Spectrally-resolved Gas Puff Imaging:

Two-field (n_e, T_e) 2D edge plasma diagnostic with μs temporal resolution

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Motivation

- 2D measurement of plasma edge electron density (n_e) and temperature (T_e)
- Turbulence measurements with high spatial (≤ 5 mm) and temporal (10 μs exposure time, 20k frames/s) resolution
- Characterization(n_e and T_e) of coherent turbulent structures (Blobs)

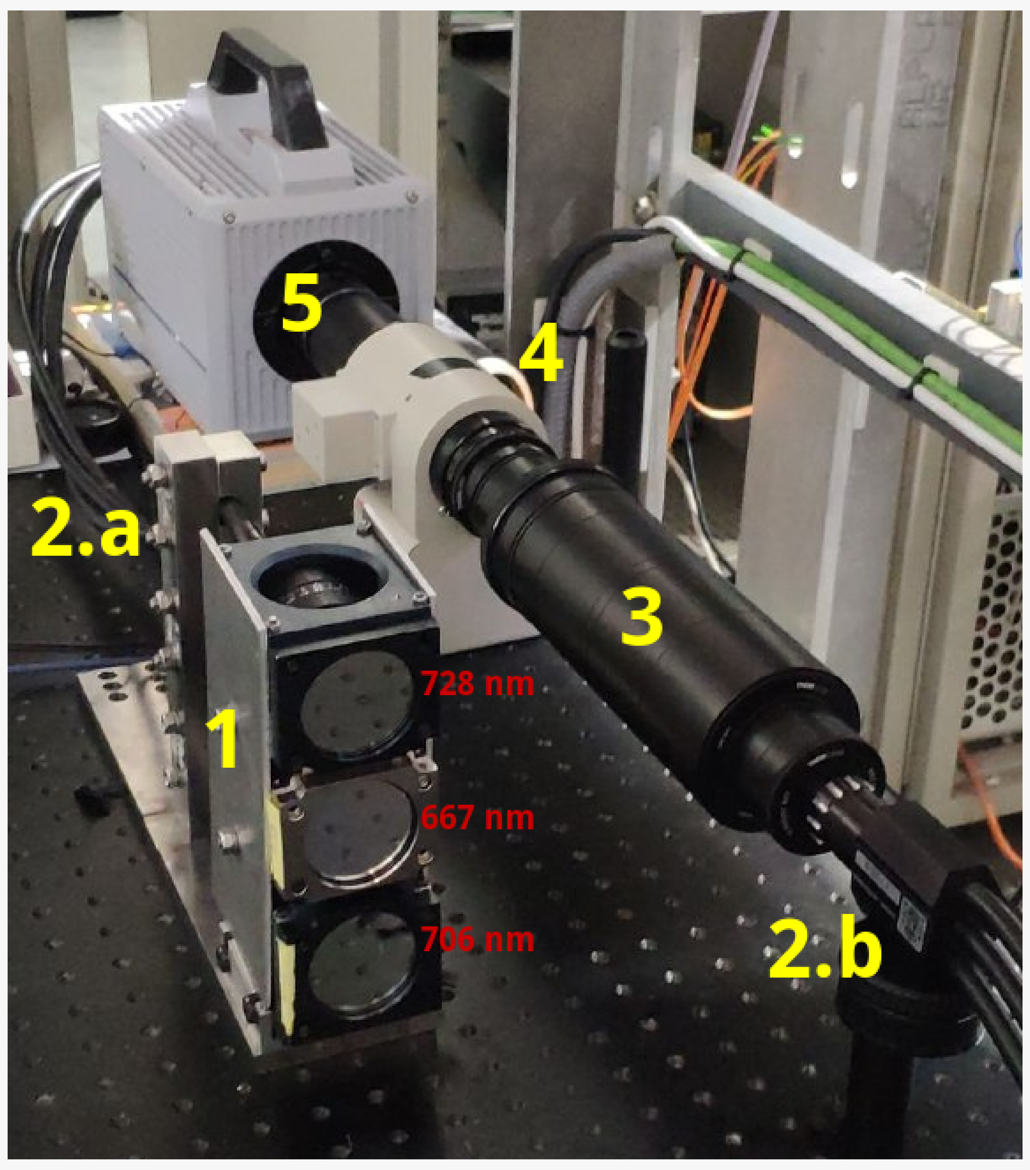
Background

Spectral Gas Puff Imaging[1, 2] combines two well established diagnostic techniques:

