CXRS 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).*

ABSTRACT

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 measurements on JET) may be hindered. The current CXRS system on JET consists of a suite of instruments, 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. Preliminary 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 form heavier impurity ions. The effect of CX ion "plumes[4]" 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[5], developed to standardize spectral line fitting on JET and other plasma devices, such as ASDEX-Upgrade.

CXRS SYSTEMS ON JET [1,2,3]

- JET core Charge Exchange Recombination Spectroscopy (CXRS) [1,2] consists of:
  - Two horizontally mounted periscopes (octants 1 and 7) viewing the heating neutral beams (octant 8, primarily PINI's 6 and 7)
  - Three vertical views of NBI PINI's and background plasma
  - 44 spatial views/periscope covering from outboard mid-plane to beyond the magnetic axis
  - 7 instruments providing coverage of spectral range from 430 to 750 nm
- JET edge Charge Exchange Recombination Spectroscopy (eCXRS) [3] consists of:
  - Three periscopes viewing the heating NBI PINI's
    - 22 paired vertical views on Octant 4
    - 15 vertical Octant 8 views extending into core region
    - Slight toroidal offset from the NBI's allows for toroidal and poloidal rotation measurements
  - 2 instruments providing coverage of spectral range from 430 to 750 nm

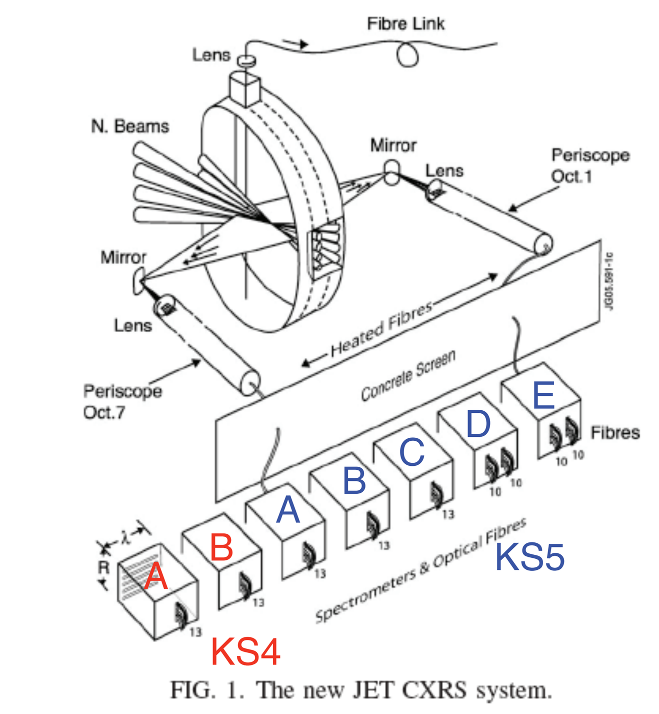

*Figure 1: Fig. 1 from Ref. [1] showing details of the JET **core** CXRS system, viewing Octant 8 neutral beams.*

