Transits, Spots, and Eclipses: The Sun's Unique Role in Outreach

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Abstract The author shares her experiences exploiting the sun in the service of outreach, and encourages AAVSO observers to take advantage of the sun's ongoing reawakening from the minimum of its activity cycle to engage in both solar observing and solar-based outreach.

1. Introduction: our variable sun

Our sun is considered a variable star, showing variations in two distinct ways. First, as viewed from Earth, Mercury and Venus occasionally transit in front of the sun. The most recent opportunity was a transit of Mercury on November 11, 2019. At Central Connecticut State University (CCSU)'s Copernican Planetarium we projected a NASA live feed of the event onto the dome while a telescope with a solar filter was set up on the roof for in-person viewing (Figure 1). Anyone alive today who hasn't viewed a transit of Venus needs to have themselves cryogenically frozen, or build a time machine, because there's not going to be another opportunity until 2117. Transits of Mercury happen about every decade or so, with the next on tap for November 2032. But transits of Venus are far rarer and clustered in pairs eight years apart, with the last tandem occurring in 2004 and 2012.

Fortunately for short-lived human observers, our sun is also a variable star in the sense that it has an ever-changing number of sunspots, areas of intense magnetic activity that appear darker than the average surface (the photosphere) because they are cooler and hence less luminous. There are also hotter and thus brighter than average areas called faculae. While one might expect the brighter and dimmer areas to cancel each other out, in the case of stars similar to our sun the brighter areas tend to dominate on average, except when large sunspots are visible (Kopp *et al.* 2016). Therefore, as counter-intuitive as it might seem, the overall brightness of the sun measured over the electromagnetic spectrum (or total solar irradiance) is generally about 0.1% higher when sunspot activity is at its maximum versus where it is now, coming out of minimum, because higher sunspot activity correlates with higher amounts of faculae and other forms of energetic activity.

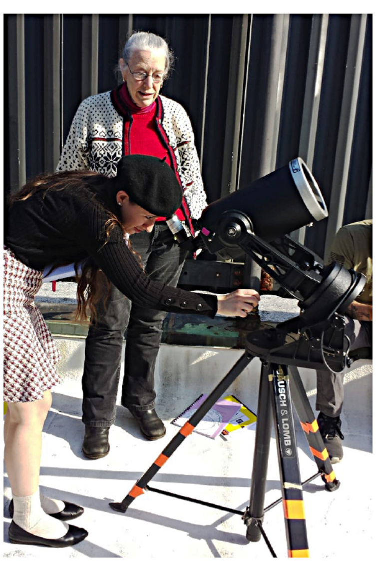

Figure 1. CCSU students observing the November 22, 2019, transit of Mercury.

The AAVSO is dedicated to the careful observation of stellar variability in all its forms, including that due to transits and spots. The AAVSO Exoplanet Section (https://www.aavso.org/exoplanet-section) not only provides a target list of confirmed exoplanets that are observable through standard amateur equipment, but also offers a CHOICE online course on Exoplanet Observing. More exciting is the role of AAVSO observers in the TESS (Transiting Exoplanet Survey Satellite) Follow-up Observing Program (TFOP), where amateur astronomers can play a significant role in weeding out false-positives. While there is no AAVSO observing section generally devoted to the study of spotted stars, observers have contributed observations of a number of such stars to the AAVSO International Database, for example CT Vir, MS Ser, and AX CrB. Since these stars generally vary by only a few tenths of a magnitude (or less) they are suited for CCD rather than visual observations. But there is one particular spotted star that is not only well-suited to visual observing, but has the bragging rights of owning of its own observing section—the sun. The AAVSO Solar Section (https://www.aavso.org/solar) aggregates observations from observers around the world into a monthly *Solar Bulletin*. Over time, the long-term trends of solar activity become apparent, including the semi-regular nature of the approximately 11-year-long solar cycle. The *AAVSO Solar Observing Guide* (available in seven languages) leads the interested observer through the theory and practice of safe solar observing.

