A Novel Hybrid Computational Framework for Solar Alfvén Wave Analysis and Tokamak Heating Optimization Using Parker Solar Probe Data

Das, Aryav (School: Park Tudor School)
Kolli, Saikrish (School: Paul Laurence Dunbar High School)

Efficient ion heating remains a major obstacle in magnetic fusion because radio-frequency waves often deposit too much of their energy into electrons rather than fuel ions. Existing ion-cyclotron range of frequencies (ICRF) optimization methods rely on device-specific parameter scans, leaving an important gap: whether wave physics measured in natural plasmas can be translated into guidance for fusion heating design. This project tests that idea by using near-Sun solar-wind observations from NASA's Parker Solar Probe (PSP) to guide ICRF heating choices in MAST-U-relevant tokamak plasmas. We developed a cross-domain workflow that combined PSP wave diagnostics, dimensionless parameter mapping to tokamak equilibria, AORSA full-wave heating calculations, and kinetic and reduced-model analysis with codes like Gkeyll and BOUT++. PSP data were used to characterize Alfvénicity, compressibility, and spectral structure, which were then mapped to candidate tokamak operating conditions and RF launch settings. Across 100 total candidates, the PSP-informed campaign identified the strongest ion-heating cases. The best PSP-guided configuration produced 0.046416 W of absorbed ion power, compared with 0.019721 W for the best reference case, a 2.36× improvement. The ion-heating fraction also rose from 0.01325 to 0.03256, a 2.46× gain, showing that the optimized settings redirected a larger share of absorbed power into ions rather than electrons. In parallel, the hybrid workflow achieved an 84× runtime speedup, demonstrating that physically informed optimization can be more efficient. These results show that space-plasma measurements can provide design guidance for fusion heating, opening a new path toward more efficient fusion plasmas and a future towards clean energy

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