Artificial intelligence enables new insights into solar magnetic field

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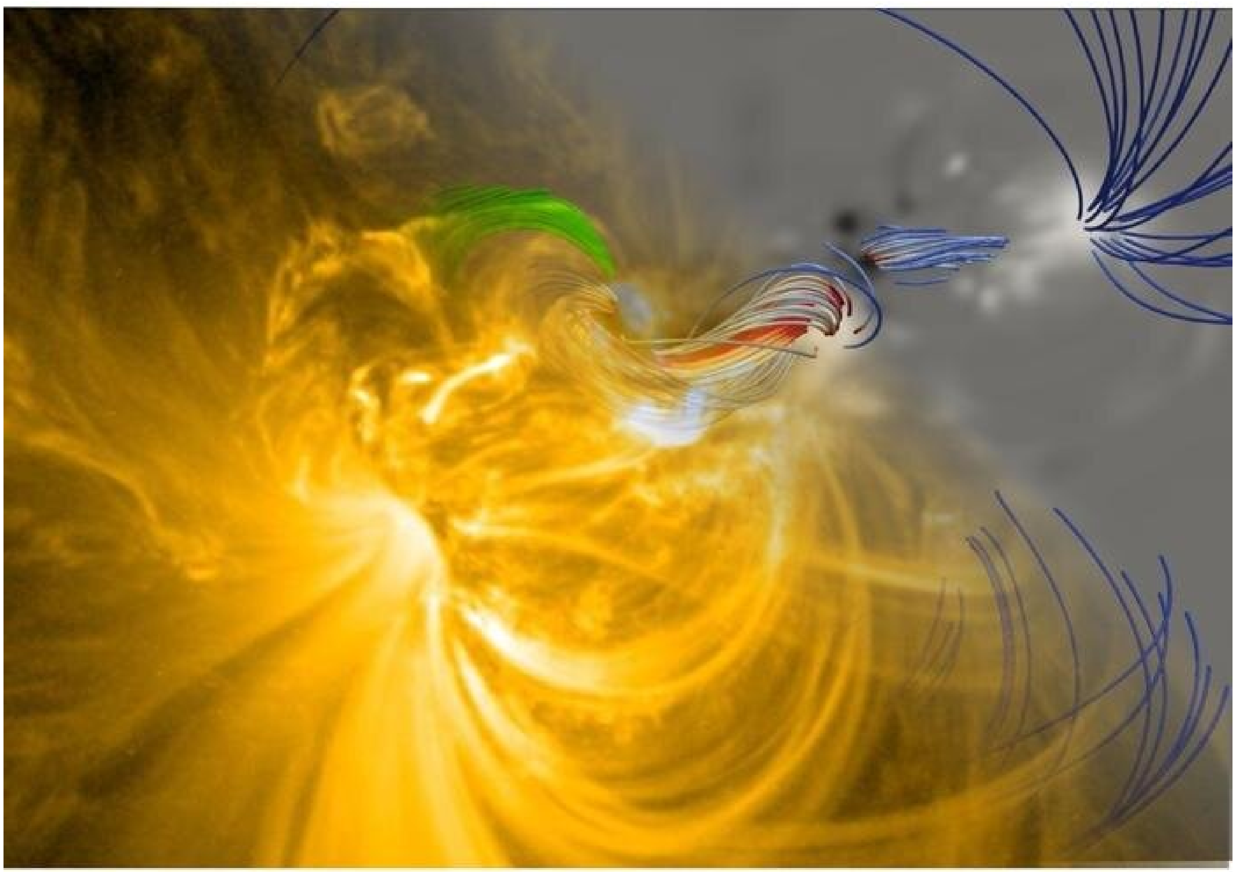


