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Historic Documents of 2013

Heather Kerrigan, Editor

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SEPTEMBER

NASA's *Voyager 1* Reaches Interstellar Space

SEPTEMBER 12, 2013

On September 12, 2013, the National Aeronautics and Space Administration (NASA) announced that its unmanned *Voyager 1* spacecraft had officially entered interstellar space. *Voyager 1* reached a location that was more than 12 billion miles from the sun—approximately 130 times farther than Earth—and was the first human-made object to travel this far. What began in the 1970s as a historic mission to study Jupiter and Saturn now presents NASA with a unique opportunity to map the previously uncharted outer boundaries of our solar system.

The Voyage Begins

The *Voyager* program evolved from a 1960s proposal for NASA to embark on a "Grand Tour" of the solar system that would explore the planets from Jupiter to Pluto. The Grand Tour was ultimately scaled back due to NASA budget cuts, but some elements were preserved and formed the foundation of the *Voyager* program. The program involved two spacecraft, *Voyager 1* and *Voyager 2,* both of which would explore Jupiter and Saturn. It was later decided that *Voyager 2* would also travel on to Uranus and Neptune.

These missions were preceded by the *Pioneer* program, which performed first-of-its-kind explorations of the sun and several outer planets, and helped inform the NASA engineers' design of the *Voyager* program and spacecraft. Six of the eight *Pioneer* spacecraft launched prior to the *Voyager* missions, gathering information about the general interplanetary environment and the effects of solar activity on Earth. *Pioneer 10* was the first to pass through the Asteroid Belt and study Jupiter up close, charting the planet's radiation belts, studying its magnetic field, and discovering that it was a predominantly liquid planet. *Pioneer 11* also examined Jupiter, making the first observation of the planet's polar regions, before traveling on to Saturn where it identified three new moons and an additional ring around the planet. Neither *Pioneer* spacecraft has returned a signal to Earth since 2002 and 1995, respectively.

The *Voyager* missions were approved in 1972 and scheduled to launch in 1977 at a time when they could leverage a special planetary alignment to effectively slingshot from one planet to the next, aided by the planets' gravitational pull. Each spacecraft would follow its own flight path and travel at a different speed. NASA's Jet Propulsion Lab built and continues to operate both *Voyager* spacecraft, which feature a variety of instruments ranging from television cameras and ultraviolet sensors to plasma detectors and cosmic-ray and charged-particle sensors. Both spacecraft were also equipped with a special gold-plated record that featured sounds and images from Earth in case they were found by intelligent life forms in other planetary systems. The records' audio not only included natural sounds such as whale song and volcano eruptions, but also music by artists from

Mozart to Chuck Berry and greetings in fifty-five different languages. The records were also engraved with pictorial instructions on how to use them and a pulsar map to show where the spacecraft had come from.

Voyager 1 launched on September 5, 1977, sixteen days after *Voyager 2* launched. Although it launched later, *Voyager 1* reached Jupiter and Saturn first, taking iconic images that have appeared in textbooks, magazines, and newspapers for decades. It was the first spacecraft to return detailed images of these planets and their moons, and made a number of new discoveries. In March 1979, the spacecraft spotted a never-before-seen ring around Jupiter. It also discovered two new moons, Thebe and Metis, and took detailed pictures of other moons including Callisto, Ganymede, Europa, and Io. In fact, *Voyager 1*'s pictures of Europa's surface led scientists to believe there may be ice or an ocean underneath. One of the spacecraft's more notable findings was that Io had active volcanoes and a mottled yellow-brown-orange surface that proved the moon had an active interior like Earth's. This was the first time active volcanoes had been seen on another body within the solar system. The following year, *Voyager 1* traveled on to Saturn where it discovered three new moons—Prometheus, Pandora, and Atlas. It also found a new Saturnian ring, labeled the "G" ring.

Once *Voyager I* completed its primary mission in 1980, NASA focused on tracking it as it moved to exit the solar system. In 1988, *Voyager 1* passed the last known distance of *Pioneer 10,* becoming the farthest machine ever sent from Earth. The spacecraft transmitted its last images on February 14, 1990, sending a series of images used to create the "Solar System Family Portrait"—a mosaic of sixty individual frames showing six of the planets in relation to each other. Together, *Voyager 1* and *Voyager 2* returned a total of 5 trillion bits of scientific data, enough to fill more than 7,000 audio CDs, to Earth during their primary missions.

