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# Behaviour of Ar XVII Spectra in Sawtoothing Discharges at TEXTOR-94

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## Introduction

Sawtooth processes are routinely observed in the core of hot tokamak plasmas. Up to now, information about the sawteeth has been obtained from the broadband x-ray radiation measured by arrays of pin diodes, the emission at the electron cyclotron frequencies (ECE) and FIR interferometry / polarimetry. These diagnostics provide high sensitivity and time resolution, well below 1 ms, but they only measure the properties of the electrons. Due to experimental constraints, similar diagnostics for the plasma ions have less sensitivity and time resolution.

In order to obtain more information about the plasma ions, a high resolution x-ray spectrometer in Johann mount has been installed at TEXTOR-94. The x-ray spectra provide information on the central values of the ion temperature, the toroidal plasma motion, the electron temperature and the charge state distribution of highly ionized ions. All this information is obtained simultaneously from the spectra. As a result, phase shifts and delays between different plasma parameters are detected with high reliability and synchronization errors between different diagnostics including time delays due to different toroidal and poloidal locations are safely excluded. The x-ray spectrometer, as well as the extension to an x-ray polarimeter, will be described in more detail in [1]. In this paper, results on the behaviour of He-like ArXVII in sawtoothing discharges with auxiliary heating by neutral beam injection (NBI) are presented.

## Experiment

Two series of measurements with plasma current of 390 kA, NBI power of approximately 1.3 MW and plasma densities of $2.8*10^{19}$ $m^{-3}$ (shot # 82518) and $3.7*10^{19}$ $m^{-3}$ (shot # 82526) were performed to study the relative time behaviour between different plasma parameters during sawteeth oscillations. Argon was injected into the plasma during the flat top phase of discharges, the argon flow was adjusted to avoid saturation of the position sensitive multi-wire proportional counter used for x-ray detection. The resulting concentration of argon was well below $10^{-3}$ of the electron density, leading to less than a 5% increase in the total radiated power. A total of 6000 spectra per discharge were taken with a frequency of 2 kHz. The count rate was limited to 400 000 $s^{-1}$ by the detector, resulting in only a few hundred counts per spectrum. This was sufficient for intensity measurements, but not for precise spectral analysis. In order to obtain high-quality spectra with about 100 000 counts, the data from many sawteeth were added selecting synchronous spectra relative to the sawtooth crash.

To add the spectra, discharges were chosen, where the sawtooth amplitude and the sawtooth period differed by less than 5 %. The times of the sawtooth crashes were determined from the electron cyclotron emission (ECE) in the plasma center. The ECE emission signal was first low pass filtered with a cut off frequency of 500 Hz. Then the time of maximum slope at the sawtooth crash was found by applying a peak search procedure to the differentiated signal. This procedure removed both broadband high frequency noise and fluctuations due to MHD mode activity. The averaging procedure was of course limited to plasmas where stable and reproducible sawteeth were observed. Experimentally this corresponds to plasmas with $q_a < 4$, low impurity content and intermediate plasma densities.

The spectra have been analyzed similar to [2] by fitting a line-of-sight integrated synthetic spectra to the experimental data. The shape of both the temperature and the density profiles were approximated from q-profiles [3] with the central temperature obtained from a fit to the spectra. The radial distribution of the different charge states due to diffusion was obtained from model calculations with the STRAHL-code from independent argon gas puff experiments [4]. The calculations show that for these plasma conditions the radial shape of the ratio $Ar^{15+}$ / $Ar^{16+}$ is insensitive to the diffusion coefficient and can be closely approximated by coronal equilibrium. Changes in the profiles for electron temperature and density during the sawtooth were not taken into account.

**Results**

All plasma properties, which were measured by x-ray spectroscopy, were modulated with the sawteeth as shown in figure 1. The ion temperature and the electron temperature increased in phase with the sawteeth as well as did the toroidal plasma rotation and the line intensity. The ratio between Li-like to He-like argon ions decreased during the sawtooth ramp. During the rising phase of the sawtooth, phase shifts and delays between the different parameters were not observed within the time resolution of the measurement.

Although, for these beam heated plasmas, the ion temperature was higher than the electron temperature, the modulation of the electron temperature was larger than the modulation of the ion temperature. The toroidal plasma rotation, as well as the intensity of the resonance line w ($1s^2 - 1s2p\ ^1P_1$) and the ratio $Ar^{15+} / Ar^{16+}$ were also modulated with the sawtooth. In the sawtooth crash, the plasma rotation dropped by 30 km/s, corresponding to about 25% of the maximum rotation speed of about 120 km/s. The ratio $Ar^{15+}$ / $Ar^{16+}$ decreased with increasing electron temperature, as would be expected from the coronal equilibrium, even though the density of Li-like argon was much higher than expected from the coronal equilibrium. This was probably due to charge exchange of the beam neutrals with the $Ar^{16+}$ ions [1,5]. The intensity of the w line increased with the electron temperature, which reflected both the rise in density and the temperature dependence of the excitation rate.

Still surprising was the behaviour of the plasma parameters at the sawtooth collapse. At the crash, the new equilibrium was obtained within the resolution of the diagnostic, i. e. within 2 sample points, corresponding to 1 ms, and no delay was observed. Even the plasma rotation and the ArXVI / ArVXII obtained their new equilibrium within the resolution of the measurement. These results were found for the experiments with high and with intermediate electron density.

