Tomographic inversion of XICS spectroscopic measurements for radial electron temperature in WEST

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Introduction: The WEST tokamak is equipped with an imaging X-ray crystal spectrometer (XICS) [1]. It has 3 sets of spherically bent crystals, mounted on a patented rotating table [2], targeting 3 different ionic species (Ar XVII, Ar XVIII, Fe XXV). The remotely controlled table allows to choose the crystal facing the plasma before each pulse. The measurements are analysed to compute line of sight(LOS)-integrated electron temperature profiles T_e, from a spectral line intensity ratio, ion temperature profile T_i, from the Doppler broadening of the lines, and toroidal rotation velocity v_{rot} from the Doppler shift.

Ar XVII spectra: The diagnostic is installed in the Johann configuration. Each component, crystal and camera, is placed tangentially on the Rowland sphere. The curvature of the crystal in the meridional plane enables the wavelength focus on the same plane on the camera. The same curvature in the perpendicular plane allows to create a symmetrical image of the plasma height on the 2D detector. 2D raw spectra are measured as shown in Fig. 1. The axes are transformed to obtain the wavelength scale in the x-axis and the plasma height on the y-axis, expressed by an impact parameter from the central line of sight going through the plasma centre.

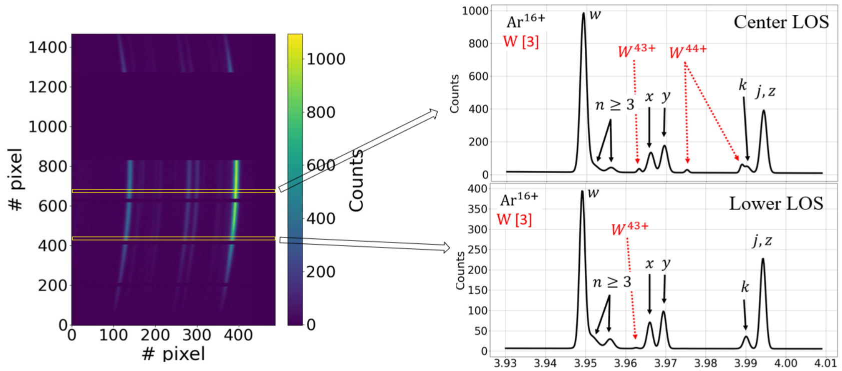

Figure 1: *2D raw Ar^{16+} spectra from XICS and 2 1D spectra corresponding to two different lines of sight.*

Slices are then made to obtain 1D spectra on which are identified the Ar lines of interest. Those used to compute T_e profiles are the Ar^{16+} resonance line w and the Ar^{16+} dielectronic satellite line n≥3. The whole 2D spectrum is treated assuming a Gaussian distribution to fit the spectral lines : $I_i(r) \propto A(r)exp\left(-\left(\lambda-\lambda_0-\lambda_0\frac{v(r)}{c}\right)/2\omega(r)^2\right)$. The Gaussian's amplitude, width and shift are then used to compute LOS-integrated profiles of T_e, T_i and v_{rot} respectively as a function of the impact parameter, see Fig. 2.

Tomographic inversion: The goal of tomographic inversions for tokamak plasmas is to reconstruct the spatial distribution of the emissivity within a given volume from the sum of the radiation emitted along a volume of sight. This is called an inverse problem, to solve a linear system of equations to obtain the emissivity vector $\overrightarrow{f}$ given a measurement dataset $\overrightarrow{f}$ and a computed geometry matrix mapping the whole volume V_{ij} [5]: $\overrightarrow{m} = \sum_j V_{ij} \times \overrightarrow{f}$. In general, tomographic inversion are ill-posed problems because the measurements themselves cannot provide all the information needed to reconstruct the object, and some errors are added such as technical noises due to the diagnostic components. As a result, several possible solutions are available and the more complete is the acquisition system, the fewer the possible solutions. In order to solve this problem, an accurate geometry matrix has to be implemented, taking into account the whole volume of sight available from the diagnostic. This matrix has to describe each element of emission within the volume and for all the volume of sight of the diagnostic and to give them a statistical weight. B-splines can be also implemented in order to smooth upon few voxels the solution. The computations are based on a least-square method in order to minimize the loss between the measurements and the reconstructed image : $\psi(\overrightarrow{f}) = ||\overrightarrow{m} - V\overrightarrow{f}||^2 + \theta\Gamma(\overrightarrow{f})$. Regularization parameters, in the previous relation a scalar θ and an operator $\Gamma(\overrightarrow{f})$, can be applied to the least-square computation to also improve the smoothness of the solution and to fasten the convergence. Tikhonov regularization is one of the regularization methods, often used for models with a large number of parameters. Derivative of first and second degrees can be used to constraint the behavior of the function. Tomographic inversion with Tikhonov regularization can thus induce accurate radial emissivities which are used to compute radial T_e.

Electron temperature inversion: The temperature obtained is deduced from measurements integrated along lines of sight. They cannot be compared directly with other local T_e measurements, e.g. those of the ECE radiometer.

To extract the local T_e from the crystal spectrometer, we must use tomographic inversion. Theoretically, this method consists in few steps. First, the Gaussian's amplitude, width and shift are extracted experimentally from measurements. To invert these quantities, we need to take the moments of integration of the Gaussian distribution function to have access to each component : $M_{n,i} = \int d\lambda I_i(r)(\lambda - \lambda_0)$. The inversion of each moment gives thus access to the inverted Gaussian's components. As an example, Fig. 2 shows

Figure 2: *LOS-integrated and inverted T_e profiles from XICS diagnostic.*