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Ion temperature measurement on tokamak Golem

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1. Abstract

In Scrape-Off Layer of tokamak Golem we performed a measurement of the Ion temperature using a swept ball-pen probe. A python script was developed for easy loading, fitting and plotting of the acquired and calculated data. The ion temperature can be estimated from the electron branch of BPPs I-V characteristics with a temporal resolution up to 10 μs. A temporal profile of ion temperature was created by measuring with a stationary probe placed at radial position of 60 mm.

2. Description of the used method

Plasma potential is given by equation $\Phi^{BPP} = \Phi - \alpha_{BPP} T_e$, where T_e is the electron temperature in eV and Φ is the plasma potential. Coefficient α_{BPP} was empirically found for deuterium plasma as $\alpha_{BPP} = 0.6$. The plasma potential is separating the I-V characteristic of ball-pen probe (BPP) into ion and electron branch. By applying positive swept voltage above plasma potential the electron branch is measured. The electron branch of the I-V characteristic is the sum of an ion current, exponentially decaying with coefficient Ti, and an electron current, saturated or linearly increasing with the probe voltage. Thus the coefficient T_i can be estimated from the exponential part of the curve using a 4-parameter fitting formula :

$$I(V) = I^-_{sat}[1 + R(V - \Phi)] - I^+_{sat}\exp((\Phi - V)/T_i). \tag{1}$$

Hence:

$$Isat^- = \exp(0.6) I^+_{sat}. \tag{2}$$

We can write:

$$I(V) = exp(0.6) I^+_{sat}[1 + R(V - \Phi)] - I^+_{sat}\exp((\Phi - V)/T_i), \tag{3}$$

where the fitting parameters obtained are the ion temperature (T_i), plasma potential (Φ), ion saturation current ($^+_{Isat}$) and linear increase of electron current is described by slope (R).

2.1. Signal clean up

Ball-pen probe is swept on a frequency of 50 kHz, which results in parasitic capacitive current created in coaxial cable. Before any further processing of data capacitive current needs to be removed. We can reconstruct capacitive current from coupling constant and offset of signal. We can obtain these parameters from linear fit of current measured and derivative of voltage applied on probe. The linear fit along with the capacitive current removal is shown on Figure 1.

Furthermore lowpass filter needs to be applied on signal to remove structures with much higher frequency than the voltage sweeping frequency. Typically 5 harmonic frequencies can be visible using fourier analysis. Thus lowpass filter used was set to (300 kHz). Higher frequencies than 300 kHz are under the background noise level. The result is shown on Figure 2.

After capacitive current and background noise is removed the signal can be separated into individual I-V characteristics, which can be fitted using a 4-parameter fit. However, the parameter Φ is unknown. In order to find Φ we need to separate the I-V characteristic into ion and electron branch according to BPPs floating

