Anomalous transport and multi-scale drift turbulence dynamics in tokamak ohmic discharge as measured by high resolution diagnostics and modeled by full-f gyrokinetic code

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The complex interaction between large-scale mean E×B flows, meso-scale zonal flows and fine-scale micro-turbulence excited due to specific profiles of plasma parameters and leading to anomalous transport is an important area of experimental and theoretical research in magnetically confined plasmas.

In this paper the global gyrokinetic full particle distribution particle-in-cell simulations performed for Ohmic discharge of small research FT-2 limiter tokamak are for the first time validated against experimental data obtained both with a set of standard tokamak diagnostics and by sophisticated microwave backscattering techniques characterizing the tokamak turbulent dynamics and transport phenomena at micro, macro and intermediate scales.

As a result of the simulation carried out with the ELMFIRE code an overall reasonable agreement between the numerical expectations and the experimental estimations of the electron and ion effective heat conductivity profiles obtained from the primary experimental profiles is achieved. The agreement obtained at the macro-level was strengthen at the micro-level and for intermediate turbulent scales using the Doppler reflectometry (DR), radial correlation reflectometry (RCR) and Doppler Enhanced Scattering (ES) microwave diagnostics.

The turbulence dynamics at the micro-scale measured by DR at FT-2 were compared to the ELMFIRE predictions using synthetic DR diagnostics. As a result, not only the experimental DR spectra frequency shift, but its width and even the shape of the spectra was well reproduced by synthetic diagnostic indicating comparable rotation and spreading of the selected turbulent density fluctuations. The turbulence radial correlation length dependence on its frequency provided by the modeling appears to be in reasonable agreement to that given by RCR. The fluctuation poloidal rotation velocity profile obtained by the DR is very close to that obtained from the synthesized DR spectrum and also close to that given by ES and to the value produced by ELMFIRE for plasma E×B drift velocity. The large spectral width of the DR and ES spectra is explained by fast and strong variation of radial electric field observed in the modeling. Giant oscillations of the field at a frequency of approximately 30-50 kHz much smaller than the typical drift wave frequency, but much larger than the inverse energy confinement time, observed by DR and ES as well, are attributed to the geodesic acoustic mode (GAM). This attribution is supported by comparison of the oscillation frequency dependence on the radial position with analytical prediction for the GAM frequency accounting for the impurity contribution. The dispersion of radial electric field estimated from the ES is found to be comparable to the huge \( E_r \) dispersion provided by the gyrokinetic modeling. Moreover the GAM correlation length and phase velocity determined using ES technique appears to be close to those obtained by the ELMFIRE. The interrelations of GAM and drift wave turbulence in experiment and gyrokinetic modeling are compared.

The detailed agreement of ELMFIRE data to the measured mean equilibrium E×B flows, oscillating meso-scale zonal flows and turbulence spectra observed with DR and ES technique as well as a reasonable fit of thermal diffusivity data and FT-2 density and temperature profiles provides the first example of correct global tokamak modeling.