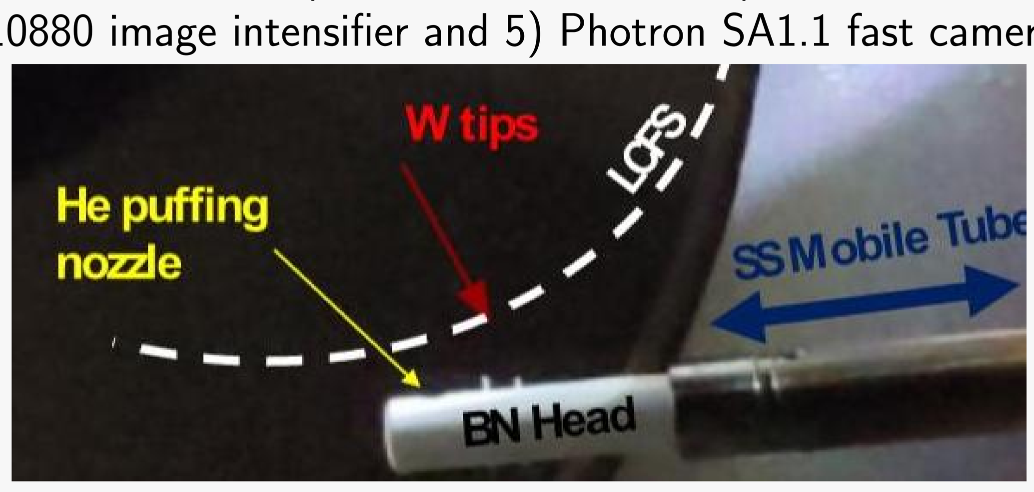
- GPI is a diagnostic that uses fast camera to capture perturbations in visible light emission caused by local neutral injection
- He-I line ratio[3] is a spectroscopic technique that determines n_e and T_e from ratios of emission intensities

SGPI

SGPI consists of optical and puffing systems: Optical system is comprised of three 50mm lenses with interference filters (667nm, 706nm and 728nm, FWHM = 1 nm) light from which is combined by the means of triple opto-fiber bundle into a single image that is projected to a 2-stage (GEN-II + GEN-I) image intensifier, then, after the amplification, image is recorded by a fast camera. Puffing system is formed by a retractable stainless steel tube with Boron-Nitride injector head augmented with tungsten pins (for spatial referencing).



(a) Optical system of SGPI: 1) Lens block with interference filters installed, 2) Opto-fiber triple-bundle image transmission line, 3) Relay lens coupling, 4) Hamamatsu C10880 image intensifier and 5) Photron SA1.1 fast camera



(b) Movable puffing injector assembly

Figure 1: Optical and puffing systems of SGPI

Injector position optimization

The location of injection is chosen such to minimise the angular deviation, α, between local magnetic field and line of sight (LoS) within injection volume. This allows to approximate integration along the fieldline with integration along LoS.

