Statistical comparison of synthetic and observed Lyman line profiles of quiescent prominence fine structure

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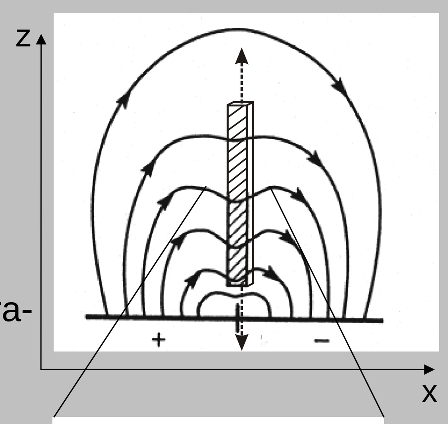
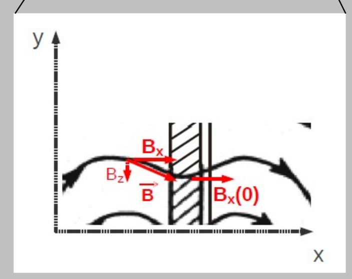
Abstract. In our previous work (Gunár et al., 2010) we have used several statistical criteria to compare the hydrogen Lyman line profiles from a quiescent prominence observed on 25 May 2005 by SoHO/SUMER with the synthetic ones computed using the 2D multi-thread model. The prominence observations in the whole Lyman spectrum (including Lyman alpha) were carried out during the 15 MEDOC observing campaign. Histograms of line-profile characteristics, such as integral intensities, Lyman decrement, asymmetry of peaks, depth of central reversal, for observed and synthetic profiles were compared. In present work we are doing similar statistical comparison for other prominences observed during the observing campaign. It is still not known whether each prominence fine-structure thread has its own prominence-corona transition region (PCTR) or a prominence has only its general PCTR. We use the statistical comparison of observed and synthetic Lyman spectra to test these two scenarios.

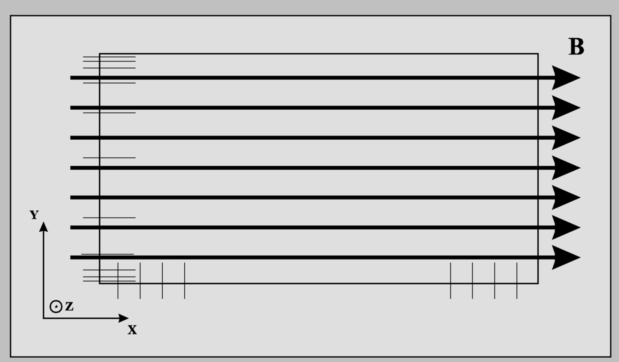
2D prominence fine-structure models

Prominence composed of vertical threads.
2D model of one vertical thread:

- vertically infinite fine-structure thread embedded in dipped magn. field
- 2D MHS equilibrium of Kippenhahn-Schlüter type (Heinzel & Anzer 2001)
- solution of 2D radiative transfer by the MALI method (Auer & Paletou, 1994) with usage of the short characteristics (Kunasz & Auer 1988)
- 12-level plus continuum hydrogen atom
- partial frequency redistribution (PRD) is assumed for the Lyα and Lyβ lines







- p_o – boundary coronal pressure
- M_0 – column mass along x in the slab center
- $B_x(0)$ – horizontal field in the dip center
- T_0 – temperature at the thread center
- T_{tr} – temperature at the thread boundary
- δ – thread thicknessin y-dimension (across magn. Field)
- γ_1 – gradient exponent of temperature along the magn. field
- γ_2 – gradient exponent of temperature across the magn. field
- γ_3 – gradient exponent of the column mass across the magn. field (set to 2 for all models)

The radiative transfer in x-direction is solved in scale of column mass *m* instead of the geometrical equidistant x-scale.

