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RELATIONSHIP BETWEEN CONFINEMENT AND CORE PLASMA FLUCTUATIONS IN THE W7-AS STELLARATOR

S.Zoletnik[1], M.Saffman[2], N.P.Basse[2,3], W.Svendsen[2,3], G.Kocsis[4], M.Endler[5]

[1] *CAT-SCIENCE Bt. Detrekő u. 1/b H-1022 Budapest, Hungary*
[2] *Risø National Laboratory, DK-4000 Roskilde, Denmark*
[3] *Niels Bohr Institute, DK-2100 Copenhagen, Denmark*
[4] *KFKI-RMKI P.O.Box 49 H-1525 Budapest, Hungary*
[5] *Institut für Plasmaphysik, D-85748 Garching, Germany*

1. Introduction

Anomalous transport remains a Gordian knot in fusion plasma physics. Fluctuations in plasma parameters due to turbulence is believed to be the primary cause of this anomaly, leading to energy and particle losses far greater than those expected from neoclassical transport theory. In this paper, density fluctuations during confinement changes are studied.

For measurements of density fluctuations in the core plasma of W7-AS a two channel CO_2 laser scattering system has been developed. It allows correlation of the signals from two parallel measurement volumes with a transverse separation d of several cm's. The analysing wave-vector κ is directed along the major radius and identical for each volume. The optical system has been designed to allow the relative position of the two measurement volumes to be rotated. Measurements were made with the laser beams propagating through the plasma along vertical chords.

In the plasma core scattering of laser radiation has been used widely for turbulence measurements, [1]. The main drawback is that the spatial resolution along the direction of propagation of the beam is limited. Fluctuations with wavenumber κ and spatial scale $\Lambda = 2\pi/\kappa$ scatter radiation at a small angle $\theta_s = \lambda/\Lambda = \kappa/k$, where $k = 2\pi/\lambda$ is the wavenumber of the laser radiation. The characteristic axial resolution along the laser beam is then given by $L = 4w/\theta_s$. Even for relatively large wavenumbers, say $\kappa \sim 50$ cm^{-1}, $\lambda = 10.6$ μm, and beam waist $w = 0.5$ cm we find $L \sim 2.4$ m which is longer than the size of the plasma. The measurements reported here thus represent an integration along a chord passing through the plasma volume. The product of the cross sectional area $A = \pi w^2$ and the integration length L defines the measurement volume which takes the form of a thin, elongated cylinder.

2. Density fluctuation κ-scaling law

We analyse two wavenumber scan experiments. In each of these, a series of similar shots were made where κ was changed from shot to shot. The results indicate a change in the power law scaling of the turbulence spectral density with κ at a characteristic wavenumber. Similar findings were reported recently from TORE SUPRA, [2].

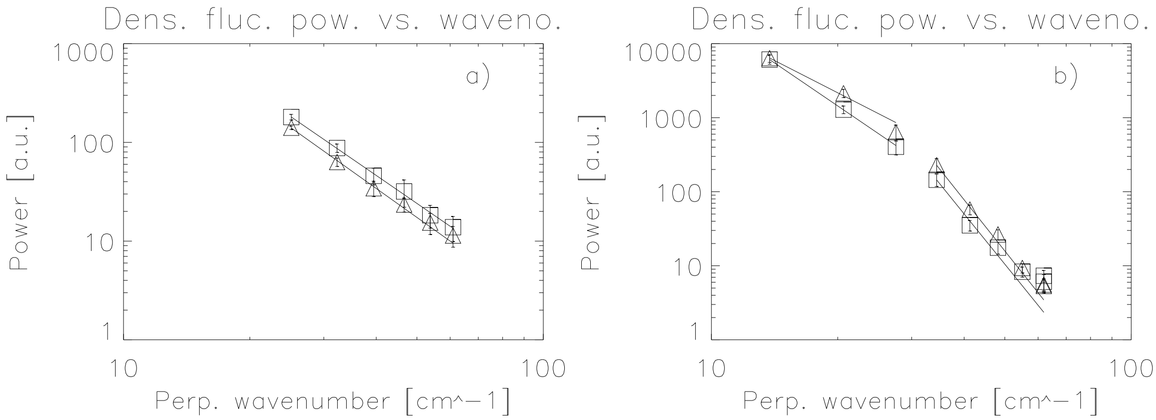

Fig. 1. a) Scattered power at 100 kHz vs. wavenumber for first scan, b): Second scan. The frequency resolution was 10 kHz. Data points from channels 1/2 are marked with triangles/squares, respectively. Fits to the data are drawn as solid lines.