While we have considered these two kinds of variable activity as separate and distinct for the sake of our discussion, anyone who has taken the opportunity to observe sunspots during a transit knows that nature is not that simple. Indeed, while the Kepler Space Telescope (RIP) proved to be a transiting exoplanet discovering fiend (discovering thousands of transiting exoplanets), it also detected other types of stellar variability, including spotted stars. At these distances we don't observe the starspots directly, but instead see the small deviations in the brightness of the stars due to transient spots and splotches. As in the case of our sun, this activity varies in three ways. First, individual spots only last for a certain length of time, typically anywhere from several hours to a few months. Second, as the star rotates you will view different spots. Third, the overall activity waxes and wanes in a cyclical manner, for example an approximately 11-year cycle for our sun. Therefore time-series observation of these "spotty" stars not only divulges the existence of the spots, but computer models can also be used to estimate the sizes and likely latitudinal distribution of spots (Luo *et al.* 2019), along with the rotational cycle, and, if we watch it long enough, estimate the starspot cycle.

These are exactly the same types of observations we have been doing with our own sun for centuries, and in some cases, longer. Therefore, while we might have to wait a few years for the next opportunity to view a transit of our own star, the sun's natural cycle of activity (now slowly sliding out of minimum) is an excellent starting point for teaching about the properties of stars. In addition, our star, the star that most people would agree is the most important star to their personal lives, is also a powerful hook for opening up discussions of the importance and fascinating world of variable stars with the general public, including children.

Figure 2. Using colored filters to read "secret messages." Note the plastic UV beads are white/clear in the classroom light.

2. Solar outreach

Sidewalk astronomy involving the sun is always fun, as long as one takes care to make safety the number one concern. When local students from an urban high school visited our campus, I set up a telescope with a white light solar filter outside the Student Center. As they exited the building, I invited the teens to look through my filtered 6-inch Schmidt-Cassegrain, an instrument I only use for solar observing (having removed the finder scope for safety). They suspiciously squinted skyward and asked what I was looking at. I enthusiastically offered "The Sun!" After a quick safety lesson in which I explained my equipment they eagerly accepted what for most was their first look through a telescope. Most of them simply couldn't believe what they were seeing. They had heard of sunspots, but to think that you could actually see them with your own eyes seemed like magic. The icing on the cake was learning the relative size of those sunspots to our Earth. To a person, they were astounded. They had no idea of scale in the solar system; after all, to all but global travelers, the Earth seems so incredibly huge.

Projection methods are also available for solar observing, and when working with large groups, especially involving young children, projection is recommended. One option is the commercially available Sunspotter, a folded refractor that projects an image of the sun on the base of a triangular wooden frame. It is relatively easy to use, so children can help to set it up and aim it at the sun by minimizing the shadow projected by a small wooden gnomon. The Sunspotter offers enough resolution to allow for the viewing of sufficient sunspot groups and spots to track the overall sunspot cycle (Larsen 2013). Therefore, schools and other astronomy outreach groups can use the instrument as a hands-on educational tool to safely monitor solar activity over long periods of time and compare their observations to the published solar activity values (for example in the AAVSO *Solar Bulletin*). The sight of sunspots projected on the paper screen amazes children of all ages. But they are soon disappointed when the sun begins to disappear, drifting out of the field of view. The moment is infinitely teachable: why did it appear to move, they ask. Is the sun really moving, or are we moving, I reply. The best part of outreach, especially with children, really is the questions, meandering from topic to topic and, invariably, ending up at black holes, and then extraterrestrials.

If we observe transits of stars outside our solar system, what would an extraterrestrial astronomer observe if they were looking back at our sun? If they were oriented in just the right way they would see both types of activity—transits and evidence of the sunspot cycle. Wells *et al.* (2018) determined that 68 currently known exoplanets are positioned in such a way that any similar astronomical technology to our own could be used to observe at least one planet in our solar system transiting the sun. It is therefore possible that any alien civilizations that exist in our galaxy able to view our sun at the right orientation could discover the existence of our planetary system by noting the variability of our sun through transits. Such an idea is not only fascinating to astronomers, but students and the general public as well. Who knows who could be watching us right this moment?

