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Measurement of argon-ion temperature and flow velocities in TJ-K

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Introduction

The laser-induced fluorescence (LIF) [1, 2, 3] is a well approved diagnostics for ions in low temperature plasmas. It allows to measure, spatially resolved, the ion-velocity distribution function (IVDF). From the IVDF, the ion temperature and the mean ion velocity can be calculated. Thus, it provides insights in the physics of plasma processes, which is not only important for improving the quality of processes in industrial applications as, e.g., plasma etching, but also for a detailed understanding of plasma-wall interactions as well as plasma dynamics in fusion devices.

A LIF diagnostic was build up and installed on the torsatron TJ-K. For the first time, argon-ion-temperature profiles were measured in TJ-K. Two different types of discharges were used, a high B-field discharge with 8.3 GHz ERCH, a low B-field discharge with 2.45 GHz ERCH. Generally the ion temperature gradient is low for all discharges. The ion temperatures were found to be $T_i \approx 2$ eV for the high field and $T_i \approx 1$ eV for the low field discharge. The T_i profiles are used in a particle and energy balance to investigate the electron-ion energy exchange. Power modulation experiments allow for time-resolved investigation [4] of the ion dynamics. First results are also presented.

Laser induced fluorescence

The spatial resolution of the LIF diagnostics is limited by the observation volume given by the crossing point of the laser beam and the detection optics. The cross section surface of the laser beam is about 10 mm^2 and the width given by the detection optics can be as small as 0.5 mm. The system consists of a diode laser with an optical output of 25 mW at 668.6 nm and a mode-hop-free tuning range of 20 GHz. It is modulated with an acoustic optical modulator. For wavelength measurements a combination of a wave meter and an iodine cell is used. The wave meter is from Advantest and has a resolution of 0.1 pm and an absolute error of 2 pm. The iodine cell reduces the absolute error to 0.1 pm. The fluorescence light is filtered through an interference filter with a bandwidth of 2.5 nm and is detected with a photo multiplier tube. For data acquisition, a 24-bit 100 kS/s PC card is used. The ion temperature can be measured with a resolution of 0.02 eV and the mean velocity with a resolution of 60 m/s.

Profile Measurements

The laser was irradiated through an outer port of TJ-K such that toroidal flow and temperature measurement were possible. The fluorescence light was collected through the upper port. The optic was radially movable to get profile information. The profiles are horicontal cuts in the poloidal plane of the upper port. Under the assumption that the plasma parameters are constant on flux surfaces a transformation of the data for the upper port to the outer port is possible. Thus the T_i profiles would be compared with profiles from the Langmuir probes. The profiles shown in Fig. 1 were measured in two different discharges a high field discharge with 1.2 kW and 8.3 GHz resonant heating (lefz) and a low field discharges with 1.8 kW at 2.45 GHz (right).

Generally the ion temperature profiles have low gradients. The electron temperature profiles are hollow and the density is centrally peaked. The high field discharge has an higher energy content than the low field discharge, although the heating power is lower. This effect is more pronounced for the ions.

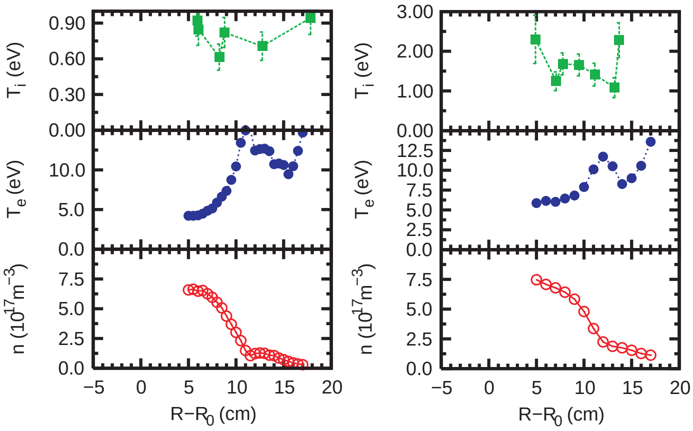

Figure 1: Profiles of ion temperature, electron temperature and density are shown. On the left side the low field discharge with 2.45 GHz resonant heating. On the right side the high field discharge with 8.3 GHz resonant heating.

Ion power balance

The ion power balance is a common method to determine the diffusive flux. All energy gain and loss mechanisms were compared with the convective flux. The remaining part of the balance should be related to the diffusion.

For the energy gain ionization and electron-ion energy transfer were taken into account. The loss terms are due to recombination and ion-neutral collisions. The integral of sources and sinks over the volume inside the flux surface gives the power flux through the flux surface. In toroidal coordinats the integration has the form.

$$P(r) = 4\pi R_0 \int_0^r \sum (\text{sources-sinks}) \cdot r' \cdot dr'$$

The convective particle flux $\Gamma(r)$ is given by the analogous integration of the particle sources and sinks which are due to ionization and recombination. Each ion carries the thermal energy, so the energy flux related to the particle flux is given by.

$$P_{con}(r) = -3/2\Gamma(r)T_i(r)$$

The rate coefficients for ionization and recombination were taken from Lechte et. al. [5]. To get a more descriptive comparison with the diffusion the flux densities are plotted in Fig. 2 and 3.

First it is assumed that the neutral density is constant and the neutrals are at room temperature. In Fig. 2 the power balance is shown for a low field and a high field discharge. The convective power flux is dominating over all other terms. Thus the balance is negative which would either lead to a negative diffusion coefficient or there is a missing ion heating component. A possible error source is, however, the assumption on the neutrals.

