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Are Sunspots Different During This Solar Minimum?

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For hundreds of years, humans have observed that the Sun has displayed activity where the number of sunspots increases and then decreases at approximately 11-year intervals. Sunspots are dark regions on the solar disk with magnetic field strengths greater than 1500 gauss (see Figure 1), and the 11-year sunspot cycle is actually a 22-year cycle in the solar magnetic field, with sunspots showing the same hemispheric magnetic polarity on alternate 11-year cycles. The last solar maximum occurred in 2001, and the magnetically active sunspots at that time produced powerful flares causing large geomagnetic disturbances and disrupting some space-based technology.

But something is unusual about the current sunspot cycle. The current solar minimum has been unusually long, and with more than 670 days without sunspots through June 2009, the number of spotless days has not been equaled since 1933 (see http://users.telenet.be/j.janssens/Spotless/Spotless.html). The solar wind is reported to be in a uniquely low energy state since space measurements began nearly 40 years ago [*Fisk and Zhao,* 2009].

Why is a lack of sunspot activity interesting? During the period from 1645 to 1715, the Sun entered a period of low activity now known as the Maunder Minimum, when through several 11-year periods the Sun displayed few if any sunspots. Models of the Sun's irradiance suggest that the solar energy input to the Earth decreased during that time and that this change in solar activity could explain the low temperatures recorded in Europe during the Little Ice Age [*Lean et al.,* 1992].

Because little is known about what causes a prolonged dearth of sunspots, scientists are combing through recent solar data in efforts to find some clue to the Sun's unusual behavior.

Recent Sunspots: Tiny Pores Without Penumbrae

In 2005, scientists from the U.S. National Solar Observatory (NSO) examined solar measurements made over the previous 13 years by the observatory's McMath-Pierce telescope at Kitt Peak, Ariz. These measurements included data on the infrared intensity, temperature, and magnetic fields inside sunspots. They use the most sensitive probe of sunspot magnetic fields currently available (an infrared spectral line of neutral iron at 1564.8 nanometers) and represent the longest time sequence of such observations.

A draft of that early work was posted on the Internet and led to some misunderstanding when a few authors from other fields cited that post and erroneously concluded that a lack of sunspots could explain global warming. The same data were later published [*Penn and Livingston,* 2006], and the observations showed that the magnetic field strength in sunspots were decreasing with time, independent of the sunspot cycle. A simple linear extrapolation of those data suggested that sunspots might completely vanish by 2015.

These observations caused researchers to wonder whether the characteristics of sunspots are different now than in other solar cycles. Sunspots are composed of a dark central core (the umbra), in which magnetic field is oriented perpendicular to the surface, surrounded by a lighter-colored ring (the penumbra), in which magnetic field lines are mostly parallel to the surface [*Solanki,* 2003]. The intensity and magnetic fields of large sunspots have been observed in the past to change, as seen by ground-based telescopes, in sync with the solar cycle [*Albregtsen and Maltby,* 1981].

Some observations from space-based instrumentation also have reported seeing cyclic variations in sunspot brightness in concert with magnetic field fluctuations [*Norton and Gilman,* 2004]. These observations were made with instruments that measure magnetic flux, which is the average field strength over an area of the sunspot, rather than magnetic field strength directly.

Yet although the Sun's magnetic polarity has reversed and the new solar cycle has been detected, most of the new cycle's spots have been tiny "pores" without penumbrae (see Figure 1); in fact, nearly all of these features are seen only on flux magnetograms and are difficult to detect on white-light images.

What could be happening? Clues can be found in the McMath-Pierce's infrared magnetic measurements, which are able to calculate the total magnetic field strength directly (not the flux) in the umbrae. These measurements also have the advantage of observing the sunspots in the infrared spectrum, which guarantees the reduction

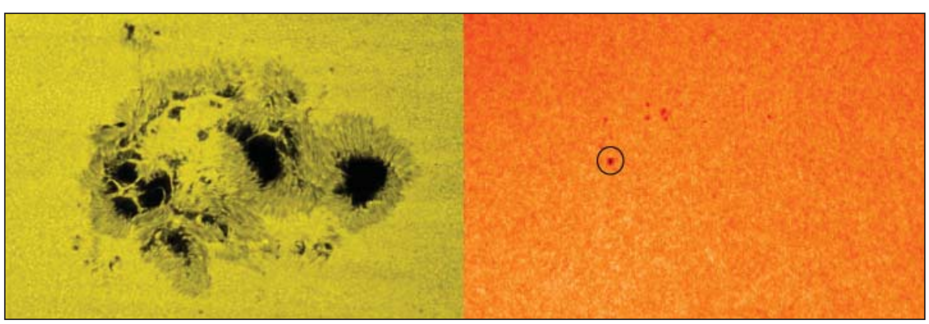

Fig. 1. (left) An image of a sunspot group near the maximum of the last solar cycle, cycle 23, taken at the McMath-Pierce telescope, Kitt Peak, Ariz., on 24 October 2003. The sunspots clearly show a dark central umbra surrounded by a brighter, filamentary penumbra. The magnetic fields range from 1797 to 3422 gauss. (right) An image consisting only of pores—weak sunspots with no penumbral structure—taken from the Michaelson Doppler Imager (MDI) instrument on the Solar and Heliospheric Observatory (SOHO) spacecraft on 11 January 2009; this is an example of what is observed today at solar minimum. The lower pore (seen as the dot in the center of the black circle) had a magnetic field of 1969 gauss; the others were not measurable. Presently, the solar surface is mostly devoid of spots. Both images have the same spatial scale and are roughly 250,000 kilometers across.