Admittedly, the most effective outreach activities are more than a simple "one and done." Offering multiple opportunities to engage with the material more clearly demonstrates the connections between various aspects of astronomy (and relationships with physics, for example), and more accurately represents the scientific endeavor. Fortunately, there's a lot one can actually do with the sun in terms of outreach. I've hosted many three-hour Saturday morning workshops for 7th graders, and in my experience, it takes a lot of individual activities to fill that time. The sun provides a great unifying theme that bridges multiple fundamental laws of nature. For example, the various forms of light (the electromagnetic spectrum) can be easily demonstrated through the use of cheap plastic beads that change color when exposed to UV. Couple a handful of these beads with a pipe cleaner and you have a bracelet that doubles as a UV detector. Children are fascinated by the beads' ability to detect these invisible rays, even on cloudy days. The use of filters in astronomy is easy to demonstrate, using colored plastic film and "secret messages" written in particular colors (Figure 2). Attendees apply this knowledge to pictures of the sun taken at different wavelengths.

Similarly, an exploration of the properties of bar magnets and horseshoe magnets leads to a short lesson on the magnetic field of the sun, complete with pictures of the sun showing not only how individual sunspot groups change over time, but the apparent motion of sunspots due to the sun's rotation. The similarities between bipolar sunspot groups, prominences, and the physical magnets the students had previously experimented with become readily apparent. Styrofoam models of the sun are then constructed, with the children adding their own sunspot groups, faculae, and prominences (Figure 4). We cap this off with actual observations of the sun (weather permitting), both in white light and hydrogen alpha (thanks to the availability of small, commercially available "solar telescopes").

As previously explained, children will notice that the sun drifts out of the field of view of the Sunspotter (or a telescope that is not tracking), which leads to a discussion of the rotation of the Earth. We can easily turn this around and demonstrate how the apparent motion of the sun in the sky caused by the Earth's rotation can be used to tell time. Children make simple sundials and (weather permitting) take them outside to be used. Otherwise, flashlights are handed out and they observe how the shadows shift as the "sun" appears to move through the day. Many printable templates for simple sundials can be found online, but my personal favorite is the "Pocket Sun Clock" (with accompanying lesson plan) available in the Astronomical Society of the Pacific's *The Universe at Your Fingertips* (Fraknoi 1995) (Figure 3).

The planetarium is the capstone of our time together, where I not only run through the obligatory constellation stories, but can speed up the yearly apparent motions of the sun in our sky, demonstrating the relationship between the sun and the seasons, and how this relationship changes depending on an observer's latitude. Children love watching the moon fly by as I put the sun through its annual paces along the ecliptic, pausing to point out the ever-shifting positions of the bright planets.

For those who are concerned about aligning outreach activities with educational standards (in some cases a demand of school-funded outreach such as field trips), the activities I have described above align with standards PS4.B Electromagnetic radiation, ESS1.A The universe and its stars, and ESS1.B Earth and the solar system, of the Next Generation Science Standards (NGSS), which have either been adopted or adapted by most states (NSTA 2014). There's a lot of science in sun-based activities, as well as opportunities for creativity. For example, I encourage children to decide which part of the solar-activity cycle their individual sun model represents, and design the numbers of spots, faculae, and prominences accordingly.

But undoubtedly the greatest solar outreach opportunity of recent memory was the Great American solar eclipse of August 2017. That was a very busy time for professional and amateur astronomers alike, putting in considerable efforts in outreach to assure that the public enjoyed the eclipse safely. I noticed many children in the audiences of my eclipse talks at libraries and community centers, and I was even invited to visit a local elementary school to discuss safe eclipse viewing in an age-appropriate way. I have always found children to especially appreciate silly visuals, so I was accompanied to every public eclipse talk by BB the eclipse-chasing bunny, an old plushy who has been my lucky charm at five total solar eclipses (Figure 5). BB's job in this circumstance was to demonstrate to children how to safely observe with their solar eclipse glasses (Larsen 2019).

A common question asked at these pre-eclipse outreach sessions was how eclipse glasses could be used after the main event. Again, this is a perfect opportunity to explore the solar-activity cycle. Approximately 3% of all sunspots are

Figure 3. Seventh graders setting up their Pocket Sun Clocks. Note the UV bead bracelets have changed color in the sunlight.