The total column density along x (Heinzel et al., 2005):

$$M(y) = M_0\left(1-\left|\frac{y}{\delta}\right|^{\gamma_3}\right) \quad \text{for } |y|\le\delta$$
$$M(y) = 0 \quad \text{for } |y|>\delta$$

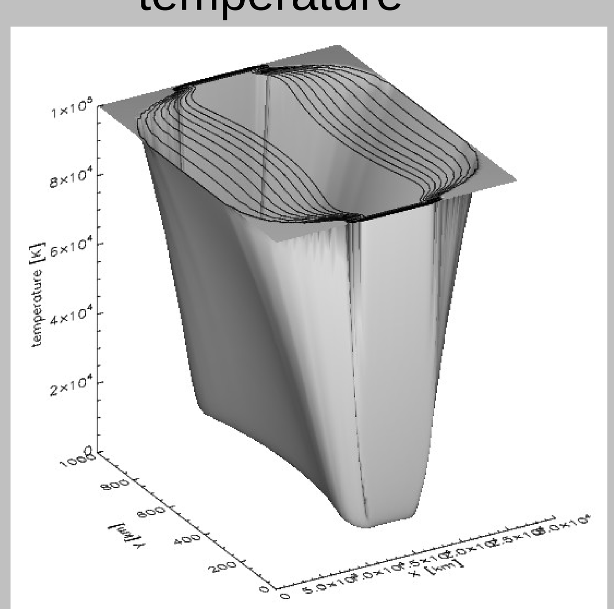
Temperature structure (Heinzel et al., 2005):

$$T(m,y) = T_{\rm cen}(y) + [T_{\rm tr} - T_{\rm cen}(y)]\left\{1-4\frac{m}{M(y)}\left[1-\frac{m}{M(y)}\right]\right\}^{\gamma_1}$$

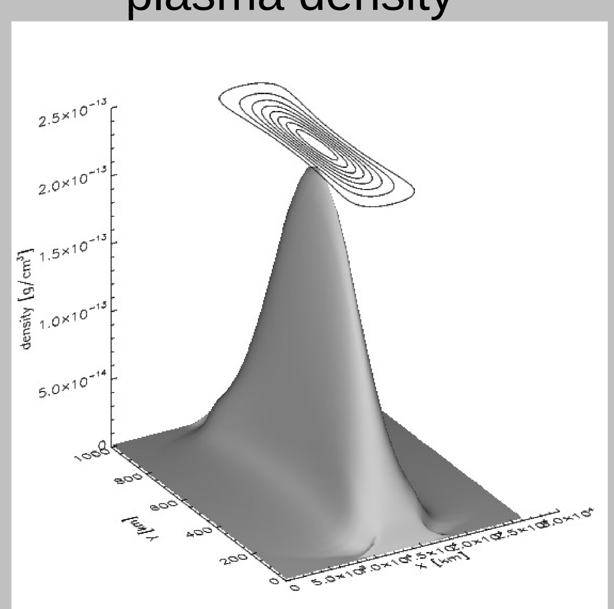
where $T_{\rm cen}(y)$ is defined as:

$$T_{\rm cen}(y) = T_{\rm tr} - (T_{\rm tr}-T_0)\left(1-\left|\frac{y}{\delta}\right|^{\gamma_2}\right), \quad \text{for } |y|\le\delta$$
$$T_{\rm cen}(y) = T_{\rm tr}, \quad \text{for } |y|>\delta$$

temperature



plasma density



(Model1_8000_Mo8.5E-5_Bxo7_po2E-2)

2D multi-thread models with LOS velocities

(Gunár et al., 2007)

The total emerging intensity

$$I_{\rm total}(\lambda) = \left[\ldots\left[\left[I_{\lambda(1)}\times\exp(-\tau_{\lambda(2)}) + I_{\lambda(2)}\right]\times\exp(-\tau_{\lambda(3)}) + I_{\lambda(3)}\right]\times \ldots + I_{\lambda(N-1)}\right]\times\exp(-\tau_{\lambda(N)}) + I_{\lambda(N)},$$

