

Space resolved measurements of plasma parameters using x-ray spectroscopy of He-like argon

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Imaging x-ray spectrometers are being used for the investigation of many of the present and the next generation of devices for magnetic fusion such as TEXTOR, NSTX, K-STAR and W7-X. For ITER, imaging x-ray spectrometers are planned to measure the ion temperature and the toroidal and the poloidal plasma rotation. Originally, Bitter et. al. [1] proposed to apply modified Johann spectrometers with two-dimensionally shaped crystals for that purpose. Spherically bent crystals have been in use for high resolution x-ray spectroscopy to optimize the throughput and the spectral resolution [2, 3]. In this paper, we show first measurements of the spatially resolved plasma parameters on TEXTOR.

Experiment

TEXTOR is equipped with two x-ray spectrometers, a horizontal spectrometer which is sensitive to vertically polarized radiation and a vertical spectrometer for horizontally polarized x-ray radiation. It has been shown that the x-ray radiation from TEXTOR is not polarized and therefore the 2 spectrometers have been used independently. Both spectrometers are of the Johann type, in order to achieve high spectral resolution without reducing the solid angle by entrance slits. In the horizontal spectrometer, the cylindrically bent crystal has been replaced by a spherically bent quartz crystal, cut 11-20, radius 3.850 m. The spectral resolution $\lambda/\Delta\lambda$ of the crystal was 5000 and instead of the original 1-dimensional detector a 2-dimensional x-ray Multi-Wire-Proportional-Detector with dimensions 100 * 300 mm² and a linear resolution of 0.4 mm has been used. The overall resolution of the spectrometer was then 4300. The crystal was limited vertically to 4 cm to improve the spatial resolution. The imaging properties of spherically bent crystals have been discussed in more detail in [2, 4].

The spatial resolution in the plasma is about 1.9 cm. The overall range in the plasma is limited by the size of the observation flange of $17 \times 12 \text{ cm}^2$ at the torus vessel, the range in the plasma is then $\pm 9 \text{ cm}$ around the midplane in the torus center, i. e. about 20% of the central plasma can be observed. A sketch of the imaging properties of a spherical Bragg crystal spectrometer is shown in fig. 1. On TEXTOR, the plasma is between the sagittal and

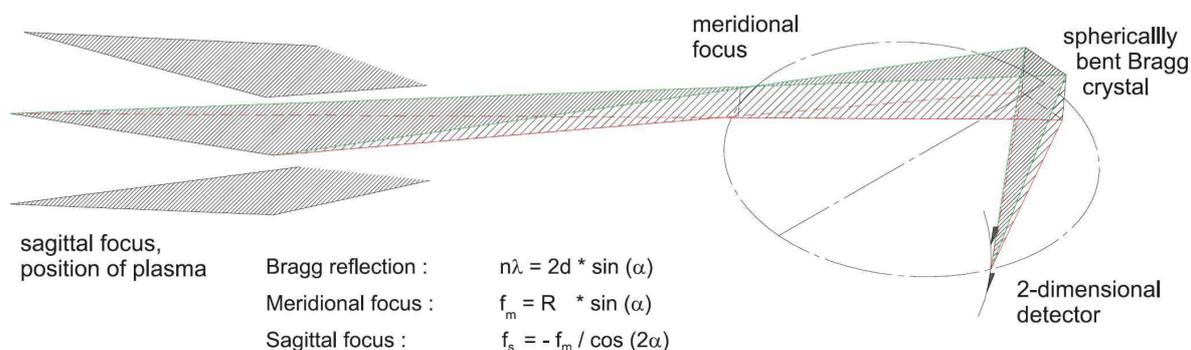


Fig. 1 Focussing of a spherical Bragg crystal. The crystal has the imaging properties of a monochromatic spherical mirror.

the meridional focus. The sagittal focal lines are horizontal and hence parallel to the midplane of the tokamak device, and therefore no variations of the plasma parameters are expected along the sagittal focal lines. The imaging properties of a spherical Bragg crystal are symmetric relative to the radius line and the Bragg condition is fulfilled on a cone. The intersection of the Bragg cone with the detector plane is then a conic section, for Bragg angles above 45 deg. and the detector perpendicular to the line of sight, the focal lines are ellipses.

