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THE LYMAN α AND LYMAN β LINES IN SOLAR CORONAL STREAMERS

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ABSTRACT

We use the plasma parameters derived from a new global 2.5D three fluid model of the solar wind to compute the Lyman-α and Lyman-β line profiles. The emergent hydrogen radiation is calculated by solving the statistical equilibrium equations for a 10 level hydrogen atom + continuum along a one-dimensional line of sight. We do not make any assumption about the formation mechanisms of the lines. We study the effect of Doppler dimming. We find that the width of the Lyman-β line more accurately reflects the plasma temperature than that of the Lyman-α line. Thus inferred temperatures from Lyman-α observations should be considered as lower limits for the plasma temperature. We also present calculations of the relative contribution of resonant scattering and collisional excitation in the Lyman line intensities.

1. INTRODUCTION

We perform radiative transfer calculations in non local thermodynamic equilibrium (NLTE) to predict the properties of the hydrogen lines in the corona. A large amount of our knowledge of the solar extreme ultraviolet (EUV) corona comes from the observations of the first two H I Lyman lines at 1215.67 Å and 1025.72 Å. To infer the coronal plasma properties from observations it is necessary to get the line profiles with enough spectral resolution. From the knowledge of the line width one can derive the temperature of the hydrogen atoms. If the coupling due to charge exchange between hydrogen atoms and ions is strong enough, then the proton temperature is equal to the hydrogen temperature. In our case, this coupling is strong enough at densities above 10^6 cm^{-3}, i.e. within the whole streamer.

2. CORONAL RADIATION

The coronal model is obtained from a 2.5-D global three fluid solar wind model with electrons, protons, and α particles (Li et al., 2006). A hot coronal boundary, electron heat flux and Coulomb coupling lead to a non-isothermal streamer in which all three species have the same temperature. The plasma properties in the streamer are shown in Fig. 1 for two heights of the line-of-sight (LOS).

We solve the radiative transfer (RT) equations and the statistical equilibrium (SE) equations in NLTE for a 10 level + continuum hydrogen atom. The velocity dependent boundary conditions for the RT equations are determined by the radiation coming from the disk. The emergent intensity $I_\nu(\mu)$ at an angle $\theta = \cos^{-1}\mu$ between the normal to the surface and the LOS is given by:

$$I_\nu(\mu) = \int_0^{\tau_\nu} S_\nu(t)\mathrm{e}^{-t/\mu}\,\mathrm{d}t/\mu\ , \tag{1}$$

with τ_ν the optical depth at frequency ν. Using the formulation of the equivalent two-level atom, the line source function is:

$$S^l_\nu = \varepsilon^* B^* + (1-\varepsilon^*)\tilde{J}_\nu. \tag{2}$$

ε^* and B^* account for all the processes that can affect the creation and the destruction of photons in the transition at frequency ν, introducing a non-local and non-linear coupling between the radiation and the plasma. The scattering term $\tilde{J}_\nu$ is expressed as:

$$\tilde{J}_\nu = \frac{1}{\varphi_\nu}\int_0^\infty R(\nu',\nu)J_{\nu'}d\nu'. \tag{3}$$

The incident radiation is given by:

$$J_\nu = \frac{1}{4\pi}\oint I_0\left(\nu + \frac{\nu_0}{c}\mathbf{V}\cdot\mathbf{n}', \mathbf{n}'\right)\mathrm{d}\mathbf{n}'\ , \tag{4}$$

with $I_0(\nu,\mathbf{n})$ the specific intensity of the incident radiation, $\mathbf{n}'$ the direction of the incident photon, and $\mathbf{V}$ the radial velocity. J_ν is calculated at a given height, taking into account the center-to-limb variations of the incident radiation. In Eq. 3, φ_ν is the normalized absorption profile of the line, and $R(\nu',\nu)$ is the angle-averaged frequency redistribution function. To compute the frequency redistribution function for all Lyman lines up to

