
National Aeronautics and Space Administration
NASA
IBEX: The Edge of Our Solar System
Sun
Termination Shock
Bow Shock
Heliopause
Heliosheath
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What defines the boundary of our solar system?

What do we mean when we say something has an edge, or a boundary? Some things, like a table or a soccer field, have clear edges and boundaries. Other objects, like cities and towns, have boundaries that are not as easy to see. It is hard to say where they end and something else begins if you are looking at them from a distance. The Solar System is more like a neighborhood than a table or a soccer field.

You could say that the Solar System extends as far as the influence of the Sun. That could mean the influence of the Sun's light, or the influence of the Sun's gravity, or the influence of the Sun's magnetic field and solar wind.

Could the reach of the Sun's light be a good way to decide how far the Solar System extends? The light from the Sun gets fainter as you move farther away, but there is no boundary where the light stops or where it suddenly weakens. How about gravity? Just like light, the influence of the Sun's gravity extends without limit, although it is weaker farther away from the Sun. There is not a boundary at which it stops.

A view of Chicago as seen from the International Space Station. Determining the boundaries of neighborhoods in Chicago from this view would be challenging. Credit: NASA

What else can we use to define the solar system's boundary?

Scientists use the interaction between the solar wind and the interstellar medium to define the boundary of our Solar System.

What is the solar wind?

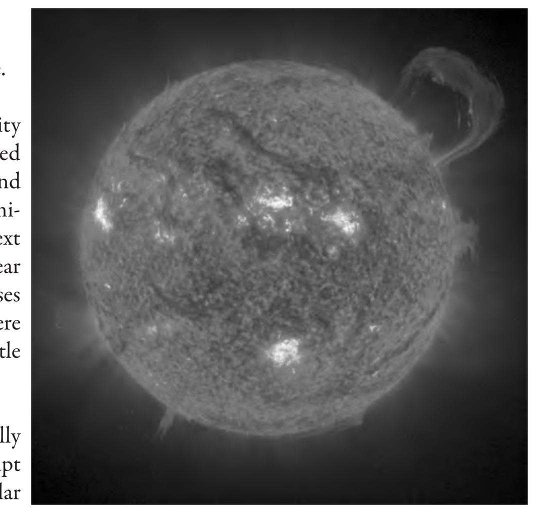
The solar wind is a stream of charged particles, also called plasma. Plasma is similar to gas, but its particles have a different structure and charge. Plasma forms when a gas becomes extremely hot. When this happens, the gas' atoms gain lots of energy. This energy causes the electrons to detach from the nuclei of the gas' atoms. When the negatively charged electrons detach, the positively charged protons and neutral particles called neutrons in the nuclei are left. These positively charged nuclei are called ions. When a gas is so hot that the electrons and protons split apart to form electrons and ions, we say that the gas has been ionized. Plasma is an ionized gas.

The solar wind particles flow off the Sun at about one million miles per hour (1.6 million kilometers per hour). These particles come from the outermost layer of the Sun, called the corona. The corona is a very hot place, about 1.8 million °F (1 million °C). High temperatures cause particles to move faster, so the particles in the corona move very fast. Some of the particles move so fast that the Sun's gravity is not strong enough to hold them down, and so they fly off, becoming part of the solar wind.

By the time the solar wind reaches Earth, the particles are moving at about 500,000 miles per hour (800,000 kilometers per hour). That is about 500 times faster than most supersonic airplanes. The number of charged solar wind particles and how fast they are moving fluctuate as the activity level of the Sun changes during its 11-year cycle.

Over the course of 11 years, the Sun's magnetic activity level increases gradually and peaks. The peak is called "solar maximum". At solar maximum, the number and frequency of solar activity in the form of flares, prominences, and sunspots is generally at its highest. The next solar maximum is predicted to occur around the year 2012. The magnetic activity of the Sun then decreases gradually to a point called "solar minimum", when there are fewer (and sometimes no) sunspots and there is little solar flare or prominence activity.

