

# A spacecraft is flying closer to the Sun than ever before, promising to unravel a mystery that has lasted over 100 years.

NASA's Parker Solar Probe spacecraft flew a record-breaking close to the Sun, helping to decipher how the solar wind is heated and accelerated, improving space weather predictions and understanding of cosmic plasma.

Data collected from unprecedented distances by the Parker Solar Probe is helping scientists better understand how the solar wind is heated and accelerated. These findings not only improve the ability to predict space weather, but also expand our understanding of how plasma – a state of matter composed of hot, charged particles – operates around stars and in the universe.

Close-up measurements from NASA's Parker Solar Probe provide unprecedented detail in how the solar wind absorbs energy and then rushes out of the Sun. The research, published in the journal *Geophysical Research Letters*, answers some long-standing questions about how energy and matter move within the heliosphere – the vast region of space directly influenced by the Sun's activity.

The heliosphere extends far beyond the orbits of Earth and the Moon, affecting every planet in the Solar System and reaching into interstellar space. Any changes in this region can trigger powerful space weather phenomena.

Kristopher Klein, associate professor at the Lunar and Planetary Laboratory at the University of Arizona and the lead researcher, said that in a society increasingly reliant on technology, understanding the impact of the Sun – the star we 'live with' – is particularly important.

A prime example is the coronal mass ejection, when the Sun throws large amounts of atmospheric matter into space. These flares contain extremely fast-moving charged particles that can collide with Earth's magnetic field, disrupting satellite and radio signals. They can also increase radiation exposure for passengers on flights over polar regions.

## Why is the Sun's atmosphere important to Earth?

According to Klein, if we had a better understanding of the Sun's atmosphere – the environment through which high-energy particles travel – the ability to predict the trajectories and impacts of eruptions as they spread across the Solar System and toward Earth would be much more accurate.

Although it's difficult to imagine the Sun having an 'atmosphere' since it's essentially a giant mass of plasma with no solid surface, decades of research have revealed its internal structure quite clearly. At the center is the core, where hydrogen atoms fuse into helium, releasing the energy that sustains the Sun's existence and radiates into space.

Surrounding the core are several different layers, the outermost of which forms the Sun's atmosphere. The photosphere is the layer visible to the naked eye, where sunspots appear. Above that is the chromosphere – a thin region that can produce solar flares and create a dappled appearance when observed with a telescope. Further out is the corona, a faint ring of plasma often obscured by the Sun's glare and only clearly visible during total solar eclipses.

Since its launch in 2018, the Parker Solar Probe has come closer to the Sun than any previous spacecraft. After a complex orbit with seven gravitational aids from Venus, the spacecraft achieved its first closest approach on Christmas Eve 2024. These repeated approaches allow scientists to redraw the Sun's 'outer boundary' in a way that was previously impossible.

### **Temperature paradox in the solar corona.**

One of the Sun's greatest mysteries lies in its temperature pattern. As the plasma moves outward from the core, the temperature plummets from around 27 million degrees Fahrenheit to about 10,000 degrees Fahrenheit in the photosphere. But then, instead of continuing to cool, the temperature soars to over 2 million degrees Fahrenheit in the corona.

This sudden warming phenomenon is thought to stem from complex interactions between charged particles and extremely strong magnetic fields – which can twist, stretch, and then spring back. Despite decades of research, the detailed mechanisms behind this process remain largely unexplained.

Klein said scientists know there's always a continuous stream of heat being pumped into the solar wind, but the question is what mechanism generates that heating. Previously, they relied primarily on simple models and computer simulations. Now, thanks to the Parker Solar Probe and measurements of particle velocity distributions at extremely close distances, these models can be more accurately calibrated to directly calculate how the heating process occurs.

Before Parker made those daring close approaches – which the mission team likened to 'kissing the Sun' – the data collected was quite limited. The closest flyby brought the spacecraft to within just 3.8 million miles of the Sun's surface. Prior to that, researchers relied heavily on simplistic assumptions about how charged particles are distributed in space.

### **The new model rewrites our understanding of the solar wind.**

One of the central questions is how the solar wind gets heated as it accelerates away from the Sun's surface. With new measurements and calculations, the research team believes they are 'rewriting' our understanding of how energy moves in the Sun's outer atmosphere.

To achieve this, Klein's team developed a computational tool called the Arbitrary Linear Plasma Solver (ALPS). This tool allows for direct analysis of the actual particle distribution measured by Parker, rather than forcing the

data into idealized models. This enables researchers to calculate how waves propagate within the plasma and how the heating rate changes as particles rush outward.

At the point of no return – where the solar wind completely separates from the Sun's gravitational pull – the particles begin to cool, but much more slowly than would be predicted if only expansion were considered. Klein describes this slow cooling as "damping," a crucial clue that still needs a complete explanation.

By combining ALPS with data from Parker, the research team was able to precisely measure how energy is distributed among different types of charged particles in the solar wind. According to Klein, this capability not only helps to better understand the Sun, but could also be applied to many other cosmic environments affected by hot plasma and magnetic fields, such as interstellar gas, accretion disks around black holes, or neutron stars.

If scientists can decipher the mechanism of energy dissipation in the solar wind, they could extend that knowledge to other astronomical systems where plasma plays a central role in the formation and evolution of the universe's structure.

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