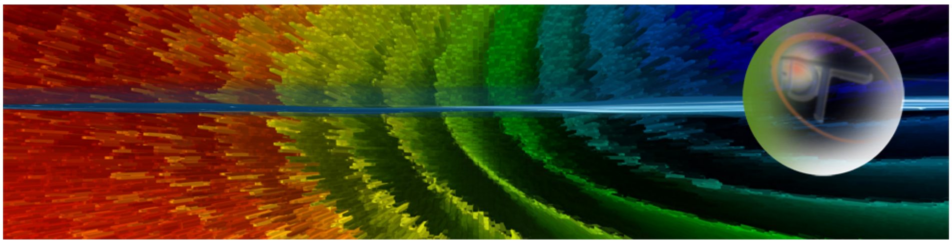

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Measurements of Fluctuations in Tokamak Plasmas

(Conference Title: Measurements of Fluctuations in Tokamak Plasmas)
Optical Imaging Measurements of Turbulence and Instabilities in Tokamak Plasmas*
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Abstract:

Magnetically confined fusion-grade plasmas exhibit a wide range of macroscopic and microscopic instabilities that strongly impact their performance, particle and energy confinement, and stability. The combination of large density and temperature gradients, populations of multiple species of thermal and energetic particles, and magnetic geometry drive instabilities that result in turbulence and magneto-hydrodynamic instabilities over a range of scales. Characterizing, understanding, predicting, and controlling turbulence and its resulting transport is of central importance to fundamental plasma physics and is critically important to the development of fusion energy. Because of the high temperatures typically encountered in tokamak plasmas (T ≤ ~ 10 keV, ~100,000,000 K), remote sensing technologies are typically required to measure the parametric behavior, spatiotemporal characteristics, and complex dynamics and interactions of these instabilities. Active and passive optical, microwave and beam-based techniques have therefore been developed and exploited to diagnose plasma instabilities. We focus here on measurements of density and temperature fluctuations utilizing optical emissions from a hydrogenic neutral beam (~1-3 MW, E~30-45 keV/amu) that is injected to heat, fuel, rotate and drive current in toroidal plasmas. Via appropriate viewing geometry with respect to the neutral beam, magnetic flux surfaces and field lines, high spatial resolution measurements of low-wavenumber, ion gyroscale instabilities can be obtained. Beam Emission Spectroscopy (BES) and Ultra-Fast Charge Exchange Recombination Spectroscopy UF-CHERS) diagnostics have been developed to measure density and ion temperature, respectively. BES measures Balmer-alpha (n=3-2) photons emitted from collisionally excited neutral beam atoms. UF-CHERS observes Doppler-broadened charge exchange emission from intrinsic carbon impurity ions (CVI, n=8-7). Critical diagnostic requirements include achieving adequate spatial resolution as well as high photon flux, which insures that photon noise dominates electronic noise and also maximizes sensitivity to low-amplitude fluctuation signals; normalized fluctuation amplitudes are typically ñ/n<1% in the core regions of high-performance plasmas with frequencies f<1 MHz. Sufficient SNR is achieved with high throughput and high-transmission optical systems, high-quantum-efficiency PIN photodiode or APD detectors, specialized low-noise, high-gain preamplifiers and high-transmission narrow band interference filters (BES) or a prism-coupled volume phase holographic transmission grating (UF-CHERS). Measurement capabilities include identification of turbulence and energetic particle mode characteristics and evolution, equilibrium and high-frequency flows, turbulence imaging, turbulence and flow dynamics across transport bifurcations, and parametric dependence of turbulence on key plasma parameters such as rotation and magnetic shear, normalized plasma pressure, and electron-to-ion temperature ratio. Measurements are compared with nonlinear simulations that are used to predict plasma transport behavior in next-generation burning plasma experiments. Developmental ideas for future optical diagnostic concepts, such as employing Lyman-alpha based emission to achieve higher signal-to-noise and improved spatial resolution, will be introduced.

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