Real-Time Coronal Magnetic Field Modeling Using Physics-Informed Fourier Neural Operators

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Coronal magnetic fields are a driving force behind the formation and evolution of solar energetic particle events, which are known to disrupt critical ground and space infrastructure, causing significant economic damage. However, studying the Sun's corona has been a significant challenge in heliophysics due to the complexity of the magnetic field structures in solar active regions. Magnetohydrodynamics (MHD) simulations help us model these complex environments but require solving specific partial differential equations over a wide range of spatial and temporal scales, making their computation take days to weeks to solve. This study combines the divergence-free condition from Gauss Law with Tensorized Fourier Neural Operators (TFNO) to predict the coronal vector magnetic field B(x,y,z) up to 8.3 Megameters (Mm) above the photosphere from a single 33 km tall layer B(x,y,0). The model was trained on 254 high-resolution samples of the simulations, achieving $R^2=0.820$, RE=0.326, and predictions within 2 seconds per sample. This work demonstrates the viability of a physics-informed approach for predicting non-force-free coronal magnetic fields and provides a faster method of studying them compared to simulations using Bifrost MHD.

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