Sun's coldest region stores secret to heating million-degree corona, study finds

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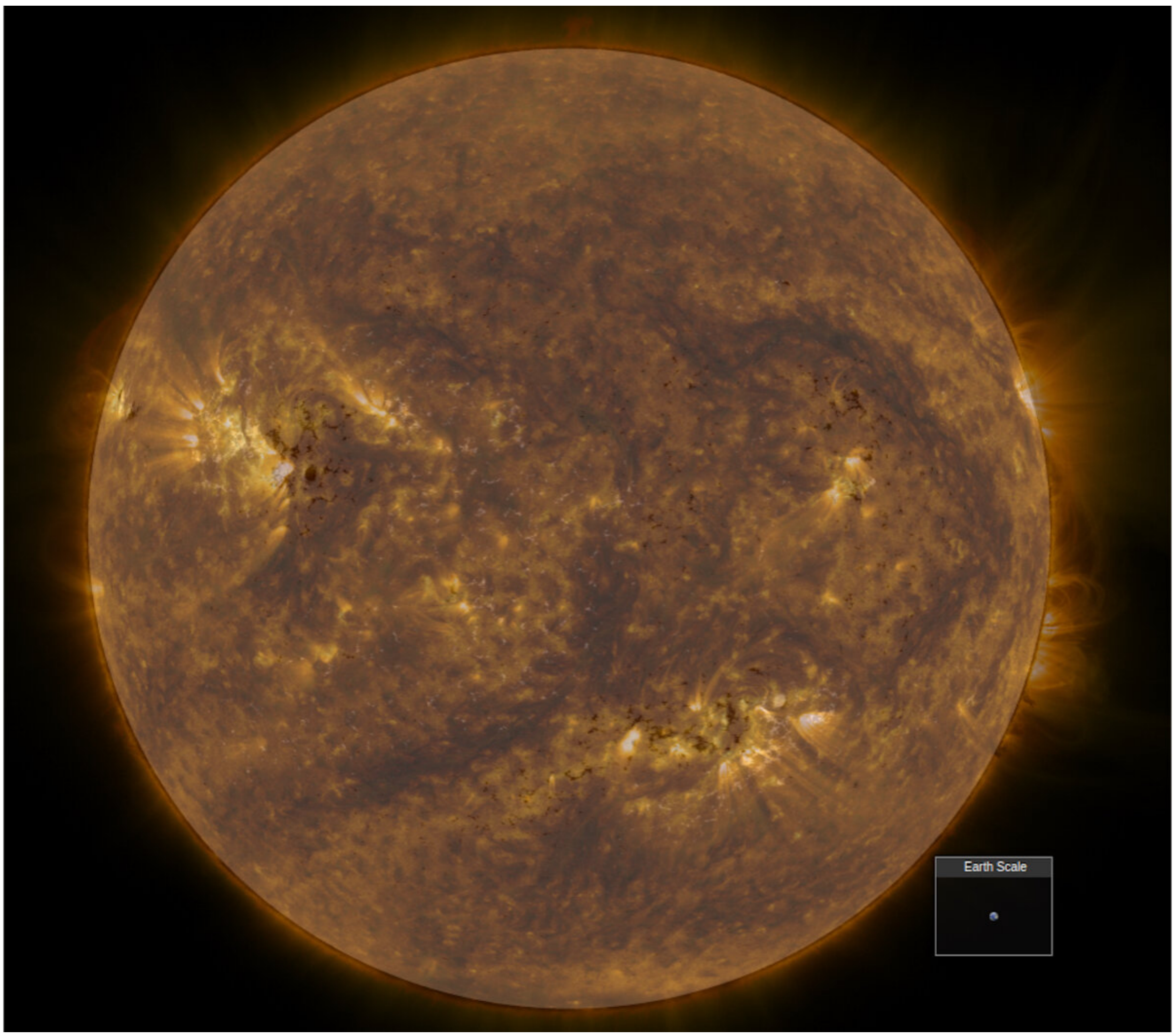

Extreme ultra-violet emission by solar coronal plasma at millions of degrees. Credit: Atmospheric Imaging Assembly (AIA) on board NASA's Solar Dynamics Observatory (SDO) spacecraft

Nearly 5,000 kilometers above the sun's surface lies a century-old question for solar physicists—how are temperatures in the star's upper atmosphere (corona) hundreds of times hotter than temperatures at the sun's visible surface?