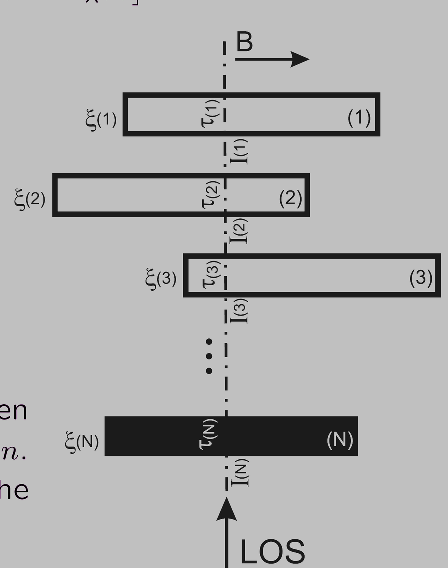
where $I_{\lambda(n)}$ and $\tau_{\lambda(n)}$ are defined as

$$I_{\lambda(n)} \equiv I(\lambda-\Delta\lambda^{(n)})$$
$$\tau_{\lambda(n)} \equiv \tau(\lambda-\Delta\lambda^{(n)}).$$

$\Delta\lambda^{(n)}$ is the Doppler shift for the thread n

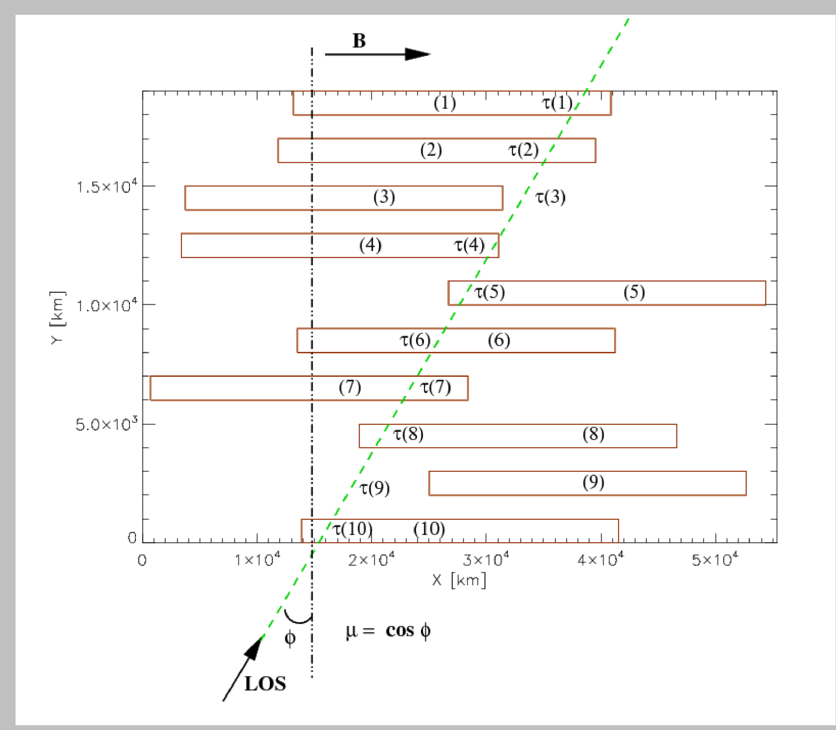
$$\Delta\lambda^{(n)} = \lambda_0\frac{\xi^{(n)}}{c},$$

where λ_0 represents the line-centre wavelength of a given spectral line and $\xi^{(n)}$ is the LOS velocity of thread n. Positive values of $\xi^{(n)}$ represent velocities towards the observer.



