

The value of density measurements in stellar coronae

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Abstract. The grating instruments on board Chandra and XMM-Newton now allow measurements of electron densities. These rely on the ratios of fluxes in emission lines, where one line depends on both collisional and radiative decay rates. The electron density is required to constrain the physical extent of the emitting region, and large samples of measurements are of interest in the context of trends in coronal activity. Here we discuss the important He I-like ions and the differences in densities that result when different current data bases are used.

REQUIREMENTS FOR MEASURING PLASMA DENSITIES

The spectrum emitted by an X-ray plasma reflects the physical conditions of the plasma, especially the plasma temperature and the plasma density. While different plasma temperatures affect an X-ray spectrum quite strongly (broad band continuum emission and appearance and disappearance of strong lines originating from ions in different ionization stages), the effects of different densities are rather subtle. This is demonstrated with Fig. 1, where two simulated spectra are shown. For simplicity we chose an isothermal plasma in one case with a high density and in the other with a low density. It can be seen that differences are only detectable in a few emission lines, and therefore density measurements in X-ray plasmas can only be carried out with high-resolution spectroscopy.

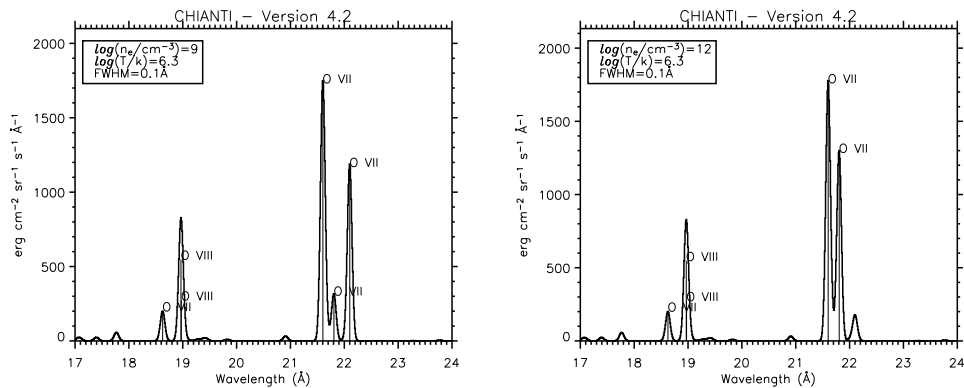


FIGURE 1. Simulations of spectra with low densities (left) and high densities.

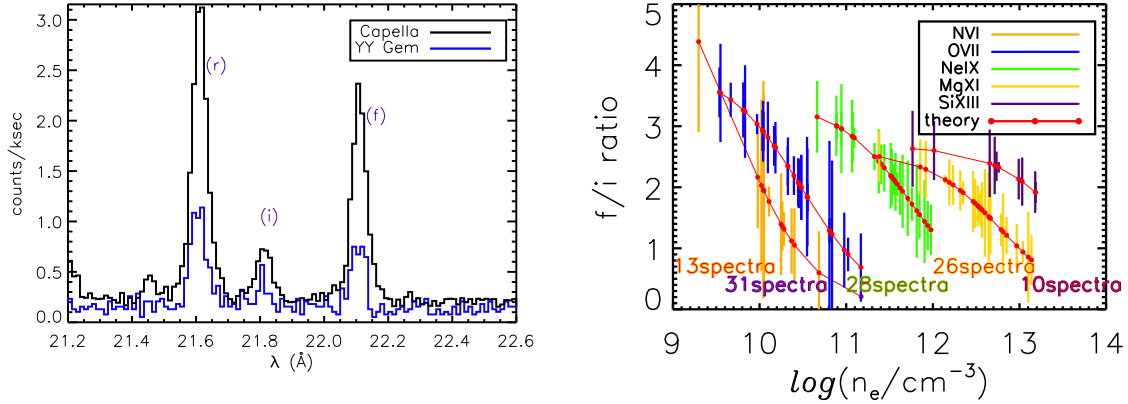


FIGURE 2. **Left:** Chandra LETGS measurements of the O VII He-like triplets for Capella and for YY Gem (blue), scaled to the distance of Capella. The spectra show different behaviour in the ratio of the lines marked with (i) and (f). **Right:** Density measurement with different He I-like ions for a large sample of stellar coronae. Error bars (1σ statistical errors) are large due to faint intercombination lines in the case of large f/i ratios. Mg XI and Si XIII cannot constrain densities below $10^{12.5} \text{ cm}^{-3}$.

