Electron temperature fluctuation measurements in W7-X: Initial results from OP1.1

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High resolution electron temperature and plasma density diagnostics are necessary to study the relationship between turbulence and transport in magnetically confined plasma. The neoclassically optimized stellarator Wendelstein 7-X (W7-X) is designed to approach steady-state conditions relevant to a fusion reactor, and high precision electron temperature (T_e) fluctuation measurements are possible through the radiometry of Electron Cyclotron Emission (ECE).

Two ECE radiometers that measure emission from the second harmonic of the electron gyrofrequency are currently operational on W7-X [1]. The T_e profile is measured using an extremely broadband, absolutely calibrated 32-channel radiometer, while T_e fluctuations are measured using a 16-channel "ZOOM" device. Both radiometers have 300 kHz video amplifiers and are used to measure heat waves in W7-X [2]. The latter radiometer has a variable local oscillator frequency and uses narrow bandwidth intermediate frequency filters of 150 MHz over a 4 GHz range for high spatial resolution [3]. The radiometers share a line-of-sight, and the ECE viewing path is shown in Figure 1 along with the region measured by the ZOOM device while set to observe emission between 146-150 GHz. This measurement range corresponds to approximately 6 cm on the high-field side (HFS) of the magnetic axis in W7-X.

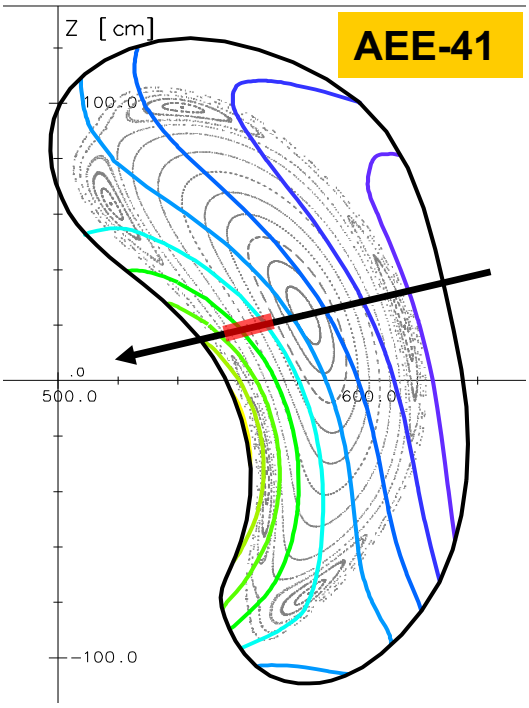

Figure 1: The ECE beam path (black arrow) and an example range measured by the ZOOM device (red box) are shown over vacuum flux surfaces (grey dashes) and |B| contours (solid lines) in W7-X.

The ZOOM device was used as a radial correlation radiometer [4] during the initial operation phase of W7-X that was sensitive to fluctuations

with radial wavenumber $0.3<k_r<5$ cm^{-1}. Under stationary plasma conditions, the ZOOM device is sensitive to radiation temperature fluctuations of less than 0.3% for integration times greater than 300 ms.

ECE Radiation Spectra Modeling

The ECE radiation temperature profile is measured to be asymmetric across the magnetic axis with contributions from relativistically down shifted emission and multiple polarization radiation affecting frequencies corresponding to the low-field side (LFS) of the magnetic axis. In addition, there is a region of harmonic overlap above 150 GHz where 3rd harmonic emission is expected.

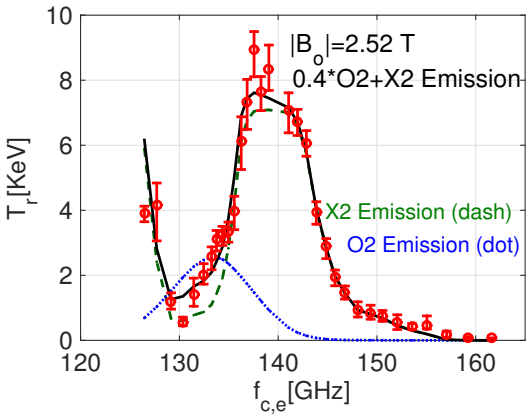

Figure 2: ECE radiation spectrum from W7X discharge XP:20160114.012. Measured ECE (red circles), modeled X2 contribution (green dashes), modeled O2 contribution (blue dots), modeled combination (black line).

An iterative procedure is used to match the measured ECE radiation temperature profile to a modeled spectrum using the TRAVIS ray tracing code [5]. Initial results indicate that the emission from the HFS of the magnetic axis is dominated by high-optical depth radiation in the extraordinary wave polarization, where $\tau_{X2} > 3$, while emission from the LFS of the magnetic axis is affected by low-optical depth radiation in the ordinary wave polarization, where $\tau_{O2} < 1$. A single-pass ray tracing model is used for the extraordinary wave emission model, while 3-passes through the plasma are used for the ordinary wave emission model.

