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The Galactic Environment of the Sun

The heliosphere appears to protect the inner solar system from the vagaries of the interstellar medium

Priscilla C. Frisch

Pieces of interstellar matter are constantly passing through our solar system. These galactic visitors—atomic particles and bits of dust—flow through interplanetary space and may collide with the major bodies in the solar system—the earth and the other planets. Although each particle is microscopic, their total mass in the solar system is enormous. Indeed, about 98 percent of the gaseous fraction in the *heliosphere*—the volume of space filled by the solar wind—consists of interstellar material! How do these particles interact with a planet's environment? Do they have a significant impact on a planet's atmosphere? No one knows.

These questions take on special significance in light of the fact that the interstellar medium—the sun's galactic environment—is not a homogeneous substrate. Astronomers have discovered that interstellar material is organized into clouds of dust and gas with elaborate features resembling filaments, worms, knots, loops and shells. Within a relatively small region of space, just a few thousand light-years across, the interstellar medium may exhibit a broad range of temperatures, densities and compositions. Indeed, astronomers' understanding of the interstellar medium has been up-ended in the past decade as the physical and structural complexity of interstellar material has unfolded. It is now evident that the sun must have experienced a broad range of galactic environments in its 5-billion-year history.

How does the solar system respond to a change in its galactic environment?

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Part of the answer must lie with the solar wind—the hot, ionized gas that blows out from the sun. As it happens, the solar wind modulates what can (and cannot) flow into the solar system. Given that the solar wind is itself a variable phenomenon (changing in strength periodically with an 11-year solar cycle), the relation between the solar wind and the invading particles from the interstellar medium is in constant flux. Sorting out the complex interplay between these dynamic phenomena has become a fascinating area of research. Here we describe what space scientists and astrophysicists have learned about the sun's galactic environment and its interaction with the solar system.

The Solar Neighborhood

We tend to think of our neighborhood in the Milky Way galaxy as motionless: Various nebulae and dust clouds look pretty much the same as when astronomers first photographed them more than a century ago. But this perception of a tableau frozen in space is deceiving. Over the course of millions of years, interstellar clouds form and dissipate as stars and supernovae stir up the interstellar matter. Fierce stellar winds produced during star formation evacuate cavities in the molecular clouds in which the stars are born. When subsequent supernovae explode in these cavities, violent shock fronts are produced that ram into surrounding material and sweep interstellar gas into “supershells” that may break out of the parent molecular clouds and propagate outward through the low-density regions of space. The atoms within these clouds are partially ionized by stellar radiation and collisions with each other, and by x rays from shocked gas within the evacuated “superbubble” cavities.

Some supershells are also threaded by magnetic fields, which trap ions that may be in the vicinity. It is this combined image of various activities that should be held in mind when we consider our local galactic environment.

Our sun is also in motion. Relative to the average motion of the most commonly measured nearby stars, the sun moves with a speed of about 16.5 kilometers per second, or nearly 50 light-years per million years. The sun's path is inclined about 25 degrees to the plane of the galaxy and is headed toward a region in the constellation of Hercules near its border with Lyra. The sun oscillates through the plane of the galaxy with an amplitude of about 230 light-years, crossing the plane every 33 million years. However, the sun's motion relative to the local stellar neighborhood should not be confused with its movement around the center of the galaxy, since the whole solar neighborhood (including the sun) orbits the galactic center once every 250 million years. Just as we do not include the earth's velocity around the sun when calculating the speed of an airplane (we are only interested in the ground-speed), astronomers do not include the sun's galactic orbital velocity when describing its local motion.

The interstellar cloud currently surrounding the solar system—often referred to as the *Local Interstellar Cloud*—is warm, tenuous and partially ionized. Like all interstellar clouds, our local cloud is made of dust and gas, with the dust fraction making up about one percent of the cloud's mass. The elemental composition of interstellar clouds is much like that of the sun, about 90 percent hydrogen and 9.99 percent helium. The heavier elements make up the remaining 0.01 percent.



Figure 1. Our “neighborhood” in the Milky Way lies just inside one of the galaxy’s great spiral arms, the Orion Arm. The majority of the brightest stars are distributed along a section of sky known as Gould’s Belt (*dashed ellipse*), which also marks the distribution of the nearby star-forming regions in the Orion spiral arm. Stellar winds from these star-forming regions—such as the Scorpius-Centaurus association—push “shells” of interstellar material into the sun’s path. The sun is currently on the edge of such a shell (not visible at this scale). The actions of interstellar winds and the sun’s own motion through the galaxy may alter the sun’s local galactic environment on time scales as brief as a few thousand years. The author discusses what space scientists know about the interaction between the solar system and its changing galactic environment. (Courtesy of the National Geographic Society. Adapted from the supplement to the October 1999 issue of *National Geographic*.)

The sun is on the edge of what is sometimes called the *Local Bubble*, a great void in the distribution of interstellar gas in the nearby galactic neighborhood. As voids go, the Local Bubble interior is one of the most extreme vacuums yet discovered. The very best laboratory vacuum is about 10,000 times denser than a typical interstellar cloud, which in turn is thousands of times denser than the Local Bubble. The Local Bubble is not only relatively empty (with a density of less than 0.001 atoms per cubic centimeter); it is also quite hot, about one million degrees kelvin. By comparison, the interstellar cloud around the solar system is merely warm, about 7,000 degrees, with a density of about 0.3 atoms per cubic centimeter.

