Visible spectro-tomography: from low temperature laboratory plasmas to the WEST tokamak

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With the former Tore Supra tokamak being modified in the frame of the WEST project, the X-ray imaging crystal spectroscopy and the helium beam emission spectroscopy (He BES) diagnostics are being significantly upgraded. These two diagnostics, mandatory to address the physics of transport, are designed for spatially and temporally resolved kinetic profile measurements from the core to the edge of plasma.

In parallel, a visible spectroscopy-tomography setup is being prototyped to extend the 1D radial He BES measurement of the electron temperature (T_e) and density (N_e) to a 2D map of the scrape-off layer. The diagnostic is currently being developed on the stable low temperature low pressure magnetized plasma column of the Mistral set up at the PIIM laboratory [1].

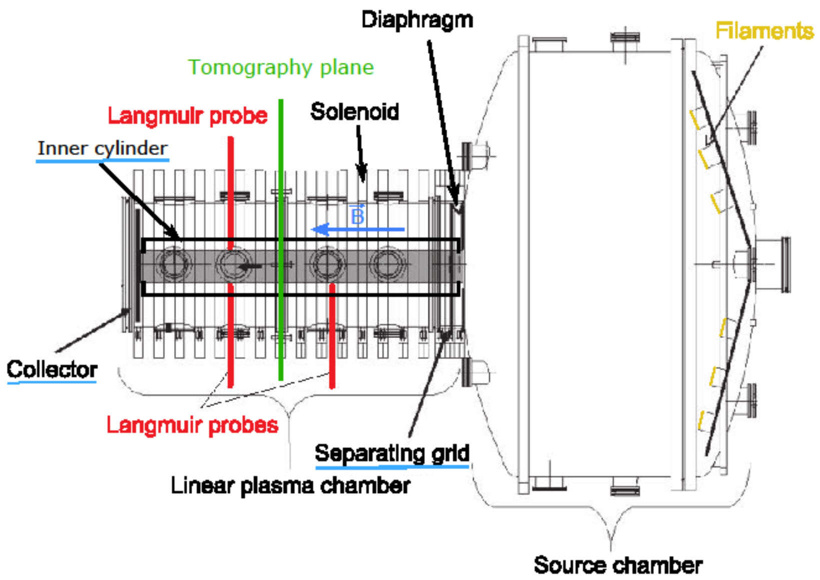

Figure 1 - Schematic view of the Mistral setup showing the diagnostics position and the different tunable parameter controlling the discharge. The size is 1 m length and Ø 1.4 m for the chamber source and 1.5 m length and Ø 0.4 m for the linear plasma chamber.

In Mistral the plasma is generated by 30 to 40 eV primary electron emitted by 32 tungsten filaments in the source chamber. The magnetic field and different polarized surfaces (underlined in blue on Figure 1) in both the source and linear plasma chamber allow an accurate, stable over several hours, and reproducible control of the plasma behaviour. The neutral pressure is typically in the range 1.10^{-4} to 6.10^{-4} mbar and the confinement magnetic field in the linear plasma chamber is set from 150 to 200 Gauss. In this experimental conditions the plasma exhibits a steady rotating mode extended along the axis of the linear plasma chamber with a characteristic frequency of 3 to 8 KHz [2], [3]. Different optical and electrostatic diagnostics have been used to study the so-called flute modes. However none of them have been able to clearly evidence the physics involved. Nevertheless transport induced by **E**x**B** drift appears as the most likely mechanism. We expect the new spectro-tomography diagnostic, while being tested, to bring new insight trough the mapping of density and temperature of the different species in a radial plasma slab.

The spectro-tomography technique is the combination of the well-known spectroscopy technique and the widely used tomography analysis method (e.g. for medical imaging). The spectroscopy allows the determination of the plasma parameters, such as electron, ion, neutral and metastable temperature and density, from emission lines. Classical spectroscopy studies are performed with a single line of sight (LoS). In this case the plasma parameters obtained from the spectrum analysis are integrated values along the LoS. The loss of spatial resolution comes from the fact that the measured signal correspond to the integral, over the LoS length, of local emissivity of the optically thin plasma. With $i = 1,..,L$ intersecting LoS, the tomography technique gives access to the local plasma emissivity, divided into pixels from $j = 1, \ldots, N$, through the so-called tomographic relation: $f_i = \sum_i \sum_j T_{ij} g_j$ [4]. The measured signal, f_i, on the i^{th} line of sight is linked to g_j the local emissivity of the plasma in the j^{th} pixel, through the transfer matrix T_{ij}. Thus the transfer matrix inversion gives access to the emissivity of the plasma. However the discretisation of the problem leads to an ill-conditioned and underdetermined transfer matrix. Consequently much care is needed in the inversion process. Therefore instead of directly solving the system, we aim for the local emissivity g_j through the minimisation of $\phi = \frac{1}{2}\left(T_{ij}.g_j - f_i\right)^2 + \alpha R$ with α a positive weighting parameter and R a regularizing functional.

Several methods have been developed to obtain the best regularisation [5]. In the tomography inversion code developed at the PIIM laboratory, numerical tests have shown that a second order regularizing functional of the plasma emissivity is the most suited with our experimental setup. No further hypothesis is made on the plasma shape or position. Figure 2 shows the result of a tomographic inversion performed on a ghost image with similar features as the rotating plasma observed in Mistral. To validate the tomographic inversion we compare the solution to a discretized ghost image on the pixel grid used to perform the tomography. From this comparison we make sure to obtain a physical solution of the system. Then we compare the signal measured on the LoS on the ghost image and on the tomographic inverted solution.