Figure 2 shows an example measured and modeled ECE spectrum from discharge XP:20160114.012. 40% of the modeled ordinary wave polarization emission is necessary to minimize the squared deviation between the measurement and the model. This is pertinent to measurements of radiation temperature fluctuations because the low optical depth emission contains plasma density fluctuations and is not radially local. For this reason the radiation temperature fluctuation measurements are limited to the frequency range between 140 and 150 GHz, where $\tau_{X2} > 3$ and the modeled fraction of emission in the ordinary polarization is negligible. Under these conditions the spatial region sampled by the ZOOM device can be scanned through the steep electron temperature gradient region measured between approximately $10<r_{eff}<30$ cm on the HFS of the magnetic axis.

First radiation temperature fluctuation measurements

A 7-10 KHz coherent fluctuation was consistently observed in the ECE signal at approximately 148 GHz during the initial operation phase of W7-X. A spectrogram of the ECE channel measuring at 148 GHz is shown in Figure 3 along with the auto power spectra for a representative plasma discharge (XP:20160301.009). The channel at 148 GHz measures emission from near the foot of the steep electron temperature gradient region on the HFS of the magnetic axis on the inboard side of W7-X. A mode was also measured in a similar frequency range through correlation reflectometry as well as a set of Mirnov coil signals [6], and it is possible that the fluctuations measured by the ECE are not electron temperature fluctuations but are due to magnetic flutter. The coherent fluctuation is measured near the location of the 4/5 non-resonant rational surface in the standard configuration of OP1.1, and the magnetic configuration dependence of the mode is currently under investigation.

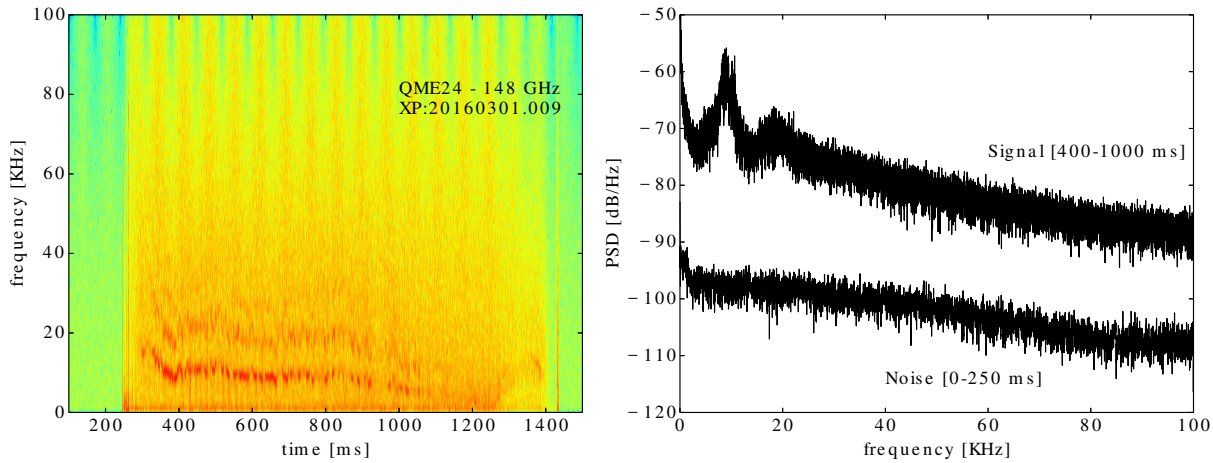

Figure 3: Spectrogram (left) and auto-power spectral density (right) of the ECE channel at 148 GHz from XP:20160301.009.

In the region of interest for T_e fluctuation measurements, the profile measuring ECE system is not sensitive to fluctuations below approximately 3%. The ZOOM device was used to measure the envelope of the 7-10 KHz mode shown in Figure 3. The fluctuation intensity of the 7-10 KHz envelope was measured to be at or below the detection limit of the standard ECE system. The measured fluctuation intensities and the coherence between each channel and the zoom channel at 148 GHz shown in Figure 4. There are two peaks in the measured intensity envelope. The peak centered at 148 GHz has a broad radial extent with a full-width at half-maximum of approximately 4.1 cm.

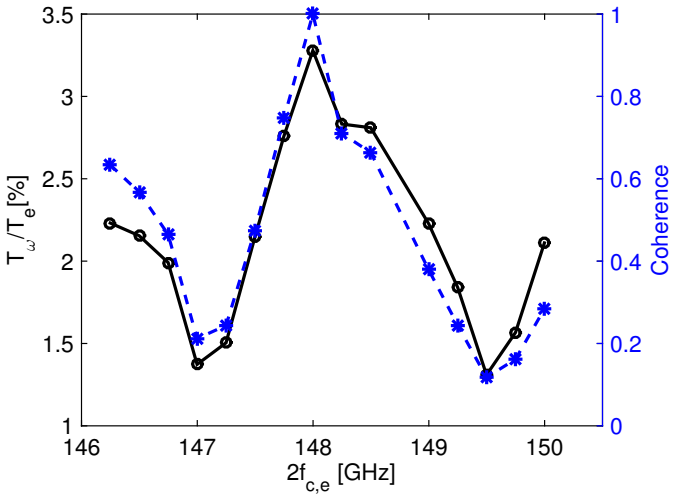

Figure 4: Envelope of the 7-10 KHz fluctuation measured by the radial correlation radiometer: normalized intensity (black line) and coherence (blue dashed line) between each channel and the channel at 148 GHz (130 ms integration time, 0.4% sensitivity).

Acknowledgements

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