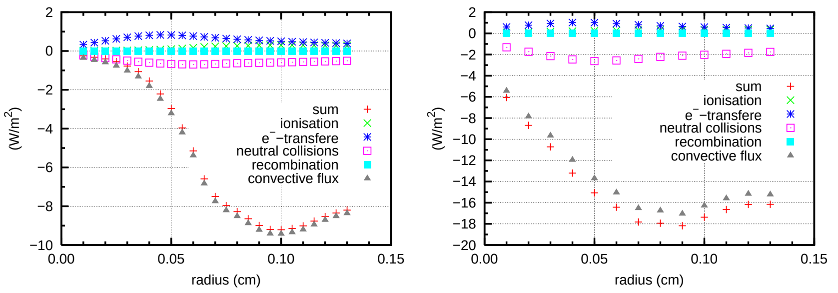

Figure 2: Ion power balance for the low field discharge (left) and the high file discharge (right) with neutral temperature of 0.026 eV.

If we consider that the plasma can heat the neutrals the assumption of $T_n = 0.026$ eV can be wrong. A higher neutral temperature would lead to a lower neutral density and a reduced ionization rate. This in turn reduces the convective loss. While the energy sources are unefected since the lower ionization rate is compensated with higher temperature of the newly born ions. However a positive diffusive ion heat flux, as shown in Fig. 3, is reached not till $T_n \approx 1/2\ T_i$. Neutral temperatures of $T_n = 0.4$ and 0.8 eV for the low and the high field discharge respectively, seems unlikely since the neutrals are not confined by the magnetic field. Thus additional contributions to ion heating as trough turbulence could be indicated. Further theoretical and experimental investigation are necessary to make a quantitative predication of an anomalous ion heating process.

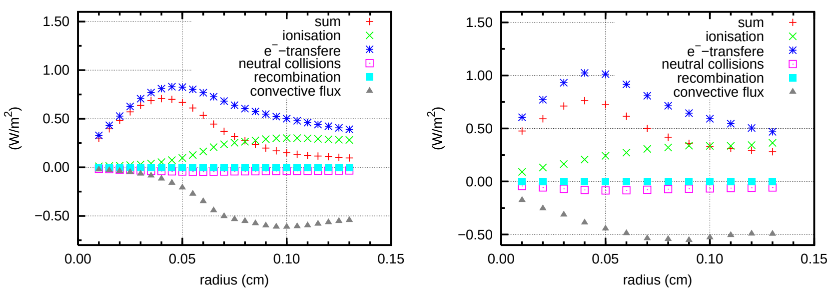

Figure 3: Ion power balance for the low field discharge (left) with assumed neutral temperature of 0.4 eV. And for the high file discharge (right) with an assumed neutral temperature of 0.8 eV.

Phase resolved ion temperature

In repetitive phenomena like in a pulsed plasma it is possible to perform a phase resolved LIF measurement. One Way would be to synchronize the laser modulation frequency with the pulse frequency. ν_{laser} should be $1/2\nu_{plasma}$ so there will be an illuminated period and a dark period of the plasma modulation. A simple subtraction of the dark period from the illuminated gives the fluorescence signal. Averaging over many period gives a better signal to noise ratio. But it is not needed to synchronize the laser modulation with the plasma modulation. By the knowledge of the time traces of photo multiplier tube the laser modulation and the plasma modulation one can determine for each time step to which phase it corresponds and if its dark or illuminated. In Fig. 4 phase resolved measurements of three pulsed discharges are shown. They were obtained in low field Ar discharges with plus frequencies of 10, 1000 and 21000 Hz. In the 10 Hz discharge the density and the temperature are falling to 0 in the off phase. While in the discharge with 1 kHz modulation the ion temperature is nearly constant. And a modulation with 21 kHz leads to a case where the density is also constant.

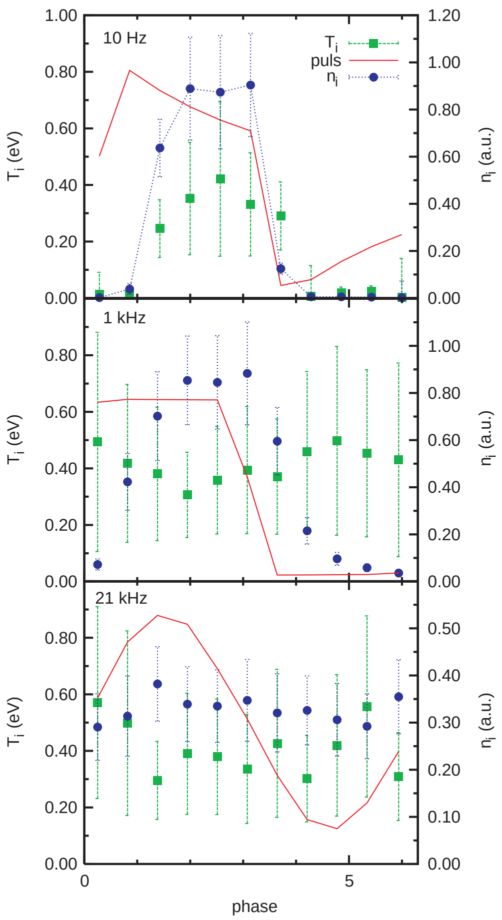

Figure 4: Phase resolved T_i and n_i for three different plasma modulation frequencies. From top to bottom: 10 Hz, 1 kHz and 21 kHz.

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