SPACE PHYSICS

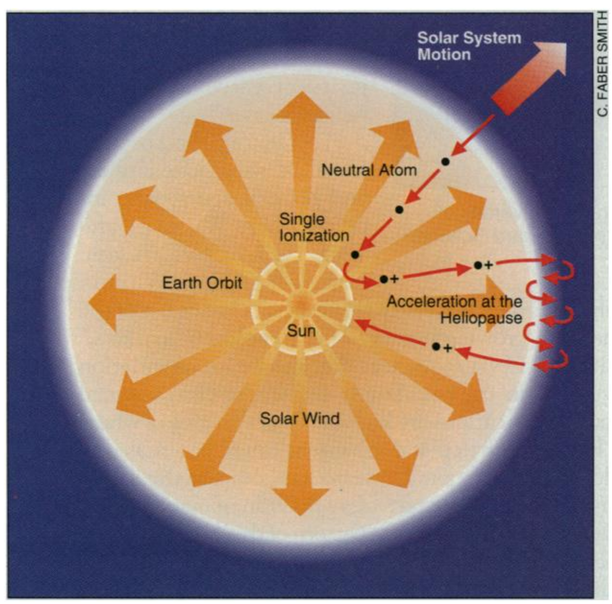
Found: Messengers From The Interstellar Medium

The sun and the solar system hover in a great, invisible cocoon, swept clean of interstellar material by the wind of charged particles that streams away from the sun. Scientists would love to study the thin interstellar gas that lies outside this cocoon, but until recently they thought they might have to go three times the distance of Pluto to get a sample.

Now, however, evidence from Russian and U.S. satellites has pinned down a 20-year-old hypothesis suggesting that a bit of the interstellar medium is leaking into the solar system, says James Adams of the Naval Research Laboratory. The results, which Adams and his colleagues announced in part last year in *The Astrophysical Journal* and in more complete form last week at a meeting in Uzbekistan, suggest that one kind of cosmic rays—so-called anomalous cosmic rays—originate as neutral atoms of interstellar medium. To other astrophysicists, that finding raises hopes of studying material from outside the solar system without leaving the vicinity of Earth. Says collaborator Glen Mason of the University of Maryland, "These cosmic rays can tell us about the processes beyond where we can send spacecraft."

Scientists first speculated that the anomalous cosmic rays are messengers from the interstellar medium in order to explain their odd composition. Twenty years ago, when satellites started measuring the various ions bombarding Earth, researchers noticed a group of outliers—a set of cosmic rays whose mixture of elements set them apart from others and, indeed, from anything else in the solar system. It seemed possible that these cosmic rays didn't come from the usual cosmic ray sources—the sun or energetic sources elsewhere in the galaxy.

One clue to their origin was the fact that these anomalous cosmic rays were dominated by oxygen and nitrogen, the elements that hold their outer electrons the tightest. To theorists Rueven Ramaty and Lennard Fisk of NASA Goddard Space Flight Center, the pattern suggested that anomalous cosmic rays might simply drift into the solar system from the interstellar medium. While charged particles need tremendous energies to blast through the electromagnetic forces generated by the solar wind, a nucleus that clung tightly enough to its electrons might stay neutral and thereby slip right through the outward rush of solar wind.



A long, winding road. Anomalous cosmic rays drift into the solar system as neutral atoms, get ionized and swept outward by the solar wind, then flung back in again.

To explain how these leisurely neutral atoms become the speeding charged particles that were detected, Ramaty and Fisk's scenario included another step. When the neutral particles drifted close enough to the sun, ultraviolet radiation would finally ionize them. As soon as a single electron got knocked off the nuclei, they would get swept back outward by the solar wind, all the way to the "termination shock"—a turbulent area believed to lie well beyond Pluto, where the solar wind runs into the interstellar medium. The shock wave thought to be created there would act as a natural accelerator, hurling the ions back into the solar system toward Earth.

Even Ramaty, one of the theory's originators, admits that the whole scheme seemed "far fetched." But he's more confident now that observers have brought back evidence supporting the theory's main testable prediction: The anomalous cosmic rays should have lost only one electron. Cosmic rays from the sun, by contrast, lose all their electrons before they are emitted, and galactic cosmic rays get stripped bare by interactions with interstellar gas during their journey through millions of light-years of interstellar space. "The key to confirming the scenario is testing for single ionization," says Adams.

That's what he and his colleagues did by combining data from the Soviet satellite Cosmos, which moves inside Earth's magnetic field, and the U.S. probes IMP-8 and IC-3, which orbit outside it. By comparing the number of anomalous cosmic rays found outside the magnetic field with the number inside it, Adams could determine how well the particles were penetrating the field—a process that depends on charge, with more highly charged ions being less efficient at penetrating the field. Adams and his colleagues found that the data indicated an average charge of one, just as Ramaty and Fisk's theory predicts.

Bolstering the case for single ionization was the evidence that the ions penetrate the field fast enough to build into a belt of charged particles at the fringes of Earth's atmosphere. "The [outer] atmosphere accumulates this stuff," says Adams. For most of the ions, he explains, their venture into the magnetic field is a one-way trip. They can readily enter it because they carry only a single positive charge, but when they reach Earth's upper atmosphere, brushes with air molecules strip them of their other electrons. The resulting high-positive charges make them slaves to the magnetic field. The ironic conclusion: These ions could only have ended up so close to Earth if they had started out in the interstellar medium. In fact, Adams says, "it's hard to conceive of them being present without this mechanism."

If so, the isotopic composition of the anomalous cosmic rays should reflect that of our galaxy at large. Soon the recently launched SAMPEX (Solar Anomalous Magnetospheric Particle Explorer) satellite will be measuring those isotopic fingerprints. Comparing them with the isotopic ratios in the solar system will tell us how special the material that made up the solar system really is. The comparison might lend support to the idea, invoked by some theorists, that the solar system is enriched with material from a supernova, whose shock could have triggered its formation by precipitating the collapse of a primordial cloud of dust and gas.

John Simpson of the University of Chicago, who codiscovered the anomalous cosmic rays, is also looking forward to comparing their isotopic fingerprints with those of galactic cosmic rays. That might show, he says, whether the other cosmic rays also originate as atoms of interstellar medium that gain their enormous energies when they are caught in the blast of distant supernova explosions—or whether more exotic origins have to be invoked.

Even the anomalous cosmic rays haven't run out of mysteries. Just how they might be accelerated at the termination shock is still uncertain, says Simpson. But a flotilla of spacecraft may soon send back news of this putative giant accelerator in the sky. That's the final lonely job of Pioneers 10 and 11 and Voyagers 1 and 2, now that they have passed the last planets and helplessly speed into deep space.

–Faye Flam