Non-Maxwellian electron distribution functions in magnetized fusion plasmas

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Non-Maxwellian distribution functions are ubiquitous in magnetically confined fusion plasmas. Investigation of their properties is not only important for predicting and understanding the plasma behaviour in fusion experiments, but also for optimizing scenarios of plasma discharges. In addition, the study of these distributions can reveal physics features or exploit properties that are analogous to those observed in other laboratory or astrophysical plasmas. Well-known examples are the runaway and slideaway electron distributions produced by a strong electric field, as well as electron and ion distributions associated to non-inductive current drive by waves or neutral particle injection. Other sources of non-Maxwellian electron distributions, such as spatial diffusion due to magnetic turbulence, energetic ions collisional relaxation on electrons, or damping of MHD modes, offer less familiar, but very interesting examples, with analogies to inertial fusion or magnetosheath plasmas.

The main drivers of non-Maxwellian electron distributions in magnetically confined plasmas are first presented and their roles in fusion experiments are discussed. Examples of computed distribution functions of various kinds and of measurements connected with their presence are presented. Then, novel results are shown of a new class of non-Maxwellian distributions that have been revealed in the high-performance JET experiments of recent campaigns (both in Deuterium and in Deuterium-Tritium). The experimental finding that has allowed to discover these distributions is a discrepancy between electron temperature measurements by Electron Cyclotron Emission (ECE) and by Thomson Scattering (TS), which appears only in high-temperature phases (typically, for temperatures higher than 5 keV). Such a discrepancy has been observed for more than 30 years, first in TFTR [1], then in JET [2], but so far never understood.

In order to perform a systematic analysis of this effect, a model for bipolar perturbations of the electron distribution function has been developed, allowing analytic calculation of the EC emission and absorption coefficients [3]. The model is characterised by three perturbation parameters: the momentum p_0 at which it is centred, its width δ in momentum and its amplitude f_0. The analysis carried out using this model shows that the discrepancy observed on an extensive data base of recent JET discharges [4] is an evidence of electron distribution functions presenting a bipolar distortion in the vicinity of the electron thermal velocity. An example of the comparison between experiment and model for a specific data set (Deuterium Baseline discharges with Ne injection) is shown in Fig. 1.

In order to investigate the cause of this perturbation, two distinct physical mechanisms have been studied. 1) Fokker-Planck computations with a newly developed kinetic code, using a full integro-differential collision operator, have demonstrated, for the first time, that collisional relaxation on the electrons of energetic ion tails (always present in JET high-performance discharges) can be responsible precisely for this kind of bipolar distortions. 2) Linear and non-linear gyrokinetic computations performed with the GENE code have shown that Kinetic Ballooning Modes (present in JET at high electron beta) can also produce a bipolar distortion of the electron distribution function around the thermal velocity. This is similar to the effect observed in the magnetosheath [5] and due to the Landau damping of Kinetic Alfvén Waves [6].

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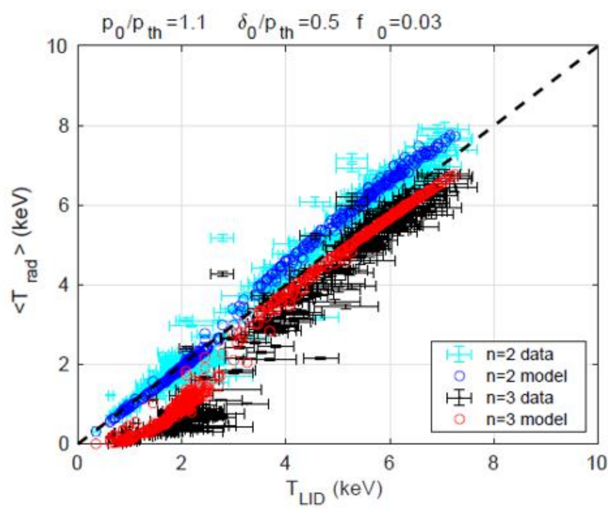

***Fig. 1**: ECE radiation temperature measured by a Martin-Puplett interferometer vs TS temperature measured by LIDAR technique. Data (with error bars) and model estimates for the two harmonics. Perturbation parameters are shown at the top.*