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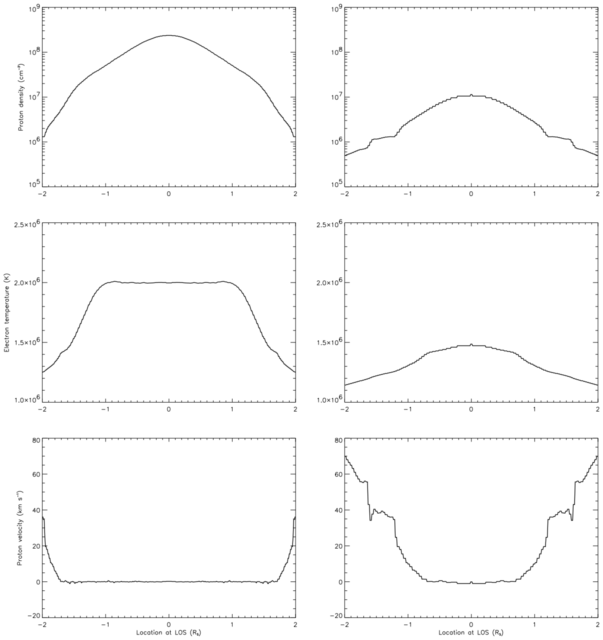

Figure 1. From top to bottom: n_p, T_e, and v_p at a distance of 0.05 R_S (left) and 0.88 R_S (right) above the limb, plotted against the location along the line-of-sight in units of the solar radius R_S, where the origin is at the centre of the LOS.

Ly-9, we use partial redistribution in frequency (PRD): a linear combination of R_{II} (well suited to describe the scattering of radiation in the Lyman resonance lines) and R_{III} (close to complete redistribution (CRD); also used for all other lines). We assume isotropic scattering. The redistribution function R_{III} is taken to be equal to the complete redistribution function.

A detailed study of the emergent radiation of hydrogen in the Lyman lines is presented in Labrosse et al. (2006) without taking into account the Doppler effect due to the radial motion of the plasma. The results presented in the following section include the Doppler effect. However the conclusions are the same as in Labrosse et al. (2006).

3. RESULTS

Fig. 2 shows that the decrease of the intensity with altitude is more pronounced for Lyβ than for Lyα, a first indication that they relate to the plasma parameters in different ways. We observe a strong coupling between Lyβ and Hα: the ratio of intensities in these two lines is constant with height. Hα photons can be absorbed and subsequently lead to the emission of Lyβ photons.

We fit the computed line profiles with a gaussian to obtain the width and thus a temperature T_H. As is clearly seen on Fig. 3, the width of the Lyβ line is a good indicator of the plasma temperature. On the contrary, the temperature derived from the Lyα line significantly underesti-

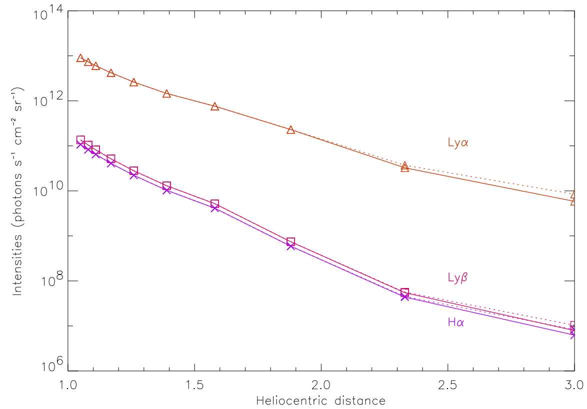

Figure 2. Integrated intensities of Lyα, Lyβ, and Hα vs. heliocentric distance. Dotted lines: no Doppler effect (V=0).

mates the mean plasma temperature and the temperature at the centre of the LOS within the streamer base (below 2 R$_S$).

