



Revealing the properties and structure of the interstellar medium

- The interstellar medium is the mixture of gas and dust present in the vast expanse of space between stars. It has been modelled as individual, warm, partially ionised clouds surrounded by hot, ionised gas.
- However, new observations raise serious doubts concerning the accuracy of these assumptions.
- Through his continued and collaborative research, Dr Jeffrey L Linsky at the University of Colorado, USA, identifies key limitations within the existing models.
- His team's results could lead to deeper insights into the properties of the interstellar medium and its influence on the surrounding environments of stars and their exoplanets.

The vast expanse of space between stars might appear to be empty, but it actually contains immense quantities of gas and dust. This material began its life as lighter elements that were fused together in the cores of massive stars, before being flung into space in violent supernova explosions. This mixture of gas and dust is known as the interstellar medium (ISM) and plays a vital role in the evolution of galaxies. Professor Emeritus Jeffrey L Linsky at the University of Colorado, USA, who has been studying ISM for many years, explains that 'the ISM transports the chemical elements that are created in the cores of exploding supernovae to dense clouds, which go on to form new stars and planets as they collapse under their own gravity.'

The ISM's behaviour is heavily influenced by its interaction with stars, which send out constant streams of energetic charged particles in all directions. These streams are called 'stellar wind' or 'solar wind' in our Solar System, perhaps best known for creating the vivid aurorae seen in Earth's polar regions. As they push against the ISM, stellar winds create roughly spherical bubbles which surround the stars that created them and shield entire planetary systems from damaging interstellar radiation. These bubbles are called astrospheres or the heliosphere for our Solar System. Their boundaries stretch far beyond the orbits of a stars' orbiting planets and asteroids. So far, the only manmade objects to have escaped the heliosphere are the Voyager 1 and 2 probes, which each took over 40 years to cross its outer edge.

Moving through local environments

Linsky explains that an astrosphere's boundaries are far from rigid. The pressure balance between local interstellar gas and the outflowing solar and stellar winds determines the size of the heliosphere or

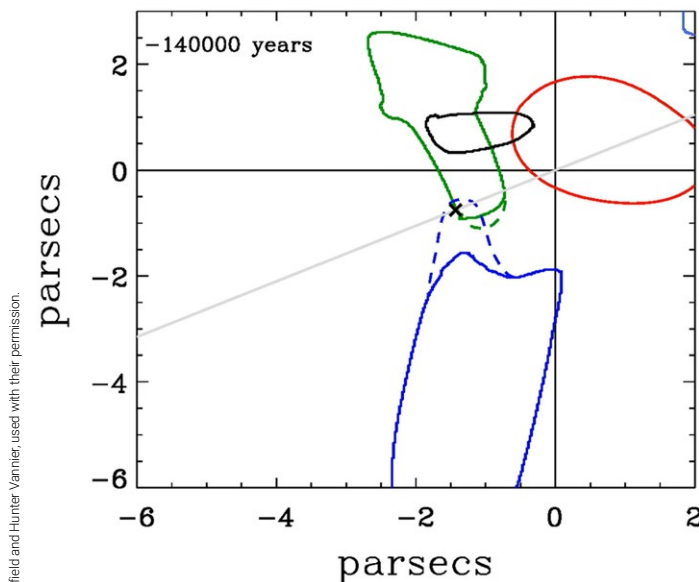
astrosphere. As they move through space, these bubbles will naturally encounter clouds of denser gas and dust, surrounded by regions where interstellar material is much sparser. In turn, these changes will alter the pressure balance between an astrosphere and its surrounding ISM, causing the astrosphere to alternatively grow and shrink over time.

