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Turbulence in Magnetically Confined Plasmas[1]

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Experimental characterization of plasma fluctuations has lead to significant insights into the dynamics of turbulent transport processes in magnetically confined fusion plasmas. Fluctuations on the scale of the ion gyroradius result in cross-field transport of particles, energy and momentum at rates that significantly exceed collisional (neoclassical) transport. The energy confinement time and, ultimately, fusion power are thus strongly dependent on this turbulent-driven transport. Turbulent eddy structures are found to be highly anisotropic ($k_{||} \ll k_{\perp}$), with the magnetic field defining a symmetry direction: parallel wavelengths scale with machine size, while perpendicular wavelengths scale with gyroradius. Measurement techniques using optical, microwave, beam, and laser-based methods have been developed to remotely probe relevant fluctuations in density, temperature, potential and velocity, including density imaging. Measured fluctuation characteristics are generally consistent with gyrokinetic simulations of drift wave turbulence: correlation lengths scale with ion gyroradius (ρ_I); amplitudes scale with $\rho^*(=\rho_I/a)$; decorrelation rates scale with the acoustic timescale, $\tau_c \sim a/c_s$; and wavenumber spectra peak near $k_\theta \rho_I \sim 0.25$ and $k_r \rho_I \sim 0$. Measurements of potential fluctuations and poloidal turbulence flows show evidence for $n = 0$, $m = 0$ zonal flows, including the coherent geodesic acoustic mode. These nonlinearly driven flows saturate turbulence via flow shearing. Such flows appear crucial to L-H confinement transitions and core barrier formation. Dependencies of turbulence on critical transport parameters will be reviewed in tokamak, stellarator and spherical torus geometries. Understanding these dependencies, as well as challenging and validating simulations, will be crucial to confidently predicting transport and confinement in burning plasmas.

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