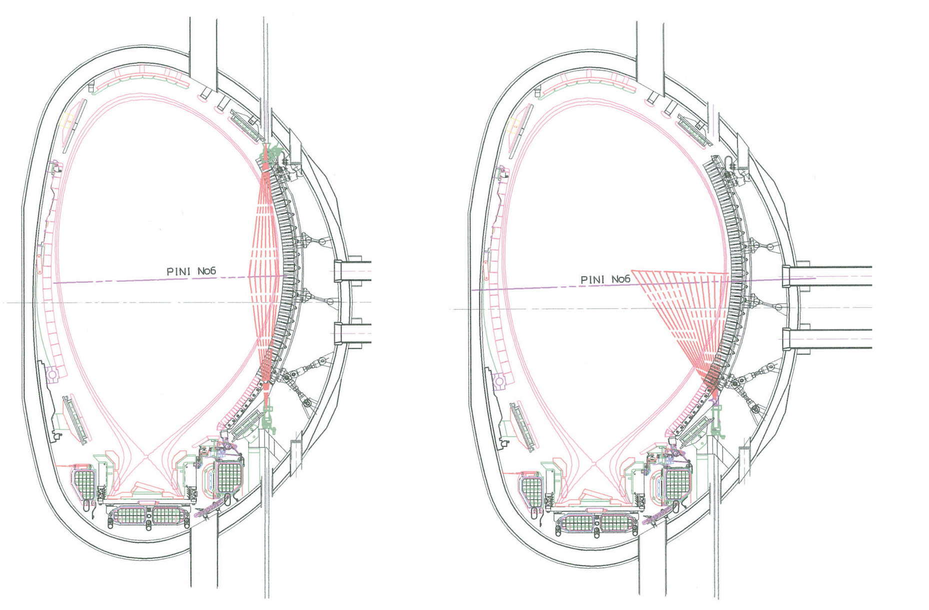

*Figure 2: Line-of-sight coverage of the JET **edge** CXRS system (KS7), viewing Octant 4 and Octant 8 neutral beams.*

SIMILARITY: normalized dot product[6]

- The "Similarity" of two curves (**A** and **B**) can be defined as: $S=|\mathbf{A}\bullet\mathbf{B}|/(|\mathbf{A}||\mathbf{B}|)$
  - For radial profiles (e.g. T_i, v_T), the profile curves are vector-ized by interpolation onto a common radial grid (radius used as a set of basis vectors.)
  - Offsets due to (potential) calibration errors are removed by the normalization.
  - $0 \le S \le 1$, and typically (for radial profiles of CXRS parameters) $S \approx 1$
- It is useful to define the "Dissimilarity" of two profiles: $D = 100\%*(1-S)$
  - D can then be interpreted as the % difference between two curves.
- This is only one (of many) possible quantified measures of the agreement between data.

MEASUREMENT COMPARISONS

- Good agreement between core CXRS measurements of C VI.
  - Instrument KS5C (tuneable, Czerny-Turner, XCAM) compared to KS5D (fixed, Kaiser Optical, Roper).
  - Both instruments set to cover the C VI CX line at 529.0 nm.
  - Both view the same NBI PINIs (octant 8), but from opposite toroidal directions.
  - $D_{Ti} \sim 0.12\%$ ($S_{Ti} \sim 0.9988$), $D_{vT} \sim 1.89\%$ ($S_{vT} \sim .9811$)

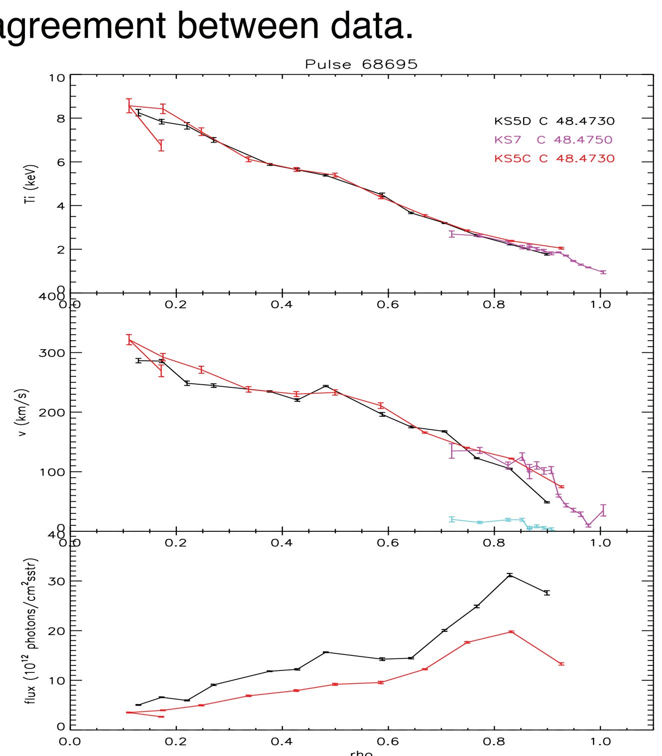

Figure 3: Profile comparisons between three JET CXRS instruments measuring C VI.

MEASUREMENT COMPARISONS (contd.)