In order to have a reasonable variation of the plasma parameters in the central region, we have chosen a discharge with low plasma current and hence high q_a at the plasma edge. Under these conditions, the plasma column shrinks and the plasma parameters vary measurably in the observed region. The plasma conditions have been obtained by ramping down the plasma current and puffing in argon gas by a fast piezo valve. The data were then taken in the subsequent phase where the plasma current was constant.

As expected, the focal lines are curved. A scatter plot of the data is shown in fig.2, together with the data which have been corrected with the theoretically expected ellipses. The variation of the spectral intensity along the vertical extend is different for the lines in the spectrum, indicating the variations of the electron temperature and the relative abundance of the ionic species. The spectra as shown in fig.2d are then fitted to a detailed theoretical model which includes all the relevant atomic processes such as electron impact

excitation, both of He-like and of Li-like argon as well as dielectronic, radiative and charge exchange recombination and inner shell ionization. The variation of the electron temperature and density, and the densities of the different ionization stages of argon ions are taken into account by integration along the lines of sight.

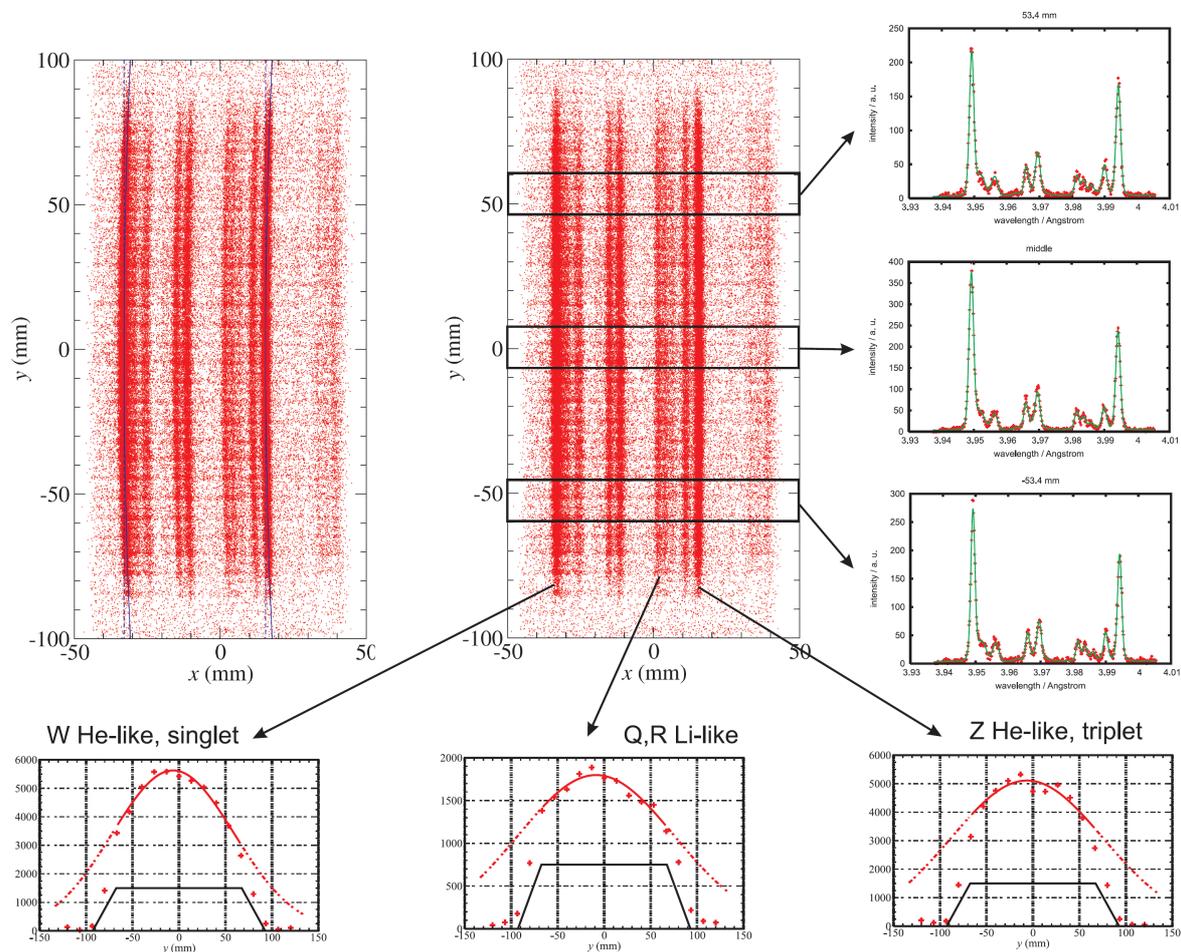


Fig 2 Scatter plot of a 2-dimensional spectrum of He-like argon
 a) left: raw data with theoretical ellipses
 b) middle: corrected for curvature
 c) lower: histograms along spectral lines (vertical)
 d) right: spectra and fit at indicated vertical positions

Results and discussion

