SPACE SCIENCE

Long-Awaited Probe Gets New View of the Sun

For John Simpson, a cosmic-ray physicist at the University of Chicago, a 35-year dream was fulfilled this week when the Ulysses space probe reached the apex of its flight over the south pole of the sun. It was at the very dawn of the space age, during a 1959 round table organized by the American Geophysical Union, that Simpson suggested sending a spacecraft above the sun's poles to sample cosmic radiation funneling in from interstellar space and observe the solar wind of charged particles that flows out from the sun. The hardware to hurl a spacecraft into this uncharted territory had not even left the drawing board at that point, recalls Simpson. "I was rash enough to be confident that ultimately something could be done."

Now, with data flooding in from Ulysses, Simpson's confidence is being amply rewarded. Ulysses is the first spacecraft to climb high out of the ecliptic plane, the narrow band of space extending out from the sun's equator in which the planets orbit. It is painting an unprecedented three-dimensional picture of the sun's influence on its surroundings. As physicists pore over this picture, they hope to unravel mysteries such as the nature of the forces that drive the solar wind. They are already finding a few surprises, including a lower-than-expected cosmic ray flux at high solar latitudes and hitherto unobserved long-period waves in the sun's magnetic field. "It's just an invaluable new data set," says David McComas of the Los Alamos National Laboratory, a member of the Ulysses solar-wind plasma experiment team.

The rewards are especially sweet because for a long time it seemed that Simpson's dream was destined to remain grounded. Even after the European Space Agency (ESA) and the U.S. National Aeronautics and Space Administration (NASA) backed the idea in the late 1970s, the project seemed jinxed. First, a proposed U.S. companion to the European-built Ulysses fell victim to the budgetary ax. Then, with the launch already 3 years behind schedule, the 1986 Challenger disaster brought another 4-year hiatus.

Ulysses' value stems from its unique vantage point, outside the ecliptic plane. While the solar wind has been intensely studied from within the ecliptic, the results are very difficult to interpret. For one, the sun's rotation twists its magnetic field lines into spirals, which in turn distort the solar wind. And for another, short-lived variations in the sun's magnetic field and the density of the corona—the ultrahot halo of ionized gas, or plasma, lying above the sun's surface, where the charged particles that make up the solar wind originate—cause "gusts" in the wind that collide with the slower moving flow ahead, further distorting the picture.

The solar wind should be less disturbed far from the sun's equator, in the territory now being mapped by Ulysses. Not only are the effects of the sun's rotation largely removed, but the wind should also flow faster and more steadily. This is because, at the sun's poles, its magnetic field lines fan out into interstellar space, making it easier for the solar wind to escape the sun's magnetic field. And as Ulysses flies over the sun's poles, it is also getting the first good look at large patches of low-density corona called polar coronal holes, which are formed near the origin of the outwardly pointing field lines. Fortunately, given the fact that Ulysses was simply flown in the first available launch window, the spacecraft is arriving at a prime time to study these coronal holes, which develop more readily when the sun is least active. "The beauty of having the mission at this stage of the [11-year] solar cycle...is that we have the sun at a relatively quiescent phase," says ESA project scientist Richard Marsden of the European Space Research and Technology Center in Noordwijk, the Netherlands.

ESA

Great ball of fire. Computer-generated model of the sun, its halolike corona, and spiraling magnetic field lines *(shown in blue)*. Ulysses is now surveying the region above the south pole, where field lines mostly radiate out into space.

Ulysses began its climb into the tranquil space away from the ecliptic following a gravity slingshot maneuver performed during the probe's 1992 encounter with Jupiter (*Science*, 11 September 1992, p. 1503). Since Ulysses reached a latitude of 36 degrees south of the sun's equator, about a year ago, it has been bathed in a smoothly flowing stream of charged particles, mostly protons and electrons, traveling at around 750 kilometers per second—about twice the average speed of the solar wind in the ecliptic. "We're seeing the pristine solar wind," enthuses McComas of Los Alamos.

Ulysses has, however, encountered some deviations from this uniform flow, which occur when large volumes of plasma are ejected from the corona. The probe was expected to observe these coronal mass ejections from time to time, but at least two of the six ejections it has so far identified at high latitudes unexpectedly contain material at a higher pressure than the surrounding wind, so they expand as they travel out from the sun.

