a magnetic polarity opposite that of the following (easterly) spot. A region or line separating the two opposing polarities exists, running in a roughly north–south direction that is known as the neutral line or magnetic inversion line. Sometimes sunspots rotate at a speed exceeding 1° an hour, wrenching the neutral line to a more east–west direction. This formation of the spots in sunspot jargon is known as **tongues**, and in appearance resembles the traditional yin-yang pictogram. This movement results in twisted magnetic field lines that precipitate events such as solar flares. Should the clumping of umbral spots consist of only a single concentration confined within a 3° area, it is called a **unipolar** sunspot group. On occasion an apparent bipolar group can contain numerous sunspots of differing polarities, all involved with a mutual penumbra. This assemblage is called a **multipolar** group.

Near the middle of the second week of growth a group typically maxes out in area and number of individual spots. Around this time, and for up to a month later the signs of decay begin to appear. Pores and tiny sunspots start to dissolve, while the following spot divides and fades until it disappears. As this is happening, the leading spot becomes symmetrical (rounder) in shape. Slowly the leading spot shrinks away, leaving any attending faculae that eventually disappear.

The transformations in this pattern can be identified by several classification schemes that solar astronomers have devised over the years. Max Waldmeir devised one well-known, and often used system in the early twentieth century. His Zurich sunspot classification system established nine classes labeled A, B, C, D, E, F, G, H, and J, each identifying the various stages of sunspot development. Excellent for cataloging a spot's lifecycle, the Zurich system fell short of the practical requirement needed in the mid to late twentieth century: the accurate prediction of solar flares. It is well known a solar flare can disrupt spacecraft and modern communication equipment, a concern of all people during the late twentieth century (Table 2.1 and Fig. 2.17).

Predicting when and where eruptive solar activity was most likely to happen took a significant step forward in the 1960–1970s when Patrick McIntosh created the extended version of the Zurich sunspot classification system. McIntosh altered the nine-class Zurich to a seven-division system. Two additional sub-classes were instituted describing the penumbra of a

Table 2.1 McIntosh sunspot classification system

Zurich class (modified)	
A	Individual spot, concentrated unipolar group, no penumbra
B	Bipolar group, no penumbra
C	Bipolar group, one spot with penumbra
D	Bipolar group, penumbra about both spots, length less than 10°
E	Bipolar group, penumbra about both spots, length 10°–15°
F	Bipolar group, penumbra about both spots, length greater than 15°
H	Individual spot, unipolar group, with penumbra
Largest spot within group	
x	No penumbra
r	Rudimentary penumbra surrounds only part of spot
s	Symmetric penumbra, 2.5° or less in north–south diameter
a	Asymmetric penumbra, 2.5° or less in north–south diameter
h	Symmetric penumbra, greater than 2.5° in north–south diameter
k	Asymmetric penumbra, greater than 2.5° in north–south diameter
Distribution within the group	
x	Unipolar group, class A or H
o	Very few or none, tiny spots between leader and follower
i	Many spots between leader and follower, none with developed penumbra
c	Many spots between leader and follower, one or more with developed penumbra

group's largest spot and the distribution of spots within the group. The added data derived from the three-letter McIntosh Classification System made it possible to more accurately forecast solar flares, giving amateur and professional astronomers an indication of when and where flares were likely to take place.

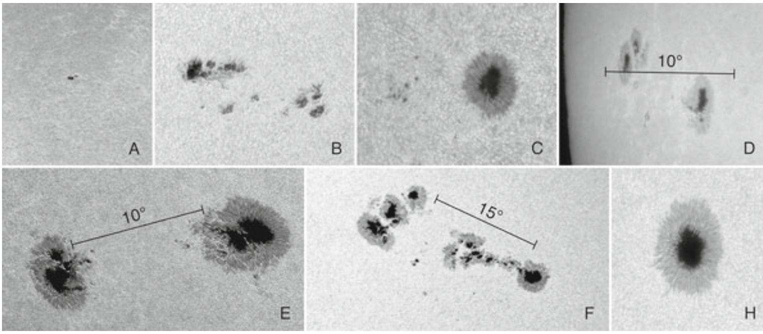

Fig. 2.17 Examples of the Zurich modified (McIntosh) group classes. Across the top is A, an individual spot with no penumbra, B is a bipolar group with no penumbra, C is bipolar, and in this case, the leading component has a penumbra. Groups D, E, and F have fully developed penumbra around the leading and following spots, however their separation varies as per the class (A, D and F from Jamey Jenkins. B, C, and H courtesy of Art Whipple. E is courtesy of Eric Roel)

Sunspot classification is a visual procedure requiring the astronomer to carefully inspect each sunspot group and conclude where that group falls within the descriptive language of the code letters. When all three areas of class are found, then the McIntosh classification for a sunspot group has been determined.

For example, upon inspection an observer concludes that a sunspot group is a bipolar group, has penumbra surrounding both sunspots, and has a length less than 10° of solar longitude (D), that the penumbra around the largest spot in the group is asymmetric with a north–south diameter less than 2.5° (a), and lastly, there are many smaller spots between the leader and follower, none with developed penumbra (i). String these three categorizing letters together, and the McIntosh classification is "Dai."

Understand of course that a group classification does now and again change over the course of a day, when the group experiences shifts in appearance; just like a daily sunspot count it is a variable metric, only absolutely accurate at the time of the observation.

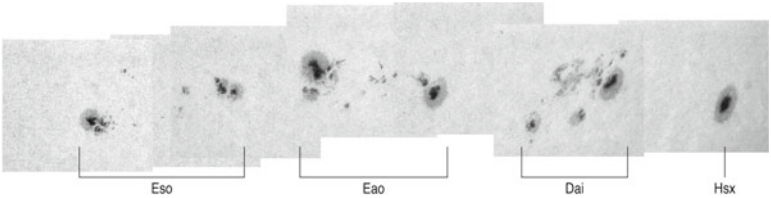

Fig. 2.18 Stretching across the face of the Sun on July 9, 2000 were four sunspot groups having differing McIntosh classifications (Courtesy of Art Whipple)

If direct observation is your mode, use a magnification suitable to determine the characteristics of the sunspot group. Usually no more than 50–100X is necessary, the seeing conditions are usually the limiting factor regarding magnification. No specific supplementary filters are necessary; however an orange or red filter will darken umbrae, making tiny spots between the leader and follower a bit easier. Individual spots, a unipolar concentration or any group lacking a penumbra will be accented too. Visually determining a spot diameter or a group's length takes practice. A reticule with a scale is useful when measuring dimensions directly, or a crosshair when timing a feature's drift in order to calculate heliographic dimensions.

Projection observers can accurately sketch a group's position and appearance on a report form and use separate templates to determine longitudinal length. Correction for limb foreshortening is accomplished with an angular measuring template.

Practice makes perfect in the classifying of sunspot groups. New observers will find it to their advantage to compare daily observations with those classifications published by professional astronomers. Mees Solar Observatory in Hawaii provides sunspot classifications daily on their web page. This activity will sharpen your skills, and develop an intimate comprehension of a sunspot's lifecycle.

If you are intent on observing an elusive white light flare, noting the McIntosh classification of groups on the visible disc of the Sun is essential to recognizing when and where to search (Fig. 2.18).

Observing White Light Flares

One of the most energetic yet least viewed events in our solar system is the white light flare (WLF). Solar flares are a manifestation resulting from the swift release of energy that has built up between opposing magnetic fields in an active region. A flare is generally best seen in the light of H-alpha, its outlet of greatest visible light emission. Flares go off several times per day during solar maximum while the solar minimum produces relatively few flaring events. Historically, it is noteworthy to mention that the first solar flare observed was a WLF by Richard Carrington, and confirmed by Richard Hodgson. The date was the 1st of September 1859.

The H-alpha flare (see section "Solar Flares" later in this chapter) is often seen beginning as a bright point or two, growing in size and brightness over a period of several minutes to a few hours. The rise to peak brightness in a solar flare is called the flash phase. To become a WLF, a solar flare must become so energetic and intense that its light "spills" out of the spectral regions of normal emission, and into the surrounding solar continuum. When that happens, the flare becomes visible at wavelengths outside H-alpha, which is the white light of the photosphere. This peak release of energy when the flare is glowing in white light is conspicuous for perhaps 5–10 min during the flash phase. Consequently, observing at the right time is *everything* with this type of observation. A white light flare appears as a single knot, or possibly two blobs located on either side of the neutral line or maybe within the spot's penumbral region. Expect an intensity approaching 1.5 I_{phot}. Although truly bright examples are rare, astronomers believe that a less intense variety of WLF can be observed more often.

The keys to spotting any WLF are deciding when and where to look, developing a methodical approach to the search, and optimizing the telescope to increase your chances of finding the elusive flare. Sunspot groups that have developed into McIntosh classifications of D, E, and F often produce flares. Chances increase for those groups that are sub-class ki or kc, though not limited to those classes; groups of Dai, Dso, and Hsx have, on occasion produced flares.

Begin by familiarizing yourself with the classes of groups currently on the Sun. Pay close attention to irregular and/or detached penumbra within a sunspot and areas of clustered spots between the leader and follower.

Table 2.2 Keys to locating a white light flare

1. Search McIntosh classes D, E, F, particularly those sub-classes of ki and kc
2. Set up an observing time when frequent checks can be made at the telescope
3. Observe in blue light inclusive of the G-band, where flares are known to go into emission

As was said, timing is critical and an occasional look at the Sun will hardly lead to success in spotting a white light flare! Most of us cannot monitor a possible flare producing sunspot group continually, but it is reasonable to take a few moments throughout a weekend morning or afternoon, such as when working outdoors or gardening, to scan the suspected sunspot group periodically for any WLF activity (Table 2.2).

Because only the brightest WLFs will be visible on a projection screen, use the direct viewing approach for your search. A prudent choice in the filtering system is the best way to optimize a telescope for observing a WLF. The idea with any optimization is to boost the contrast between the flare and surrounding photosphere, do this with a visual density objective filter principally transmitting in the *blue* spectral region. Mylar filters such as the Tuthill Solar Skreen fall into this category. You can take this a step further by combining a mild blue eyepiece filter with the safe mylar objective filter to intensify contrast of the flare a bit more.

You can also search for WLFs using video imaging methods by using a narrower band filter (10 nm or less) centered near 430.0 nm in the solar spectrum rather than the standard eyepiece filter. This filter will encompass the so-called G-band, which also goes into emission during a solar flare. This practice will dramatically raise your chance of catching a WLF, but the transmission characteristics of this narrow band filter may necessitate using a photographic density objective filter. The increased amount of light transmitted with the photo density filter is **not** safe for visual observing, therefore only photographic or video observations are acceptable.

When you spot a WLF, note to the nearest second if possible, the time of the beginning of the observation and the flare's disappearance, where on the Sun it occurred, its appearance, and a determination of relative brightness compared to the photosphere at specific times. Report these observations to the appropriate recording organization, such as the A.L.P.O. Solar Section or the B.A.A. Solar Division (Fig. 2.19).

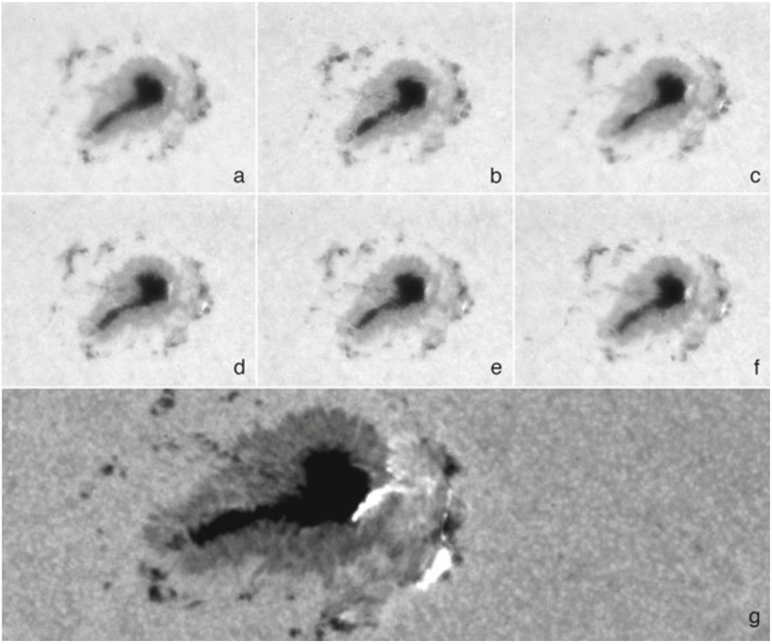

Fig. 2.19 Fortunate capture of a WLF. These images (**a** through **f**) were collected on 24 November 2000 by veteran observer Art Whipple. The photos illustrate the minimal time involved in a WLF's flash phase; only 1 min has transpired from (**a**) (15:08 UT) when the flare first became visible as a bright point until peak brightness is attained at (**f**) (15:09 UT). Image (**g**) is for comparison, obtained near peak brightness from outer space by the Transition Region and Coronal Explorer (TRACE) spacecraft, a mission of the Stanford-Lockheed Institute for Space Research and part of the NASA Small Explorer program (Courtesy of Art Whipple)

Lower Chromosphere

Directly above the photosphere is the atmospheric layer known as the chromosphere. During a total eclipse of the Sun the chromosphere (meaning sphere of color) is glimpsed as the pinkish-red ring encircling the solar limb. A nearly transparent gaseous region, the chromosphere is about

2,000 km thick (no more than 10 arc sec at the limb) and has an average temperature near 10,000 K.

Novice observers often wonder why on ordinary days they can't see the chromosphere through their standard "white light" telescope. The answer is quite simple: the light of the photosphere outshines the relatively feeble light of the chromosphere. In the past, other than during a total solar eclipse, chromospheric observing was accomplished with instruments that dispersed or broke apart the Sun's light into its various components. After separating the many wavelengths, the astronomer was able to view selected spectral regions where the chromosphere is brightest, *and* the photosphere becomes relatively opaque. These instruments, the spectroscope and spectrohelioscope, are powerful yet delicate tools that facilitated the first continuous studies of the chromospheric limb, and the first observations of the chromospheric disc.

Today's typical amateur astronomer rather than considering spectrographic techniques most often utilizes the add-on monochromatic filter, or a special solar telescope that passes only a specific wavelength of chromospheric light.

There are two wavelengths in the solar spectrum an amateur studying the chromosphere commonly makes use of: the Calcium-K (393.3 nm) or H-alpha (656.3 nm). When H-alpha or Ca-K features are viewed, light outside their wavelength is suppressed and remarkable details become visible. Filters are available for other specialized studies of the chromosphere including the Ca-H line, Hydrogen Beta, Sodium D, and Helium D3. These are dedicated products that optimize the viewing of select solar characteristics that may not be glimpsed in the more popular filters.

Ca-K filters make discernible lower chromosphere features which are affected by local magnetic fields. For instance, weak magnetic fields determine dark zones; stronger magnetic fields create brighter patches; however rather unexpectedly the strongest magnetic fields (i.e. sunspot umbra) look the darkest (Fig. 2.20).

Since the calcium spectral lines are broad, a filter with a bandwidth of 2.2 Å is suitable to isolate the K-line. The typical Ca-K filter will show a region approximately 500–2,000 km above the photosphere. This encompasses

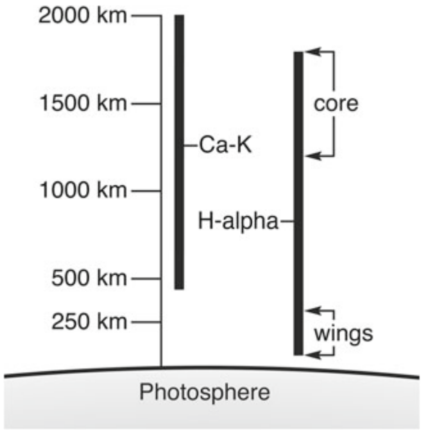

Fig. 2.20 The chromospheric heights visible through Ca-k and H-alpha filters (Data courtesy of Alexandra Hart)

the core height of the H-alpha line, so some Hα features will be visible, but for the most part they remain faint and ill-defined given that they emit weakly in the light of calcium (Fig. 2.21).

