SMALL SCALE DENSITY FLUCTUATIONS IN TORE SUPRA: RUPTURE IN THE SCALING LAW

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1. Introduction

Energy confinement is one of the main issues in tokamaks. Indeed, the energy transport is much larger than the one predicted by neoclassical theory and it has to be understood in order to be able to control the confinement. Anomalous transport could be explained by plasma turbulence. But what is the nature of this turbulence?

The ALTAIR diagnostic was built to observe turbulence on TORE SUPRA. This diagnostic is based on coherent forward scattering from an infrared CO_2 laser. The scattering signal is proportional to the density fluctuations at the scale corresponding to the scattering wavevector. The observed scale is around 1 cm, corresponding to turbulent scale range. This diagnostic is original because of its good wavelength resolution. It is then adapted for scale studies, like the density fluctuation k-spectrum.

Former experiments [1] were done in the 3 to 15 cm^{-1} wavenumber range. It was shown that above 6 cm^{-1}, the density k-spectrum shows a k^{-3} dependence.

The goal of this work was to pursue this study for larger k's, closer to the wavevectors range of backscattering diagnostic. Before showing these results, we introduce the ALTAIR diagnostic which is modified to be able to reach larger k's.

2. ALTAIR modified for larger k exploration

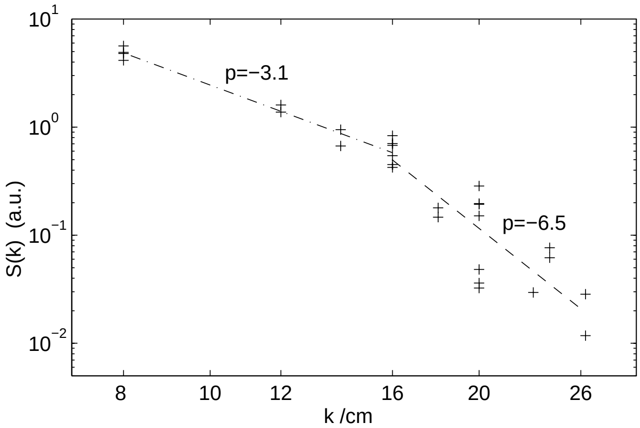
Detailed description of the ALTAIR diagnostic and its implementation on the TORE SUPRA tokamak is given by A. Truc et al [3].

This device is based on coherent Thomson scattering. The probing beam is generated by a CO_2 laser ($\lambda = 10.6\mu m$). Heterodyne detection is used to keep the whole scattering information (modulus and phase of spatial Fourier transform of electronic density). ALTAIR offers 2 scattering channels at two independent wavevectors: the probing beam is equally divided in 2, frequency shifted beams. The scattering volume will be almost the same for both channels.

In order to reach k wavenumbers around 10 cm^{-1}, the scattering angles are very small (at the order of 1 mrad). The probing and reference beams are then almost overlaid along a vertical chord in a poloidal plane of TORE SUPRA. The scattering wavevectors could be oriented in any direction perpendicular to this chord. Because the scattering angle is small, the scattering volume is the whole chord. Nevertheless partial vertical localization is possible since we know density fluctuations are mainly perpendicular to magnetic lines: signal is coming from where scattering wavevector is perpendicular to magnetic lines. The vertical localization will be function of the wavevector angular resolution and the magnetic field orientation profile along the chord. Typically, the scattering volume could be reduced to a fourth of the plasma diameter.

In order to reach shorter scales (larger k's), ALTAIR is slightly modified in order to increase scattering angles. With the new configuration, for one scattering channel the wavenumbers can be chosen between 5.5 and 26 cm^{-1}. The second channel will be used as a scattering intensity reference to compensate diagnostic time deviations (like laser power). Its scattering wavenumber is fixed at 8 cm^{-1}. With this modification, for the same k value, the k resolution is now twice larger.

