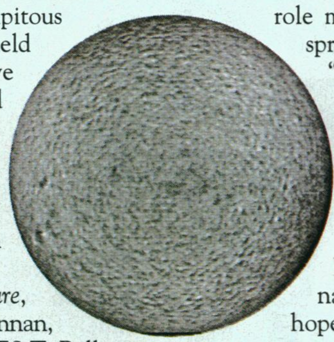
Taking the Pulse of the Sun in Records of the Solar Wind

For years, helioseismologists have been studying the subtle heavings of the sun's surface, gathering clues to conditions thousands of kilometers below in its exterior. Their ultimate goal is to get a glimpse of the very core of the sun, where the density of matter is so great that nuclei fuse, generating the sun's heat and light. That goal has remained elusive. But now, a serendipitous discovery in a very different field of science may finally have provided that long-awaited view into the sun's core. It comes from a study of the solar wind, the vanishingly thin mist of charged particles that streams out from the sun into deep space.

In this week's issue of *Nature*, David Thomson, Carol Maclennan, and Louis Lanzerotti of AT&T Bell Laboratories in Murray Hill, New Jersey, announce their discovery in solar wind records of so-called g-mode oscillations—a kind of seismic shiver predicted by theorists and long sought by observers that is thought to emanate from the solar core. "If what they say is true," says helioseismologist Timothy Brown of the High Altitude Observatory in Boulder, Colorado, "I'm going to be astonished."

Astonishment seems to be the order of the day. "These are startling results; it's something people have difficulty accepting," says space physicist Jack R. Jokipii of the University of Arizona. The abstruse mathematics the Bell Labs group used to reveal the oscillations accounts for some of the hesitancy, as do the high stakes. If g modes are there, "it's really a breakthrough," says Jokipii. "It would provide a new window to study the sun and a new tool to understand the physics of the solar atmosphere and solar wind." And if the discovery is confirmed, solar physicists may have a powerful clue to their most notorious problem: the failure to measure as many of the elusive subatomic particles called neutrinos as theorists predict should be coming from the fusion reactions in the sun's core.

Neutrinos were the furthest things from Thomson and his colleagues' minds when they began analyzing records of charged particles in the solar wind, gathered in interplanetary space by spacecraft such as Ulysses and Voyager. Thomson and Maclennan are not even solar wind specialists but time series analysts, people who use mathematical methods to unearth regular signals buried in random noise. The three researchers were trying to understand the recent loss or damage of several satellites in Earth orbit. Strong surges of charged particles can harm sensitive electronics, so they wanted to know what role might have been played by a spray of particles coming from a "coronal hole"—a region of the sun's atmosphere that spews an especially powerful jet of particles into space. As the sun's surface rotates every 25 days or so, coronal holes sweep past Earth like searchlights, creating a periodic signal that the Bell Labs group hoped to pick up.



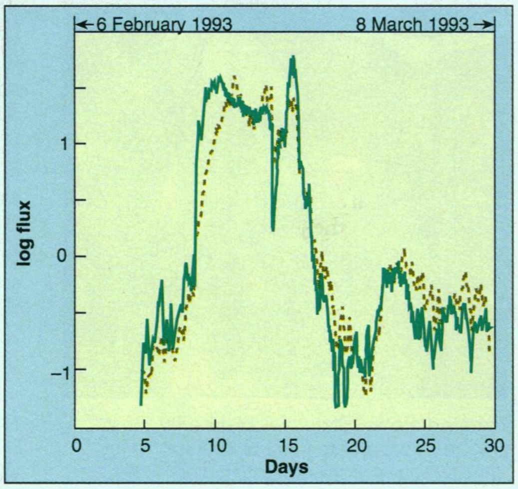


PHOTO: JOHN W. HARVEY/GONG SOURCE: DAVID THOMSON

Oscillations there and here. Shallowly driven quiverings have long been recorded on the sun's surface *(image)*, but oscillations in the solar wind may come from the sun's core. (Solid line is the total data; dotted line is the portion that has solar periodicities.)

To the surprise of the researchers, their analysis revealed not only the signature of the sun's rotation, but also sharply defined, periodic signals with much shorter periods, from hours to days. By conventional thinking, nothing in the solar wind itself could be generating oscillations with such short periods. So after testing their results to reassure themselves that the signals were real, the Bell Labs trio looked to the sun. There the only possible source seemed to be the helioseismologists' postulated g-mode (for gravity) oscillations.