Leaving the Heliosphere

NASA officially announced that *Voyager 1* had crossed into interstellar space on September 12, 2013, stating that the spacecraft was "in a transitional region immediately outside the solar bubble, where some effects from our sun are still evident." The same day, *Voyager's* plasma wave science team, led by University of Iowa physics and astronomy professor, Don Gurnett, published a report proving *Voyager 1*'s location in the journal *Science.* Scientists speculated several times over the preceding year that *Voyager 1* had achieved this milestone, causing some to be skeptical that NASA was correct this time. Yet Gurnett's team provided an analysis of data that indicated the spacecraft had actually reached interstellar space in August 2012.

The sun's influence on our solar system can be felt well beyond the planets and into an area of space called the heliosphere. Within that area, charged particles and plasma coming from the sun constantly swirl in the form of a solar wind. That wind begins to slow down and interact with interstellar space at a point called the heliosheath. From this point on, the plasma flowing through space becomes cooler and denser than the solar wind, and it is this distinction that scientists used to confirm *Voyager 1*'s location. The spacecraft's plasma detector, which specifically measures plasma density, temperature, and speed, stopped working more than thirty years ago, but the Voyager team was able to use vibrations picked up by the spacecraft's antennas to calculate the density of the surrounding space.

In April 2013, *Voyager 1* transmitted data indicating it had detected a coronal mass ejection, or "a massive burst of solar wind and magnetic fields," which scientists determined had actually occurred in March 2012. The burst of solar material had plowed into interstellar plasma, causing it to oscillate. Those oscillations were in turn picked up by *Voyager 1*'s antenna and translated into measurements of plasma density. Those measurements, and the fact that it took more than a year for the solar particles to reach *Voyager 1*, led scientists to believe that the spacecraft had indeed left the heliosphere and entered interstellar space. The Voyager team discovered further proof of the spacecraft's location while reviewing earlier data for comparable measurements. They found that *Voyager 1* had registered similar information in late fall of 2012 following another solar flare, and that in 2004 the spacecraft had crossed the "termination shock," or the point in space at which the solar wind's speed drops abruptly, slowed by wind coming from interstellar space. Further calculations showed that *Voyager 1*'s instruments first detected a change in particle density on August 25, 2012 that was characteristic of interstellar space, and that subsequent density measures had not changed significantly since then. Taken together, these findings gave scientists the proof they needed to announce that the spacecraft had entered interstellar space.

"We have been cautious because we're dealing with one of the most important milestones in the history of exploration," said Ed Stone, *Voyager* project lead scientist. He continued, "Only now do we have the data—and the analysis—we needed." Stone said he had called three meetings of the Voyager team to discuss the data before making a final determination. "In the end, there was general agreement that *Voyager 1* was indeed outside in interstellar space," Stone said. "But that location comes with some disclaimers—we're in a mixed, transitional region of interstellar space. We don't know when we'll reach interstellar space free from the influence of our solar bubble."

NASA officials hailed the announcement as a major achievement. "*Voyager* has boldly gone where no probe has gone before, marking one of the most significant technological achievements in the annals of the history of science, and adding a new chapter in human scientific dreams and endeavors," said John Grunsfeld, NASA's associate administrator for science in Washington, D.C. "Perhaps some future deep space explorers will catch up with *Voyager*, our first interstellar envoy, and reflect on how this intrepid spacecraft helped enable their journey," Grunsfeld added. On December 3, Stone was presented with NASA's Distinguished Public Service Medal in recognition of his work for the *Voyager* program. The citation accompanying the award commended Stone "for a lifetime of extraordinary scientific achievement and outstanding leadership of space science missions, and for his exemplary sharing of the exciting results with the public."

The Mission Continues

Voyager mission control personnel still communicate with and receive data from both spacecraft every day, though the signals are very dim. NASA officials say that *Voyager 1* has enough battery power to continue operating its fields and particles instruments through at least 2020. NASA will begin turning those instruments off one by one to conserve power, with the last one expected to power down in 2025. *Voyager 1* is expected to continue sending engineering data for several years after that, but then will go silent.

In the meantime, its continued operation provides NASA with an opportunity to collect information about previously unexplored regions of our solar system. The spacecraft's current mission, the Voyager Interstellar Mission, is to "extend the NASA exploration of the solar system beyond the neighborhood of the outer planets to the outer limits of the Sun's sphere of influence, and possibly beyond." It will seek to characterize the environment of the farthest parts of our solar system and define its outermost boundary, known as the heliopause, which no spacecraft has ever reached. The spacecraft is also tasked with taking measurements of the interstellar fields, particles, and waves.

Voyager 1 is expected to reach the Oort Cloud, viewed by many as the edge of our solar system, in approximately 300 years.

—Linda Fecteau

Following is a press release from the National Aeronautics and Space Administration (NASA) from September 12, 2013, on the Voyager *spacecraft's mission into interstellar space.*

DOCUMENT

NASA Announces Voyager 1 *Reaches Interstellar Space*

September 12, 2013

Whether and when NASA's *Voyager 1* spacecraft, humankind's most distant object, broke through to interstellar space, the space between stars, has been a thorny issue. For the last year, claims have surfaced every few months that *Voyager 1* has "left our solar system." Why has the Voyager team held off from saying the craft reached interstellar space until now?

