Guidelines for the Observation of White Light Solar Phenomena

Edited by

Jamey Jenkins

Asst. Coordinator, ALPO Solar Section

Originally compiled by

Rik Hill

Lunar and Planetary Labratory

University of Arizona

A Handbook of the Association
of Lunar & Planetary Observers
Solar Section.

January 2010

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Established 1947

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Acknowledgements

Welcome to the world of solar astronomy. The purpose of this book is to bridge the gap between the casual and serious observer wishing to contribute to the knowledge of the nearest star, our Sun. We are a division of the Association of Lunar and Planetary Observers, organized by Walter Hass in 1947; this Section being established in 1982. The function of the Solar Section is to *stimulate, organize, and disseminate* amateur work in the field of solar morphology. Through the archiving of solar observations we provide a resource for the professional community to supplement their research programs. While we do not offer recommendations regarding sunspot counting or radio flare patrolling, we do accept and archive submitted observations of that nature from observers. Any member wishing to involve themselves deeply in such work should additionally contact the American Association of Variable Star Observers (AAVSO) at 49 Bay State Road, Cambridge, MA. 02138 for guidance. Many of our observers participate in both organizations.

Solar morphology is a particularly rewarding field of study for the amateur astronomer since the features of the Sun are the most active and changing in the whole of the solar system. Because of this dynamic, solar activity requires diligent observing. Some work can be done within the space of a day or two while other projects require a commitment of many days, often consecutive. Neither type of observing is any more important than the other, so observers that make a contribution either way are encouraged to do so. The work of the Solar Section and consequently the focus of our efforts is the recording of visual and photographic observations of the Sun. There is a particular emphasis on photographic observations in white and monochromatic light since these are of the most use to the professional community. Space limitations will require some presumptions on our part that you, as an observer are familiar with astronomical terminology and principles. If you are a novice please contact the Solar Section Coordinator for guidance.

The preparation of this booklet required advice from a number of professional and advanced amateur astronomers to insure that the work of the Solar Section would have immediate and lasting value to astronomy. We gratefully acknowledge the support and aid of those listed below. For our observations to retain value, it will take dedication and commitment from our observers towards producing reliable data that will, by virtue of its own high quality be in demand now and in the future.

—ALPO Solar Section

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About Solar Observing

Solar Observing in General

The late Jim Loudon a space science and astronomy lecturer with the University of Michigan, had about the best definition of a star, and the Sun is a typical star. He said, "The Sun and any star for that matter is a very big, very hot, ball of glowing gas."

"Brevity is the soul of wit!" says Shakespeare, and Jim was a witty fellow. But this simple sentence says an awful lot, accurately defining the very essence of the Sun. The Sun though an average star is still enormous with a diameter of 1.4 million kilometers. It has a "surface" temperature of 5600K, but in the center is over fifteen million kelvins while in the corona, around three million kelvins. The kelvin is a temperature measurement system based on absolute zero. For conversion purposes, degrees Celsius + 273.15 equals kelvins. Though many have tried for the last four hundred years no one has shown the Sun to be other than nearly spherical within error of measurement.

The Sun does not *burn*, and this term should never be used as it is very misleading, especially to the general public. The gas of the Sun glows from the energy of fusion turning hydrogen into helium. Lastly, the Sun is gas throughout. Granted, at the pressures and temperatures in the center it would not seem like it, but here too it is a gas, in plasma form.

So Loudon's definition covers the main points pretty well, and it's easy to remember!

The Sun is not generally viewed in its proper perspective among objects in the universe. When we speak, we often speak of THE Sun. But do we say THE Jupiter, or THE Mars? Nope. We find that the Sun was placed in its own category in antiquity when its relationship to the stars was unknown; like THE stars, THE planets, THE galaxies, and THE Moon. The result? This causes most amateur astronomers to see solar studies as a separate discipline from *real* astronomy. As such solar astronomers share a special comraderie among their brethren solarphiles.

Why do we amateurs study the Sun? Beyond the obvious responses of being the life giver to the planet or the closest placed star, the answer may be found in the shear dynamics of the Sun! An ever changing view given the observer, in some cases on time scales of a few minutes, can be an attractive alternative to the almost static views presented elsewhere in the sky. Sunspots grow and decay, flares burst, prominences erupt or rain onto the "surface" below; each day presents a new face to the Sun. Solar observing can be fun, exciting, and forever interesting. Now you understand, why we amateurs study the Sun.

Solar observing, while attractive to the astronomer for those reasons does however present a few obstacles that the typical night sky observer doesn't face. Some of these hurdles include safety, local seeing conditions, and suitable instrumentation. The amateur astronomer, by cleverly addressing these obstacles, we are confident will find it possible to make useful observations, and thereby contribute to the knowledge of the nearest star, THE Sun.

Safety and the Sun

Unless special equipment or techniques are in use, any observer looking even the shortest amount of time at the Sun through an optical instrument will forever damage his eyes! This is a lesson that must be "burnt" into the brain of all potential solar observers from the beginning.

Here are two examples that will help make the point to everyone concerned. First, just hold a piece of paper in the focal plane of any telescope focused on the sun. What occurs? The paper is instantly ignited from the heat of the Sun!

Secondly, the United States Air Force in the last century conducted a series of experiments with rabbits and the effect of nuclear explosions to their visual senses. Rabbits have similar eye structure to that of humans. From a distance of fifty miles the fireball of a twenty megaton bomb burned a hole in the retina and vaporized the liquid surrounding the iris of the rabbit's eyes. Bombs of this size do not generate even the smallest part of the energy produced by the Sun in a billionth of a second! The dangers involved in solar observing can never be overemphasized.

On the other hand, a careful approach and proper knowledge allows one to safely observe the Sun without reservation. The safest method of white light observation is the projection method by which the Sun's image is viewed indirectly after it has been projected onto a white screen by the telescope.

Another safe method is the Herschel Wedge (a special prism) *with* secondary filters at the telescope eyepiece. Objective filters having special reflective coatings on a glass or mylar material are the most often used appliance.

One solar filter to warn about using as there may still be some on the market is the so-called "solar eyepiece filter" that comes occasionally with a lower end department store telescope. This device is intended to screw into the base of an eyepiece which is then inserted into the telescope focuser. The filter is no more than a dark green "welder's glass" which does indeed darken the Sun's brightness. While the transmission of infrared light is retarded with these filters, serious danger is the possible shattering of the filter from focused heat at the telescope's focal plane. Shattering takes but a moment and then the eye is exposed to the blinding light and heat of the Sun. The wise and cautious solar observer will discard this type of filter immediately.

Seeing Conditions and the Sun

Veteran solar observer Gordon Garcia once noted that, "seeing is everything!" What Gordon was referring to was the blanket of turbulent air that surrounds our planet and how it effects our view of objects in space.

Observing celestial bodies has been compared to looking out at the world from the bottom of a swimming pool. In the same way that the intervening water distorts our view of the people and objects at the poolside, the atmosphere plays havoc with our view of the stars, planets, and all celestial bodies, including the Sun as we look out into space from the surface of the earth. In solar observing this is even more pronounced as the Sun tends to heat up the air and our surroundings resulting in even greater turbulence between you and the outside universe.

While the upper atmosphere can cause seeing problems, the worst disturbances appear to occur closer to the observer. Indeed, some authorities claim that as high as 90% of the disturbances to the atmosphere can be traced to the first 100 meters of air above the ground!

In solar observing, the ability to see 1-arc second detail or better is desired for the best work. It is estimated that such occurs only 1% of the time. This means that astronomers have had to adopt programs that can take advantage of these rare moments of fine seeing. The past method most commonly used with professionals was to have an automatic film camera photograph at regular intervals (once a minute or less) and then just weed out the bad images. A modification of this was to have some sort of atmospheric monitor that will trigger a shutter when it detects seeing of good quality. These are costly and complex techniques. Amateur astronomers could make a significant contribution in this field by adopting these plans and simply *visually* monitoring the seeing and imaging only when those moments of best seeing occur; in effect, becoming the monitoring system yourself.

Modern digital media allow the acquition of hundreds of images for pennies on the dollar compared to older film techniques. This means it is now cost feasible to literally ignore monitoring of seeing conditions, shoot blindly and capture at least a few moments of fine seeing. Maybe.

Improving Local Seeing

Horizontally, seeing is drastically changed by the lay of the land, including man made structures. Even at major observatory complexes, chosen for their excellent seeing, the quality of the sky on any given night can vary from excellent at one telescope to unusable at another. Daytime seeing can particularly vary like this. Observers should be aware of factors that can better their chances of having improved seeing conditions.

Avoid buildings anywhere near, or beneath, the path between the telescope and Sun. This is especially important with the common metal garden shed often used as observatories by the amateur observer. Domes will be a problem no matter what the observer does. The heated metal about the slit will disturb the air. In fact, many astronomers consider observatories places where bad seeing is created and retained. Ideally some sort of open air observatory or one where the optics are in the open air feeding an image into an enclosure are to be sought out.

Observers should take precautions when locating an observatory, making sure that nothing is blocking the prevailing winds at their site. Such obstructions are known to increase turbulence.

Many night sky telescopes have flat black surfaces that face skyward. For that kind of observing this is not a problem. But for daytime observing the Sun hitting anything flat black in or around the telescope should be avoided at all costs. All surfaces that face the Sun should be white. Tests done at Kitt Peak in the 1970's showed significant heating as soon as any color other than white was used, this included polished aluminum. Even an off white color was markedly warmer when exposed to sunlight than pure titanium white. Only surfaces that are seen by the eyepiece should be flat black. If you construct your own solar telescope, you will find it highly advantageous to use a larger than necessary tube with an aperture stop slightly bigger than the primary optic (lens or mirror) to keep sunlight off the interior walls of the telescope. This will help reduce disturbing air currents within the tube.

With such considerations in mind during construction you will find that even a modest 4-inch telescope specially built for solar observing will many times out perform a similar aperture night sky telescope adapted to solar observing.

Does All Bad Seeing Results From Heat?

If you have ever looked with a telescope at a rising planet or star in the night sky you have undoubtedly been struck by the little spectrum they form as they rise through the thick layer of atmosphere near the horizon. This prismatic effect of our atmosphere is called *atmospheric refraction*. As soon as you get more than 25 degrees away from the zenith, this refraction becomes greater than one arc second. There is a way around this deterioration: filter the view, so you observe in only one color.

Even broad band filters, like those used in planetary observation will improve the situation. But the **narrower** the bandwidth of the filter, the lower in the sky you can achieve a potential resolution of arc second quality. This is a very important factor in photography.

Filters are also used to enhance the contrast of selected features and to a lesser degree improve the performance of some refracting telescopes.