Never reliably detected on the sun, these hypothetical quiverings originate, according to theory, in the core of the sun, where layers of different density undulate under the influence of gravity. Solar physicists believe these oscillations are mostly trapped in the deep interior. So it had never occurred to anyone that g modes could propagate into the solar wind. Nevertheless, the solar wind oscillations fell in the right range of periods, from about 1 hour to 10 days. Their periods tended to be evenly spaced, as those of g-mode oscillations are supposed to be. And the solar wind oscillations seemed to be constant in amplitude and frequency over several years of observations, another hallmark of g modes.

All well and good, responded helioseismologist Douglas Gough of the University of Cambridge when Thomson and his colleagues consulted him, but where were the p modes? These are pressure oscillations in the sun, like acoustic waves, that set the whole sun ringing like a bell. P modes, which originate at shallower depths in the sun, do show up clearly at the sun's surface, and helioseismologists have been analyzing them for years. If g modes can leave their mark on the solar wind, the p modes could be there too. With Gough's encouragement, Thomson and company went looking for p modes, which have periods of between 4 and 20 minutes. They found 90 of them. "That in itself increases, in my opinion, the plausibility that these [solar wind oscillations] have something to do with the solar modes," says Gough.

Thomson and colleagues strengthened their claim another notch when, in response to a review of their paper, they looked for g-mode–type oscillations in another set of spacecraft data, on the solar magnetic field that threads the solar wind. The reviewer had pointed out that charged particles, where Thomson and his colleagues first saw the oscillations, could not possibly maintain recognizable oscillations out beyond Earth's orbit on their own; particles of different energies travel at different speeds, so any oscillation involving charged particles alone would quickly be smeared to unrecognizability. If the oscillations were real, the reviewer pointed out, the solar wind's magnetic field had to be oscillating as well, driving the pulsations in the particle counts. Sure enough, Thomson found the same g-mode periods in magnetic field data as he had seen in the charged particles.

That leaves the question of how oscillations in the sun itself might set the solar wind's magnetic field to shivering. Thomson and his colleagues suggest, and Gough concurs, that the motions due to g modes at the sun's surface could be wiggling the ends of the magnetic field lines that stream outward from the sun in the solar wind, like ropes shaken back and forth at one end. The shaking would cause magnetic waves, called Alfvén waves, to run out along the magnetic field lines, accounting for the magnetic and particle oscillations detected beyond Earth. Lending support to the idea that motions at the sun's surface can set up long-range oscillations in the solar wind, Jokipii has just reported that the Ulysses spacecraft, during its pass over the southern pole of the sun, seems to have picked up long-period magnetic oscillations. What drives them, he thinks, is the jiggling of magnetic field lines by gas rising and sinking in the polar regions of the sun.

But even though the Thomson group's claim has stood up to all scrutiny so far, many solar physicists are cautiously waiting for independent confirmation. "Thomson apparently has a very good reputation as an analyzer of time series," explains Jokipii, "but most of us don't have the background to understand really how he did it. That's where the skepticism comes from." Researchers are also wary because the implications of the claims are so large.

If the oscillations are real, for example, it would alter the way solar wind specialists calculate the migration of charged particles through the solar system, says Lanzerotti. And if the g modes are real, it will be a boon to solar physicists. Coming from the sun's energy-producing core, g modes could carry clues to the apparent neutrino shortage. Many physicists suspect that the missing neutrinos might somehow be evading detection. But by studying the strength and timing of the modes, solar physicists could test an alternative idea: that the problem lies in researchers' understanding of the solar core, leading them to expect more neutrinos from fusion there than are actually produced. The exact nature of the g modes might be part of the explanation: By mixing the hydrogen fuel and the helium ash of fusion, they might change the workings of the core in a way that could account for the shortage.

The solar wind may soon have some competition as a potential source of these clues. The Global Oscillation Network Group, a global network of sophisticated telescopes dedicated to helioseismology, already has three of its six sites up and running. They should get better-than-ever data on p modes and intensify the effort to detect g modes directly. And the Solar and Heliospheric Observatory is due for launch in November with three helioseismology instruments on board. But solar wind data are already there for the taking, notes Gough. "There may be a lot of people around the world," he says, "who have the information on their computers and don't know it."

