PARAMETER DEPENDENCIES OF TEMPERATURE FLUCTUATIONS AND THEIR CORRELATION WITH DENSITY FLUCTUATIONS IN W7-AS

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Abstract

Electron temperature fluctuations down to a level of 0.1% can be measured with correlation radiometry of the electron cyclotron emission. The fluctuation spectra found can be characterized by two different components below and above about 10 kHz, propagating into different radial directions with strongly differing phase velocities. The high frequency component disappears under grad $T_e = 0$ conditions and is in-phase correlated with density fluctuations. The behaviour might qualitatively be understood in the frame of convective micro-turbulence. Parameter scans of density, temperature and the gradients of these quantities show that the "universal dependency" is on the local temperature: the temperature fluctuations normalized to the local temperature gradient decrease with increasing temperature.

1. Introduction

The radial electron heat transport is assumed to be driven in part by fluctuations of density, electric field, temperature and magnetic field. Temperature fluctuations at the plasma edge can be measured using probes. Correlation radiometry of the electron cyclotron emission (ECE) has made the measurement in the plasma core possible [1,2,3]. The sensitivity of a single ECE radiometer channel to temperature fluctuations is limited by the inherent thermal noise (wave noise) of the blackbody emission. The method developed at W7-AS [1,5] makes use of a pair of identical multichannel radiometers viewing the same plasma volume with two Gaussian beams symmetric to the horizontal midplane of W7-AS. Due to the observation along different lines of sight, the thermal noise decorrelates. The relative sensitivity to temperature fluctuations reached is about 0.1. The beam waist of a single sightline is about 2 cm. The resulting sensitivity to poloidal wavenumbers is limited to $k_\theta < 3.5$ cm^{-1}. The radial resolution is typically 0.5 cm, the temporal resolution about 1 MHz. The resolutions are sufficient to study the fluctuations in more detail.

2. Parameter dependencies

The temperature fluctuation spectra consist of two components with different physical properties [4]. A strong component below about 10 kHz propagating inward and a broad component extending into the 100 kHz range propagating outward. The turbulent high frequency component is assumed to be the one which might be transport relevant. A quantitative analysis of transport is not possible due to the lack of information about the poloidal electric field fluctuations and their phase relation to the temperature fluctuations. However as a first attempt, parameter studies of the temperature fluctuation level have been carried out as the electron heat diffusivity shows characteristic dependencies. In a series of discharges the radial fluctuation level, i.e. the square root of the relative spectral fluctuation power integrated over the frequency range 20-60 kHz, at 6 radial positions on the high field side of the temperature profile (see Fig. 1) has been investigated for dependencies on discharge parameters.

Broad flat temperature profiles can be conducted in W7-AS by using off-axis power deposition of the ECRH. In this case the temperature gradient vanishes in the radial observation region and fluctuations above 20 kHz disappear completely [4,6]. The low frequency component is unaffected by this measure.

The disappearance of the high frequency component would be expected if a turbulent mixing process is assumed which exchanges plasma volumes on the scale of a mixing length. In this case the turbulence, which itself might depend on local parameters, would only be observable by a temperature diagnostic through a finite temperature gradient. Density fluctuations in the observation region are not significantly affected by the flattening of the temperature profile. Assuming this process, for all parameter studies the local fluctuation level has therefore been divided by the local temperature gradient.

Because of the clear dependence of energy confinement time on heating power, the fluctuation level has been measured as a function of ECRH power in the range of 290 to 830 kW. As found already earlier [7], the fluctuation level decreases with increasing heating power. This result is in clear contradiction assuming a direct connection between transport and fluctuation level. From drift-wave calculations an increase of the normalized temperature fluctuations with the square root of T_e is expected [8]. The power scan results in a local temperature variation of 700 to 2000 eV. Again the experiments are in contradiction to the expectations. The fluctuations decrease with T_e^{α}, with $\alpha = -3/2$ as shown in Fig. 1.

