Investigation of Optically Grey Electron Cyclotron Harmonics in Wendelstein 7-X

N. Chaudhary, J. W. Oosterbeek, M. Hirsch, U. Höfel, R. C Wolf, and W7-X Team
Max-Planck-Institut für Plasmaphysik, 17491 Greifswald, Germany

1. Introduction

For confinement reasons, the W7-X stellarator plans to work at high plasma densities aiming at detached steady state operation. At a magnetic field of 2.5 T, for these plasmas above a density of 1.2×10^{19} m^{-3}, the optically thick X2 mode (120-160 GHz) of electron cyclotron emission (ECE) is in the cutoff and hence there is no direct access to electron temperature (Te) profiles from the standard ECE diagnostic [1]. The W7-X stellarator has a large aspect ratio, which results in spectrally well-separated ECE harmonics compared to tokamaks with a small aspect ratio and it is easier to study non-overlapped ECE harmonics (70,140,210…GHz). For plasmas above the X2 cut-off, higher harmonics provide the only access to ECE. For such cases, the diagnostic capabilities of higher harmonics are explored as high-density measurements of electron temperatures profiles. For this purpose, a Michelson interferometer (MI) was used to scan the higher harmonics in W7-X for different plasma parameter to study the emission and optical depth of these harmonics. The experimental results are compared with the radiation transport calculations (TRAVIS) to get the optical depth of these harmonics.

2. Michelson Interferometer as an ECE diagnostic

For a magnetic field of 2.5 T, the standard W7-X operation, ECE from higher harmonics lies in the range of 50-500 GHz and to address this radiation one requires a diagnostic that can probe broadband emission in the microwave and infrared range. A Fourier transform spectrometer is one of the suitable candidates to achieve this task as it has been previously used for the same purpose at other large magnetic confinement devices such as JET. The biggest challenge to scan these harmonics is strong stray radiation [2] from non-absorbed electron cyclotron resonance heating power. For this purpose, a multimode stray radiation notch filter [3] was developed. A Michelson Interferometer [2] was commissioned at W7-X in operational phase 1.2 b to scan these harmonics. It shares the same line of sight (almost perpendicular to the magnetic field lines to reduce the Doppler shift in emission) as the radiometer [1], which scans only the X2 mode of ECE. In addition, the Michelson Interferometer can access both polarisations of ECE, X and O mode, by a wire grid beam splitter.

2.1 Hot-cold calibration

The objective of this diagnostic is to provide the absolute radiation temperature corresponding to the broadband ECE from W7-X. For this purpose, an absolute calibration was performed with a source emitting blackbody radiation and a bolometer detector at liquid helium temperatures was used to detect the sensitivity (V/K) changes of the system with respect to change in temperature of blackbody emission.

2.1.1 System description

The source for calibration was placed at a small angle to the input waveguide of MI to avoid the multiple reflections inside the system. The optical path difference between the two arms of MI was achieved by moving one mirror in sinusoidal fashion with a motor at a frequency of 22Hz corresponding to a temporal resolution of 44 ms. The maximum optical path difference of 32 mm was achieved leading to a spectral resolution of < 5 GHz. The mirror position data were taken at an increment of 10 microns corresponding to a minimum optical path difference of 20 microns and hence the maximum frequency that can be scanned is approximately 7500 GHz.

2.1.2 Interferogram from a blackbody

The calibration data was collected at different temperatures of a blackbody for multiple averaging cycles consisting of 30,000 averages per cycle. Further, two amplification stages were used to enhance the signal. One such interferogram at two different temperatures of a blackbody is shown in figure 1.

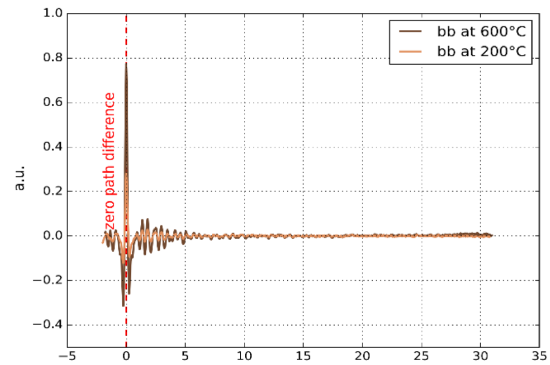

Figure 1 Broadband interferogram from blackbody emission

2.1.3 Frequency dependent sensitivity

The absolute system response can be determined by performing a Fourier transform on the interferogram shown in figure 1. One such spectrum is shown in figure 2. The total number of FFT bins taken into account are 2048 corresponding to 2^{11} as a prerequisite. This provides a spectral resolution of the emission of approximately 3.66 GHz.

