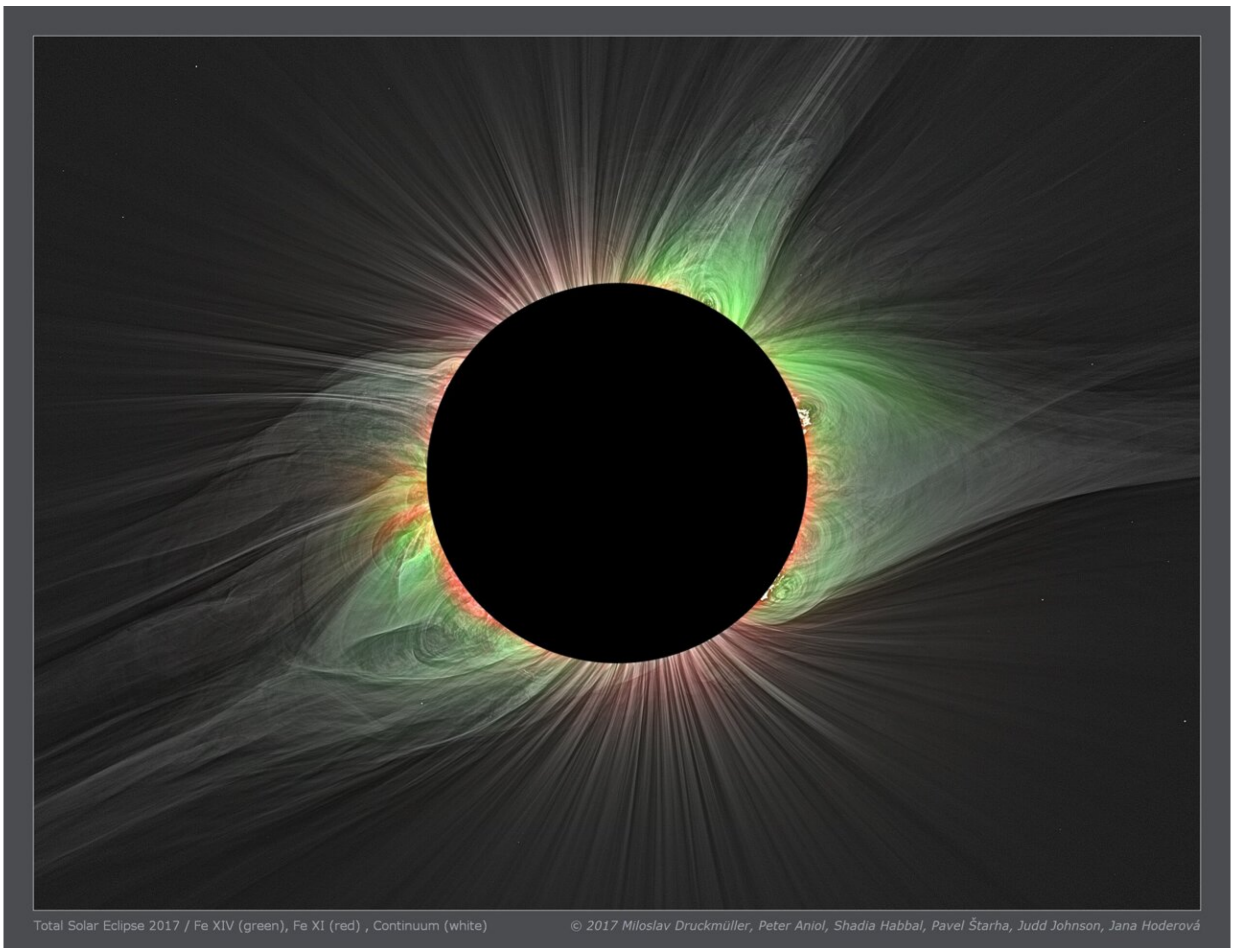
Total solar eclipses shine a light on the solar wind with help from NASA's ACE mission

June 16 2021, by Mara Johnson-Groh



Special filters enable scientists to measure different temperatures in the corona during total solar eclipses, such as this one seen in Mitchell, Oregon, on August 21, 2017. The red light is emitted by charged iron particles at 1.8 million degrees Fahrenheit and the green are those at 3.6 million degrees Fahrenheit. Credit: M. Druckmuller and published in Habbal et al. 2021

From traversing sand dunes in the Sahara Desert to keeping watch for polar bears in the Arctic, a group of solar scientists known as the "Solar Wind Sherpas" led by Shadia Habbal, have traveled to the ends of the Earth to scientifically observe total solar eclipses—the fleeting moments when the Moon completely blocks the Sun, temporarily turning day into night. With the images, they've uncovered a surprising finding about the Sun's wind and its wispy outer atmosphere—the corona—which is only visible in its entirety during an eclipse.

From more than a decade's worth of total eclipse observations taken around the world, the team noticed that the corona maintains a fairly constant temperature, despite dynamical changes to the region that occur on an 11-year rotation known as the solar cycle. Similarly, the solar wind —the steady stream of particles the Sun releases from the corona out across the solar system—matches that same temperature.