"We have been cautious because we're dealing with one of the most important milestones in the history of exploration," said *Voyager* Project Scientist Ed Stone of the California Institute of Technology in Pasadena. "Only now do we have the data—and the analysis—we needed."

Basically, the team needed more data on plasma, which is ionized gas, the densest and slowest moving of charged particles in space. (The glow of neon in a storefront sign is an example of plasma.) Plasma is the most important marker that distinguishes whether *Voyager 1* is inside the solar bubble, known as the heliosphere, which is inflated by plasma that streams outward from our sun, or in interstellar space and surrounded by material ejected by the explosion of nearby giant stars millions of years ago. Adding to the challenge: they didn't know how they'd be able to detect it.

"We looked for the signs predicted by the models that use the best available data, but until now we had no measurements of the plasma from *Voyager 1*," said Stone.

Scientific debates can take years, even decades to settle, especially when more data are needed. It took decades, for instance, for scientists to understand the idea of plate tectonics, the theory that explains the shape of Earth's continents and the structure of its sea floors. First introduced in the 1910s, continental drift and related ideas were controversial for years. A mature theory of plate tectonics didn't emerge until the 1950s and 1960s. Only after scientists gathered data showing that sea floors slowly spread out from mid-ocean ridges did they finally start accepting the theory. Most active geophysicists accepted plate tectonics by the late 1960s, though some never did.

Voyager 1 is exploring an even more unfamiliar place than our Earth's sea floors—a place more than 11 billion miles (17 billion kilometers) away from our sun. It has been sending back so much unexpected data that the science team has been grappling with the question of how to explain all the information. None of the handful of models the Voyager team uses as blueprints have accounted for the observations about the transition between our heliosphere and the interstellar medium in detail. The team has known it might take months, or longer, to understand the data fully and draw their conclusions.

"No one has been to interstellar space before, and it's like traveling with guidebooks that are incomplete," said Stone. "Still, uncertainty is part of exploration. We wouldn't go exploring if we knew exactly what we'd find."

The two *Voyager* spacecraft were launched in 1977 and, between them, had visited Jupiter, Saturn, Uranus and Neptune by 1989. *Voyager 1*'s plasma instrument, which measures the density, temperature and speed of plasma, stopped working in 1980, right after its last planetary flyby. When *Voyager 1* detected the pressure of interstellar space on our heliosphere in 2004, the science team didn't have the instrument that would provide the most direct measurements of plasma. Instead, they focused on the direction of the magnetic field as a proxy for source of the plasma. Since solar plasma carries the magnetic field lines emanating from the sun and interstellar plasma carries interstellar magnetic field lines, the directions of the solar and interstellar magnetic fields were expected to differ.

Most models told the Voyager science team to expect an abrupt change in the magnetic field direction as *Voyager* switched from the solar magnetic field lines inside our solar bubble to those in interstellar space. The models also said to expect the levels of charged particles originating from inside the heliosphere to drop and the levels of galactic cosmic rays, which originate outside the heliosphere, to jump.

In May 2012, the number of galactic cosmic rays made its first significant jump, while some of the inside particles made their first significant dip. The pace of change quickened dramatically on July 28, 2012. After five days, the intensities returned to what they had been. This was the first taste of a new region, and at the time Voyager scientists thought the spacecraft might have briefly touched the edge of interstellar space.

By Aug. 25, when, as we now know, *Voyager 1* entered this new region for good, all the lower-energy particles from inside zipped away. Some inside particles dropped by more than a factor of 1,000 compared to 2004. The levels of galactic cosmic rays jumped to the highest of the entire mission. These would be the expected changes if *Voyager 1* had crossed the heliopause, which is the boundary between the heliosphere and interstellar space. However, subsequent analysis of the magnetic field data revealed that even though the magnetic field strength jumped by 60 percent at the boundary, the direction changed less than 2 degrees. This suggested that *Voyager 1* had not left the solar magnetic field and had only entered a new region, still inside our solar bubble, that had been depleted of inside particles.

Then, in April 2013, scientists got another piece of the puzzle by chance. For the first eight years of exploring the heliosheath, which is the outer layer of the heliosphere, Voyager's plasma wave instrument had heard nothing. But the plasma wave science team, led by Don Gurnett and Bill Kurth at the University of Iowa, Iowa City, had observed bursts of radio waves in 1983 to 1984 and again in 1992 to 1993. They deduced these bursts were produced by the interstellar plasma when a large outburst of solar material would plow into it and cause it to oscillate. It took about 400 days for such solar outbursts to reach interstellar space, leading to an estimated distance of 117 to 177 AU (117 to 177 times the distance from the sun to the Earth) to the heliopause. They knew, though, that they would be able to observe plasma oscillations directly once *Voyager 1* was surrounded by interstellar plasma.