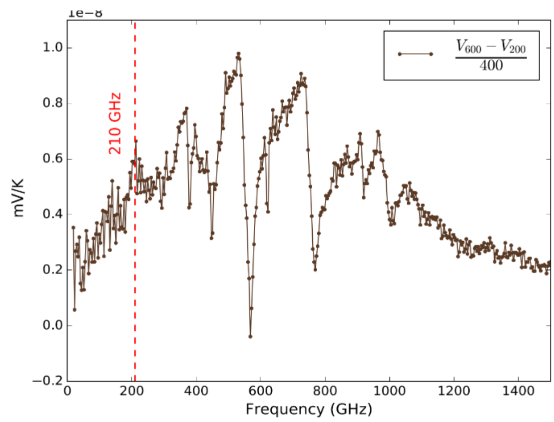

Figure 2 Broadband spectrum from blackbody emission

3. Experimental broadband ECE

The MI diagnostic was commissioned in operational phase 1.2b of W7-X and data were collected for different plasma parameter including two types of plasmas; electron cyclotron resonance heated (ECRH) and NBI heated. For the ECRH plasmas, the stray radiation from non-absorbed ECRH power at 140 GHz was problematic in scanning ECE. This stray radiation dominates the ECE signal and the information about harmonics is lost. Hence a stray radiation notch filter [3] was developed and used to attenuate this stray radiation at 140 GHz. ECE radiation was scanned in both polarization X and O mode from MI and examples of such broadband ECE is shown in the following sections.

3.1 X mode

The X mode spectra shown in figure 3 is corresponding to an NBI heated plasma discharge. Te was approximately 1 keV and the plasma density (ne) was increasing continuously. One can see that the X2 mode emission is decreasing and ultimately reaching its cutoff. For the same parameters, the X3 mode emission is not varying much with a change in density, which indicates blackbody conditions. Hence this is a typical example showing the motivation behind this work, which is to investigate X3 mode to provide electron temperature in high-density plasmas where the standard ECE (X2 mode) is in the cutoff.

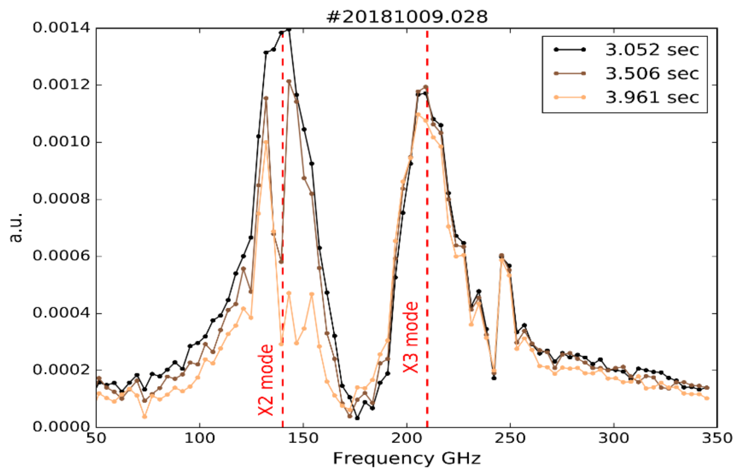

Figure 3 broadband X mode of ECE

3.2 O mode

An O mode ECE spectrum is shown in figure 4 to show the diagnostic capabilities of the MI at W7-X. The plasma conditions are the same as for X mode shown in the previous section except that the

