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Interstellar space, and step on it!

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It's a long way from Baltimore to the outer edge of the solar system - 15 billion kilometres at least. But it is here that scientists and engineers hope to begin an unprecedented journey into the void of interstellar space. The Innovative Interstellar Explorer is the brainchild of Ralph McNutt of Johns Hopkins University in Maryland, who is proposing to send a craft into the region of space that lies beyond the solar system. Working with a group of mission scientists called Team-X at NASA's Jet Propulsion Laboratory in Pasadena, California, McNutt's team has come up with a design for a probe that could travel 200 times further than the sun in as little as 25 years.

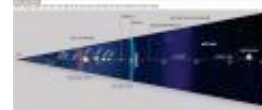
A launch window will open up in 2014 when the powerful gravitational pull of Jupiter will give the IIE the extra oomph it needs to speed it on its way out of the solar system. That means it could be heading off to begin the first detailed survey of interstellar space as early as 2040. Earthbound civilisation would at last be on its way to exploring the stars, a journey that could have profound implications not only for physics and astronomy but also for climatology, geology and evolutionary biology.

How so? It's all to do with the way the Earth is bombarded by cosmic rays as they zip through the galaxy. Our solar system is partially protected from this potentially damaging radiation by the "heliosphere", a giant magnetic bubble produced when the solar wind, a stream of charged particles that emanate from the sun, hits interstellar space.

The strength of the heliosphere's magnetic shield determines just how many cosmic rays get through, and there are hints that this fluctuates enormously over time. But we don't fully understand what causes these variations. Maybe the IIE can provide an answer and solve a few terrestrial mysteries into the bargain.

Astronomers have known since the 1950s that the entire solar system is moving at supersonic speeds through the Milky Way. Nearby star-forming regions in the galaxy have blasted material along the sun's path, so that the concentration of interstellar dust and gas varies as we move through it. For most of the past 3 million years, says Priscilla Frisch, an astrophysicist at the University of Chicago, the sun has been travelling through a region of space called the Local Bubble. No one can be sure how the Local Bubble formed, though astronomers suspect that it was the result of a supernova explosion that blew a bubble around 400 light years across in the interstellar medium. With each teaspoonful of it containing less than one atom, the Local Bubble is a much emptier place than surrounding regions of the Milky Way.

Yet it is far from a featureless void. Clouds of interstellar dust and gas float around inside the Local Bubble. At some point during the past 44,000 to 150,000 years, the solar system entered one of these



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Into the void



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Journey to the edge of the solar system

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denser pockets called the Local Fluff, a cloud of mostly hydrogen and helium about 30 light years across. We are still travelling through this cloud and are expected to do so for the next 10,000 to 20,000 years.

All these extra fast-moving hydrogen and helium nuclei in the Local Fluff act as cosmic rays slamming into the heliosphere. But far from increasing the numbers of cosmic rays reaching Earth, Frisch believes that the Local Fluff protects the solar system. According to her calculations, the magnetic-field interactions between the cosmic rays and the turbulent solar wind at the edge of the solar system serve to boost the strength of the heliosphere's magnetic field. This means that the heliosphere can deflect greater numbers of galactic cosmic rays, leading to a decrease in the numbers entering the solar system.

There is evidence to suggest that the effects were felt here on Earth. Ice cores from Greenland and Antarctica contain the isotope beryllium-10, which forms when cosmic rays smash into the atmosphere and settles onto the ice sheets and in marine sediments. Levels of beryllium-10 isotopes found in ancient ice cores suggest that 140,000 years ago the cosmic ray intensity was 20 to 40 per cent greater than it is today. So could the drop to today's level have been produced by changes in the density of interstellar dust as the sun went from the Local Bubble into the Local Fluff?

The best way to know if this scenario is correct is to study the heliopause, the turbulent boundary between where the solar wind stops blowing and interstellar space begins. Examining it up close should tell us exactly how the sun's magnetic field deflects the galaxy's cosmic rays.

What lies beyond

It could also tell us what has caused the field to weaken and strengthen at various times over the ages. The insights provided by IIE could be immensely powerful when correlated with geological measurements, perhaps even revealing the solar system's true pathway through the galaxy. "I think you might be able to do astronomy with geology when all this is better understood," says Frisch.

You might also gain insights into evolutionary biology too, points out John Scalzo, an astronomer at the University of Texas in Austin. According to Scalzo, evolutionary biologists don't always consider the possibility that mutation rates could be influenced, among other factors, by the varying intensity of cosmic rays reaching Earth. Not only is this assumption wrong, there is mounting evidence to suggest that variations in cosmic rays play other roles in shaping the advance of life.

Last year Alex Pavlov of the University of Colorado in Boulder and his colleagues calculated that Earth experiences a dramatic increase in the number of cosmic rays when the solar system passes through extremely dense interstellar clouds. They predict that the sheer density of charged particles entering the upper atmosphere may break nitrogen bonds in the air and catalyse the decomposition of ozone. Reporting in *Geophysical Research Letters* (vol 32, p 1), the team calculates that at least 40 per cent of the ozone layer could be lost the world over and as much as 80 per cent in polar regions. This could be devastating for life on Earth. They also calculate that the abundance of nitrogen oxides in the stratosphere would soar by a factor of 100, increasing the amount of acid rain.

The case Pavlov and his colleagues considered was extreme, where a very dense molecular cloud - a rare thing in the galaxy - squeezes the heliosphere down until it is almost the size of the Earth's orbit, causing it to let more cosmic rays into the solar system. Nevertheless, even in less extreme situations, ozone loss could be substantial. Scalzo and his colleague David Smith, for instance, calculated that the solar system needs to pass through a cloud that's only 10 times as dense as the Local Fluff to squash the heliosphere and reduce its ability to shield us from cosmic rays.

