Daniel K. Inouye Solar Telescope produces its first magnetic field maps of the sun's corona

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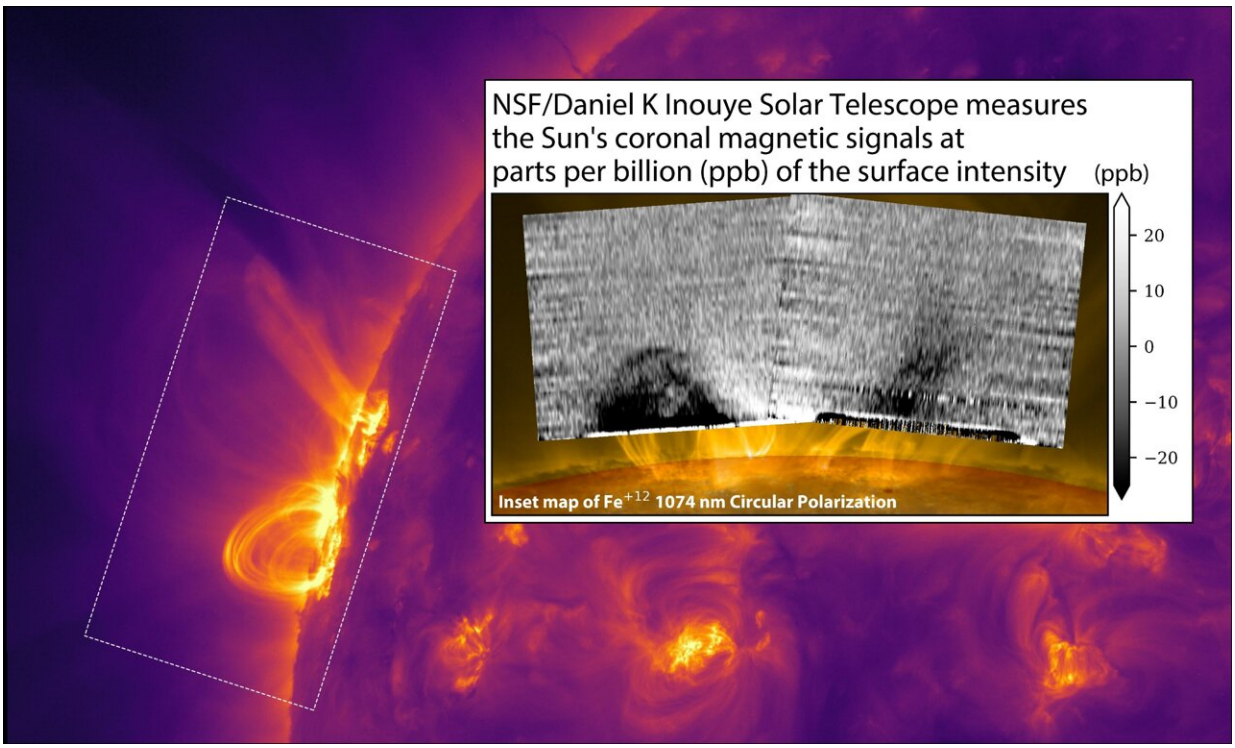

The NSF Daniel K. Inouye Solar Telescope presents its first map of the solar coronal magnetic field signals as measured using the Zeeman Effect. The Zeeman Effect polarizes the coronal emission, which requires the advancements of the Inouye Solar Telescope to measure as its signals are only a few parts per billion of the sun's surface brightness. The background image identifies the region observed in detail by Inouye as imaged by NASA's Solar Dynamics Observatory in ultraviolet light. Credit: NSF/NSO/AURA

The Daniel K. Inouye Solar Telescope, the world's most powerful solar telescope, operated by the NSF National Solar Observatory (NSO), achieved a major breakthrough in solar physics by successfully producing its first detailed maps of the sun's coronal magnetic fields.

This milestone, led by NSO Associate Astronomer Dr. Tom Schad, was published in *Science Advances*, and promises to enhance our understanding of the sun's atmosphere and how its changing conditions lead to impacts on Earth's technology-dependent society.

The corona, or the sun's outer atmosphere, greatly influences solar winds and space weather events like solar flares and coronal mass ejections. However, the magnetic forces that drive these events and the corona are challenging to measure.

The telescope directly mapped the strength of the magnetic field in the solar corona, the outer part of the solar atmosphere that can be seen during a total eclipse. This breakthrough promises to enhance our understanding of space weather and its impact on Earth's technology-dependent society.

