NASA's Parker Solar Probe sheds new light on the sun

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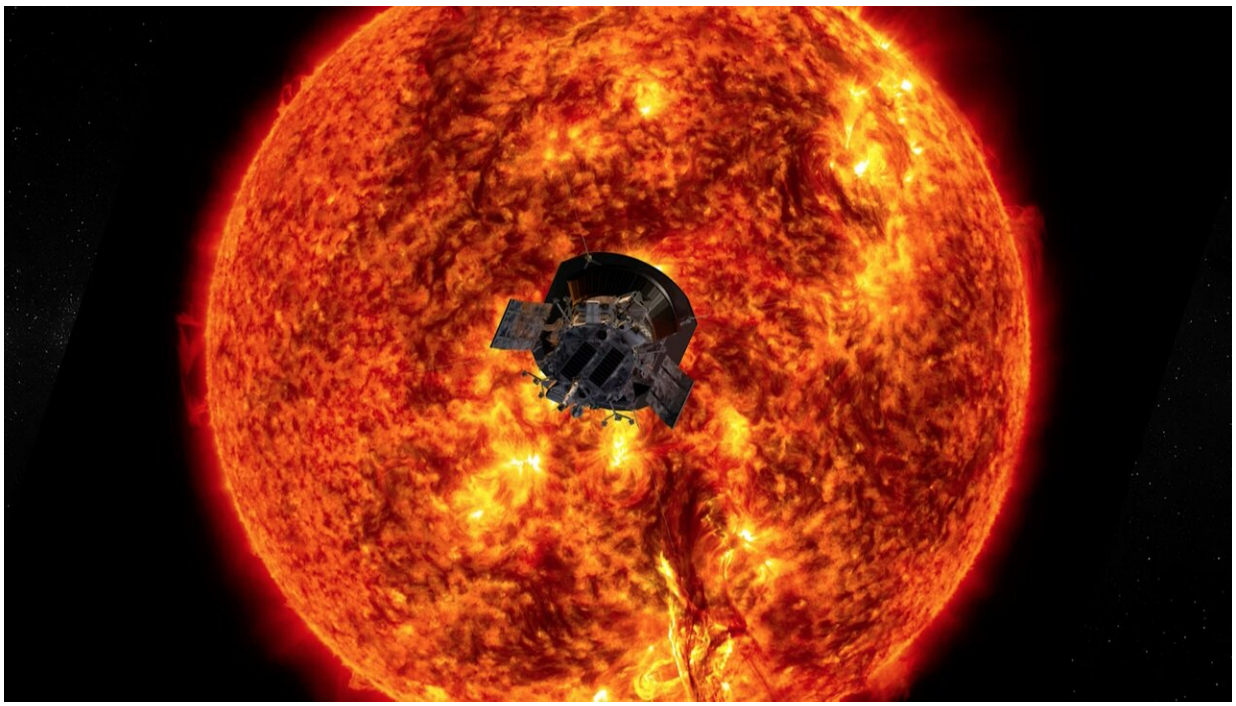


Illustration of Parker Solar Probe. Credit: NASA/Johns Hopkins APL

In August 2018, NASA's Parker Solar Probe launched to space, soon becoming the closest-ever spacecraft to the Sun. With cutting-edge scientific instruments to measure the environment around the spacecraft, Parker Solar Probe has completed three of 24 planned passes through never-before-explored parts of the Sun's atmosphere, the corona. On Dec. 4, 2019, four new papers in the journal *Nature* describe what scientists have learned from this unprecedented exploration of our star—and what they look forward to learning next.

These findings reveal new information about the behavior of the material and particles that speed away from the Sun, bringing scientists closer to answering fundamental questions about the physics of our star. In the quest to protect astronauts and technology in space, the information Parker has uncovered about how the Sun constantly ejects material and energy will help scientists re-write the models we use to understand and predict the space weather around our planet and understand the process by which stars are created and evolve.

"This first data from Parker reveals our star, the Sun, in new and surprising ways," said Thomas Zurbuchen, associate administrator for science at NASA Headquarters in Washington. "Observing the Sun up close rather than from a much greater distance is giving us an unprecedented view into important solar phenomena and how they affect us on Earth, and gives us new insights relevant to the understanding of active stars across galaxies. It's just the beginning of an incredibly exciting time for heliophysics with Parker at the vanguard of new discoveries."

Though it may seem placid to us here on Earth, the Sun is anything but quiet. Our star is magnetically active, unleashing powerful bursts of light, deluges of particles moving near the speed of light and billion-ton clouds of magnetized material. All this activity affects our planet, injecting damaging particles into the space where our satellites and astronauts fly, disrupting communications and navigation signals, and even—when intense—triggering power outages. It's been happening for the Sun's entire 5-billion-year lifetime, and will continue to shape the destinies of Earth and the other planets in our solar system into the future.