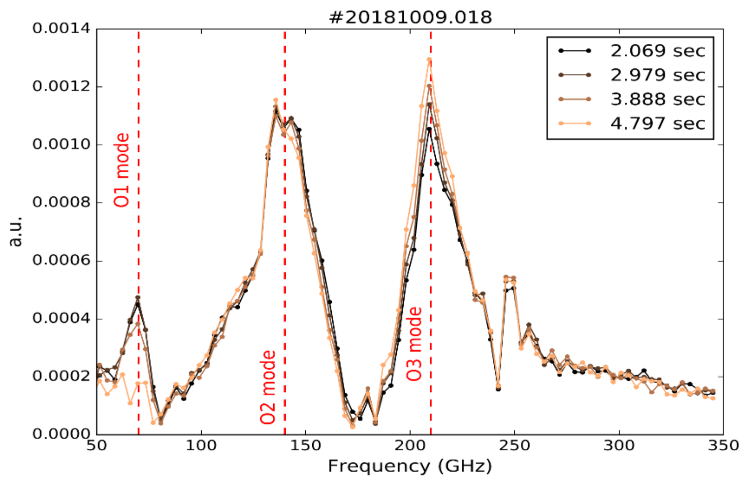

Figure 4 broadband O mode of ECE

plasma density is a bit lower. Hence, one can observe the O1 mode going to cut-off.

4. The optical depth of ECE harmonics

As seen in Figure 3, the X3 mode is not varying with an increase in density, which motivates further to look into the optical depth of this mode. The X3 mode of ECE as a function of ne*Te is shown for a variety of experimental plasma conditions and from radiation transport calculations in figure 5. As absorption coefficient of ECE is proportional to ne*Te, one can observe that for high absorption the ratio of X3 mode of ECE and Te becomes constant. Hence, this can be taken as a sign of high optical depth of X3 emission for those parameters.

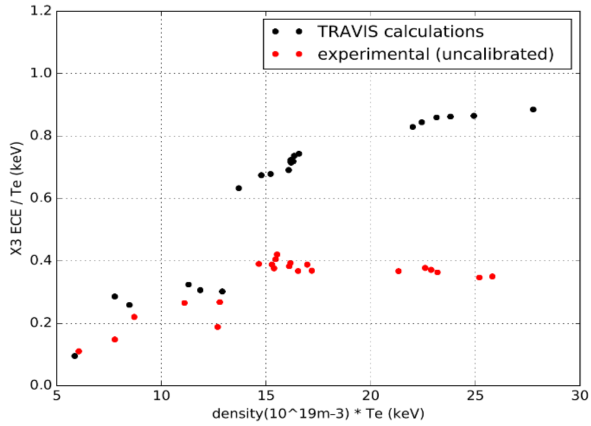

Figure 5 X3 emission/Te as a function of absorption

5. X3 mode of ECE as a proxy for Te?

For the plasma parameters where X3 has high absorption, the Te measured from Thomson scattering diagnostic is shown in figure 6. A clear agreement between Te from Thomson scattering and X3 mode of ECE can be observed. Further data analysis is planned with forward modeling of the system with TRAVIS and MINERVA framework.

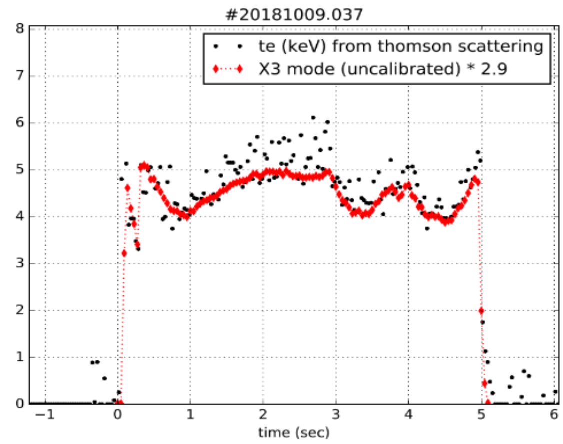

Figure 6 X3 emission and Te from Thomson scattering for a W7-X plasma discharge with high density*Te

Acknowledgment

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Reference

[1] M.Hirsch et al., this conference

[2] J.W. Oosterbeek et al., 'Michelson Interferometer design in ECW heated plasmas and initial results', Fusion Engineering and Design, 2019

[3] N.Chaudhary et al., Proceedings of 20th workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, May 14-17, 2018, Greifswald, Germany, EPJ Web of Conferences