When the solar wind is particularly strong, especially during solar maximum, the charged particles can disrupt satellites and electrical grids on Earth. A very strong solar wind can also cause auroras, also known as the Northern or Southern Lights.



The Sun, as seen by the SOHO spacecraft. Credit: SOHO (ESA and NASA)

What is the interstellar medium?

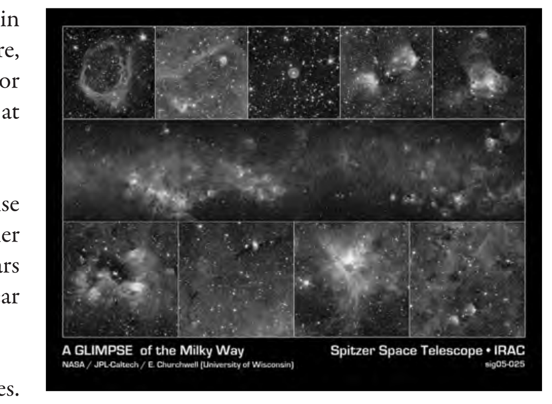
As the solar wind streams away from the Sun, it races out toward the space between the stars. We think of this space as "empty," but it contains traces of gas and dust, called the interstellar medium (ISM). The solar wind blows against this material and clears out a bubble-like region in this gas. This bubble that surrounds the Sun and the Solar System is called the heliosphere. This is not a bubble like a soap bubble, but more like a cloud of foggy breath that you breathe into chilly winter air. Scientists believe that the closest parts of the heliosphere's boundary are 90 times farther away than the distance between the Earth and Sun, around 9 billion miles. That's about two-and-a-half times farther than Pluto is from the Sun. The ISM is mostly made of clouds of hydrogen and helium. The rest of the ISM mostly consists of heavier elements like carbon. About one percent of the ISM is in the form of dust, usually silicates.

In some places in space, the ISM is not dense at all, but it is much more dense in other regions. However, even the densest parts of the ISM are 10^{14} (100,000,000,000,000 or 100 trillion) times less dense than the Earth's atmosphere. The density of the ISM ranges from 0.003 particles per cubic centimeter in regions of hot ionized gases, or plasma, to more than 100,000 particles per cubic centimeter in regions where stars form. To compare, there are, on average, about 2.5×10^{19} (25 quintillion or 25,000,000,000,000,000,000) molecules of air at sea level in the Earth's atmosphere.

Stars form in regions of the ISM that are dense enough for gravity to pull the gas and dust together to make compact, hot spheres. These protostars eventually become so dense and hot that nuclear fusion begins, and they become stars.

Although they are not alive, stars have life cycles. They are born from the ISM, grow, and die. A star that is much more massive than our Sun dies in an explosion called a supernova. After it explodes, the former star's material is recycled into the ISM.

Exploding stars continually replenish the ISM with their material. In turn, gravity pulls the ISM material together to form more stars.



Gas and dust clouds in our Milky Way Galaxy, as seen by the Spitzer Space Telescope. Credit: NASA/JPL-Caltech/E. Churchwell (Univ. of Wisconsin)

