Advanced X-ray Diagnostics for Large Scale Dense Plasmas

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Future GSI-experiments with intense heavy ion beams and the kilo-joule PHELIX-laser necessarily deal with large scale dense plasma objects. These plasmas might be either created by lasers to serve as a target for advanced studies of heavy ion beams interacting with matter or as intense back-lighter sources or may be created by intense heavy ion beams for, e.g., studies of strongly coupled plasmas.
The key issue and the request in common for the success of these experiments is a detailed characterization of large scale dense plasmas. Standard methods obviously fail due to the large optical thickness even for x-ray transitions. We therefore have undertaken an extended research program on this issue.
The novel aspect in this research is to base plasma diagnostic methods on forbidden line transitions with low transition probability A. This circumvents photo-absorption because the line center optical thickness τ_0 is proportional to A:

$$\tau_{0,ij} = \frac{1}{4}\lambda_{ji}^2 \frac{g_j}{g_i} A_{ji}\, n_i \left\{1 - \frac{g_i n_j}{g_j n_i}\right\} \varphi_{ij}\left(\omega = \omega_{ji}\right) L_{eff}\,.$$

This approach, however, is highly non-trivial because transitions with low radiative decay values A are, first, difficult to observe and, second, they are highly dependent on density variations (because in dense plasmas collisional rates easily approach the radiative decay rate even for highly charged ions) and this denies their diagnostic use.
Despite these obstacles we have successfully developed a new concept for large scale dense plasma diagnostics introducing intercombination and two-electron transitions from autoionizing states as diagnostic and as reference lines [1,2]. We also performed atomic structure calculations to establish the required data [1].
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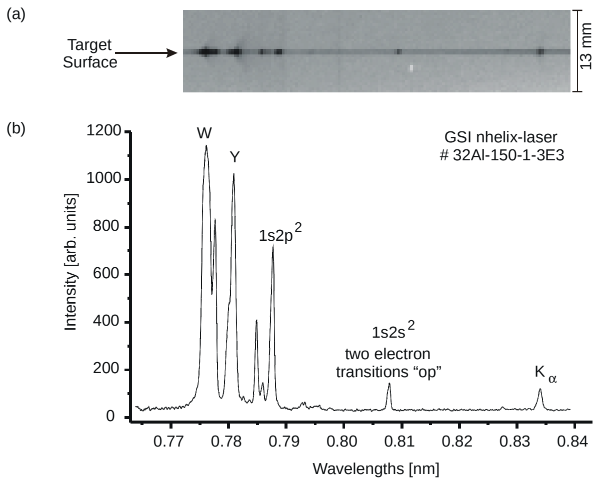

Figure 1: X-ray image of Al and spectrum near the target surface. Two-electron transitions have large intensity.

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energies between 17 – 60 Joules, varying spot sizes from about 200 μm until 2 mm and laser pulse duration of 15 ns. Space resolved high resolution Argon K-shell X-ray radiation near λ = 0.8 nm has been obtained with spherically bent mica crystals [3] and Kodak DEF X-ray film in the 2nd reflection order. X-ray images were digitized with a 10.000 dpi EUROCORE drum scanner. Spectra have been corrected for filter transmission, crystal reflectivity, film response and non-linear dispersion using SCALE.

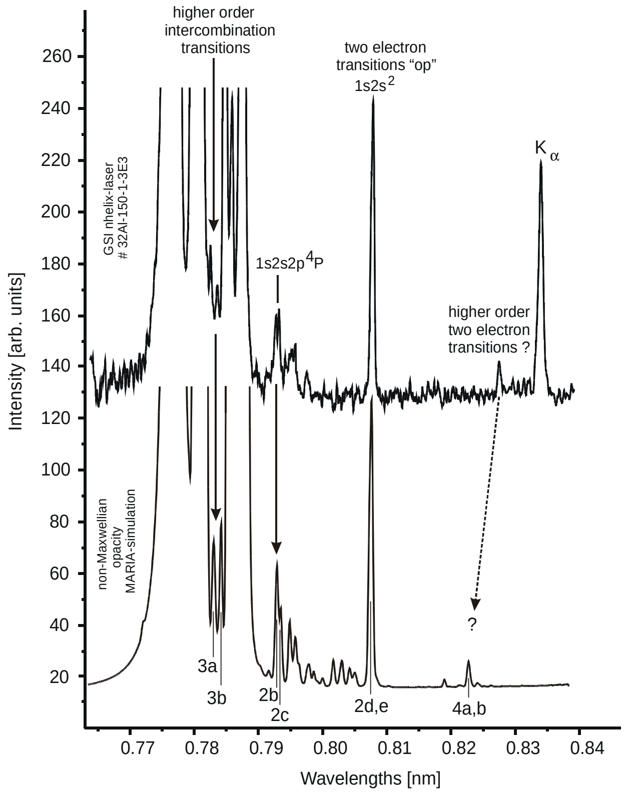

Figure 2: Large scale dense plasma diagnostic based on forbidden satellite transitions. Two-electron transitions serve as reference lines. Excellent agreement between the simulations and the experiment is obtained.

Figure 1 shows the plasma image and the corresponding spectrum near the target surface. Figure 2a demonstrates the intense observation of the requested forbidden satellite transitions. Fig. 2b shows the non-Maxwellian simulation which compares well with the experiment. The excellent agreement demonstrates the success of the present approach for the complicated case of large scale dense and non-Mawellian plasmas. The developed methods are therefore of general use and may readily be applied to PHELIX plasmas.

References

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