The maximum electron and ion temperatures, as well as the relative abundance of the Li/He-like argon ions are shown in fig.3. The electron temperature decreases from the maximum in the plasma center to about 80% at $r/a = 0.2$, the ratio Li/He-like ions rises by 50%. The ion temperature is slightly smaller than the electron temperature and shows no clear dependence on the observed range. This may be attributed to the ion temperature

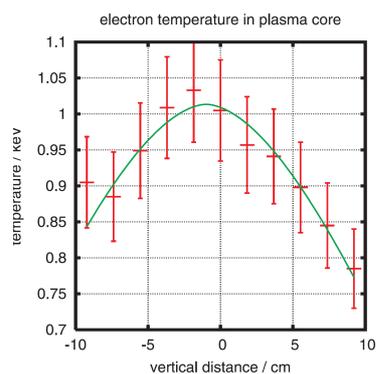


Fig 3a Ion and electron temperature in the plasma core

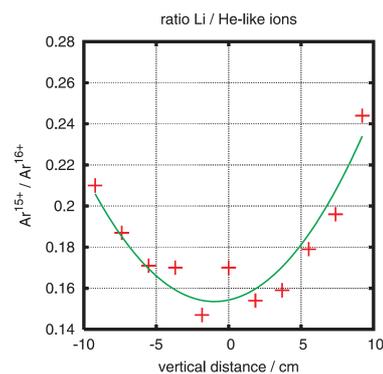
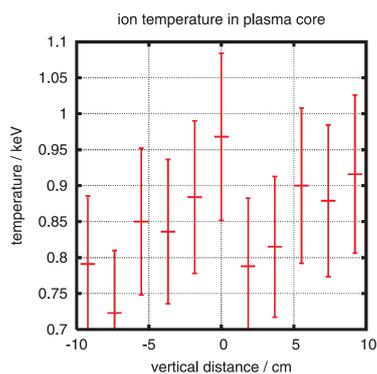


Fig 3b Ratio Li- / He-like argon ions

profile which in ohmically heated plasmas is broader than the electron temperature profile or to the larger statistical errors: Whereas the electron temperature varies approximately with the square root of the intensity ratio $(I_{w(He)}/I_{k(Li)})^{0.5}$ between the He-like resonance line and the Li-like line excited by dielectronic recombination, the ratio Li/He is proportional to the line intensities originating from the collisionally excited He- and Li-like ions, and the ion temperature varies with the square of the line width.

The measurements demonstrate that the imaging Bragg spectrometers are suitable to determine the plasma parameters in hot plasmas space resolved. More complete results are expected if the access to the plasma is widened. The apertures should extend to at least half of the plasma radius in order to include the region, where the electron temperature and hence the x-ray intensities are high. For the measurement of the ion temperature profile, the counting statistics must be improved either by extension of the measurement time or by replacing the 2-dimensional multi-wire-proportional-counters by segmented linear devices or by solid state detectors, which allow higher count rates.

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