Seminar

==

Institute for Plasma Research

==

Title: Study of electron dynamics in tokamak plasma through Electron Cyclotron (EC) emission using Radiometer

Speaker: Mrs. Varsha Siju
Institute for Plasma Research, Gandhinagar

Date: 19^{th} February 2024

Time: 10:30am

Venue: Seminar Hall, IPR

Abstract

Study of both thermal as well as non-thermal electron dynamics is important to characterize the tokamak plasma. Thermal electron temperature is one such fundamental parameter that plays a pivotal role in achieving and sustaining controlled fusion reactions governing particle confinement, collisional transport, energy transport, etc. [1]. Lately, instrumentation techniques based on Electron Cyclotron Emission (ECE) viz. Michelson Interferometer (MI) [2] and Radiometer are utilized for thermal electron temperature determination. Radiometers are known to provide localized temperature measurements with high spatial (≤1cm) and temporal resolutions (≤10µs) and utilize microwave instrumentation and sensors that work at room temperatures (RTP). These features outshine the usage of radiometers for localized temperature measurements.

The direct dependence of cyclotron frequencies on toroidal magnetic fields (B_T) provides a constraint on the receiver hardware as tokamaks are usually operated at a varied range of toroidal magnetic fields depending upon the experimental requirements. To address this issue various techniques have been used worldwide like wideband sources, sweep sources etc. but these are quite costly and have a complex architecture. This motivates me to design a simple new architecture that is cost effective and at the same time satisfies the measurement requirements at varied B_T. A 16-channel super-heterodyne radiometer system is designed, developed, installed and successfully operational at ADITYA-Upgrade (ADITYA-U) tokamak for localized thermal/radiation temperature measurements at fixed as well as varied toroidal magnetic fields, spatially and temporally. This multiple channel hardware unit (*a combination of Radio Frequency (RF) and Intermediate Frequency (IF) unit*) can perform localized measurements at fixed as well as different magnetic fields thereby improving the receiver's dynamic range. The designed system provides a spatial resolution of 1.2cm and a high temporal resolution of 10µs. The ECE radiometer with a high spatio-temporal resolutions is sufficient to investigate continuous localized thermal electron temperature dynamics for optically thick plasma ($\tau >> 1$). Also, for an optically thin plasma ($\tau < 1$), it plays an important role in investigating the non-thermal electron dynamics that are non-local and have a broad spectrum, which is an indicative of the presence of temperature fluctuations as well as kinetic instabilities that significantly affect the ECE signatures. [3]

The effect of kinetic instabilities on electron cyclotron emission (ECE) from runaway electrons (RE's) is observed and investigated through the 16-channel broadband ECE Radiometer diagnostic at ADITYA-U tokamak. A single and/or multiple step rise of up to 20 – 40% in the ECE radiometer signal amplitude within few microseconds; along with occasional step like modulations are observed consistently for the low density ($n_e \leq 1x10^{19}m^{-3}$) plasma discharges at Aditya-U for the first time. Pitch Angle Scattering (PAS) of RE's triggered by kinetic instabilities is a possible cause for this sharp rise in the ECE signatures [4-10]. Among the positive effects of PAS are energy blocking: The PAS increases the synchrotron radiation and thus lowers the radiative energy limit for the runaway electrons. Pitch angle scattering (PAS) transfers electron momentum $P_{\parallel}$ to $P_{\perp}$ which can enhance the power of ECE. Thus, the ECE radiometer can be utilized to study the PAS events that are typically exhibited by the non-thermal electrons in plasma discharges. Since PAS is known to limit the on-axis runaway energy, one can explore the possibility of utilization of this phenomenon as a suitable alternative or complementary technique for runaway dissipation/mitigation.

Nascent observations of the ECE radiometer signals show that additional gas puff that is usually provided to improve the electron density of a tokamak plasma can have a significant effect on the occurrence of such events. Further, it is also observed that they also have the potential to vary the trigger timings of occurrence of PAS events or even lead to their complete avoidance. "PREDICT" code - an acronym for Production of Runaway electrons and Energy DynamIcs Code for Tokamaks that employs the relativistic test particle model validates these experimental findings of the radiometer diagnostic for the first time [11, 12]. PAS being a redundant phenomenon, a small database of such discharges is obtained and various discharge parameters are investigated to understand the predictability of these events and pre-estimate their occurrence. Trigger conditions from the database so generated are used as an input to the PREDICT code and model the PAS event occurrence. A reasonable consistency has been found with the ECE observations. This could be a novel method for early runaway eviction by exploring the experimental trigger conditions for PAS occurrence (*known for runaway energy limiting*) validated as an abrupt steep jump in ECE signatures and to the best of the author's knowledge is a field yet to be explored. Particularly for the ADITYA-U tokamak such investigation is not performed earlier and this motivates us to study and generate a database that can help understand the trigger conditions for such events.

References

1. J.F.M van Gelder, PhD Thesis, Utrecht University, Netherlands (1996).
2. Liu Yong et al., Plasma Science and Technology, Volume 18, Issue 12, pp. 1148 (2016).
3. S. Varsha, et al., Journal of Instrumentation. Vol.16 (2021).
4. Varsha Siju, et al., Rev. Sci. Instrum. 93, 113529 (2022)
5. Jaspers R, Ph.D. Thesis, Eindhoven University of Technology, (1995)
6. Chang Liu, Ph.D. Thesis, PPPL,(2017)
7. R.J.Zhou et al Plasma Phys. Control Fusion 55 (2013).
8. Z.Y.Chen. et al., Chin.Phys.Lett. Vol.24.No.11 (2007)
9. V.V.Parail, et al., Nuclear Fusion 18 3(1978).
10. J.R.Martin-Solis et.al., Physics of Plasmas, Vol9,No.5 (2002)
11. Santosh P. Pandya, PhD thesis, AIXM0036, Aix-Marseille University, France, (2019)
12. Ansh Patel, et.al., IEEE Transactions on Plasma Science, DOI: 10.1109/TPS.2022.3152082, (2022)