SOLAR PHYSICS

SOHO Turns an Unblinking Eye on a Turbulent Sun

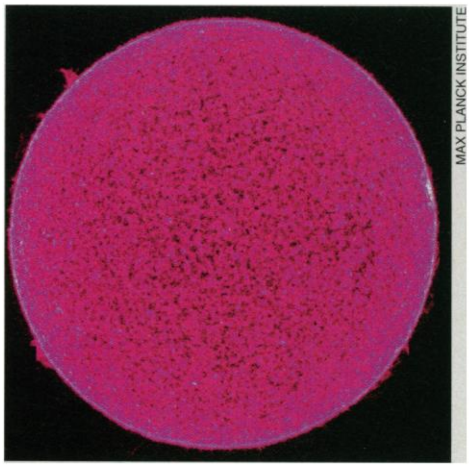
Three months ago, a unique spacecraft began to stare down the sun. Taking up station 1.5 million kilometers from Earth, at the point where the gravitational fields of Earth and the sun balance, the European Space Agency's (ESA's) Solar and Heliospheric Observatory (SOHO) aimed a battery of 11 instrument packages at the sun, ranging from particle detectors to spectrometers and sophisticated imaging cameras and coronagraphs. The scrutiny has gone on 24 hours a day, 7 days a week since then, and it will continue for at least another 21 months. Last week, at ESA headquarters in Paris, SOHO researchers announced what they have learned so far.

Part of the news is simply that the spacecraft is living up to its promise to give a complete picture of the sun—"from the very deepest regions of the atmosphere nearly all the way out to the Earth," says John L. Kohl of the Harvard-Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, principal investigator (PI) for one of SOHO's instruments. "We are getting an extremely complete data set, and with a lot of work we will have dramatically improved our knowledge about the sun," says Klaus Wilhelm of the Max Planck Institute for Aeronomy near Göttingen, Germany, another PI.

But the imaging instruments have already yielded surprises, including spectacular pictures of the sun's violent atmosphere that suggest that even in its current lull of activity, the sun is unexpectedly turbulent. And SOHO observations are also confirming what scientists have suspected for the past few decades: that the sun's magnetic field accounts for much of its observed behavior. "Magnetic fields are the mother of all solar phenomena," says PI Guenter Brueckner of the U.S. Naval Research Laboratory in Washington.

SOHO, which ESA developed and now operates in collaboration with NASA, was launched last year on 2 December and reached its station at the Lagrangian point L1 on 14 February. Its first 3 months have been enough to dispel the view that the lulls in the sun's 11-year cycle of activity are periods of real calm. SOHO's Large Angle and Spectrometric Coronagraph Experiment (LASCO) has observed several enormous eruptions from the sun's atmosphere that launched billions of tons of gas into space at velocities of hundreds of kilometers a second. Such coronal mass ejections are familiar at the sun's activity peaks, but now, says Brueckner, it seems that "even at the solar minimum the solar magnetic field is extremely active."

The ionized gases in the corona follow the field lines, revealing the field and the structures within it, such as "current sheets." As a result, Brueckner's team has been able to use LASCO's imaging devices to identify the magnetic changes that drive the mass ejections. They found that the magnetic field periodically flips from a dipole structure, similar to a bar magnet, into a less stable quadrupole structure, which has four poles. Says Brueckner, "We see these current sheets brighten while this quadrupole activity is going on." And then, after a peak of brightness, "it suddenly blows up, and you get one of these big coronal mass ejections."



Hot zone. Ultraviolet image from SOHO reveals the base of the million-degree corona.

The mass that escapes from the sun in these ejections and in the normal solar wind carries a message about the primordial solar system, SOHO has found. By analyzing the solar wind, SOHO investigators have learned that the relative abundances of different isotopes of magnesium in the solar wind are close to those found on Earth, indicating that the sun's cool surface probably preserves a good sample of the primordial solar system's makeup. Says PI Peter Bochsler of the University of Bern in Switzerland, "These isotopes have been preserved on the solar surface without, as we believe, any change."

In addition to the solar wind's composition, SOHO researchers hope to learn what drives it. They want to find out how the sun heats the halo of gases around it, known as the corona, to more than a million degrees Celsius when the actual visual surface of the sun, the photosphere, is only 5600 degrees. Already researchers have found some evidence. Wilhelm reports that his team has for the first time seen small explosions—20,000 of them per minute—in an area where the temperature of the solar atmosphere increases rapidly from several thousand to a million degrees.

Many solar physicists believe that shifting magnetic fields power these explosions. And to learn about the flows of gas that might stir the magnetic fields, researchers are pinning their hopes on a promising technique called helioseismology, in which investigators study oscillations of the solar surface driven by sound waves traveling inside the sun. Douglas Gough of Cambridge University, co-investigator on three experiments aboard SOHO, says that the sound waves, in turn, probe conditions beneath the photosphere. "You can deduce fluctuations in sound speed by looking at the difference in time [for waves] going from A to B rather than from B to A," says Gough. "Therefore, for the first time ever, we have been able to map small-scale flow beneath the surface of the sun."

Observations from SOHO's Solar Oscillations Investigation package have shown that the regions with stronger magnetic fields tend to correlate with regions of converging flow, whereas regions of divergence have little or no magnetic field. Gough believes that the energy stored in the magnetic field in the convective zone under the photosphere drives the activity observed in the corona.

Another conclusion, which Gough calls "extremely tentative" because he has not had time to confirm it, comes from observations by another instrument package, known as VIRGO, which monitors large-scale oscillations that penetrate all the way to the center of the sun. "It is no more than a hint yet, but it is an exciting hint: The variation of the sound speed [with depth] is smoother than in the theoretical models," says Gough. Theorists predict that the speed of sound should show jumps corresponding to layers of different composition deep in the sun. "This suggests to me that the distribution of helium abundance is smoother than in the theoretical models," he says.

A smoother distribution of helium would have a profound effect on models of nuclear fusion in the core of the sun, for helium is a key part of the reaction chain. And a change in the theorists' understanding of the sun's internal engine could help solve one of the most nagging problems in solar physics: Why do detectors on Earth pick up only a fraction of the neutrinos that theorists think that engine should be producing? The finding "would have implications for the solar neutrino problem; that is why this is so important. But we have to wait for much longer observations before we can be sure," says Gough. Over the 2 years, SOHO looks set to help solve this and many other puzzles about our nearest star.

–Alexander Hellemans

Alexander Hellemans is a science writer in Brussels.