K-Grains

K-grains are observed in monochromatic Ca-K or Ca-H light and have a correlation to and similar appearance to continuum bright points. Discovered by Hale and Ellerman (1903–1904) they were originally called "minute calcium flocculi" with solar astronomers later adopting "K-grains" in the 1960s. As with bright points, K-grains require superb resolution due to their diminutive size. K-grains experience short (approximately 10 min) lifetimes in which they are seen to brighten and dim repeatedly while sometimes drifting away from their original location. K-grains tend to form solely in areas away from active regions within the interior cells of the chromospheric network.

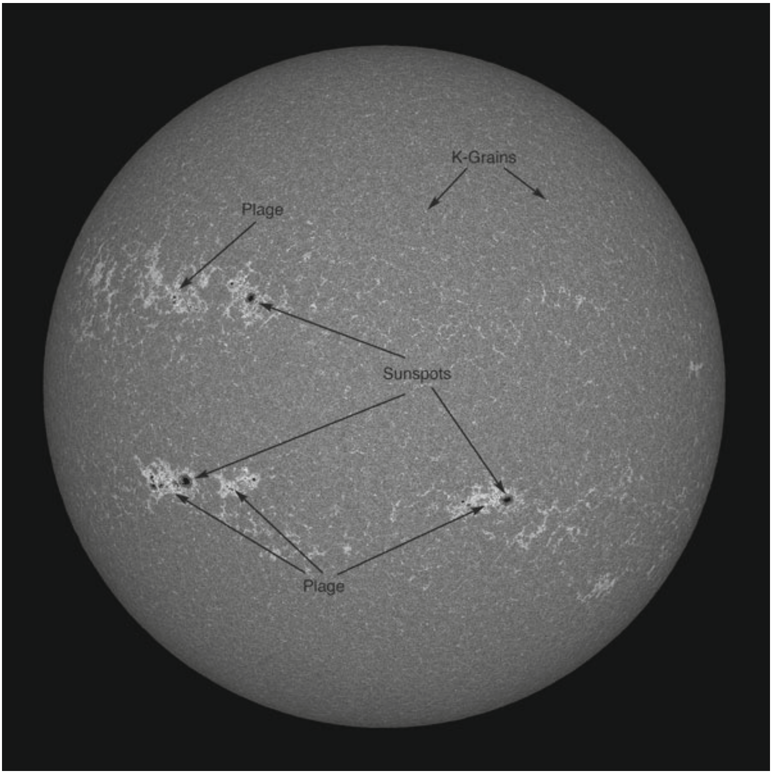

Fig. 2.21 The lower chromospheric Sun visible through a 393.3 nm Calcium-K filter on 30 June 2012. Indicated are the most obvious features: sunspots, plage, and K-grains (Courtesy of Christian Viladrich)

Chromospheric Network

The chromospheric network is a low contrast, fine mottled latticework or web-like structure that covers the Sun's face. In the quiet solar regions it is visible with slight difficulty in the light of Ca-K as a bright pattern, and with a bit greater difficulty (better in the wings) in H-alpha reversed, the web pattern then appearing dark. An improved visibility is noticed near active regions and plage.

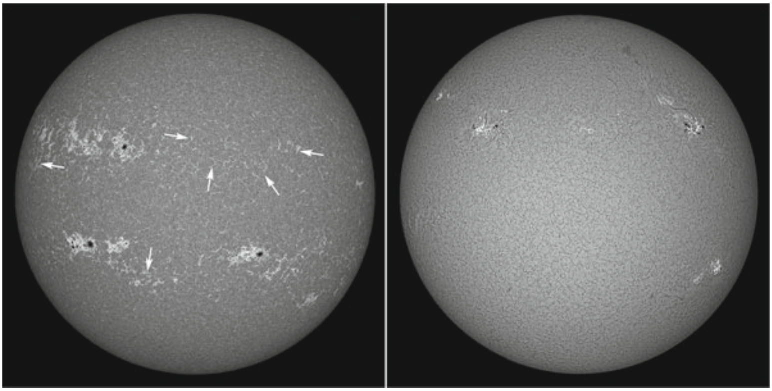

Fig. 2.22 The chromospheric network appears as the weak yet bright background pattern visible in the *left hand* Ca-K image, and *dark* in the *right hand* H-alpha image, spicules and fibrils limit the view of the network (Images courtesy of Christian Viladrich and Fabio Acquarone, respectively)

The network overlays the supergranular cells found in the photosphere. *Supergranules* are enormous versions of individual granules, each with a diameter about 30,000 km, although usually not easily seen if at all in white light. A continuously evolving feature, supergranules possess a lifetime approximating a day or so. Fluid motions within the supergranules carry magnetic field lines to the periphery of the supercells allowing the formation of the chromospheric network.

Coarse bright mottles appearing as miniscule patches in conjunction with bright point filigree are located along the boundaries of the supercells forming the network. From the mottles protrude larger dark appearing (on the disc) gas jets called *spicules* and another feature, the *fibrils* that follow the horizontal magnetic field lines sometimes found in the chromosphere. In the literature these two features are occasionally referred to as *dark mottles*. The spicules and fibrils provide an effective means of preventing the observer an unimpeded view of the underlying chromospheric network (Fig. 2.22).

Plage

The French word for beach is plage. *Plage* (pronounced PLA-juh) on the Sun refers to the patchy bright regions with enhanced temperature found most often near sunspots. Plage are visible predominantly in Ca-K, but also well in H-alpha light. Spicules avoid plage, but they do cluster at its edges.

It is believed that a relationship of some sort exists between the plage of the chromosphere and the faculae, a photospheric feature typically residing in a much smaller area. Faculae are explained by depression sidewall leakage and scattered light; plage on the other hand, indicate areas where underlying flux tubes are emerging. Plage embodies many tiny, bright features. It has been estimated that on average the area of a plage is 30 % filled with emerging magnetic flux tubes. The reconnection of magnetic fields is another occurrence associated with plage. *Reconnection* is the rearranging of broken magnetic field lines with newer emerging flux tubes. Since the relationship between faculae and plage is not completely known, this remains one of the mysteries for the professional astronomer to solve. From the amateur observer's standpoint, remember that these are two separate features, and should not be confused as one and the same (Fig. 2.23).

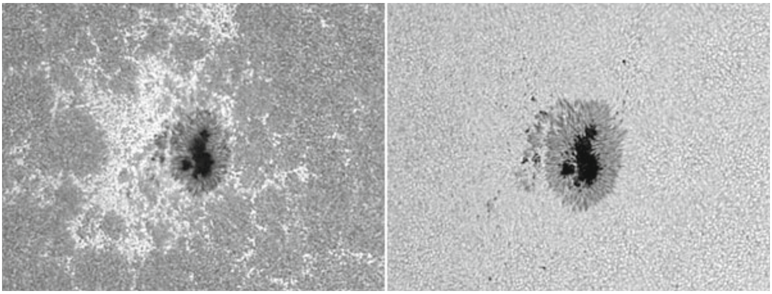

Fig. 2.23 Compare the two images of the same sunspot on the same day. The Ca-K filtered image on the *left* reveals a complex plage system about the spot. The *right hand image* was taken in the solar continuum through a green filter no plage is visible (Courtesy of Christian Viladrich)

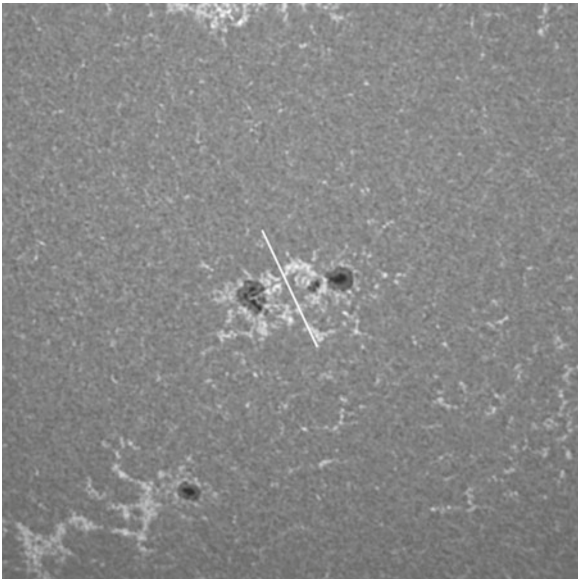

Fig. 2.24 The *white line* in this bipolar sunspot group symbolizes the area where magnetic polarity of the group reverses. The actual neutral line may not necessarily be a line segment but may follow an irregular path. Notice the plage has separated, creating a "plage corridor" extending on either side of the neutral line (Courtesy of Alexandra Hart)

A lower chromosphere feature, a plage can surround a sunspot as a cloud-like form with no particular consistency in brightness or shape; plage intensity disperses gradually as it reaches deeper into the less active regions of the Sun. Just as faculae precede sunspot development, small elliptical shaped plage may appear prior to sunspots. These early seen plage are customarily bright and may accompany arch filaments located within an emerging flux region (EFR). As the sunspot group grows, and if it is bipolar, the plage divides between the leading and following spots along the group's neutral line (a pathway where magnetic polarity reverses); this division is called the *plage corridor*. Early sunspot groups are noted for their sharp, thin corridor that becomes blurred with time, eventually disappearing and dissipating as the host group and attending plage decay (Fig. 2.24).

Upper Chromosphere

Those chromospheric features, excluding the aforementioned, are attributed to the mid to upper chromosphere, and are often viewed with a filter passing light at a wavelength of 656.3 nm, the H-alpha line.

The H-alpha filter is generally positioned to isolate the core of the spectral line (<1.0 Å) and show the mid-region of the chromosphere or about 1,500 km above the photosphere. Observing in the "wings" or off-band, up to about 2 Å in H-alpha, brings the view down much closer to the photosphere, somewhat less than 500 km from the surface.

Some mid to upper chromospheric features are visible in both the light of H-alpha and Ca-K, though in Ca-K rather fleetingly if at all. Features glow or are in emission at certain spectral wavelengths, affecting how bright they appear at other wavelengths. Consequently, prominences while bright in H-alpha are relatively faint when viewed in Ca-K (Fig. 2.25).

Spicule Patterns

Viewed in H-alpha at the limb of the Sun, a spicule appears bright because it is an emission feature seen before the cool, dark background of outer space. Spicules form the pinkish-red ring encircling the Sun that is seen during an eclipse, resembling what many early observers thought were "gas-jets". There is a tendency for spicules to merge together, making it exceedingly difficult but not impossible to recognize individual jets. They are seen to project from the limb at an angle near 70°–90° and often are larger at the polar regions of the Sun, protruding no more than 10 arc sec above the surface.

Spicules are hot gas, moving vertically at a speed approaching 50,000 km/h, and then abruptly ending their life in less than 10 min, by either falling back into the Sun or disappearing completely.

On the disc of the Sun, the spicules become absorption features (also called dark mottles) viewed before the brighter solar disc, creating interesting patterns given aesthetically pleasing names. Clusters of spicules are

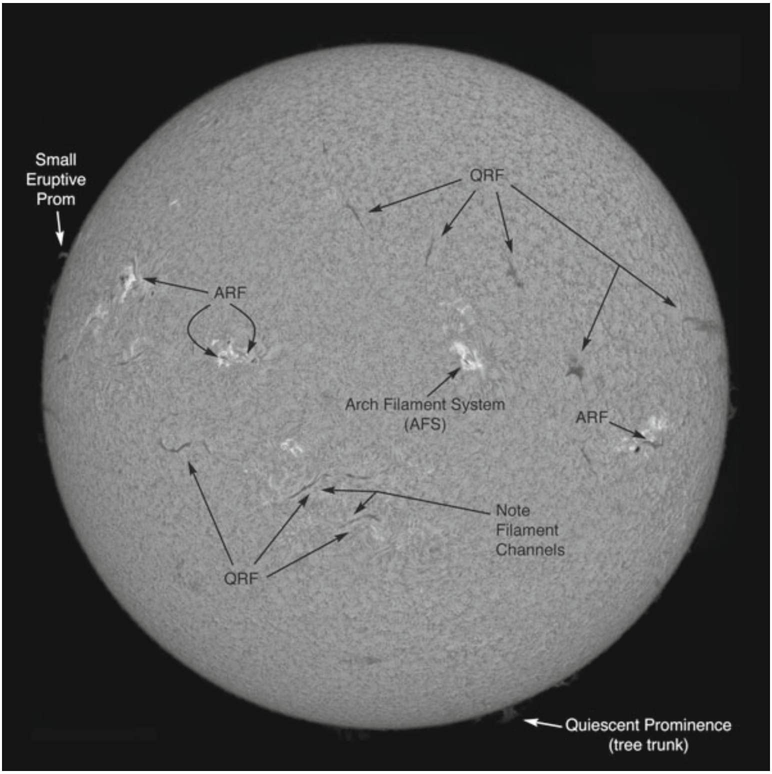

Fig. 2.25 **Whole disc image with H-alpha features. A number of quiet region filaments (QRF) are spread over face of the Sun. Two located near the *lower center* have a *light appearing undertone* where it is evident that the spicules and fibrils are bent to provide the filament an opening, the filament channel. *Right of center* within the plage region is seen several members of an arch filament system (AFS), while to the *left of center* are located two active regions and several smaller active region filaments (ARF). The solar limb contains a variety of prominence features including a quiescent (tree trunk) prominence, and what appears to be a small erupting prominence (Courtesy of Alexandra Hart)**

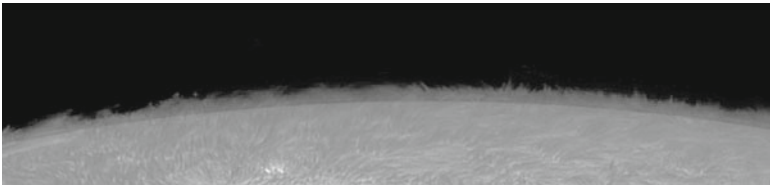

Fig. 2.26 Spicules on the limb of the Sun (Courtesy of Eric Roel)

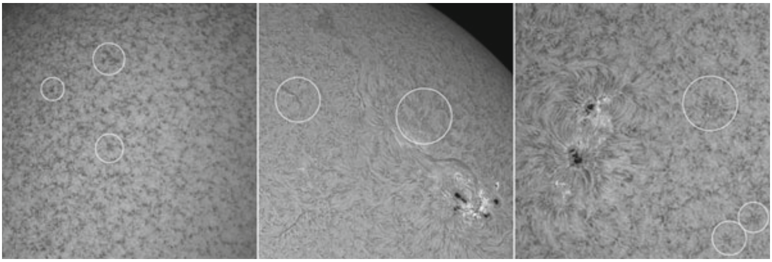

Fig. 2.27 Spicules on the solar disc. In the *left image* bushes can be seen *dotting* the image, three examples are *circled*. The *center picture* has two chains *circled*, the left most illustration lies beneath the filament. The significant difference between the bush and chain is in alignment. Bushes are clusters of spicules while chains are in columns and rows. *On the right* three rosettes are shown (All images courtesy of Fabio Acquarone)

referred to as a *bush*. Under good seeing conditions the fine spicules of a bush provide a striking multi-dimensional effect. If the spicules are aligned to form a column or row, they are known as a *chain*.

One of the more eye-catching shapes is that of the *rosette*, the radiating of spicules from a central point, like that of a flower petal. Rosettes form at the crossroad of two or three supercells of the chromospheric network. The radiating pattern is fashioned from bright mottles at the rosette's center, and alternating bright and dark mottles about the center (Figs. 2.26 and 2.27).

Fibrils

An active region containing sunspots with a strong magnetic field has influence over the neighboring spicules. Those located nearby become bent and enlarged, their projections following the local magnetic field lines. Visible in H-alpha light, this sometimes results in spectacular patterns of swirls, carpet-like formations, or whirlpool type effects.

These affected spicules are known as *fibrils*, dark mottles that follow the transverse or horizontal magnetic fields that run parallel to the solar surface. Individual fibrils can be 10,000–11,000 km in length, and display thicknesses of about 2,000 km.