The Local Bubble lies within a ring of young stars and star-forming regions known as *Gould’s Belt*. The Belt is evident in the night sky as a band of very bright stars that sweeps in a great circle from the constellations Orion to Scorpius, inclined about 20 degrees relative to the galactic plane. The north pole of Gould’s Belt lies close to the *Lockman Hole*, a region in the sky with the least amount of intervening interstellar gas between the sun and extragalactic space. Star formation regulates the distribution of interstellar matter, including the boundaries of the Local Bubble. The closest star-forming region on the outskirts of the Local Bubble is about 400 light-years away in the Scorpius-Centaurus association. The molecular clouds

from which stars are formed are both cooler (less than 100 degrees) and denser (over 1,000 atoms per cubic centimeter) than the Local Interstellar Cloud.

A plot of the sun’s course through our galactic locale shows that the sun has been traveling through the Gould’s Belt interior in a region of very low average interstellar density for several million years. The sun is unlikely to have encountered a large, dense interstellar cloud in this relatively benign region during this time. Although our solar system is in the process of emerging from the Local Bubble, the sun’s trajectory suggests that it will probably not encounter a large, dense cloud for at least several more million years. The consequences of such an encounter for

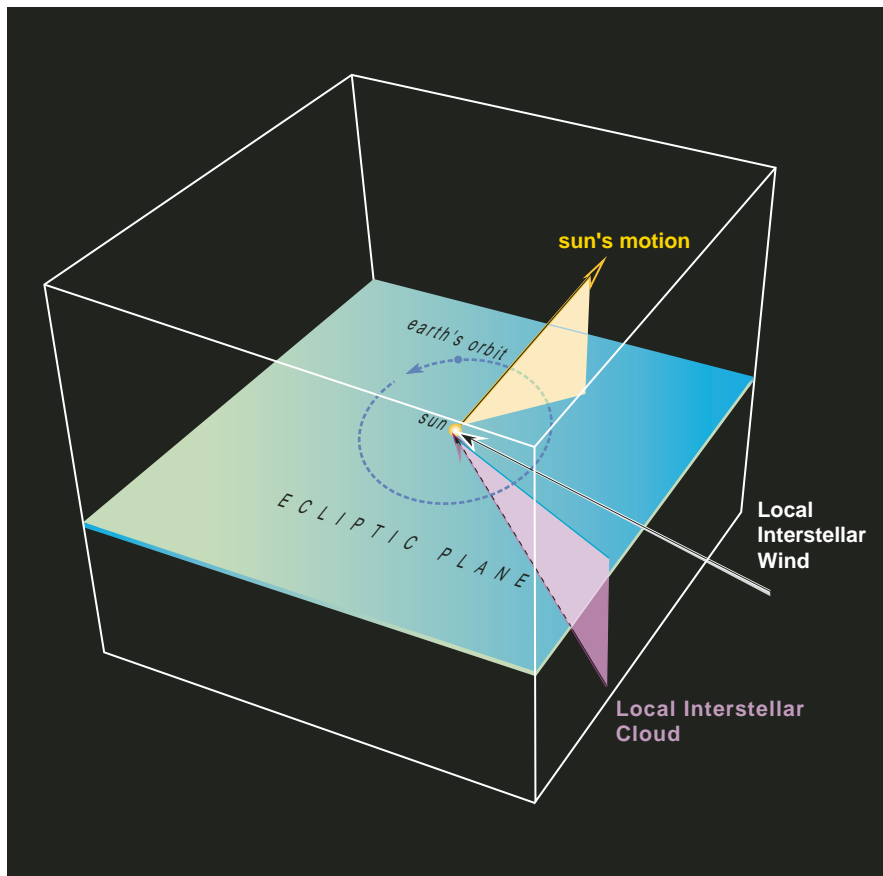


Figure 2. Relative motions of the sun (yellow arrow) and the Local Interstellar Cloud (violet arrow) result in a Local Interstellar Wind (white arrow) that flows through the solar system at about 26 kilometers per second. The Local Interstellar Wind appears to enter the solar system at an angle just above the ecliptic plane. Sorting out the relative motions of the sun and the interstellar winds with respect to the local galactic environment is a nontrivial scientific problem.

the earth's climate are unclear; however, one wonders whether it is a coincidence that *Homo sapiens* appeared while the sun was traversing a region of space virtually devoid of interstellar matter.

Despite the absence of massive clouds within 100 light-years, it seems likely that the local galactic environment changes in subtle ways on much shorter time scales. The low density of the Local Bubble permits the products of supernova explosions—such as superbubbles and shock fronts—to expand easily into the void and sweep past the sun. Indeed, within the past 250,000 years the sun has entered the outward flow of material from the star-forming region of the Scorpius-Centaurus association. There is even some suspicion that the interstellar environment may have changed within the past 2,000 years! This is uncertain, however, because astronomers have an incomplete understanding of the structure of the local interstellar cloud complex.

The cloud around the solar system is part of the outflow of material from the

Scorpius-Centaurus association. If we adopt the viewpoint of a person who is stationary with respect to the average motion of the nearest stars, then the motions of the sun through space and the Local Interstellar Cloud are seen to be nearly perpendicular. In other words, the interstellar cloud complex around the sun is sweeping past the solar system in a direction roughly perpendicular to the sun's movement with respect to the local solar neighborhood. The result of these two motions is that we observe interstellar material flowing toward the sun at about 26 kilometers per second from a direction close to the plane of the ecliptic and within about 15 degrees of the center of the galaxy. Because this material flows through the solar system, it has been dubbed the *Local Interstellar Wind*.