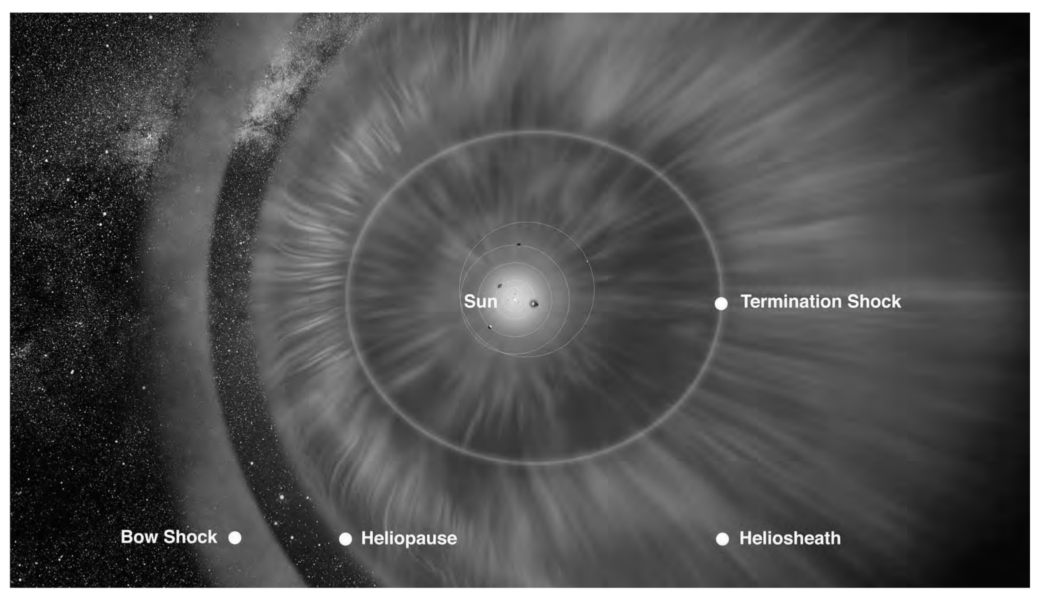
What happens when the solar wind and the interstellar medium collide?

The boundary of our Solar System is defined by the region where the solar wind and the interstellar medium collide. Even though the interstellar medium has a low density, it still has a pressure, similar to air pressure. The solar wind also has a pressure. Close to the Sun, the solar wind has a large pressure and can easily push the interstellar medium away from the Sun. Further away from the Sun, the pressure from the interstellar medium is strong enough to slow down and eventually stop the flow of solar wind from traveling into its surroundings.

The parts of the boundary, as shown to the right, are:

- the termination shock, the innermost part of the boundary where the solar wind slows down
- the heliopause, the outermost part of the boundary, and
- the heliosheath, the part in between the inner and outer boundary

Since the Sun is moving relative to the interstellar medium around it at a speed of about 500,000 miles per hour (800,000 kilometers per hour) in its orbit around the center of the Milky Way Galaxy, the heliosphere forms a wave or shock in the interstellar medium like a boat in the ocean. This is called the bow shock or bow wave.

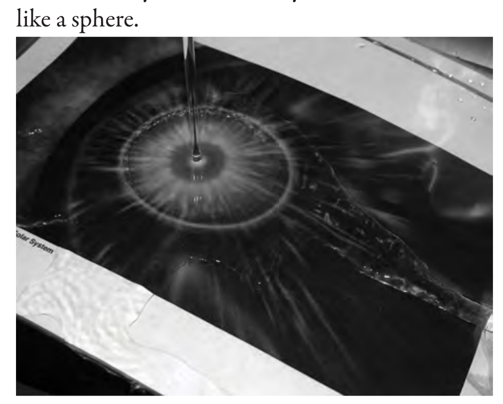


Credit: NASA/IBEX/Adler Planetarium

What is the termination shock?

The termination shock is the boundary marking one of the outer limits of the Sun's influence, and is one boundary of the Solar System. In this part of the Solar System, solar wind particles move more slowly when they begin to press into the interstellar medium. The solar wind is made of plasma, and when it slows in this way, it goes through many changes. The solar wind plasma gets squished together, or compressed, like people crowded together in a tiny room. When it is compressed, it also becomes much hotter, in the same way a bicycle pump tube heats up in your hand when you vigorously push the air through it to inflate a tire. Also, the solar wind carries some of the Sun's magnetic field outward, which now gets stronger at the termination shock and twists around. We have only two direct measurements of the solar wind speed and the magnetic field strength at the termination shock; these were made by the Voyager 1 and Voyager 2 spacecraft. Voyager 1 reached the termination shock on December 16, 2004 at a distance of 8.4 billion miles (14.1 billion kilometers) from the Sun. Voyager 2 reached the termination shock on August 30, 2007 at a distance of 7.8 billion miles (12.6 billion kilometers) from the Sun. The discrepancy in distances and dates can be explained by the fact that Voyager 1 is traveling faster than Voyager 2, and that the termination shock is not at a uniform distance from the Sun.

