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Benchmarking of Atomic Physics Rates and Collisional Radiative Models for Laboratory and Astrophysical Plasmas for Ar, Fe, and Ge studied on the Tokamak FTU

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I) INTRODUCTION

Benchmarking of the atomic physics rates and collisional radiative models for Ar, Fe, and Ge is relevant for both laboratory and astrophysical plasma physics. The atomic physics rates are used to determine the charge state distributions, radiative cooling properties and transport/particle confinement in magnetically confined fusion plasmas and estimates of electron temperature and density in astrophysical plasmas. The investigation of Fe is purely astrophysically motivated. Ge atomic rates were investigated for use as a temperature diagnostic in ECRH heated reverse sheer plasmas in which temperatures of at least 5 keV have been measured. Argon is of interest in both types of plasmas especially for tokamak radiative cooling experiments.

Trace amounts of these impurities have been introduced into ohmically (~1 MW) and ECRH (~0.8 MW) heated FTU Tokamak (Frascati, Italy) plasmas using the laser blow off technique (LBO) or gas puffing. The target plasmas have a central electron temperature, $T_e(0)$, of ~ 2 keV, a central electron density, $n_e(0)$, of ~ $1x10^{14}$ cm^{-3}, and an impurity density, $n_{Z,LBO}(0)$, of ~ $5x10^{11}$ cm^{-3}

II) CHARGE STATE DISTRIBUTIONS

The charge state distributions (CSDs) were determined from the spatial brightness profiles of the ions in the FTU plasma. Time dependent spectra as well as spatial brightness profiles of intrinsic as well as injected impurities have been obtained from four radially scanable, photometrically calibrated spectrometers in the 1 to 1700Å range (two VUV spectrometers and both a rotating and a bent crystal X-ray spectrometer). All the spectrometers could be positioned to view the plasma from a minor radius of 0 to 25 cm (r_{minor} = 30 cm). The brightness profiles of a given impurity were measured by scanning the spatial view of each spectrometer on a shot to shot basis during a series of similar plasmas.

The measurement of the CSD of a given element was possible for the dominant charge states in the plasma which depended on the central electron temperature. For Ar the dominant charge states were the H-like to the Mg-like ions. For Fe and Ge, Li-like to the K-like ions were the ones of interest. The Li/Be line ratios for Ge is an important temperature diagnostic in the 4 - 8 keV temperature range.

To benchmark the atomic physics, these spectra and spatial brightness profiles have been compared with the time dependent simulations from the MIST [1] and Tore Supra transport codes which computed the fractional abundances with a given set of atomic physics rates, the measured electron temperature, the electron density, and the anomalous impurity particle transport. The ionization/recombination rates used were those from the Hebrew University Lawrence Livermore Atomic Code [2,3,4] (HULLAC), AdPak[5], Mazzotta[6], Mattioli[7] and Arnaud-Rothenflug[8]/Raymond[9] (AR85/AR92). The excitation /recombination rates in the CR model was generated by the HULLAC atomic data package. A collisional radiative model computed the line brightnesses which were then compared with experiment.

As an example, the LBO experiments done with Fe are shown in figs 1 & 2. The experimental time evolution of Fe^{23+}(Li-like), Fe^{22+}, Fe^{15+} (Na-like), and Fe^{14+} are shown in fig. 1 for a central line of sight of the spectrometers. The MIST simulation included a D = 5000 cm^2/s, a convection peaking factor of S = 1 and the atomic physics rates of Mazzotta. The time evolution of the impurities are well simulated for the higher charge states in the core plasma but are not as well simulated in the outer regions. Limitations of the transport code to properly simulate the impurity dynamics of the LBO at the plasma edge and not the atomic physics is the most likely problem.

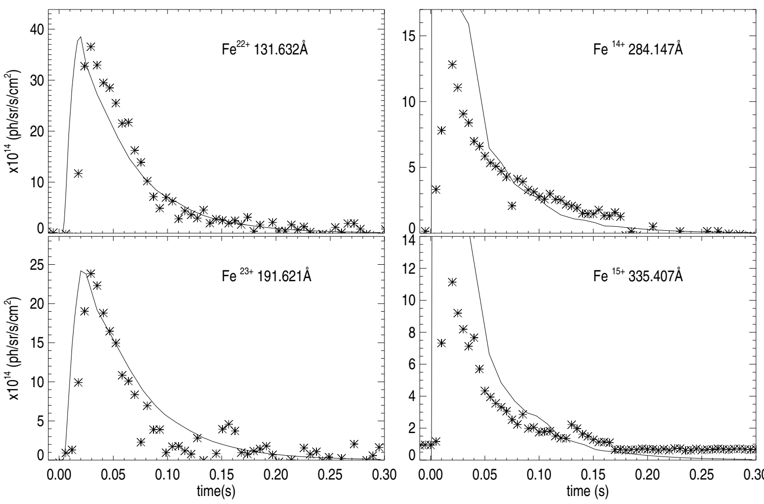

Fig. 1. Time histories of selected line emission during an LBO of Fe (* experiment, — simulation with Mazzotta physics rates).