Quality of Seeing in Daytime Skies

With the Sun there are several seeing quality indicators. When the seeing is what we call better than one arc second, granulation will be clearly resolved. If the seeing is on the order of 1 to 2-arc seconds the appearance of granulation is mottled. From 2 to 5-arc seconds the granulation is only occasionally as good as mottled and any pores will pop in and out of view. Any seeing condition experienced worse than this is considered to be useless.

Sometimes observers use descriptive terms to deliniate the quality of the atmosphere. For instance, "fair" could represent 2 to 5-arc second seeing. “Poor” could be defined as worse than 2 to 5-arc seconds. When reporting observations to the Solar Section indicate the quality of seeing by **arc seconds** rather than the purely subjective descriptions of poor, fair, good, etc.

Study Local Observing Conditions

By studying the Sun at various times throughout the day, under a variety of weather conditions and noting the relevent air quality, you may discover circumstances in which your local seeing is better than average. Perhaps your best seeing occurs early in the morning, before the Sun has had a chance to heat up local rooftops; or at mid afternoon with the Sun high in the sky and a light breeze from the east or west. Some observers find late afternoon to bring conditions that allow fine detail to be seen.

The point here is to pay attention and experiment with your observing schedule. Many sites will have an optimum time of day and set of conditions that will favor solar observing. Study your site and discover those times and conditions.

By applying suggestions gleaned from this booklet you can maximize the use of your observing site to produce results that rival observations made at professional observatories.

A Telescope for Solar Observing

Any telescope may be used for observing the Sun so long as the view is a safe one. Most serious observers however, have through experience determined that in the amateur ranks and with the several designs available, the refracting telescope is better suited for most types of solar observing.

For instance, consider that compound telescopes such as the Maksutov or Schmidt-Cassegrain are not well suited for solar projection because they are suceptible to internal heat damage. The refractor with its unobstructed light path does not have this issue. An unobstructed path also facilitates maximum contrast of low contrast solar features. Why? Because more light will become concentrated in the Airy disc and not in the surrounding diffraction rings. The secondary mirrors of a Mak or SCT disrupt the ideal Airy pattern. The same is true regarding a classic Newtonian.

Mechanically, the refractor also has plenty of back focus to easily adapt the necessary appliances for monochromatic observing (amplifiers, end-loading filters, tilting mechanisms, etc.).

An Optimized Telescope

Often an observer will construct or modify an existing telescope for strictly observing the Sun. Here are a few thoughts to keep in mind when creating a telescope intended for solar observations.

A primary consideration in designing a solar telescope is that there should be as few optical elements as possible in the instrument. In solar observing, image abberations, scattered light and heating of optical components are extremely damaging to the quality of the final image. Many solar features are of low relative contrast and such effects tend to easily "wash-out" the view.

A further point to keep in mind is that the more optical components in a system, the quality of each should be at least equal to the desired wavefront within the system. Wavefront is defined as the imaginary surface representing the corresponding points of a wave that vibrate in unison—in this case light waves transversing the telescope's optical path. The delicate details of the Sun require optics capable of delivering near their theoretical limits. This results in greater expense and fabrication time for each component. Therefore our goal in a dedicated solar telescope ought be to keep it simple, while delivering sharp and contrasty images.

The instrument should be capable of resolving to 1-arc second. This means the aperture must be at least five inches (125mm) diameter, which is not meant to say that useful work can't be done with less. If an observer has a smaller telescope they should make the best of it rather than putting off work until the ideal telescope is obtained! In the past apertures of 1.6-inches (40mm) have been used to some advantage in various observing projects. As discussed earlier, with apertures larger than 4 or 5-inches a telescope's performance will on occasion be limited by local seeing conditions. But then again let this not be a deterrent to observing. Daytime seeing can be notoriously bad. Quite often the problem is the heating of instruments, surrounding buildings, or some other detrimental local seeing effect. Because of this the maxim was coined that 1-arc second seeing is achieved only 1% of the time during daylight hours, even at the very best of sites. So apertures greater than 4 or 5-inches would be sky limited nearly 99% of the time! Ground based instruments of 6-inches aperture and greater perform essentially the same most, *but* not all of the time.

To summerize, whether you adapt a conventional night sky telescope or purchase/assemble a dedicated solar telescope—the key to repeatable success is found in simple, well-made medium aperture optics used in conjunction with a specific methodology to your observing program.

How to Locate the Sun in a Telescope

Ordinarily one wouldn't think that finding the Sun through a telescope would be a challenge, it is easily visible in the sky. *Safety though is our concern*, and sighting along the telescope tube is just as dangerous as looking at the Sun through an unfiltered finder.

The usual means of locating the Sun with a telescope is to watch the telescope's shadow on the ground. When the telescope it pointed at the Sun, this shadow will be smallest.

Several telescope manufacturers produce pinhole solar finders that are superb for locating the Sun. To prevent injury we suggest any optical finder on your telescope be removed, or at least capped when doing solar observing.

White Light Observing

White Light Solar Observing

By definition, white light observing means that you are seeing the Sun in the combined colors of light from the solar spectrum. This can also be known as observing in the solar continuum.

In white light the Sun appears much as it does in the sky. The projection method of viewing yields the truest color rendition; while an over the objective filter typically offers a white, orange or blue cast to the Sun. The view through a Herschel Wedge is dependent on the color of any supplementary filters located between the wedge and the eyepiece.

White light observing affords the solar observer an economical means into the realm of daytime astronomy. Narrow band observing, such as in hydrogen alpha light can be an expensive undertaking for the amateur, the cost maybe becoming a discouragement. It is however possible to "tool up" a telescope for white light observing with the addition of just a single inexpensive accessory, be it a projection screen or a white light objective filter.

The layer of the Sun that we see in white light is called the *photosphere*. The most obvious features located here are *sunspots*. Sunspots can be large or small, singular or in clusters known as groups. Sunspot groups grow in complexity then decay with time. The white light observer will also view *faculae,* extensive vein like patches seen near and often encompassing sunspot groups. Solar *granulation* is visible across the entire photosphere when the seeing is steady.

Granulation gives a textured or orange peel appearance to the solar disc—it is the combined effect of individual granules—each being the top of a column of gas rising from the convective layer of the Sun. Features called *light bridges* may divide sunspot umbra and are quite common, unlike the rarer *white light flares* (WLFs).

Morphology or the recording of the changing appearance of the Sun and its sunspots is the main focus of white light observers in the ALPO Solar Section. We encourage observers to record sunspot growth/decay via paper and pencil sketching or by photography through the use of modern digital imaging techniques. It is possible for the amateur to make significant contributions to the acquisition of data regarding solar morphology. Quality observations are in demand that do not require sophisticated equipment, but will require a compelling interest on the part of the observer, and careful attention to detail.

Appliances for Solar Observing

Many who begin white light observations modify night sky telescopes for solar observing. Unlike the typical astro telescope designed to gather light, the solar telescope must reject almost all of the light that falls on the aperture. The means of achieving this light rejection are discussed in the following pages, but again always keep in mind that: **solar observing is the only inherently dangerous observing an amateur astronomer can do**. If you take one false step, one unsafe procedure, it could and likely will result in irreversible blindness.

But as stated earlier— with proper care and knowledge one can safely observe the Sun without the slightest amount of fear or reservation.

Solar Projection

The safest method of observing the Sun is the projection method. With this arrangement an eyepiece is inserted in the telescope's focuser to project an image of the Sun onto a white screen. No filters are used, but safety is assured because the Sun is viewed *indirectly*. The analogy of a slide projector comes to mind with the solar image formed by the objective serving as the slide and the eyepiece as the projection lens. It's easy to see that the farther the screen is from the eyepiece, the larger but dimmer is the projected image of the Sun.

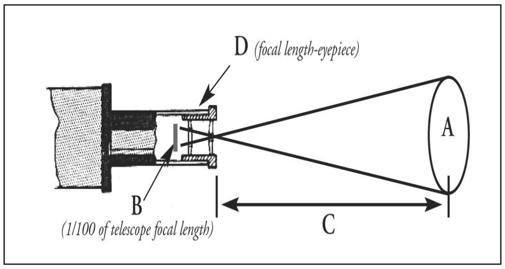
Refractors and most Newtonian telescopes are both suitable for solar projection but it is wise to avoid a compound telescope such as the Maksutov or Schmidt-Cassegrain since heat from the Sun can damage internal components such as baffle tubes. Heat may also damage expensive multi-element eyepieces by melting cement that is used between lenses. Older Huygens or Ramsden designs are okay since they contain no cemented elements. These eyepieces usually can be picked up second hand, purchased from some optical suppliers, or even assembled at home from standard lenses.

Projection is done onto a flat white card stock or bristol board material. The key when using solar projection is providing a shaded environment for the projection screen, so that the contrast of solar features is not compromised. Many clever observers have adapted various apparatus ranging from a light weight wooden box to an oatmeal carton to serve as the "shade" for the screen.

We recommend the use of a portable observing box called the Hossfield Pyramid. The device is simply a "pyramid" shaped box many times constructed of sturdy cardboard or thin wood. The small end of the box attaches to the projecting eyepiece and the viewing screen is located at the base of the pyramid. Paint the inside of the box flat black and make allowance for an access window on one side to permit the observer to see the projection screen.

Solar projection is an ideal means for obtaining whole disc drawings of the Sun. A grid system may be incorporated on the screen for transferring spot positions to the recording form or the form itself may be attached to the projection screen and spot positions gently drawn on it. How sturdy an outfit one has, and how easily the observer can access the screen are the determining factors for efficiency.

Calculating projection distances and the diameter of the solar disc may be performed on the basis of this simple formula: **A = B x (C / D)**. The desired diameter of the projected solar disc is **A**; the diameter of the sun at the telescope's focal plane is **B** (calculated as approximately 1/100th of the focal length of telescope); **C** is the distance from eyepiece to screen; and **D** is the focal length of the projecting eyepiece. See below.



This formula while not absolutely perfect owing to the varying size of the solar disc throughout the year is accurate enough to design a system that permits minor adjustments to the projection distance. A disc diameter of 18 cm (approximately 7-inches) is the preferred size. Alternately, an observer could by trial and error hold a piece of stiff white paper behind the eyepiece, and then by varying the distance to the paper and refocusing the eyepiece find the necessary separation suitable for the desired projection diameter.

Figures 2 and 3 illustrate a simple homemade Hossfield Pyramid made of black foam board, white card stock, spray adhesive, and masking tape. Attached to the star diagonal, the open end of the pyramid is always in the shade providing a bright contrasty view of the solar disc and white light features.

White Light Observing

Herschel Wedge

The Herschel Wedge is a thin wedge shaped, unsilvered prism with optically flat surfaces. John Herschel developed the concept long ago and several commercial units are found on the market today. By reflecting a small percentage of the Sun's light to the eyepiece the Sun's intensity is reduced dramatically.

Note— A HERSCHEL WEDGE IS NOT SAFE IF USED ALONE— additional filtration *is* required between the prism and the eyepiece to provide safe viewing.