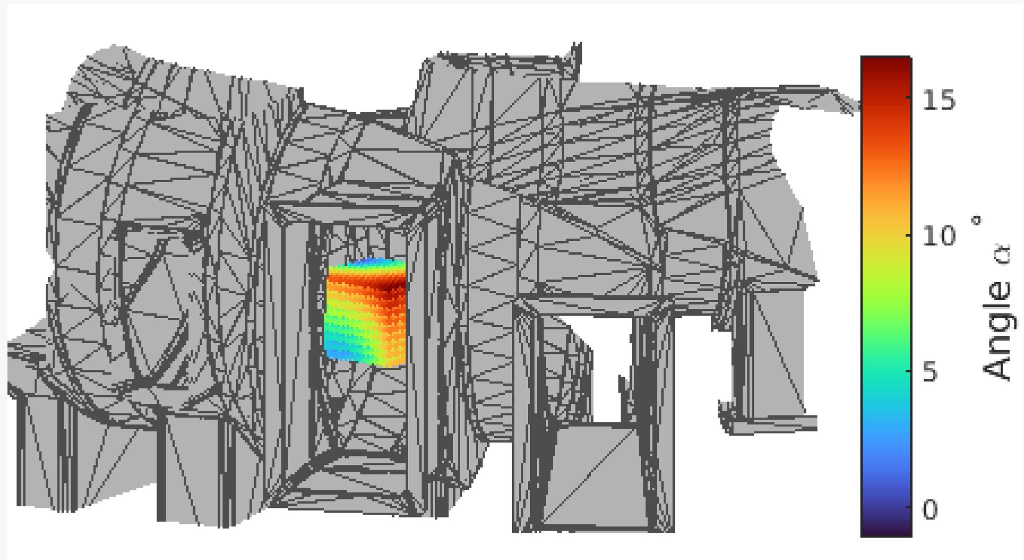


Figure 2: Angle α (colour coded) calculated in vicinity of chosen injection point with vacuum vessel of TJ-II

Spatial resolution limit

Spatial resolution along given LoS is limited by the non-tangential component of the projection, which in the first approximation can be estimated: $\sin(\alpha)\Lambda$, where Λ is the characteristic size of the plume ($\sim$5 cm). Additional discrepancy comes from slight differences in viewing angles between separate lenses.

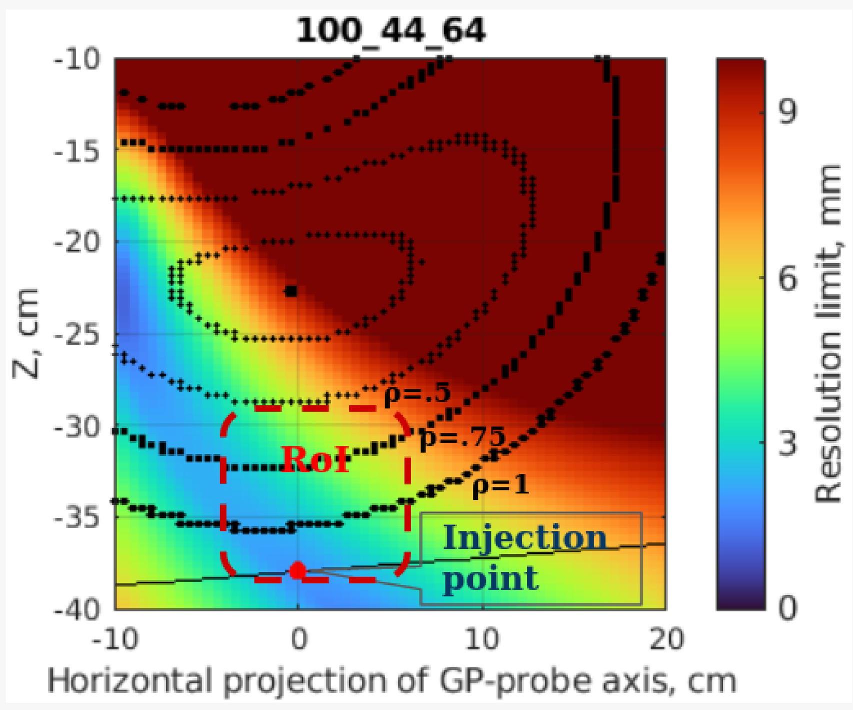


Figure 3: Estimation of maximal potential spatial resolution from angle α, including difference in viewing angles of lenses

Collisional-Radiative Model

CRM developed in Julich [4, 5] that is currently used for supersonic Helium beam diagnostic [6] was re-purposed for data analysis. However, application of any other CRM is straightforward as it only provides an interpolation map for the obtained ratios. Allowing for future changes and comparison of different CRMs.