DENSITY MEASUREMENTS WITH HE-LIKE TRIPLETS

The He-like ions provide a valuable method of measuring the electron density (n_e), in principle over a wide range of electron temperatures (T_e). The method [see 1] depends on the competition between collisions between the $1s2s^3S$ and $1s2p^3P$ levels and the radiative decay in the forbidden line ($1s2s^3S - 1s^2^1S$). The ratio of the flux in the forbidden line to that in the intersystem (+magnetic quadrupole) line, then becomes sensitive to n_e , and can be parameterized as $f/i = R_0/(1 + n_e/N_c)$, where R_0 is the ratio in the low density limit and N_c is the critical density. Both R_0 and N_c contain atomic data relating to collisional and radiative rates. Fig. 1 shows simulated spectra for O VII at densities of 10^9 cm^{-3} and 10^{12} cm^{-3} , between which the ratio depends on n_e .

The Chandra LETGS measurements of Capella and YY Gem (Fig. 2) show clear differences in f/i ratios, which indicate different densities in the two coronae.

The atomic rates have different dependences on $Z - 1$, where Z is the nuclear charge, but should depend smoothly on $Z - 1$, for the ions of interest. Fig. 3 (left) shows the parameters R_0 and N_c as a function of $Z - 1$. This brings out the differences between the data bases CHIANTI and APEC and shows $\log N_c$ from [2]. Values of R_0 are indicated by different colours; this plot suggests that the data in R_0 for C V and N VI in CHIANTI need to be re-examined, and that those for Si XIII warrant closer examination. Note that $\log N_c$ depends linearly on $Z-1$.

The right hand panel of Fig. 3 shows the resulting variation of the ratio f/i for O VII, indicating the importance of accurate atomic data when observed ratios are close to the low density limit. Measured densities will always be averages, but the He-like triplets formed at high temperatures probe only high densities (above 10^{12} cm^{-3}), while low-temperature ions measure only lower densities ($\sim 10^{10} - 10^{11} \text{ cm}^{-3}$); this leaves two cases unexplored: low densities in hot plasma and high densities in cool plasma.

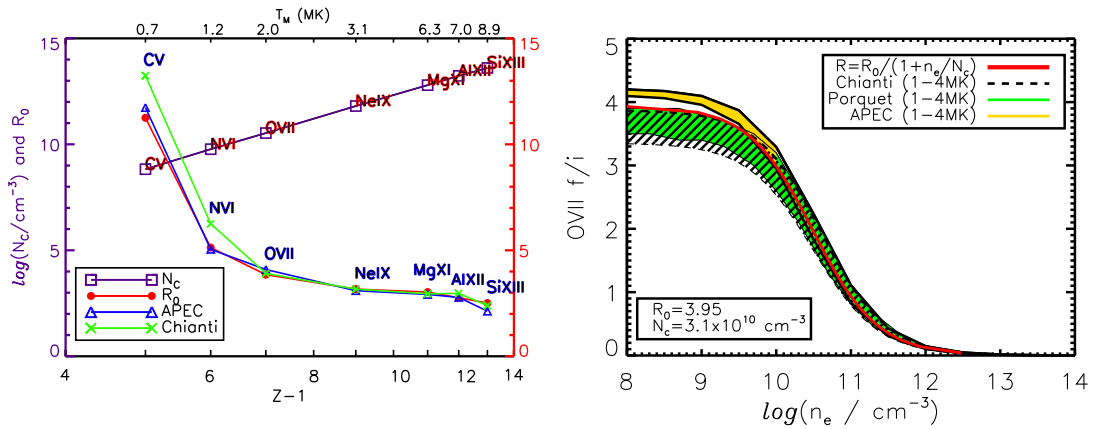


FIGURE 3. Left panel: comparison of R_0 (from different data bases) and N_c [2, in purple]. Right panel: density-dependent f/i line flux ratios for O VII.

WHAT CAN WE LEARN FROM DENSITY MEASUREMENTS?

In stellar coronae the density measurements provide an important link between physical and geometrical properties, through the Emission Measure $\text{EM} = n_e^2 \times V$ (n_e : electron density and V : emitting volume). Densities are also needed to explore the optical depths of the lines: $\tau \propto \int n_e dl$, where ℓ is the path length (cm), and hence emitting areas.

RESULTS AND CONCLUSIONS

A survey of density measurements was carried out by [3]. Densities were measured from the He-like triplets (O VII and Ne IX) probing densities at temperatures 2×10^6 K and at 4×10^6 K. Measurements from higher-Z ions (Mg XI and Si XIII) result only in low-density limits $< 10^{12.5} \text{ cm}^{-3}$ (Fig.2, right). The observed range of f/i ratios shows that real differences in n_e do occur between different coronae.

Accurate atomic data are essential in order to use these and other diagnostics of n_e , thus exploiting the excellent new spectra being obtained. Values of n_e can then be used to constrain physical models of the atmosphere.

ACKNOWLEDGMENTS

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