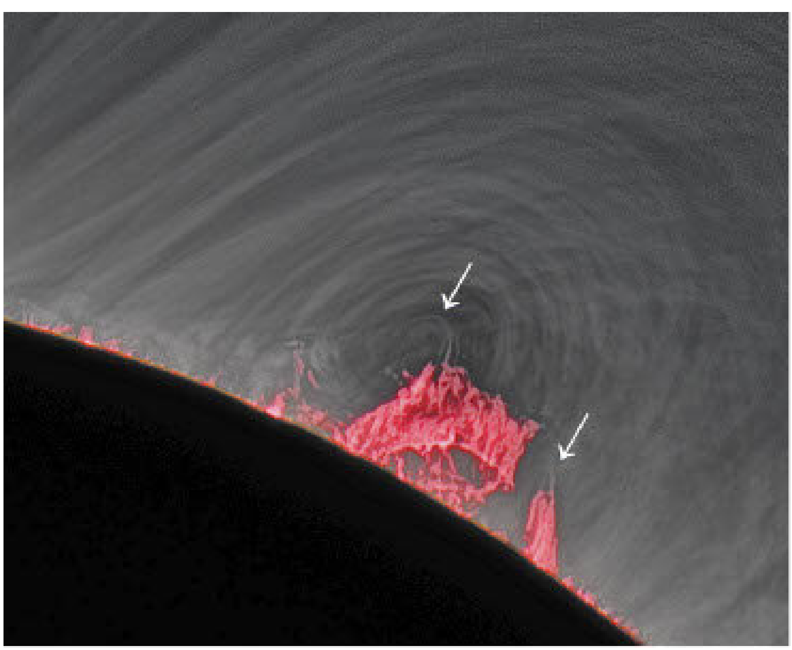
"The temperature at the sources of the solar wind in the corona is almost constant throughout a solar cycle," said Shadia Habbal, a solar researcher at the University of Hawaii who led the study. "This finding is unexpected because coronal structures are driven by changes in the distribution of magnetized plasmas in the corona, which vary so much throughout the 11-year magnetic solar cycle."

The new findings, published in the *Astrophysical Journal Letters*, are helping scientists better understand the solar wind, which is a key component of space weather that can impact electronics hardware and astronaut activities in space. The results could also help scientists understand a longstanding solar mystery: how the corona gets to be over a million degrees hotter than lower atmospheric layers.

More Than Just Pretty Pictures

Scientists have used total solar eclipses for over a century to learn more about our universe, including deciphering the Sun's structure and explosive events, finding evidence for the theory of general relativity, and even discovering a new element—helium. While instruments called coronagraphs are able to mimic eclipses, they're not good enough to access the full extent of the corona that is revealed during a total solar eclipse. Instead, astronomers must travel to far-flung regions of the Earth to observe the corona during eclipses, which occur about every 12 to 18 months and only last a few minutes.

Through travels to Australia, Libya, Mongolia, Oregon, and beyond, the team gathered 14 years of high-resolution total solar eclipse images from around the world. They captured the eclipses using cameras equipped with specialized filters to help them measure the temperatures of the particles from the innermost part of the corona, the sources of the solar wind.



A close-up view of a prominence (the pinkish areas) – the coolest and most complex magnetic structure in the corona. Prominences are directly linked to overlying hot arches (the grey loops) in the corona. Their dynamics drive the variable solar wind and eruptions called coronal mass ejections. Prominences are also thought to be directly linked to regional temperature changes in the corona throughout a solar cycle, as they increase with solar activity. Credit: Habbal et al. 2021

The researchers used light emitted by two common types of charged iron particles in the corona to determine the temperature of the material there. The results unexpectedly showed that the amount of the cooler particles—which were more abundant and found to contribute most of the solar wind material—were surprisingly consistent at different times during the solar cycle. The sparse hotter material varied much more with the solar cycle while the solar wind speed varied from 185 to 435 miles per second.

"That means that whatever is heating the majority of the corona and solar wind is not very dependent on the Sun's activity cycle," said Benjamin Boe, a solar researcher at the University of Hawaii involved in the new research.

The finding is surprising as it suggests that while the majority of solar wind is originating from sources that have a roughly constant temperature, it may have wildly different speeds. "So now the question is, what processes keep the temperature of the sources of the solar wind at a constant value?" Habbal said.

The Dynamic Sun

The team also compared the eclipse data with measurements taken from NASA's Advanced Composition Explorer, or ACE, spacecraft, which sits in space 1 million miles away from Earth in the direction of the Sun and was also essential in revealing the properties of the dynamic component of the solar wind. The variable speeds of the dynamic wind were distinguished by the variability of the iron charge states associated with them. The spacecraft data showed that the speeds of the particles seen in the variable solar wind changed in relationship to the iron charge states associated with them. The high temperature sheaths around events called prominences, discovered from eclipse observations, were found to be responsible for the dynamic wind and the occasional coronal mass ejection—a large cloud of solar plasma and embedded magnetic fields released into space after a solar eruption.

While the team doesn't know why the sources of the solar wind are at the same temperature, they think the speeds vary depending on the density of the region they originated from, which itself is determined by the underlying magnetic field. Fast-flying particles come from low-density regions, and slower ones from high-density regions. This is likely because the energy is distributed between all the particles in a region. So in areas where there are fewer particles, there's more energy for each individual particle. This is similar to splitting a birthday cake—if there are fewer people, there's more cake for each person.

The new findings provide new insights into the properties of the solar wind, which is a key component of space weather that can impact space-based communication satellites and astronomical observing platforms. The team plans to continue traveling the globe to observe total solar eclipses. They hope their efforts may eventually shed a new light on the longstanding solar mystery: how the corona reaches a temperature of a million degrees, far hotter than the solar surface.

More information: Shadia R. Habbal et al, Identifying the Coronal Source Regions of Solar Wind Streams from Total Solar Eclipse Observations and in situ Measurements Extending over a Solar Cycle, *The Astrophysical Journal Letters* (2021). DOI:

10.3847/2041-8213/abe775

Provided by NASA's Goddard Space Flight Center