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Charge exchange recombination spectroscopy measurements from multiple ion species on the Joint European Torus

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* *See the appendix of M.L. Watkins, et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006)*

A programmatic goal of the Joint European Torus (JET) facility in 2009 is to implement an ITER-like wall, which implies a significant reduction in the amount of carbon present in JET discharges. As a result, carbon charge exchange recombination spectroscopy (CXRS) measurements (currently the preferred ion temperature and rotation measurement on JET) may be hindered. The current CXRS system on JET consists of a suite of instruments[1,2,3], simultaneously observing multiple ion species. CXRS measurements of ion temperature and rotation (toroidal and poloidal) are made (in the core[1,2] and at the plasma edge[3]) both on typical ion species, such as carbon, beryllium, and helium (C, Be, He), as well as on puffed impurity ion species, such as argon, neon, and nitrogen (Ar, Ne, N). A detailed comparison between simultaneous CXRS measurements of various ion species is presented. Results indicate that the toroidal ion temperatures (T_i) and rotations (v_T) measured from C, Ne, Ar, and N are in agreement to within instrumental errors. He/Be measurements have proven difficult because of the complexity of the spectra in the 468.5 nm region, though the results are not inconsistent with the measurements from heavier impurity ions. The effect of CX ion "plumes[4,5,6]" is being investigated as a confounding factor in the He/Be spectra. The implementation of an ITER-like wall, and subsequent reduction in carbon edge impurity lines, may simplify the complexity of the He/Be spectra, especially if the concentration of Be in JET plasmas increases. Results include analysis using the new CXSFIT routine[7], developed to standardize spectral line fitting on JET and other plasma devices, such as ASDEX-Upgrade.

Observations

When attempting to assess how well two measured values agree, there are a number of statistical markers that can be used. The "similarity" of two curves (**A** and **B**) can be defined[8] as the normalized dot product: $S \equiv |\mathbf{A} \bullet \mathbf{B}|/(|\mathbf{A}||\mathbf{B}|)$. For radial profiles (e.g. T_i, v_T) from different instruments the profile curves are made into "vectors" by interpolation onto a common radial grid, where the radius values are used as a set of basis vectors. Offsets in the measured quantities due to possible calibration errors are removed by the normalization, allowing a comparison of the profile shape (between two instruments) to proceed. By definition, $0 \leq S \leq 1$, and for typical radial profiles of CXRS measurements, $S \approx 1$. For this reason, it is useful to define the "dissimilarity:" $D \equiv 100\%(1-S)$, which can be thought of as the percent difference between two radial profile curves.

The CXRS instruments on JET typically produce data at 100 Hz, i.e. with an integration period on the order of 10 ms. Each JET pulse yields between 500 and 1000 frames of data for a given CXRS instrument. Figure 1 shows a comparison between two CXRS instruments (KS5C: tuneable; KS5D: fixed wavelength), both set to measure the 529.0 nm C VI CX line. "By eye" it is clear from Fig. 1a that T_i and v_T measurements from these two instruments are in good agreement. Not surprisingly, the "dissimilarity" for these instruments (Fig. 1b, c) are D_{Ti}=0.064±0.002 %, and D_{vT}=0.524±0.003 %.

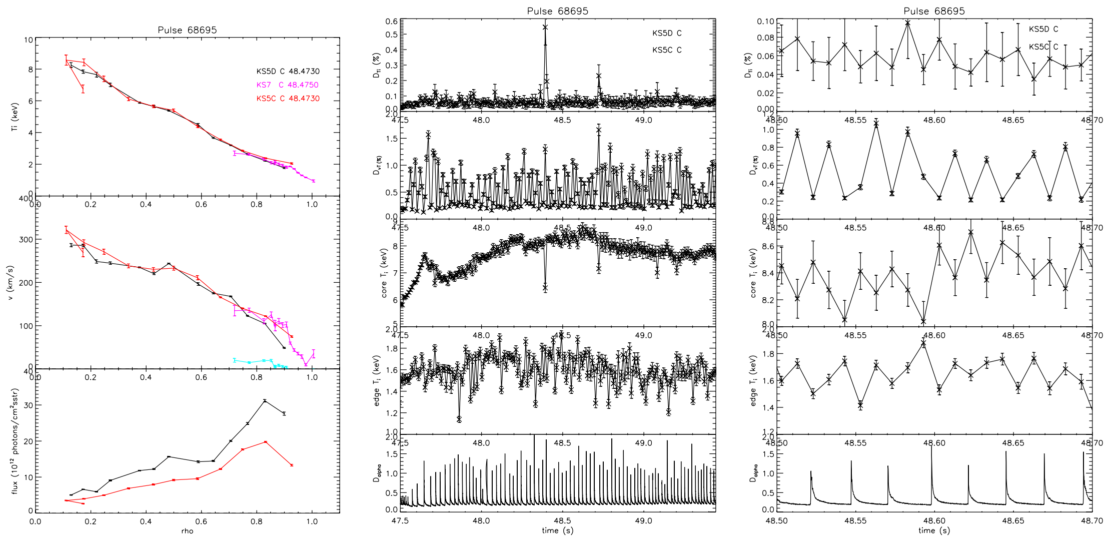

Figure 1: Comparison between three JET CXRS instruments, showing (a) profile measurements of T_i, v_T, and photon flux from C VI. (b) The time evolution of the "dissimilarity" of the two core instruments, which observe the same NBI PINIs, but from opposite toroidal directions. (c) A more detailed time history, showing that D_{vT} has a correlation with the occurrence of large Type-I ELMs.

KS5D C:	D_{Ti} (%)	S_{Ti}	D_{vT} (%)	S_{vT}
KS5C C	0.12 ± 0.04	0.9988	1.89 ± 0.07	0.9811
KS5C C/Ar	0.20 ± 0.05	0.9980	0.72 ± 0.09	0.9928
KS5C C/Ne	0.76 ± 0.05	0.9924	4.03 ± 0.12	0.9597
KS5C Ar	15	0.85	34	0.66
KS5C N	2.28 ± 0.04	0.9772	1.14 ± 0.02	0.9886
KS5C He/Be	1.23 ± 0.02	0.9877	3.65 ± 0.10	0.9735
KS7A C	0.69 ± 0.14	0.9931	5.84 ± 0.98	0.9416
KS7C C	0.131 ± 0.003	0.99869	2.74 ± 0.01	0.9726

Table 1: CX line brightness weighted average of D and S between C and other ions for T_i and v_T measurements analyzed with CXSFIT in JET discharges. The KS5 instruments cover ~0<r/a<~0.9, while KS7A covers ~0.35<r/a<~0.75 and KS7C covers ~0.75<r/a<~1.

Discussion

Overall, there is a high level of agreement between the multiple measurements of T_i and v_T in JET plasmas. Across instruments and across ion species, S~0.99, compared to the theoretical maximum of S=1. Nevertheless, this analysis suggests that there could be resolvable (though small) differences between ion species at high CX signal levels.

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