Image alignment

In order to calculate pixel-wise ratios of intensities images have to be precisely aligned. To achieve this tungsten tips were added to the construction of the injector which are heated by the plasma and provide black body radiation sufficient to be seen through filters:

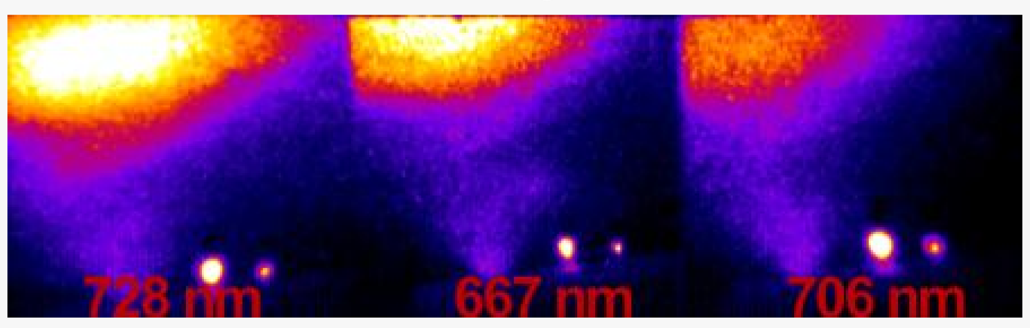
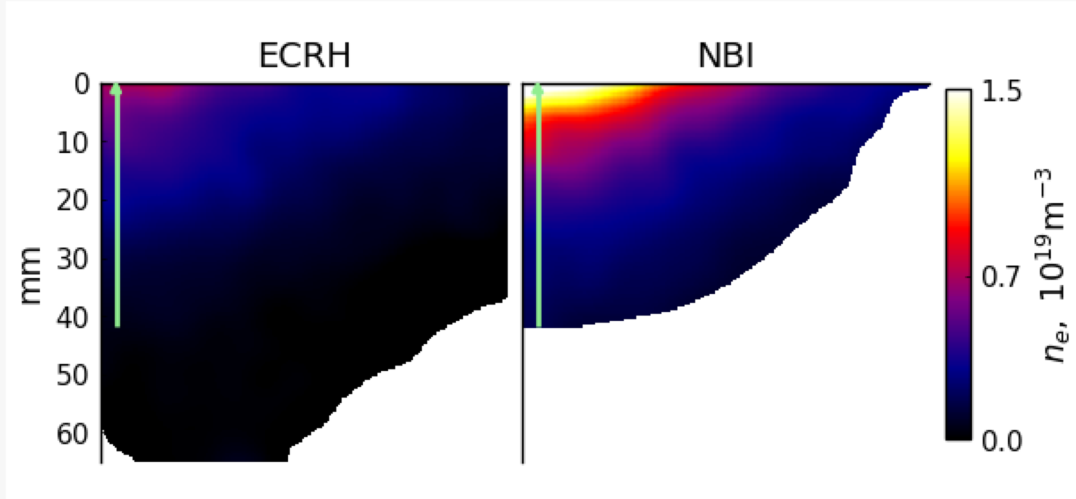