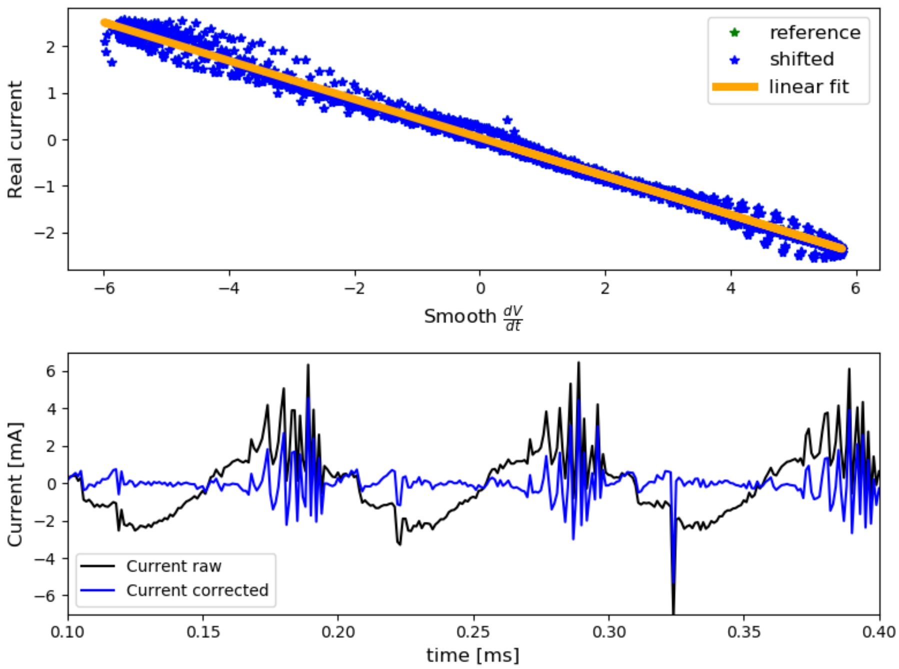

Figure 1: Capacive current removal, shot: 31992

potential and perform a primary fit, which will estimate the plasma potential. Thus a secondary fit can be performed from the plasma potential. Since the data points tend to fluctuate significantly more toward higher swept voltage, we are using a weighted fit. The weighted fit is giving 'weight' to each data point according to weight $= \frac{1}{\sigma}$, where σ is the standard deviation of each data point over 0.5 ms. Also the unweighted fitting method is plotted for a comparison. Tertiary fit can be also performed if the amplitude of a swept voltage is less than three times the T_i measured. In this case the linear increase of electron current does not affect the shape of I-V characteristic and we can set the parameter R = 0. Example of a fit starting at plasma potential is shown on Figure 3

The temporal profile of ion temperature can be created using a simple for loop over all I-V characteristics. Standard deviation of each resulting optimisation parameter can be obtained from covariance matrices. The diagonals provide the variance of the parameter estimate. Standard deviation errors can be calculated as $\sqrt{diag(cov)}$.

3. Results

Using swept Ball-pen probe we were able to measure the ion temperature during discharge 31992 on tokamak Golem. The Discharge parameters along with measured ion temperatures are shown on Figure 4