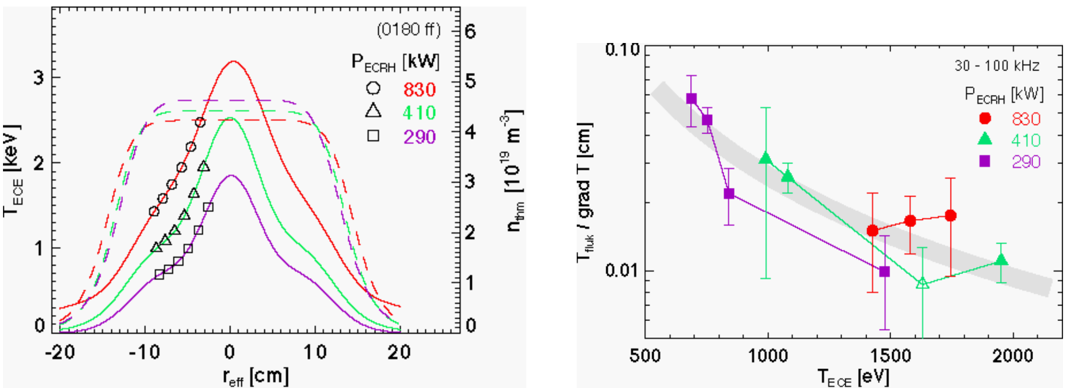

Fig. 1. Temperature (solid lines) and density (dashed lines) profiles for 3 different ECRH heating powers. Temperature fluctuation measurements are conducted in the gradient region of the high field side as indicated in the temperature profiles (left figure). The rms-value of the high frequency component of the fluctuations normalized to the local temperature gradient is decreasing with increasing local temperature.

Plasma turbulence depends on the electron density. With reflectometry measurements a decrease of the density fluctuations with increasing density is observed. A density scan in the frame of the temperature fluctuation studies has been conducted at constant heating power of 450 kW. The relative temperature fluctuation level decreases with increasing density. Because of constant heating power, besides the density profile, the temperature profile changes as well.

Various combinations of the local quantities, temperature and density. i.e. pressure, pressure gradient and collision frequency were tested to look for dependencies of the local fluctuation level. No clear correlation could be found. As before, the only dependency found is the temperature dependency as given in Fig. 3 (left).

Higher densities lead to a stronger decrease of the fluctuation level with electron temperature.

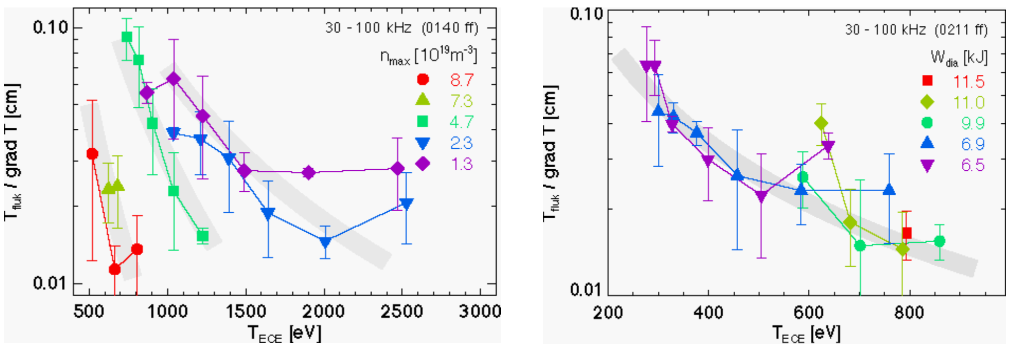

Fig. 2. The figures give the variation of the normalized temperature fluctuations as a function of the local electron temperature. Increasing the electron density from 1.3 to 8.7 $10^{19}m^{-3}$ increases the exponent of the T_e-dependence from -2 at low to -3.5 at high density (left figure).The right figure summarizes the results of a scan of the edge rotational transform between 0.34 and 0.365. Under constant heating conditions the temperature profile varies while the density profile is almost constant with a peak density of 8 10^{19} m^{-3}. The total stored energy varies from 6.5 to 11.5 kJ. The fluctuations can be described by a "universal" dependence like $T_e^{-1.2}$.