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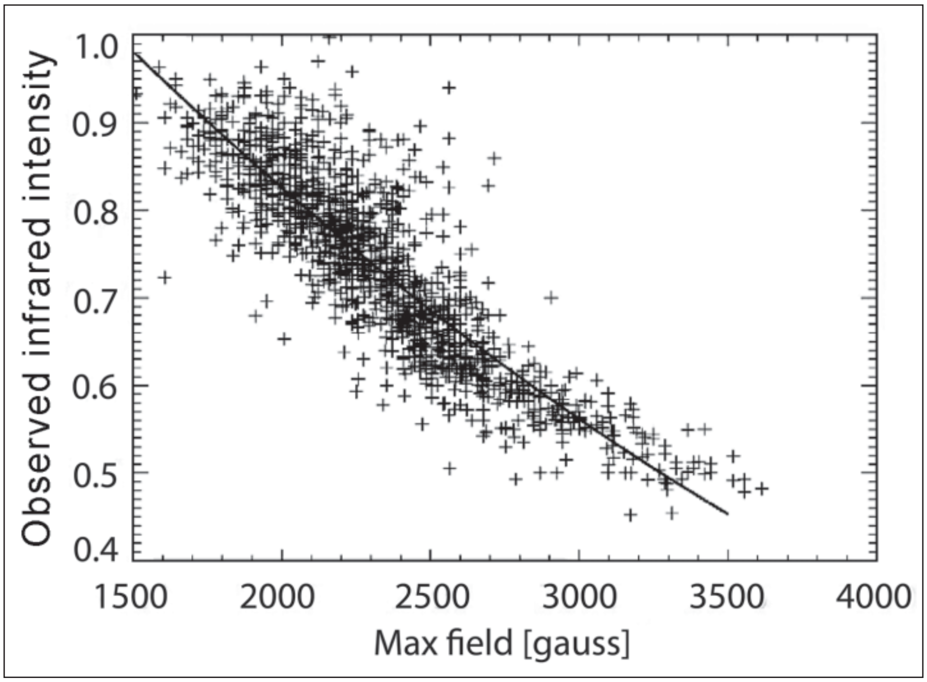

Fig. 2. The observed infrared intensity in the darkest position of sunspot umbrae is plotted versus the magnetic field strength for 1392 sunspots (using the Zeeman splitting of the neutral iron spectral line at 1564.8 nanometers). A quadratic fit to the data is also shown. The measurements are from the entire data set observed from 1992 to 2009.

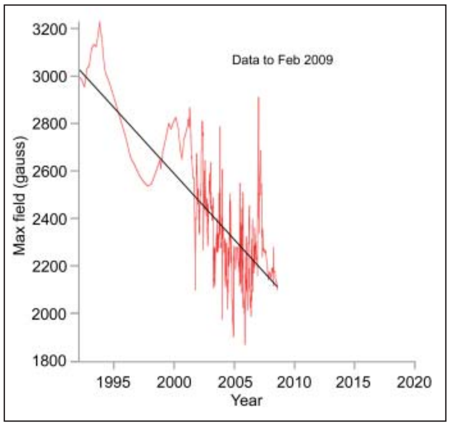

Fig. 3. The maximum sunspot field strength is plotted versus time, during the period from 1992 to February 2009; a 12-point running mean is shown, and a linear fit to the data is plotted. Apart from a few measurements, the linear trend has been seen to continue throughout this solar minimum.

of telescopic scattered light, a factor especially important while observing small sunspots. Recent observations of small spots suggest that throughout the time period covered by the infrared data, the relationship between umbral magnetic field strength and infrared intensity (measured at the darkest position in individual spots) has remained constant (see Figure 2).

This reveals that sunspots seen currently are not independently getting more intense in the infrared; sunspots today still follow the same infrared intensity and magnetic field strength relationship seen in previous years. Instead, magnetically weaker sunspots are seen more frequently now in conjunction with high infrared intensities. Indeed, recent work [*Schad and Penn*, 2008] using data from the NSO Kitt Peak Vacuum Telescope suggests that slight changes in the average sunspot umbral radius during the past 11 years can explain much of the observed magnetic and intensity changes.

A Future Dearth of Sunspots?

Four years after the first draft paper, the predicted cycle-independent dearth in sunspot numbers has proven accurate. The vigor of sunspots, in terms of magnetic strength and area, has greatly diminished.

Figure 3 shows the decrease in field strength now found with respect to time (1992–2009), which still shows a linear trend independent of the solar cycle. Because of the nature of the observing program, the earliest measurements in this plot are probably skewed toward higher magnetic field values (larger sunspots); nonetheless, the linear trend in the magnetic field value is clear even excluding all pre-1995 data. The data show the same spots as shown in Figure 2, and as implied, the mean infrared intensity of sunspot umbrae is also increasing with time.

Whether this is an omen of long-term sunspot decline, analogous to the Maunder Minimum, remains to be seen. Other indicators of the solar activity cycle suggest that sunspots must return in earnest within the next year.

Because other indications point to the Sun experiencing an unusual period of minimum solar activity, it is critically important to measure the Sun's magnetic activity during this unique time. Scientists will continue to observe the Sun using infrared diagnostics at the McMath-Pierce telescope with keen interest.

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