While solar wind physicists puzzle over this observation, their colleagues working on Ulysses' cosmic-ray experiment have a quandary of their own: They've encountered less cosmic radiation than expected. The problem for cosmic-ray physicists working in the ecliptic plane is that many of the particles shooting into the solar system from interstellar space must follow very long paths along the magnetic field lines wound into a spiral by the sun's rotation, and many just don't complete the journey.

Above the sun's poles, however, the sun's outwardly reaching magnetic field lines should act like a funnel, guiding cosmic radiation in toward the sun. Ulysses did record an increase in cosmic radiation as it passed beyond about 40 degrees latitude, says Bruce McKibben of the University of Chicago. But "the magnitude of the increase is rather smaller than the simplest models had led us to believe." Indeed, it's only as the craft has approached the apex of its climb over the sun's south pole that Simpson's Chicago team has observed the marked increase in cosmic radiation it had predicted.

Ulysses itself may have provided the answer to this puzzle, however. Researchers working with the spacecraft's magnetometers have detected a class of magnetic waves that doesn't show up clearly at lower latitudes. A team headed by André Balogh of London's Imperial College has recorded waves with periods of 10 hours or more in the magnetic field lines emanating from near the sun's south pole—similar in form to the waves in a guitar string when it is plucked.

These Alfvén waves would impede incoming cosmic particles, says Balogh: "It's like trying to walk through mud."

Detailed analysis of these same waves, and of the composition of the solar wind, could unravel the mysteries of the processes that accelerate the solar wind. Some theorists have speculated that magnetic waves close to the sun add momentum to charged particles leaving the corona, while others have proposed that the sun's magnetic field acts like the constricted neck of a rocket nozzle, from which material is ejected at high velocity. Data from Ulysses should reveal the relative importance of these two processes. "That will have to be sorted out by doing a lot of careful modeling," says U.S. Ulysses project scientist Edward Smith of the Jet Propulsion Laboratory in Pasadena, California.

While the data already gathered by Ulysses will keep the modelers busy for years, the mission is far from over. After reaching its highest southerly latitude of 80.2 degrees on 13 September, Ulysses is now swooping toward the sun's north pole, and will pass over it about 1 year from now. And beyond that, mission scientists hope the project will be continued for a second orbit of the sun. ESA is already in favor, and although NASA hasn't yet made a firm commitment, the signs are positive. The proposal is to keep Ulysses in action until 2001, when the sun will be at its most active. The sun's magnetic field will then be highly disordered, and coronal mass ejections will be daily events. Understanding this turbulent environment will test the skills of mission scientists to the limit, but they are eager for the challenge. Indeed, after waiting 7 years to get Ulysses off the ground, they are anxious to wring as much data from the spacecraft as possible. "Not continuing the mission would be really crazy," says Balogh.

–Peter Aldhous

ASTRONOMY

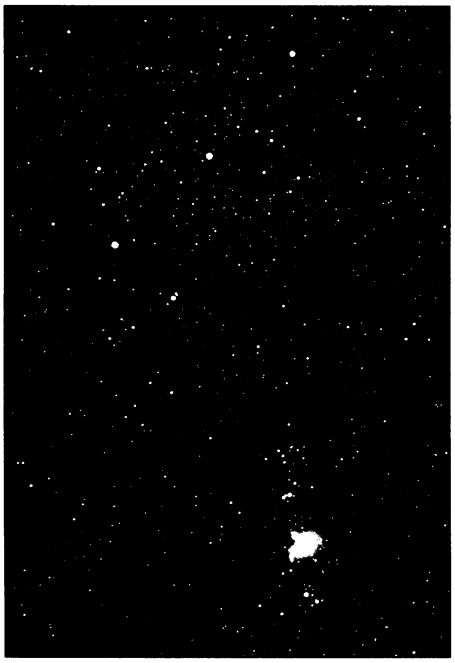
A Constant Star Suddenly Flares Up

Stars, although they blow up once in a while, have a reputation for dependability: Shakespeare's Cassius described himself as "constant as the Northern star," and sailors still use the predictability of stellar positions to steer their courses. For astronomers, one of the most enduring emblems of stellar steadfastness has been the x-rays given off by so-called hot stars, whose surface temperatures range from 10,000 to 60,000 degrees kelvin. Day after day, year after year, these celestial objects seem to generate an unvarying amount of x-rays.