In W7-AS the confinement strongly depends on the edge value of the rotational transform. The total stored energy can vary by a factor of two and more under otherwise constant conditions of heating power and density. It is found that the lowest fluctuation level is found for plasmas with highest confinement. This might be a hint pointing to a connection between turbulence and transport. Unfortunately the profile of the rotational transform is not sufficiently known to plot the local fluctuation levels measured against local values of the rotational transform. The experiments are therefore interpreted as a variation of the local temperature under constant density conditions. As in the power scan, all measured fluctuation levels decrease with temperature in the same way as found in the power scan (Fig. 3 right).

The search for parameter dependencies is connected with the question whether local or non-local parameters determine the turbulence and the confinement. This question cannot be answered finally. But it seems that the possibility to sort the measurements by temperature and temperature gradient, points to local plasma parameters. Summarizing all scans, it is supposed that the temperature fluctuations can possibly be described by a general law, which might besides the temperature and density profiles be determined also by their gradient lengths and other parameters characterizing the magnetic configuration and local shear etc.:

$$\tilde{T}_e = \nabla T_e \cdot \tilde{\Lambda}(T_e, n_e, L_T, L_n, \ldots), \quad \tilde{\Lambda} \propto 1/T_e^{\alpha}, \quad 1 \le \alpha \le 3.5$$

However, besides the dependencies described, no other ones have been found. The temperature dependency might be caused by increasing parallel heat exchange with increasing temperature.

3. Correlations with density fluctuations

In a combined experiment of correlation radiometry and reflectometry where both diagnostics share the same lines of sight, correlations between density fluctuations and temperature fluctuations have been found. The correlations are in-phase and are observed only for the high frequency turbulent component of the temperature fluctuations (Figs. 3) and are only found under conditions where both diagnostics view the same plasma volume, as has been verified on a shot-to-shot basis by shifting the reflectometry postion along the density gradient. The maximum coherence found is about 0.3, probably due to the well-known fact, that not all phase fluctuations seen by the reflectometer are caused by density fluctuations. The correlation rapidly deacrease with increasing distance between the observation volumes of reflectometry and ECE. The in-phase correlations of temperature and density fluctuations confirm the assumption of convective turbulence: inward convection increases both temperature and density and vice versa, respectively [9].

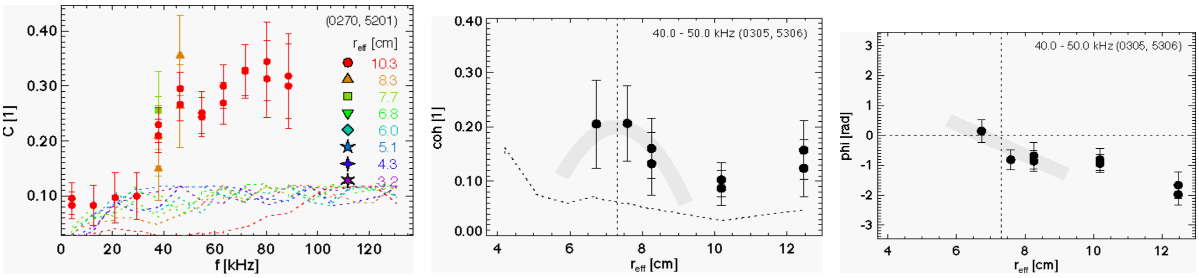

Fig. 3. Results as obtained with the combined reflectometer correlation radiometer experiment. Correlation between density and temperature fluctuations are found only for the high frequency component of the temperature fluctuations above about 30 kHz (left figure). The correlations are maximum if the radiometer and the reflectometer are viewing the same plasma volume and decrease rapidly with increasing distance (central figure). In the common volume the density and the temperature fluctuations are in phase. The phase change with distance reflects their radial propagation (right figure).

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