The origin of the Local Bubble and the Local Interstellar Cloud is still an open question. Some astronomers believe the void is a region of space between spiral arms of the galaxy that has been evacuated by shock waves of suc-

cessive star-formation episodes in the Scorpius, Centaurus and Orion constellations and the Gum Nebula. Others believe that the void was created by a supernova explosion (in the Scorpius-Centaurus association) that evacuated a "hole" in a pre-existing low-density portion of the interstellar medium. (The term "Local Bubble" was originally coined with the idea that the solar system was sitting inside a supernova remnant.) So the Local Interstellar Cloud appears to be either material pushed aside by the winds of star formation or a supershell marking the edge of a superbubble.

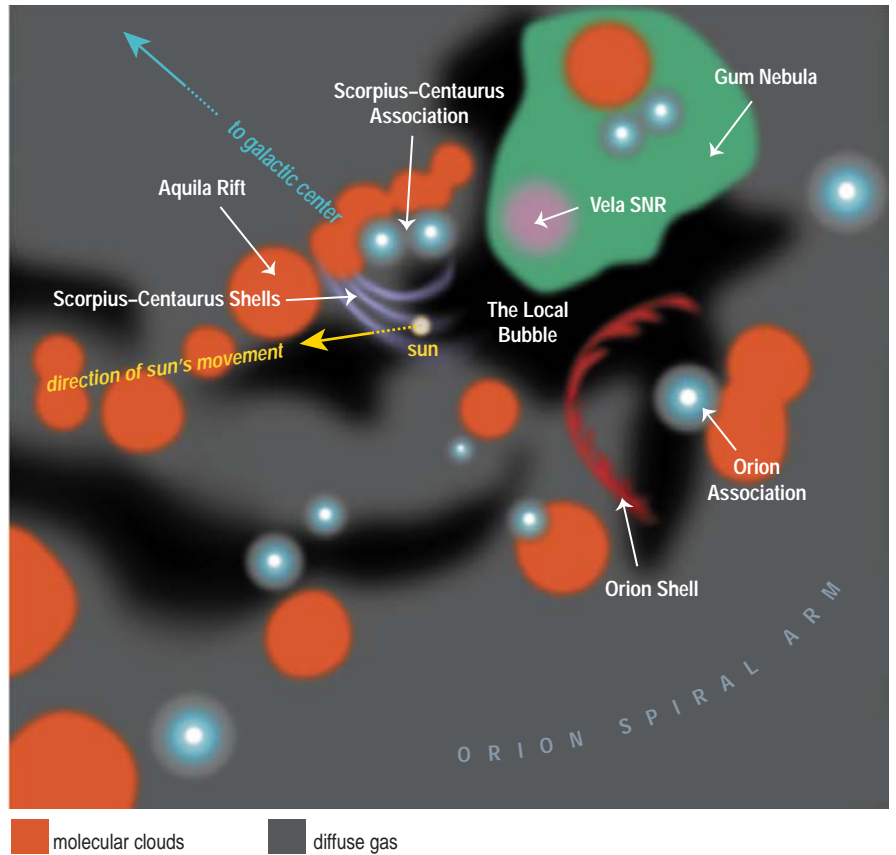
The Heliosphere

As the Local Interstellar Wind blows through our solar system, it must pass through another wind—that produced by our own sun. The solar wind is a hot plasma—consisting of charged particles (mostly protons, helium nuclei and electrons)—that streams outward from the sun at high speed. Its source is the solar *corona*, the tenuous, million-degree plasma surrounding the sun that is evident during a total solar eclipse as a halo of brilliant "hair" surrounding the darkened disk. The solar wind also contains an embedded magnetic field that is wrapped into a tight spiral pattern by solar rotation. From the coronal region the supersonic solar wind blows out far beyond the orbit of Pluto before it is stopped by the charged component of the interstellar gas.

As the solar wind blows out toward the outer solar system, its density decreases. At a distance of 1 astronomical unit (or AU, the distance from the sun to the earth), the solar wind typically has a density of about 5 particles per cubic centimeter and a speed of about 400 kilometers per second. At about 80 to 100 AU, a termination shock is formed as the solar wind slows down from supersonic to subsonic speeds. The solar wind finally stops at the *heliopause*—the "stagnation" surface between the solar wind and the ions of the interstellar medium about 130 to 150 AU from the sun—which forms the boundary of the heliosphere. Both the average density and velocity of the solar wind vary with the activity cycle of the sun (and with the sun's latitude).

Models of the heliosphere suggest that it is shaped something like a water droplet. This shape is largely determined by the flow of the charged component of the interstellar gas around the

Figure 3. Galactic environment within 1,500 light-years of the sun contains gas clouds of various densities and temperatures. The sun has been passing through a hot, very low-density region—the Local Bubble (black)—for several million years, and it is now embedded in a shell of warm, partly ionized material (violet) flowing from the Scorpius-Centaurus star-forming region. Cold, dense molecular clouds (orange), such as the Aquila Rift, can inhibit the flow of these shells, but the low-density bubble around the sun readily allows such interstellar material to sweep over the solar system. The Vela supernova remnant (SNR, pink) should ultimately cool and expand to form shells of material similar to that surrounding the sun (see Figure 4). The Gum Nebula (green) is a complex region of ionized hydrogen that forms a major “landmark” in our local galactic neighborhood. Astrophysicists are currently engaged in reconstructing the history and the fine structure of the various components in the sun’s galactic environment.



solar-wind plasma. Although the interstellar medium is only about 30 percent ionized (again mostly protons and electrons), these charged particles do not want to traverse the magnetic fields embedded in the solar wind (because the Lorentz force binds them to the magnetic field). Thus the interstellar plasma is compressed and diverted around the heliosphere. Since neutral interstellar hydrogen atoms trade electrons back and forth with interstellar protons, a small portion of the neutral interstellar hydrogen is also compressed and diverted at the boundary of the heliosphere, forming an observable phenomenon called the hydrogen wall.

