# DIAG-6 Cross Comparisons of Charge Exchange Recombination Spectroscopy (CXRS) and X-Ray Imaging Crystal Spectroscopy (XICS)

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| **TG priority:** High | **Start date:** 2014 | **Status:**  On-going | **Personnel exchange:**   |
| **IO priority:**   | **End date:**   | **Motivation:**   |

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| **Device /****Association** | **Contact****Person** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2014** | **2015** | **2016** |
| C-Mod  | M. L. ReinkeJ.E. Rice | Desirable |   | Considering |   |
| ITER  | R. Barnsley | Desirable |   |   |   |
| J-TEXT  | Z. Chen | Desirable |   |   |   |
| NSTX-U  | L. Delgado-AparicioK. Hill | Desirable |   |   |   |
| Tore Supra  | C. Fenzi | Desirable |   |   |   |
| JET  | N. Hawkes,M. von Hellermann,A. Shumack | Desirable | Considering |   |   |
| KSTAR  | S.G. Lee | Desirable | Committed |  Committed  |   |
| EAST | B. Lu, Y. Shi | Desirable |   | Committed |   |
| TEXTOR  | O. Marchuk | Desirable |   |   |   |
| LHD  | S. Morita, N. Pablant | Desirable |   |   |   |

**Results for 2015**

* Cross comparisons of XICS and CXRS from KSTAR were committed. The measured core toroidal rotation and ion temperature have shown in reasonable agreement with various plasma discharges, and the initial results were presented in the “1st IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis”,
* a two-Gaussian fitting for the CXRS measurements without beam modulation have shown in good agreement with the XICS results from KSTAR,
* cross comparison experiments have done from EAST and detail analysis is ongoing.

**Plans for 2016**

* More cross comparison experiments will be perform at KSTAR and EAST,
* Ar impurity transport studies will be carried out at KSTAR.

**Background:** Demonstrating our understanding and control of high-temperature, magnetically confined plasmas relies heavily on being able to measure its quasi-steady kinetic properties. The electron species is well diagnosed with active techniques for the density, Thomson scattering (TS) and interferometry, and both active and passive methods for the temperature, TS and electron cyclotron emission (ECE). Detailed cross-validation of TS and ECE temperature measurements has recently been completed up to 8 keV (White – 2012). In contrast, the density, flow and temperature profiles of the ion species have traditionally been characterized by a single method using Doppler spectroscopy of discrete line-emission. The majority of experiments have utilized charge exchange recombination spectroscopy (CXRS – also known as CER or CHERS) where the emission is enhanced and localized by interaction with externally injected high energy neutral particles. The development of CXRS since the 1980s, accelerated by the common use of heating beams to provide the high energy neutrals, has identified a number of corrections due to atomic physics (von Hellerman - 1995, Bell - 2000), and the technique is mature and well established in the tokamak community. Most analysis uses light impurities such as carbon, but CXRS has been demonstrated for heavier atoms such as argon and, more recently, on hydrogenic species (Grierson - 2012).

There also exists a long history of Doppler analysis being performed on x-ray line-emission emitted from partially ionized impurities in the bulk plasma. Strong Doppler broadening of line emission from metallic impurities, such as iron (Bitter - 1988) or nickel (Danielsson - 1992) were observed on TFTR and JET, respectively, but these measurements suffered from a lack of spatial localization. X-rays are emitted from the bulk plasma over a wide range of normalized minor radius, and individual measurements provide an average value. This has recently been overcome by using advanced x-ray imaging detectors to image Bragg diffracted emission from a spherically-bent crystal, allowing for sufficient spatial coverage and resolution to apply Doppler tomography techniques to find local flow and temperature data. This approach, x-ray imaging crystal spectroscopy (XICS), should be differentiated from x-ray crystal spectroscopy (XCS) of only a few discrete chords which is unable to properly constrain an inversion. While early success with XICS has been demonstrated (Ince-Cushman – 2008, Reinke – 2012), and its use is expanding, no systematic comparison of the XICS and CXRS techniques has been completed.

 ITER plans to rely more heavily on XICS for core temperature and flow measurements as compared to present experiments, due to weaker penetration of neutrals at energies favorable for light impurity charge exchange. ITER will also have a substantial alpha population, and collisional coupling of highly charged impurities to this slowing down distribution may alter the apparent impurity temperature relative to the bulk ions. This has already been suggested as a cause for differences in carbon and deuterium temperatures in DIII-D plasmas (Grierson – 2012). This makes it prudent to validate XICS and the relevant high-Z impurity transport physics to the level that has been done by CXRS (over decades) prior to ITER operations. Many devices around the world are developing or have now deployed XICS, with a smaller number having both fully operational CXRS and XICS diagnostics.

**Methodology:** Two main goals are to be investigated:

1. verification of the Doppler tomography method
2. validation of the physics of impurity-ion coupling in the presence of non-thermal ions

XICS and CXRS will be compared in plasmas with varying ion-impurity collisionality and fast-ion pressure. Both L-mode and H-mode plasmas should be explored, as well as Ohmic plasmas with neutral beam “blips”. Whenever possible, local comparisons should be made using inversions of XICS data with the minimum of *a-priori* information.

Where applicable, comparisons between XICS of different charge states and impurities will also be used, as well as comparison between XICS-based Ti and Te from TS and/or ECE at high collisionality.

Devices with edge/pedestal CXRS diagnostics can also make important contributions by comparing active CXRS with Doppler spectroscopy of intrinsic emission localized near the boundary.

Detailed verification of Doppler tomography codes will be completed using a common set of “base case” input profile and equilibrium data. Attempts will be made to define standardized analysis codes and tools. Discussion of the impact of various topics should be included; natural line broadening, intrinsic vs. extrinsic impurities, poloidal impurity density asymmetries, etc.

Spectra from XICS instruments also feature satellite emission which, when normalized to emission from resonance lines can be used as a function of electron temperature. Where possible, comparisons between line-ratios and TS and ECE measurements should be made and compared to predictions from atomic physics modeling.

**Primary Tasks:**

1. On devices with both CXRS and XICS, document localized measures of Ti, toroidal rotation, poloidal rotation and radial electric field
	1. On devices with only CXRS and discrete XCS, document consistency between line-averaged Ti deduced from CXRS and measurements from XCS. Emissivity profiles for the XCS emission should be derived from impurity transport simulations.
2. On devices without CXRS, document comparisons of Ti and Te at high collisionality.
3. On devices with pedestal CXRS, document comparisons between NBI-based Ti and rotation and that from Doppler tomography of intrinsic signal
4. On devices with CXRS and XICS or discrete XCS, demonstrate equivalent real-time feedback control of toroidal rotation using both measurements as observers.

**Secondary Tasks:**

1. On devices with TS/ECE and XICS document localized measurements of Te from emissivity line ratios.
2. Verify multiple codes for XICS analysis and develop common standards for numerical codes.

**References**

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(Ince-Cushman – 2008) A. Ince-Cushman, *et al*. Rev. Sci. Instrum. **79** 10E302 (2008)
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