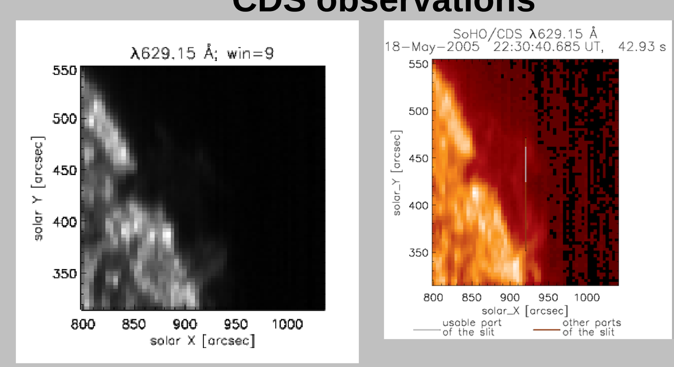
Synthetic profiles of hydrogen Lyman lines for hundred such realizations of the multi-thread model of 10 threads with random shifts along the magn. field and random LOS velocities assigned to each thread are calculated. Then, properties of synthetic profiles are statistically compared with those of the observed profiles. The profile properties are as follows: The integral intensity, Lyman decrement – the integral intensity of the line to the integral intensity of Lyβ, profile asymmetry – ratio of intensities at the peaks round the central reversal and reversal depth – intensity in central reversal to average intensities from both peaks.