Whereas the fast decay of the electron temperature was expected from ECE measurements and mode analysis, and the intensity of the resonance line was expected to follow the electron temperature, the fast decay of the toroidal plasma rotation and hence toroidal momentum is rather surprising and not covered by theory yet. The fast changes of the plasma parameters during the sawtooth crash will be analyzed in more detail in the future.

References


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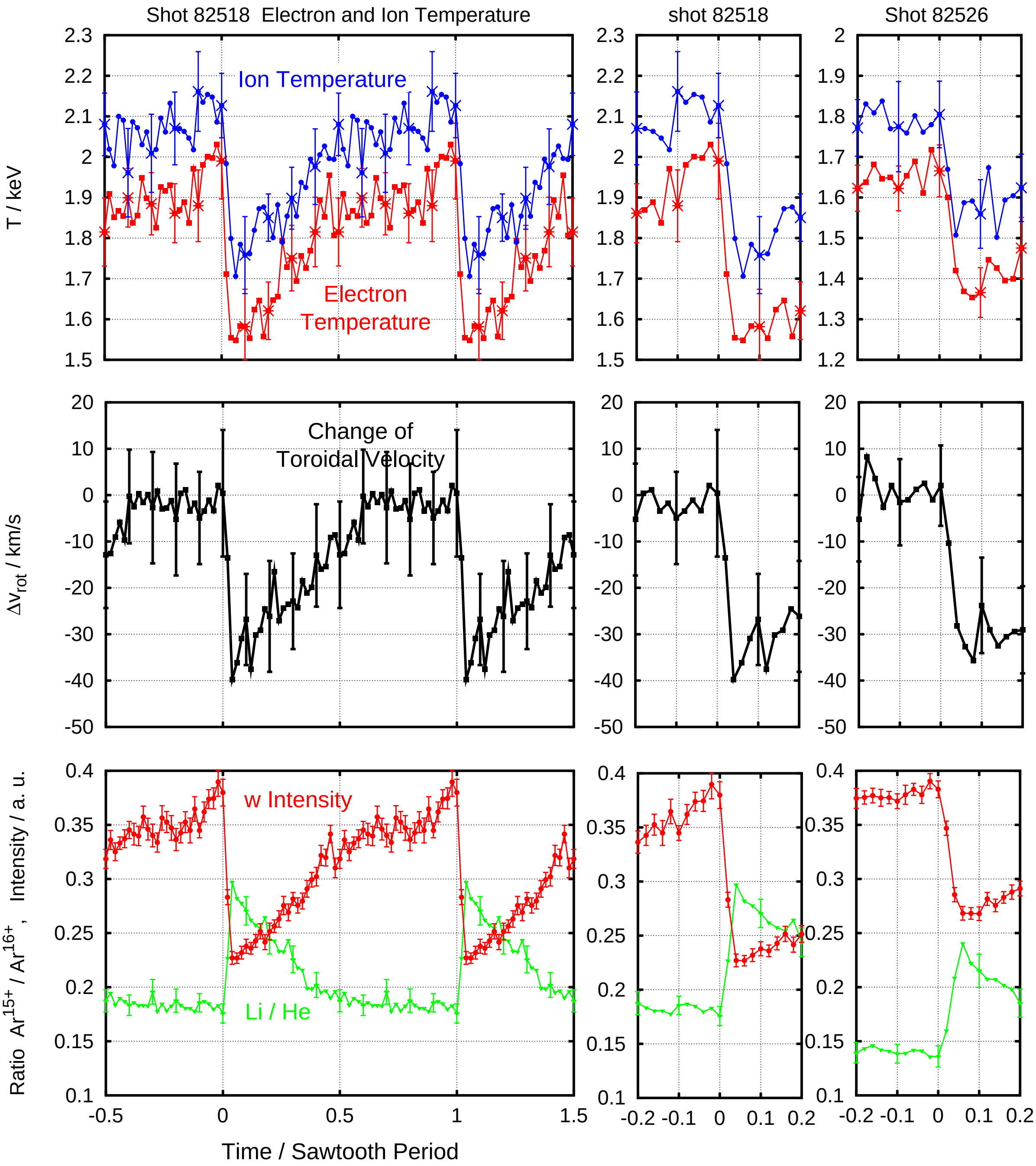


*Fig 1:*

*Modulation of plasma parameters as measured by x-ray spectroscopy at TEXTOR-94 for 2 different plasma conditions. The data were taken during the flat top phase of 4 identical shots, with a total observation time of 12 s. The data were summed up relative to the sawtooth crashes. The sawtooth averaged signals were duplicated beyond the interval [0, 1] to improve the visual impression. The electron and ion temperature, the toroidal plasma rotation, the intensity of the resonance line w ($1s^2$ – $1s2p\ ^1P_1$) and the ratio Li-like / He-like Argon are shown. At the right hand side, the behaviour around the sawtooth crash is shown, for densities of $2.8{*}10^{19}$ $m^{-3}$ (shot # 82518) and $3.7{*}10^{19}$ $m^{-3}$ (shot # 82526) respectively. Each data point corresponds to an integration interval of 0.5 ms. The error bars indicate a statistical error of $2\sigma$.*