From Eq. (2) we identify the first term of the right-hand side with the collisional component and the second term with the radiative component of the source function. Fig. 4 shows that Lyβ is mostly formed by collisional excitation in the streamer. Note that the collisional component of Lyα is not negligible in the streamer base.

4. CONCLUSION

The width of the Lyβ line is a better indicator of the streamer temperature than the width of the Lyα line. It is due to the formation mechanisms of the lines, and the coupling of Lyβ with Hα.

From our NLTE radiative transfer calculations, we obtain new estimates of the radiative and collisional contributions of the Lyman line intensities in a non-isothermal streamer. These new values may have some importance in the derivation of element abundances.

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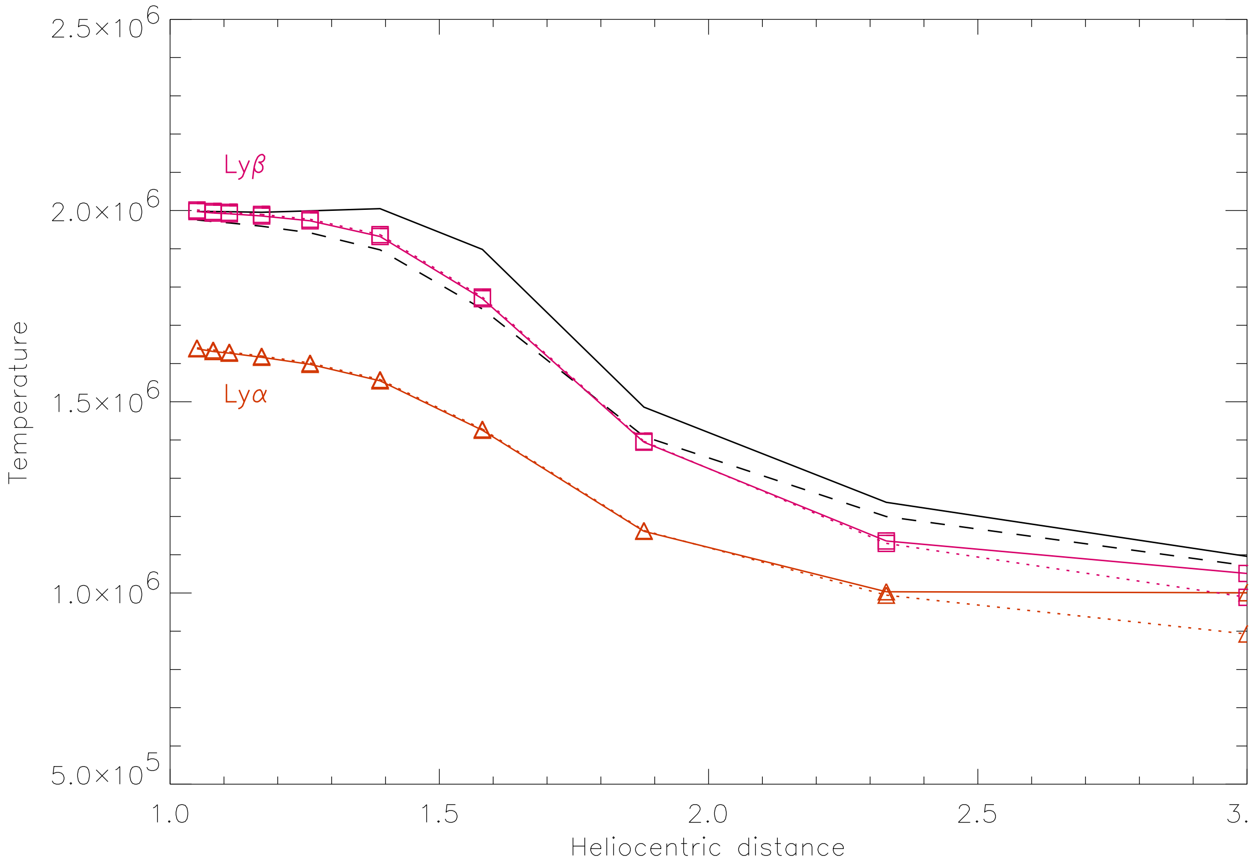

Figure 3. Temperature derived from the width of Lyα, Lyβ, temperature at centre of LOS (solid line), and mean temperature (dashed line), vs. heliocentric distance. Dotted lines: no Doppler effect (V=0).