The multi-thread model at view angle ϕ

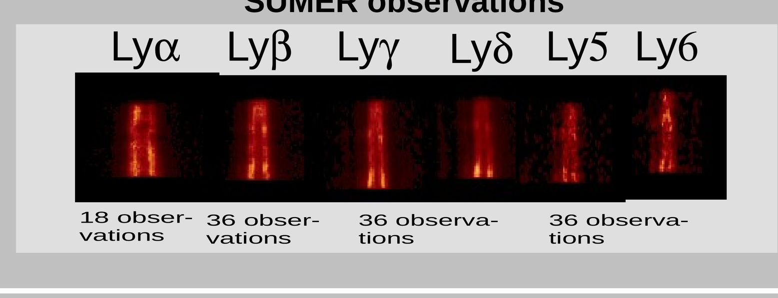


Prominence observations of May the 18, 2005

CDS observations

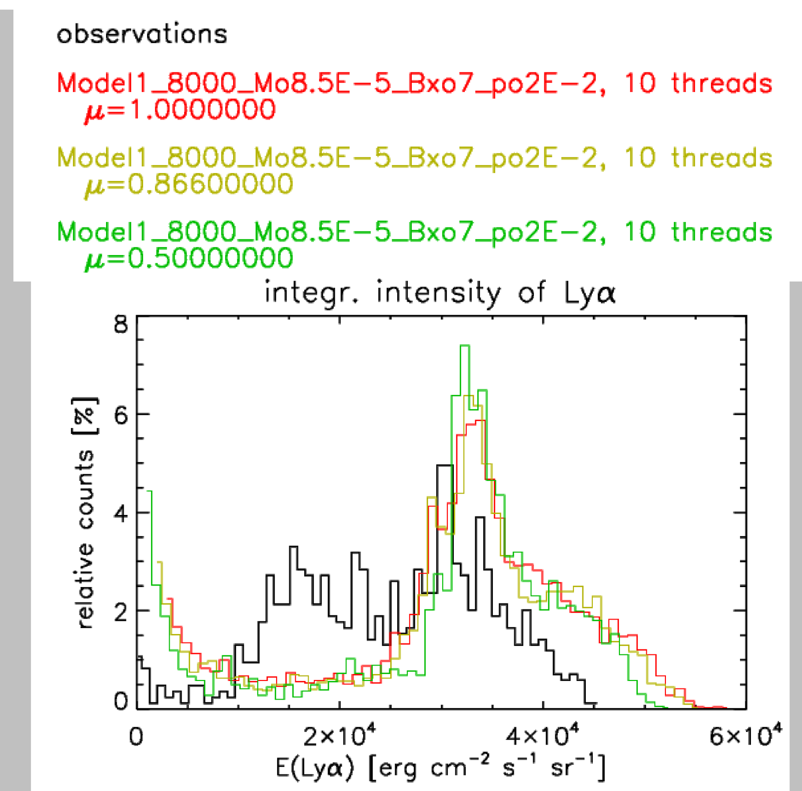


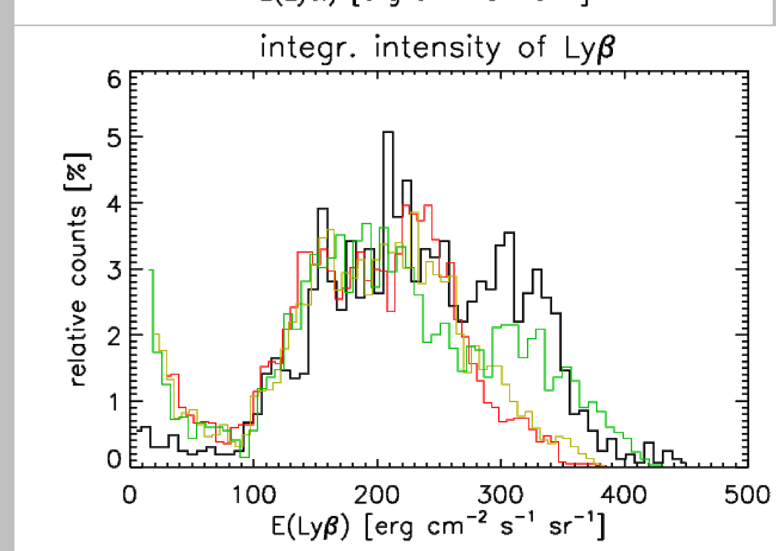
SUMER observations



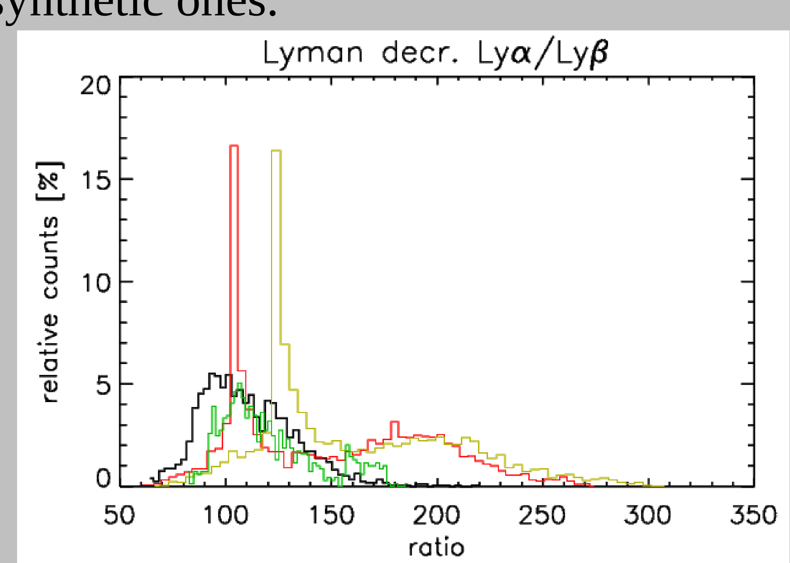