Another phenomenon that may be found outside the heliosphere is a bow shock, which would be produced if the heliosphere were moving faster than the speed of sound through the Local Interstellar Cloud. Since the speed of sound in the cloud is about 9.6 kilometers per second, and the relative sun/cloud velocity is 26 kilometers per second, one would assume that the heliosphere would have a Mach 2.5 bow shock. However, there is a good possibility that the Local Interstellar Cloud contains a weak magnetic field, which, if it were stronger than about 3 or 4 microgauss would inhibit the formation of a bow shock. Bow shocks form when the substrate material is unable to carry off disturbances faster than the object causing the disturbance is itself moving. If a magnetic field is present, then the tension in the magnetic field lines can transport the disturbance away (similar to the way in which the whole string vi-



Figure 4. Vela supernova exploded 11,000 years ago, forming a (remnant) shell of warm, ionized filaments that is still moving rapidly but will cool and slow down within the next few million years. The electrons and protons in the shell will eventually recombine to form neutral hydrogen atoms. The end result will be a warm, tenuous, neutral cloud complex traveling slowly through space, similar to the interstellar cloud surrounding our sun.

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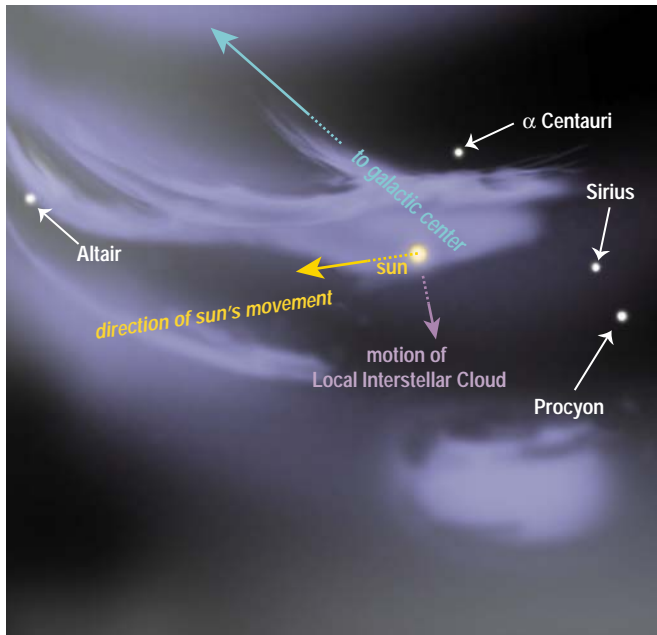


Figure 5. Nearby interstellar medium—within 10 light-years of the sun—is dominated by a shell of material, the Local Interstellar Cloud (violet), that flows outwards from the Scorpius-Centaurus association. This part of the shell is moving (violet arrow) perpendicularly to the sun's motion in space and so cuts across its path (yellow arrow). The boundaries of the clouds are based on optical and ultraviolet observations of some nearby stars (such as Sirius, Alpha Centauri and Altair), which reveal the relative amounts of the gases in front of the stars. The motions are shown with respect to nearby stars.

brates when a violin string is plucked). The stronger the interstellar magnetic field, the faster it carries away pressure disturbances. Current estimates of the strength of the interstellar magnetic field lie between 1 and 5 microgauss.

Material Inside the Heliosphere

Although the ions in the interstellar medium are deflected around the heliosphere, a majority of the neutral interstellar atoms (mostly hydrogen and helium) flow cleanly into the solar system. Remarkably, about 98 percent of the diffuse gas within the heliosphere (excluding material associated with planetary bodies and comets) is interstellar material. In fact, the densities of the interstellar material and the solar wind are equal near the orbit of Jupiter. These surprising results can be understood if one appreciates that the solar wind must fill an increasingly large volume of space in the outer solar system, so that its density decreases with the inverse square of its distance from the sun. In contrast, the density of the neutral component of the interstellar wind changes very little as it flows through the heliosphere, until it is finally ionized.