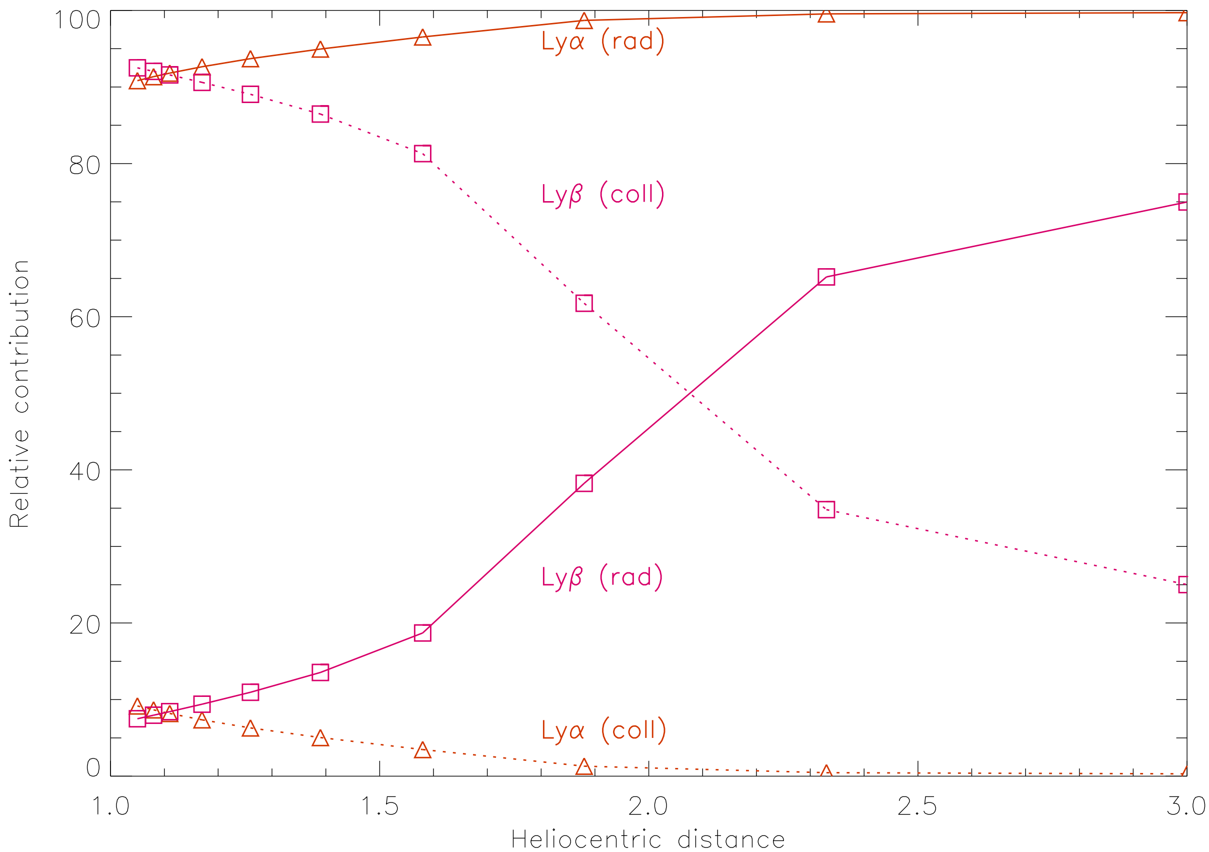

Figure 4. Relative contribution of the scattered (solid line) and collisional (dotted line) components for Lyα and Lyβ vs. heliocentric distance.