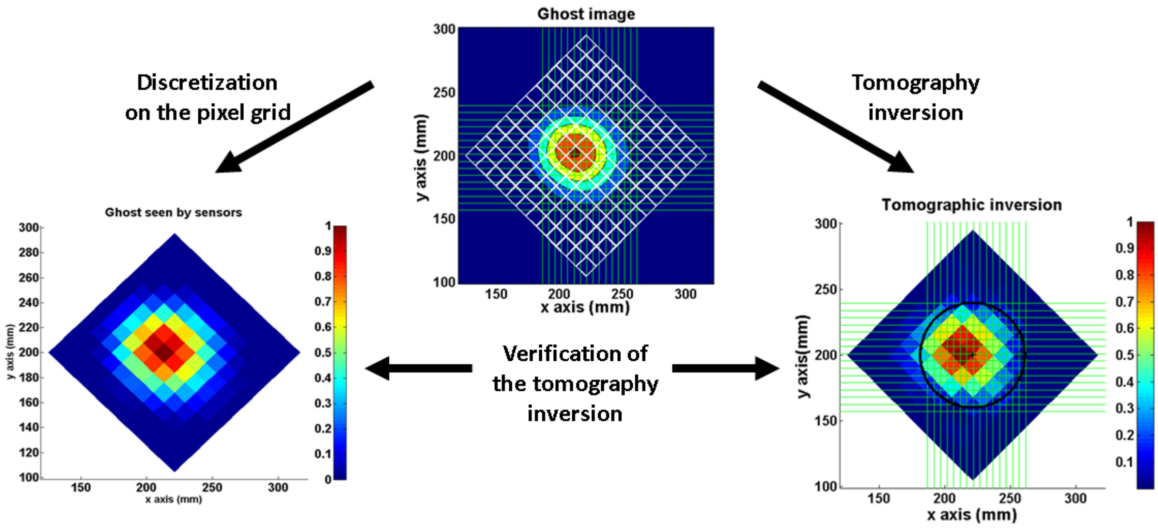

Figure 2 - Validation of the tomographic inversion code developed at the PIIM laboratory.

Figure 2 shows that for a plasma of diameter 80 mm a setup with 32 parallel LoS (green lines) and a square pixel grid (white grid) of 12x12 pixels a resolution of 9x9 mm² can be achieved with a good physical agreement.The spectro-tomography experimental setup being developed will provide up to 128 LoS set on a parallel or hand fan pattern. We expect to be able to image the Mistral plasma from the column centre up to a radius of 15 cm with a resolution under 1 cm.

Nevertheless imaging a large number LoS on a single spectrometer is a challenge. A meticulous characterisation of the Isoplane 160 imaging spectrometer has been carried out to precisely measure the physically available height of the entrance slit and therefore estimate the number of LoS that can be fitted on the entrance slit. An argon spectral lamp has been used to uniformly light the spectrometer over the 15 mm height of the entrance slit. Figure 3 shows two constant emission line ratios calculated from the simultaneous acquisition of 64 spectrums distributed over the total height of the image field plane. When the light source is a low temperature plasma, the emission lines selected gives access to the electron temperature and density [6]. From Figure 3 we see that the Isoplane 160 imaging spectrometer has an effective entrance slit height of 11 mm. Consequently this parameter as well as the optical fibre diameter limit the number of LoS available for the tomography. The first experiments will be carried out with 200 μm diameter optical fibre to optimize the brightness of the system. The number of LoS is thus limited to 40. Regarding the time resolution, two amplified ccd cameras will be used, the ProEM ccd for high accuracy spectrum with low brightness plasma and the 4 Quick E for fast acquisition spectroscopy.

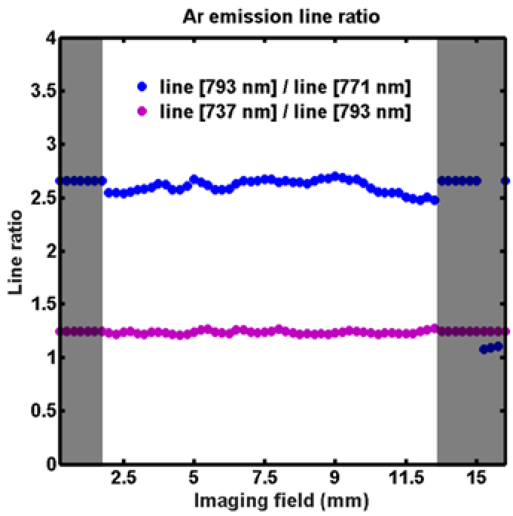

Figure 3 - Argon spectral lamp emission line ratio as a function of the imaging field height. The optical centre of the spectrometer is located at the position 7.5 mm. The dark areas correspond to slit height where the spectrometer does not allow accurate OES measurement.

In conclusion, the visible optical emission spectro-tomography diagnostic will provide, temporal and spatial resolution of the KHz rotating phenomenon observed in a low temperature low pressure magnetized plasma column. While testing the spectro-tomography on the Mistral setup a new LoS holder is being developed to reduce drastically the present dimension of the system. The objective is to have an OES spectro-tomography diagnostic implementable on a wide range of low temperature laboratory plasma discharge, such as magnetron discharge, as well as on the WEST tokamak.

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