Measurement of turbulent electron temperature fluctuations on the ASDEX Upgrade tokamak using correlated Electron Cyclotron Emission

S.J. Freethy[1,2], G.D. Conway[1], I. Classen[3], A.J. Creely[2], T. Happel[1], B. Vanovac[3], A.E. White[2], ASDEX Upgrade Team[1]

[1] *Max Plank Institute for Plasma Physics, 85748 Garching, Germany*

[2] *Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

[3] *FOM Institute DIFFER, 5612 AJ Eindhoven, The Netherlands*

Much progress has been made over the past few decades in understanding and modelling the underlying turbulent mechanisms and gyro-kinetic modelling codes are now often able to reproduce experimental heat fluxes within error bars (see for example [1, 2]). Validation of non-linear gyrokinetic code predictions against measurements of the underlying turbulent micro-structure, such as fluctuation amplitude, correlation length, fluctuation phase relations and spectral index, can serve to help refine and reduce turbulent transport models further.

For the measurement of turbulent electron temperature fluctuations a Correlation Electron Cyclotron Emission (CECE) radiometer is used [3, 4, 5, 6, 7]. Recently, a specral decorrelation type CECE radiometer has been developed for ASDEX Upgrade [8]. In this paper, we cover the transport analysis and progress towards Gyrokinetic validation using measurements taken with this radiometer.

CECE is sensitive to comparatively long wavelength fluctuations relevant for studying Ion Temperature Gradient (ITG) and Trapped Electron Mode (TEM) turbulence. The calculation of the sensitivity of the diagnostic as a function of wavelength is described by Bravenec [9] and is completely defined by the spatial volume of the measurement in the plasma. For CECE the radial resolution is set by a combination of the broadening mechanisms for the ECE line radiation (predominantly the relativistic mass change as a function of electron energy and the re-absorption of the ECE radiation by the plasma [10]) and the filter bandwidth and spacing. For the current setup, the perpendicular wavenumber limit $k_{\perp,\mathrm{lim}} = 2\sqrt{2}/w_{\mathrm{meas}}$ is 0.76 cm^{-1}. w_{meas} will be reduced from 3.7 cm to 2.0 cm in the next experimental campaign with the installation of a new focussing mirror, giving an increased $k_{\perp,\mathrm{lim}}$ limit of 1.4 cm^{-1}.

We present here measurements of broadband temperature fluctuations that were made in two Helium plasmas with magnetic field of 2.5 T, plasma current of 800 kA, core line-averaged density of 2.1×10^{19} m^{-3} and 4.6×10^{19} m^{-3} respectively, 0.52 MW of Ohmic heating and 0.67 MW of Electron Cyclotron Resonance Heating. This is the first time that core electron temper-