In use, a Herschel Wedge replaces the diagonal on the telescope. For the same reasoning that solar projection is not a suitable option for a compound telescope, a Wedge is not suitable either. Heat will be present within the optical tube assembly, heat that could damage internal components. A Newtonian reflector is adaptable, but again best suited for a Herschel Wedge is the refracting telescope.

With a refractor light passing through the objective strikes the front surface of the Wedge, approximately 5% of this light is reflected to the eyepiece. The remaining 95% of light passes through the backside of the wedge (a need for protection from burns here) and a small portion is absorbed by the prism itself.

Since the Sun is still nearly 5% of its normal brightness, additional filtration is required. Many observers employ neutral density (ND) filters with a value from .6 - 3.0 ND. Sometimes a linear polarizing filter is placed in the filter pack between prism and eyepiece to permit minute adjustment of the Sun's brightness. Colored glass filters, as in planetary observing may also be used to replace or supplement the ND filters. Colored filters have the advantage of enhancing contrast of certain white light features visible in the photosphere.

Lastly, between the Wedge and eyepiece, as a "safety buffer" we recommend the use of an infrared (IR) rejection filter. Ultimately, always follow the manufacturer's guidelines in the use of the Wedge, but the addition of a good IR filter can only protect your eyes, and not harm them.

Experienced solar observers have said that the key to using a Herschel Wedge is allowing the telescope's components to warm to a point of temper ture equilibrium. Once the optics and air within the tube have settled down, the view is superb, often being limited only by atmospheric conditions.

Objective Filters

A number of external solar filters exist on the market that reduce the light and heat entering your telescope. The amount of light you reject will depend on the type of work you intend on doing. High resolution photography generally requires a *thinner* density filter (2.5 - 4.0 ND) to allow more light to pass than is recommended for visual use. Objective filters intended for visual use are somewhat denser being rated at a neutral density of about 5.0.

At the time of this writing there are two basic types of objective filters available. These are the aluminized flexible-film types (usually an optical grade mylar) and the metal coating on glass types. If made properly and of high quality, both work excellently and for *general* observing neither is to be preferred over the other. The mylar-type are coated with aluminum and often produce a blue-white or neutral image of the sun. Glass filters are usually coated with a metal film (i.e. Inconel) and will produce an orange or nearly neutral view. Infrared and ultraviolet radiation should be removed with either type.

Try out a variety of filters before you buy one of your own. Ask for opinions from other observers and then maybe purchase smaller sizes of several brands/types

Fig. 2

Fig. 3

to use (off axis on a reflecting telescope or on axis with a refractor) until you can make up your own mind on a preference.

When you get beyond general observing, factors to consider with the purchase or assembly of an objective filter include: the peak transmission of the wavelength it passes (that is, what color the Sun appears through the telescope), the aperture and consequently the resolution one desires, and the cost involved. Some filters pass more light from the blue end of the spectrum giving the sun a bluish-white appearance. In white light observing this will favor observing faculae, granulation, or white light flares. Filters that transmit more so toward the red spectral region tend to perform well on sunspot detail, but facular views become diminished.

An excellent choice is an objective filter giving a neutral (basicly white) view. With the addition of broadband (planetary type) filters at the eyepiece to this filter it becomes possible to selectively enhance the contrast of those features you wish to study.

It is vital to understand that when a glass or mylar filter is placed in front of an objective, it becomes a part of the optical train of that telescope. The quality of an objective filter is indicated by the degree of distortion (or wavefront error) it imparts to the telescope. Mylar-type filters always hinder the performance of a telescope to some degree. Fortunately, the degree can be surprisingly minimal, and the quality of mylar filters within a particular brand tend to be uniform because of consistent manufacturing tolerances of the substrate and coatings.

With glass filters the accuracy of the optical surface (glass) **must** equal or exceed that of the other elements in the assembly or the performance of the telescope suffers; the greater the inaccuracies, the greater the distortion of the view. When seeing effects are taken into account these distortions are not so apparent at the low magnifications used during whole disc observing. However, they become obvious when one attempts to increase magnification for close-up looks of solar detail. Granulation may never be visible, pores may wash out and disappear, and fine penumbral filaments are beyond resolution. Imagine viewing through a window pane of your home. Some filters are made of the same glass with a quality factor not much better.

Since optically flat plates are difficult to manufacture the cost of proportionately larger sizes increases dramatically. Smaller than full aperture, but high quality glass filters costing less can be used, but at the price of reduced resolution (because the aperture of the telescope will now be determined by the sub-diameter of the objective filter).

Many sources state that the optimum aperture for daytime solar observing is in the 4 to 5-inch range, and on most days this will be found to be true. It is also true, however, that occasionally local seeing conditions permit sub-arc second viewing which can then be realized only with a larger aperture. Does the added expense of increased aperture justify those few times when sub-arc second viewing is permitted? Amateurs such as Art Whipple (USA) and Wolfgang Lille (Germany) have sucessfully demonstrated the limited, but powerful potential of larger than 5-inch aperture telescopes when used for white light solar observing.

So as you can clearly see, the choice of a filter is determined by a variety of factors ranging from what features you wish to observe to the available funds. A rule of thumb in filter selection as with choosing a telescope is to secure the finest quality product you can afford. It is pointless to obtain a poorly made filter that distorts the view through a high quality telescope and prohibits one from seeing as fine of detail as the telescope and atmosphere permit at a given time.

Testing a New Filter

When placing a new filter on the telescope be certain that there is no possibility that the filter could come off unintentionally. Duct tape, and no astronomer worth his salt is without some, can be used as a backup method of securing the filter onto the telescope.

After you get your filter(s) you may want to perform a few simple tests before placing your eye in the way of the exit pupil. First, with the filter on the telescope and NOT pointed toward the Sun, but at a blank area of sky, take out the eyepiece. Now hold a white file card or sheet of paper up near the open end of the focuser. You should not see light coming out of the focuser onto the card. If you do the filter is not safe for visual observations without either additional filtration or some form of further light rejection.

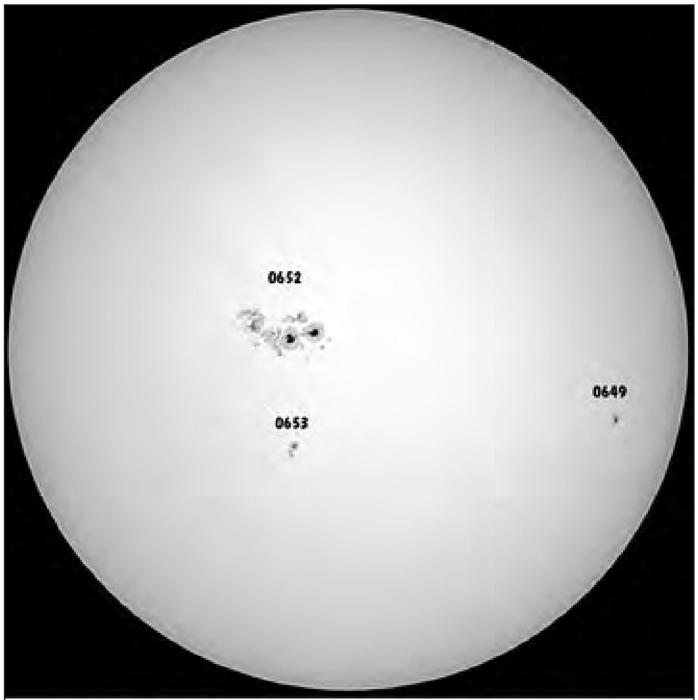
A second test, performed only after the filtration is found safe, is to determine the optical quality of your filter/telescope combination. Wait for a day when the seeing is good. Use a higher magnification but not so high that the view becomes extremely dim. Find a sunspot, a small umbral spot would be perfect. Now slowly go from just inside focus to just outside. The spot should defocus symmetrically. If it becomes elongated in one direction on one side of focus and elongated perpendicular to that on the other side of focus, the filter should be rejected. This is a classical example of astigmatism that can be caused by either a poor optical quality filter *or* a cell that is straining or pinching the filter in some manner. Be sure to also perform this test on a star (without the filter) at night first to satisfy yourself that the problem is not the telescope or collimation. If it passes this test look further for granulation, or a mottled appearance to the surface of the sun. The aperture of the telescope will have to be four inches or greater, though on occasion it has been photographed with smaller. A six inch aperture will readily show details in the penumbrae of sunspots.

A third check will determine the scatter in the filter/telescope combination. Scatter will decrease the contrast of solar features, sometimes to the point of masking detail. For this test you will not only need pretty good seeing, but you will need a fairly dust and haze free day as well. In sky quality terminology this is known as transparency. If your site is never free of these, then pick a day when it is minimal given your prevailing conditions.

Astronomers frequently check transparency by holding their hand at an arms length and blocking the Sun with their fist. For the best conditions there should be little or no bloom beyond the fist. If the sky is still too bright to look at with the Sun blocked completely by the fist then there is considerable scattering inherent in the sky. As said above, this may be unavoidable.

Using around 100x move the telescope so the solar limb cuts through the center of the field. In the best of filters the region beyond the limb will be black. Few filter/telescope/sky combinations will display this. But if the sky beyond the limb appears extremely foggy or hazy and the limb indistinct, even on the best days, it could be a defect of the filter introducing light scatter.