The first discovery of interstellar matter within the solar system was made in the 1960s by a spacecraft observing the earth's *geocorona*, a layer of neutral hydrogen atoms that forms in the outermost part of the planet's atmosphere. The spacecraft detected a weak fluorescent glow of Lyman-alpha ultraviolet radiation—effectively a “marker” for neutral hydrogen—that had a different spatial distribution than the geocorona. A Lyman-alpha photon is emitted when an electron in a neutral hydrogen atom falls from the first excited energy level of the atom to the ground level. In interstellar space, the hydrogen is comparatively “cold” so that electrons are in the ground state. However, when neutral interstellar atoms flow into the solar system and approach the sun, the intense Lyman-alpha photon radiation from the solar atmosphere pumps the electron into the first excited state. The electron then naturally decays down to the lowest energy level again and emits a Lyman-alpha photon in the process, creating a weak interplanetary ultraviolet glow. (Recent results from the TRACE instrument aboard the SOHO satellite provide sensitive maps of the interplanetary Lyman-alpha glow,

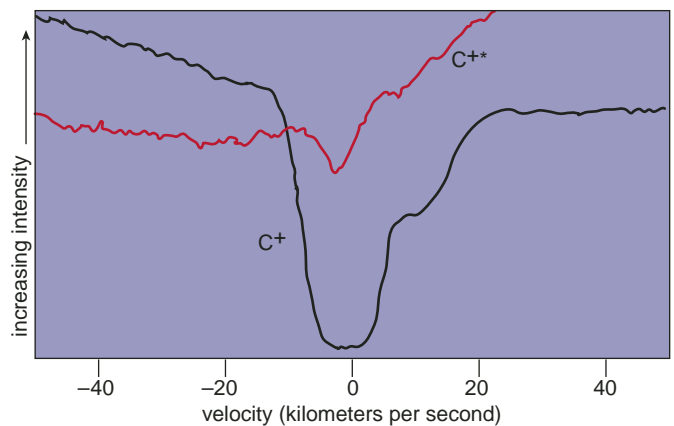


Figure 6. Absorption of ultraviolet light by interstellar gas in our line of sight to the star Eta Ursae Majoris reveals characteristics of the intervening gas, including its composition and velocity with respect to the sun. Here absorption lines reveal the relative absorption of ultraviolet photons (with a wavelength of 1,335 angstroms) by ionized carbon (C^+) in the interstellar cloud material between the star and the earth. Doppler shifting of these absorption lines reveals that the carbon atoms (and hence the intervening cloud materials) are moving at various velocities with respect to the sun (positive velocities are moving away from us, negative velocities toward us). The bulk of the material is not moving toward or away from the sun; however the asymmetry of these absorption lines (on either side of 0 kilometers per second) indicates that at least two gas clouds of differing velocities are present. The weakly absorbing line (red, C^{++}) is produced by the collision of carbon ions with electrons in the gas. Its strength relative to the primary absorption line (black) reveals the ionization of the gas cloud (if the cloud's temperature is known). (Data from the Hubble Space Telescope.)

showing active regions of Lyman-alpha emissions on the backside of the sun.)

Since this discovery in the 1960s, many other manifestations of interstellar matter have been discovered within the solar system. Astronomers now know that most of the interstellar hydrogen atoms are ionized within several AU of the sun, partly by photo-ionization from solar radiation and partly by charge exchange with the solar wind. The helium atoms, on the other hand, penetrate to within a fraction of an AU of the sun before they are ionized by the solar photons. Some neutral helium atoms escape ionization, however, and are attracted by the sun's gravitation to form a focusing cone downwind of the sun. The earth passes through this focusing cone at the end of November every year.

As the interstellar atoms are ionized, they are “picked up” by the solar wind plasma and swept out to the heliosphere's termination shock. Since these *pickup ions* are products of the interaction between the solar wind and the neutral atoms of the interstellar medium, their measurement offers clues to the composition of the interstellar medium. Helium pickup ions were originally

discovered near the earth by a team led by Eberhard Möbius, now at the University of New Hampshire, in the mid-1980s. More recently, as the Ulysses spacecraft left the inner solar system, the onboard SWICS instrument (of George Gloeckler at the University of Maryland and Johannes Geiss at the International Space Sciences Institute in Maryland) was able to detect and identify additional elements in the pickup ion population, including nitrogen, neon and oxygen, as well as isotopes of helium and neon. Each of these elements is found partially in neutral form in interstellar gas, and the neutrals can enter the heliosphere without diversion by the Lorentz forces. Comparing the abundances of pickup ions with the abundances of ions in the nearby interstellar gas provides important clues about the original ionization level of the cloud feeding interstellar material into the solar system.

Once the pickup ions reach the termination shock they are accelerated up to cosmic-ray energies, forming a component known as the *anomalous cosmic-ray population*. This anomalous population is seen as a bump tacked onto the low-energy end of the galactic cosmic-ray spectrum. These particles are “anomalous” because their energies are too low for them to have entered the heliosphere from the outside, indicating that they must have formed within the solar system. As it happens, these anomalous cosmic rays return to the inner solar system where some are captured by the earth’s magnetosphere. In other words, these particles zip back and forth through the heliosphere: They are blown into the solar system as interstellar neutral atoms, blown out to the termination shock as pickup ions and then returned to the inner solar system as anomalous cosmic rays!

Atomic particles are not the only visitors from outer space that find their way into the solar system. A team led by Eberhard Gruen of the Max-Planck Institute discovered “large” dust grains (between 0.2 and 6 micrometers in diameter) inside the heliosphere with dust detectors aboard the Ulysses and Galileo satellites. These dust grains were flowing with the same velocity and direction as the Local Interstellar Wind. (Smaller dust grains are charged and therefore excluded from the solar system by Lorentz forces just outside the heliopause.) The largest dust grains have trajectories that are relatively unaf-