"The Sun has fascinated humanity for our entire existence," said Nour E. Raouafi, project scientist for Parker Solar Probe at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland, which built and manages the mission for NASA. "We've learned a great deal about our star in the past several decades, but we really needed a mission like Parker Solar Probe to go into the Sun's atmosphere. It's only there that we can really learn the details of these complex solar processes. And what we've learned in just these three solar orbits alone has changed a lot of what we know about the Sun."

What happens on the Sun is critical to understanding how it shapes the space around us. Most of the material that escapes the Sun is part of the solar wind, a continual outflow of solar material that bathes the entire solar system. This ionized gas, called plasma, carries with it the Sun's magnetic field, stretching it out through the solar system in a giant bubble that spans more than 10 billion miles.

The dynamic solar wind

Observed near Earth, the solar wind is a relatively uniform flow of plasma, with occasional turbulent tumbles. But by that point it's traveled over ninety million miles—and the signatures of the Sun's exact mechanisms for heating and accelerating the solar wind are wiped out. Closer to the solar wind's source, Parker Solar Probe saw a much different picture: a complicated, active system.

"The complexity was mind-blowing when we first started looking at the data," said Stuart Bale, the University of California, Berkeley, lead for Parker Solar Probe's FIELDS instrument suite, which studies the scale and shape of electric and magnetic fields. "Now, I've gotten used to it. But when I show colleagues for the first time, they're just blown away." From Parker's vantage point 15 million miles from the Sun, Bale explained, the solar wind is much more impulsive and unstable than what we see near Earth.

Like the Sun itself, the solar wind is made up of plasma, where negatively charged electrons have separated from positively charged ions, creating a sea of free-floating particles with individual electric charge. These free-floating particles mean plasma carries electric and magnetic fields, and changes in the plasma often make marks on those fields. The FIELDS instruments surveyed the state of the solar wind by measuring and carefully analyzing how the electric and magnetic fields around the spacecraft changed over time, along with measuring waves in the nearby plasma.

These measurements showed quick reversals in the magnetic field and sudden, faster-moving jets of material—all characteristics that make the solar wind more turbulent. These details are key to understanding how the wind disperses energy as it flows away from the Sun and throughout the solar system.

One type of event in particular drew the eye of the science teams: flips in the direction of the magnetic field, which flows out from the Sun, embedded in the solar wind. These reversals—dubbed "switchbacks"—last anywhere from a few seconds to several minutes as they flow over Parker Solar Probe. During a switchback, the magnetic field whips back on itself until it is pointed almost directly back at the Sun. Together, FIELDS and SWEAP, the solar wind instrument suite led by the University of Michigan and managed by the Smithsonian Astrophysical Observatory, measured clusters of switchbacks throughout Parker Solar Probe's first two flybys.

"Waves have been seen in the solar wind from the start of the space age, and we assumed that closer to the Sun the waves would get stronger, but we were not expecting to see them organize into these coherent structured velocity spikes," said Justin Kasper, principal investigator for

SWEAP—short for Solar Wind Electrons Alphas and Protons—at the University of Michigan in Ann Arbor. "We are detecting remnants of structures from the Sun being hurled into space and violently changing the organization of the flows and magnetic field. This will dramatically change our theories for how the corona and solar wind are being heated."

The exact source of the switchbacks isn't yet understood, but Parker Solar Probe's measurements have allowed scientists to narrow down the possibilities.

Among the many particles that perpetually stream from the Sun are a constant beam of fast-moving electrons, which ride along the Sun's magnetic field lines out into the solar system. These electrons always flow strictly along the shape of the field lines moving out from the Sun, regardless of whether the north pole of the magnetic field in that particular region is pointing towards or away from the Sun. But Parker Solar Probe measured this flow of electrons going in the opposite direction, flipping back towards the Sun—showing that the magnetic field itself must be bending back towards the Sun, rather than Parker Solar Probe merely encountering a different magnetic field line from the Sun that points in the opposite direction. This suggests that the switchbacks are kinks in the magnetic field—localized disturbances traveling away from the Sun, rather than a change in the magnetic field as it emerges from the Sun.

Parker Solar Probe's observations of the switchbacks suggest that these events will grow even more common as the spacecraft gets closer to the Sun. The mission's next solar encounter on Jan. 29, 2020, will carry the spacecraft nearer to the Sun than ever before, and may shed new light on this process. Not only does such information help change our understanding of what causes the solar wind and space weather around us, it also helps us understand a fundamental process of how stars work and how they release energy into their environment.

The rotating solar wind

Some of Parker Solar Probe's measurements are bringing scientists closer to answers to decades-old questions. One such question is about how, exactly, the solar wind flows out from the Sun.

