Three Cheers for the Photosphere

By Jim Daley
Ludwig Schupmann Observatory and Springfield Telescope Makers

Introduction

This is the story of the design, construction, and imaging results of a homemade solar telescope. The goal was to develop a diffraction-limited instrument of the highest possible optical contrast (minimum light scatter and optimum operational wavelength) for observing delicate photospheric features including granulations, faculae, and, of course, fine sunspot detail.

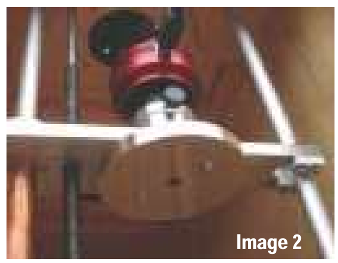
Beautiful and scientifically important as the chromospheric features are, these observations seem to be overemphasized by the amateur. This is understandable given the profusion of relatively small H-alpha telescopes available today. Keep in mind, though, that just a few average-size photospheric granules outshine the entire chromosphere, including the corona itself (about seven granules would light the Earth the same as one full moon, typical of the illumination level during a total solar eclipse). In a way, the chromosphere is the Sun's will-o'-the-wisp! Most of the life-giving solar radiation falling on Earth is emitted at the top of a deep convective zone and is called the photosphere. This layer is so thin that we can consider it a surface. This surface is defined by the sharp solar limb which has a depth, or gradient, on the order of 0.5 arcseconds, perhaps 300 kilometers, as viewed from Earth.

To further advance our understanding of the Sun's physical processes, astronomers using large solar telescopes employing adaptive optics have recently made significant discoveries while observing the photosphere (nature and motions of intergranular lane bright-points for instance). Observations of the photosphere's changing details, some on time scales of a few minutes, provide one of the most fascinating and challenging of amateur astronomy pursuits. It is this area that I have concentrated my recent amateur efforts as well. It is due to the technique known as "lucky imaging" (LI) that high resolution photospheric observations can be performed practically every clear day from my backyard observatory located in southern New Hampshire.

My Solar Telescope

Many of the ideas for my solar telescope were gleaned from the pioneering work of German amateur Wolfgang Lille, whose film photography of white-light solar features are still among the best obtained by an amateur. My instrument (**Image 1**) has an objective lens of 8 inches clear aperture and a 172-inch focal length. This single-element biconvex lens is made of highly polished coronagraph-quality BK-7 crown glass and provides the lowest possible light scatter of any high-transmission focusing element. The lens is bent for zero coma and aspherized to correct spherical aberration. Operating at f/21.5, the field is diffraction-limited over the entire solar disk at the selected imaging wavelength. This field is far greater than needed for most work. The second element is a 3.5-inch (3-degree prism angle) Herschel wedge made from optical-grade fused silica. The wedge is used with its critical face at an 8-degree tilt angle and is located about 36 inches before focus, thus folding the instrument to a more manageable length. This critical face is highly polished and, being uncoated, scatters less light (in the reflected direction) than that of the objective by at least a factor of ten! About 94 percent of the solar heat and light (roughly 50 watts) is transmitted through the Herschel wedge and sent to a light trap made of blackened copper sheet and located outside the tube. It is cooled by natural convection and radiation. The reflection from the second (back) surface of the wedge falls on a thick (blackened) copper plate and is heat-sunk to an air-cooled, finned radiator located on the outside of the tube.

The objective's focus falls at normal incidence on a perforated 3.37-inch-diameter, concave field-stop mirror (**Image 2**). Note that the solar image is 1.6 inches in diameter at the field-stop mirror, thus the mirror must be sized in order to explore the entire solar limb. This mirror takes no part in the imaging process, but simply reflects most of the remaining and optically harmful solar energy (about 2 watts) back down the path, through the wedge, and into the aforementioned light trap. Only the light passing through a 0.340-inch, centrally drilled hole in the mirror can reach the sensor. This drilled hole is the system field stop and is sized to just fully illuminate the sensor's 4.30 x 3.36 mm chip yielding a system unvignetted field of view of 3.36 x 2.62 arcminutes. The sensor is located about 2.3 inches beyond the hole-mirror at a far-red focus and is bandwidth limited with an interference filter mounted in the camera's nosepiece. The filter, when slightly tilted, operates at 705.7 nm and its bandwidth is 1.0 nm (FWHM) centered on a temperature sensitive titanium oxide (TiO) absorption band. Impressed with images from the Big Bear Observatory's New Solar Telescope, where a larger TiO filter is used, I adopted it for my telescope. Because the filter bandwidth is relatively narrow, the telescope's in-band longitudinal color is less than 1/20 wave, thus the theoretical Airy disk is preserved.



