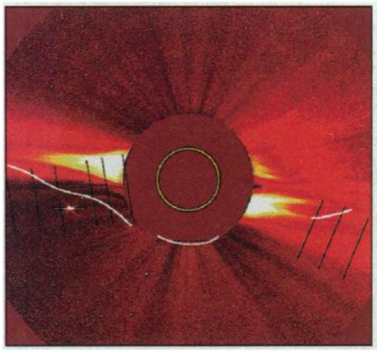
SOLAR PHYSICS

Two Spacecraft Track the Solar Wind to Its Source

"The wind bloweth where it listeth," says the King James Bible, "but [thou] canst not tell whence it cometh." That surely holds true for the wind of particles that starts somewhere in the tangled forest of magnetic fields and turbulent gases near the sun's surface and blows throughout the solar system. Solar physicists' best guess has been that one component, a steady, fast wind that blows at up to 800 kilometers a second, originates near the sun's poles. The wind's other component, more capricious and slow, seems to come from somewhere within a broad region around the solar equator called the streamer belt. Now, by tracing the source of the solar wind from several different vantage points, a new study may have finally pinpointed the source of the slow wind—while calling into doubt the standard wisdom on the fast wind.

The study relied on two spacecraft: the Solar and Heliospheric Observatory (SOHO), which observes the sun from near Earth, and Galileo, which passed behind the sun while in orbit around Jupiter and transmitted radio signals through the gases near the solar surface. Together, the observations caught the slow wind dribbling from long, narrow structures called stalks, which tower over the arched magnetic fields of the streamer belt like the spikes on a Prussian helmet. The findings also hinted that the fast wind emerges in patches over most of the sun—not just from near the poles.

Reported in *Astrophysical Journal Letters* by Shadia Habbal of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts, Richard Woo of the Jet Propulsion Laboratory in Pasadena, California, Silvano Fineschi of CfA, and others, the study's conclusions about the fast wind are controversial—"revolutionary," as a skeptical Jack Gosling of Los Alamos National Laboratory in New Mexico puts it. But most researchers say the mystery of the slow wind is as good as solved. "It's a giant step forward," says Alan Title, a solar physicist at the Stanford-Lockheed Institute for Space Research.



HABBAL ET AL./ASTROPHYS. J. LETT.

Hot wind. The solar corona, as seen by instruments aboard SOHO. White line marks boundary between slow wind (near streamers) and fast wind.

The wind escapes from the solar corona—the sun's hairy halo of ionized gas, or plasma, which is somehow heated to temperatures hundreds of times higher than the solar surface itself (see sidebar). Much of the corona is bottled up by magnetic field lines that loop back to the surface. Near the solar poles, however, field lines wander off into space from regions called the coronal holes. Those holes, researchers assumed, allow the hot particles to rush out unimpeded and form the steady, fast wind that spacecraft sometimes detect. Meanwhile, the slow, ragged wind seen at other times somehow billows out from the constrained corona closer to the sun's equator.

In earlier work, Woo and collaborators had probed for the source of the slow wind by monitoring the communications beams of interplanetary spacecraft, such as the solar probe Ulysses, as they dipped behind the sun. The researchers looked for "scintillation," or scattering, of the signals close to the edge of the sun. "It's like a headlight scattered by fog: The headlight looks bigger," says Woo of one scintillation effect. The scintillation should pinpoint regions of unsteady flow in the plasma near the solar surface—possible sources for the ragged, unsteady slow wind. Woo and his colleagues measured the strongest effects where the radio waves passed through the stalks towering over magnetic arches.

To prove that the stalks really are the wellsprings of the slow solar wind, Habbal, along with Woo, Fineschi, and their col-

Turning Up the Heat in the Corona

Last year, an instrument aboard the Solar and Heliospheric Observatory (SOHO) spacecraft dazzled solar physicists by finding oxygen ions in the sun's corona at temperatures of 100 million degrees Celsius—many times hotter than expected. In a forthcoming issue of *Solar Physics*, the team that operates SOHO's Ultraviolet Coronagraph Spectrometer (UVCS) drops another bombshell: a strong hint of the mysterious mechanism that heats the corona and drives the solar wind (see main text).

