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Edge Plasma Turbulence Analysis For High Plasma Density

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Introduction

Turbulence studies in Tokamaks are essential since plasma microturbulence is a potential source of anomalous transport. Although a weak turbulence level is required in plasma central region, radial turbulent diffusion is favorable at the edge to broaden particle and energy load on plasma facing components. It is then important to measure this turbulence and to identify which parameters control this turbulence.

In Tore Supra Tokamak, the far infrared coherent scattering diagnostic ALTAIR, is dedicated to turbulence and transport studies [1]. The measured signal is proportional to the electronic density fluctuations contained in the plasma cylinder crossed by the laser beam, where the scattering wavevector is perpendicular to the magnetic field lines. The safety factor profile determines the signal spatial localization along the chord, in a poloidal plane [2]. Turbulence level, correlation time and velocity shear at the edge, can be measured from ALTAIR signals.

Former experiments in DIII-D Tokamak [3] showed there is a relation between turbulence level at the edge of the plasma and radial electric field shear in the same region. Using ALTAIR capabilities in Tore Supra, we investigate here the relation between turbulence level and velocity shear at the edge.

Discharges where plasma density is increased to high values are considered. Former results [4, 5] showed edge plasma turbulence reduction when plasma density was increased to average values around $4.10^{19} m^{-3}$. Our interest here is to pursue these experiments to higher densities. Two sets of ohmic discharges are considered: One with helium gas and limiter configuration, the other with deuterium gas and ergodic divertor configuration.

Velocity shear at the plasma edge

Typical ALTAIR signal frequency spectrum shows two different humps for opposite frequency ranges. They correspond to opposite poloidal velocities through Doppler effect. This velocity shear is linked to the inversion of radial electric field in the edge region ($r/a \approx .92$) inducing $\vec{E} \times \vec{B}$ drift shifts in opposite directions [4]. The fluctuation propagation of the inner side of plasma is in the electron diamagnetic drift direction.

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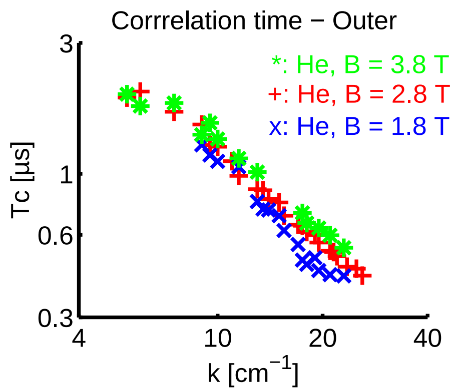
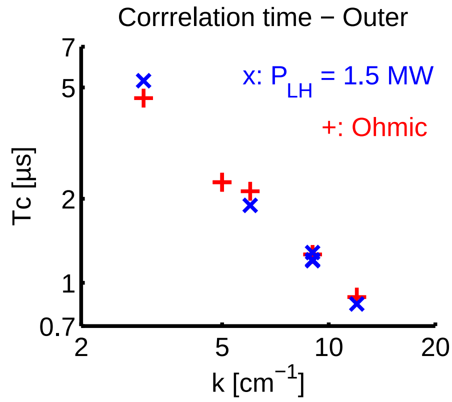
Using complex filtering which differentiates frequency signs, it is possible to extract from the signal the part corresponding to each side of poloidal velocity inversion radius. Contributions coming from both parts (referred to inner and outer part) can be separately studied. For each separated signal, poloidal velocities are estimated by the phase derivative [6].

Density fluctuation correlation time

Density fluctuation level time evolution is given by the signal modulus separately for inner and outer side. The density fluctuation correlation time that we consider here, is the time width of the ALTAIR signal modulus selfcorrelation function.