3. Density fluctuation k-scaling law



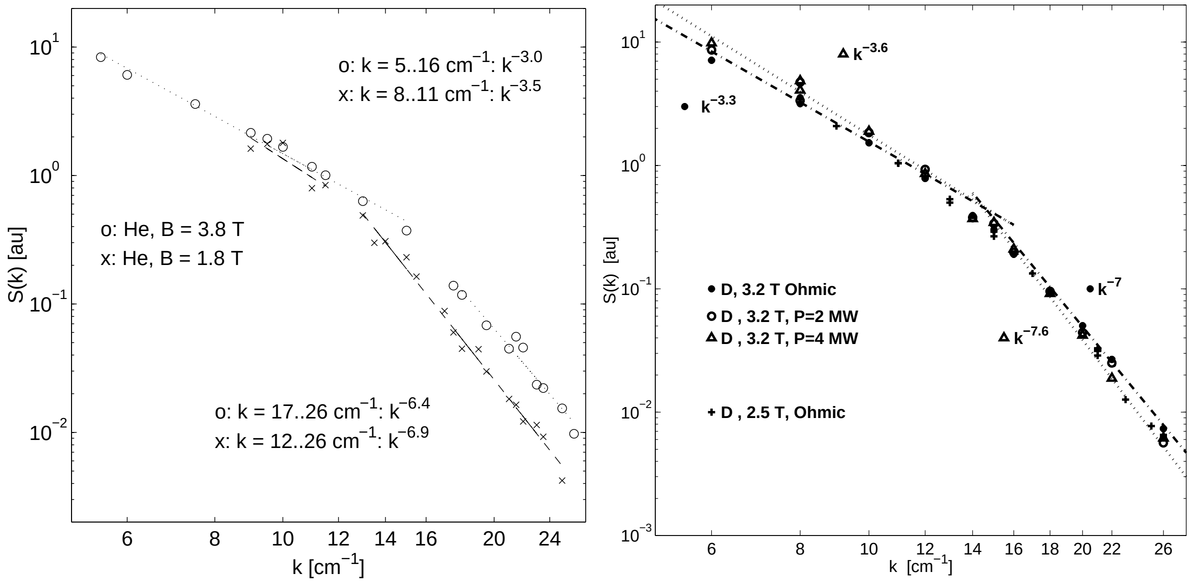
A first fluctuation k-spectrum was obtained on an ohmic plasma: if the beside figure confirms previous observations below 15 cm^{-1}, we notice also that the intensity decreases with a larger slope after 15 cm^{-1}. What is the physical origin of this transition? Further experiments with different plasma conditions (to change typical plasma scales) were necessary to identify this effect.

Experiments are mostly done on simple reproducible ohmic plasmas. Several identical plasma shots are required to explore the whole k range. Two experiment sessions are then considered: the first with deuterium, the second mostly with helium (and a few shots with deuterium). The mean density is around 3x10^{19} m^{-3}. For each gas, experiment sets are done with three different toroidal magnetic fields, (1.8, 2.8 and 3.8 T for helium, 2.5, 3.2 and 3.8 T for deuterium). The plasma current is determined in order to keep the security factor at the value of 3.5 near the edge of the plasma. The magnetic field line orientation profile is then always the same along ALTAIR chord. We fixed the wavevector orientation in order to observe the plasma gradient and edge lower zones for both scattering channels. For the deuterium experiment session only, the plasma has first an ohmic phase, and then additional heating is turned on (mostly at ionic cyclotronic frequency). Some shots are done in presence of the ergodic divertor. For helium, shots are purely ohmic.

The figures hereunder show density fluctuations k-spectrum for the explored tokamak plasma conditions. The left one is for helium with different magnetic fields. The second figure shows results for deuterium with different additional heating powers.

Every experiment confirms former observations: below 14 cm^{-1}, density fluctuations scale as $k^{-3\pm0.2}$. For our experiments, this slope is slightly larger. This may be explained by the modification made on ALTAIR: the k resolution is twice larger for the new configuration. Simulations on resolution effects showed this could increase the slope to -3.5, due to a larger k integration.

Above this k value, the new slope is found to be inbetween -6.4 (Helium, B=3.8T) and -7.2 (Helium, B=1.8T) and even -7.8 (Deuterium, B=3.2T, 4MW additional power). The intensity decreases faster for smaller toroidal magnetic field, or in presence of additional heating. The localization variation with k could not explain such a transition.