The new UVCS findings show that those sizzling temperatures reflect mainly the ions' whirling motion around the magnetic field lines that stretch from the sun. Along the field lines, the ions slide outward at much lower energies, moving at velocities corresponding to temperatures from 15 to 100 times cooler. The disparity favors one of several contending theories about what boosts the corona as a whole to temperatures hundreds of times hotter than the solar surface, says John Kohl of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts, and principal investigator of UVCS. "This is exactly what you would expect to see" if waves on the field lines were creating the energetic ions, like a person's gyrating hips twirling a Hula Hoop, he says.

This "cyclotron resonance" theory (*Science*, 21 June 1996, p. 1738) predicts rapid gyrations but slower longitudinal movement, just as the Hula Hoop receives little up- or downward kick from the hips. UVCS can clock the ions in both directions by collecting the light they scatter or emit, which is affected differently—through the train-whistle, or Doppler effect—by the two kinds of motion, explains Silvano Fineschi of CfA, a UVCS team member. The measurements confirm that, in spite of the oxygen ions' searing temperatures measured across the field lines, they are moving along the lines at much lower speeds. A similar but smaller disparity, which is also consistent with the cyclotron resonance theory, turned up in the much more numerous hydrogen ions in the corona.

Other researchers are impressed by the results but cautious about claiming that the long-standing coronal-heating problem has been solved. "It's getting pretty hard to get away from cyclotron heating," says Joseph Hollweg of the University of New Hampshire, Durham. But he says that other possibilities—such as heating by shock waves or frequent, tiny flares—haven't yet been eliminated.

–J.G.

leagues, set out to measure the wind speed there. That's where SOHO came in. The team used SOHO's Ultraviolet Coronagraph Spectrometer (UVCS) as a kind of solar speedometer. The UVCS, explains its principal investigator, co-author John Kohl of CfA, collected light that is emitted by oxygen ions deep in the solar atmosphere, then scattered in all directions off other oxygen ions flowing outward in the solar wind. The faster the wind, the weaker the scattering, because the so-called Doppler shift lengthens the wavelengths seen by the fast-moving ions, making them unable to resonate with the light and scatter it.

The team correlated their speedometer readings with images of the magnetic arches and stalks made by another SOHO instrument, the Large Angle Spectroscopic Coronagraph. They also did a new search for scintillation by analyzing measurements of the Galileo communications signal. Strong radio scintillation, slow wind, and the stalks all turned up in the same places. "It's real exciting," says Steven Suess of NASA's Marshall Space Flight Center in Huntsville, Alabama. "I think 90% of their conclusions are absolutely accurate."

The other 10%, says Suess, concerns the fast wind. Although the fast wind is thought to originate in small regions near the poles, spacecraft far from the sun detect it at low latitudes. Solar physicists have explained this by assuming that field lines emerging from the polar coronal holes splay steeply outward, like the petals of a daisy, allowing the wind to spread out after it escapes. But to sustain high speeds even after it spreads out, the wind must get a tremendous boost from some unknown acceleration mechanism in the coronal holes.

The new UVCS measurements show, however, that the fast wind blows at a wide range of latitudes, even near the sun. What's more, radio scintillation combined with observations from Ulysses suggest that when gusts of plasma and other features rise from the sun's surface near the poles, they don't expand much in latitude. That suggests, say Woo and Habbal, that the fast wind must originate not just near the poles, but from patches of open field lines all over the sun.

That's heresy to many solar physicists. Although some models have predicted the stray fields, says Randolph Levine, who did early work on the subject at CfA, researchers have tended to think of the sun's magnetic field as well anchored except in the polar regions. But the idea that the fast solar wind blows from all across the sun "simplifies our ideas about what's going on," says Habbal, because it would eliminate the need for some special boost in polar regions. What comes out, fast or slow, would depend only on the local magnetic topology.