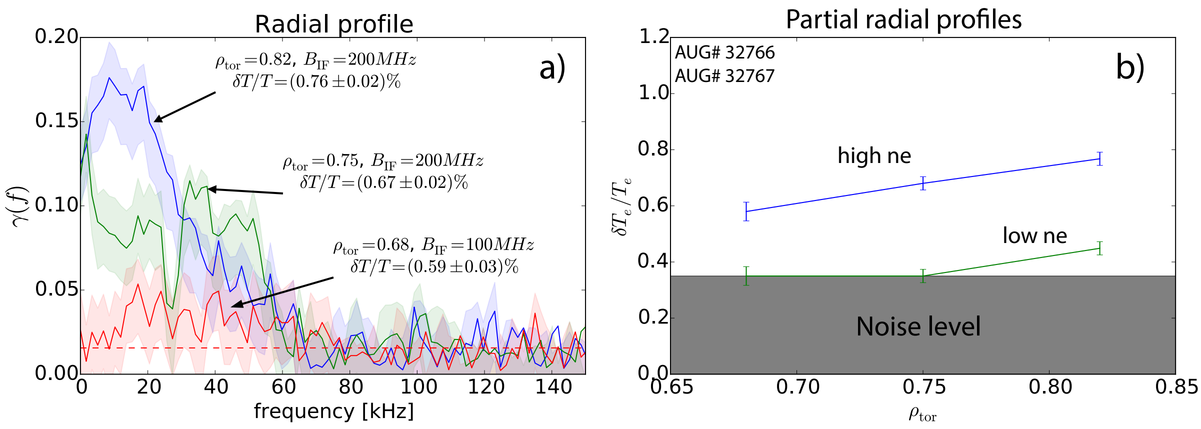

Figure 1: a) Three coherence spectra corresponding to braodband temperature fluctuation at three radii. The relative fluctuation amplitude is proportional to the integral. b) Partial radial profiles for plasmas of two densities. The higher density plasma has nearly a factor of 2 smaller fluctuation amplitude in this wavenumber range.

ature fluctuations have been measured in Helium tokamak plasma discharges, and comparisons with measurements typically made in Deuterium are important. ITER will initially run "non-nuclear" fuel plasmas, Helium, with a mix of Hydrogen and/or Deuterium, and understanding turbulent transport and predicting turbulent transport in all phases of ITER operations is of great interest.

Fig. 1 a) shows a radial profile of temperature fluctuations for AUG shot 32766. The magnitude of the coherence $\gamma(f)$ [11] is shown for three channel pairings. The integrated fluctuation levels are $\delta T/T = (0.76 \pm 0.02)\,\%$, $(0.67 \pm 0.02)\,\%$ and $(0.59 \pm 0.03)\,\%$ up to 100 kHz and at normalised toroidal flux radius of ρ_{tor} = 0.82, 0.75 and 0.68 respectively. The statistical noise limit, $1/\sqrt{N}$, is shown as a horizontal red dashed line. Figure b) shows partial profiles for plasmas of two densities. $\delta T_e/T_e$ goes down by 37 % in the higher density plasma in the outer channel, whereas the inner two channels are unable to distinguish the fluctuations from the noise.

For CECE measurements to be representative of temperature fluctuations the plasma must be sufficiently optically thick such that fluctuations in density do not lead to significant fluctuations in the measured radiation temperature. A discussion on the effect of optical depth on the measurement of temperature fluctuations can be found in Peters [12]. For our three measurement pairs, in the low density case, at ρ_{tor} = 0.82, 0.75, and 0.68 the optical depths are 3.0, 4.1 and 5.4 respectively. This is considered optically thick for our application.

Transport and power balance analysis for this pair of plasmas has been performed using the TRANSP code. Fig. 2 shows selected results from this analysis. Top left shows the electron den-

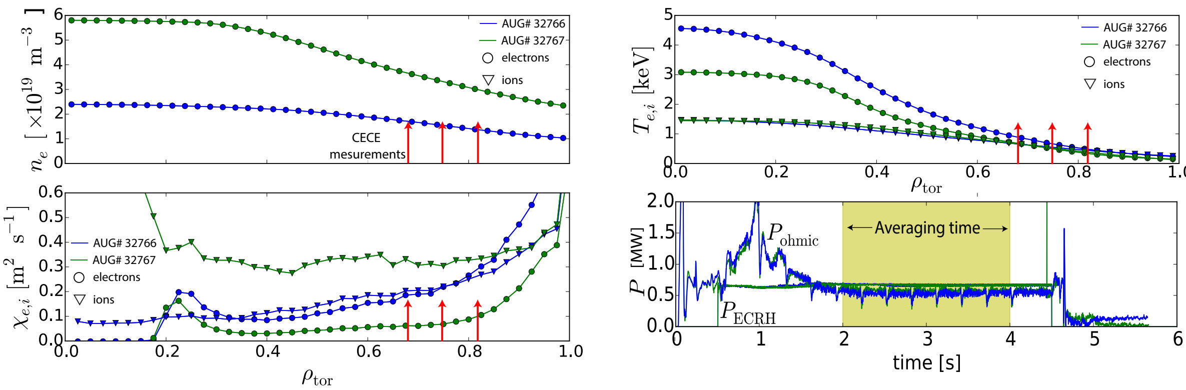

Figure 2: Top left shows the electron densities for the two shots 32766 (blue) and 32767 (green). Top right show the electron (circles) and ion (traingles) temperatures for the two shots. Bottom left shows the electron and ion heat flux values calculated from TRANSP. Bottom right shows the Ohmic and ECRH power for the two shots.