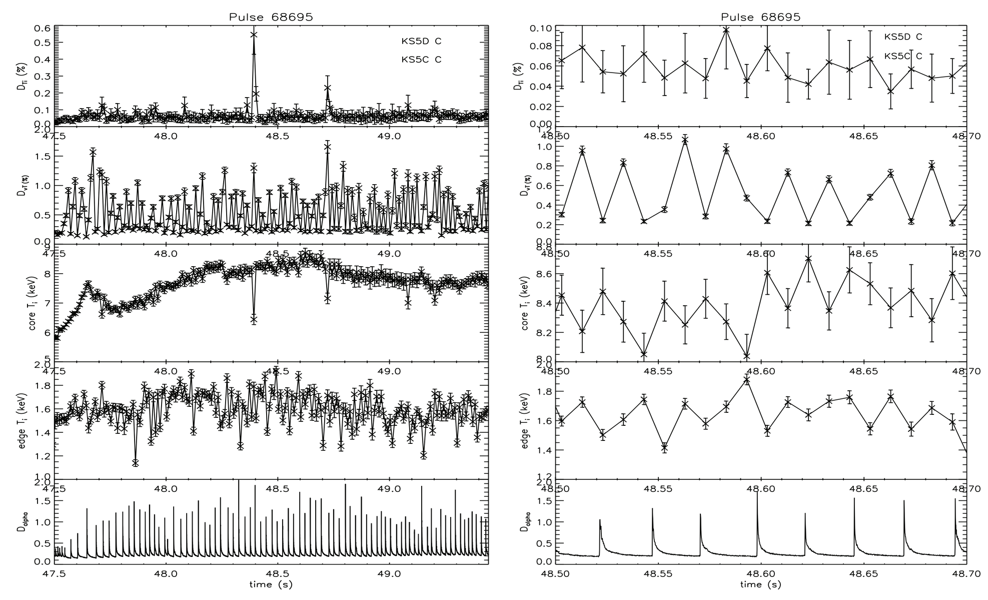

Figure 4: The "dissimilarity" of the C VI T_i and v_T profiles during a JET discharge with large Type-I ELMs. D increases at the ELM.

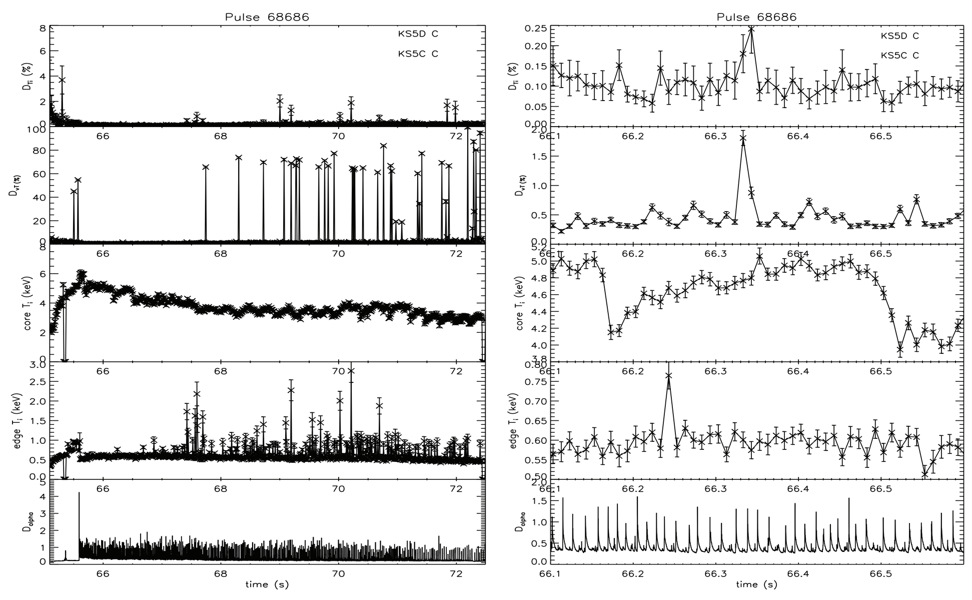

Figure 5: The "dissimilarity" of the C VI T_i and v_T profiles during a JET discharge with sawteeth and smaller Type-I ELMs. D remains relatively constant.