The corona: The launch pad of space weather

The sun's magnetic field generates regions in the sun's atmosphere, often rooted by sunspots, that store vast amounts of energy that fuel explosive solar storms and drive space weather.

The corona, the sun's outer atmosphere, is a superheated realm where these magnetic mysteries unfold. Mapping coronal magnetic fields is essential to understanding and predicting space weather—and to protect our technology in Earth and space.

Why it matters

Earth's magnetic field shields us from solar winds, protecting our atmosphere, and making life possible. However, the electromagnetic fields and energetic particles from extreme solar eruptions can disrupt satellites, power grids, and other systems we need in our increasingly technological society.

Understanding these dynamic interactions, which change on timescales ranging from days to centuries, is crucial for safeguarding our infrastructure and current way of life.

Measuring the corona's magnetic properties has long challenged astronomers and the limits of technology. Today, the Inouye Solar Telescope is the most advanced facility designed to study the corona, and has made a crucial first step in resolving these mysteries by producing its first coronal magnetic field maps—the most detailed to date.

The Inouye Solar Telescope's first maps of the corona's magnetic field

Since the 1950s, solar physicists have mapped the magnetic fields on the sun's surface, providing valuable insights. However, maps of the magnetic field in the zones above the surface, like the corona, have long been sought as it is in these locations that solar storms originate. The Inouye, located near the summit of Maui's Haleakalā in Hawai'i, now provides the capabilities to meet this critical need.

The Inouye has created its first detailed magnetic field maps of the solar corona using the Zeeman Effect, which measures magnetic properties by observing spectral line splitting. Spectral lines are distinct lines that appear at specific wavelengths in the electromagnetic spectrum,

representing the light absorbed or emitted by atoms or molecules.

These lines act like "fingerprints," as they are unique to each atom or molecule, allowing scientists to identify the chemical composition and physical properties of celestial objects by looking at their spectra. When exposed to a magnetic field, like in the sun, these lines split, which gives us an insight into the object's magnetic properties.

Previous attempts at detecting these signals, last reported two decades ago, lacked the detail and regularity needed for extensive scientific investigation. Today, the Inouye's unmatched capabilities allow for detailed, regular studies of these crucial signals.

Technological marvel

Typically, one can only view the sun's corona—a region one million times fainter than the solar disk—during a total solar eclipse, when most of the sun's light is blocked and Earth's sky goes dark.

The Inouye, however, uses a technique called coronagraphy to create artificial eclipses, allowing it to detect extremely faint polarized signals—a billion times fainter than the solar disk—highlighting its unparalleled sensitivity and solidifying its status as a unique window to our home star.

The Inouye accomplishes this with its Cryogenic Near-Infrared Spectropolarimeter (Cryo-NIRSP), one of the telescope's primary instruments used to study the corona and map its magnetic fields. This instrument was designed and built by the University of Hawai'i Institute for Astronomy.

"The Inouye's achievement in mapping the sun's coronal magnetic fields is a testament to the innovative design and capabilities of this trailblazing

unique observatory," said Tom Schad, scientist at NSO, and first author of the study. "This breakthrough promises to significantly enhance our understanding of the solar atmosphere and its influence on our solar system."

Future prospects

This milestone marks the beginning of a new era in solar physics. The Inouye's success in mapping the sun's coronal magnetic fields reaffirms its vision and mission, and opens new frontiers in understanding the sun's influence on space weather.

"Just as detailed maps of the Earth's surface and atmosphere have enabled more accurate weather prediction, this thrillingly complete map of the magnetic fields in the sun's corona will help us better predict solar storms and space weather," says Dr. Carrie Black, NSF program director for the NSO.

"The invisible yet phenomenally powerful forces captured in this map will propel solar physics through the next century and beyond."

Christoph Keller, NSO Director, said, "Mapping the strength of the magnetic field in the corona is a fundamental scientific breakthrough, not just for solar research, but for astronomy in general."

"This is the beginning of a new era where we will understand how the magnetic fields of stars affect planets, here in our own solar system and in the thousands of exoplanetary systems that we now know about."

Ongoing and future studies will refine diagnostic tools and techniques, leading to deeper insights into the sun's magnetic environment and its impact on Earth and our solar system.

More information: Thomas Schad, Mapping the Sun's coronal magnetic field using the Zeeman effect, *Science Advances* (2024). DOI: 10.1126/sciadv.adq1604. www.science.org/doi/10.1126/sciadv.adq1604

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