Answering key questions

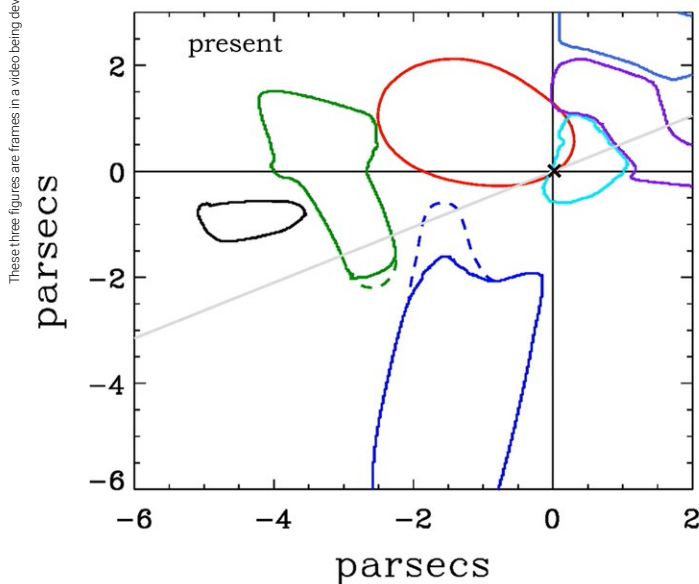
Although astronomers now understand how these changes occur, it has so far proven more difficult to predict them. In their research, Linsky and his colleagues have identified key questions that need to be answered: what are the 3D structures and properties of the ISM in the solar neighbourhood, and what are the physical causes for these structures?

The heliosphere's recent past also presents a third question: what changes in the size of the heliosphere have occurred in the last million years and will occur as the Sun moves through high- and low-density regions of the ISM? Finally, the aim of astronomers to determine the impact of this behaviour on our home planet leads to a fourth question: what changes in the ultraviolet and high energy radiation from the Sun and space incident on the Earth could have occurred as the size and shielding properties of the heliosphere change over time, and how these changes alter the environment for life on Earth?

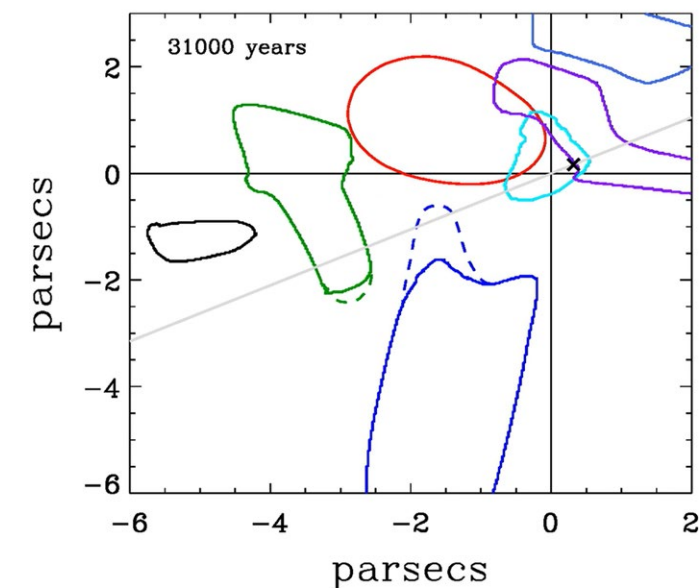
The pressure balance between local interstellar gas and the outflowing solar and stellar winds determines the size of the heliosphere and astrosphere.



Location of the Sun along its trajectory (diagonal line) through interstellar clouds. The 'x' marks the Sun's location at 140,000 years before present, as it entered the Aql cloud (green).



Today, the Sun has likely entered a region where the local interstellar cloud (red) and the G-cloud (blue) overlap.



At 31,000 years in the future, the Sun will have traversed most of the G-cloud and will be about to enter the Gem cloud (purple).

Over the past 30 years, astronomers, including Linsky and his colleagues, have begun to answer these questions by observing the specific wavelengths of light absorbed by different atoms and ions in the ISM. To calculate the motions of interstellar material, they can measure their 'radial velocity', the velocity along the line of sight. Due to the Doppler effect, characteristic patterns of emission and absorption are either shifted to shorter wavelengths if the material is moving towards us, or longer wavelengths if it is moving away. By observing these shifts along different lines of sight, astronomers can use radial velocity to calculate the speed of the ISM relative to the Solar System.

