ENABLING ADAPTIVE DETACHMENT CONTROL: NOVEL INSIGHTS FROM CALIBRATION-FREE X-POINT PHASE DIFFERENCE

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Sustaining divertor detachment is essential for reactor operation but remains challenging in ELMy H-mode plasmas. Conventional diagnostics like Langmuir probes suffer from erosion [1], while tomography requires absolute calibration and intensive computation [2]—limiting real-time control during ELMs.

We present X-IRIS (X-point Ionization and Radiation Interface Structure), as shown in Fig.1, a novel, non-invasive, calibration-free method for detachment monitoring. It uses phase shifts between spectroscopic sightlines near the X-point, responding to turbulent filament transport, to infer divertor energy dissipation and entropy dynamics without requiring calibrated measurements [3]. The detailed configurations of the utilized diagnostics are depicted in Fig. 2.

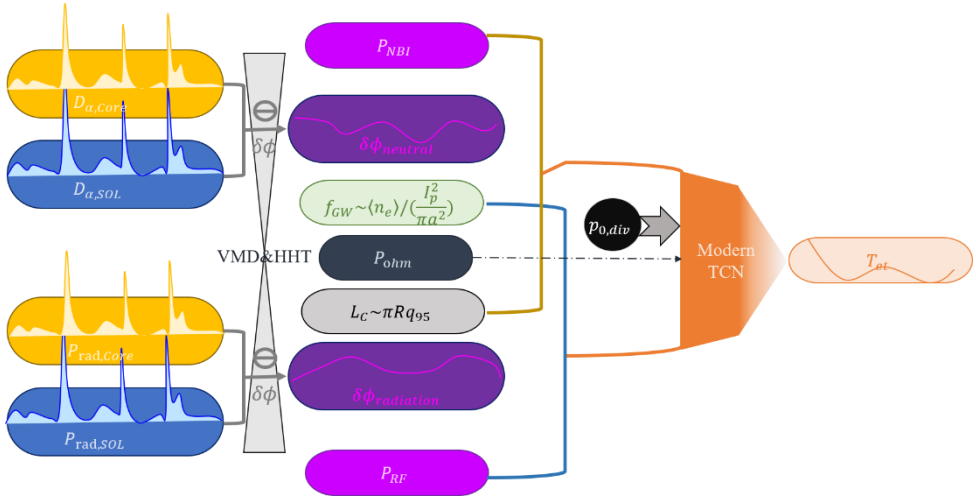

Fig.1 Framework of X-IRIS

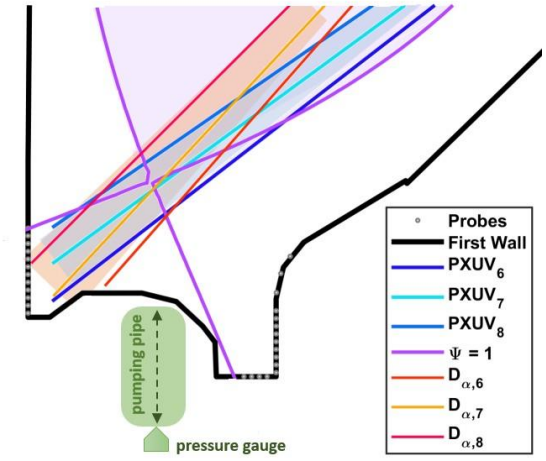

Fig.2 Poloidal diagram of the detected areas of interest

Validated across heating schemes (e.g., Fig.3), X-IRIS reveals how cross-separatrix flow asymmetry affects detachment and distinguishes the roles of NBI and RF heating in power dissipation. This approach paves the way for efficient, calibration-independent monitoring in future tokamaks.

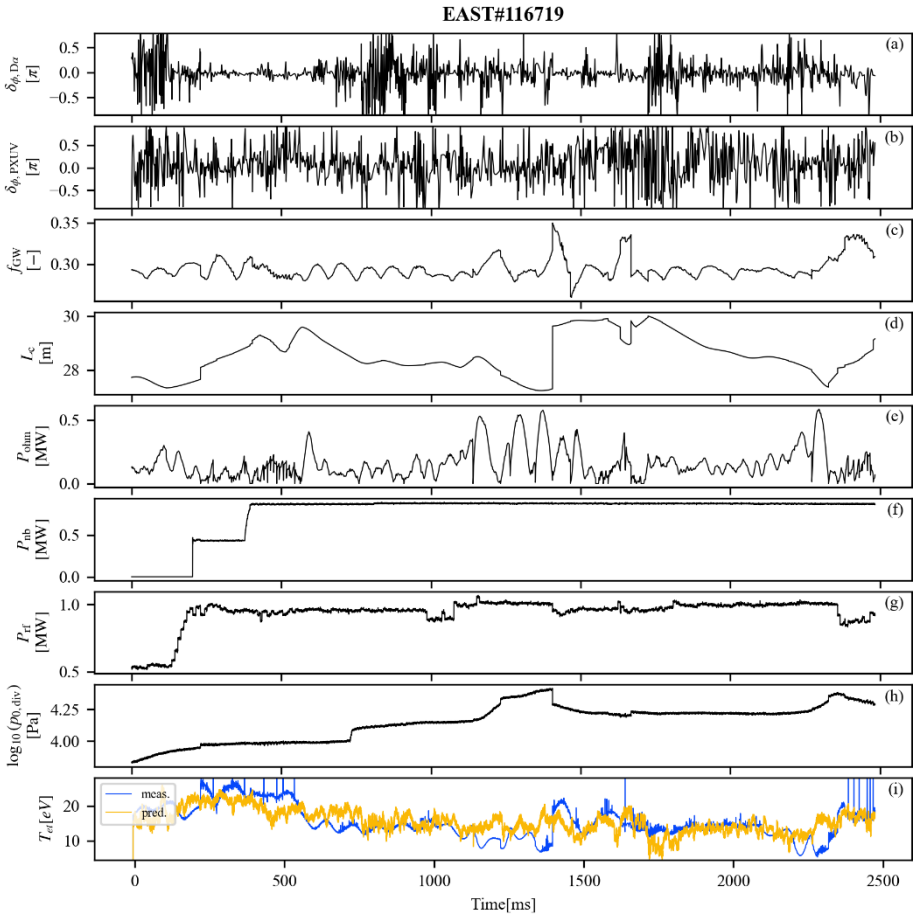

Fig. 3 Segments of an unsteady NBI and RF synergetic heating discharge applied with X-IRIS.

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