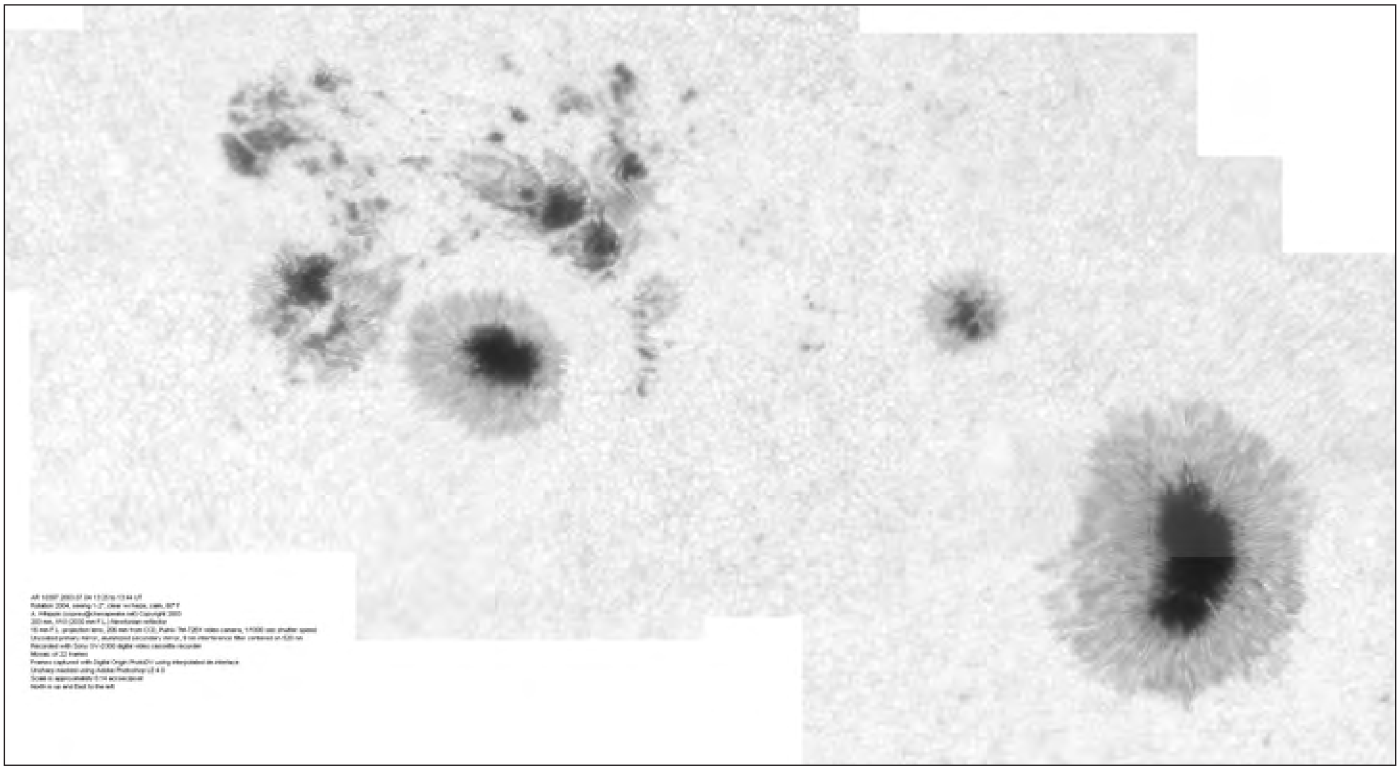
A collection of images from our observers.



Carrington Rotation Number: 2019 2004 July 22, 12:03 UT
Altitude: 17 Seeing: 1", Sky Condition: Hazy, Wind: Calm
Telescope: Mak-Cass (Meade ETX 125), Fork Mounting, Electric Drive
Aperture: 125mm, FL 1900, F/15, AstroSolar Photofilm
Photo System: Afocal, 40mm MaxView, Orion W15 Yellow Filter
Nikon Coolpix 4300, 12.2 mm fl, Exposure Time: 1/394 sec. Photo File # 040722a
Howard Eskildsen P.O. Box 830415, Ocala, FL 34483

HowardEskildsen@msn.com

AR9415 Rotation 1974 20010405.1450UT
125mm refractor @ f/44 #58+2415 Tech Pan
Seeing—2" jenkinsjl@yahoo.com



White Light Features

Visible Features

As you look at the face of the Sun for the first time you may notice dark blotches on the visible surface or photosphere. These are sunspots. You will likely notice too that the spots will cluster into bunches known as sunspot groups. An increase in magnification will reveal that the individual spots are themselves composed of several parts: a darker center called the umbra, surrounded by a less dark or mottled penumbra. If your sky is unusually calm and your filter a good one, you may well see that the penumbra is composed of dark hair-like penumbral filaments radiating outward from the umbra with brighter penumbral grains trapped between them.

Individual sunspots may be crossed by bright streaks without internal structure. These are light bridges. At the same time you may notice the entire visible surface of the Sun is a mottled filigree known as granulation. Some of the cells of the granulation may be filled in but they will not be as dark as the umbra in sunspots. The larger of these are called pores.

Surrounding the sunspot groups, seen especially well near the limb, are bright venous patches called faculae. Now let's look at these and other features in a little closer detail.

Limb Darkening

Jim Loudon, a space science lecturer from the University of Michigan, gave this definition of a star, and the Sun is a star. He described it this way: "The Sun, or any star for that matter, is a very big, very hot, ball of glowing gas."

Because of gravity this gas is highly compressed toward the center and extremely hot. It gets cooler radially outward from the center and is coolest at the surface or photosphere, about 5000K. The proof of this radial decrease in temperature is the limb darkening. Observing the solar disk projected onto a viewing screen you are looking through the photosphere at the hot, opaque center. But as you look more and more toward the limb you are seeing less through the hot dense layers and more through the cooler less dense photospheric layers. This gives the Sun a three dimensional spheroid appearance in the telescope, see figure 4.

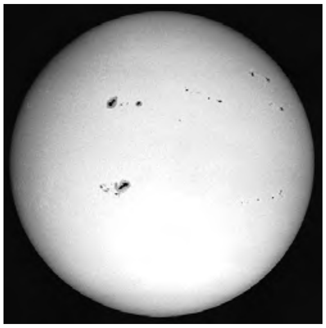


Fig.4 Limb darkening

Limb darkening is not the same at all wavelengths. It is stronger toward the ultraviolet (UV) and almost nonexistent in the infrared (IR). Further out in the extreme UV and shorter wavelengths the limb tends to become brighter than the center of the disk. Here we are seeing the layers above the photosphere where the temperature rises again. By the time you begin to approach the wavelengths of X-rays you are looking at the Sun's outer atmosphere, the solar corona.

Faculae

Faculae (plural of facula) are the extensive, bright filagree patches seen near and often completely encompassing sunspot groups. Their contrast against the photosphere is low but due to limb darkening they are well seen around the limb, as in figure 5. Occasionally a facular region will be bright enough to be seen well into the disk but this is quite rare. All sunspot groups are associated with facular regions but the converse is not true. Faculae can exist without the presence of a sunspot group, as in the case of polar faculae, whereas sunspots have never been seen farther from the solar equator than the heliographic latitude of 50 degrees. Faculae usually appear at a given location prior to the appearance of sunspots and often outlive a sunspot group by several rotations. The veins of faculae exhibit a loose granulation with a cell size of 1 to 2 arc seconds. During the dissolution of a sunspot group

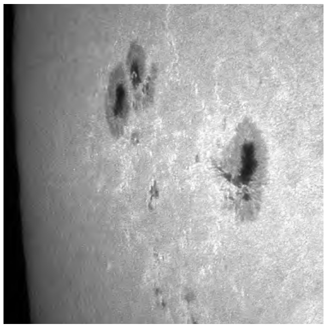


Fig.5 Faculae at the solar limb

the facular material will form a light bridge that quite often divides up one or more of the larger spots. It appears just to spread and swamp the spot as the group dissolves.

As stated above, faculae frequently mark the site where a sunspot group just dissolved or is about to come into being. These faculae are usually big, bright and compact. If the facular material is very bright, this can mean that the sunspot group about to be born will be an active one. Observers should be alert to these faculae. They should concentrate their observing efforts on any newly formed bright faculae or bright faculae that come around the limb, especially if there was not a group at that longitude/latitude during the previous rotation. These features give a warning of upcoming activity and indicate previous activity that occurred on the opposing side of the Sun.

Fig.6 Light bridges

Light Bridges

These are loosely defined as any material that is brighter than umbral material which divides an umbra, and often penumbra as well. There seems to be a rough correlation that the younger a sunspot group is, the thinner will be the light bridge structures that cross it. The older, more evolved groups commonly have light bridges that seem to be no more than large incursions of photospheric material. So, younger sunspot groups are more likely to display the thin wispy but bright streamers through sunspots.

Both faculae and light bridges have a granular appearance. This may, at first, seem contradictory but this can be observed using specialized techniques that block the bright light of the photosphere. Even the thin light bridges, the streamers, in the best seeing resolve into small granules. The lifetime of these light bridges can be less than a day for the thinner ones to a week or more for the more massive forms. The more massive bridges appearance usually signal the beginning of the end for a sunspot group.

During the process of dissolution, the light bridge, which may start out as a bright facular like streamer, will gradually take on the appearance of normal photospheric material. The process resembles the way a sinking ship is slowly swamped by the ocean. A tell tale sign that this process is under way is a sunspot that is fan shaped where a light bridge has cut across leaving part of the umbral material directly bordering the photosphere while the penumbra is spread out like an oriental fan on the opposite side.

Granulation

The entire photosphere, or bright white light surface of the Sun, is divided into small convective cells, about 2-3 million over the whole Sun, called granulation. Each cell, known as a photospheric granule, ranges in size from 1-5 arc seconds with most being 2-3 arc seconds and a mean size being 2.5 arc seconds. They are separated from each other by thin barriers of darker material less than half an arc second in width called intergranular walls. The granulation and intergranular walls enclosing the cells are evidence for convection as a method of heat transfer in this region of the Sun. Like a bubbling pot of oatmeal the heat is carried by the plasma as it moves upward, brightly hot, then stops, releases the energy and cools as it does, then falling back along the walls as darker material. Granules have short lifetime with most surviving only 5 to 10 minutes. Generally, the longer the lifetime of a granule the larger it will be. With telescope apertures of 4 to 5-inches an observer may begin to study granulation. However, the seeing at the observing site must be of the highest quality. The observer must be very sensitive to changes in size, shape, and brightness on a time scale as short as two minutes or less.

Pores

Among the photospheric granules are some that are filled in by material that is darker than the intergranular walls but not as dark as the interior of an umbra. These are pores. They form and dissolve in a matter of a few minutes to an hour and range in size from 1-5 arc seconds, with the majority between 2-3 arc seconds. Like the granulation there is a similar correlation between longevity and size. The larger pores have a good chance of surviving and becoming sunspots. Pores will tend to survive longer and commonly exhibit slower changes than granules. Disturbances between developing pores are commonplace involving the formation of dark filaments between them or simply changes in the granulation between them.

Sunspot Umbrae

As larger pores grow in size and darkness they become increasingly stable. Some continue to grow in size and darkness (though the vast majority of pores do not) until they exceed the single pore size limit (about 5 arc seconds). These are now umbral spots. Many of these will rapidly develop a rudimentary penumbra which usually do not last long. The main distinctions of umbral spots from pores are the darkness and size. They are usually irregular in shape and, after acquiring a penumbra, become quite ragged on the umbra/penumbra border. Additionally, penumbral filaments often appear to sprout from the umbra if the seeing is good enough.