When the thin gas in the upper chromosphere adheres to a local magnetic field, the finger-like fibrils are seen that indicate the location of lines of magnetism. Fibrils are known to unite regions of opposing polarity. Remember the science class experiment with the iron filings and the bar magnet. The same magnetic alignment principle is in effect on the Sun, often times visible in a bipolar sunspot group. Large sunspots are known to cause fibrils to diverge around a spot, giving the appearance of the thickening of a penumbral region. This effect is known as a *superpenumbra*. Exceptionally large groups can establish equally large regions of radial swirled fibrils, a condition that is designated a *vortex* (Fig. 2.28).

Emerging Flux Region

Earlier in this chapter the basic scheme of how sunspots are birthed, as seen in white light, was presented. That process began with the appearance of facula and pores. Some of the pores decay as others grow and develop into larger sunspots, and so on. There is a piece of the story, which the white light observer is not privileged to witness, but the monochromatic observer can view.

To more fully understand the development of an active region we must begin with the processes working deep in the Sun. Recall from Chap. 1 that the Sun generates a magnetic field between the radiative and convective zones in an area called the tachocline. The resultant lines of magnetism

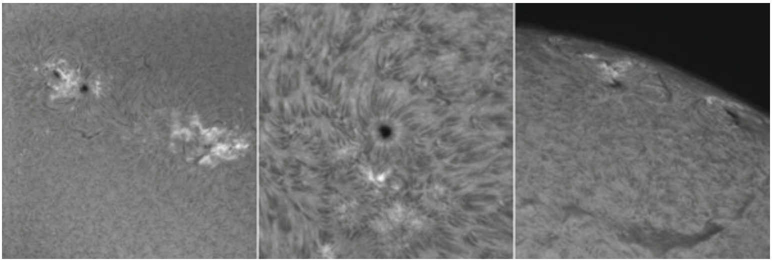

Fig. 2.28 Spicules near strong transverse magnetic lines bend and become fibrils. Fabio Acquarone obtained the far *left image* illustration showing the classic "iron filings" alignment found about the *upper left corner* bipolar sunspot group. In the *center* is a unipolar group, in which the fibrils radiate from the spot, giving the false impression of an enlarged penumbra or superpenumbra. *On the right* two sunspot groups appear at the solar limb with a swirling vortex of fibrils surrounding them (Center and right images courtesy of Alexandra Hart)

running from the Sun's north and south poles are wrapped around and around the Sun by differential rotation. Over time the vertical motion of plasma in the convection zone causes a kinking or tangling of the elongated magnetic field lines. The tangled lines develop regions of increased magnetic strength in the convection zone known as magnetic flux tubes. A process called buoyancy allows a flux tube to rise to the surface and poke through the photosphere. Basically, that is the process of magnetic flux emergence.

As the magnetic flux tubes initially break the surface, areas known as *ephemeral regions* develop which are not nearly as bright as plage, and contain no pores. These areas are known to also occur outside the sunspot zone, but most are formed within it.

To the monochromatic observer the initial beginning of an active region, known as the *emerging flux region* (EFR), is the early development of plage. Also seen in Ca-K, tiny flux tubes often less than 600 km in diameter poke through the solar surface allow a peek into the solar interior, hence the reason they appear bright. Some small tubes will merge together to form larger, more intense structures which begin to stifle convection forming

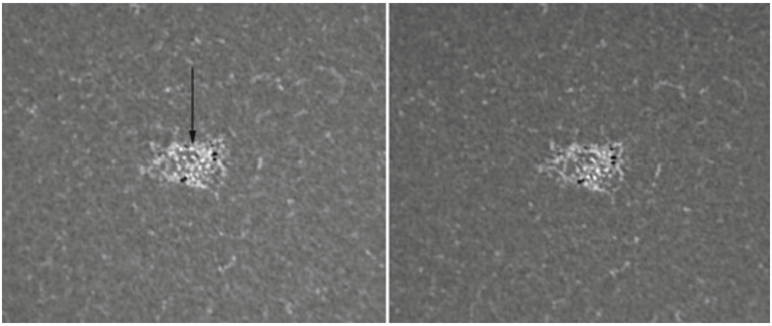

Fig. 2.29 Emerging Flux Region prior to being designated AR1130 by Alexandra Hart from 28 November 2010. The *arrow* indicates several "bright points" which may be Ellerman bombs. Image on the *left* is from 12:37 UT, *on the right* at 13:02 UT (Images courtesy of Alexandra Hart)

pores, which then become visible to the white light observer. Several other monochromatic features are known to accompany an emerging flux region, including the arch filament system and Ellerman bombs (Fig. 2.29).

Arch Filament

During the emergence of flux, as an active region grows, a unique type of fibril may be observed in H-alpha, the *arch filament system*. An arch filament system (AFS) when observed from above in early plage is composed of dark, thick threads that always overlay the bisecting neutral line of the active region. Their form may materialize as straight lines or include slight curvatures. Because an arch filament is low in the chromosphere, observing it at the limb can be difficult depending on its height, but not impossible. On the limb an arch filament is visible as an emission feature, bright against the dark sky background.

The AFS, because it follows the magnetic field lines of opposing polarity is frequently an arch-shaped feature. Height can vary from system to system with an observed variability of 4,000–15,000 km. The filaments tend to last around 30 min, their transformation seemingly tied to visible changes

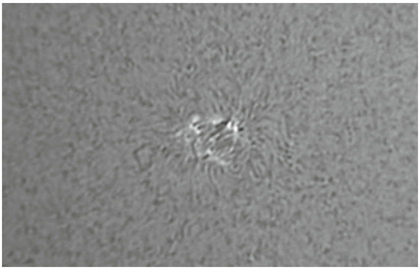

Fig. 2.30 Arch filaments found in this emerging flux region designated AR1130 from 28 November 2010 are seen as the *thick*, *dark threads* crossing from *lower left* to *upper right* over the numerous bright points (Image courtesy of Alexandra Hart)

within the emerging flux region. Three days is the accepted period for a developing sunspot group to harbor an AFS.

It is theorized that arch filaments are caused by the constriction of plasma consequential from the new emerging flux, which as the plasma becomes denser creates a flow downward at both ends of the arch due to the influence of gravity. What we usually see through the spectroscope in the AFS is upward flow (Doppler shifted blue) near the peak of the arch, and downward flow (Doppler shifted red) at the arch's feet or foot points, which will be anchored in the active region, at the flux tube points of opposite polarities. As a sunspot group matures you will find the AFS is transformed into a *field transition arch* (FTA), similar to the AFS, but more stable and possessing weaker appearing thin, gray, fibril-like features also anchored in the magnetic bi-poles (Fig. 2.30).

Ellerman Bomb

Another typical feature associated with the emerging flux region and mature active regions are the bright points, having a diameter of 3 arc sec or less, known as Ellerman Bombs or in spectrographic circles, *moustaches*. Ferdinand Ellerman, a contemporary observer of George E. Hale who likened the brightenings to solar hydrogen bombs, is their namesake.

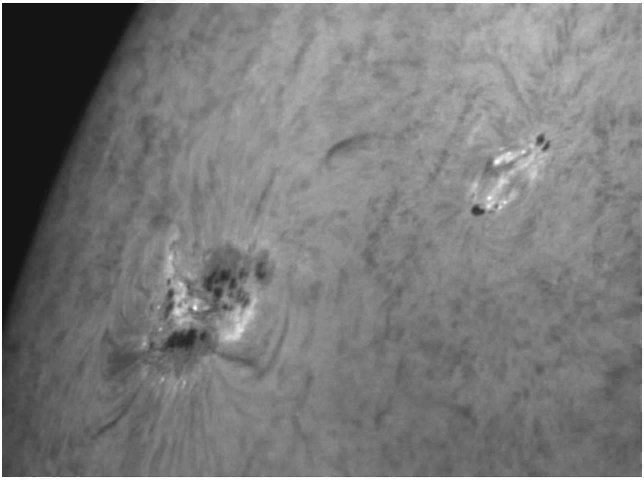

Fig. 2.31 Ellerman bombs (*small dots*) visible around the perimeter of AR1429 and the nearby emerging flux region on 4 March 2012. Image obtained –0.5 Å off-band from H-alpha (Courtesy of Jim Ferreira)

When observed spectrographically the appearance of the bright point is that of a strong absorption in the centerline of H-alpha and a bold emission in the wings of the line, hence the name moustaches.

Ellerman bombs occur low in the chromosphere, 600–1,100 km above the surface, and therefore appear best in the wings of the H-alpha line. Bombs last in the range of 5–10 min before disappearing and have been known to pop back into view after a half hour or so. Look for Ellerman bombs within the interior of a new emerging flux region, around the edges of sunspots, or at the base of spicules and active filaments. Ellerman bombs figure to be the result of magnetic reconnections in the chromosphere (Figs. 2.31 and 2.32).

Prominences and Filaments

Other than the solar flare, a prominence is the most stunning event to be seen on the Sun. The prominence (abbreviated in amateur circles as the prom) is a cloud of gas suspended above the solar surface. The cloud may

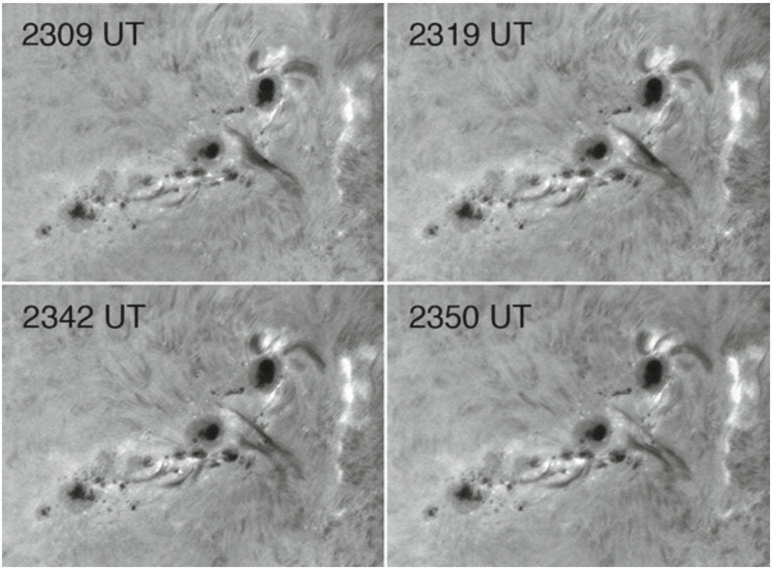

Fig. 2.32 Changing appearance of Ellerman bombs in AR1515 on 3 July 2012 between 2309 UT and 2350 UT. Jim Ferreira imaged this event −0.5 Å off-band from H-alpha (Courtesy of Jim Ferreira)

condense out of the lower corona, be thrown up by an ejection from below, or define a sheared neutral line by gas captured amongst the twisted bundles of magnetic field set up above the photosphere. The novice and at times the general public often make the mistaken assumption that a prominence and a solar flare are one in the same feature. The two can and do have a link, but they are totally different features; a prom being as defined above, while a solar flare is the swift release of energy accumulated within the magnetic field of an active region.

Typically a prominence has a relatively cool temperature near 10,000 K and a density hundreds of times that found in the immediate chromosphere and corona. Dimensions of a prom can vary, but a height of 40,000 km and a length of hundreds of thousands of kilometers are easily attainable. The wise solar observer always keeps in mind this "tongue in cheek" rule regarding a prom: "when it comes to a prominence, almost anything is possible".

Viewed ideally in H-alpha and at the solar limb, prominences are beautifully profiled features seen in emission (bright) against a dark background sky. Under these conditions proms can be watched with a filter having a bandwidth of 1–2 Å. A wider bandwidth filter up to about 10 Å (consequently passing some continuum light) will also show limb prominences, but an occulting cone or disc is necessary to safely block the blindingly radiant light of the photosphere. To view a prominence upon the solar disc requires an H-alpha filter with a bandwidth less than 1.0 Å, where unless the prom is especially energetic, it will appear as an absorption feature, a gray to black ribbon-like structure known as a *filament*. Prominences and filaments are the same feature, they just are observed on the Sun at different locations.

Filaments associated with a sunspot group tend to be narrow and dark, sometimes winding among the group; the longer, gray, thick varieties are found in the quiet regions of the Sun, changing their appearance over time ever so slowly. A prominence associated with an active region is identified as an *active region filament* or ARF. A prominence appearing in a quiet spot on the Sun is called, a *quiet region filament* or QRF.

Proms/filaments are not limited to the sunspot zones either; a filament can appear in the higher solar latitudes, practically anywhere on the Sun. In fact, located about 10° outside the sunspot zones is a "prominence zone", which during the 11-year solar cycle migrates toward the solar equator just as the sunspots do.

Because plasma clings to magnetic field lines, and magnetism supports prominences, a prom will outline the shape of its host field. Note that as the magnetic field evolves, the prom's shape will change. This characteristic provides one channel for mapping magnetic fields as they occur on the Sun.

There exists a significant connection among a prominence, a solar flare, and an active region. A prom/filament is likely to develop where conditions result in the elevation of dense gas above the solar surface. One possible condition comes about as a solar flare manipulates material through thermal instability: resulting in cool gas condensing in the lower corona, and the subsequent condensation raining down onto the Sun's surface. Another connection related to all proms and filaments is the shouldering effect of gas by the magnetic fields produced by flux tubes located inside and outside active regions that poke through the photosphere.

Thirdly a solar flare, one of the most violent energy events in our solar system can disturb an existing prom/filament from the Sun. In most cases the ejected or erupted material falls back to the Sun; however a particularly spectacular eruption can lead to the ejection of tons of material from the corona, a so-called *coronal mass ejection* or CME. The CME if directed toward Earth frequently results in nightly displays of the aurora, and disruption of the near-Earth space environment. These three circumstances are found within photospheric active regions.

Through the years various schemes intended to classify and organize prominences have been proposed. Factors determining classification schemes have included: the physical appearance of the body (morphology), the prom's relationship to sunspots, motions of the prom, a feature's spectroscopic characteristics, or the prom's place of origin – the chromosphere or corona. The reality unfortunately is that no single scheme can easily describe *all* the possible forms a prominence assumes. Donald H. Menzel, John W. Evans and F. Shirley Jones in a system that will be presented later in this section did make an interesting attempt at prominence categorizing in the 1950s. The present discussion however is not focused on classifying prominences, but rather only describing the forms that a prominence assumes. Therefore, at this point only two divisions of proms shall be considered, those that to some degree are stable, and those that are not and have a bursting nature.

Early chromospheric observers, such as Fr. Secchi, using a wide slit on their spectroscope recognized two contrasting groups after having studied a large number of prominences. These groups are: *quiescent* (meaning quiet/static) and *eruptive* (meaning active/moving). For the most part a quiescent prominence behaves in a calm manner, changing appearance only slightly with time. One could say a quiescent remains somewhat sedate. The quiescent prom, identified with the previously mentioned QRF, often originates in the corona with matter **descending** toward the photosphere. On the other hand an eruptive prominence many times originates in the chromosphere with its matter ejecting or **ascending** toward the corona. Eruptive proms appear agitated, and by and large are associated with active regions, hence the acronym ARF applies.

Since the distance to the Sun is great, and even though some prominences are large, prominence morphology in real time does appear gradual. However, don't think that an eruptive prominence's development necessarily proceeds at a turtle's pace; dramatic changes can be seen within a minute or less! Eruptions may easily exceed 200 km/s. A quiescent prom does not always remain quiet either; it can become unexpectedly disturbed and erupt into space. And because an ARF or QRF may have erupted, don't think the show is over; the feature may reappear minutes or 1–7 days later in the same solar region.

As stated earlier, these features are best observed in H-alpha, where they are in brightest emission. However, occasional viewing off-band may be essential if an eruptive feature has been Doppler shifted. While it is possible to observe prominences and filaments in the light of calcium (Ca-K), the view most times is quite dim, and ill-defined.

Following you will find descriptive material that outlines some of the more commonly documented forms, beginning with the descending quiescent type and progressing to the ascending eruptive variety. It would take an entire book devoted to this one topic to do complete justice, so don't be surprised if during your own observing sessions you find an example or two that fail to fit within these familiar prominence types. Remember the rule of thumb regarding proms and filaments: that anything seems possible.