ZWO ASI120MM camera mounted on its focus rail—note the focus lead screw and reflecting field stop mirror. A quickly-removable panel provides access to this section.

The light level is slightly too great even after the interference filter, so I machined a cell in the back of the aluminum field-stop mirror where weak, high-optical-quality neutral-density filters can be placed as needed for different detectors (mechanically shuttered CCDs, for example).

Great effort was spent avoiding heat buildup within the telescope tube, thus minimizing tube currents. Optical light-scatter is also extremely low as the imaging results demonstrate. (**Image 3**)

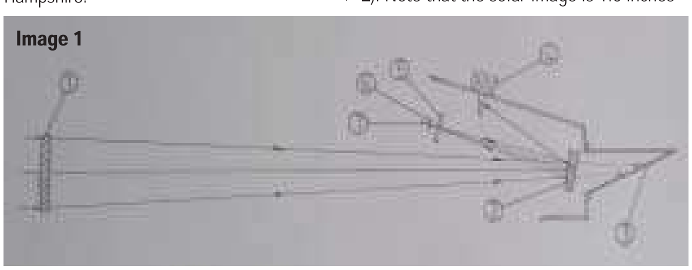
The images essentially show what is seen in "white light;" however, cooler dark regions, like the umbra, are further darkened by the TiO filter, thus revealing the unaffected umbral dots and fine structure with greater contrast. This is because the TiO absorption band makes its appearance at umbral temperatures, intergranular lanes, and other cooler regions. The theoretical angular resolution of the instrument is about 0.71 arcseconds and the smallest details observed confirm this. I think of this instrument as a prototype and scalable to much larger apertures, perhaps as large as 2 meters! Indeed, modern glass technology makes this possible. But, back to Earth, an amateur version scaled to 12-inch aperture is entirely practical.

Solar Observing in General

It is vital, and I can't overemphasize this, that the aperture of a backyard solar telescope be as high above ground level as possible. This makes the equatorially mounted, long-focal-length refractor the amateur's only practical high-power instrument in this work. This is because 1) the objective lens, which seals the tube, is much higher above ground turbulence than any other arrangement (Newtonians, for example); and 2) the enclosed wooden tube shields the optical path by averaging the local thermal variations. These tiny cells (heat shimmer) rather quickly dissipate with height and even at 12 feet above ground level their optical impact is greatly reduced. This is the principal reason long refractors consistently show cleaner Airy disks under most conditions, day and night! During the summer Sun's meridian passage (a time when I almost always get the best solar images) the objective lens is about 14 feet above ground level. The outside south wall of the observatory must be coated with high titanium dioxide content white paint to keep it cool and thus free from rising surface heat streamers which may cross the telescope's line-of-sight. You can see why the great solar observatories are of the tower type or located on a high-altitude lake peninsula or causeway, such as the Big Bear Solar Observatory's NST, currently the most powerful solar telescope.

Imaging and Processing

The principal imaging detector is a ZWO ASI120MM CMOS fast (monochrome)



Optical diagram (not to scale). Circled numbers indicate important components: 1) Single-element objective lens. 2) Fused silica Herschel wedge. 3) Convection-cooled, open-sided sheet copper light and heat trap. 4) Externally cooled heat sink and light trap to intercept the Herschel wedge back-reflection energy. 5) Polished aluminum field restrictor (stop) sends most of the solar energy from the Herschel wedge back upon itself and into the light trap. 6) Titanium oxide Interference filter (705.7 nm). 7) Sensor focal surface.