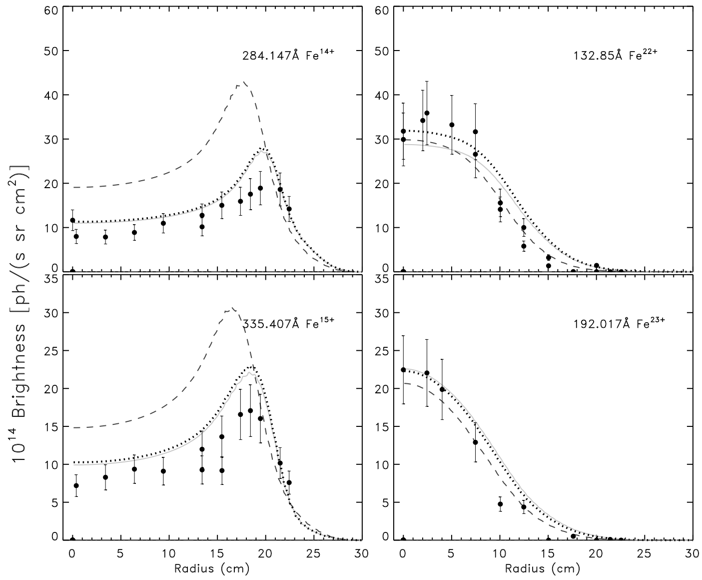

Fig. 2. Spatial Profiles of selected line brightnesses taken 400 ms after an LBO of Fe and the simulations with different atomic physic rates. (— Mazzotta, ····· AR92, ---- AdPak)

In fig. 2 brightness profiles of Fe are shown at 40 ms after the injection which is just after the peak in the highest charge state and avoids the impurity dynamics modeling problem. Simulations were done with three atomic physics rates. The older AdPak rates do not simulate the spatial profiles. The simulations using AR92 and Mazzotta yielded very similar results and were in good agreement with the measurements. The spatial positions of the ions predicted with AR92 and Mazzotta rates are correct although the brightnesses of Fe^{14+} and Fe^{15+} are slightly over predicted. These rates are a significant improvement over the rates of AdPak

III) RADIATIVE COOLING CURVE

A radiative cooling curve was computed from HULLAC for argon. The radiation channels considered included spectral line power (most significant), radiative recombination, dielectronic recombination and bremsstrahlung. The impurity CSD determined by the spatial profile measurements was incorporated in the calculations of the HULLAC cooling curve. Therefore, the plasma temperature (radial location) for each radiating charge state was correct in the cooling curve.

The bolometry emission and the emissivities simulated with the AdPak and HULLAC [[10]] cooling curves are shown in figure 3 for an argon puff. In the analysis, the bolometry emissivities before the gas puff were subtracted from the emissivities during the puff. This removed any radiation from the intrinsic impurities yielding just the emissivities from argon. Emissivity profiles were generated from the both the HULLAC cooling curve and the AdPak cooling curve assuming coronal equilibrium. The agreement between the estimates using the HULLAC cooling curve and the bolometric profiles was fair. The discrepancies are reduced when the correct particle transport is included in the calculations. The HULLAC cooling curve provided a better estimate of the radiative losses than AdPak.

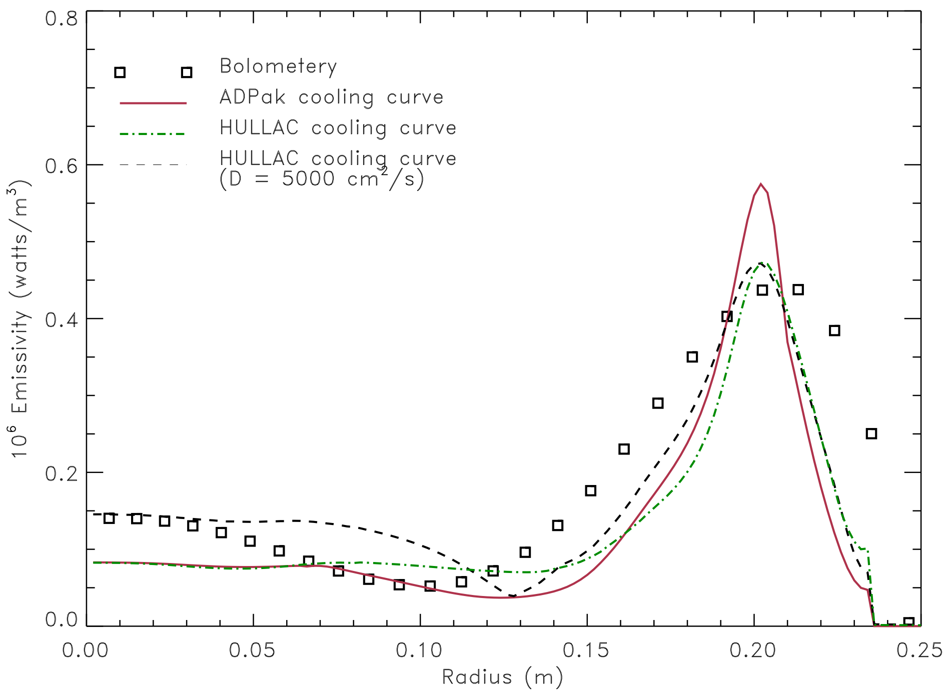

Fig. 3 Comparison of the Emissivities from Bolometry and predictions from the AdPak and HULLAC Cooling Curves

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