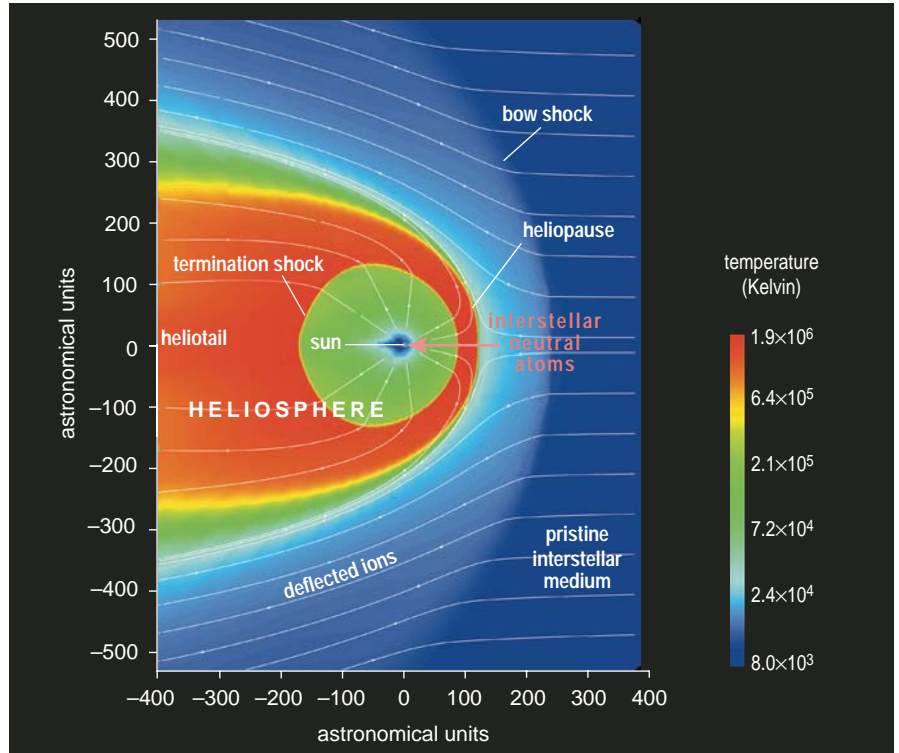


Figure 7. Solar wind emanating from the sun fills a volume of space around the solar system—called the heliosphere—that interacts with the flow of matter in the interstellar medium. The solar wind is an ionized gas that slows down to subsonic speeds at the termination shock and effectively stops at the heliopause, which defines the edge of the heliosphere. Charged particles (white lines), mostly hydrogen ions, in the interstellar wind are deflected around the heliosphere’s edge (the heliopause), whereas neutral particles (pink arrow), primarily hydrogen and helium atoms, penetrate the heliosphere. The interstellar wind also “blows” against the solar wind (white lines inside the heliosphere) forcing it to flow with the interstellar wind to form a *heliotail*. Since the solar wind changes with the solar cycle, and the interstellar medium is a heterogeneous structure, there is an ever-changing interaction between the heliosphere and its galactic environment. Here the boundaries of the heliospheric features are mapped according to their relative temperatures. (Courtesy of Gary Zank, University of Delaware.)

ected by the solar wind or solar-activity cycles. Much like the interstellar helium atoms, these dust particles are focused downwind of the sun, and the earth passes through this focusing cone at the end of November every year. Dust grains of intermediate sizes may be focused in the plane of the ecliptic or diverted from the plane, according to the polarity of the magnetic field embedded in the solar wind, which changes every

11 years with the phase of the solar cycle. (Once again the Lorentz force is important since it binds these charged interstellar grains to the solar wind.)

A Changing Galactic Environment

We do not know whether the interstellar cloud complex flowing past the sun is a homogeneous structure. On the basis of more distant interstellar clouds, it’s quite possible that the Local Inter-

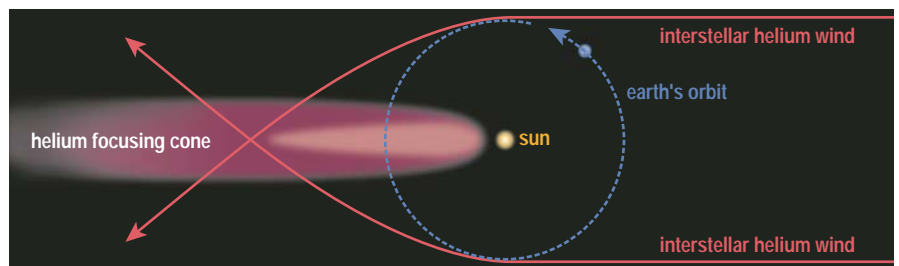


Figure 8. Interstellar helium (pink arrows) that enters the heliosphere is focused by the sun’s gravity to form a helium focusing cone in a direction pointing away from the incoming Local Interstellar Wind. About 10 percent of the neutral interstellar particles are helium atoms. The earth passes through the focusing cone near the end of November every year.

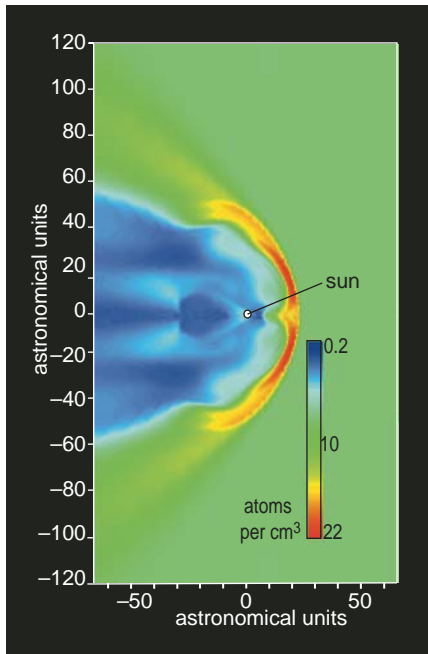


Figure 9. Simulations of the heliosphere show that it would become unstable after encountering a moderately dense interstellar cloud (containing about 10 atoms per cubic centimeter). The sun is currently embedded in an interstellar cloud (the “local fluff”) with an average density of about 0.3 atoms per cubic centimeter. Such disturbances of the heliosphere would alter the composition of the interplanetary medium and affect the atmospheres of the outer planets. Encounters with clouds of greater densities (1,000 atoms per cubic centimeter) might alter the atmospheres of the inner planets, including the earth. (Courtesy of Gary Zank, University of Delaware.)