–Richard A. Kerr

IMMUNOLOGY

How the T_H2 Response Is Marshaled

Different enemies sometimes require different weapons. That lesson applies to the immune system as well as to warfare. While the immune system faces some pathogens that have invaded cells, it must also combat others that have yet to enter a cell or that do their damage strictly from the outside. To attack internal pathogens, the immune system relies heavily on a battalion of cells known collectively as "cell-mediated immunity," which can identify infected cells and clear them. On the other hand, to fight invaders that are, say, floating in the bloodstream, the weapon of choice is antibodies.

While this general picture has been understood for some time, recently it has been refined by the remarkable finding that, in this war, two sets of immune cells are the equivalent of field marshals—and are powerful enough to lock each other in the barracks if they so choose, keeping one of the two classes of immunological weaponry off the field of battle. While the immune system typically calls out both battalions, this cross-regulatory system allows for a finely tuned attack, and in some extreme cases, for unknown reasons, it favors one weapon exclusively. Now researchers at Columbia University and DNAX Research Institute of Palo Alto, California, have teamed up to elucidate how it is decided which field marshal gets to write the battle plan.

As described in a report on page 245, Columbia University's Paul Rothman, Alessandra Pernis, and co-workers investigated the molecular workings of these two field marshals—white blood cells known as types 1 and 2 T helpers, or T_H1 and T_H2. The researchers found that the absence of a specific molecule on the surface of T_H1 cells helps them gain the upper hand over T_H2 cells. This finding may ultimately help to explain why the troops that make up cell-mediated immunity get called into action rather than antibodies. "It's a very nicely done piece of work that will have substantial implications," says National Institutes of Health (NIH) immunologist William Paul. Paul adds that this work fits in nicely with a similar finding about the molecular workings of T_H2 dominance published by Kenneth Murphy of the Washington University School of Medicine and colleagues in the June issue of *Immunity*.

The current study focuses on the fact that T_H1 cells secrete a chemical messenger called interferon γ (IFN-γ), which in turn stimulates production of cell-mediated immunity. IFN-γ also inhibits T_H2 cells, which direct antibody production. The researchers explored the molecular basis for this and asked why IFN-γ does not shut down proliferation of T_H1 cells.

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>
> **—William Paul**

They focused on a cascade of events triggered by IFN-γ that allows T_H1 cells to emerge as supreme commander. The cascade includes several "signal transducing factors" (STFs), chemicals that pass a signal received at the cell surface to the cell nucleus. In this case, the STFs shut down the ability of T_H2 cells—but not of T_H1 cells—to proliferate. What the Rothman group found was that IFN-γ induced T_H2 clones (derived from mice) to produce a protein known as STF-IFNγ, the final messenger in a signal's journey to the nucleus. IFN-γ, however, had no such effect on T_H1 clones.

Through a complicated series of experiments on the roles of different STFs, the researchers deduced that the key difference between the T_H1 and T_H2 responses lay in the receptors for IFN-γ on the surfaces of the two different cell types. The full IFN-γ receptor consists of two chains, designated IFN-γRα and AF-1; the Rothman team discovered that while both clones have the IFN-γRα chain, only the T_H2 cells have the AF-1 chain. They further showed that genetically engineering the AF-1 chain into T_H1 clones led them to produce STF-IFNγ. This system apparently allows T_H1 cells to shut down reproduction of their T_H2 rivals while remaining unaffected themselves.

Although some researchers wonder what relevance this in vitro finding will have to living organisms, Rothman thinks the finding may well have clinical applications. He suggests it could help researchers determine whether a person afflicted by an autoimmune or infectious disease has mounted primarily a T_H1 or T_H2 immune response. And that could be a critical diagnostic tool for, say, leishmaniasis, a devastating skin disease that can be controlled by a T_H1 response. Currently, distinguishing between T_H1 and T_H2 is a cumbersome process that involves growing clones of different cell populations.

Whether the work yields practical applications likely will depend on whether Rothman, Pernis, and others can further illuminate the workings of T_H1 and T_H2 cells. Still, this study is shining a light on the immune system's military strategy—a strategy that a mere decade ago was a black box.

–Jon Cohen