The new evidence makes this idea "hard to dismiss," says Lockheed's Title. But he, like other solar physicists, isn't ready to follow that shift in the scientific winds just yet.

–James Glanz

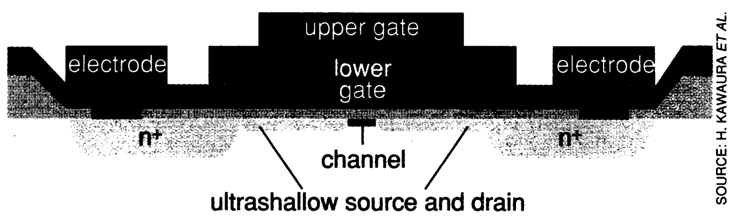
ELECTRONICS

Terribly Tiny Transistor Unveiled

TOKYO—Circuit designers at NEC Corp. have probed what some thought was a lower limit on the size of microelectronics—and found some give. A transistor's gate—the narrow electrode that controls the flow of electrons through the device depending on whether it is "on" or "off"—can be made only so small. Too small, and electrons will manage to sneak through even when the device is off. Some researchers had put this lower limit at 30 nanometers (billionths of a meter).

But at a recent conference* in Japan, a group at NEC's Fundamental Research Laboratories in Tsukuba led by Hisao Kawaura announced that, by combining a novel design with high-precision techniques for carving semiconductors, it has developed an experimental transistor with a gate just 14 nanometers across. That's 20 times smaller than in the transistors found on the densest commercially available chips. "Nobody has yet reported work at such small dimensions," says Sandip Tiwari, a small-device researcher at IBM's T. J. Watson Research Center in Yorktown Heights, New York. The device is mainly a proof of principle, however, as its design isn't suited to being packed in large numbers on a chip.

To create an ultrasmall gate that doesn't leak electrons, the NEC group varied a common transistor design known as a metal-oxide semiconductor field effect transistor, or MOSFET. In these devices, a central semiconducting channel lies between current-carrying source and drain regions. These so-called n^+ regions are created by "doping" the base material with impurities that carry an excess of electrons. Above the channel is the gate electrode. The gate turns the transistor on or off by controlling the conductivity of the channel, either allowing electrons to flow from source to drain, or cutting off the current.



Hat trick. A hat-shaped upper gate electrode opened the way to shrinking the gate itself in this experimental transistor.

The NEC team added a second gate, shaped something like a top hat, with the crown above the lower gate and brims above both sides of the channel. Ordinarily, the n^+ regions abut the channel, but this second gate allowed the researchers to leave insulating gaps between the channel and the n^+ regions. To create a route for current, a voltage applied to the upper gate attracts electrons to the surface of the base material, forming conductive ultrashallow source and drain regions. These electrically induced regions are far shallower than anything that can be formed with present doping techniques; and the shallower source and drain confine the current so that a narrower gate can control it.

Microcircuit designers usually lay out such features by shining light through a stencillike mask. The light imprints the features onto a light-sensitive coating, or resist, on the semiconductor, establishing the pattern for later fabrication steps. To make their ultrasmall device, the NEC group replaced the light and mask with a tightly focused electron beam, says team member Toshitsugu Sakamoto. They also developed a new high-resolution organic resist, which yielded even greater precision, much as a sharper pencil on finer grained paper yields more precise and consistent lines.

IBM's Tiwari says the new transistor "is very encouraging." But both Tiwari and the researchers themselves caution that it will take a lot more work to turn this strategy of electrically induced source and drain regions into a practical device. For one thing, the present double-gate design would make it difficult to pack these transistors densely. The device also takes a lot of power and doesn't switch on and off with the needed speed and consistency. But even if the new transistor won't make it out of the laboratory, says Sakamoto, "This is a good structure for testing the limits for gates."

–Dennis Normile

* International Conference on Solid State Devices and Materials, Hamamatsu, 19 Sept.