Descending Prominences

Many start the life process as a small active region prominence located perhaps at the perimeter of an AR where the prom connects to an outside source of opposing magnetic polarity (another active region or a new emerging source of magnetic flux, called a *dipole*) or positioned along the shearing neutral line of an AR. Many times a filament is found winding its way through a sunspot group, or a quiet region of the Sun where local fibrils tend to bend themselves into a pathway or opening parallel to the filament. This magnetically neutral region called a *filament channel* is situated below the filament and appears lighter, the result of restrained spicules and fibrils that are outlining the chromospheric network.

Initial development of a typical quiescent prominence may take 24 or more hours. The parenting active region, if one exists will eventually decay,

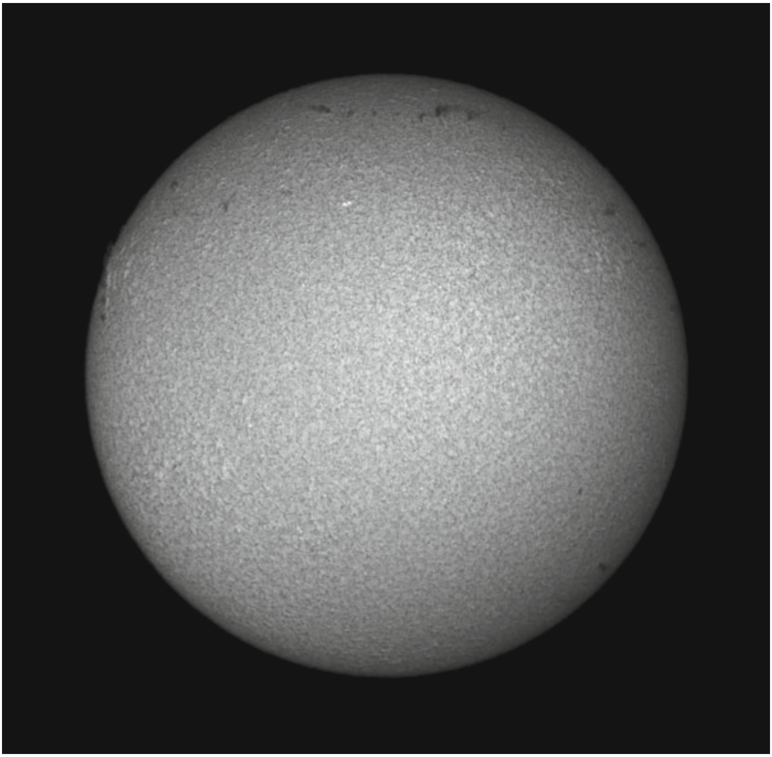

Fig. 2.33 The drifting of filaments to the polar regions of the Sun forms a polar crown. In this instance Thomas Ashcraft captured a string of filaments in the northern zone on 16 May 2010 (Courtesy of Thomas Ashcraft)

perhaps leaving the filament to broaden and lengthen into an enormous quiescent QRF, drifting gradually from the sunspot zone toward the poles.

Quiescent proms originating in the sunspot zones tend to have a shorter lifespan than those found in the higher polar latitudes, two solar rotations compared to about five, respectively. Differential rotation of the Sun causes the lengthening of filaments as they slowly drift toward the solar poles. Some of these drifting filaments make it to the upper latitudes, joining other filaments already there to form a so-called, *polar crown*. This unusual feature ordinarily occurs at about ±70° heliographic latitude (Fig. 2.33).

The quiescent prominence exits by slowly disintegrating, flowing down to the surface, or by becoming *activated* and erupting. Activated means that the normally static quiescent is undergoing unexpected change, and is experiencing increased movement. A quiescent prominence/filament under these conditions is termed an *active quiescent*. Visible disturbances resulting from activation include: physical growth of the prominence, a change in brightness (darker for a filament and brighter for a limb feature), or a disorderly shifting of material within the feature.

Nearly all prominences achieving heights in excess of 50,000 km (approximately 65 arc sec) are known to habitually erupt within a day or two. Passing shock waves (see Moreton Waves) emanating from a solar flare can cause a rapid waving effect to the prom/filament that precipitates activation. And lastly, a quiescent can become activated for simply no apparent reason.

Material flows are typically descending, flowing from the prominence to the surface region. Should flow appear to be between two or more quiescent structures, these features are said to be *interactive*. The nearly horizontal flow of knots and streamers between individual components is infrequently detectable, however when it is, it may include interaction with a form of celebrated prominence renowned as a *tornado* (see following pages).

The *hedgerow* is the representative descending quiescent prominence. The name is derived from the obvious similarity in appearance to the rows of trees and hedges left along the edge of a farmer's field, serving as a windbreak. The grouping can be composed of a number of individual proms (the row in hedgerow), each having a slightly differing form. Or it may be one large prom, a gaseous composite structure made of a vertical palisade of "threads and fibers", each thread having a diameter of less than 300 km. Time-lapse movies clearly show considerable internal motion as hedgerow gases stream down the threads and into the lower chromosphere. It is not clear how the gas in the hedgerow is replaced, but it must be or else the prom would exhaust its supply long before most disappear (Fig. 2.34).

The ends of the hedgerow are often magnetically anchored to the solar surface. Normally a stable, quiet feature, when one end of a hedgerow breaks free from below, this is understood to be a sign that the prominence

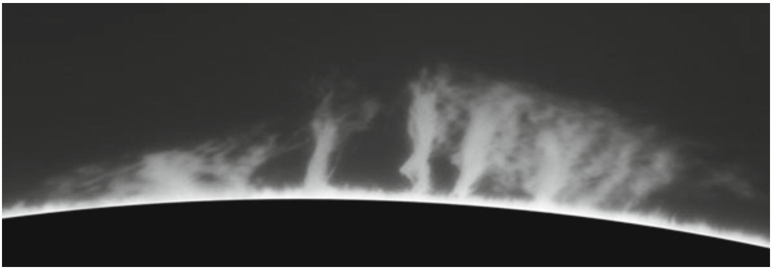

Fig. 2.34 A very typical hedgerow formation on the solar limb composed of a field of individual trees (Courtesy of Alexandra Hart)

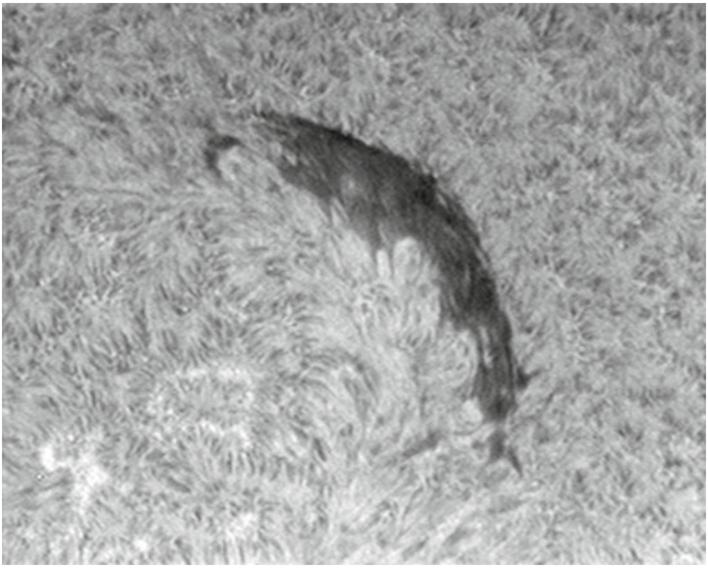

Fig. 2.35 Here is a quiescent filament located on the disc of the Sun showing a smooth *topside* and a *lower scalloped side* (Courtesy of Gordon Garcia)

is about to erupt. Viewed at a steep angle from Earth, as in Fig. 2.35, the filament sometimes presents a smooth edge on the upper side while the lower inside edge appears scalloped. These scalloped points are identified as *barbs*. The lower side projections often extend to the area where an active region magnetic field reverses polarity, the neutral line. The smoother upper side is less ragged because of its interaction with the supporting, and also constricting magnetic field.

Another feature of a quiescent prominence, particularly the hedgerow, includes so-called ascending *bubbles* and *plumes*. Contrary to the normal down flow occurring in the quiescent prom, dark convex-shaped bubbles are seen to develop unexpectedly below the base of the prom, but situated above the chromosphere's spicules. These bubbles subsequently initiate a small scale, turbulent up flow through the prominence that is dubbed, a plume. A bubble can spawn a number of plumes in its several hour lifetime, new plumes appearing approximately every 5–10 min. A superb illustration of the effect is found in the Ferriera images found in Fig. 2.36.

Other Descending Forms

Numerous other forms of the quiescent prominence exist; common nicknames describing their appearance include, but are not limited to the haystack, tree trunk, mound, and coronal cloud, floating arch, double arch, coronal rain and tornado.

Prominence loops are particularly beautiful limb structures that fall into three different categories. Following the outburst of an intense flare, the solar material ejected into the corona sometimes begins to cool and condense into a motionless "dot" above the sunspot active region. Intensity of the dot increases as it expands downward toward the AR outlining the first type, a so-called *post flare loop*, with material flowing back onto the underlying surface at nearly 10 km/s. Sometimes the material flow is down both sides of a loop, and at times it can be seen rising up one side and flowing down the other. Post flare loops often have a lack of uniformity to their brightness, the upper loop region routinely appearing brighter than the arches.

If the loop is incomplete and open near the top a second type of post flare loop develops, this is *coronal rain,* consisting of faint streams and knots of gas pouring back from the gap intermittently through the chromosphere. Many times a flare loop system associated with a strong magnetic field will consist of a grouping or cluster of numerous thin loops (approximately 20)

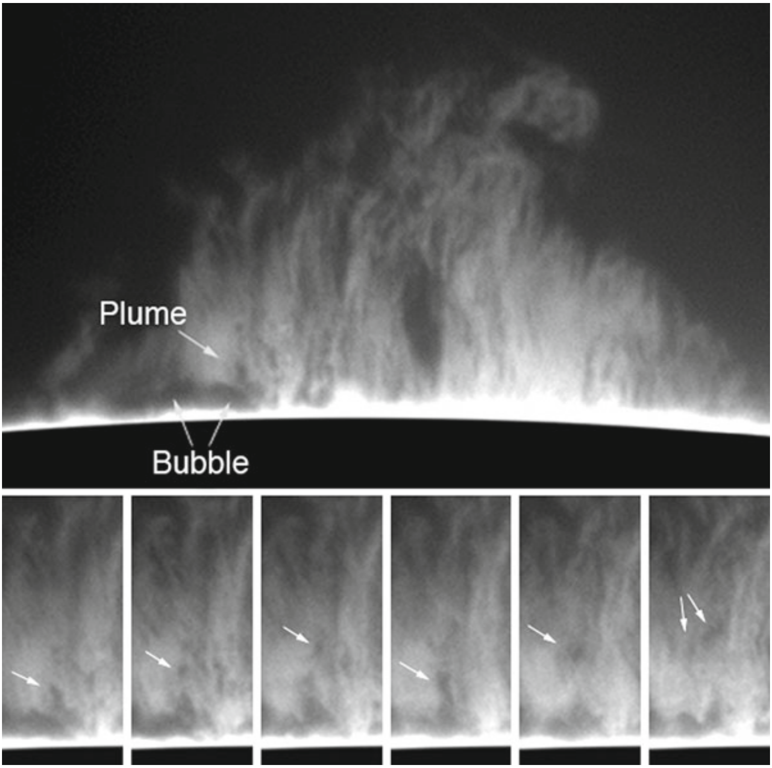

Fig. 2.36 Bubbles and plumes in a quiescent prominence. Bubbles of hot plasma develop instabilities, producing an up flow or plume of hot plasma that rises at nearly 20 km/s. Images extracted from a 42-min H-alpha movie on 28 August 2011 (Courtesy of Jim Ferriera)

called an *arcade*. Arcades are strikingly similar in appearance to a child's "slinky" spring toy with the arch foot points located near the active region's magnetic poles. This is to say, a loop crosses the active region's neutral line just as does an arch filament system. Loops are not long-lived features, several hours of activity is the norm.

The third type of loop is the *flaring arch*, similar in appearance to a post flare loop; the flaring arch develops as a flare expels the flowing material directly into a magnetic loop rather than condensing it from coronal material.

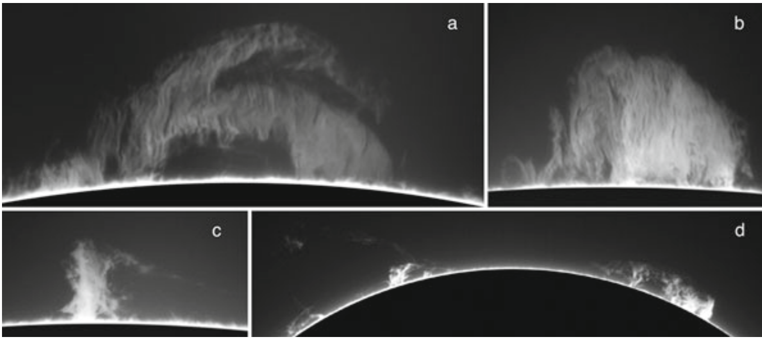

Fig. 2.37 Collection of descending quiescent proms. Figure (**a**) is a classic floating arch, (**b**) would be called a haystack or maybe a curtain depending on your point of view. If you look closely perhaps you can see the profile of a *facing-left elephant*, standing on the Sun. Another classic, the *tree trunk* is captured in figure (**c**). The wide field view of (**d**) contains a quiescent formation on the *right* and several eruptive proms on the *left* (Figure (**a**) courtesy of Alexandra Hart; Jim Ferriera provided the balance)

The *coronal cloud* is an ill-defined patch or blob, dissimilar from the dot of post flare loops, suspended in the corona with material streaming from it to the surface below. A good example can be found with Fig. 2.38a, nicknamed here because of its shape, the kite.

The *mound* and *pyramid* forms are similar in appearance other than the rounded peak of the mound and the sharper summit of the pyramid. Both are low bodies in which the near chromosphere width of the feature should exceed the height. The straight or curved *pillar* can fool you into thinking an eruption is happening. If the feature is long-lived and relatively motionless, the possibility of the pillar being an edge-on view of another QRF (i.e. floating arch, Fig. 2.37a) is good.

One of the more unusual prominence formations is the *tornado*. Solar astronomer Charles A. Young in 1910 referred to this prom as a "cyclone or whirling waterspout capped with a great cloud." The form is difficult to distinguish because a tornado is ordinary quite small, and its rotating nature is not immediately evident to the casual observer. Since some column-like prominence types do not rotate (i.e. pillar), spiral or helical motion of the prominence must be observed for it to be classified a

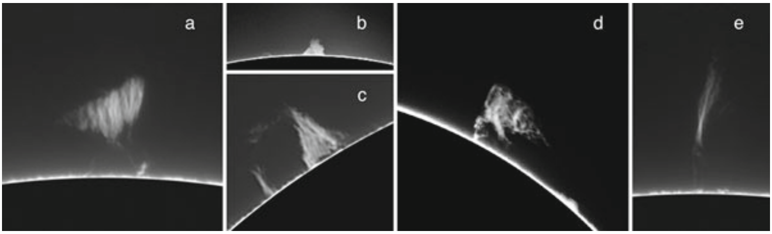

Fig. 2.38 A few unusual and not so unusual prominences. In figure (**a**) notice the *kite shape* and the apparent streaming of material from the corona. Closer inspection reveals two faint streamers extending from the "detached" coronal cloud to the tiny curved pillar feature below. A slightly deformed mound was captured in figure (**b**); often these become activated and erupt. Two formations appear in (**c**), on the *left* is a straight pillar while to the *right* is a pyramid. The pillar if turned 90° could possibly be another pyramid or maybe a mound. An unusual tornado was imaged in (**d**), with rotation spotted between several photos in the stubby "Y" shaped column. The smokestack emitted from the *top* appears "windswept". Figure (**e**) might be an unconfirmed tornado or just an anomaly of a prominence. In the original photograph two faint streamers (as in the kite) appear forming a column that extends vertically from the lower chromosphere to the seemingly detached material above (Figures (**a**) and (**e**) courtesy of Jim Ferreira, (**b**) and "(**d**) courtesy of Jamey Jenkins and (**c**) courtesy of Alexandra Hart)

tornado. The first confirmed tornado was spotted on 29 August 1869 by an observer named, Zollner. Color drawings done about an hour apart clearly indicate the twisting helical motion of this prominence, making it the first cyclone observable on the Sun (Fig. 2.38).