sities for the two shots 32766 (blue) and 32767 (green). Top right shows the electron (circles) and ion (triangles) temperatures for the two shots. Bottom left shows the electron and ion heat flux values calculated from TRANSP. Bottom right shows the Ohmic and ECRH power density for the two shots, as well as the coupling power density between ions and electrons. We can clearly see that, for the higher density case, there is a far greater ion heat diffusivity compared to the electron heat diffusivity, whereas for the lower density case the diffusivities are approximately equal. CECE measurments are made in these plasmas over the region $0.6 < \rho < 0.9$

Fig. 3 shows the inverse normalised gradient scale lengths, which are the main drivers for the drift wave instabilities which give rise to the turbulence, q, collisionality ν^*. We see that although L_n is relatively unaffected, the temperature gradient scale lengths a/L_{T_e} and a/L_{T_i} go up across the CECE measurement region in the higher density shot. Estimated uncertainties on the gradient scale lengths and TRANSP thermal diffusivities ar 20-30 %. Further linear and non-linear gyrokinetic modeling is required to better understand this transport behaviour and progress in this modelling has already been made.

In summary, a Correlation ECE radiometer has been developed for ASDEX Upgrade. Using this diagnostic we have, for the first time, measured electron temperature fluctuations on ASDEX Upgrade and for the first time in Helium plasmas. A partial radial profile of $\delta T/T$ shows a trend increasing with radius in the range of $\rho_{\rm tor}$ from 0.68 to 0.82. Further a density scan was made showing that $\delta T/T$ decreases with increasing density, if everything else is held constant. Initial profile analysis shows that for this data set, a/L_{T_i} and a/L_{T_e} tend to increase over the CECE measurement region, whereas a/L_n changes very little. The increase in collisionality might lead to reduced long wavelength temperature fluctuations[13] and reduced electron ther-

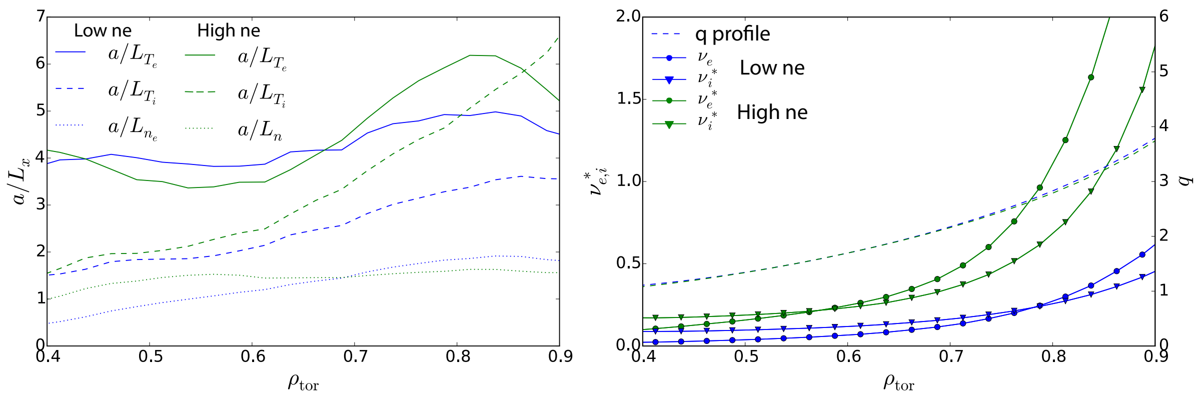

Figure 3: a) Normalised inverse gradients, for both high and low density case. The ion temperature gradient increases in the higher density case. b) q profile and electron and ion collisionalities for both high density and low density helium plasmas.

mal transport, but it is challenging to interpret the increase in ion heat transport based solely on the changes in the low-k temperature fluctuations. Comparison with density fluctuation measurements, detailed linear stability analysis, and non-linear gyrokinetic simulations with the GENE code are planned for the near future to probe the multi-channel transport response of these L-mode plasmas.

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