As alluded to above, the interiors

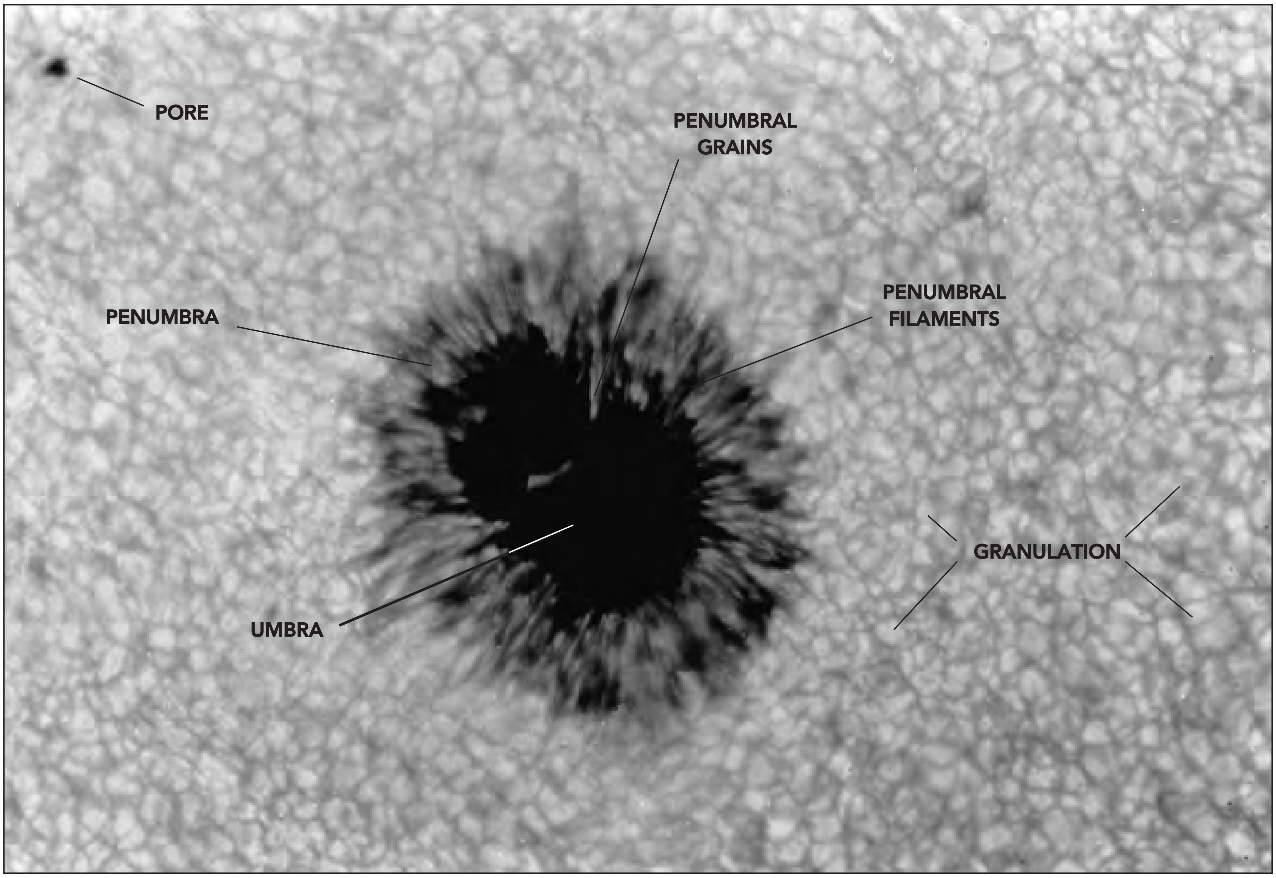


Fig.7 Big Bear Solar Observatory image showing various detail near a sunspot.

of umbrae are not the smooth black that they first appear to be. They are composed of dark granular cells and small bright spots or points called **umbral dots**. Do not confuse these with "umbral spots". Color can be noted within umbrae from a black to a deep reddish-brown. In specialized long exposure photography where all but the light of the sunspot umbra is masked off, an umbral granulation similar in dimensions to that of the photosphere is seen.

Umbral details require an aperture greater than 4-inches as they are small. Umbral photographs where only the light of the umbra is allowed to exit the telescope require exposures of only 2-5 times longer than photospheric exposures. What this tells us is that the umbrae are only a few magnitudes dimmer than the surface of the Sun and would be brighter than Sirius if placed in the sky alone!

Sunspots are the result of surface magnetic fields disturbing the normal convection processes we spoke of earlier. The sunspots are cooler and therefore appear darker than the surrounding photosphere because energy within the area of a sunspot that is radiated away from the Sun cannot be replaced as quickly through convection due to the sunspot's suppressingly greater magnetic field.

Sunspot Penumbrae

Penumbrae often start out as intergranular material that is near to or bordering an umbral spot. As rudimentary penumbrae they are usually dark and elongated and usually do not evolve past this stage, especially if the umbral material is particularly disorganized (i.e. only a collection of small umbral spots scattered over a fairly large area). These rudimentary penumbrae are grouped into two classes: the evolving, or the dissolving. If the umbra is large and well developed, the penumbra will form a structure of dark penumbral filaments in a radial system about the umbra. These filaments are similar to the granulation in convective nature, but are modified by strong horizontal magnetic fields. Between the dark, descending filaments are bright rising penumbral grains. These should not be confused with the granulation or photospheric granules. Overlying these filaments and grains are the dark, shadowy, translucent fibrils. At resolutions poorer than 1-arc second fibrils and dark filaments cannot be separately distinguished. Mature, radially symmetrical penumbrae are common about old sunspots. But there is a more rare type of penumbra that is highly modified by complex magnetic fields. It is usually seen engulfing an entire sunspot group with filaments of different widths in different areas of the sunspot group. The appearance can be quite chaotic. At times islands of the penumbral material can be seen detached from any umbral material. This is rare and observers should be alert to such an appearance. This condition rarely lasts for more than one day and a number of observations over a short time span should be attempted to note any changes in appearance.

Within well developed penumbrae can be found dark islands of umbral material only slightly larger than pores. Sometimes the umbral material will stretch across the penumbra and directly border the photosphere. Also, in the penumbrae, can be found bright regions of material as bright or brighter than the surrounding photosphere. These dark and bright regions often go through rapid changes and should be watched closely. The bright regions may slowly be drawn out and fade to become ordinary filaments or may grow larger and become a light bridge. If one is very fortunate and diligent, these bright intrusions may potentially be the beginnings of a white light flare!

The border between the umbra and penumbra is usually ragged with the filaments looking like extensions of the umbra. A thin region may be seen here appearing as a brightening of the penumbra, this is termed the inner bright ring. The filaments are brightest near the umbra and get darker out towards the edge giving the penumbra a well defined outer boundary. Beyond this where the filaments and fibrils project out into the photosphere, there can be seen several different phenomenae. One is the brightening (about 10%) of the granules in a ring adjacent to this outer boundary. This is termed the outer bright ring. The other is the organization of the intergranular material in the adjacent granules into rings concentric with the outer boundary of the penumbra. The granules then appear to have formed chains about the penumbra. Often the granules of these chains encroach on the penumbra slowly dissolving it. Conversely, penumbrae are often created by the formation of such chains about an umbral spot in which the intergranular material gets darker and wider until the granules themselves are compressed becoming the bright penumbral grains.

To reiterate—a FIBRIL is a dark, semi-transparent, web-like structure that overlays the penumbra proper. The penumbra itself is composed of dark PENUMBRAL FILAMENTS and bright PENUMBRAL GRAINS, whereas the photospheric granulation is composed of granules. These terms and several others are sometimes misused and frequently confused.

Sunspot Evolution

As sunspots cross the visible disk of the Sun they exhibit many changes in their apparent structure that have been well documented. When near the limb there are several that are most obvious. Perhaps the most widely known of these is referred to as the Wilson Effect.

When a rather symmetrical (circular) sunspot approaches the west limb of the Sun, the penumbra away from the limb decreases in width more rapidly than the side closest to the limb. The reverse is seen for a spot coming into view on the east limb. A sunken "saucer-like" impression to the sunspot is the result.

This has been cited as proof that sunspots are cavity like regions in the photosphere. Recent measurements have shown that the effect is not as prominent as once thought. Factors such as poor seeing, photographic effects, photometric asymmetries of the foreshortened penumbra, and the fact that sunspots are normally more evolved on the west limb than the east have all been used at one time or another to account for the Wilson Effect. Astronomers today believe the depression effect is the result of gas within a spot's magnetic field being thinner and less substantial than the surrounding photosphere. The "thinner" gas of the sunspot is therefore more transparent, allowing one to look deeper into the photosphere. Since the magnetic field of the umbra is greater, one consequently sees further through this region than the penumbra.

To summarize, the evolution of an individual sunspot goes as follows: For as much as a week or two before spot formation a region of the Sun will exhibit the bright faculae. They form patchwork best seen at the limb but with blue light (like that passed by the Mylar-type filters) seen well onto the disk. A granule will darken until its interior is as dark as the intergranular material thus becoming a pore. Most pores do not evolve beyond this point but quickly fade away. Some however, will darken and grow to three arc seconds or larger until they acquire umbral intensity. These are then called umbral spots. The vast majority of sunspots do not evolve past this stage. Next the formation of a penumbra takes place, rudimentary and irregular at first, but later it may become symmetrical and more extensive if the spot evolves further. The penumbra may now increase and become more complex as small motes of umbral material and bright spots appear within its boundaries. This is now considered a full mature and active sunspot. It is usually surrounded by others at this point and to continue this discussion further we must consider more complex structures.

Sunspot Groups

Sunspot Groups, simply put are magnetically associated clusters of sunspots. The sunspots within a group may be of differing ages and are often surrounded by numerous pores if the group is a well developed one. A group evolves in more or less the following fashion.

A few pores will form a small cluster in an area of less than ten heliographic degrees on the disk of the sun. After a day or so these will darken and become sunspots, often separating into two concentrations. In each, one pore will develop more rapidly (in just a few hours) becoming a small sunspot. The leading concentration's ("leading" in terms of the Sun's rotation) main spot will form more rapidly than that of the following. Most groups do not evolve past this point and may stay this way for a few days and then dissolve. If the group continues to evolve, the leader spot will usually form a penumbra followed shortly thereafter by penumbral formation about the small spots, and possibly some detached penumbral material. These two sunspots will usually have pores, umbral spots, and detached penumbral material between them. Now the large sunspots will rapidly separate in longitude while the axis of the group as measured from the center of the large preceding sunspot to the center of the follower, will rotate so its inclination with the solar equator decreases. These sunspot groups are magnetically bipolar in that the leading and following spots will be of an opposite magnetic polarity.

After these initial evolutionary steps the group continues to grow in area and number reaching a maximum size around the middle of the second week. Toward the end of that week or as late as a month later the group will begin to break up. First the smaller spots and pores will dissolve and then the following sunspot will subdivide and shrink in size until it too is gone. All the while the leader or preceding spot is getting increasingly round and symmetrical. Soon all that is left will be the preceding spot, round with a uniform penumbra about it, which simply shrinks in size over several days or weeks. The faculae that preceded the formation of the group by many days will then be the only remaining white light traces of activity, living on for several additional weeks or longer.