Near Earth, we see the solar wind flowing almost radially—meaning it's streaming directly from the Sun, straight out in all directions. But the Sun rotates as it releases the solar wind; before it breaks free, the solar wind was spinning along with it. This is a bit like children riding on a playground park carousel—the atmosphere rotates with the Sun much like the outer part of the carousel rotates, but the farther you go from the center, the faster you are moving in space. A child on the edge might jump off and would, at that point, move in a straight line outward, rather than continue rotating. In a similar way, there's some point between the Sun and Earth, the solar wind transitions from rotating along with the Sun to flowing directly outwards, or radially, like we see from Earth.

Exactly where the solar wind transitions from a rotational flow to a perfectly radial flow has implications for how the Sun sheds energy. Finding that point may help us better understand the lifecycle of other stars or the formation of protoplanetary disks, the dense disks of gas and dust around young stars that eventually coalesce into planets.

Now, for the first time—rather than just seeing that straight flow that we see near Earth—Parker Solar Probe was able to observe the solar wind while it was still rotating. It's as if Parker Solar Probe got a view of the whirling carousel directly for the first time, not just the children jumping off it. Parker Solar Probe's solar wind instrument detected rotation starting more than 20 million miles from the Sun, and as Parker approached its perihelion point, the speed of the rotation increased. The strength of the circulation was stronger than many scientists had predicted, but it also transitioned more quickly than predicted to an outward flow, which is what helps mask these effects from where we usually sit, about 93 million miles from the Sun.

"The large rotational flow of the solar wind seen during the first encounters has been a real surprise," said Kasper. "While we hoped to eventually see rotational motion closer to the Sun, the high speeds we are seeing in these first encounters is nearly ten times larger than predicted by the standard models."

Dust near the Sun

Another question approaching an answer is the elusive dust-free zone. Our solar system is awash in dust—the cosmic crumbs of collisions that formed planets, asteroids, comets and other celestial bodies billions of years ago. Scientists have long suspected that, close to the Sun, this dust would be heated to high temperatures by powerful sunlight, turning it into a gas and creating a dust-free region around the Sun. But no one had ever observed it.

For the first time, Parker Solar Probe's imagers saw the cosmic dust begin to thin out. Because WISPR—Parker Solar Probe's imaging instrument, led by the Naval Research Lab—looks out the side of the spacecraft, it can see wide swaths of the corona and solar wind, including regions closer to the Sun. These images show dust starting to thin a little over 7 million miles from the Sun, and this decrease in dust continues steadily to the current limits of WISPR's measurements at a little over 4 million miles from the Sun.

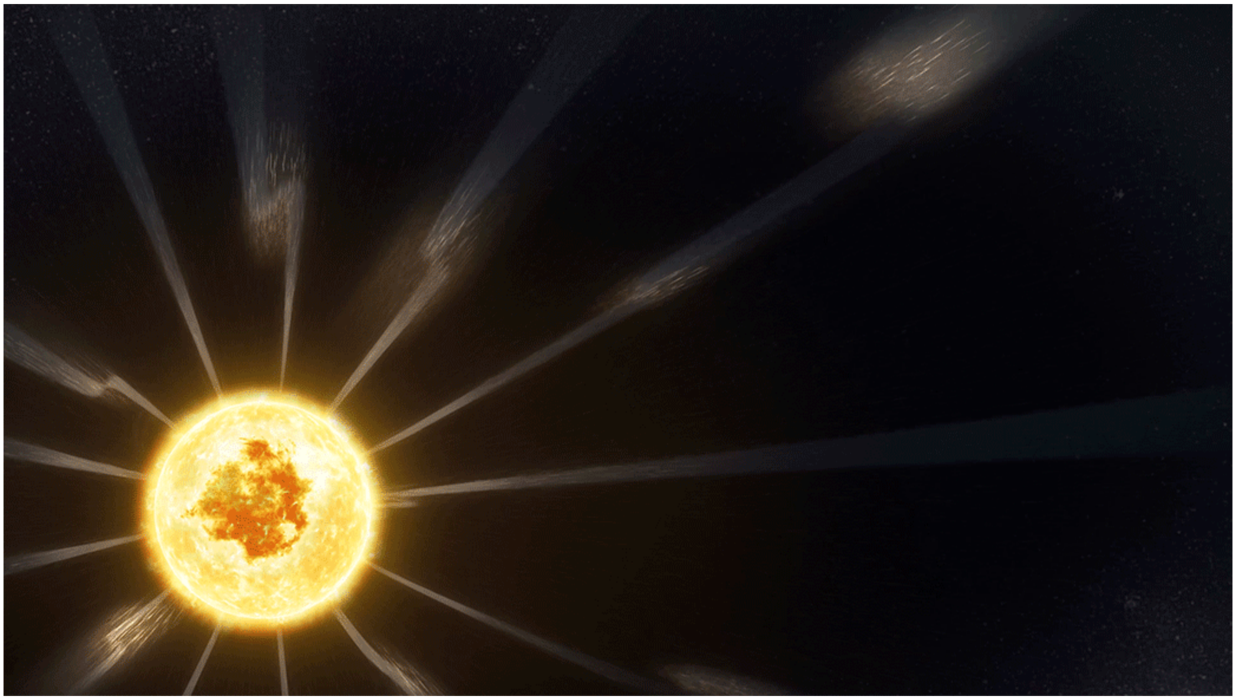
"This dust-free zone was predicted decades ago, but has never been seen before," said Russ Howard, principal investigator for the WISPR suite—short for Wide-field Imager for Solar Probe—at the Naval Research Laboratory in Washington, D.C. "We are now seeing what's happening to the dust near the Sun."