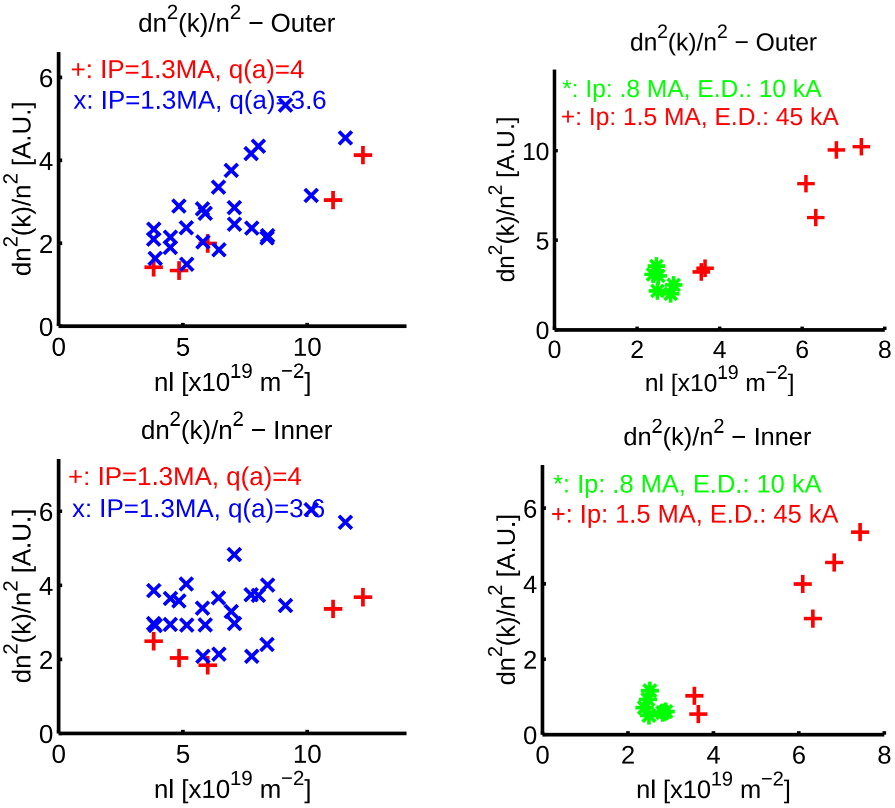


This density fluctuation correlation time is first related to the observed scale. The above left plot shows how correlation time varies with scattering wavenumber. Shots are ohmic discharges with helium gas for various toroidal magnetic field between 1.8 and 3.8T. The correlation time decreases almost like a k^{-1} scaling law. This behavior was found to be the same in gas turbulence flows [7]. For comparable experiments, but with a twice larger wavenumber resolution dk, right plot shows close time values for same k: The resolution has no effect. A basic description of this phenomenon is given by Kolmogorov theory: This correlation is characteristic of turbulence structure lifetime at the observed scale. Structures at a specific scale in the inertial range are stretched to a twice smaller size structure. The time for this process is larger for larger scale structures. The resolution insensitivity shows this process is not a smooth variation with scale, but discrete jumps in scale space.

Turbulence strengthening when plasma density rise

Density ramp up have been made, reaching high densities (between 3 and $12.10^{19} m^{-3}$). Two sets of experiments are considered: either helium ohmic discharges with limiter configuration, or deuterium ohmic discharge with ergodic divertor. For most of discharges, plasma current is around 1.5 MA. Density scans are progressively done during the shot. The scattering wavenumber is 12 cm^{-1} for helium discharges, 10 cm^{-1} for deuterium.

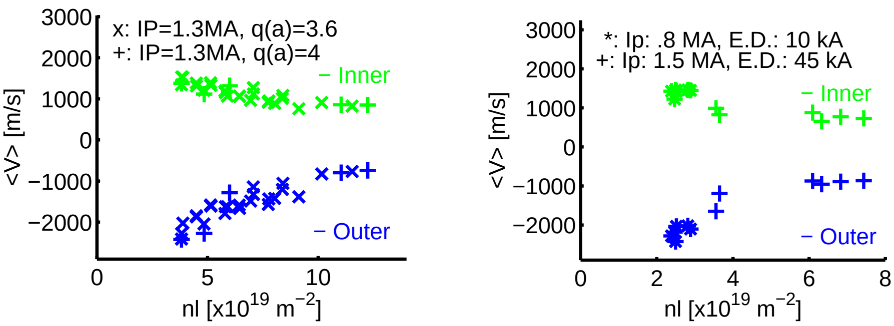
Relative density fluctuations rate dn^2/n^2 is estimated using ALTAIR signal level $dn(k)^2$ as numerator, and square lineic density n_l^2 as denominator.