All this activity is the result of magnetic fields being generated by the rotation of the Sun and the boiling motions of convection in the Sun's outer layers. Through these motions creation of electrical currents give birth to the magnetic fields, which then evolve through an all repeating cycle of more current and stronger magnetism. Eventually, a field is powerful enough to rise to the surface with it's pocket of gas and become what is known as an active region. This begins the evolutionary process spoken of earlier.

Sunspot and Sunspot Group Classification

This scenario for the development of sunspots and sunspot groups has been described by numerous systems of classification over the last several hundred years. The most popular and well know system was until recently, the one developed by M. Waldmeier of the Zurich Observatory, in 1938. Accordingly, this became known as the Zurich Sunspot Classification System. The system consisted of nine classes lettered A through J, but omitting I. It delineated the characteristic evolutionary stages of sunspot groups, although not all groups went through all classes during development and decay. The majority of groups would go through only part of the sequence and then reverse their development or skip ahead to one of the later classes. Generally, the larger the area of the group, the more asymmetrical will be its growth curve. While group areas tended to increase from class A through J this was not absolutely the case. A large group tends to have an asymmetrical growth curve, rising rapidly from class A to E and then decaying more slowly as it goes from E to J, spending the majority of its decay time in classes G to J.

Recently there has been a greater emphasis on the study of solar flares, the most energetic events in our solar system. The Zurich Classification System worked poorly as a predictor of which sunspot groups would produce flares. It was known that groups of classes D, E, and F produced the most flares, however not all such groups produced flares. Even the most active and complex group, Class F, only had a moderate chance of producing a flare in a given 24-hour period. A new classification system was devised by Patrick McIntosh of the National Oceanic and Atmospheric Administration's Space Environment Services Center in 1966. His system is only slightly more complex but provides a wealth of more information about individual sunspot groups. This system has been adopted by the ALPOSS in white light observing.

In the McIntosh system the classification consists of three letters (i.e. Hsx). The first letter is a modified Zurich Class. This basically retains the old Zurich Classes but omits G and J which in this system would be redundant. This Modified Zurich Class was used to be an inducement for seasoned observers that might otherwise be reluctant to convert to the new system. The second letter describes the Largest Spot in the group; not necessarily the leading spot, but the largest one. The third letter assesses the Sunspot Distribution within the group.

Let's first define two critical terms:

Unipolar Group - A single spot, or compact cluster of spots, with the greatest separation between spots being less than three heliographic degrees. With a Class H group the separation is taken to be the distance between the outer border of the main spot penumbra and the most distant attendant umbra.

Bipolar Group - Two or more spots forming an elongated cluster with a length of three or more heliographic degrees. If there is a large principal spot, then the cluster must be greater than five degrees in extent in order to be bipolar.

Now we can go on to define the various parameters of the system:

—MODIFIED ZURICH CLASS—

A - A unipolar group with no penumbra. This can be either the early or final stage in the evolution of a group.

B - A bipolar group with no penumbrae on any spots.

C - A bipolar group with penumbra on one end of the group, usually surrounding the largest leader umbrae.

D - A bipolar group with penumbrae on spots at both ends of the group and a length of less than 10 degrees.

E - A bipolar group with penumbrae on spots at both ends of the group and a length of 10 to 15 degrees.

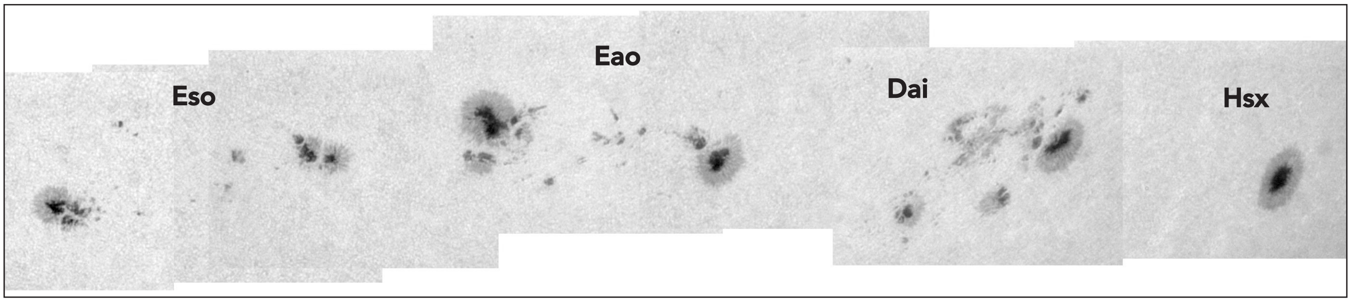


Figure 8. Panoramic view of several sunspot groupings from the 9th of July, 2000 by Art Whipple. The McIntosh Classification code is inserted above each group as an example of how the system functions.

F - A bipolar group with penumbrae on spots at both ends of the group and a length greater than 15 degrees.

H - A unipolar group with a penumbra, usually the remains from a bipolar group.

—TYPE OF LARGEST SPOT—

x - No penumbra (groups of Class A or B).

r - Rudimentary penumbra that usually only partially surrounds the largest spot. Penumbra will be granular rather than filamentary, appearing brighter than a mature penumbra. The width of the penumbra will be only a few granules, and may be either forming or dissolving.

s - Small, symmetric spot with a mature, dark filamentary penumbra of circular or elliptical shape with a clean sharp border. If there are several umbrae in the penumbra, they will form a tight cluster mimicking the symmetry of the penumbra. The north-south diameter is 2.5 degrees or less.

a - Small, asymmetric spot with irregular surrounding penumbra and with the contained umbrae separated from each other. The north-south diameter is 2.5 degrees or less.

h - A large symmetric spot; like type s, but the north-south diameter is greater than 2.5 degrees.

k - A large asymmetric spot; like type a, but the north-south diameter is greater than 2.5 degrees.

—SUNSPOT DISTRIBUTION—

x - Unipolar group of Modified Zurich Classes A or H (i.e. a solitary spot).

o - Open distribution with a leader and a follower spot and few or no spots between them. Any spots between will be very small umbral spots.

i - Intermediate distribution where numerous spots lie between the leader and follower spots.

c - Compact distribution where the area between the leader and follower spots contains many spots with at least one having a penumbra. In extreme cases the entire group may be enveloped by one complex penumbra.

The illustration above is a graphic example of how the classification system works. Remember that the first letter (upper case) is descriptive of the group using the Modified Zurich Class system; the second letter (lower case) refers to the largest spot in the group; and the third letter (also lower case) is the assessment of the distribution of sunspots throughout the group. Practice in classifying sunspot groups may be accomplished by comparing visual appearances of spot groups at the eyepiece with the descriptions included herein; then checking your work against the classifications logged daily by the professional observatories, many of which are posted on the internet. As the adage goes, practice makes perfect.

This is the system that all ALPOSS observers who classify sunspot groups are encouraged to use, especially those involved in the detection of solar flares. It only takes a minute or so longer to add the other two parameters but the information contained therein is much greater.

The Solar Cycle

The solar cycle was discovered by Heinrich Schwabe, a pharmacist in Dessau, Germany. He was an amateur astronomer who used his observing to help him escape the rigors of his inherited occupation as an apothecary. In the year 1826 the project of observing and noting sunspots was suggested by a friend in a nearby town. The paradigm of that time was that sunspots were capricious and haphazard. The recording of them would seem no more than an idle pastime. Noted astronomers of that time and before were nearly unanimous in their declared belief that there was no pattern or uniformity to the appearance of sunspots. They were simply a curiosity. Even the great Wm. Herschel had proclaimed that he "saw no reason to suspect that their abundance and scarcity were subject to orderly alternation." It is amazing that such a project was suggested, and even more so that it was engaged! Schwabe was not under any illusions of great discoveries and undertook the project in hopes of discovering an intermercurial planet. The plan was to search for a transit of such a body by noting all black spots seen. Schwabe noted the cycle then made a preliminary announcement of his discovery of a ten year periodicity to sunspots. Subsequent observations bore out his hypothesis which eventually became scientific law. In 1857 Schwabe received the Royal Astronomical Society's Gold Medal for "his choice of an original and appropriate line of work and in the admirable tenacity of purpose with which he pursued it." He observed the spots for a total of 43 years and passed away on April 11, 1875 at the age of 86.

Today the sunspot cycle is well established by an additional 150 years of accurate observations and by further historical research. The number of sunspots varies with a period of 8 to 15 years with the average being about 11.1 years. Note

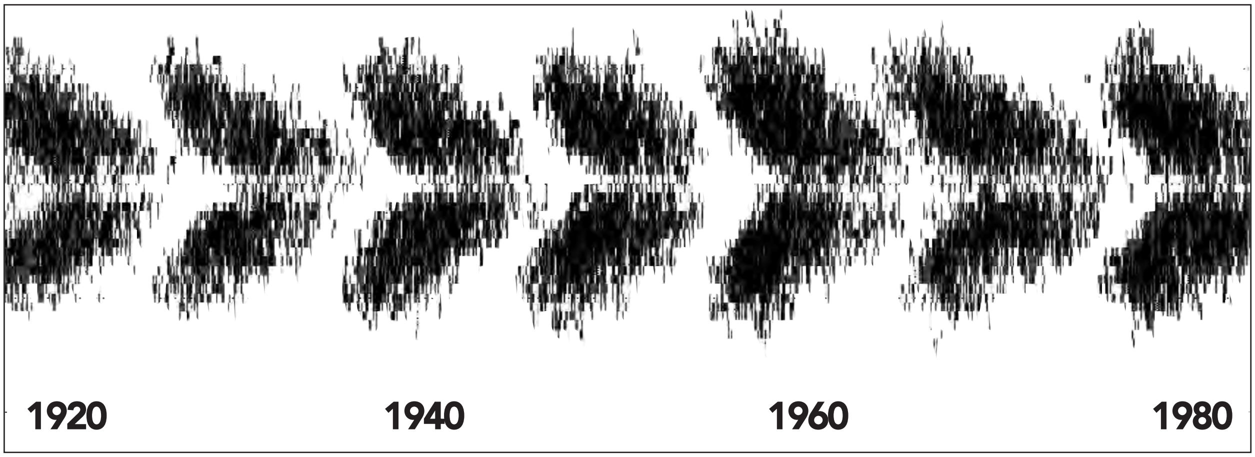


Figure 10. Classic Butterfly Diagram of time plotted against latitude of sunspot development. Courtesy Hathaway/NASA/NSSTC

that this is half of a magnetic cycle. This longer magnetic cycle was not discovered until the 20th century. Sunspot groups in a given cycle in the north hemisphere may have leaders that are positive polarity and followers that are negative. During that cycle the opposite will be true in the southern hemisphere. In the next cycle the polarities in each hemisphere will be reversed. Hence the magnetic polarity cycle in sunspots is two sunspot number cycles long. The mean maximum number of sunspots can vary by as much as three times from cycle to cycle. The rise to maximum is usually about three to four years with the remainder of the cycle being a slower decay to minimum. This rise is rarely without irregularities and variances in mean numbers of sunspots—as much as 50% are common.