Now one of these reliable hot stars has shown some startlingly erratic behavior. On page 1689, two astronomers at the Max Planck Institute for Extraterrestrial Physics in Munich report that Zeta Orionis, the leftmost star in Warrior's belt of the famed Orion constellation, suddenly displayed a dramatic burst in x-ray brightness over the span of 2 days in 1992. In contrast to the variable x-ray emissions of stars like our sun, "we had never seen a flarelike event on [a hot star]," says one of the investigators, Jürgen Schmitt. Astronomers are now scrambling to explain the blast, a complex task made more difficult because they've never been sure how these stars generate x-rays at all.

Schmitt and colleague Thomas Berghöfer spotted the x-ray eruption earlier this year, when they were studying observations taken by the German x-ray satellite ROSAT. According to one of ROSAT's instruments, Zeta Orionis' production of "hard," or high-energy, x-rays rose by 30% over a period of 48 hours in late September 1992. When next observed in February 1993, the star's hard x-ray production had decreased but was still higher than before the flare. At the same time, its output of "soft" or low-energy x-rays was up by 20%. By September 1993, both hard and soft x-ray emissions had returned to their constant ways.

Until astronomers figure out how these stars generate x-rays in the first place, they will be hard put to explain Zeta Orionis' flare-up. The basic quandary is that only gases heated to millions of degrees emit x-rays, yet the surface temperatures of stars such as Zeta Orionis do not approach that mark. Nor do hot stars have the immense magnetic fields that allow cooler sunlike stars to produce x-rays; the magnetic fields trap and condense pockets of gas, heating them to sufficient temperatures for x-ray emission. "We're not really sure where the x-rays come from," says Michael Corcoran, who studies hot stars at the National Aeronautics and Space Administration's Goddard Space Flight Center in Maryland.



JOHN SANFORD/PHOTO RESEARCHERS

Erratic emissions. Zeta Orionis *(leftmost of three-star group near top of photo)* loosed an unexpected blast of x-rays in 1992.

More than a decade ago, a few astronomers did put forth a theory about these x-rays: The answer, they said, was blowing in the wind. Hot massive stars can generate huge stellar winds, which are waves of gaseous material streaming off the surface. The speed of these stellar winds often varies, so there should be times when a fast-moving gust overtakes a slower moving breeze. When they collide, the theory holds, resulting shock waves could heat gases to millions of degrees. This mechanism can also be reconciled with the consistency of x-ray emission. "There just has to be lots and lots of little shocks to keep the x-rays constant," explains theorist Stan Owocki of the Bartol Research Institute in Delaware.

Berghöfer and Schmitt argue that their x-ray flare stems from an abnormally large shock wave. In a model they developed to match the ROSAT data, Zeta Orionis at some point puffs out a relatively slow-moving dense shell of gas, one that after 2 days is moving at 570 kilometers per second (km/s). The stellar wind then returns to normal, a smooth stream of less dense gas traveling at 1600 km/s. This quicker gas catches up to the dense slow shell, Schmitt explains, and the collision creates a shock wave that propagates outward at 1000 km/s and generates x-rays as it heats the gases. As the shock wave extends, adds Berghöfer, it should lose energy and start to generate more soft x-rays than hard, as the resulting lower temperature gases would produce lower energy radiation.

Although Berghöfer and Schmitt's conjecture fits the satellite observations, other hot-star modelers argue that the data are just too limited to conclude that the event was caused by a propagating shockwave. A crucial problem, says Owocki, is that ROSAT only caught the initial x-ray rise and didn't keep observing Zeta Orionis to establish a decaying curve, which would be much stronger evidence for a cooling shock wave. As a result, Schmitt, Berghöfer, and other astronomers plan to step up their monitoring of Zeta Orionis and similar hot stars, hoping this eruption—unique to date—won't be unique for long.

–John Travis