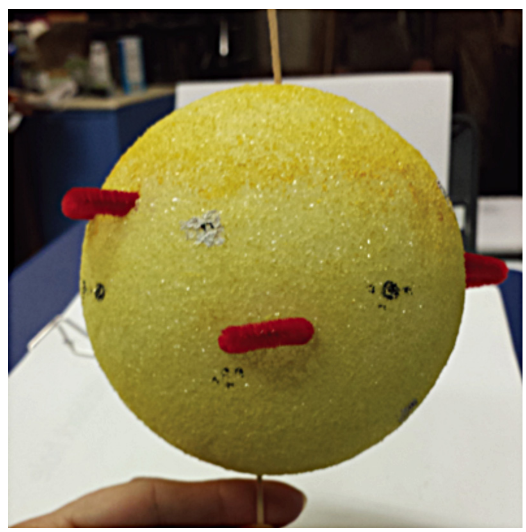

Figure 4. Solar outreach model. Faculae are made with white correction fluid, the sunspots with a black marker, and prominences with red pipe cleaners. Toothpicks represent the rotational poles.

Figure 5. BB the eclipse-chasing bunny at the Australia total solar eclipse in 2012.

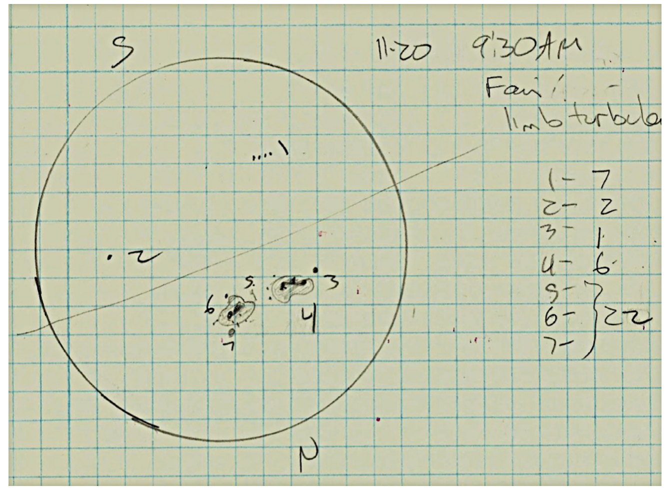

Figure 6. One of the author's early solar observations, demonstrating the learning curve for solar observing. Upon further reflection, "Groups" 5, 6, and 7 were later realized to comprise a single group.

larger than the theoretical resolving power of the human eye, ~ 70", especially near the peak of the solar cycle (Vaquero and Vázquez 2009). But observers have discerned sunspot groups less than half this size without optical aid (MacRobert 1989). It is therefore not surprising that records of sunspot observations date back two millennia, long before the invention of the telescope (Vaquero and Vázquez 2009). With the sun currently waking up from its solar minimum doldrums, it's time to dust off those solar eclipse glasses, check them for defects, and get back to the roots of solar observing (but done far more safely than the ancient methods of viewing the sun through clouds, haze, or smoked glass). It's also not too early to begin planning both our outreach and individual travel plans for the next Great American solar eclipse on April 8, 2024. While the path of totality will stretch northeast from Mexico, crossing several US states before ending in Labrador in Canada, the entire continental US will experience some of the partial phase of the eclipse. Since the sun will be about halfway to the next solar maximum at that time, we should be able to couple our viewing of the partial phases with observing sunspots. Several warm-up events will occur before then, including the October 25, 2022, partial solar eclipse visible from parts of Europe, northeastern Africa, and the Middle-east, the April 20, 2023, total/annular eclipse visible from Southeast Asia and Australia, and the October 14, 2023, annular eclipse visible from much of North America, Central America, and South America. Helpful resources are listed at the conclusion of this article.

3. A personal story

Every backyard observer, no matter how expert, started somewhere. This is true both in general, and with variable star observers more specifically. In the summer of 1989, while I was completing my Ph.D. and shortly after being hired as a faculty member at CCSU, I attended the famous Stellafane Convention on Breezy Hill in Vermont for the sixth time. At Stellafane you meet many colorful characters, and one of the most colorful in the late 1980s was Casper "Cap" Hossfield, former chair of the AAVSO Solar Section (1963–1979). Every year he would lug an eclectic array of gear up to the hill, including seismographs, a purported gravity wave detector, and his trademark Hossfield pyramid solar projection system with which he would show people sunspots. That particular year I wandered over to his set-up and looked over the pyramid with interest, the only excuse Cap needed to launch into a detailed explanation of the wonders of solar observing. Two months later, I was the proud owner of a solar filter for my six-inch Bausch and Lomb Schmidt-Cassegrain, and was submitting sunspot observations to Cap in service of the American Radio Relay League. The possibility of helping ham radio aficionados communicate more effectively by simply counting sunspots seemed too easy. I was right.