A tornado prominence comes in two varieties. The more common form has a column or pillar with a stream of matter flowing from its peak. Sometimes this stream is bent over and nearly reaches back to the chromosphere. The second form, seen less frequently, has a skeletal-type columnar structure, constructed of single, helically bound streamers with no matter emerging from the top. An increase in a tornado's rotational speed may result in its eventual obliteration, a rupture reminiscent of an Earthly whirling "dust devil". They have been known to even abruptly rise into the corona and fade away (Figs. 2.39 and 2.40).

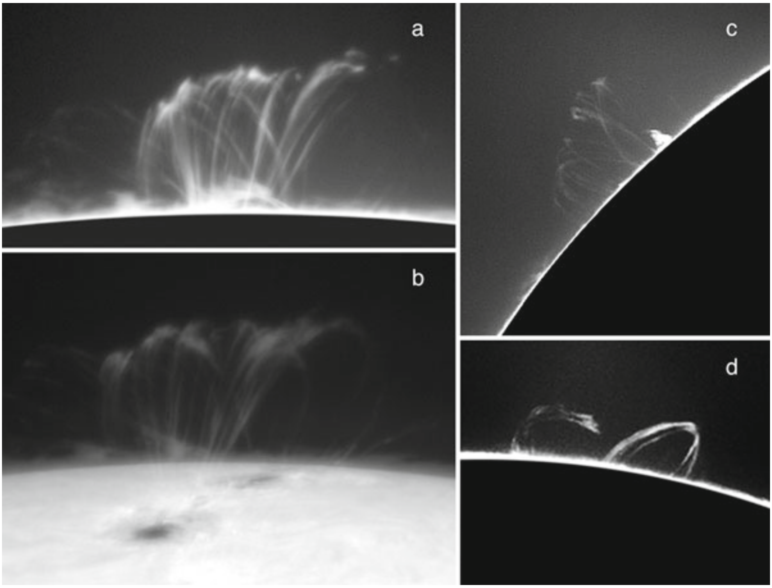

Fig. 2.39 Loops are one of the most spectacular sights in our solar system. The *left* figures (**a**) and (**b**) are of the same event from 22 September 2011. The height above the limb measures 70,000 km as (**b**) shows the numerous loops (arcade) emanating from foot points of opposing magnetic poles of the sunspot group. In (**c**) faint post flare loops and coronal rain appears above the sunspot group rotating around the east limb of the Sun. The streamers of rain are immediately to the *left* of the bright eruption occurring in the chromosphere. Figure (**d**) illustrates a classic loop and an unconnected loop. Notice the variation in brightness within each. The unconnected loop is likely to complete the connection as more material descends to the feet ((**a**) and (**b**) courtesy of Jim Ferreira, (**c**) and (**d**) courtesy of Jamey Jenkins)

Fig. 2.40 (continued) Look specifically for downward movement of the streamers and the bright knot (bomb) about to splash in the lower chromosphere. The event occurred on 31 October 2010, top frame at 1655 UT and the last frame at 1701 UT (Courtesy of Jim Ferreira)

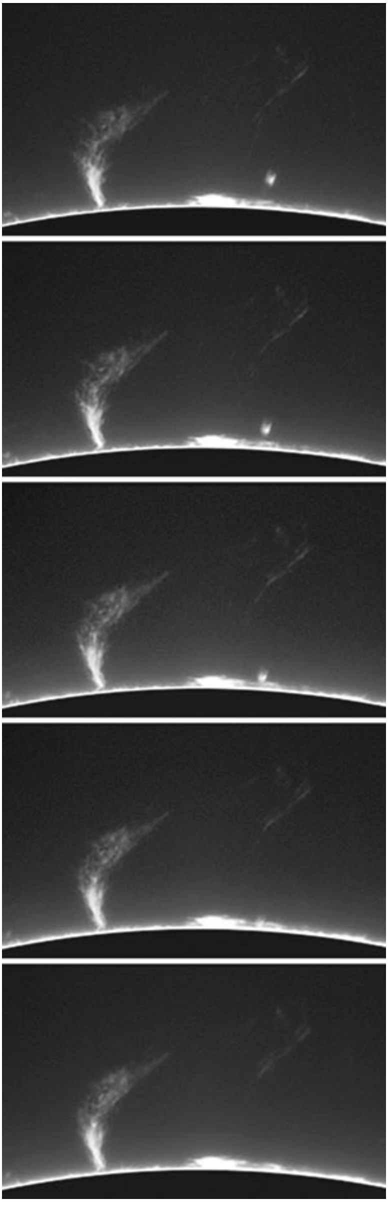

Fig. 2.40 **This is a unique series of images (*top* to *bottom*) looking at the west solar limb by Jim Ferreira. He has photographed coronal rain and what Jim has dubbed a "coronal bomb". The descending material is falling from the *upper right* toward the bright flaring region near the center.**

Ascending Prominences

When a prominence/filament erupts, it does so away from the Sun. An eruption can be a slow fading thing as with a large QRF, or a violent forceful projection having a velocity in excess of 2,000 km/s, as observed during an event called a spray. Regardless of the event, a prominence/filament as it ascends occasionally disperses material outside the gravitation influence of the Sun; even then an unpredictable amount every so often descends back to the chromosphere.

A filament may display several markers of an impending eruption. For instance, a QRF or ARF may exhibit an unstable motion, a cascade of material flowing through the filament or both. Moreover it would not be unusual to perceive an increase in brightness below an erupting filament. When a stable prominence reaches a height greater than 50,000 km, this is a sure sign of it becoming *activated* or triggered, and later erupting. Other visible signs of a possible eruption include an increase in the size of the filament or a change in intensity; that is a filament on the disc becoming darker and if observed on the limb substantially brighter. The activation process may last for an hour or so and in some cases activation unexpectedly dissipates as the prominence returns to a normal state.

An active region filament generally erupts swiftly, while a quiet region filament more often than not erupts slowly. The difference is found in the strength of the surrounding magnetic fields. Magnetic fields present about an ARF are much stronger than those found in the quiet Sun.

What is the root cause of an eruption? Outside disturbances intruding upon a prominence cause its eruption. The active region filament is often disturbed by the huge amounts of thermal and particle energies released during a solar flare or other magnetic disruption.

Activation follows when processes presented in a variety of differing scientific models, release large amounts of magnetic energy. One possible explanation says simply that as new magnetic flux emerges near older magnetic flux, a reconnection or realignment of the magnetic fields occurs. During this realignment process energy may be released. How the magnetic energy is converted to kinetic energy (explosive gas pressure) is unknown, and remains one of the mysteries of solar physics to be solved.

Quiet region filaments sometimes erupt for no apparent reason, but one known cause of activation is the passing of a shockwave called the Moreton wave. Initiated by a massive solar flare the Moreton wave will as it passes, lift a filament so that it oscillates several times precipitating activation while it causes the filament to become Doppler shifted in and out of visibility. A filament in this situation is termed a *winking filament*.

Disparition Brusque

A French expression used in filament studies, *disparition brusque* (DB) means literally to lift off or the "rapid disappearance" of a filament. Mature quiescent proms become activated, perhaps by a Moreton wave or a nearby emerging flux region and begin a slow rise of several hundred kilometers/second into the corona. The rise of the disparition brusque normally lasts less than a few hours. Sometimes the cause of the activation is unknown (see section "Hyder Flare"). The filament may simply fade away, or gradually break up and disappear as it rises higher and higher.

In certain cases involving large filaments, a DB precipitates the expulsion of several billion tons of matter from the Sun. This coronal mass ejection or CME may result in the ejected particles being swept to our vicinity in space by the solar wind, prompting electrical havoc and initiating beautiful auroras on our planet.

Surge

A surge is a controlled or collimated, relatively continuous expulsion of material, blown away by an underlying low-level compact, or simple-loop solar flare. It is a post-flare event possibly compelled by pressure or gravitational effects. A surge is collimated because it is bound by the magnetic field of the AR's primary sunspot. A surge will often burst outward at any angle from vertical to nearly horizontal attaining a possible elevation of several hundred thousand kilometers, lose inertia, and perchance fall back onto itself with a great splashing effect. The velocity of a typical surge is less than 200 km/s, less than the escape velocity of the Sun, which at the photosphere is about 600 km/s. A period of activity lasting perhaps 10–20 min is expected for small surges, and about 60 min for the largest examples. The event may reappear hourly in about the same location.

A surge viewed on the disc of the Sun is, by and large, moving in the direction of the Earth and unless especially energetic will appear dark (absorption), growing elongated (comet-like appearance) from the direction of the flare, and Doppler shifted toward the blue wing of the H-alpha line. The Doppler Effect results from the compressing or stretching of light waves because the object is rapidly moving toward or away from the observer. To the observer of a Doppler shifted eruption, the surge will begin to fade, gradually becoming transparent until it has disappeared completely. By tuning the center wavelength of an H-alpha filter toward the blue wing, the filament will reappear unless it has been completely obliterated.

When detectable at the Sun's limb, a surge appears as a bright jet or spike in emission, which grows swiftly, and then either falls back into the chromosphere along established magnetic field lines, or breaks apart and disappears completely.

The *puff*, also called a *smokestack*, is a smaller variant of the classic surge, with an appearance suggestive of its name. Visible as a blue shifted feature with a lifetime of several minutes, they are seen in an active region as well as in an emerging flux region. A puff/smokestack appears as an individual knot of material ejected at surge velocity disappearing completely, or like the surge falling back along the lines of its confining magnetic field (Fig. 2.41).

Spray

While a surge is a continuous burst of collimated material, the spray is a single ejection of filament material in an uncontrolled pattern, with matter going in various directions. Again the volatile nature of a solar flare is the progenitor, but in this case the flare is much larger. The velocity of many sprays exceeds 200 km/s and have been known to go beyond 2,000 km/s, easily attaining the Sun's gravitational escape velocity.

Two categories of spray are recognized: the *flare spray*, resulting in the throwing out of plasma due to the violent effect of a solar flare, and the *prominence spray* which is the eruption of an overlying filament above the neutral line.

The flare spray is visually impressive with matter scattering over a large area of the Sun. A prominence spray may begin with the lofting of a

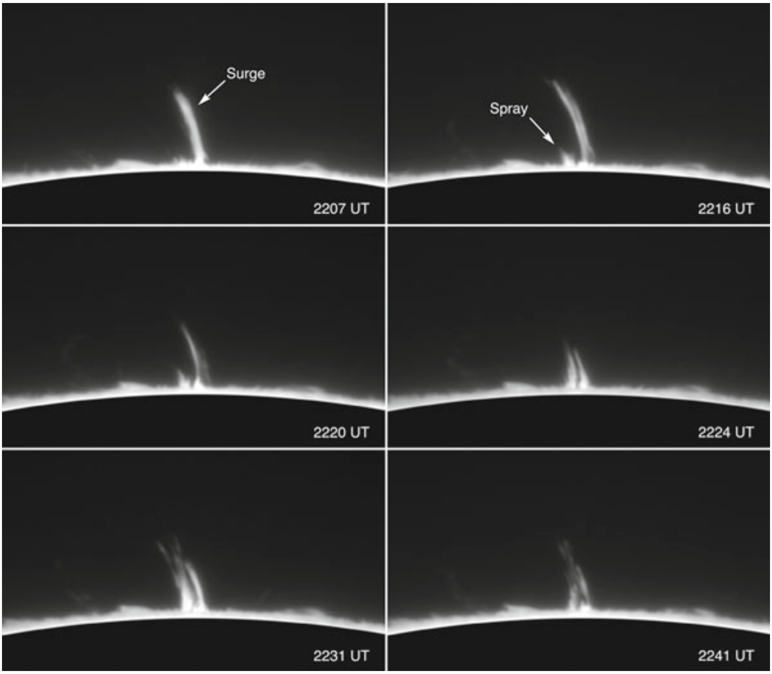

Fig. 2.41 Two events are happening in this series of images obtained 6 August 2011. At 2207 UT the *tall pillar* (surge) has erupted, successive images capture the ejected matter falling back along the lines of magnetic force near their place of origin. At 2216 UT a spray has erupted to the *left* of the surge, expelling matter in several directions (Courtesy of Jim Ferreira)

small filament, which appears to sustain an incredible amount of outward pressure until it bursts, spraying material also over a great deal of the Sun. The prominence spray is seen as the less vigorous of the two events (Fig. 2.42).

Limb Flare

Observers are advised to watch for bright knots or mound-like shapes that may appear suddenly at the limb. These blobs could be the result of a flare happening as an active region is either passing over the west limb or newly

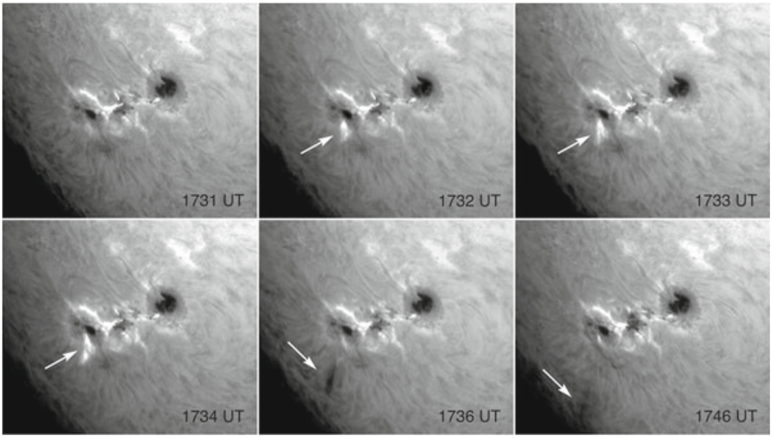

Fig. 2.42 Spray on the solar disc. On 24 September 2011 within AR1302, Jim Ferreira imaged a flare and spray prominence. In the first image at 1731 UT the prominence is not evident, however 1 min later at 1732 UT the eruption is visible as an emission event (material is bright), by 1736 UT the ejected material has become less energetic, and appears as a dark absorption feature. It is speculated that the particularly powerful ribbon flare (*upper right* to spray) is the precipitator to the event (Courtesy of Jim Ferreira)

coming around the east limb. Either situation is ideal for observing post flare loop development or viewing the ejection of material as a puff, surge or spray. Differentiating between a limb prom and a limb flare is accomplished by observing any movement of the feature. A prominence will change position and appearance while a flare will likely just change intensity (Fig. 2.43).

Coronal Mass Ejection

The *coronal mass ejection*, abbreviated CME, is a huge bubble of coronal gas flowing out of the Sun, and propagating as a shock wave in the solar wind. Reaching the Earth in several days, a CME is responsible for geomagnetic storms and their consequences, such as aurora displays and communication disturbances. The content of a CME bubble is plasma (a soupy mix

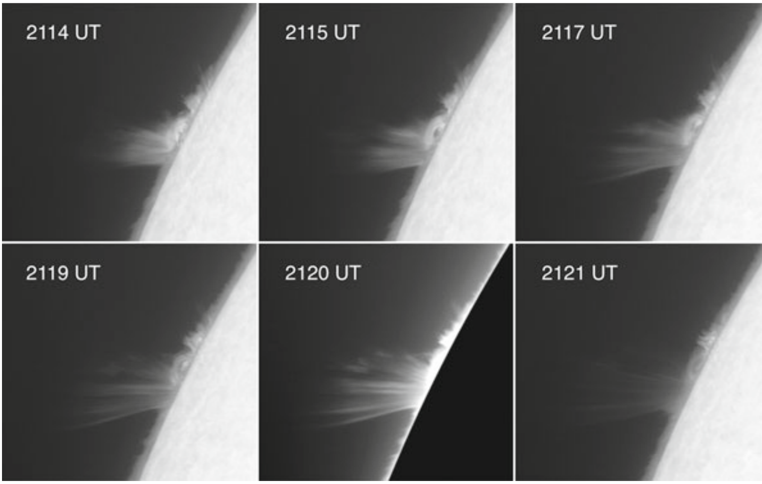

Fig. 2.43 Limb flare and a 48,000 km high surge prominence appear on the Sun's east limb on 17 August 2012. The image from 2120 UT is masked to remove the overexposed disc permitting greater detail of the prom to be visible (Courtesy of Jim Ferreira)

of electrons and protons), but sometimes it may incorporate lesser quantities of other elements, including helium or iron. Events follow the 11-year solar cycle in frequency with an average of more than three bursts a day at solar maximum, and at solar minimum barely more than one per week.

