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ION-TEMPERATURE AND ROTATION-VELOCITY PROFILE MEASUREMENTS FROM A SPATIALLY RESOLVING X-RAY CRYSTAL SPECTROMETER ON THE ALCATOR C-MOD TOKAMAK*

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A new spatially resolving x-ray crystal spectrometer (XCS) [1] capable of measuring continuous spatial profiles of high resolution spectra ($\lambda/d\lambda > 6000$) of He-like and H-like Ar Kα lines has been installed on the Alcator C-Mod tokamak. [2,3] The spectrometer enables greatly improved measurements of (a) ion-temperature (T_i) and (b) intrinsic-rotation-velocity profiles (v_ϕ) with excellent spatial (~1 cm) and temporal (~10 – 20 ms) resolution, as well as (c) study of the atomic physics of highly charged ions. Tomographic inversion enables inference of local line emissivity, T_i, and v_ϕ from the chord-integrated spectra. [4] Good measurements of the T_i profiles and gradients are important for comparison of measured ion thermal transport with a leading theory, which is based on ITG (Ion-Temperature-Gradient) induced turbulence. Also, plasma rotation profiles and gradients are strongly correlated with transport barriers, which can lead to greatly reduced transport. In particular, the new spectrometer will help in understanding intrinsic or self generated rotation, which is of importance for reactor plasmas.

Experiment

The imaging spectrometer [2,3] consists of two spherically bent crystals and four two-dimensional Pilatus II pixel detectors; [5] one crystal diffracts the He-like spectra (~3.94 Å), and the other crystal disperses the H-like spectra (~3.73 Å) of Ar. Both crystals are quartz 102, and have radii of curvature near 1.4 m. He-like Ar spectra are simultaneously measured

from ~50 or more chords covering r/a = 0 - 0.8. The C-Mod imaging XCS serves as a prototype for an ITER imaging XCS, which the U. S. will build.

Results

A non-inverted, spatially resolved spectrum of He-like Ar Kα lines is illustrated in Fig. 1, taken from discharge 1070614011, a 0.8-MA H-mode discharge with 3 MW of ICRF heating. Ion temperature, T_i, and plasma rotation velocity, v_ϕ, are inferred from Doppler broadening and Doppler shifting, usually of the resonance line, w.

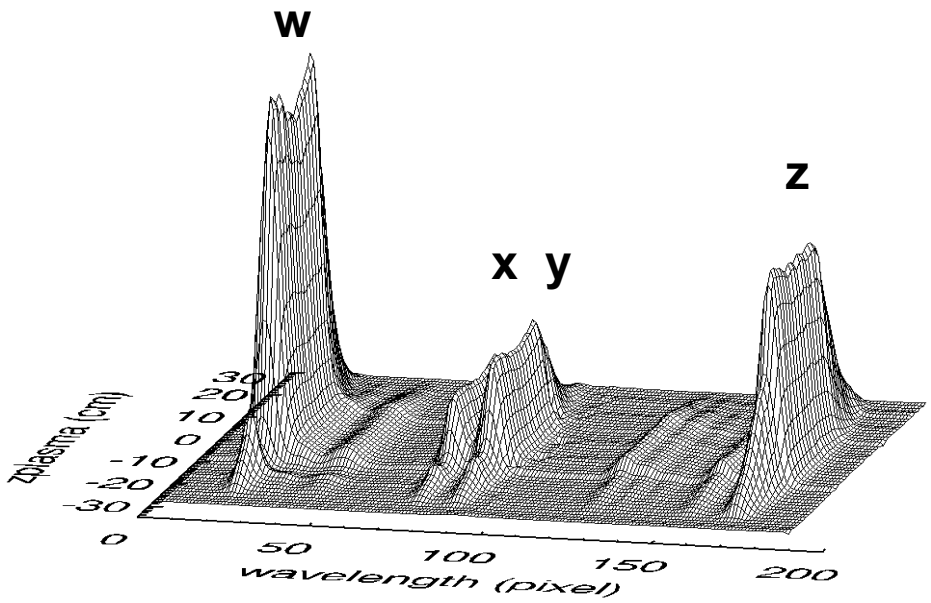

Fig. 1 Measured He-like Ar spectra as a function of z_{plasma}, or vertical height in the plasma at the center.

The imaging XCS on Alcator C-Mod provides data for determination of profiles of T_i and v_ϕ with very good spatial (1 cm) and temporal (10-20 ms) resolution. The spatially resolved T_i and v_ϕ profiles inferred from the non-inverted line w in Fig. 1 are plotted as a function of time in Figs. 2 and 3. During the ICRF-heated, H-mode phase, between 0.75 and 1.2 s, the non-inverted T_i increases from about 1 keV to 2 keV in the center, and the T_i profile broadens; the toroidal rotation velocity changes from -15 km/s at time 0.3-0.6 s to about +40 km/s in the core.