The first series consisted of Hydrogen limiter plasmas with $\iota = 0.344$ at good confinement, see *Fig. 1* a). The discharges were with 450 kW of ECRH heating and a toroidal magnetic field of 2.5T. The line averaged density was kept at 8×10^{19} m^{-3}. The plotted fluctuation power is measured at 100 kHz and averaged over 200 ms, where the plasma was stationary.

The second scan was done in transient separatrix limited Deuterium shots, $\iota = 0.563$, 2.5 MW of NBI heating, 2.5 T field and rising line averaged density, ending at 2.2×10^{20} m^{-3}, see *Fig. 1* b). As the plasmas were short-lived, we have averaged the fluctuation power over 50 ms where the plasmas were quasi-stable. The average ion temperature for both scans was 500 eV (from charge exchange measurements). This leads to Larmor radii of 1.3 mm (48 cm^{-1}) and 1.8 mm (34 cm^{-1}), respectively.

Fits to the data were calculated, assuming that the fluctuation power scales as κ^{-m}, with m to be determined. For both scans the scaling exponent at small wavenumbers is close to 3 ($m = 3.0$ and 2.9 for channels 1 and 2 in the first scan and $m = 2.9$ and 3.9 for channels 1 and 2 in the second scan). It is generally seen that the slope of the scaling decreases with increasing frequency.

Studying *Fig. 1* b), the slope of the scaling changes at around 30 cm^{-1}. Above the transition wavenumber the exponent was found to be $m = 7.1$ and $m = 7.0$ in the two channels. This transition should correspond to a characteristic scale length of the plasma. Indeed 30 cm^{-1} is quite close to the equivalent ion Larmor radius for the discharges. The transition is observed at all times during the shots; therefore it can not be attributed to different time dependent κ-spectra being added. No transition is seen in *Fig. 1* a). In those discharges the expected transition is around 48 cm^{-1}, where the signal is small.

The transition scale observed in TORE SUPRA is about half the size of the ion Larmor radius.

3. Change in fluctuation during induced confinement change

Around certain values of the edge rotational transform the plasma confinement properties of the W7-AS stellarator depend strongly on the edge rotational transform and magnetic shear, [3]. These parameters can be affected by an ohmic current in the plasma,

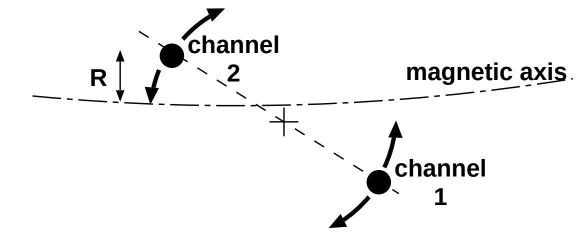

Fig. 2. Top view of the measurement geometry for rotation of the two measurement volumes.

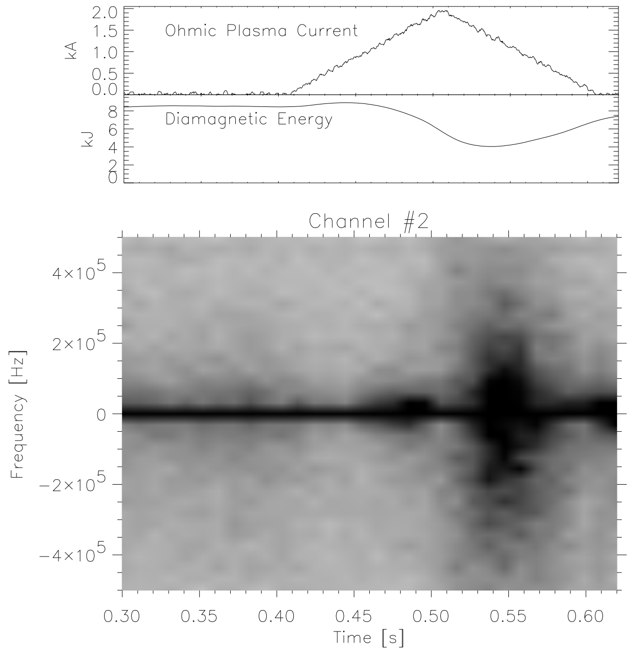

Fig. 3. Change in scattered light power spectrum and plasma energy during a current ramp in the plasma. The power scale is linear (shot 47192, κ = 20 cm^{-1}).

thus a series of identical discharges were analysed in which a confinement change was induced by driving a 2 kA ohmic toroidal current in the plasma. The two vertical measurement volumes were rotated shot-by-shot around a vertical axis situated between the two volumes and close to the plasma magnetic axis (see *Fig. 2*). The experiment was performed for $\kappa = 20$ and 30 cm^{-1}.