During the beginning of the cycle, at the low ebb, new cycle sunspot groups form in high latitudes. These are recognized by the change in magnetic polarity. The alert observer may note the unusually high latitude (either north or south) and suspect a new cycle spot. As the cycle progresses the groups begin to appear in lower (more equatorial) latitudes. Until the end of a cycle the old cycle sunspot groups can be seen hugging the heliographic equator and the new cycle spots will be up around 40-50 degrees latitude. This migration of sunspot groups during a cycle was discovered and announced in 1863, by the English amateur astronomer, Richard Carrington and later elaborated upon by Gustav Sporer.

This variation of latitude with age of the solar cycle prompted E.W. Maunder, well know for his discovery of a hiatus in solar cycles from about 1645-1700, to plot sunspot latitudes against time. The result was a diagram called the "Butterfly Diagram" (Fig.10) which clearly shows the equatorial migration of sunspot groups during the course of a solar cycle. This diagram also shows that particularly active cycles tend to have early spots at higher latitudes. A plot of these for solar cycles from the mid-19th century to present hints at a periodicity in early sunspots being formed at higher latitudes of a hundred years or more. This is in line with suspected longer solar activity cycles and auroral records.

Recently, there has been suggestions that there may be some preference to sunspot group formation by longitudes. Observations bear this out on a short time scale of a few months to a year or more, but as yet longer term trends of this nature have not been proven.

Solar Rotations

Because the Sun is not a solid body it does not have a uniform rotation rate with respect to latitude. The spots seen at the equator rotate faster (about 25 days) than the spots nearer the poles (about 27 days at 30 degrees either side of the equator). The mean period is 25.38 days but because of our own motion about the sun, the synodic period is 27.2753 days.

Solar rotations are based on Richard Carrington's photoheliographic series from Greenwich in which rotation number one began on November 9, 1853. From that date the synodic period rotation numbers, called Carrington Rotations are determined. Since that time there have been over 2000 rotations of the Sun.

Flares

Because of their importance to amateur and professional astronomers, flares are discussed in greater detail in a separate section. Let it suffice here to say that flares are sudden releases of energy and mass from active regions. Most often they are observed in the chromosphere using Hydrogen Alpha or Calcium-K narrow band filters on telescopes. If they are energetic enough, they can be seen at broader band wavelengths and thus become White Light Flares (WLF). These were once thought to be very rare events but through some specialized techniques (not as expensive as the filtration mentioned above) they can be observed on ocassion in the more evolved groups.

In summary, there is a wide variety of brightnesses among the solar phenomena. The brightest are the white light flares, followed by faculae, normal photospheric material within the granule walls, the intergranular material, pores, penumbrae, and lastly the dark sunspot umbrae.

Active Regions

An *active region* is as the name implies, a region of activity on the Sun. Active regions can contain one or more sunspots. The National Oceanic and Atmospheric Administration (NOAA) assigns consecutive numbers to active regions as they are observed on the Sun, providing a way of cataloging this activity. Two observatories must observe a region before it is assigned a number unless a flare is observed within a region then it may be numbered before it is confirmed by the second observatory. The current numbering system began on January 5, 1972 and has been consecutive since that time. A typical "name" for an active region may be AR6085, AR abbreviates active region. As the Sun rotates, the same active region may be seen crossing the face of the Sun more than once. If this is the case the region will be given a new number, long lived active regions may receive several numbers.

Active regions are referred to only by a 4-digit number, so when number 10,000 was reached on June 14, 2002 all following regions were still addressed by the last four numbers of their name. For example, AR10056 is yet known as AR0056.

Observing Solar White Light Flares

by

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Solar activity is not just gauged by the number of sunspots observed. There are many other manifestations of solar activity also quantified that indicate well the level of activity. Flare production and strength are two such parameters. Flares are sudden discharges of energy and subatomic particles that take place in and around large sunspot groups as magnetic fields change above the groups. Flares release prodigious amounts of energy across most of the electromagnetic spectrum and are thus observable by a number of techniques. Larger flares can emit as much as a thousandth the energy of the sun during the duration of that flare. Subatomic particles are shot out at various speeds as well. These releases take different times to traverse the space between Earth and Sun but eventually impact the Earth's atmosphere causing changes in propagation of radio waves and the beautiful aurorae seen at temperate and polar latitudes.

Typically, flares last a few minutes to as much as four hours though most are from ten to twenty minutes in duration. More energetic flares tend to be of longer duration, especially when observed in shorter wavelengths. In visible spectrum observations done by amateurs the relationship is not quite as good. Flares are best seen in monochromatic light such as H-alpha or the H and K lines of calcium where only light of one absorption line is allowed to enter the telescope. Since flares are in emission in these lines, whereas the rest of the disk of the Sun is generally in absorption, they appear quite bright against the disk. In some cases flares can be so energetic that they will even be seen in the light of the continuum of the spectrum (between the dark absorption lines) as viewed in the amateur's telescope. These White Light Flares or WLFs were once thought to be relatively rare.

Not all sunspot groups produce flares. In 1938, M. Waldmeier devised the Zurich Sunspot Classification of these groups. It consists of nine steps or classes (A through J, omitting I) that delineate characteristic evolutionary stages of sunspot groups, though not all groups go through all classes. Most groups go only part way through the sequence and then either rapidly go backwards through the classes or decay to the final class. In general, the greater the area of a group the more asymmetrical will be its growth curve. So a large group will rise rapidly from class A to E and decay more slowly as it goes from E to J. Groups of classes D, E, and F are the big flare producers. But not all such groups produce big flares. This was a problem for flare forecasters on whose work various broadcast and space industries depended. Even with the most active class, F, a forecaster had a marginal chance of predicting flare probability in any given

24 hour period. In order for flares to be studied, a reliable system for identifying flare producing sunspot groups was needed. An observer would have to spend much time at the telescope observing every well developed group in hopes of seeing these elusive events. It would have been highly advantageous, on the basis of a few parameters, to weed out many less productive groups.

In 1966, Patrick McIntosh of the Space Environment Services Center of the National Oceanic and Atmospheric Administration, introduced a sunspot classification system that improved the older Zurich system. The new classifications consist of three letters. First is the Modified Zurich Class. It basically retains the old Zurich Class but G and J were removed as being redundant. A Modified Zurich Class was used rather than a totally new system making it easier for observers that might be reluctant to switch to the new system. The Second letter represents an assessment of the Largest Spot of the group. This is not necessarily the leading spot, but rather the LARGEST. The third letter represents an assessment of the Spot Distribution within the group. It takes only slightly longer than the old system to classify all the groups on the sun for a given day using the McIntosh System, but the information returned and usefulness of the new system makes it worth the slightly added effort. In order to understand this system better, refer to pages 18-21 of this book for a discussion of Sunspot Group Classification using the McIntosh System.

This system has proven an accurate predictor of flares in the many years of its use. Indeed, it has helped solar astronomers understand better the relationship between flares and sunspots. Sunspot groups that produce flares are relatively rare. Because of this it has taken several solar cycles of observations to demonstrate the effectiveness of the new system. Using the old Zurich system it was found that groups of class F were most likely to produce flares. But only a 40% flare probability in a 24 hour period could be predicted using this parameter alone. With the McIntosh System, using Modified Zurich Class F, the probability improved to 60%. Using just the Largest Spot class of "k" the probability in 24 hours was 40-50%. If just Spot Distribution category "c" were used, flare probability went up to about 70%. But, when all three dimensions of this system were used, classes Fsi, Fki and Fkc, showed a probability of up to 100% for production of M flares in a 24 hour period and the McIntosh Class of Fkc had a further probability of up to 50% in X flares (x-ray) production! This surpasses any former method of flare prediction used, including sunspot area.

In optical regions of the spectrum flares are classified by **size**: (All degrees are heliographic.)

s - subflare of less than 2 degrees area.

1 - "Importance 1" flares, greater than 2 degrees but less than 5.1 degrees in area.

2 - "Importance 2" flares, greater than 5.1 degrees but less than 12.4 degrees area.

3 - "Importance 3" flares, greater than 12.4 degrees but less than 24.7 degrees in area.

4 - "Importance 4" flares, greater than 24.7 degrees in area.

and by their **brightness**:

F - faint or barely noticeable

N - Normal or noticeable

B - Bright or obvious

This means that a 2B flare is one that was bright and between 5.1 and 12.4 square heliographic degrees area. An SF would be a faint subflare, the most common type. For other parts of the electromagnetic spectrum, like x-ray, there are other classification systems. But since amateur solar astronomers conducting a White Light Flare Patrol, or WoLF Patrol, will be observing in the visible spectrum these will not be discussed here.

Flares occur in places where magnetic change is taking place or where the neutral line between areas of different polarity lies. There are some precursors to solar flares in these places. Filaments near the flare site may go into rapid motion or may change brightness due to such motion in the line of sight if you are observing in relatively monochromatic light (doppler shifting). In larger flares the first sign is a pulse in hard x-ray and a slower pulsing in soft x-rays. Following this there may be flashes seen in longer wavelengths including optical. (This is again in rather monochromatic visible light and I know of no case where this has been reported in broad band white light.) The pulses are caused by electrons being shot through the corona at nearly half the speed of light causing oscillations in coronal plasma above the site which generates the radio bursts (called type III bursts) at frequencies from about 10 to 800 Mhz (note its the FM Band). Receive these emissions and you will be forewarned of the optical flare.

Lacking a magnetograph, amateur astronomers must look for flares (in monochromatic light, continuum or broad band white light) in the most common places where they occur. The priority list of McIntosh classes to be watched are: Fkc, Fki, Ekc, Eki, Dkc, Dai, Dso and Hsx. These are the most flare productive groups of the 64 classes in order of productivity. In the latter class, flares usually occur just beyond the outer penumbral boundary. Patrick McIntosh once advised me to also watch groups that suddenly arrange their spots in a line. He called this a "linear accelerator" and a good bet as a site for flares.

Within these groups one should watch:

-penumbrae that are chaotic, disturbed, or detached

-great clusters of smaller spots and penumbral bits between the main spots

-thin light bridges or light bridges caused by detachment of penumbrae

-sunspots with or without penumbrae, that are breaking apart without reducing in area

-and rapidly moving spots in a group.

Observing WLFs requires some special equipment and precautions. The goal here is to maximize contrast between the flare and its surroundings. Thus all optics should be very clean since scattering from dust and other contaminants on your optics will scatter light and reduce contrast. The telescope f/ratio should be long, f/20 or longer is good and helps to reduce apparent defocussing from optical heating and normal, daytime seeing. According to studies by Bray & Loughhead (1963), daytime seeing is 1 second of arc only about 1% of the time at a good site. So, reducing the aperture of your telescope, especially those big light buckets, to 4-6 inches will result in little or no loss of resolution and will yield an improvement in image steadiness and contrast by producing an unobstructed aperture. This will more than make up for any perceived losses.