At the rate of thinning, scientists expect to see a truly dust-free zone starting a little more than 2-3 million miles from the Sun—meaning Parker Solar Probe could observe the dust-free zone as early as 2020, when its sixth flyby of the Sun will carry it closer to our star than ever before.

Putting space weather under a microscope

Parker Solar Probe's measurements have given us a new perspective on two types of space weather events: energetic particle storms and coronal mass ejections.

Tiny particles—both electrons and ions—are accelerated by solar activity, creating storms of energetic particles. Events on the Sun can send these particles rocketing out into the solar system at nearly the speed of light, meaning they reach Earth in under half an hour and can impact other worlds on similarly short time scales. These particles carry a lot of energy, so they can damage spacecraft electronics and even endanger astronauts, especially those in deep space, outside the protection of Earth's magnetic field—and the short warning time for such particles makes them difficult to avoid.



Parker Solar Probe observed switchbacks — traveling disturbances in the solar wind that caused the magnetic field to bend back on itself — an as-yet unexplained phenomenon that might help scientists uncover more information about how the solar wind is accelerated from the Sun. Credit: NASA's Goddard Space Flight Center/Conceptual Image Lab/Adriana Manrique Gutierrez

Understanding exactly how these particles are accelerated to such high speeds is crucial. But even though they zip to Earth in as little as a few minutes, that's still enough time for the particles to lose the signatures of the processes that accelerated them in the first place. By whipping around the Sun at just a few million miles away, Parker Solar Probe can measure these particles just after they've left the Sun, shedding new light on how they are released.

Already, Parker Solar Probe's ISʘIS instruments, led by Princeton University, have measured several never-before-seen energetic particle events—events so small that all trace of them is lost before they reach Earth or any of our near-Earth satellites. These instruments have also measured a rare type of particle burst with a particularly high number of heavier elements—suggesting that both types of events may be more common than scientists previously thought.

"It's amazing—even at solar minimum conditions, the Sun produces many more tiny energetic particle events than we ever thought," said David McComas, principal investigator for the Integrated Science Investigation of the Sun suite, or ISʘIS, at Princeton University in New Jersey. "These measurements will help us unravel the sources, acceleration, and transport of solar energetic particles and ultimately better protect satellites and astronauts in the future."

Data from the WISPR instruments also provided unprecedented detail on structures in the corona and solar wind—including coronal mass ejections, billion-ton clouds of solar material that the Sun sends hurtling out into the solar system. CMEs can trigger a range of effects on Earth and other worlds, from sparking auroras to inducing electric currents that can damage power grids and pipelines. WISPR's unique perspective, looking alongside such events as they travel away from the Sun, has already shed new light on the range of events our star can unleash.

"Since Parker Solar Probe was matching the Sun's rotation, we could watch the outflow of material for days and see the evolution of structures," said Howard. "Observations near Earth have made us think that fine structures in the corona segue into a smooth flow, and we're finding out that's not true. This will help us do better modeling of how events travel between the Sun and Earth."

As Parker Solar Probe continues on its journey, it will make 21 more close approaches to the Sun at progressively closer distances, culminating in three orbits a mere 3.83 million miles from the solar surface.

"The Sun is the only star we can examine this closely," said Nicola Fox, director of the Heliophysics Division at NASA Headquarters. "Getting data at the source is already revolutionizing our understanding of our own star and stars across the universe. Our little spacecraft is soldiering through brutal conditions to send home startling and exciting revelations."

Data from Parker Solar Probe's first two solar encounters is available to the public online.

Parker Solar Probe is part of NASA's Living with a Star program to explore aspects of the Sun-Earth system that directly affect life and society. The Living with a Star program is managed by the agency's Goddard Space Flight Center in Greenbelt, Maryland, for NASA's Science Mission Directorate in Washington. Johns Hopkins APL designed, built and operates the spacecraft.

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Provided by NASA's Goddard Space Flight Center

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