A similar shock is formed when you run water from a faucet into a sink. When the stream of water hits the sink basin, the flowing water spreads out at a relatively fast speed, forming a disk of shallow water that quickly moves outward, like the solar wind inside the termination shock. Around the edge of the disk, a shock front or wall of water forms; outside the shock front, the water moves relatively slower, like what happens outside the termination shock. However, the water shock is only 2-dimensional, or flat. The boundary of our Solar System is 3-dimensional, like a sphere.



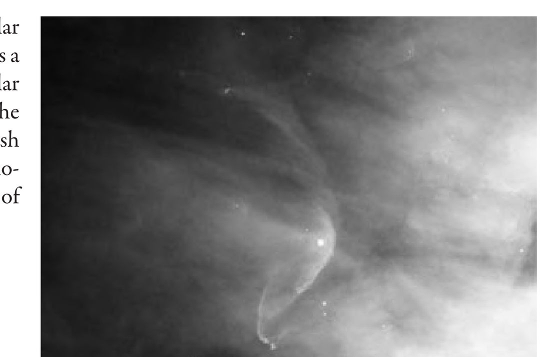
Credit: NASA/IBEX/Adler Planetarium

What is the heliopause?

The heliopause is the boundary between the Sun's solar wind and the interstellar medium. The solar wind blows a "bubble" known as the heliosphere into the interstellar medium. The outer border of this "bubble" is where the solar wind's strength is no longer great enough to push back the interstellar medium. This is known as the heliopause, and is often considered to be the outer border of the Solar System.

What is a bow shock or bow wave?

There are two possible configurations of our Solar System based on how fast the Solar System is moving and the density of the medium through which it is traveling. A bow wave or bow shock will form in front of the heliosphere as the Sun moves through the interstellar medium. A bow wave is similar to the water formation and movement at the prow of a boat, while a bow shock is similar to the shockwave that forms in front of a supersonic jet.

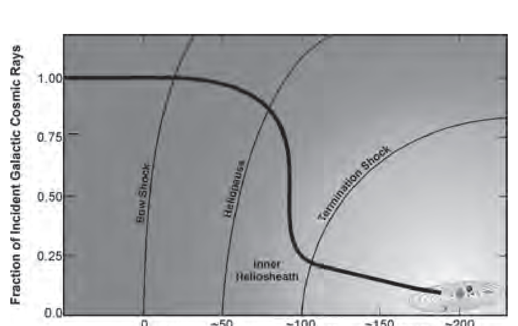


LL Ori, a star in the Orion Nebula. Credit: NASA/Hubble Heritage Team

BZ Cam, star in the constellation Camelopardalis. Credit: Image Credit: R. Casalegno, C. Conselice et al, WIYN, NOAO, MURST, NSF

How does the solar system's boundary affect me?

The boundary of the Solar System protects us from harmful cosmic rays. Cosmic rays are energetic particles that are often made when a star explodes; other cosmic rays come from the Sun or from as far away as other galaxies. If cosmic rays impact something, they can do damage to atoms and molecules. If the Solar System did not have a boundary, or if the boundary changed size so that it was inside the orbit of the Earth, then there would be at least four times the amount of cosmic rays that would reach our part of the Solar System. Luckily the Earth's magnetosphere protects us from some of the cosmic rays that come from outside our Solar System. However, if there were a dramatic increase in the number of cosmic rays entering the Solar System, it could change the amount of high-energy cosmic rays that would be able to reach Earth's surface. Damage to the Earth's ozone layer could occur, and cosmic rays may cause damage and mutation to DNA.