There is more to solar observing than simply counting the numbers of individual spots, because solar activity is more closely aligned with the number active regions (or "groups") visible on the sun than the total number of individual spots. An isolated spot simultaneously counts as a "group" and a "spot" because it denotes the location of a distinct active region (Figure 6). Solar activity is therefore described by the Wolf number (defined by famed solar observer Rudolf Wolf in 1848), calculated by weighting the number of groups by a factor of ten and then adding in the total number of spots: $10g+s$. It is much easier to determine the identity of individual groups when the sun is relatively quiet, such as when it is coming out of solar minimum, as it is now (http://sidc.oma.be/silso/). But as the sun approaches solar maximum and the field gets more crowded, it takes experience and consistent observations to get a good handle on where one group ends and the next begins. My decision to start solar observing near solar maximum certainly added an extra level of challenge to the activity.

After several months of patience and encouragement from Cap, he dangled another carrot in front of me, asking if I would consider sending my observations to the AAVSO, a group that monitors variable stars. What Cap could not have known was that after becoming an AAVSO observer I not only became a member, but Janet Mattei invited me to become involved in developing a grant-funded educational project, *Hands-on Astrophysics*, a means to bring astrophysics to classrooms by using variable stars. Janet afterwards tasked me with delivering a presentation on the project at the AAVSO annual meeting, where I met Dorrit Hoffleit, who afterwards became highly influential in my research on the history of women in science. Janet then sealed the deal by encouraging me to run for AAVSO Council, and the rest, as they say, is history.

Dorrit was fond of recounting the story of how, as an intern at the Maria Mitchell Observatory, Janet Mattei started on her road to becoming the Director of the AAVSO by unexpectedly taking Dorrit's place hosting an AAVSO meeting "all because of the Nantucket fog" (Larsen 2009, 62); my road to being President of the organization (and later Secretary and Co-Solar Section Chair) started with a chance encounter at Stellafane and some spots on the sun. Everyone's pathway to variable stars is different, but it often comes down to unexpected experiences, and a mentoring hand. By offering both, we will assure the continued success of the AAVSO long after we have individually submitted our own final observations.

4. Conclusion

The sun is our star and belongs to all of us. Too often we take it for granted, and don't appreciate its identity as a variable star. The sun might reliably appear in our sky (clouds permitting) every single day, but no two sunrises are the same. Similarly, every (safe) view of the sun through a telescope has some unique quality. Even a sun devoid of spots can sometimes be seen to have faculae strung along the limb, if you trade your disappointment for patience. More importantly, no two solar cycles are the same. The numbering system used to identify individual cycles was developed by Wolf in 1861, with Cycle 1 defined to have begun in 1755 (https://www.stce.be/news/312/welcome.html). Cycle 25 began in December 2019 and is expected to peak between around 2025 (Potter 2020). What tricks does the sun have up its sleeve for this cycle? Our star will divulge the answer in its own time, so accept its invitation to watch it unfold for yourself. Remember, it is far easier to learn how to separate sunspot groups if you begin your education when the sun is relatively quiet. Now is the perfect time to start your personal solar observing journey, and the AAVSO Solar Section provides you with both the information you need to get started and the opportunity to engage in the process of scientific data collection.

Teachers with access to a solar projection system are also encouraged to invite children to keep an eye on our star, with changes visible not only from day to day, but month to month, and year to year. Imagine middle school students who begin observing the sun now, just after minimum, and continue to monitor their star until high school graduation, when it should be reaching maximum. What a powerful lesson in the truth that the ability to do science is open to us all, and that learning is a life-long endeavor.

As the sun awakens from solar minimum, let's harness a solar energy of a different kind, the energy of our enthusiasm, to light the fire of wonder in the next generation, and recruit and train the next generation of AAVSO members and observers.

5. Additional resources

American Astronomical Society 2024 Eclipse Webpage: http://eclipse.aas.org

Great American Eclipse: https://www.greatamericaneclipse.com/

International Astronomical Union Working Group on Solar Eclipses: https://sites.williams.edu/iau-eclipses/

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Weather Predictions for Solar Eclipses: http://eclipsophile.com

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