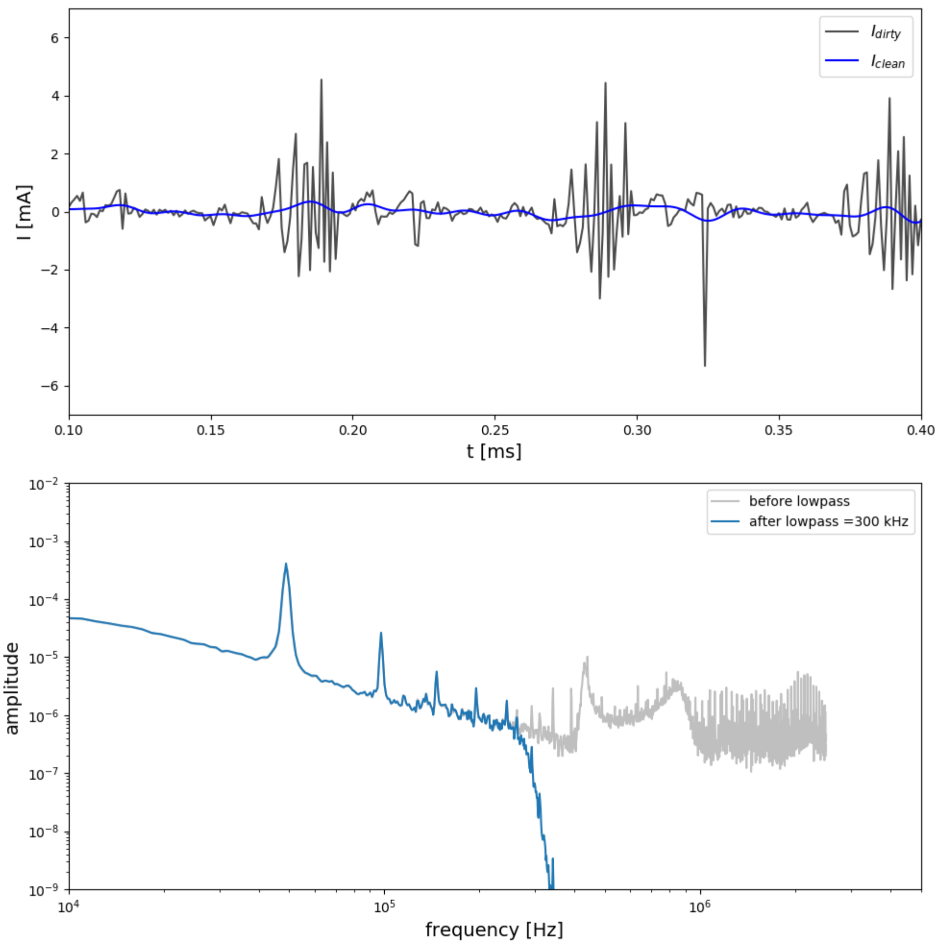

Figure 2: Filtering and a Fourier analysis of signal, shot: 31992

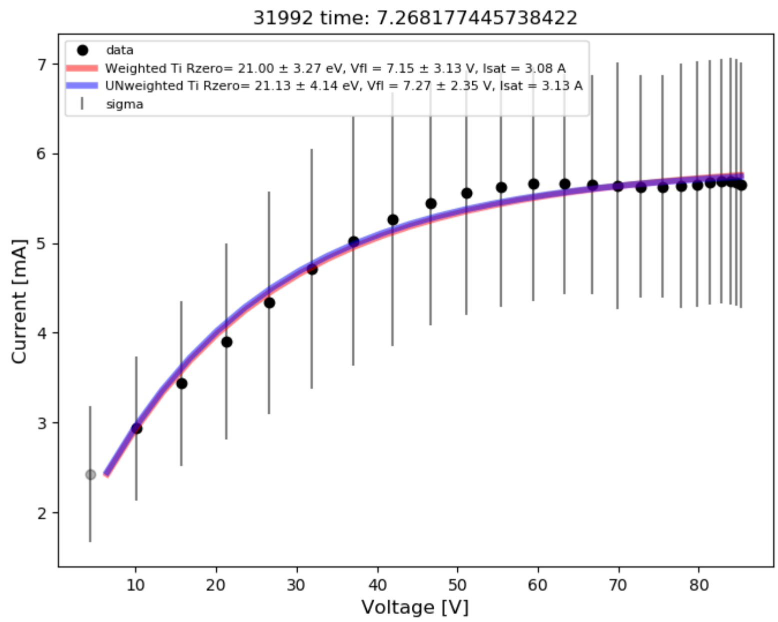

Figure 3: Example of 4-parameter fit of the electron branch, shot: 31992

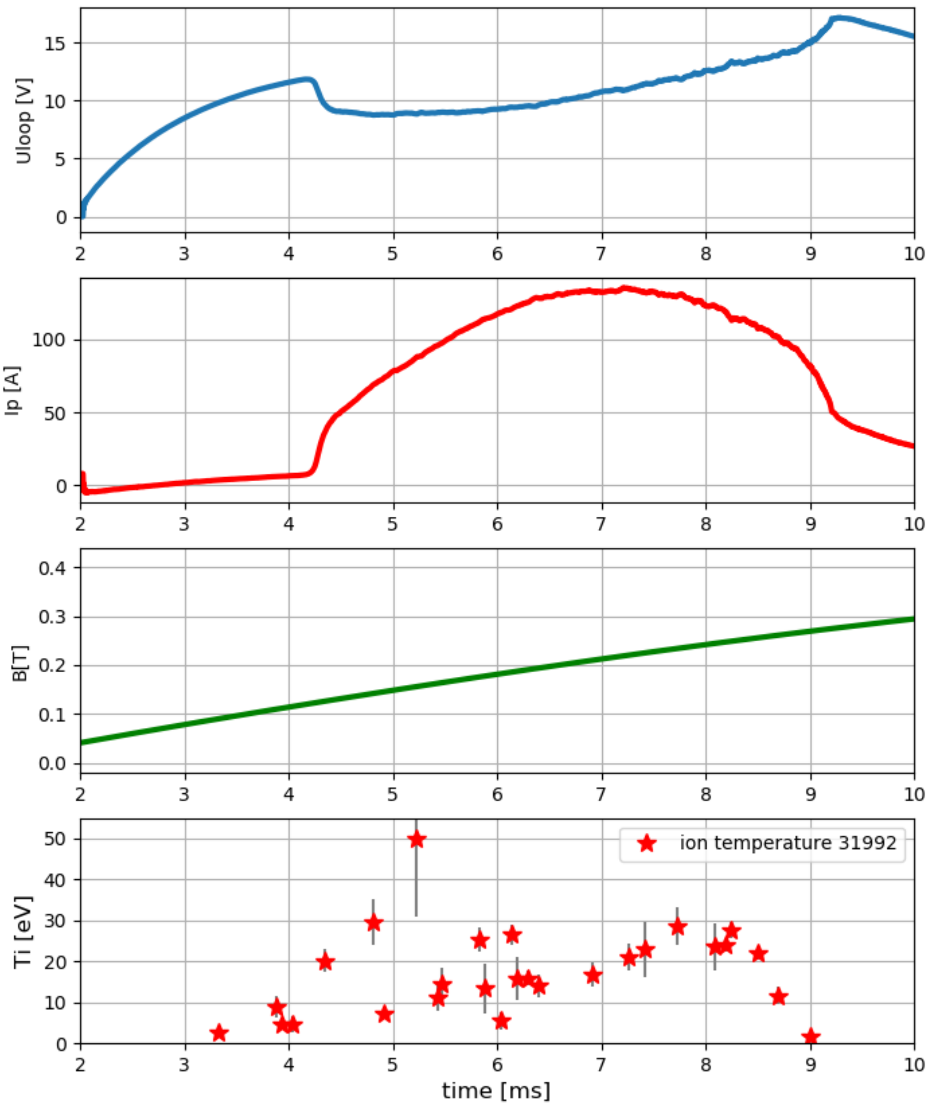

Figure 4: Temporal profile of plasma parameters, shot: 31992