An international team of scientists has a new answer to the question—commonly referred to as the sun's coronal heating problem—with new observational data obtained with the 1.6-meter Goode Solar Telescope (GST) at Big Bear Solar Observatory (BBSO), operated by NJIT's Center for Solar Terrestrial Research (CSTR).

In a study published in *Nature Astronomy*, researchers have unveiled the discovery of intense wave energy from a relatively cool, dark and strongly magnetized plasma region on the sun, capable of traversing the solar atmosphere and maintaining temperatures of a million degrees Kelvin inside the corona.

Researchers say the finding is the latest key to unraveling a host of related mysteries pertaining to Earth's nearest star.

"The coronal heating problem is one of the biggest mysteries in solar physics research. It has existed for nearly a century," said Wenda Cao, BBSO director and NJIT physics professor who is co-author of the study. "With this study we have fresh answers to this problem, which may be key to untangling many confusing questions in energy transportation and dissipation in the solar atmosphere, as well as the nature of space weather."

Using GST's unique imaging capabilities, the team led by Yuan Ding was able to initially capture transverse oscillations in the darkest and coldest region on the sun, called the sunspot umbra.

Such dark sunspot regions can form as the star's strong magnetic field suppresses thermal conduction and hinders the energy supply from the hotter interior to the visible surface (or photosphere), where temperatures reach roughly 5,000 degrees Celsius.

To investigate, the team measured activity related to numerous dark features detected in an active sunspot recorded on July 14, 2015 by BBSO's GST—including oscillatory transverse motions of plasma fibrils within the sunspot umbra in which the magnetic field is more than 6,000 times stronger than Earth's.

"Fibrils appear as cone-shaped structures with a typical height of 500-1,000 km and a width of about 100 km," explained Vasyl Yurchyshyn, NJIT-CSTR research professor of heliophysics and BBSO senior scientist. "Their lifetime ranges from two to three minutes and they tend to reappear at the same location within the darkest parts of the umbra, where magnetic fields are strongest."

"These dark dynamic fibrils had been observed in the sunspot umbra for a long time, but for the first time, our team was able to detect their lateral oscillations that are manifestations of fast waves," said Cao. "These persistent and ubiquitous transverse waves in strongly magnetized fibrils bring energy upwards through vertically elongated magnetic conduits and contribute to the heating of the upper atmosphere of the sun."

Through a numerical simulation of these waves, the team estimates the energy carried could be up to thousands times stronger than energy losses in active region plasma of the sun's upper atmosphere—dissipating energy up to four orders of magnitude stronger than the heating rate needed to keep up the blazing plasma temperatures in the corona.

"Various waves have been detected everywhere on the sun, but typically their energy is too low to be able to heat the corona," said Yurchyshyn. "The fast waves detected in the sunspot umbra are a persistent and efficient energy source that may be responsible for heating the corona above sunspots."

For now, researchers say the new findings not only revolutionize our view of the sunspot umbra, but offer another important step in advancing physicists' understanding of the energy transport processes and heating of the solar corona.

However, questions about the coronal heating problem persist.

"While these findings are a step forward toward solving the mystery, the energy flux coming out of sunspots may be only responsible for heating those loops that are rooted in sunspots," said Cao. "Meanwhile, there are other sunspot-free regions associated with hot coronal loops that still await to be explained. We expect that GST/BBSO will continue providing the highest-resolution observational evidence to further unlock mysteries of our star."

More information: Ding Yuan et al, Transverse oscillations and an energy source in a strongly magnetized sunspot, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-01973-3

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