Then on April 9, 2013, it happened: *Voyager 1*'s plasma wave instrument picked up local plasma oscillations. Scientists think they probably stemmed from a burst of solar activity from a year before, a burst that has become known as the St. Patrick's Day Solar Storms. The oscillations increased in pitch through May 22 and indicated that Voyager was moving into an increasingly dense region of plasma. This plasma had the signatures of interstellar plasma, with a density more than 40 times that observed by *Voyager 2* in the heliosheath.

Gurnett and Kurth began going through the recent data and found a fainter, lower-frequency set of oscillations from Oct. 23 to Nov. 27, 2012. When they extrapolated back, they deduced that Voyager had first encountered this dense interstellar plasma in August 2012, consistent with the sharp boundaries in the charged particle and magnetic field data on August 25.

Stone called three meetings of the Voyager team. They had to decide how to define the boundary between our solar bubble and interstellar space and how to interpret all the data *Voyager 1* had been sending back. There was general agreement *Voyager 1* was seeing interstellar plasma, based on the results from Gurnett and Kurth, but the sun still had influence. One persisting sign of solar influence, for example, was the detection of outside particles hitting Voyager from some directions more than others. In interstellar space, these particles would be expected to hit *Voyager* uniformly from all directions.

"Now that we had actual measurements of the plasma environment—by way of an unexpected outburst from the sun—we had to reconsider why there was still solar influence on the magnetic field and plasma in interstellar space," Stone said. "The path to interstellar space has been a lot more complicated than we imagined."

Stone discussed with the Voyager science group whether they thought *Voyager 1* had crossed the heliopause. What should they call the region were *Voyager 1* is?

"In the end, there was general agreement that *Voyager 1* was indeed outside in interstellar space," Stone said. "But that location comes with some disclaimers—we're in a mixed, transitional region of interstellar space. We don't know when we'll reach interstellar space free from the influence of our solar bubble."

So, would the team say *Voyager 1* has left the solar system? Not exactly—and that's part of the confusion. Since the 1960s, most scientists have defined our solar system as going out to the Oort Cloud, where the comets that swing by our sun on long timescales originate. That area is where the gravity of other stars begins to dominate that of the sun. It will take about 300 years for *Voyager 1* to reach the inner edge of the Oort Cloud and possibly about 30,000 years to fly beyond it. Informally, of course, "solar system" typically means the planetary neighborhood around our sun. Because of this ambiguity, the Voyager team has lately favored talking about interstellar space, which is specifically the space between each star's realm of plasma influence.

"What we can say is *Voyager 1* is bathed in matter from other stars," Stone said. "What we can't say is what exact discoveries await Voyager's continued journey. No one was able to predict all of the details that *Voyager 1* has seen. So we expect more surprises."

Voyager 1, which is working with a finite power supply, has enough electrical power to keep operating the fields and particles science instruments through at least 2020, which will mark 43 years of continual operation. At that point, mission managers will have to start turning off these instruments one by one to conserve power, with the last one turning off around 2025.

Voyager 1 will continue sending engineering data for a few more years after the last science instrument is turned off, but after that it will be sailing on as a silent ambassador. In about 40,000 years, it will be closer to the star AC +79 3888 than our own sun. (AC +79 3888 is traveling toward us faster than we are traveling towards it, so while Alpha Centauri is the next closest star now, it won't be in 40,000 years.) And for the rest of time, Voyager 1 will continue orbiting around the heart of the Milky Way galaxy, with our sun but a tiny point of light among many.

The *Voyager* spacecraft were built and continue to be operated by NASA's Jet Propulsion Laboratory, in Pasadena, Calif. Caltech manages JPL for NASA. The *Voyager* missions are a part of NASA's Heliophysics System Observatory, sponsored by the Heliophysics Division of the Science Mission Directorate at NASA Headquarters in Washington.

SOURCE: National Aeronautics and Space Administration. Jet Propulsion Laboratory. "How Do We Know When *Voyager* Reaches Interstellar Space?" September 12, 2013. http://www.jpl.nasa.gov/news/news.php?release=2013-278.

OTHER HISTORIC DOCUMENTS OF INTEREST

FROM PREVIOUS *HISTORIC DOCUMENTS*

- NASA *Rover* Lands on Mars, *2012*, p. 373
- Saturn Science Summary, *1981*, p. 835
- Flight of *Voyager I, 1980*, p. 989

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