There are three constant attributes of an ordinary CME: a luminous leading edge, followed by a less dense cavity region that embodies the third attribute, a radiant core. It is believed that the core is composed of the material from an erupting prominence (see disparition brusque).

Discounting those unknowingly glimpsed at some total eclipses, the earliest optically perceivable CME occurred on 14 December 1971. Scientists using the OSO-7 (Orbiting Solar Observatory) of the Naval Research Laboratory employed a spaceborne coronagraph to witness the event. Making use of an external occulting disc, a coronagraph blocks light from the Sun creating an artificial eclipse. It is the "eclipse" which allows viewing the feeble light of the Sun's corona.

The eruption at the southeast solar limb from the 1971 event obtained a velocity in excess of 1,000 km/s and was labeled at the time, a coronal transient. *Coronal transients* are any short-lived changes in the structure of the corona. Characteristic expulsions average 400 km/s, and carry off nearly 10 billion tons of solar matter. Further results from the 1970s OSO-7 and Skylab missions confirmed that all prominences that attain an altitude of nearly one-third the solar radius culminate with a CME.

Often a spectacular coronal mass ejection erupts at the solar limb. However, an interesting effect, given the name *halo*, is produced if the CME is directed toward Earth. Through the coronagraph the CME is seen to expand in a radial manner about the solar disc forming a halo or donut shape. When this happens a magnetic storm is a certainty within a day or two. The first visual confirmation of a halo was on 27 November 1979.

Active regions are modeled as one source for the majority of CME phenomenon; the Sun's quiet regions while still a place of origin are less so. Magnetic reconnection is ascribed to both the CME, and solar flare activity. The magnetic fields located in some active regions are intense enough to trap plasma within the arcades (see post flare loops). When reconnection at a lower level within the arcades takes place, a sudden release of energy comes about. The helix of magnetic field left behind from the older connection and the trapped plasma rapidly expands generating an expulsion that possibly hastens a CME.

Representative observations by amateur solar observers are similar to the illustration presented by Steve Rismiller during a ½ h session on 5 March 2000 of an erupting prominence and resultant CME. By 1624 UT the leading edge, cavity, and radiant core are observable well off the solar limb (Fig. 2.44).

Menzel-Evans-Jones Classification System

There is no system of classification that can fully describe all the possible forms a prominence can assume. Regardless, a number of attempts have been made focusing on various attributes of prominences from spectral characteristics to whether they are stable or unstable. The first such system

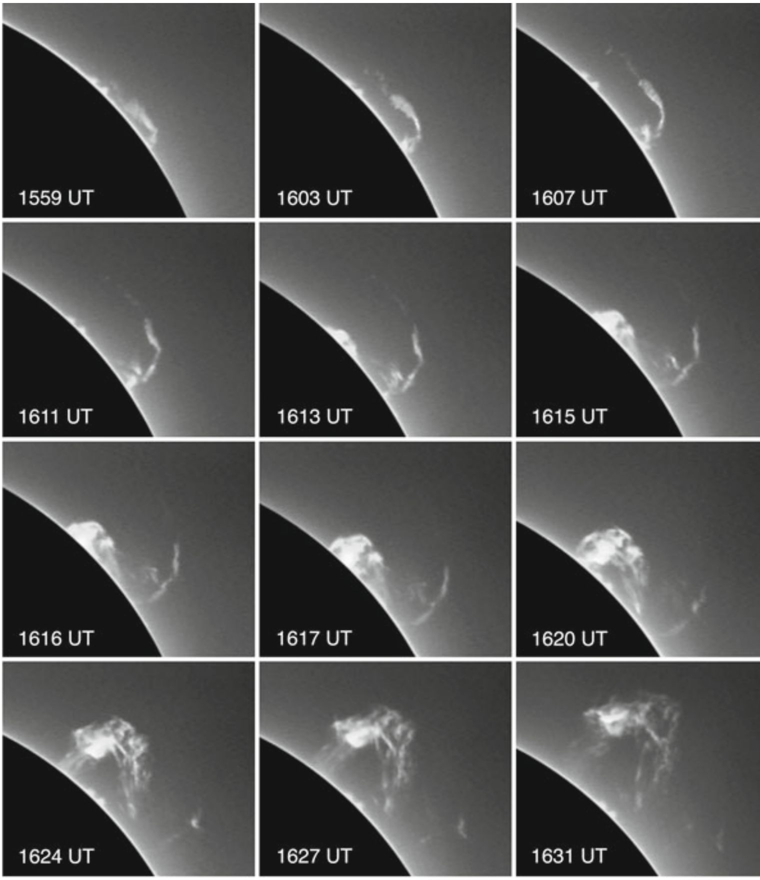

Fig. 2.44 An erupting prominence and coronal mass ejection were caught on 5 March 2000 by veteran solar observer Steve Rismiller (Courtesy of Steve Rismiller)

was devised by Fr. Secchi in the latter 1800s dividing proms into quiescent and eruptive types.

D. Menzel, J. Evans, and F. Jones in the mid-twentieth century introduced a system that separates prominences according to whether they originate in the chromosphere or the corona, and if they are attendant to sunspots.

A simple yet efficient way of cataloging commonplace prominences, the amateur astronomer wishing to maintain metrics on prominence activity is encouraged to consider this plan.

The methodology is similar to, yet pre-dates the McIntosh sunspot classification format in the use of a three-letter designation. In the Menzel/ Evans/Jones grading system, the first letter represents the place of origin of the prominence, that is whether descending from the corona (A) or ascending from the chromosphere (B). Since descending or ascending may not be immediately evident, an extended observing period will be required to determine in which direction matter is flowing. Look for knots or blobs, movement of streamers or threads. Motion in a few instances will be obvious, such as with the surge or coronal rain; infrequently horizontal movements do occur, an example being between two quiescent "tree" formations. This movement of matter from one prom to another is called *interaction*, and in the Menzel-Evans-Jones system both proms would be classified as a single hedgerow.

The majority, about 90 % of prominences will be of type A with a downward flow of material. These will have their shape maintained by local magnetic fields. Class B prominences originate in the chromosphere and rise into the corona, often unexpectedly. A prominence can change classes should it become activated.

The second letter of the classification system tells us if the prominence is related to a sunspot or not. Classes AS and BS is an active prom, whereas the AN and BN are quiescent. It may be necessary to make repeat observations for the purpose of ascertaining whether a prom is associated with a sunspot emerging around the east limb of the Sun. Equally for classification reasons, it is important to be familiar with spots disappearing around the west limb.

The final digit in the Menzel/Evans/Jones system denotes the form assumed by the prominence being classified. Rain (ASa) in this system references that which occurs in conjunction to post flare loops (ASl). Menzel's coronal rain (ANa) is defined as that in which streamers originate high in the corona, and persist for several days. Funnel shaped proms; including tornadoes would be class ASf. Types AN with sub letters b, c, and m are filamentary quiescent variations. Those resembling trees (ANc), tree

Table 2.3 Menzel/Evans/Jones prominence classification system

A-Descending coronal prominence	
S-Spot prominence	N-Nonspot prominence
(a) Rain (flare loop associated)	(a) Coronal rain
(f) Funnel	(b) Tree trunk
(l) Loop	(c) Tree
	(d) Hedgerow
	(f) Suspended cloud
	(m) Mound
B-Ascending chromospheric prominence	
S-Spot prominence	N-Nonspot prominence
(s) Surge	(s) Spicule
(p) Puff	

trunks (ANb), and mounds (ANm), may actually be hedgerows (ANd) positioned at an angle parallel to the line of sight. Suspended or detached clouds (ANf) often appear to be completely disconnected, and floating freeing in the corona. There possibly may be connecting streamers, but they are difficult to discern (see Fig. 2.38a).

The surge (BSs) class is inclusive of the spray; this system was not designed to distinguish between the two. A puff (BSp) is an individual knot of incandescence, which erupts at surge velocities. The puff then fades or falls back to the solar surface along the same path of ejection. Spicules are prominence like features, which at times reach heights near 10,000 km. In the Menzel/Evans/Jones system *peculiar* spicules are classed as BNs (Table 2.3 and Fig. 2.45).

Solar Flares

A flare is the extreme, sudden release of stored up energy found most often in the magnetic field of an active region. The violent release of energy happens as reconnection occurs between established magnetic field lines and emerging regions of lower energy flux. Reconnection, also known as realignment, generates massive electrical flows that in turn produce severe thermals. As the surrounding plasma is heated to millions of

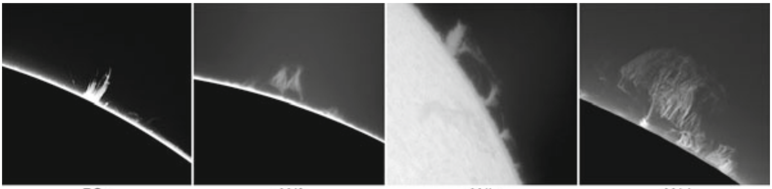

Fig. 2.45 Examples of the Menzel/Evans/Jones prominence classification system. From *left* to *right* is a spray (surge) classed as BSs, second is a suspended cloud, ANf, third is several tree trunks, ANb, and fourth is an activated hedgerow, ANd (Spray image courtesy of Jamey Jenkins, ANf and ANb courtesy of Alexandra Hart, and hedgerow image courtesy of Fabio Acquarone)

Kelvin, the charged particles (electrons, protons, and other heavy ions) as well as the residual magnetic field left over from the preceding connections are powerfully accelerated away from the Sun. A flare has the firepower of packing into a small area on the solar disc (0.01 % of the total) an equivalent of many millions of 100-megaton nuclear bombs. Often times a large-scale flare triggers a coronal mass ejection.

The bulk of flare energy is released at wavelengths beyond those in the visible spectrum. Hard X-rays, EUV (extreme ultraviolet) and microwaves are predominant. A flare visible in H-alpha will show itself as an unexpected brightening of about twice the intensity of the surrounding chromosphere.

Solar flares are not limited to H-alpha viewing. Flares can be seen in the light of calcium and although rare, when spectacularly intense in the solar continuum. Richard Carrington and Richard Hodgson made the first sighting of a flare in 1859, on a projection screen intended for sunspot observing. With the invention of the spectroheliograph some years later, monochromatic observing was made possible, and the nature of flare activity was at last revealed (Fig. 2.46).

Flare Morphology

Visually the typical flare begins as a rapid brightening of several points or *kernels* having a diameter less than 1 arc sec. These are located in most

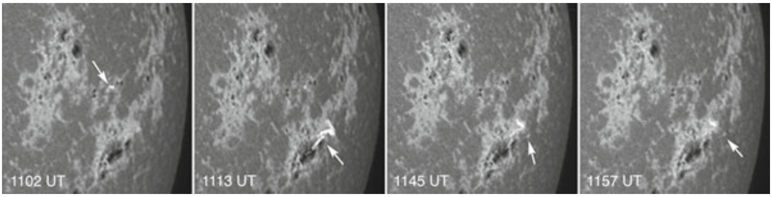

Fig. 2.46 Flare in Ca-K. Here is an illustration from 15 September 2001 of the visibility of a flare in the light of calcium. In the first image note the small subflare (*arrowed*) that is fading. Eleven minutes later in the second frame the larger compact (possibly a single ribbon flare) has attained maximum intensity. By 1145 UT the compact flare has ejected a faint filament (*arrowed*), and at 1157 UT the filament has moved farther toward the Sun's limb as the larger flare continues to fade (Courtesy of Christian Viladrich)

instances inside or near a sunspot. The kernels will grow in size and brightness; for a large flare it may take only several minutes, smaller flares possibly even less. This is then succeeded by a period of rapid brightening and growth, culminating with a peak output followed by a gradual slow retreat in intensity and then decay. There are four recognized stages of flare evolution:

- **Pre-flare/Precursor Phase:** Visible in faint X-rays, where a slow heating of the coronal plasma in the flare region occurs. This phase comprises the activation process for the release of magnetic energy. During a large event the Pre-flare phase lasts roughly 10 min. In H-alpha it makes its presence known by unusual movements of the neutral line filament, and the appearance of new emerging flux.

- **Impulsive Phase:** The rapid release of energy and particle acceleration takes place; notably there will be an increase in hard X-rays, EUV and microwave radiation. The impulsive phase of a large event lasts about a minute. Sometimes there is no impulsive phase or relatively little particle acceleration, this situation gives rise to what is known as a *thermal flare*, and exhibits a gradual rise to peak output followed by an equally slow decline.

- **Flash Phase:** In H-alpha light, the period of rapid brightening to maximum intensity, often several times the brightness of the nearby

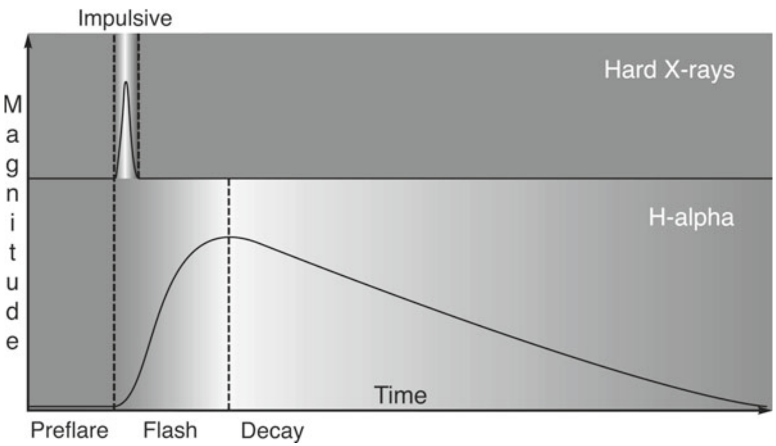

Fig. 2.47 Typical phases of flare intensity in hard X-rays and H-alpha light with magnitude (intensity) vertically graphed against horizontal time. The hard X-rays are expended during the impulsive phase, which occurs during the early moments of the flash phase

chromosphere. Depending on the type of flare event (i.e. subflare, thermal, etc.), this phase may last from several minutes to several hours.

- **Main/Decay Phase:** The gradual decline of H-alpha intensity and a return to the normal state (Fig. 2.47).

For the perceptive Sun-watcher there are specific signs to note that a solar flare could soon be materializing. One preliminary indicator is the classification of a sunspot group. For instance, a mature group of either McIntosh classification D, E, or F is particularly notorious for flare production. Also, keep an attentive eye toward a sunspot for unusual motion, or the emergence of new magnetic flux in a group. The unexpected motions indicate a twisting and distorting of the neutral line within a complex sunspot group, often producing flare output. Other well-known certainties regarding solar flare prediction include:

– The majority of large flares appear 2 years after sunspot maximum.

– Most flares happen as a group develops rather than when a group decays.

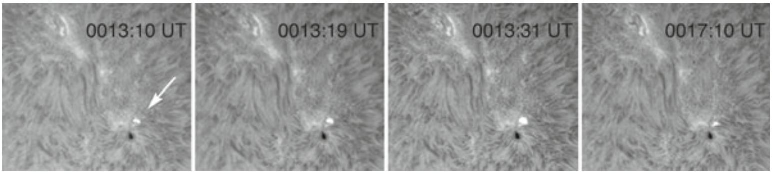

Fig. 2.48 Pictured is a compact subflare in H-alpha from 17 September 2010 near the edge of the penumbra of a small sunspot. The outburst in this case took less than 40 s to reach maximum intensity. Total time transpired to return to original brightness, 240 s (Courtesy of Jim Ferreira)

- Flare production is largely near the same position in a sunspot group.
- Flare activity happens near an active region's neutral line.
- Small flares develop as bright points near a spot on either side of a neutral line.
- Simple groups of bipolar and unipolar classes rarely produce any flares.
- Energetic flares create parallel ribbons on both sides of the neutral line.
- Small flares and a brightening of nearby plage often precede a large flare.