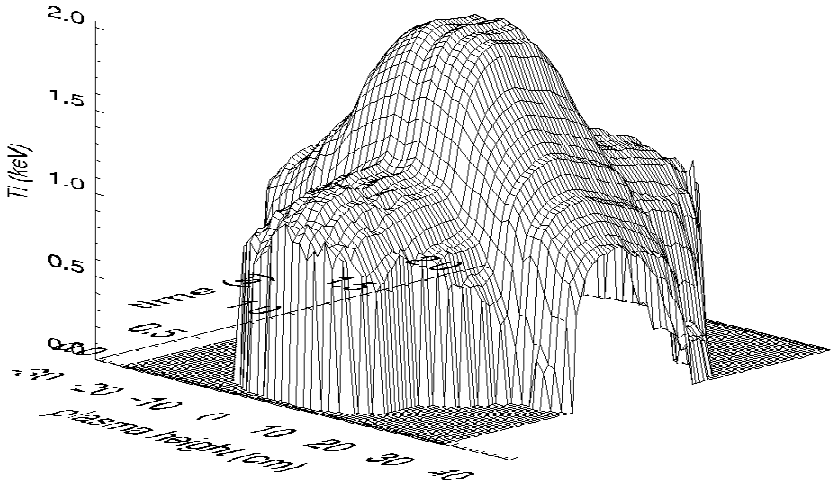

Fig. 2 Profiles of ion temperature, inferred from non-inverted spectra, as a function of time in ICRF-heated, H-mode discharge.

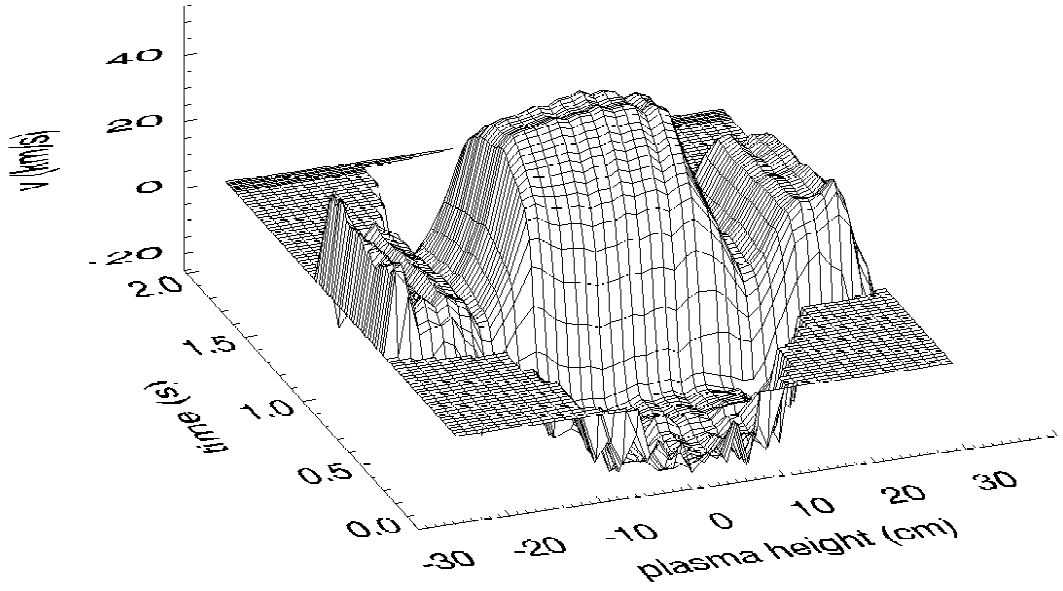

Fig. 3 Profiles of He-like Ar toroidal rotation velocity as a function of time in ICRF-heated discharge, inferred from non-inverted spectra.

Discussion

Tomographic inversion of the He-like spectra increases the central T_i for the discharge in Fig. 2 from 2 keV to about 2.5 keV, which agrees with the value of T_i inferred from the non-inverted H-like Ar spectra. The central electron temperature, T_e, is about 4 keV; therefore the He-like Ar emissivity profile is expected to be very hollow, and, thus the chordally integrated

spectra strongly weight cooler regions of the plasma, away from the center. The H-like Ar emissivity, however, is still centrally peaked at high T_e, so the chordally integrated spectral linewidths still reflect the approximate central value of T_i. At high density, when T_i and T_e should be equal, the XCS measurements of T_i agree with T_e measurements from other diagnostics. Reversals of rotation direction are observed during transitions to H-mode (Fig. 3) and to plasmas with an internal transport barrier in T_i.

The imaging XCS has been routinely taking data on C-Mod since April 2007 and is contributing to the C-Mod physics program. Since the C-Mod plasma is not heated by neutral beam injection (NBI) and, thus, has no external momentum input, one strong emphasis of the experimental program is the study of intrinsic rotation, which is of interest for reactor plasmas. Recent interesting insights on this phenomenon have been observed with lower hybrid current drive (LHCD). When the LHCD turns on, the toroidal rotation changes toward the counter-current direction on a time scale which is slower than the confinement time, and is closer to the current-penetration time. [6] The magnitude of the change in rotation is of order 40 km/s for about 1 MW of LHCD.

Acknowledgements

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