Multi-thread model of 10 identical threads calculated using the following model:

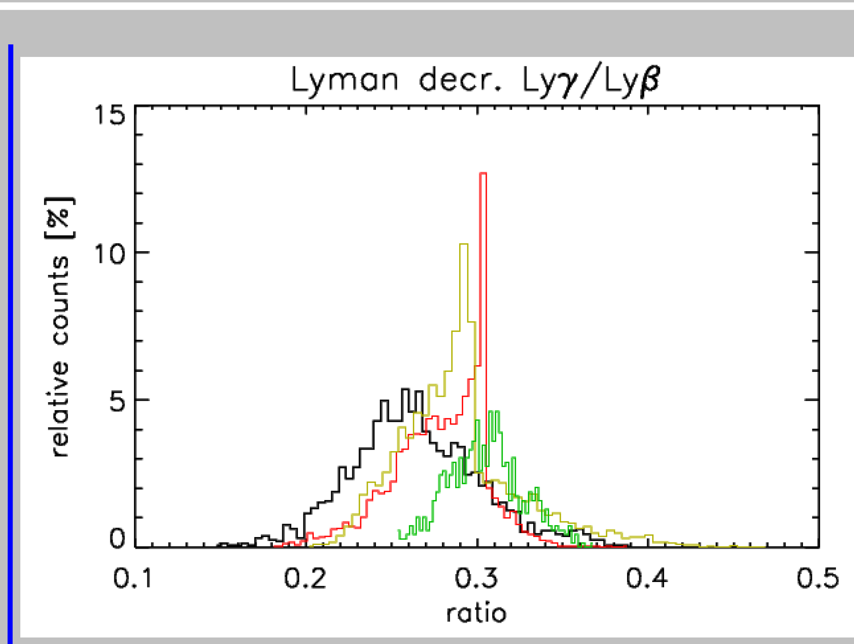
Model1_8000_Mo8.5E-5_Bxo7_po2E-2	T_0=8000 K; M_0=8.5 × 10^{-5} g cm^{-2};	$B_x(0)$=7 Gauss; p_0=0.02 dyn cm^{-2};	γ_1=10 γ_2=60