The solar telescope in its roll-off-roof observatory

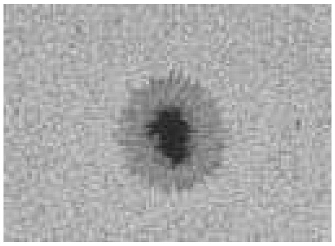


Image of a nice symmetrical sunspot (spot is 31 arcseconds wide) with surrounding granulation; umbral dots are just visible. Resolution about 0.75 arcseconds.

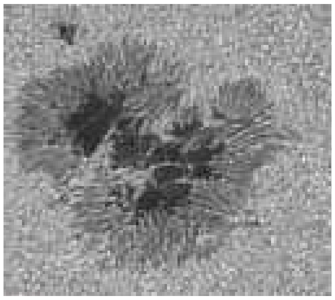
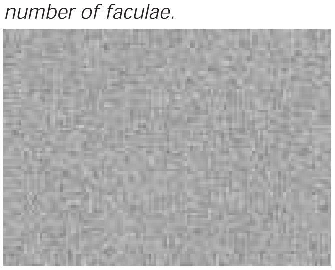


Image of a very complex sunspot with fine umbral details.

Limb image showing a great number of faculae.



Wide field (5.4 x 3.6 arcminutes) single image (no stacking) of disk-center granulation taken with the author's vintage SBIG ST-7XE CCD using the described telescope. Exposure 0.12 second. The seeing was near perfect for this image, a rare event in my backyard!

framing camera. The angular field of each pixel is 0.165 arcseconds, thus well oversampled for maximum possible resolution. AVI video files are captured with SharpCap 2.9 and video frame stacking is performed with Autostakkert. Final image enhancement is done in RegiStax6 using wavelet processing. These programs are all free Internet downloads. The typical frame rate for roughly 60-arcsecond fields (380 x 380 pixels) is 58 frames per second, and typical exposure times run about 340 microseconds, which completely "freezes" the atmospheric seeing. Because of various seeing phenomena, including coherence of seeing (which is a frame-to-frame, turbulence-caused image distortion that is mostly correctable in Autostakkert and which increases in harmfulness with greater field angles), this frame size is the one most used in my observations.

It is vital in this type of solar work to operate from a darkened room (you must be comfortably seated and see the computer screen perfectly). My observatory has a small attached computer room to the north where the camera's USB cable leads from the telescope, through the wall and directly to the laptop. For high-speed video the cable is necessarily short and some thought must be given to the layout to allow at least a few hours of observation without cable tug disturbing the telescope pointing.

Operationally, I begin an observing run by judging the image quality (and setting the telescope focus) of the free-running video on my Dell laptop. As powerful as LI is, good seeing is still very important. It is also important to open the histogram feature and set the exposure to about 60 percent full-well (avoiding saturation at the upper limit). The capture program allows you to set the gamma or contrast value (1 to 100). I usually set it at about 40.

One soon senses the cadence of the seeing and learns to start a recording at the best moments. Recording can be stopped and captured any time the seeing "blows up" or wind induced angle jitter becomes excessive. Typically, four really good videos (an eyeball estimate) of at least 20 seconds duration are selected for processing from the 25 or so recorded during an observing run.

The best video frames from each good recording are computer selected (in Autostakkert) by a contrast algorithm and presented in descending order of quality. I use the percent quality value feature to decide the number, where 100 percent is (relatively) the best. I usually cut the number of frames at 90 percent quality and use the displayed value of frames within these bounds to stack. Some videos provide only five or six good frames meeting the aforementioned criteria, while others, under great seeing, can yield up to 200 sharp frames, yet the final (after wavelet sharpening in RegiStax) results are sometimes rather similar!

There is no room in this short article to explain, in detail, all the processing steps; however, they can be learned quickly. The Internet probably has user groups that can help if you decide to try these powerful imaging techniques.

The Images

The photospheric images shown here were taken August through October 2016 during the final stages of solar cycle 24, one of the lowest-amplitude cycles in history. Fortunately, a few exciting sunspot groups appeared in this period while I was testing the instrument. Many technical improvements are underway as I learn of the tiny effects that potentially compromise results.