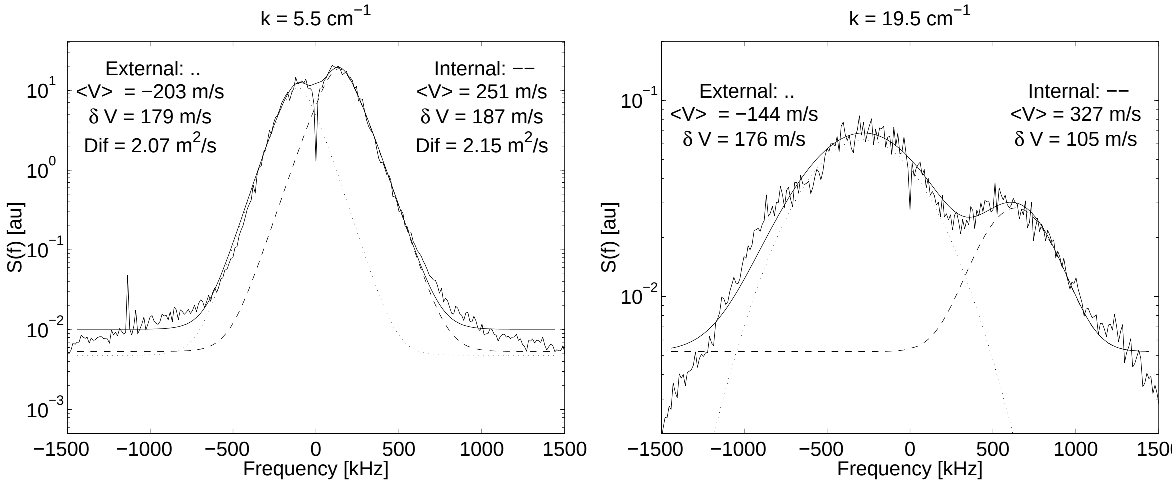


The k value at the transition is interesting to evaluate since it should correspond to a plasma characteristic scale. Unfortunately, the transition is too smooth and the results are too noisy to obtain a precise k value.

However, we notice that this transition k is around 15 cm^{-1} for large magnetic field (2.5 to 3.8 T), but around 12 cm^{-1}, for 1.8 T. Those values are of the same order in deuterium and helium.

The only main plasma parameter close to this value is the ion larmor radius: its value is around twice the scale corresponding to this k transition. If the variation with magnetic field would be in good agreement with the observation, the k transition value should also decrease when we replace helium with deuterium.

4. The scattering signal frequency spectrum



In addition to density fluctuations intensity, signal frequency spectrum shows a different behavior for k values larger than 15 cm^{-1} compared to smaller k values.

The scattering signal frequency spectrum is due to Doppler effect on plasma movement.

The spectrum shows two peaks, one in positive frequencies range, the other in negative one. The first one corresponds to the internal part of plasma where propagation is in the electronic diamagnetic drift direction. The later corresponds to the external part, beyond the radial electric field inversion point.

The form of each peak depends on the comparison between the scattering scale and the movement typical correlation scale: if the scattering one is the smaller, the scattering sees a convection like movement, the peak form gives the velocity distribution form, which is gaussian. When the scattering scale is larger, the scattering sees a diffusion like movement and the peak has a lorenzian form from which a diffusion coefficient can be calculated [2]. Inbetween these two cases, it is possible to evaluate a intermediate form, when scales are of the same order.

The figures show frequency spectra for 5.5 and 19.5 cm^{-1}, below and above the transition scale, for the same plasma condition: the gas is helium and the toroidal magnetic field is 3.8T. There is no additional heating.

For the larger scale (left figure), we observed the best fit is obtained with intermediate curves: it is possible to evaluate the velocity standard deviation and the diffusion coefficient at the same time: the later is around 2 m^2/s, in agreement with heat diffusion coefficient. The scattering scale is still larger than the movement scale.

For shorter scales, (right figure), the behavior is different. The form is not lorenzian like anymore. The best fit is obtained with gaussian functions. No diffusion coefficient could be get.

This behavior modification shows there is plasma movement specific scale inside the explored scale range.

5. Conclusion

ALTAIR modification gives us the opportunity to explore a new range of coherent scattering wavelengths. In this range, scattering signal is significantly different from shorter wavenumbers: the density fluctuations k-spectrum shows a larger decreasing slope. The scattering signal frequency spectrum for larger k's is different from small ones. We may think there is a characteristic turbulent movement scale inside this range, but our observations are not sufficient to discriminate a specific scale of the plasma. Could it be the ion larmor radius or any other characteristic scale? What is the difference between the turbulence below and over this transition? Further experiments are required to obtain a more detailed description of this phenomenon.

References

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