Similar good agreement of the integr. intensities of the sythetic and observed profiles are also for Lyγ and Lyδ for μ=0.866. For Ly5 and Ly6 the observed integral intensities are approx. 1.5-times lower than the synthetic ones.

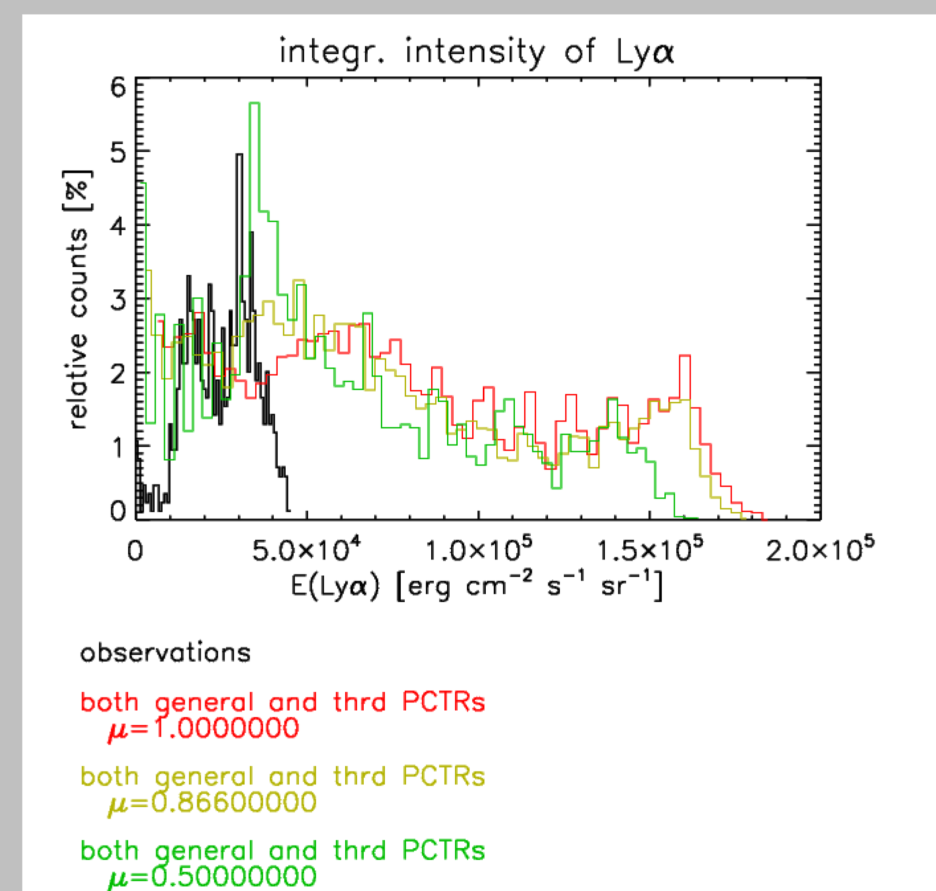




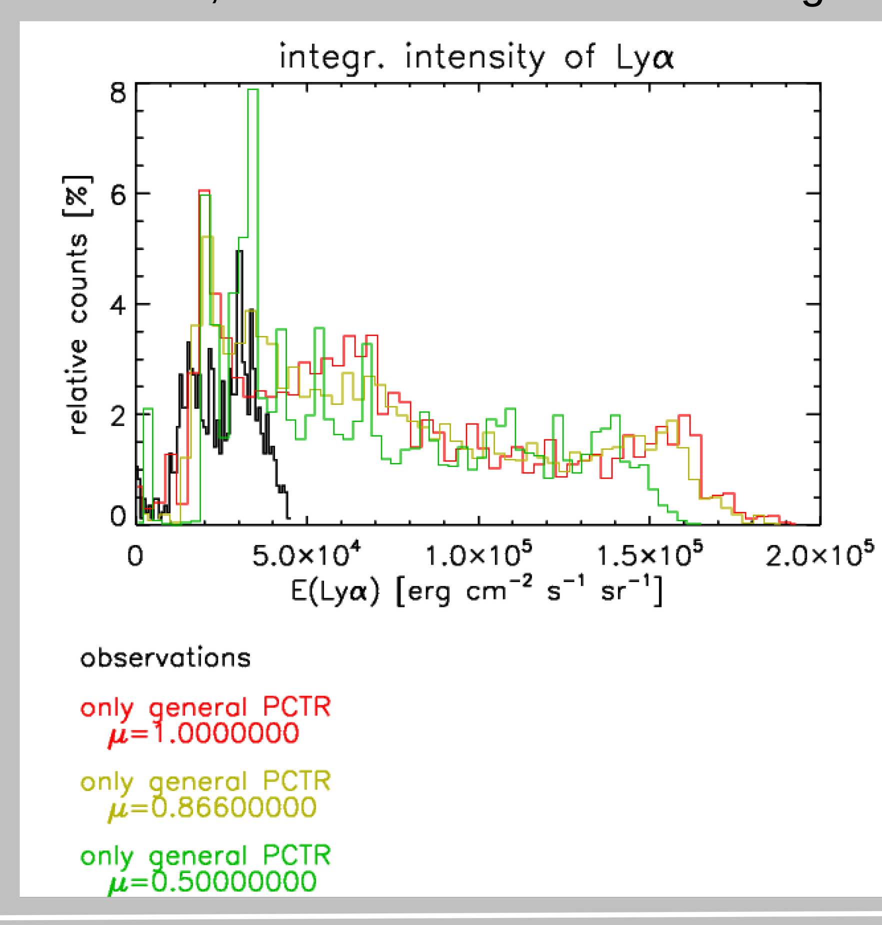
Similar acceptable agreement between synthetic and observed data also for the Lyman decrement Lyδ/Lyβ. For Ly5 and Ly6 histograms of synthetic Lyman decrements show two peaks while those of Observed data have only One. At least left peaks of the synthetic histograms agrees with positions of the peak in the observed histogram.

Histograms of profile asymmetries where in good agreement with Those of the observed data. Also for reversal depth agreement with the observations was reasonable, except for Lyα.

When outer threads with higher central temperatures T_0 =15000 and 30000 K where applied (general prominence-coronal transition region – PCTR), histograms of the integral intensities and Lyman decrement were much wider than those of observed data, as can be seen in following example:



Histograms of the asymmetry and reversal depth of synthetic profiles did not change remarkably.
Also when outer threads with lower column mass M_0=4x10^{-6} g/cm^2 were used, there was also disagreement between histograms of the integral intensities and Lyman decrement for synthetic and observed data. The situation did not changed when PCTRs of each thread was left out, as it is shown in the following example:



Conclusions

Prominence is composed of threads of similar temperatures and column mass and each thread has its own PCTR. From comparison of the histograms of integral intensities and Lyman decrements of synthetic and observed data for prominence of 18 May 2006 it was found that the multi-thread model composed of identical threads reproduces reasonably well the observed data of the lines Lyα – Lyδ. But usage of threads with slightly different temperatures and column masses could improve the results. This hypothesis still needs further investigations. It will be also interesting to test whether also more inner threads could have higher temperatures and/or lower column masses. For Ly5 and the higher Lyman lines improvements of the 2D model of one thread are still necessary.

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