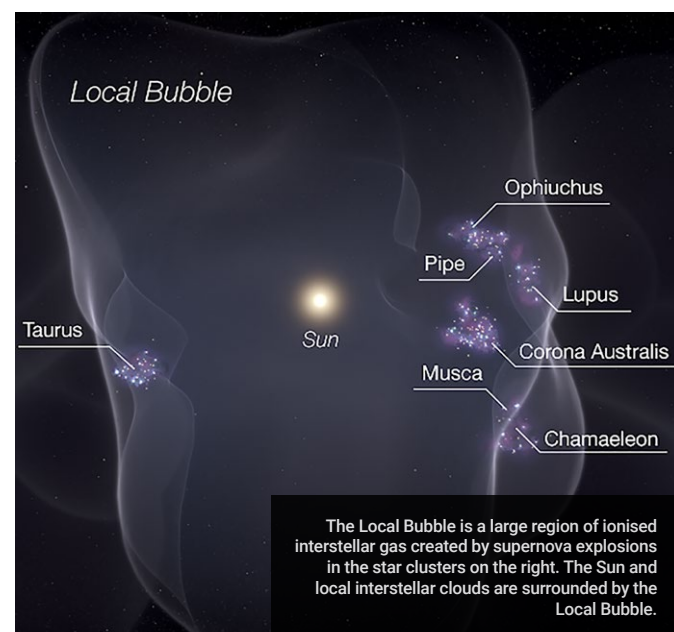
The multi-cloud model

Linsky believes that a crucial step to answering the key questions will be to build 3D models of the ISM's behaviour and evolution, which closely capture the real radial velocities observed by astronomers. If this could be achieved, it would allow astronomers to closely predict how astrospheres will interact with their surrounding environments. In 2008, Linsky and his colleague Seth Redfield developed the 'multi-cloud model' to capture these dynamics. Their model made a number of key assumptions about the properties of ISM clouds: for example, each cloud in the multi-cloud model contains warm, partially ionised hydrogen moving with the same velocity. It assumed their boundaries are sharp and don't overlap, and that the material inside has a uniform density.

Identifying gaps in the multi-cloud model

In their latest study, Linsky and Redfield examine these assumptions under close scrutiny by identifying a number of limitations which could be undermining the quality of the multi-cloud model's predictions. By identifying these gaps, Linsky now hopes to build a more comprehensive picture of the processes and structures appearing in the ISM, which more closely resembles the radial velocities of its material as observed by astronomers. Linsky and his colleagues envision that eliminating the limitations could ultimately enable astronomers to build up a more accurate and detailed model of the local interstellar medium surrounding the heliosphere. A more realistic model should help astronomers better understand how the Sun's travels through the inhomogeneous interstellar medium shape the evolution of our home planet.

Each cloud in the multi-cloud model contains warm, partially ionised hydrogen moving with the same velocity.



The Local Bubble is a large region of ionised interstellar gas created by supernova explosions in the star clusters on the right. The Sun and local interstellar clouds are surrounded by the Local Bubble.

Personal response

How is the radiation incident on Earth affected by interactions between the heliosphere and ISM?

High energy radiation (galactic and extragalactic cosmic rays) accelerated by magnetic fields in the interstellar medium produce changes that affect life on Earth in many ways. First, it produces mutations in the genetic material of humans and animals and thus, in the evolution of mankind. Second, this radiation likely also changes the cloud cover in Earth's atmosphere and climate. Third, this radiation can initiate photochemical reactions in Earth's atmosphere that can reduce the amount of oxygen and ozone in the atmosphere, allowing solar ultraviolet radiation to penetrate to the surface and mutate genetic material.

The heliosphere absorbs much of the incoming cosmic rays, thereby partially shielding the Earth from the deleterious effects of this radiation. When the Sun enters a high-density region of the interstellar medium, the size of the heliosphere will shrink minimising the cosmic ray shielding. This change in the incoming cosmic ray flux at Earth could have caused major changes in the evolution of life on Earth in the past.

What are the main challenges of using radial velocity to study the ISM?

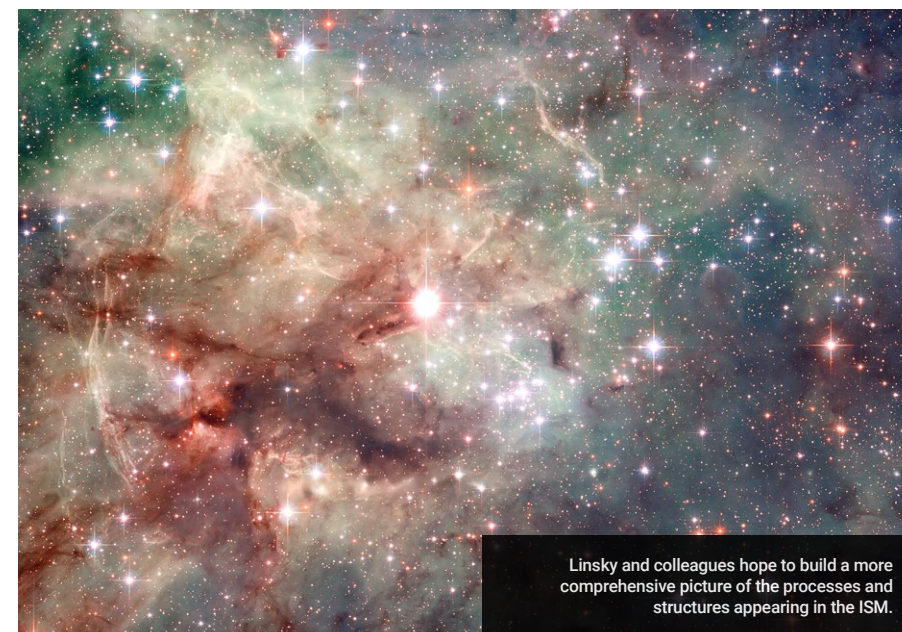
There are two main challenges. First, radial velocity measurements require very high-resolution ultraviolet spectra. Observing one sight line at a time, this is only possible with the Space Telescope