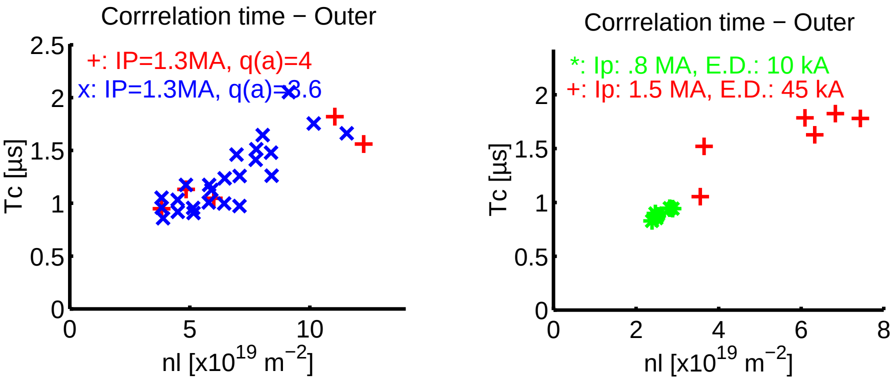
These 4 plots show an increase of the relative density fluctuation for both sets of experiments, for helium and limiter configuration (left), and for deuterium with ergodic divertor (right). Upper plots consider the outer region, lower plots, the inner one. For limiter shots, turbulence rise is only significant for the outer side.

These results are coherent with probes measurements done on the experiments with ergodic divertor. The relative fluctuation level of the ion saturation current for movable Langmuir probe plunges inside the plasma has been studied. Larger relative saturation current level is found for higher densities. Energy confinement time has also been estimated from energy balance calculations. The confinement is found to follow the L-mode scaling in its saturation phase at high density.

Velocity shear reduction and correlation time increase



The above figure shows velocities for inner and outer side in the plasma edge region. Left plot corresponds to helium ohmic discharges, right plot, to deuterium ohmic discharges. For each plot, the positive velocity corresponds to the inner side velocity. The negative one, corresponds to the outer side. For both sets of experiments, we observe velocity shear between both sides is reduced when density increases, either with and without ergodic divertor.



Further information on turbulence is given by the correlation time. The above figure shows correlation time variation with plasma density for helium (left) and for deuterium with ergodic divertor (right). These plots correspond to the outer side of velocity shear inversion radius. The results for the inner side show the same behavior.

This common behavior of turbulence level, correlation time and velocity shear is coherent with basic theoretical model based on shear effect [3]. When velocity shear is high at the edge of the plasma, the distortion of growing instabilities at the edge is more efficient. The correlation time is then shorter: structures are destroyed faster. So the instabilities are not enough growing to enhance the turbulence in the edge region. Since we measure directly the velocity shear and not only the electric field shear, the relation between shear and turbulence is even closer.

Velocity shear behavior with high density is not clarified. Formerly, velocity shear reduction was observed when ergodic divertor is turned on. This effect was linked to the modification of the radial electric field at the edge by the divertor. But there is no clear effect of density on radial profiles. In the case of density regimes, pressure gradient may also play a role through diamagnetic velocity change. These questions have to be thoroughly studied.

Conclusion

The turbulence enhancement with plasma density for ohmic shots with and without ergodic divertor is observed. The relation between turbulence rising, velocity shear reduction and correlation time extension are coherent with similar observations. Turbulence strengthening and shear reduction at high density have to be understood.

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