Another factor could be a controversial theory, proposed almost a decade ago by Henrik Svensmark and Eigil Friis-Christensen of the Danish Meteorological Institute in Copenhagen, which links cosmic rays and climate (*New Scientist*, 16 September, p 32). They claim that increasing numbers of cosmic rays promote the formation of clouds at low altitudes. These clouds reflect sunlight and keep Earth cool. A sharp rise in cosmic radiation may have triggered climate change. "It's extremely controversial," admits Scalzo. "There is some correlation between cosmic rays and climate, but the cause and effect is unknown."

To understand the true influence of cosmic rays on Earth, its climate and its life, we need to travel to the edges of interstellar space and measure the material ejected by explosions of nearby stars and the magnetic fields that influence its behaviour - something that IIE will allow us to do for the first time.

"A lot of people in the cosmic ray business want to know the intensity of cosmic rays in interstellar

space," says Donald Gurnett, a space scientist at the University of Iowa. "We don't get to measure it directly because the heliopause is in the way."

This is just one of many tasks facing IIE. McNutt's team of 11 scientists and engineers can't even be sure of what the craft might eventually achieve. What they do know is that because of the vast distances involved, it will have to move very, very quickly to answer any of these pressing questions in our lifetime. "The real key is speed," says McNutt.

The team's design uses a standard rocket to get the probe into space, and then propels the craft out of the solar system with a hybrid of cutting-edge power and propulsion technologies. The idea is to use electricity generated by the radioactive decay of plutonium to accelerate charged atoms of xenon, a gas that is easily ionised. The xenon ions then shoot out of the back of the craft, accelerating it forward. No one quite knows where the heliopause lies, however. Some estimates put it somewhere beyond 116 astronomical units (AU) from the sun - where 1 AU is the distance from Earth to the sun. If the IIE can get to 200 AU, the team is confident that the probe will be in interstellar space proper.

By Jupiter!

The team has calculated that the fastest route out of the solar system involves getting that slingshot-like boost from Jupiter's gravity (see Diagram). This could see IIE achieving a peak speed of 135,000 kilometres per hour, more than twice as fast as the Voyager probes. To take advantage of Jupiter's gravity, the mission would have to launch in 2014 when the planet is in favourable alignment with Earth. The next time Jupiter comes round is 2026.

By that time, we may have some data on the heliopause from the Voyager probes (see "Interstellar space race"), but a purpose-designed mission like IIE will give us much more - and throw up some surprises too, says Ed Stone at the California Institute of Technology in Pasadena. "Every time we have gone to a new region, we've had ideas and usually they were much too simple. Nature is much more inventive than the human mind."

For roughly half the price of the Cassini mission to Saturn, the Earth could have its interstellar Sputnik moment. Other temptations lie beyond the heliopause, such as the sun's gravitational focal point at 550 AU (see "Einstein's telescope") and the Oort Cloud of comets somewhere beyond 50,000 AU. These destinations will have to wait for another time, however, when our baby steps put the nearest stars within striking distance.

Unlike the uncrewed missions to the planets, a mission into the interstellar medium wouldn't be able to return any eye-catching photographs. Still, says McNutt, "It's a disadvantage only in that it makes you work harder. And maybe that's not such a bad thing after all."

Einstein's telescope

Einstein predicted that the gravitational fields of stars and galaxies could magnify objects that are further away along the same line of sight. His prediction was verified in 1979, and today we know of more than 100 "gravitationally lensed" objects in the sky. Light from these objects is bent by the gravity of intervening galaxies or stars that act as lenses.

The sun could do this too, raising the possibility that it could work as a telescope capable of picking out details on distant planets. Light from bodies behind the sun could be brought to a focus at a point 550 astronomical units (AU) in front of it. That's 550 times the distance between Earth and the sun. At that distance or beyond, an object immediately behind the sun would be magnified 100 million times or more.

Claudio Maccone, a retired scientist for Italian satellite manufacturer Alenia Spazio, has calculated that a modest 12-metre-wide space antenna sitting at 550 AU could resolve features as small as 80 kilometres across on Alpha Centauri, one of our nearest stars.

The idea has several drawbacks, however. It would only be able to make observations along one particular line of sight - that connecting the antenna to the sun. So examining a new object would require launching a new telescope. It would also take a spacecraft at least 55 years to reach 550 AU, so the object to be put under the cosmological microscope would have to be very important indeed.

Future journeys deep into interstellar space might rely on lightweight solar sails rather than conventional engines.

Interstellar space race

Voyager 1 is the most distant manmade object in the cosmos. It is now 100 astronomical units (AU) from the sun in an area called the heliosheath, where the sun's influence is beginning to wane. It could leave the solar system and cross into interstellar space about 10 years from now.

Both Voyager spacecraft should be dipping their toes into the edge of interstellar space before their power runs out or their radio signal grows too weak, sometime around 2020. Mission scientists believe the Voyagers have enough electricity to keep alive the instruments that measure magnetic fields, radio waves and charged particles. Voyager 2, which is now over 80 AU from the sun, also carries a working instrument that measures the intensity of the solar wind.

But to expect the trickle of measurements from the two Voyagers to answer all our questions would be like calling off all exploration of the new world after 1492. The first dispatches should probably provide just enough information to reveal how much we don't know. The Voyagers will tell us little or nothing about the structure of the galaxy's magnetic field, for instance, or the intensity of cosmic rays beyond the sun's sphere of influence. As distant as Voyager 1 is, we have still only scratched the surface of space.

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