Scientists discover solar precursors of when, where sunspots will emerge

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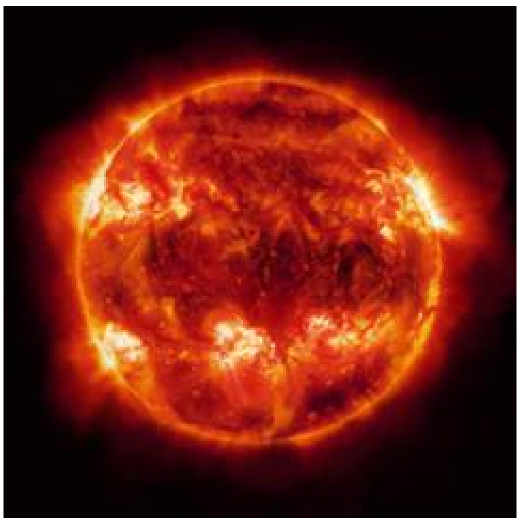

Subtle surface signs reveal when and where sunspots will emerge on the Sun, at least a day in advance, according to a team of researchers led by Northwest Research Associates (NWRA). The results were presented in science sessions and a press conference at this week's 44th meeting of the American Astronomical Society's Solar Physics Division (SPD) and give new understanding of how the Sun produces new sunspots and activity.

Using data from the Global Oscillations Network Group (GONG) and the Michelson Doppler Imager (MDI), scientists from NorthWest

Research Associates (NWRA) and the Max-Planck-Institut für Sonnensystemforschung (MPS) have found detectable signs of magnetic fields before they emerge at the solar surface to form sunspots. Statistically significant differences were found between areas that produced groups of sunspots (called active regions) as compared to areas that stayed sunspot-free. The differences persisted for at least a day prior to the first appearance of an active region. While these differences are too small to make prediction possible for any single active region, the signals were visible for small and large (future) active regions alike, thus providing insight into a key piece of the sunspot formation process.

Solar active regions are areas on the surface of the Sun with strong concentrations of magnetic field. One common model for the formation of active regions assumes that bundles of magnetic field are generated deep in the solar interior, become buoyant and rise up to the surface of the Sun. When a flux bundle passes through the surface, it forms an active region. This magnetic flux emergence is a fundamental process for the Sun and presumably solar-like stars, yet surprisingly little is known about its nature. Active regions are the source of many space weather events that can impact Earth, so understanding their formation may ultimately lead to a better understanding of space weather. The way in which active regions form can also help to determine the nature of the solar dynamo, the ultimate source of magnetic fields in the Sun. Senior Research Scientist Dr. K. D. Leka summarizes the findings of the NorthWest Research Associates group by saying, "We've shown that careful research using the visible part of the Sun can indeed tell us about what is happening underneath; these results will be a guide for further research, and ultimately improve our understanding of the Sun and all stars."

For this investigation, two sets of data were collected, one of areas of Sun in which an active region subsequently formed, and a second control group of areas where no significant magnetic field appeared at the surface. To infer the subsurface properties of the Sun, the GONG data were subjected to a technique known as helioseismic holography. This technique measures the time it takes sound waves to propagate through the interior of the Sun, which depends on the temperature and motion of the plasma through which the sound wave passes, and thus provides information about the interior. It is similar to the way in which earthquakes can be used to understand the structure of the interior of the Earth, and has also been used for imaging the far side of the Sun. Accompanying the helioseismology were surface magnetic field observations from MDI. Thus, the behavior of the Sun both under and at the surface was tracked simultaneously for hundreds of targets. A statistical method called discriminant analysis was applied, to determine whether these two groups, the pre-emergence and no-emergence groups, could be distinguished based on their magnetic and helioseismic signatures. (Interestingly, this analysis method has also been used by the Internal Revenue Service in determining which tax returns to audit.)

Surprisingly, even though individual regions could not be distinguished based on the surface magnetic field, between the two groups as a whole it was the best discriminator. This could be a result of small amounts of flux appearing at the surface, starting at least one day prior to the main emergence event; it could also be the result of a subtle bias, either of solar origin or as a result of the selection criteria, and thus not directly related to the emergence process. For example, there is a known tendency for sunspots to emerge in the same location as older, decayed active regions, so residual magnetic field from a decaying sunspot could account for the bias.

To see if the helioseismology is detecting anything more than simply the surface magnetic field, subsets of the pre-emergence and non-emergence groups were selected with matching distributions of surface field. When the analysis was repeated on these subsets, there were still significant differences. While the depth of the source of the helioseismology signals is not yet known, the pre-emergence group showed signals which might be explained by a flow converging on the emergence site just below the surface, combined with a another flow in the direction of the Sun's rotation.

While more work is needed to refine the interpretation, the results confirm the presence of changes in the solar plasma prior to the appearance of active regions. The magnitude of the differences observed by the NWRA/MPS team is smaller than that seen in other investigations which looked much deeper below the solar surface. This is quite surprising as most explanations of the formation of active regions would predict the signature to become stronger as the magnetic field approaches the solar surface. Resolving these discrepancies has the potential to provide new insight into the flux emergence process.

Dr. Frank Hill, of the National Solar Observatory comments, "These results from the GONG Network data span both basic research in astronomy and future understanding of the daily workings of the heliosphere in which our Earth resides. They are a clear demonstration of the need for continual solar observations."

Two papers describing this work have been published in The *Astrophysical Journal* (Leka et al. 2013 and Birch et al. 2013), and a third (Barnes et al. 2013) has been submitted to the same journal.

More information: "Helioseismology of Pre-emerging Active Regions. I. Overview, Data, and Target Selection Criteria," K.D. Leka, G. Barnes, A.C. Birch, I. Gonzalez-Hernandez, T. Dunn, B. Javornik, and D.C. Braun. A copy of the paper can be seen at arxiv.org/abs/1303.1433

"Helioseismology of Pre-emerging Active Regions. II. Average Emergence Properties" A.C. Birch, D.C. Braun, K.D. Leka, G. Barnes, and B. Javornik. A copy of the paper can be seen at arxiv.org/abs/1303.1391

"Helioseismology of Pre-emerging Active Regions. III. Statistical Analysis," G. Barnes, A.C. Birch, D.C. Braun, and K.D. Leka. A copy of the paper can be seen at arxiv.org/abs/1307.1938

Provided by Northwest Research Associates

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