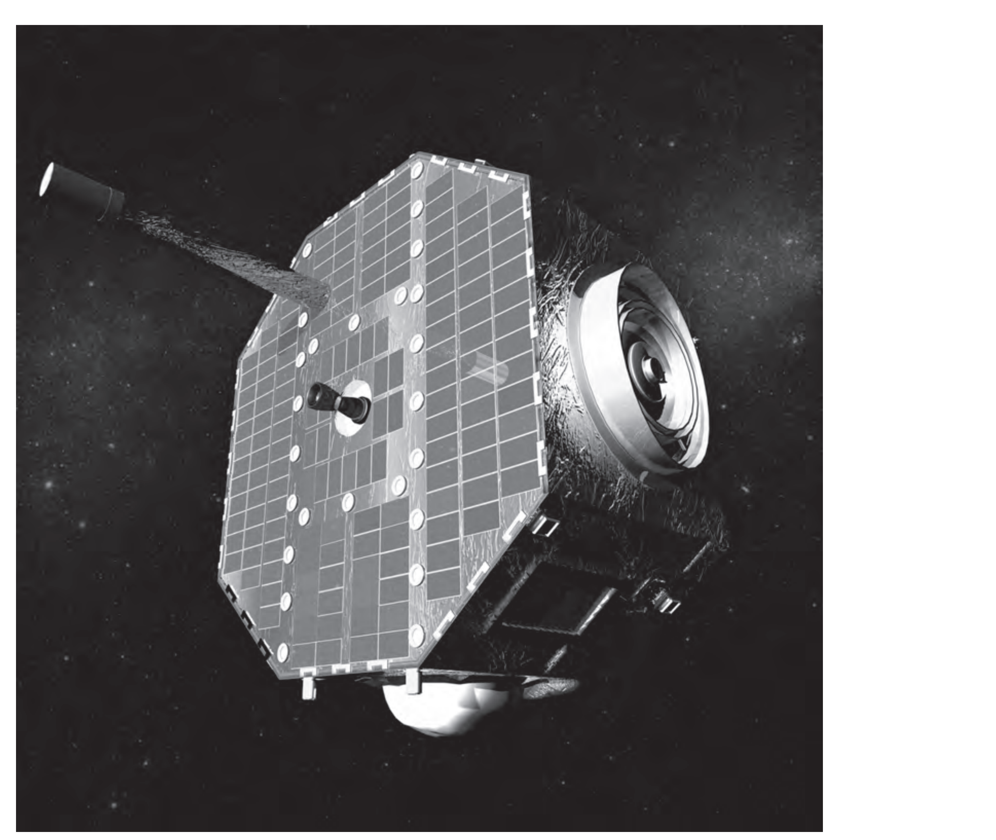


This graph depicts the percentage of high energy cosmic rays that pass through the boundary of the Solar System. 100% of them are present outside of the bow shock. There is a small dropoff in the number that make it through to the heliopause. More than 50% are stopped between the heliopause and termination shock. Only around 25% of the original number of cosmic rays permeate to the realm of the planets. (Note: 1 AU = 1 Astronomical Unit = 93 million miles) Credit: IBEX Science Team

What will we learn from the IBEX mission, and how will it help us?

NASA's Interstellar Boundary Explorer mission (IBEX) will help us create the first map of our Solar System's boundary while the spacecraft orbits around Earth. By analyzing the maps created from IBEX data, scientists can determine what the interaction of the solar wind and the interstellar medium is like in all directions toward the heliopause. For example, scientists are trying to find out if there are some areas where the interstellar medium quickly slows the solar wind, or other places where a gradual stop of the solar wind may occur. Also, scientists are trying to determine the overall shape of the "bubble." All of this information will help us understand how our Earth is shielded from harmful cosmic rays, and help us figure out how humans can safely travel to other planets and, in the distant future, to other stars.