You can increase your chance of seeing WLFs by increasing the contrast between the flare and bright photosphere. This can be done through wideband filtration, unlike the narrow band filtration of only a fraction of an Angstrom used in H-alpha observations. A good region to filter around is at 4300 Angstroms or 430nm called the G-Band. There are a number of absorption lines clustered here that go into emission in flares.When these normally dark lines become bright the difference in brightness is greater than if you were looking at a bright region of the spectrum. With a narrow band filter the contrast is much greater. Since broad band filtration will take in a fair portion of continuum it is still considered "white light".

Projection techniques will only detect the very brightest WLFs, explaining the paucity of them in the historical records. We have never received a report of a WLF by anyone using the projection method. The most simple method of observation in searching for WLFs, is to just use a mylar-type filter. The blue image of these filters, normally detested by amateurs, is quite close to our target wavelength. This is also the safest way to look for these flares. These filters are also very good for showing faculae associated with these complex groups well in towards the center of the disk. Only the highest quality filter should be used. There are some quality filters on the market and some home-made ones out of lesser quality materials. These lesser quality show a good deal of sky brightness just off the limb of the Sun. Such filters will probably scatter enough light to obliterate all but the brightest flares.

Beyond this one can obtain filters of about 100 Angstrom bandpass to use at the eyepiece WITH A MYLAR-TYPE PREFILTER!! It may be necessary to reduce the density of the prefilter but such experimentation should be done with great caution. Do not risk your eyes at any time and NEVER USE EYEPIECE FILTRATION ALONE! A prefilter is a must unless you have a specially designed solar telescope. If you are going to do this kind of observing you might do well to build a specialized telescope for the task, but that will not be discussed here. Some experimentation will likely be necessary if you want to go to narrower broad band filters but novices and the unsure are strongly encouraged to just stick with the commercial mylar-type filters. If you don't know, or aren't sure, don't do it!

When observing, first make a sketch of the region to be watched on the A.L.P.O. Solar Section Active Region observing form. Let the spot group fill the box. Once this is done observing may begin. Attempt to observe the region at least once every ten to twenty minutes, the average lifetime of a flare. To check less often would risk missing one. Be patient! It may be quite a while before you bag the first one. If you observe the McIntosh E and F groups cited in our priority list, you will be more likely to see one sooner. Do not sit constantly at the telescope. You will not see change. It is too gradual and your eye needs the rest between observations.

Note ANY changes on the form. Not all flares behave the same way and not all precursors are well known. Record time to the nearest second, start and stop. Surges have been photographed in white light but have only been viewed at the limb (see Sky & Telescope, Dec., 1961, p.330). Some of the rapid changes reported in penumbrae in history may well have been observations of such surges. The only way to be sure of such observations is to build a larger data base of observations from which patterns may emerge.

Professional observations indicate that WLFs begin as a bright point of probably granule size in one of the sites noted earlier. My own observations during cycle 22 in AR5060 and 5062 (June, 1988) tend to support this position. Other points will pop up near the first in only a couple minutes, or the single one may be seen to enlarge rapidly. These early stages are about all that happens in the smaller flares, and in sub-flares the single point, substantially brighter than the photosphere, may be the full extent lasting only a few minutes. The human eye can detect only changes that are in excess of about 10% against such a background so be aware of any brightening. Dr. Don Neidig, of Sacramento Peak Solar Observatory, in New Mexico, once expressed the suspicion that more such faint flares are visible in white light but because of the low contrast, short lifetime and smallness, go unnoticed.

In larger flares the points will grow in brightness, merge and become a bright area or, if you are very lucky, a bright ribbon. If you are so lucky, watch for a double ribbon (running on either side of the neutral line of magnetic polarity) or a shaded, penumbral-like area near the flare which could be a surge.

Observing these, the most energetic events in our solar system is an exciting, and taxing business. It's taxing in the long wait for the flares and exciting in the activity when it happens. It does not require long term commitment of daily observations but is a type of solar observing that can be done on the odd day when you have a couple hours to spare or while puttering about the yard. You just go to the telescope every ten minutes or so and make your observation. At the risk of stating the obvious, the observations will not make themselves. So make your observations and report them in a fashion where they can be useful. Thus, you will by pursuing your hobby, see the most energetic events in our solar system and be contributing to science. Remember, only a couple of hours on a Saturday afternoon may repay you with a view of more energy than has been collectively used by humans in all our years of existence!

Suggested Reading List

(Ed.note—while no list can be complete because it will be out of date yearly as new books are published, this listing will satisfy most readers and supply sources to answer many questions not addressed in this Handbook.)

Books of Primarily Historical Interest

Abbot, C.G., **THE SUN**, D. Appleton & Co., NY, 1912
Abetti, G., **THE SUN**, Macmillan Co., NY, 1961
Abetti, G., **SOLAR RESEARCH**, Macmillan Co., NY 1963
Baxter, W.M., **THE SUN AND THE AMATEUR ASTRONOMER**, Drake Publ. Inc., NY, 1973
Ellison, M.A., **THE SUN AND ITS INFLUENCE**, Macmillan Co., NY, 1955
Kuiper, G.P., editor, **THE SUN**, University of Chicago Press, Chicago, 1953
Meadows, A., **EARLY SOLAR PHYSICS**, Pergamon Press, 1970
Menzel, D.H., **OUR SUN**, Harvard University Press, Cambridge, MA, 1959
Mitchell, S.A., **ECLIPSES OF THE SUN**, Columbia University Press, NY, 1935
Moore, P., **THE SUN**, Norton, NY, 1968
Newton, H.W., **THE FACE OF THE SUN**, Penguin Books, London, 1958
Pepin, R.O., **THE ANCIENT SUN**, Pergamon Press, NY, 1979
Proctor, M., **ROMANCE OF THE SUN**, Harper & Bros. Publishing, NY, 1927
Stetson, H.T., **SUNSPOTS IN ACTION**, Ronald Press, NY, 1947
Thackery, A.D., **ASTRONOMICAL SPECTROSCOPY**, Macmillan, NY, 1961
Young, C.A., **THE SUN**, D. Appelton & Co., NY, 1898
Zurin, H., **THE SOLAR ATMOSPHERE**, Blaisdell Publishing, Waltham, MA, 1966

General Interest Reading

Giovanelli, R.G., **SECRETS OF THE SUN**, Cambridge University Press, NY, 1984
Lang, K.R., **THE CAMBRIDGE ENCYCLOPEDIA OF THE SUN**, Cambridge University Press, NY, 2001
McKinnon, J.A., **SUNSPOT NUMBERS: 1610-1985**, World Data Center, Boulder, CO, 1987
Nicholson, I., **THE SUN**, Rand McNally, NY, 1982
Noyes, R.W., **THE SUN, OUR STAR**, Harvard University Press, Cambridge, MA, 1982
Pasachoff, J.M., **THE COMPLETE IDIOT'S GUIDE TO THE SUN**, Alpha, NY, 2003
Waldmeir, M., **THE SUNSPOT ACTIVITY IN THE YEARS 1610-1960**, Zurich, 1961

Novice/Intermediate/Advanced Reading

Beck, R., **SOLAR ASTRONOMY HANDBOOK**, Willman-Bell, Richmond, VA, 1988
Bray, R.J./Loughhead, R.E., **SUNSPOTS**, Dover, NY, 1964
Bray, R.J./Loughhead, R.E., **THE SOLAR CHROMOSPHERE**, Dover, NY, 1974
Bray, R.J./Loughhead, R.E., **THE SOLAR GRANULATION**, Chapman & Hall, London, 1967
Brody, J., **THE ENIGMA OF SUNSPOTS**, Floris Books, Edinburgh, Scotland, 2002
Cram,L.E./Thomas, J.H., **THE PHYSICS OF SUNSPOTS**, Sacramento Peak, Sunspot, NM, 1981
Espenak, F., **FIFTY YEAR CANON OF SOLAR ECLIPSES 1986-2035**, NASA, Washington, D.C., 1987

Novice/Intermediate/Advanced Reading *(cont.)*

Foukal, P.V., **SOLAR ASTROPHYSICS**, Wiley & Sons, NY, 1990
Gibson, E.G., **THE QUIET SUN**, NASA, Washington, D.C., 1973
Henderson, S.T., **DAYLIGHT AND ITS SPECTRUM**, Halstead Press, NY, 1977
Jenkins, J.L., **THE SUN AND HOW TO OBSERVE IT**, Springer-Verlag, NY, 2009
Kippenhahn, R., **DISCOVERING THE SECRETS OF THE SUN**, Wiley & Sons,NY, 1994
Kitchin, C., **SOLAR OBSERVING TECHNIQUES**, Springer-Verlag, London, 2002
Kitchin, C., **OPTICAL ASTRONOMICAL SPECTROSCOPY**, IoP Press, 1995
Macdonald, L., **HOW TO OBSERVE THE SUN SAFELY**, Springer-Verlag, London, 2003
Neidig, D.F., **THE LOWER ATMOSPHERE OF SOLAR FLARES**, Sacramento Peak, Sunspot, NM, 1981
Phillips, K.J.H., **GUIDE TO THE SUN**, Cambridge University Press, NY, 1992
Sawyer, R.A., **EXPERIMENTAL SPECTROSCOPY**, Prentice-Hall, 1946 (Dover, 1963)
Spence, P., **SUN OBSERVER'S GUIDE**, Firefly Books, Richmond Hill, Ontario, 2004
Stix, M., **SUN**, Springer-Verlag, London, 1991
Strong, C.L., **THE AMATEUR SCIENTIST**, Simon & Schuster, NY, 1960
Sturrock, P.A., editor, **SOLAR FLARES**, Colorado Assoc. University Press, Boulder, CO, 1980
Sturrock, P.A., editor, **PHYSICS OF THE SUN**, D. Reidel Publishing, Dordrecht, 1986
Svestka, Z., **SOLAR FLARES**, D. Reidel Publishing, Dordrecht, 1976
Tandberg-Hanssen, E., **SOLAR PROMINENCES**, D. Reidel, 1974
Taylor, P., **OBSERVING THE SUN**, Cambridge University Press, NY, 1991
Taylor, P./Hendrickson, N., **BEGINNER'S GUIDE TO THE SUN**, Kalmbach Books, WI, 1995
Veio, F., **THE SUN IN H-ALPHA LIGHT WITH A SPECTROHELIOSCOPE**, Veio, 1991
White, O., **THE SOLAR OUTPUT AND ITS VARIATION**, Colorado University Press, Boulder, Co, 1977
Xanthankis, J.N., **SOLAR PHYSICS**, Wiley & Sons, NY, 1968
Zurin, H., **ASTROPHYSICS OF THE SUN**, Cambridge University Press, NY, 1968