Morphologically, most solar flares fall into two different categories, *compact* and *major*. Compact flares by shear number make up the majority of all solar flare events. They are as their name suggests, closely packed yet intense, some variations being so diminutive they are called *subflares* possessing an area equal to or less than 2.0 heliographic square degrees. Compact flares develop from the brightening of one or more stable loops within an active region. These flares are many times visible in H-alpha at the foot points of an existing loop and occasionally create a surge prominence. Larger compact flares may associate themselves with the complete loop system of an active region. It is not strange for a compact flare to develop near a modest sunspot or a mature unipolar group (Fig. 2.48).

A major flare is a truly large event that always involves the development of two or more ribbons of H-alpha emission. The double ribbon flare, unlike the less intense compact flare, is more climactic, sometimes being linked to the disparition brusque of an overlying ARF.

Complex active regions produce the most violent major flares because of the strong magnetic field present about their sunspots. A major flare can develop near the residue of an old active region harboring a QRF. However, unlike those found in a developing active region, this flare experiences a gradual period of the flash and main phase. This is because quiet solar regions have less powerful magnetic fields than the typical active region.

The development in H-alpha light of a typical double ribbon flare generally follows this order of events:

- At the preflare phase, a region of new flux may emerge near an existing active region filament, which is positioned above the neutral line of an active region. This filament may darken somewhat and demonstrate unusual movements while it begins a leisurely accent. An increase in brightness of the surrounding plage also may be visible.

- As the impulse phase enters, brilliant knots of emission perhaps will be seen near the emerging flux region as well as near the ends of the neutral line filament.

- A rapid progression into the flash phase occurs as the double ribbon develops; one ribbon will grow on each side of the neutral line. The ribbons represent the foot points of the loop arcade that cross the neutral line. The neutral line filament may rapidly erupt as a flare spray, or possibly assume the form of a twisted looping prominence. The peak brightness of the flare is attained.

- During the main phase, the double ribbons move away from the neutral line, normally at 2–20 km/s. As the ribbons separate, the space between them is filled with rising post flare loops that connect the opposite sides of polarity of the neutral line. The loops on the disc may appear dark or bright; on the limb they appear bright. Decay continues as the flare decreases in intensity. When the flare subsides, field transition arches develop across the neutral line, an indication the magnetic fields have returned to a normal state.

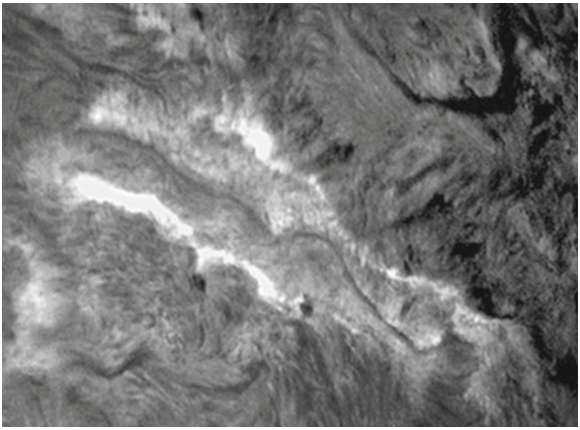

Fig. 2.49 Pictured is a classic example of a double ribbon flare near AR 9085, from 22 July 2000. The view is in the centerline of H-alpha with a 0.56-Å filter. Features to note include the thin winding filament above the neutral line, the pale channel under the filament, and the brilliant ribbons developing on either side of the neutral line. As the main phase develops, these ribbons will separate, one toward the *lower left*, the other toward the *upper right*. Post flare loops will refine across the region occupied by the blown away filament (Courtesy of Gordon Garcia)

Not all major flares necessarily follow this sequence of events to the letter; there may be instances where coronal rain is observed, or the neutral line filament could be absent, or not erupt at all. As with prominences there is a level of uncertainty with solar flares in what may be seen at the telescope at each observing session, hence the allure of observing the Sun (Fig. 2.49).

Hyder Flare

A flare that occurs some distance from an active region, in the quiet Sun, and has a relationship to the sudden disappearance (disparition brusque) of a filament is known as a *Hyder flare*. Charles Hyder, the namesake, was not the discoverer of this type of flare, but rather was the first to make an attempt in explaining how and why it develops.

Visually, the flare shape can assume a series of twisted blobs on one or both sides of a quiet region filament channel, or possibly appear as a one or two ribbon flare. Unlike the active region flare, which is far more impulsive, this event takes an extended time period to evolve. There is little if any particle emission during a Hyder event. The flash phase lasts much longer than an active region flare, up to perhaps an hour, while the main/decay phase can extend to a number of hours. Intensity is less than an active region flare, and is normally spread over a larger area. The overlying filament may simply fade away, or gradually break up and disappear as it rises higher and higher.

Reconnection is believed to be the precipitating cause for a Hyder flare. However, while a number of models exist to explain flare production, the reality is that solar astronomers still do not fully understand how and why they occur.

Moreton Wave

The solar flare causes a number of external events. A brief listing would include: post flare loops, surge and spray prominences, coronal mass ejections, aurora, communication disruptions, and so on. One unique, but very difficult to discern flare related phenomenon is the *Moreton wave*.

A Moreton wave is defined as a shock wave visible in the chromosphere radiating from a large (intense) solar flare. Solar astronomer Gail Moreton discovered these waves in 1959 while working at the Lockheed Solar Observatory. The shock is initiated during the impulsive phase of a major flare and appears as a single arc-shaped form emerging from the active region. A wave is bright in the H-alpha core and dark in the wings. The typical Moreton wave is known to transverse the solar disc at nearly 500–1,500 km/s while traveling 50,000–100,000 km from its source. Disruption of the wave usually occurs if a magnetic barrier is encountered, such as another active region.

Moreton waves are difficult to observe visually because the feature is diffuse and of low contrast. Time-lapse video clips seem to be the best means for identification. By speeding up the progression of the event and its effect on surroundings, the moving arc of a Moreton wave becomes apparent. Occasionally a wave may encounter a filament which in turn reacts like a person on Earth encountering an incoming ocean wave, that is to first be lifted up, and then to be deposited back on the ocean floor. The filament in this case will appear to blink in and out of visibility, the consequence of the rapid up and down motion caused by the passing wave. This development is known as a *winking filament*. Motion of the type described may cause an activation and later eruption of the filament.

Classification of Solar Flares

Solar flares are classified by either H-alpha observations or according to their peak flux in X-rays. For the solar observer intent on classifying any observed flare, the H-alpha method is the only means at his disposal, because it is based on criteria the amateur can measure.

The optical classification of a solar flare is derived from the heliographic area of the flare at maximum brightness in H-alpha. Also known as the "Importance Classification", it is a two-digit system, the first number representing the estimated area of the flare in millionths of the hemisphere, or in square degrees. A millionth of a solar hemisphere is 0.02 square degrees. Area is assigned a rating of 1–4, four representing the larger. Some variations of the scale include the letter "S" to designate subflares.

Square degrees on the Sun are found by measuring the extent of a feature's heliographic latitude and longitude, then multiplying the two figures to obtain the area. Measurements are normally estimations; therefore a calibrated filar micrometer or graduated reticule is ideal for visual determinations of length and width.

The second digit is a measure of the flare's brightness. The brightness of the flare is assigned f, n, or b (faint, normal, or bright). As an example, a solar flare may be classified in this system as: "Importance 2n", meaning it has an area between 250 and 600 millionths of the solar hemisphere and is of normal brightness.

Table 2.4 H-alpha classifications of solar flares

Importance	Millionths of hemisphere	Square degrees of hemisphere
S	<100	≤2.0
1	100–250	2.1–5.1
2	250–600	5.2–12.4
3	600–1,200	12.5–24.7
4	>1,200	≥24.8
Subcode for brightness	–	–
f	Faint	–
n	Normal	–
b	Bright	–

Flare classification using this system can be a bit subjective, particularly as a region nears the solar limb, where foreshortening of the feature makes estimation of area all the more difficult. Even if a flare is near the solar meridian a "gray region" exists among the terms faint, normal, or bright and their interpretation by the observer (Table 2.4).

The second and most often referenced classification scheme is a measure according to the peak flux occurring in soft X-rays (1.0–8.0 Å) performed by the Geostationary Operational Environmental Satellites (GOES). This system provides a practical measure of an event's geophysical importance, unlike the H-alpha system. The GOES system measures the relative X-ray brightness of a flare in comparison to the X-ray brightness of the remainder of the Sun. This classification is divided into a letter system of A, B, C, M, or X, each of which is again divided into nine numerical sub-categories from 1 to 9. Each letter represents a tenfold power increase. For example, an M1 class flare has ten times the power of a C1 class flare and 100 times the power of a B1 class flare.

The A-class flare is miniscule having an X-ray output near background levels. A bit stronger, but still quite weak is the B-class flare. A small flare that still has little to no effect on the Earth is the C-class. Causing radio blackouts and geomagnetic storms of minor consequence is the M-class flare. The M-class is a medium sized event.

The major flares are of classification X, providing the greatest output of emission. An X-class flare can result in a dramatic coronal mass ejection, a disruption in communication, and spectacular displays of aurora.

Table 2.5 X-ray classifications of solar flares

Classification	Peak flux in soft X-rays (1.0–8.0 Å in watts/m^2)
A (1–9)	$<10^{-7}$
B (1–9)	$<10^{-6}$
C (1–9)	$<10^{-5}$
M (1–9)	$<10^{-4}$
X (1–9)	$>10^{-4}$

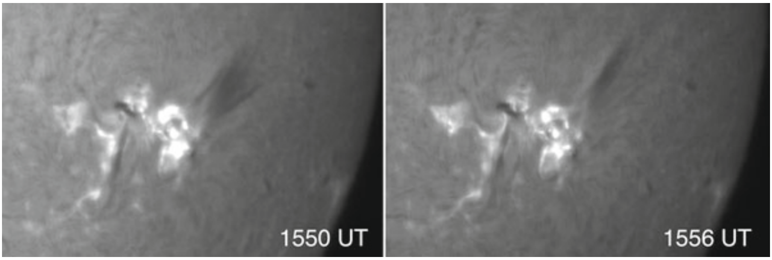

Fig. 2.50 An M3 class flare event from 25 September 2011 in AR1302. Notice the spray prominence (Courtesy of Alexandra Hart)

Whereas the divisions preceding the X class (A, B, C, and M) have nine subclasses of output, the X-class is open-ended. Flares have occurred that exceed X9, including one in 2003 that was beyond X28, the point of saturation for the GOES X-ray sensors (Table 2.5 and Fig. 2.50).

Forecasts for daily solar flare activity and flare classification reports can be found on several Internet websites. One with particularly useful information regarding several areas of geomagnetic activity pertaining to the solar observer is at spaceweather.com. The NOAA, Space Weather Prediction Center at swpc.noaa.gov/index, produces another site with highly detailed information and forecasts.

Corona

Extending further out from the chromosphere and above the transition zone, the gas becomes particularly tenuous. Here is found the pearly white "atmosphere" of the Sun called the *corona*, which means "crown". From the transition zone outward the surrounding temperature begins a conspicuous increase. Within the corona, to a distance of several million kilometers, temperatures exceed 500,000 K and at times reach numbers greater than 2,000,000 K.

The brightest region of the corona compared to the photosphere is nearly one million times fainter, and can best be seen with the aid of a device called a coronagraph, which in principle creates an artificial eclipse of the Sun. Such a device requires special conditions in order to function properly; conditions that reduce scattered light from dust, atmospheric refraction, and water vapor in the atmosphere. While views by the Earth-bound astronomer are limited, superior observations can be made with spacecraft that get above the atmosphere, supporting the coronagraph's revealing qualities.

Since the coronagraph is beyond the capabilities of the typical amateur astronomer, his observation opportunities are restricted to the several minutes of totality that occur during a total eclipse of the Sun. We are fortunate that at times the moon blocks the blinding light of the photosphere, while reducing the light scatter of the atmosphere by the lunar shadow passing from the moon to the ground. If circumstances were different, discovery of the corona would have waited many additional years (Fig. 2.51).

The corona contains various interesting structures, several of which can be seen during totality. The *streamer* is visible in the corona as a bright, thin structure emitted in a radiating fashion all about the Sun. It contains fine rope-like, looping elements reminiscent of the threads in a quiescent prominence. A streamer for the most part makes up the shape of the corona. The *helmet streamer* develops above an active region as a bright looping formation that evolves with a long pointed peak. A magnetic feature, the helmet streamer connects regions of opposing polarity and traps the coronal gas that makes up its form. The more noticeable characteristic, the pointed peak, is created as the solar wind passes between individual streamers. Occasionally a knot of coronal gas breaks away from the tip of a helmet streamer, becoming part of the solar wind. If the gas knot is sufficiently large the result is a coronal mass ejection.

The *polar plume* is also a streamer, but with a much lesser height than other streamers. Located near the north and south poles these figures are

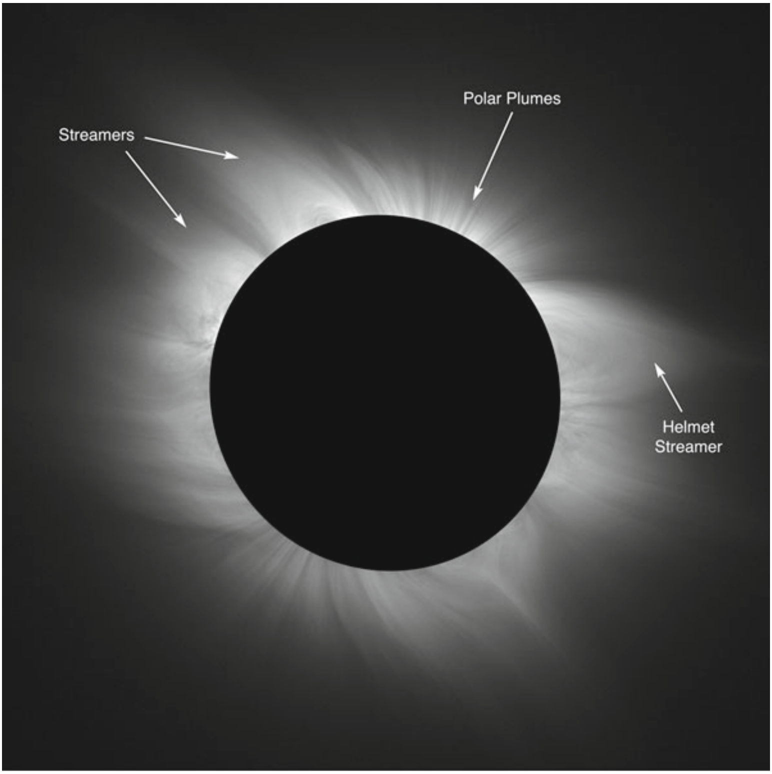

Fig. 2.51 The solar corona visible at the eclipse of 29 March 2006. This image was obtained with a 106 mm refractor through an Astrodon I-series green filter (Courtesy of Christian Viladrich)

associated with a smaller magnetic region on the Sun. Unlike the closed loops of the helmet streamer these structures result from open magnetic field lines. The plume shape is again formed by the activity of the solar wind.

The overall shape of the corona varies with the strength of the sunspot cycle. During sunspot maximum the corona is seen more fully, and is extended about the solar disc, including the high polar latitudes. The streamers seem to point in all directions. At sunspot minimum the corona becomes largely restricted to the sunspot zones, appearing chiefly near the equatorial regions and with fewer streamers (Fig. 2.52).