stellar Cloud contains relatively small structures (perhaps 100 to 10,000 AU across) with very high densities (more than 1,000 particles per cubic centimeter). If our solar system should pass through such a dense cloud fragment, the dimensions of the heliosphere would change dramatically.

My colleague Gary Zank at the University of Delaware and I have recently modeled the changes that might take place should the heliosphere encounter a dense interstellar cloud. If the density of the Local Interstellar Cloud increased to 10 particles per cubic centimeter, the heliosphere would contract to a radius of about 15 AU and the heliopause would become unstable (oscillating in and out of existence). The density of interstellar hydrogen at 1 AU would increase to about 2 atoms per cubic centimeter and dramatically alter the interplanetary environment of the earth. (By comparison, virtually all of the interstellar hydrogen is ionized before it gets to the earth’s orbit

under current conditions.) A more severe scenario—say a cloud with a density of 1,000 atoms per cubic centimeter—would alter heliosphere physics entirely and probably contract the heliosphere to within a few AU of the sun. Planets such as Saturn, Uranus, Neptune and Pluto (all of which are outside 9 AU) would be fully exposed to the flux of interstellar neutrals. Interstellar gas would overwhelm the solar wind at 1 AU. These simulations suggest that, to a certain extent, the solar wind acts to “protect” the inner planets from certain types of changes in the local galactic environment.

Changes in the sun’s galactic environment, moderate or otherwise, must have taken place in the past. Indeed there is evidence on earth suggesting that the local galactic environment has not been stable. Ice-core samples from the Antarctic show spikes in the concentration of beryllium-10 (which has a half-life of 1.5 million years) during two events, one about 60,000 years ago and another about 33,000 years ago. What events could have caused these sudden increases in beryllium? One possibility is a sudden increase in the cosmic-ray flux on the earth’s atmosphere, which would increase the precipitation of radioactive beryllium onto the planet’s surface. A couple of mechanisms have been proposed to explain such an increase in the cosmic-ray flux near the earth, including a supernova shock and an encounter with a small, but dense cloud fragment in the Local Interstellar Cloud. The supernova proposal is consistent with the observation that interstellar dust grains within 30 light-years of the sun show indications of destruction by a shock wave traveling 100 to 200 kilometers per second. Still the causes of the beryllium spikes remain uncertain.

There is also evidence for older supernova events: Enhanced levels of iron-60 in deep-sea sediments have been interpreted as indications that a supernova explosion occurred within 90 light-years of the sun about 5 million years ago. Iron-60 is a radioactive isotope of iron, formed in supernova explosions, which decays with a half life of 1.5 million years. An enhanced presence of this isotope in a geologic layer indicates the recent nucleosynthesis of elements nearby in space and their subsequent transport to the earth (perhaps as part of dust grains).

There is an avenue for further research along these lines. In principle, the deposition of interstellar matter onto geo-

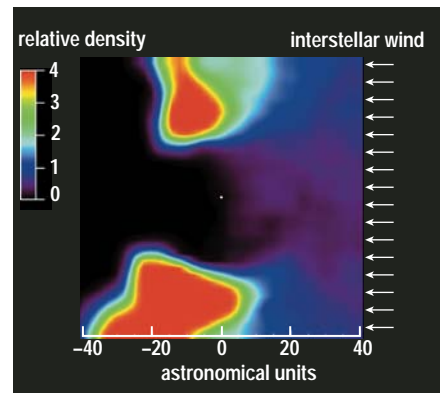
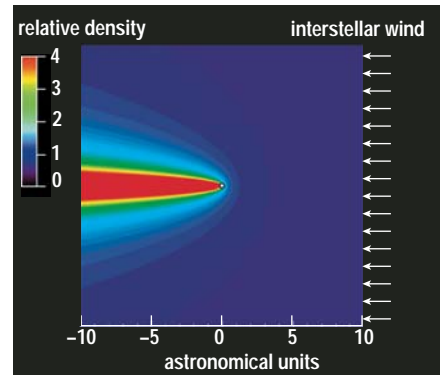


Figure 10. Distribution of interstellar dust grains flowing into the solar system varies with the size of the particle. (Some interstellar dust grains are so small that they cannot enter the heliosphere). Relatively large grains, with an average diameter of about 1.4 micrometers (*top*), are focused downstream of the interstellar wind (much like the helium focusing cone). The earth passes through this stream of dust particles through late November and early December every year. In contrast, the dynamics of smaller dust grains, with an average diameter of about 0.2 micrometers (*bottom*), are dominated by interactions with the solar wind’s magnetic field, aligning the grains near the poles. The distribution shown for the smaller grains reflects solar wind conditions expected for the year 2000. The plots show the density of interstellar dust grains relative to the density at infinity. (Courtesy of Markus Landgraf, European Space Agency.)