To learn more about the IBEX mission, play games, and sign up for monthly mission updates visit: http://ibex.swri.edu

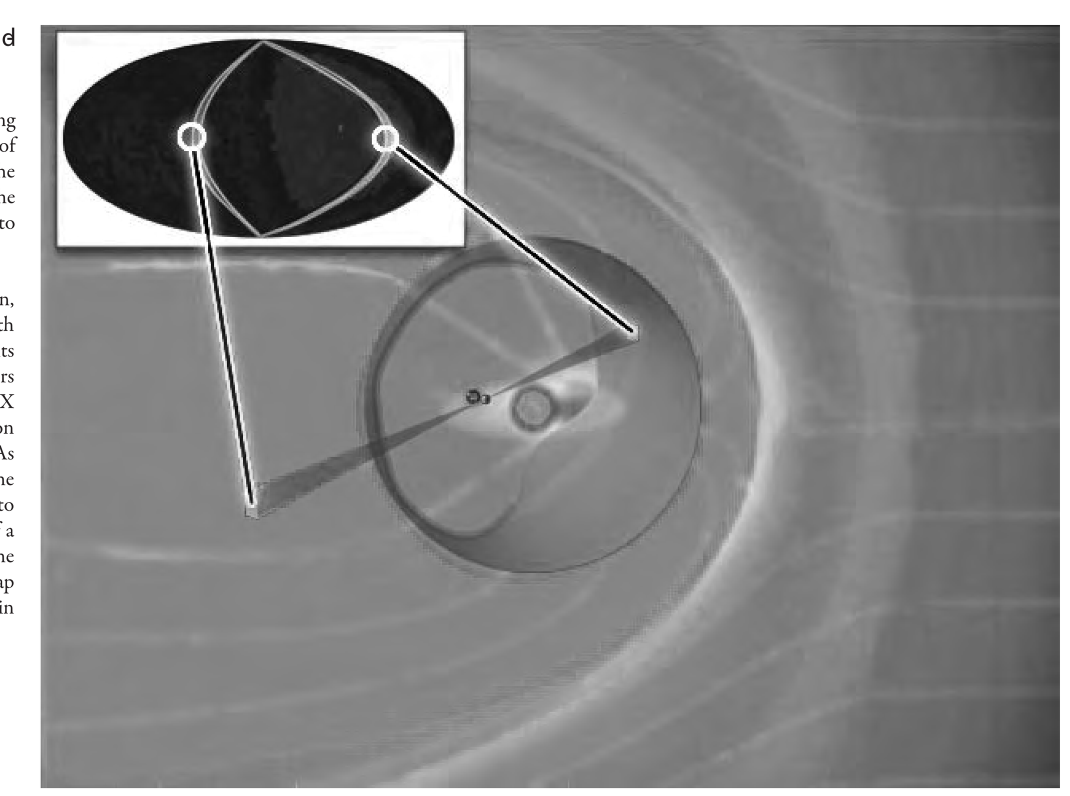


Credit: NASA/Goddard Space Flight Center Conceptual Image Lab

How will IBEX data create a map of the boundary?

The IBEX spacecraft will spin once every 15 seconds, allowing the IBEX-Hi and IBEX-Lo sensors to "see" the same parts of the sky. The direction and amount of particles in each of the energy bands will be recorded in each part of the sky over the course of IBEX's 2-year mission, allowing a map of the data to be made.

The object in the middle of the image to the right is the Sun, the smaller dot is the Earth, and the tiny dot orbiting the Earth is IBEX (not to scale). IBEX orbits Earth, and Earth orbits the Sun. As IBEX orbits Earth, the IBEX-Hi and Lo sensors "look" in opposite directions as the spacecraft spins. IBEX will know in which direction it is facing and the direction from which the particles came that it is able to detect. As IBEX orbits through an entire year, its sensors will have the opportunity to sweep across the whole sky, allowing a map to be built from the data. The image indicates a still frame of a simulation of the "building" of a map, and the image in the callout box indicates, in grayscale, what a portion of the map might look like. (Note: The final map is expected to be in color.)



Credit: The IBEX Team