Imaging Spectrograph (STIS) instrument on the Hubble Space Telescope (HST). This is time-consuming and the observing time is limited. There is no near-future instrument that will have the needed capability to continue this work. As a result, there are many directions through the interstellar medium that have not yet been studied and our understanding of the interstellar medium is limited by these unobserved sight lines.

The second challenge is that radial velocity measurements do not provide the critically needed densities that tell us the sizes of clouds. Only a factor of two separates neutral hydrogen densities that would tell us whether the nearby interstellar clouds completely fill space or are isolated structures, presumably surrounded by hot or ionised gas. There are only indirect ways for estimating the neutral hydrogen density that indicate that the nearby clouds completely fill space with no hot gas between them, but we need direct measurements of density to confirm this new model.

What new discoveries could your research eventually lead to?

We aim to build a robust three-dimensional model of the interstellar medium extending at least 30 light years from the Sun. Since the Sun is moving a distance of 80.6 light years in a million years, we should be able to reconstruct the interstellar environment that the Sun passed through in the last 370,00 years and the future environment that it will encounter in the next 370,000 years.



Linsky and colleagues hope to build a more comprehensive picture of the processes and structures appearing in the ISM.

Details



e: jlinsky@jila.colorado.edu
t: +1 303-492-7838
w: jila.colorado.edu/~jlinsky

Funding

NASA

Collaborators

- Seth Redfield
- Eberhard Moebius

Bio

Jeffrey L Linsky is Professor Emeritus in the Department of Astrophysical and Planetary Sciences at the University of Colorado and a fellow of JILA. His research interests include the local interstellar medium, stellar chromospheres, coronae, and winds. His interest in the effects of stellar activity on exoplanets led him to write the book *Host Stars and their Effects on Exoplanet Atmospheres*. He has played an active role in the development and use of NASA missions including the Hubble Space Telescope and the Chandra X-ray Observatory. He is a member of the Voyager Science Steering Group.

Further reading

- Linsky, JL, Redfield, S, (2023) [Creating a new paradigm for the local interstellar medium—A perspective](#), *Frontiers in Astronomy and Space Sciences*, 10, 1119589.
- Linsky, JL, Moebius, E, (2023) [Are the heliosphere, very local interstellar medium, and local cavity in pressure balance with galactic gravity?](#), *The Astrophysical Journal*, 942(1), 45.
- Linsky, JL, et al, (2022) [Inhomogeneity within local interstellar clouds](#), *The Astronomical Journal*, 164(3), 106.
- Linsky, JL, Redfield, S, (2021) [Could the local cavity be an irregularly shaped Strömgren sphere?](#), *The Astrophysical Journal*, 920(2), 9.
- Linsky, JL, et al, (2019) [The interface between the outer heliosphere and the inner local ISM: Morphology of the local interstellar cloud, its hydrogen hole, Strömgren shells and 60Fe accretion](#), *The Astrophysical Journal*, 886(1), 41.
- Edelman, E, Redfield, S, Linsky, JL, et al, (2019) [Properties of the interstellar medium along sight lines to nearby planet-hosting stars](#), *The Astrophysical Journal*, 880(2), 117.
- Redfield, S, Linsky, JL, (2008) [The structure of the local interstellar medium. IV. dynamics, morphology, physical properties, and implications of cloud-cloud interactions](#), *The Astrophysical Journal*, 673(1), 283.