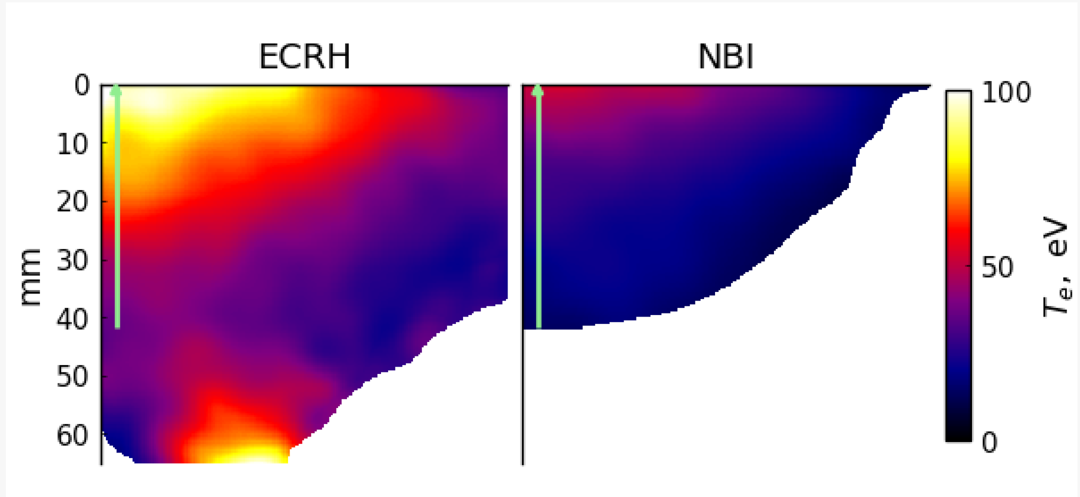
Figure 4: Spectrally resolved images obtained by the SGPI with tungsten pins visible in lower-right corner

Experimental results

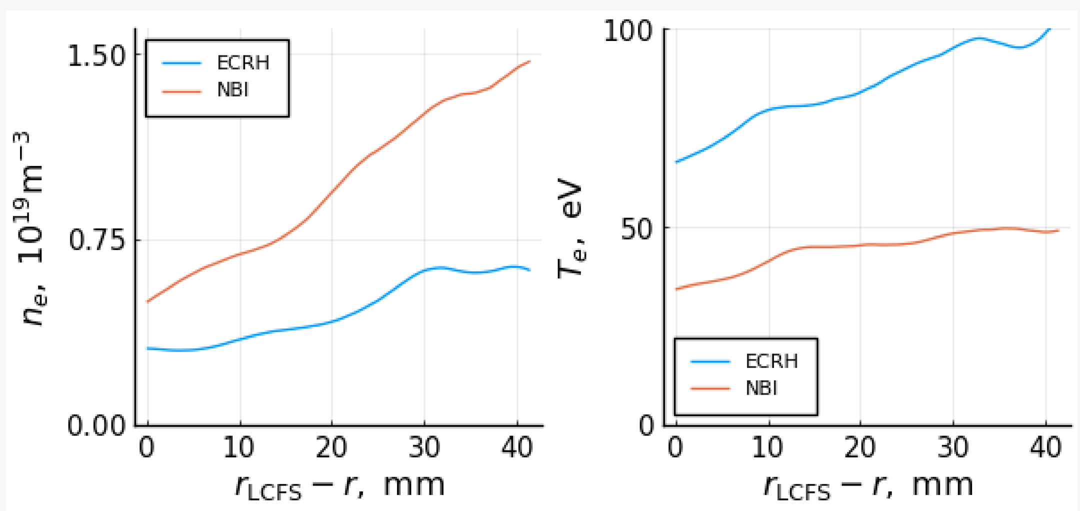
Data obtained during the experimental campaigns of TJ-II in Autumn '21 and Spring '22 was used to perform initial analysis:



(a) Density fields of typical ECRH and NBI plasmas



(b) Temperature fields of typical ECRH and NBI plasmas



(c) 1D profiles along the green arrow in Figs.5a,5b

Figure 5: First measurements with SGPI

Future work

- Spatial referencing with magnetic field
- Error propagation analysis
- Comparison of different CRMs
- Coherent structure studies

Conclusion

Comissioning of SGPI diagnostic concluded with promising results. It was confirmed that the light level achieved with intensification, in conditions of TJ-II discharges, is sufficient for exposure times as low as 5 μs. Measurements were performed in ECRH and NBI plasmas providing a sufficient dataset for further analysis and comparison of CRMs.

References

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