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Citation for published version (APA):
Carbone, E. A. D., Hübner, S., Iordanova, E. I., Vries, de, N., Jimenez Diaz, M., Palomares Linares, J. M., & Mullen, van der, J. J. A. M. (2012). Discrepancies between different electron temperature methods: probing the electron energy distribution function. In *Proceedings of the 21st Europhysics Conference on the Atomic and Molecular Physics of Ionized Gases (ESCAMPIG XXI), 10-14 July 2012, Viana do Castelo, Portugal* (pp. 1-2)

Document status and date:
Published: 01/01/2012

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Discrepancies between different electron Temperature diagnostics: probing the Electron Energy Distribution Function

E. A. D. Carbone(*), S. Hübner, E. Iordanova, N. de Vries,
M. Jimenez-Diaz, J. M. Palomares and J.J.A.M. van der Mullen

Department of Applied Physics, Eindhoven University of Technology,
P.O. Box 513, 5600 MB Eindhoven, The Netherlands
(*) e.a.d.carbone@tue.nl

A large panel of diagnostic techniques for the determination of effective electron temperatures T_e exists and they rely on different hypothesis/physical phenomena for its measurement. Due to the different underlying assumptions and physical mechanisms used for the calculation of T_e, different values of T_e may be expected while measuring a plasma in the same conditions, particularly in the case of a non-Maxwellian plasma. To each of these definitions of effective T_e, a different effective T_e can be defined using the EEDF of the plasma. In this study, we take a low pressure Argon microwave plasma as test case and compare Thomson scattering with line intensity measurements corrected by a collisional radiative model. The results are compared with those obtained from the electron particle balance (ePB).

The electron temperature found by classical global plasma models (GPMs) expresses the balance between ionization and losses in steady state situation. An intermediate pressure ($5 \leq \text{p} \leq 50$ mbar) microwave induced plasma was investigated by a combination of Absolute Line Intensity measurements and a Collisional Radiative Model (ALI-CRM). The trend as a function of the electron density/pressure agrees qualitatively with classical GPMs. However, the results are compared with Thomson scattering measurements and significant differences are found. The T_e-values of TS are found to be systematically higher than ALI-CRM and to rise for lower ionization degree.

Absolute Line Intensity (ALI) measurements can determine the atomic state distribution function (ASDF). For argon a special role is played by the 4p level block (shortly level 3). By comparing the occupation of level 3 with the ground state (level 1) density, as derived for the pressure $n_1 = p/kT_g$, we can, using the Boltzmann exponent, determine the excitation temperature T_{13}. By means of a CRM, T_{13} can be converted into T_e (see figure 1 for more details). The CRM corrects for the ionizing character of the plasma and is based on Maxwellian cross sections.

ALI is an optical diagnostic method which probes the creation temperature of the plasma; *the electron temperature needed to sustain the effective losses of electron-ion pairs through the excitation/ionization flux from the ground state Ar to the ion* Ar^+. In other terms, it is the effective Maxwellian temperature which is required to sustain the ionization flux from the ground state to the atomic ion state.

Thomson scattering (TS) is another well-known active diagnostic technique which consists of measuring the intensity and wavelength dispersion of a laser beam intensity after its scattering by the free electrons in the plasma. The scattered photon density is proportional to the electron density n_e meanwhile the Doppler width of the scattered signal gives the electron temperature T_e.

Our spectrometer collects however only photons in a range of 4 nm around the laser wavelength [1]. This means that only electrons within 0 - 5 eV are detected by TS which corresponds to the bulk of the EEDF. In the Argon system, there are no excited states below 12eV which means that only electrons with energy of ~12 eV or higher can excite argon atoms from the ground state. The EEDF will then thermalize by e-e collisions below 12 eV; a significant kink in the distribution occurs then at the excitation threshold in the case of a non-Maxwellian Argon plasma. TS measures only the electrons which are in the bulk of the EEDF and cannot then directly probe Maxwell deviations in case of an argon plasma which occur at higher energies than detected by the spectrometer.

In non-equilibrium low temperature plasmas, the electron energy distribution function (EEDF) cannot be described by a simple Maxwell distribution and it is often convenient to apply a 2-Temperature formulation. For a characterization of the EEDF, we use then a bulk temperature $T_e(bulk)$ and a tail temperature

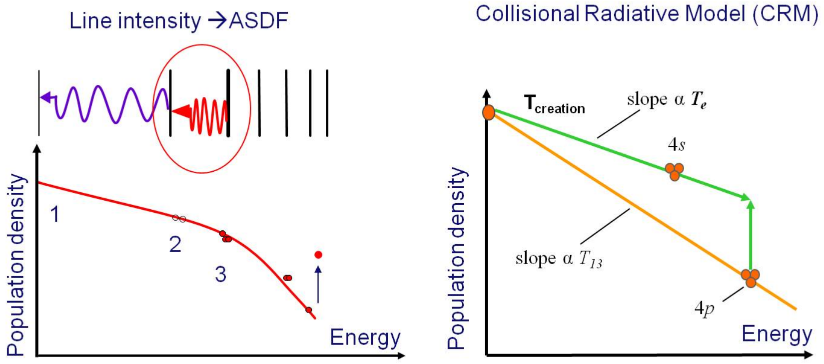

Fig. 1: Schematic of the Atomic States Distribution Function (ASDF) and the correction of the excitation temperature T_{13} into the creation temperature of the plasma via a CRM.

$T_e(tail)$ (electrons with energies above 12 eV in the case of an argon plasma). Both experimentally and theoretically, it can be shown that the departure from equilibrium ($T_e(bulk)/T_e(tail)$) depends on the ionization degree. A characterization of the plasma in terms of its ionization degree instead of its electron density proves to be more meaningful in the case of plasmas with (very) low ionization degree.

The comparison of ALI-CRM and TS allows to get insight in the deviations from Maxwell equilibrium as long as the definitions of T_e are carefully compared [4]. For instance, one need to be aware that the CRM used [5] rely on the assumption of electron saturation balance (ESB). This may be not true anymore at low pressure were losses of excited states by radiations can become important (corona balance) [6]. In the higher pressure limit (p $\geq$ 20 mbar), one may also need to correct CRMs to account for the recirculation of Ar^+ into Ar 4s via dissociative recombination which can lead to an underestimation of T_e even if the ESB equilibrium is fulfilled. These issues are also discussed in this contribution with the help of global plasma models.

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