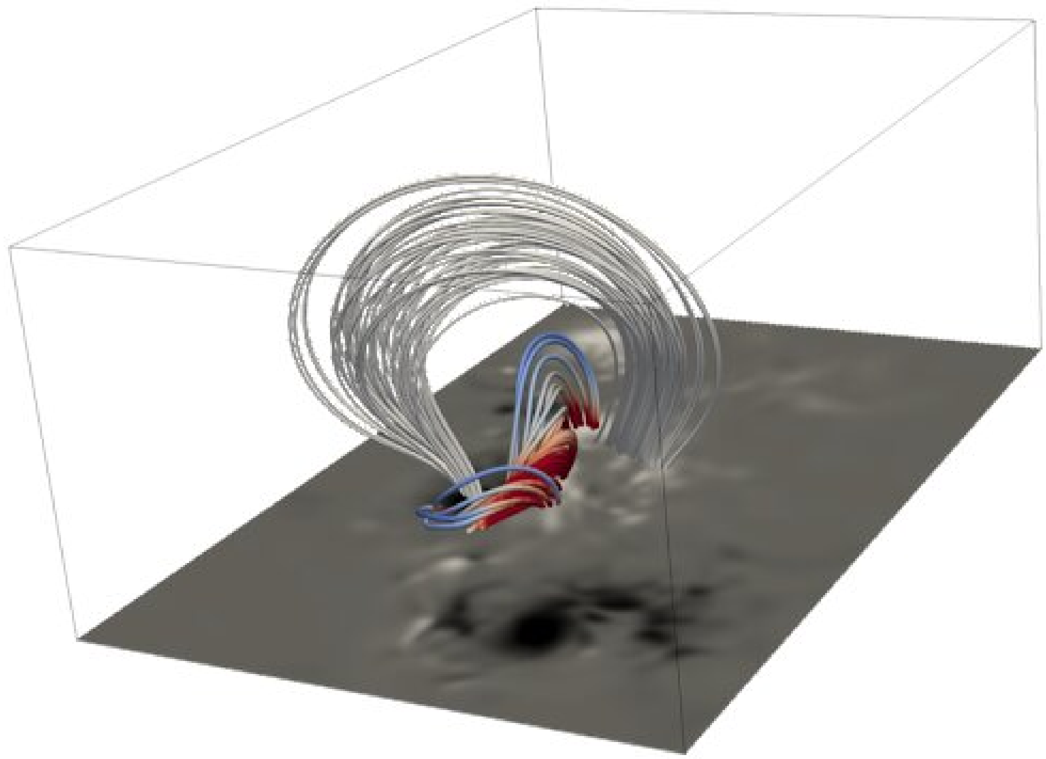
Composite of extreme ultraviolet observation (left) and magnetic field (right). The magnetic field lines are obtained from the simulation and show agreement with the outlined structures in EUV. Credit: Jarolim et. al, 2023

Scientists at the University of Graz, in collaboration with researchers from Skoltech, have achieved a breakthrough in solar physics by utilizing artificial intelligence to simulate the magnetic field in the upper atmosphere of the sun in quasi real-time. This research, published in *Nature Astronomy*, holds immense promise for advancing our understanding of the sun's behavior and its impact on space weather.

The solar magnetic field is the main driver of space weather, which can cause damage to critical infrastructures like electricity, aviation, and our space-based technology. The main source of severe space weather events are solar active regions, which are regions around sunspots where strong magnetic fields emerge through the solar surface. Current observing capabilities only allow us to measure the magnetic field at the surface of the sun, however, the energy buildup and release happens higher up in the solar atmosphere, the sun's corona.

By leveraging the capabilities of physics-informed neural networks, the team successfully managed to integrate observational data with the physical force-free magnetic field model, providing a comprehensive understanding of the connection between the observed phenomena and the underlying physics that governs the sun's activity. This cutting-edge method marks a significant milestone in solar physics and opens up new opportunities for numerical simulations of the sun.

The researchers simulated the evolution of an observed solar active region and demonstrated the ability to perform force-free magnetic field simulations in real-time. Impressively, this process only required less than 12 hours of computation time to simulate an observation series of five days. This unprecedented speed enables scientists to conduct real-time analysis and forecasts of solar activity, enhancing our ability to predict space weather events.



Simulated magnetic field lines with the observed surface magnetic field at the bottom. Credit: Jarolim et. al, 2023

The team further studied the time evolution of free magnetic energy within the coronal volume, which is linked to solar eruptive events on the sun like coronal mass ejections—large plasma clouds ejected from the atmosphere of the sun at speeds of 100–3,500 km/s. The comparison to extreme ultraviolet observations confirmed the robustness and accuracy of the methodology. Crucially, the results revealed significant depletions of free magnetic energy, both spatially and temporally, which directly correlate with observed solar eruptions.

Robert Jarolim, the lead researcher, said, "Our use of artificial intelligence in this context represents a transformative leap forward. The use of AI techniques for numerical simulations allows us to better incorporate observational data and holds great potential to further advance our simulation capabilities."

Skoltech Associate Professor Tatiana Podlachikova says, "The computing speed holds significant promise for improving space weather forecasting and advancing our knowledge of the sun's behavior."

This research conducted by the scientists at the University of Graz and Skoltech represents a remarkable advancement in the field of solar physics. By harnessing the power of AI and physics-informed neural networks, they have achieved real-time simulations of the solar coronal magnetic field, revolutionizing our ability to comprehend solar activity.

More information: R. Jarolim et al, Probing the solar coronal magnetic field with physics-informed neural networks, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02030-9

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