logically inert surfaces within the solar system should provide evidence for changes in the local galactic environment. Since the outer planets would have experienced the raw interstellar medium more often than the inner planets, it might be especially illuminating to compare the deposition of interstellar dust on bodies of the inner solar system relative to those of the outer solar system. Since the size of the dust grains that can penetrate the heliosphere depends on the strength of the solar wind, such a record would allow space scientists to disentangle the relative effects of the so-

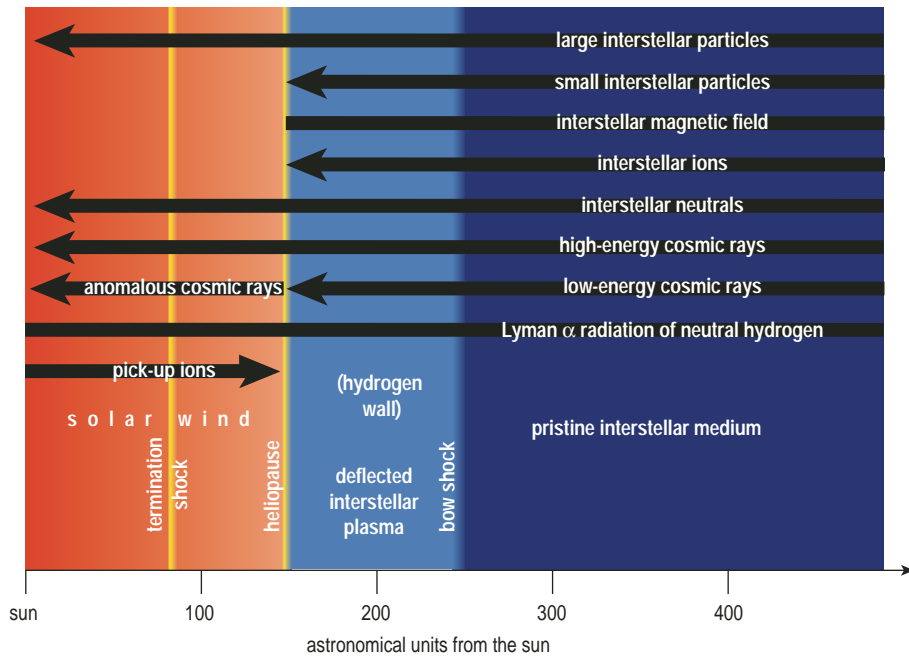


Figure 11. Various characteristics of the heliosphere and the interstellar medium will be directly assessed by the proposed Interstellar Probe mission during the spacecraft's voyage to explore the local galactic environment. With planned technology the Interstellar Probe could be outside of the heliopause within 15 years of being launched.

lar-activity cycle from variations in the galactic environment.

The planets may hold a record of past changes in the sun's galactic environment, but future changes can only be anticipated by mapping the galaxy around us. Indeed, studies of ultraviolet absorption lines suggest that there may be two interstellar clouds between the sun and the star Alpha Centauri (the sun's nearest neighbor, about 4 light-years away). Could one of these clouds be a small, dense structure embedded inside the local cloud complex? We don't know since we do not have an adequate understanding of the velocity structure of the local interstellar medium. The "cloud fragment" may be nothing more than turbulence in interstellar gas. Whatever it is, if it is real, it should sweep past the sun within the next 3,000 years.

An Interstellar Probe

Our current understanding of the sun's galactic environment is derived almost entirely by remote methods, from earth-based telescopes or near-earth spacecraft. However, the best way to explore the local galactic environment is with an interstellar spacecraft, launched into the upwind direction, beyond the "nose" of the heliosphere, and into pristine interstellar space. Preparatory studies for such a spacecraft—known as the Interstellar Probe—were recently conducted at the

Jet Propulsion Laboratory in Pasadena, California. The Interstellar Probe would be able to directly assess the interaction of a star (our sun) with its environment. By collecting information on the physical properties of the interstellar cloud surrounding the solar system, we will make the first-ever *in situ* measurements of gas and dust in interstellar space.

A direct assessment of the interstellar medium is not merely a luxury but a necessity. When we observe interstellar gas with telescopes, generally we sample clouds many light-years long. Consequently, we cannot be sure which part of the cloud we are actually measuring. On the other hand, observations of interstellar matter within the solar system reveal its nature at the entry point into the heliosphere. A comparison of the telescope data and the interstellar matter inside the solar system is not always meaningful because they don't come from the same part of the cloud. To overcome this problem and truly understand the physical properties of the interstellar cloud feeding material into the solar system, we must directly sample the cloud with instruments on board an interstellar spacecraft.

The Interstellar Probe is being designed to explore the nature of the interstellar medium and its interaction with the solar wind and the solar system. It will provide detailed information on the

composition, ionization state, magnetic-field strength and other physical properties of the cloud surrounding the sun. The result will be a quantitative understanding of how interstellar gas and dust interact with the solar wind to determine the heliosphere's properties and thus how changes in the interstellar medium would affect the heliosphere.

Results from such a mission may be forthcoming sooner than one might think. Solar-sail propulsion methods are now being considered that could propel a spacecraft with a speed of about 14 AU per year, so that the probe would emerge into the interstellar medium (about 150 AU away) within 15 years of being launched! Such a spacecraft would establish a new era, when humankind finally escapes the bounds of the solar system and looks out on the stars, rather than up at them.

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