10, 25, and 50 Years of the Astronomical League's Magazine

Compiled by Mike Stewart, Astronomical League Historian

November 1967

Keeper of the Skies

Can an amateur astronomy club know when it is fulfilling its responsibilities?

To begin with, let me point out two major ones that well-rounded clubs should have realized upon their conceptions. The first is to promote an active interest among its own members, between clubs, and (where it can) in public.

Another responsibility is that of being a community authority on stellar events. The amateur, therefore, is an earthly treasurer of the largest thing known to man—the universe! The professional cannot fill this gap since he is too busy with research. His role is that of the discoverer. The amateur is the colonizer, the utilizer of the discoveries, the guiding movement for the spread of astronomical knowledge. So amateur astronomy encompasses more than the aspects of a mere hobby.

How large is the amateur astronomer's practical collection? Knowledge and viewing the constellations, the planets, and the moon should be within the scope of every amateur.... In addition, information on satellites, periodic meteor showers, comets and asteroids, variable stars, and deep-space phenomena, such as galaxies and nebulae, should be obtainable from members of sections of the club.

The more mechanically inclined should be able to deal with telescope making and photography.

Local amateur astronomy clubs perform a vital outreach function today as in the past. Have you ever thought of yourself as a colonizer, someone who spreads knowledge about the universe?

November 1992

The Tales of the Unknown Astronomer

What a feeling, to be walking around the hallowed grounds of Stellafane for the first time! To top it off, it was the peak of the Perseid meteor shower, too. After hours of wandering, it was time to take a breather. There was just room for one more on a comfortable looking stone seat at the front of the little pink clubhouse, so I joined those who were already sitting and watching meteors. On my right was a young lady named Connie who oohed and aahed with each meteor.

A very brief conversation determined that she lived just down the hill from the convention, had read about it and the meteor shower in the newspaper, and had walked up to check it out. Then she astonished me by replying that she had never looked through a telescope.

Would you like to? I asked. May I bring my friend? came her nervous reply. When I answered of course, she quickly rounded up her 8-year-old son Timmy, and her friend Frank. Close by was my friend Steve Hubbard, who had come up from Boston with his 16-inch Newtonian.

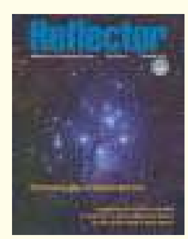
Steve happened to have his scope on M-51, and the view was very nice. All three of my guests could see the spiral arms easily. Good start!

For the next 30 or 40 minutes, we looked at many wonderful sights in many wonderful astronomers' telescopes, and never ran into one grouch.

A friendly astronomer, a simple question, and several obliging friends gave this trio their first views through a telescope. One wonders what effect Timmy's first view through a telescope had on his future. Have you ever introduced someone to the wonders of astronomy with your telescope?

December 2007

Astronomy Day 2007



From the Middle East to the middle of the Pacific, the spirit of Astronomy Day continues to thrive globally. Since its inception in 1973, Astronomy Day's mission of bringing astronomy to the people has touched hundreds of thousands of lives. It is through the tireless efforts of amateur astronomers and their uncanny ability to generate community collaboration that Astronomy Day festivities on such a large scale are possible. This year's efforts resulted in some of the most creative and well-attended Astronomy Day events to date.

To be especially commended is Gary Fujihara's AstroDay Institute in Hilo, Hawaii, winner of the 2007 *Sky & Telescope* Astronomy Day Award. Industrious planning (which started on the day after Astronomy Day 2006) resulted in their biggest event ever, attracting over 15,000 people. Over thirty collaborating organizations (including astronomy clubs, observatories, educational institutions, cultural organizations, and the media) helped to make the event a resounding success. It is inspiring to see an entire community come together in the name of astronomy and space education.

"Bringing Astronomy to the People" is now held twice each year, once in the spring and once in the fall. Astronomy Day offers clubs an opportunity to colonize. Does your club hold an outreach event for Astronomy Day?