- Core CXRS measurements of C compared with N, He/Be, Ar, etc.:
  - KS5D fixed on C VI (529.0 nm), KS5C tuned to various wavelengths on different discharges.
  - D is a measure of dissimilarity between CXRS of C and the "other" ions.
  - In practice, some CX lines in the same spectra are fit with "coupled" T_i, v_T
    - e.g. C/Ar, He/Be, C/Ne
  - As expected, scatter in D improves at higher CX line brightness.

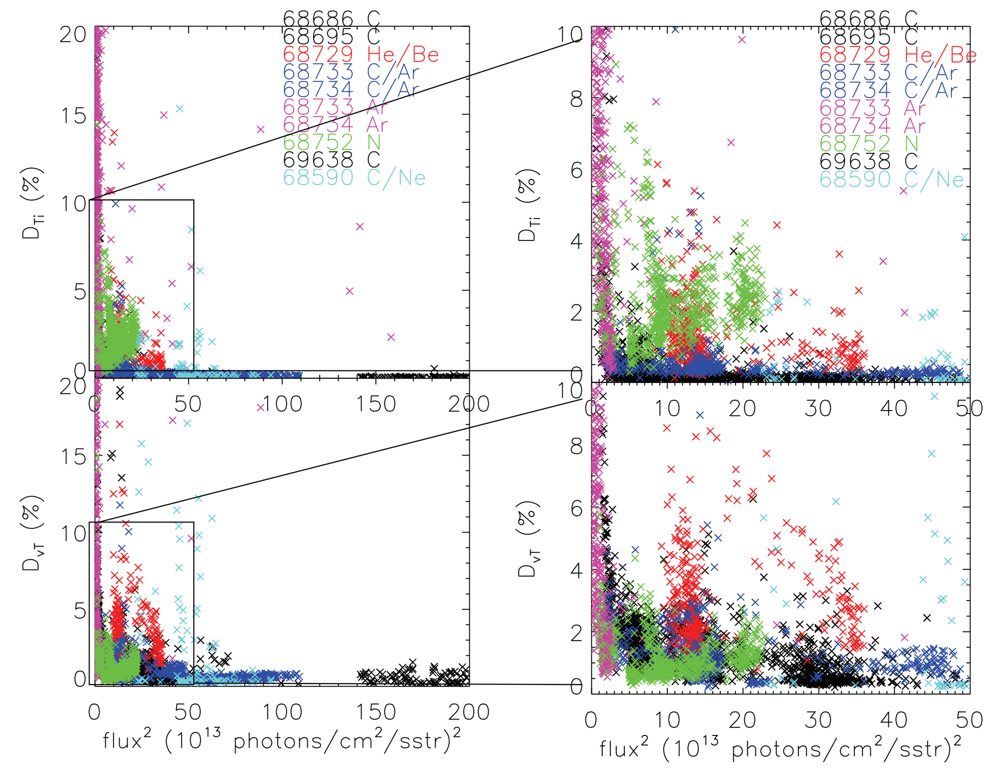

Figure 6: The "dissimilarity" between C and other ions is reduced as the total CX signal increases for both T_i and v_T measurements. Error bars suppressed for clarity of data.

- Comparison between overlapping core CXRS and "edge" CXRS measurements:
  - Core KS5D fixed on C VI (529.0 nm), "edge" KS7 tuned to various wavelengths on different discharges.

	KS5D C:	D_{Ti} (%)	D_{vT} (%)
core	KS5C C	0.12 ± 0.04	1.89 ± 0.07
	KS5C C/Ar	0.20 ± 0.05	0.72 ± 0.09
	KS5C C/Ne	0.76 ± 0.05	4.03 ± 0.12
	KS5C Ar	15	34
	KS5C N	2.28 ± 0.04	1.14 ± 0.02
	KS5C He/Be	1.23 ± 0.02	3.65 ± 0.10
edge	KS7A C	0.69 ± 0.14	5.84 ± 0.98
	KS7C C	0.131 ± 0.003	2.74 ± 0.01

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[5] on JET pulses.

SUMMARY

- Overall, there is a high level of agreement between the multiple measurements of T_i and v_T, across instruments and across ion species: $S \sim 0.99$ (maximum value of 1).
- Nevertheless, this analysis suggests that there could be resolvable (though small) differences between ion species at high CX signal levels.

REPRINTS

Electronic copy available at: http://sprott.physics.wisc.edu/biewer/EPS07poster.pdf

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