SOLAR PHYSICS

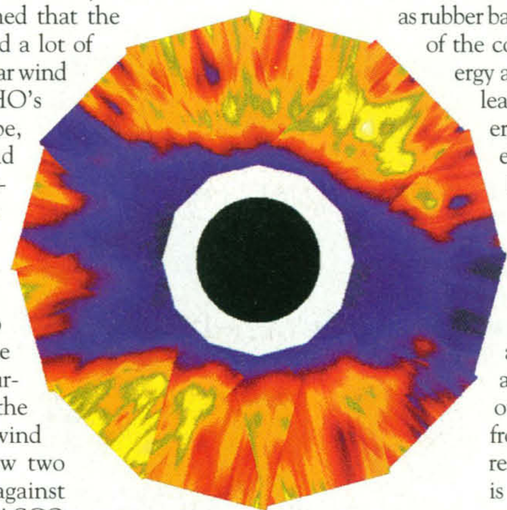
SOHO Probes the Sun's Turbulent Neighborhood

Earth's atmosphere may seem like a tumultuous place with its hurricanes and thunderstorms, but it pales next to the atmosphere of the sun. This vast mantle of gas, dubbed the chromosphere in its lower reaches and the corona at higher altitudes, is the scene of processes that heat it to millions of degrees, unleash huge jets and arcing filaments of gas, and launch great bubbles of matter called coronal mass ejections (CMEs) into space. This turmoil is felt throughout the solar system, because it generates a relentless "solar wind" that distorts Earth's magnetic field and blasts material off comets, producing their tails. Now solar physicists are getting their clearest look yet at what drives solar weather, courtesy of the European Space Agency's Solar and Heliospheric Observatory (SOHO).

From its vantage point 1.5 million kilometers sunward of Earth, SOHO's 11 instruments have been watching the sun's every move, from deep-seated pulsations in its visible surface—the photosphere—to the far reaches of the corona at distances of several solar radii. SOHO data are now beginning to put flesh on physicists' models of how processes such as the relentless dance of magnetic field lines above the solar surface—storing and then violently releasing energy—stir the corona. "It is the first time we have been able to view the sun's atmosphere at different levels and temperatures together," says Richard Harrison of the Rutherford Appleton Laboratory in the United Kingdom. Last month, 300 solar physicists gathered in Oslo, Norway, at a SOHO workshop—the first since SOHO's launch last year (*Science*, 10 May 1996, p. 813)—to discuss the results so far. They include hints that the magnetic field is directly involved in accelerating the solar wind; that the field heats the corona by carrying energy outward from the sun's churning surface; and that the eruption of solar prominences and CMEs are the visible signs of global magnetic disturbances.

Overall, the sun's magnetic field is roughly like that of a bar magnet. At lower latitudes, the field lines are "closed," arcing from pole to pole. But above the poles, the lines point out into space, and it is there that SOHO's ultraviolet coronagraph spectrometer (UVCS) has gathered evidence for the field's role in accelerating the solar wind. The UVCS, which analyzes the corona's ultraviolet spectrum, shows that where the field lines are open, gas particles "boiling off" the atmosphere seem to be accelerated to very high velocities by the field, smearing out their spectral lines. "Our spectroscopic data are telling us that in the regions where the [field] lines are open, and where there is flow of the solar wind, [spectral] line profiles are particularly wide," says UVCS team member Ester Antonucci of Turin University in Italy. The correlation between open field lines and high velocities makes the magnetic field the prime suspect in the acceleration of the wind.

The acceleration mechanism, whatever it is, seems to do its job efficiently. Researchers had always assumed that the magnetic field needed a lot of space to accelerate solar wind particles, but SOHO's visible light telescope, the Large Angle and Spectrometric Coronagraph Experiment (LASCO), has observed particles in the polar regions being accelerated to high velocities close to the surface. "The surprising result is that the acceleration of that wind seems to occur below two solar radii—this is against all theories," says LASCO team leader Guenter Brueckner of the U.S. Naval Research Laboratory in Washington, D.C.



UVCS/SOHO

High winds. Solar wind particles travel fastest (colors) near the poles of the sun, where its magnetic field lines are open.

SOHO is also gathering evidence that magnetic effects are responsible for heating the corona to its million-degree temperature, which is hundreds of times hotter than the photosphere. For example, the group working with the Michelson Doppler interferometer (MDI), which detects oscillations on the sun's surface as well as in magnetic fields, found a correlation between magnetic phenomena in the photosphere and fluctuations in the intensity of emission lines of oxygen ions much higher up, closer to the corona, indicating that energy from the churning of the surface was being transferred to the upper atmosphere. "The key word [for the energy-transfer process] is reconnection," says Olav Kjeldseth-Moe of the Institute of Theoretical Astrophysics in Oslo. "We have evidence [from the MDI] that in the regions where there are usually closed fields, some of the field lines open up." Researchers believe that the swirling of the sun's atmosphere then sweeps the lines around until lines pointing in different directions meet and reconnect. Such reconnections release huge amounts of energy from the magnetic field and hence heat up gas in the atmosphere.

According to SOHO's instruments, magnetic disturbances also drive some of the most spectacular events in the solar atmosphere, in which the corona spews huge clouds of gas into space in CMEs. Two very large CMEs took place in January and April this year, captured in spectacular photographs by LASCO, which blocks light coming directly from the sun to get a clear view of the corona. The largest CMEs launch up to a billion tons of gas into space in one go. "They are really carrying more matter than was thought before, and are explaining 50% of the slow solar wind," says Antonucci.

Antonucci reported how the UVCS team observed the twisting of magnetic fields at the onset of a CME. Field lines can be viewed as rubber bands in the ionized gas of the corona, storing up energy and later violently releasing it. "Magnetic energy is transformed into energy supplied to the lifting of the CME," she says, adding that CMEs often seem to be linked. "Sometimes one [CME] appears from a region of the sun, and immediately another one comes out from another part. This really means that there is a global kind of disruption of magnetic fields." Jean-Pierre Delaboudinière of the Institute of Space Astrophysics at Orsay, head of the extreme ultraviolet imaging telescope team, also reported that CMEs seem to trigger global disturbances: "One out of three is particularly spectacular and starts up with an exploding protuberance, a mass of gas emerging from the solar surface, which produces a spherical shock wave that propagates throughout the solar surface."

While researchers are only just beginning to fill the gaps in their solar models, they have high expectations for SOHO's steady flow of data. One factor contributing to the optimism is that the scientific groups can control their instruments directly, instead of having to follow observation schedules set by the space agency. "You can plan like in a ground-based observatory. ... This is unique," says Harrison. And, with just a few exceptions, the spacecraft and its 11 instruments have been functioning almost flawlessly. Says Harrison: "Overall, it has been a resounding success."

–Alexander Hellemans

Alexander Hellemans is a writer in Paris.