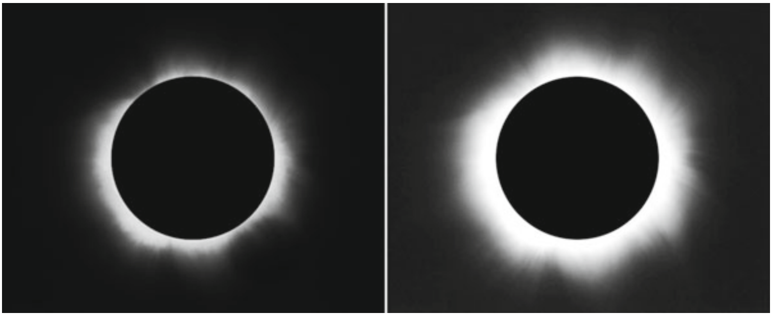

Fig. 2.52 Artist depiction of the corona at solar minimum (*left*) and solar maximum (*right*). During maximum the corona appears uniformly distributed about the equatorial and polar regions, minimum finds the corona less active in the sunspot zones and rather inhibited in the polar regions (Courtesy of Jamey Jenkins)

Solar Eclipse

A solar eclipse, or more technically an occultation, comes in four varieties. The simplest circumstance is the partial eclipse, in which the Moon does not block all of the Sun's photosphere. A partial eclipse happens because the Moon's umbral shadow has either missed the Earth, or the observer is located outside the path of the shadow as it crosses the Earth.

If the alignment of the Sun-Moon-Earth is such that the shadow does intercept Earth, but the Moon's apparent diameter is smaller than the Sun, we have an annular eclipse. An observer located in the path of annularity sees a brilliant ring of light called the annulus, surrounding the disc of the Moon. The annulus is the photosphere and while very interesting, the fringe of light prevents seeing the chromosphere or corona. All phases of any partial or annular eclipse, for safety's sake, must be treated as though one where observing the Sun on any ordinary day. Safe solar filters are absolutely necessary! (Figs. 2.53 and 2.54).

The third variation is the total solar eclipse. Every serious observer of the Sun must make a point of witnessing at least one total solar eclipse. Whereas a partial or annular event may seem blasé, the beauty and awe of

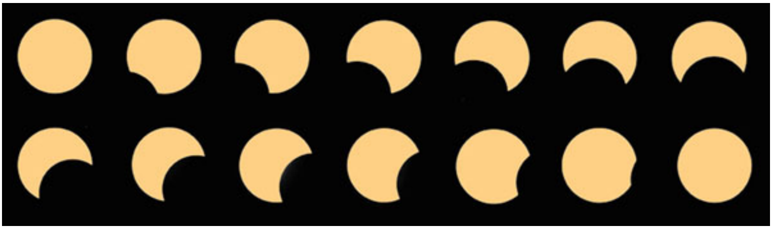

Fig. 2.53 Images of the 25 December 2000 partial eclipse. From the *upper left* to *lower right* all were obtained through a 150 mm f/4 reflecting telescope at 15 min intervals beginning at 1545 UT. In this case the western solar limb is to the *left* (Courtesy of Jamey Jenkins)

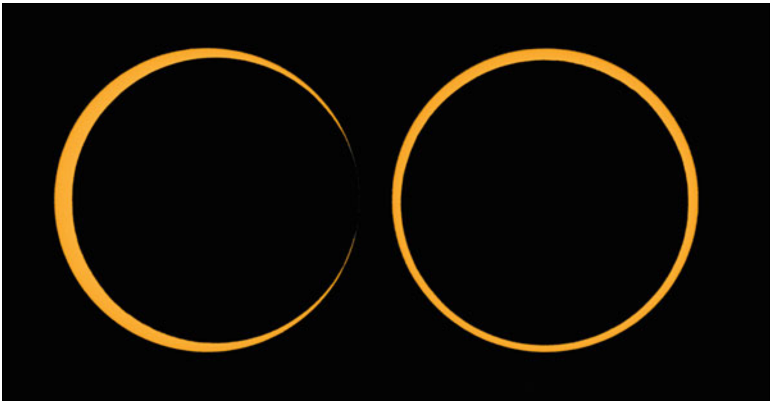

Fig. 2.54 Here is imaged 2nd contact and maximum phase of the annular event of 10 May 1994; solar east on *left*. Kodachrome 25 transparencies attained with a 203 mm aperture f/7 Newtonian telescope (Courtesy of Jamey Jenkins)

totality is inspiring, and a memory never to be forgotten. For the several minutes during totality no special filters or devices are required to see the pinkish chromospheric features or the gleaming silvery corona. A total eclipse of the Sun may afford an amateur astronomer his only firsthand opportunity to observe the corona.

During a total eclipse all the alignments are correct for the Moon to block the photosphere as seen from our vantage spot on Earth. Depending on the circumstances an observer has at most 7 min 31 s to enjoy the spectacle. The typical totality phase lasts on the order of 5 min.

The fourth and most unusual sort of eclipse is the annular/total eclipse, also known as the hybrid, in which the eclipse bounces back and forth between an annular and a total event. The cause of such a mixed up episode is the uneven curvature of our planet. High and low regions of topography affect the Moon's coverage of the Sun contrarily.

Preparations for an Eclipse

Eclipses of the Sun on occasion do happen in the observer's backyard. However, with most events you will find it necessary to travel some distance. The total eclipse pursuer will select an observing site that is located somewhere inside the approximate 100 km wide path of the lunar umbra. Your location could be directly in the mid-region of the path, a position known as the centerline, where the Moon and Sun align flawlessly. Another option to keep in mind is a site within but nearer the edge of the umbral shadow. Such a location often provides long lived spectacular vistas prior to totality, for instance sunlight sparkling through mountain peaks on the lunar limb or extended views of the so-called, shadow bands.

When you travel, sturdy lightweight equipment is called for. High quality imaging can be done with a refractor of less than 100 mm aperture. Purely visual studies can be accomplished with even somewhat smaller telescopes, or lightweight binoculars. Whatever equipment you decide to take, remember that the partial phases can only be seen through safe solar filters. Consider procuring a pair of the special "eclipse glasses" that allow naked-eye observing of the partial phases.

It is vitally important that a study is conducted of the location chosen for viewing the event. This is so as to avoiding unpleasant surprises. What are the chances at that location for cloud cover or precipitation on eclipse day? Is there a convenient spot from which the eclipse can be observed? Will you need and if so have access to a clear horizon? Remember to provide

yourself a timepiece that can be set to Universal Time; knowing the accurate time is important for eclipse activities.

Contemplate joining forces with a group of other eclipse chasers. There are several advantages of doing so, for instance a group can guide you on the best practices of eclipse observing, or guarantee the pinpointing of an ideal observing site. Having an experienced eclipse expert at your beckoning may prevent an unexpected mishap to befall a possible once in a lifetime event. Lastly, it's just more enjoyable to observe with a group of like-minded amateur astronomers.

Clothing should be considered for the weather at hand, but follow the same guidelines as when observing the Sun at home. Sunscreen is recommended, as is a long-sleeved shirt and brimmed hat. If you plan on watching the entire eclipse, pack a cooler with drink, sandwiches, or snacks. You may require a folding chair to take a break in, or bring a blanket to spread on the ground for reclining; the partial phases of an eclipse can last quite a long time.

Observing a Total Eclipse

In addition to the above mentioned arrangements, the well-thought-out eclipse chaser will prepare an activity time-line prior to experiencing the event. Because an eclipse is exciting it's easy to become preoccupied, accidentally letting the time slip away while neglecting some observational facet. By preparing a plan of action for the eclipse, nothing is overlooked.

To formulate such a "spread sheet" it's essential to know the predicted times of the various phases called *contacts* of the eclipse for the specific observing location. This information can be gleaned from a small number of online data sources that specialize in eclipse predictions. One excellent site for predictions is provided by NASA at: eclipse.gsfc.nasa.gov/eclipse.html; each prediction includes a link to various tables, maps of the path of totality, and weather prospects at many possible locations. Several additional sites are available if a web search is performed for solar eclipse forecasts.

A sky map showing the location of prominent celestial bodies surrounding the Sun will be helpful for locating Venus, Mercury and any prominent stars

that can be seen during totality. Rather than taking written notes, a voice recording device will free up your hands and eyes allowing constant eclipse watching.

Following is a step-by-step discourse of the events that happen at a typical total eclipse of the Sun. Use these insights to plan an observing program that delivers the most from the few minutes allowed to see the coronal solar features.

- First contact begins when the Moon is tangent with the Sun's west limb. This is the beginning of the solar eclipse. The succeeding partial phases will last over an hour, and can optically (naked eye or telescope) be observed **only** with proper safe filtration. The partial phases of an eclipse can also be viewed safely by indirect solar projection using a telescope or pinhole device.

- As the partial phases advance, the local air temperature will begin to drop. Secure a digital or mercury thermometer and take readings at regular 5–10 min intervals, prepare a graph later that relates the before, during, and after temperature readings. Note the habits of birds and animals as they experience the decreasing daylight and temperature; the wildlife will assume night is approaching. Are there many thin crescents on the ground beneath leaf-bearing trees? A cluster of leaves sometimes acts as a tiny pinhole camera each opening projecting an image of the Sun.

- Several minutes before totality watch for the fleetingly seen *shadow bands*. These are narrow shadowy streaks that materialize and travel in various directions. See below for more about observing shadow bands.

- From the west you may be able to spot the Moon's shadow as it glides over the terrain in excess of 2,500 km/h.

- Moments before totality two beautiful effects will be visible at the Sun's east limb. Leading are *Baily's beads*, sunlight passing between several mountainous peaks seen in profile on the lunar edge. The beads will appear as a series of bright points. Then, as the Moon obscures a bit more of the Sun the last bright point is discernible; it is called the *diamond ring*.

- When the diamond ring has disappeared, second contact or totality will have commenced; it is now safe to view the eclipse with your unprotected eyes. Can you see the reddish pink colored chromosphere extending beyond the lunar limb? Are there prominences to be spotted protruding outside the chromosphere? The shimmering corona has details also; is it possible to pick out the variously shaped streamers? Can polar plumes be discerned? What is the general shape of the corona, full and blooming or are certain areas suppressed? Take a brief moment to look away from the Sun, and notice the landscape. Is it as dark as you experience at night during a full Moon? Have the birds become completely quiet? What has the surrounding air temperature reached? Is there a rustling in the trees indicating an increase in wind speed? Briefly study with your unaided eyes or binoculars the sky surrounding the Sun; Venus will likely be the brightest star-like object, can you find Mercury or any brighter stars in the field? Some observers look for comets passing close by the Sun, are any visible?

- The total phase of the eclipse will pass quickly, if photographs are being taken work swiftly and vary the exposures times. Short exposures record the prominences and inner corona; longer exposures record the mid and outer regions of the corona. As totality nears its end, low lying prominences appear on the Sun's western limb. Take care now because the Sun's blinding light is about to burst forth beyond the lunar edge.

- Third contact happens as the diamond ring appears somewhere opposite its previous position, and then Baily's beads which are followed very shortly by the thinnest sliver of the photosphere, precipitating once more the transient shadow bands. **Safe solar filtration is necessary at third contact.**

- The Moon's shadow will exit toward the east with totality over. Leaving a recreation of the earlier partial eclipse until the Moon completely exits the Sun at fourth contact (Fig. 2.55).

Shadow Bands

As totality nears, the Sun's remaining sliver of photospheric crescent becomes progressively thinner *sometimes* creating a unique phenomenon

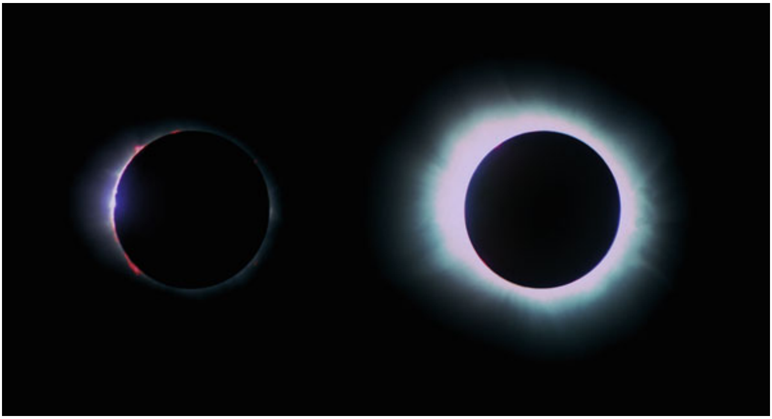

Fig. 2.55 Totality from 26 February 1979 near Brandon, Manitoba, Canada. *On the left* is the last remaining glints of sunlight before totality, a "mini-diamond ring", also notice the *reddish* prominences on the Sun's east limb. In the *right hand image* take note within the corona (3 o'clock position) of an embedded "S" shaped feature termed a sigmoid pattern (Kodachromes courtesy of by Jamey Jenkins)

that we call shadow bands. The spectacle happens just within the last few minutes prior to and following the total eclipse, each occurrence an unpredictable length of time.

Shadow bands are very low contrast, light and dark wavy forms visible on the ground or a lightly colored surface, such as a sidewalk or building. Possessing irregularly narrow widths of 20–50 mm with separations of 50–250 mm, shadow bands are fleeting, sometimes stationary, and at other times having a movement approaching 3.0 m/s.

This interesting effect develops because the thin solar crescent is illuminating lower atmospheric turbulence. Shadow band motion is the result of air mass movement. Somewhat of a novelty, not all experienced eclipse chasers have observed them; shadow bands can therefore serve as a badge of honor when spotted. Photographing a series of moving bands is particularly a challenge.

Potential shadow band observers can create an observing station designed to increase their odds for spotting the feature. All that is really required is

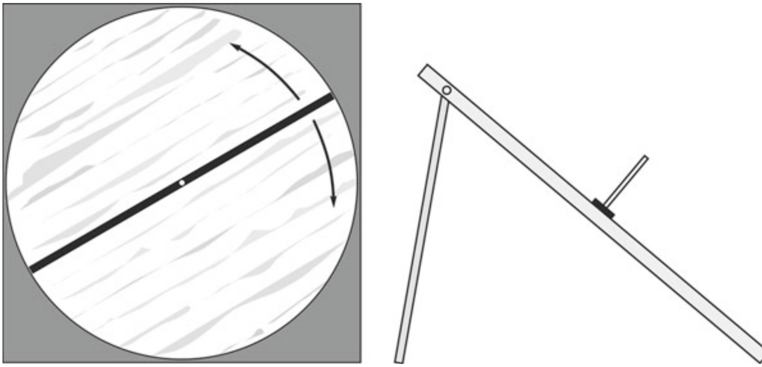

Fig. 2.56 Straight-on and side view drawings of the shadow band viewing screen. The *dark colored bar* pivots about the center, aligning with the illusive bands, and providing a reference for their detection

a flat surface with a lightly colored background, but this described apparatus includes an orientation shaft, and rotating bar for marking the bands' capricious location.

Seen at past eclipse expeditions, the station consists of a stiff white screen formed from smooth plywood, cardboard, or even cloth stretched over a wooden frame. The screen should be as large as is practical, but no smaller than 1.5–2.0 m^2. At the center of the screen a round wooden positioning dowel is fixed, protruding about 300 mm and perpendicular to the panel. Scribed with the dowel at its epicenter is a circle as large as can be fitted on the screen. Adjustable legs to prop the screen at an angle equal to the Sun's altitude during totality are required. If the Sun is at the zenith, the screen would lay flat and no support is necessary.

A straight-edged, dark colored bar with a pivoting hole of the same diameter as the dowel is situated over the positioning rod; the bar is able to rotate freely yet with enough friction so that gravity will not disturb it. The bar will have a length equivalent to the diameter of the scribed circle, and a width of about 25 mm. That describes the basic observing station (Fig. 2.56).

Shortly before totality direct the screen toward the Sun, so that the dowel serving as a pointer casts no shadow. The viewing screen will now be perpendicular to the Moon's oncoming shadow. With several minutes until second contact face the screen, but do not allow your own shadow to fall on it. Watch intently for any sign of the shadow bands. Should they appear, quickly move the bar so that it now rests parallel to the bands and perpendicular to their motion; the straightedge thus aiding in recognition. For directional studies pre-position the bar so that it points east–west, thus indicating the terrestrial direction of shadow band motions. The bands may be dull, nebulous and of low contrast; perhaps appearing stationary or rapidly in motion. Results at any eclipse are always unpredictable.

Photos of the screen with shadow bands are best obtained at a high shutter speed with the images worked later using software to increase contrast. A video illustrating the movements are edifying, and particularly become useful for reducing movement velocity. Following the third contact phase observations should be repeated to see if the shadow bands reappear.

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