As the plasma toroidally is nearly identical over the few cm separation between the two measurement volumes, the major effect of the rotation is a radial movement of the measurement chords. The change in power spectrum of the scattered laser light as a function of time and volume radial position was analysed. The time evolution of a typical power spectrum close to the magnetic axis is shown in *Fig. 3.* with the plasma diamagnetically measured energy content and the ohmic plasma current. The drop in total diamagnetic energy is clearly accompanied by a substantial increase of the scattered laser power, especially at low frequencies. The spectrum remains symmetric, i.e., waves propagating in opposite directions appear with the same amplitude. This behaviour is seen in all measurements when the measurement volume is close to the plasma magnetic axis. The picture changes if one moves further away. To demonstrate how sensitively the change depends on the position of the measurement chord the results of the shot series at $\kappa = 20$ cm^{-1} are summarized in *Fig. 4.* This plot depicts the relative change of the scattered power integrated in a frequency band compared to a time window before the plasma current ramp. Surprisingly the increase in the scattered power is present only in an 8 mm wide radial range. Outside of this there is a decrease in the power nearly immediately after the plasma current drive begins. Repeating the experiment at $\kappa = 30$ cm^{-1} one can only detect the decrease at all radial positions.

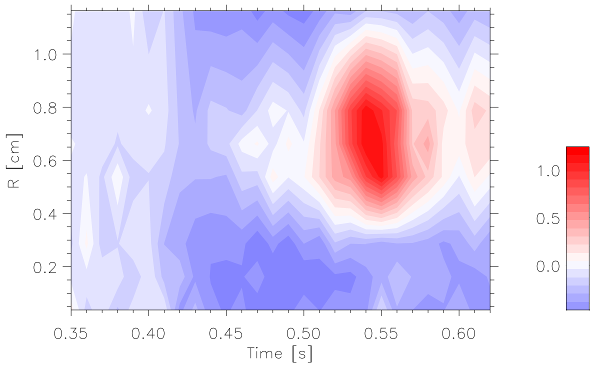

Fig. 4. Time evolution of the relative change in the scattered laser power at different radial measurement volume positions. The power displayed is in the 50-100 kHz frequency band. The reference power level is the 0.35-0.4 s time window.

The comparison of the fluctuation power spectrum change to the diamagnetic energy signal on *Fig. 3.* suggests that there are two phenomena acting during the current ramp. The immediate drop in the wideband turbulence (0.41 s) is correlated with a slight increase in the energy content. At the same time both plasma edge H_α radiation intensity and the feedback controlled gas puff rate drop indicating an improvement in particle confinement. As soon as the increase at $\kappa = 20$ cm^{-1} sets in (0.5 s), the plasma diagnostic signals respond with a reversed and much stronger change: The diamagnetic energy drops by a factor of two, the gas puff rate needed for the same line density increases by a factor of 3 and edge H_α radiation increases. All these signatures hint at a connection between the density fluctuations and the confinement quality.

The strongly limited extension in real- and wavenumber space of the fluctuation increase during the confinement change is not understood at present. A possible explanation could be formulated by assuming that the waves which cause it are propagating purely poloidally and have a narrow extent in κ space. By shifting the measurement volume radially one changes the angle between the poloidal and the analysing wavenumber. This results in a shift of the wavenumber range in which the device is sensitive. If the fluctuations were present at the plasma edge the change would be negligible over a radial shift of 0.5 cm. Consequently, these fluctuations should either have a poloidally highly asymmetric distribution localized around the upper and lower plasma edges or be confined to a small region in the plasma center. For this latter case rough estimates indicate a maximum radial extent of 1-2 cm.

It should be noted that strong localized fluctuations with similar characteristics were seen on the TEXT tokamak, [4]. In that case the fluctuations were confined to a narrow region around the inner part of the equatorial plane, had a frequency of 200-400 kHz and were limited to $\kappa = 6 - 8$ cm^{-1}.

In contrast to the localized nature of the fluctuation increase, the drop in the wideband turbulence at the start of plasma current ramp is less localized in space, κ and frequency; thus it is probably independent of the first phenomenon.

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