Multimodal Super-Resolution: Discovering Hidden Physics and Its Application to Fusion Plasmas (Abstract Reprint)

Azarakhsh Jalalvand[1], SangKyeun Kim[2], Jaemin Seo[3], Qiming Hu[2], Max Curie[1], Peter Steiner[1], Andrew Oakleigh Nelson[4], Yong-Su Na[5], Egemen Kolemen[1,2]

[1]Princeton University, Princeton, NJ, USA
[2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA
[3]Chung-Ang University, Seoul, South Korea
[4]Columbia University, New York, NY, USA
[5]Seoul National University, Seoul, South Korea

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Abstract

Understanding complex physical systems often requires integrating data from multiple diagnostics, each with limited resolution or coverage. We present a machine learning framework that reconstructs synthetic high-temporal-resolution data for a target diagnostic using information from other diagnostics, without direct target measurements during the inference. This multimodal super-resolution technique improves diagnostic robustness and enables monitoring even in case of measurement failures or degradation. Applied to fusion plasmas, our method targets edge-localized modes (ELMs), which can damage plasma-facing materials. By reconstructing super-resolution Thomson Scattering data from complementary diagnostics, we uncover fine-scale plasma dynamics and validate the role of resonant magnetic perturbations (RMPs) in ELM suppression through magnetic island formation. The approach provides new observation supporting the plasma profile flattening due to these islands. Our results demonstrate the frameworks ability to generate high-fidelity synthetic diagnostics, offering a powerful tool for ELM control development in future reactors like ITER. The approach is broadly transferable to other domains facing sparse, incomplete, or degraded diagnostic data, opening new avenues for discovery.

References

Jalalvand, A.; Kim, S.; Seo, J.; Hu, Q.; Curie, M.; Steiner, P.; Nelson, A. O.; Na, Y.-S.; and Kolemen, E. 2025. Multimodal Super-Resolution: Discovering Hidden Physics and Its Application to Fusion Plasmas. *Nature Communications*, 16: 8506.