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Cloud modeling of a quiet solar region in Hα

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Abstract. We present chromospheric cloud modeling on the basis of Hα profile-sampling images taken with the Interferometric Bidimensional Spectrometer (IBIS) at the Dunn Solar Telescope (DST). We choose the required reference background profile by using theoretical NLTE profile synthesis. The resulting cloud parameters are converted into estimates of physical parameters (temperature and various densities). Their mean values compare well with the VAL-C model.

Key words. Line: profiles – Techniques: spectroscopic – Sun: chromosphere

1. Introduction

The solar chromosphere observed in Hα shows a mass of fibrilar structures. They are called mottles when seen on the disk, spicules when seen at the limb. Studies of these structures are important to understand chromospheric dynamics and its contribution to outer-atmosphere heating.

Chromospheric observations sampling spectral profiles give the opportunity to derive physical properties of individual fine structures. We do that here for Hα using the DST/IBIS data of Cauzzi et al. (2009). Cloud modeling following Beckers (1964) is the usual method to obtain line formation parameters by matching the observed contrast profile of a structure with a theoretical one (see review by Tziotziou 2007). This approach can only be used if the studied structure is fully separated from the underlying atmosphere, and necessitates description of the latter by a background profile. Its choice or determination is crucial (e.g., Durrant 1975). We address this issue by trying different synthetic Hα profiles. We then use the method of Tsiropoula & Schmieder (1997) to derive physical parameters from the cloud model results.

2. Observations

In March 2007 a quiet-sun area near disk center was observed in Hα with IBIS at the DST (Cavallini 2006; Reardon & Cavallini 2008). These observations were presented and analyzed by Cauzzi et al. (2009). The Hα line was sampled at 24 spectral positions at step intervals of 90 mÅ in a sequence of 192 spectral scans at a cadence of 15.4 seconds. Line profiles were constructed for each pixel in the field of view (diameter 80″). For each spectral profile, the line-center wavelength was established by fitting a polynomial to the five spectral samplings with least intensity. The minimum of the fit defines the per-pixel intensity minimum and line-of-sight velocity.

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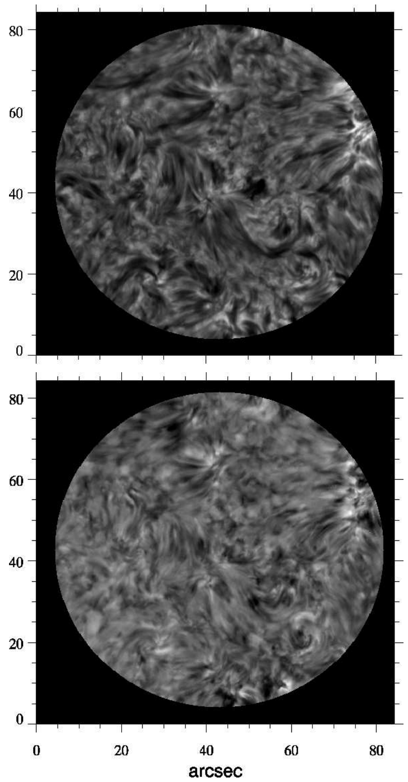

Fig. 1. *Upper image*: profile-minimum intensity. *Lower image*: profile-minimum Dopplershift, with blueshift black, redshift white.

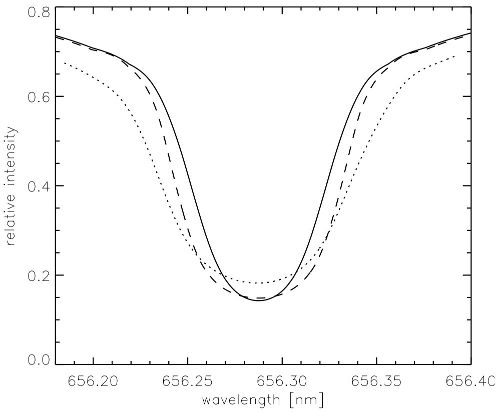

Fig. 2. Background profiles, with the intensities normalized to the continuum value. *Solid*: Kurucz model. *Dashed*: FAL-C model. *Dotted*: observed mean profile.

Figure 1 shows the minimum intensity and Doppler velocity images from a single scan taken during one of the best seeing moments. We refer to Cauzzi et al. (2009) for more detail.

3. Results & conclusions

3.1. Cloud model

The traditional cloud model delivers the four parameters source function S, optical thickness at line center τ_0, Doppler width $\Delta\lambda_D$, and line-of-sight (LOS) velocity υ_{LOS}. The model assumes an optically thin, homogeneous cloud that is illuminated by uniform radiation from below, so that these parameters are assumed constant along the LOS through the cloud. The observed contrast profiles are then matched with theoretical contrast profiles given by:

$$\frac{I(\lambda) - I_0(\lambda)}{I_0(\lambda)} = \left(\frac{S}{I_0(\lambda)} - 1\right)\left(1 - \mathrm{e}^{-\tau(\lambda)}\right), \qquad (1)$$

where $I(\lambda)$ is the local profile, $I_0(\lambda)$ the reference background profile and $\tau(\lambda)$ the optical thickness

$$\tau(\lambda) = \tau_0 \exp\left[-\left(\frac{\lambda - \lambda_c(1 - \upsilon_{LOS}/c)}{\Delta\lambda_D}\right)^2\right]. \qquad (2)$$

The parameter fitting is achieved by iterative least-square matching of the observed contrast profile with a theoretical one.

3.2. Background profile

The background profile $I_0(\lambda)$ represents the irradiation from a supposedly plane-parallel atmosphere underlying the cloud-like chromospheric structure. Its choice has a significant effect on the resulting cloud parameters. We here present Hα cloud modeling results for the IBIS scan with the best seeing using three different background profiles: a synthetic profile computed with a one-dimensional NLTE line formation code from the FAL-C (Fontenla et al. 1993) standard model which contains a chromospheric temperature rise, a synthetic NLTE profile similarly computed from the Kurucz (Kurucz 1979, 1992a,b) radiative-equilibrium model in which the temperature decreases outward without chromosphere, and the spatial-temporal average of all observed Hα profiles over the full field of view during the whole 50-min time series. The three profiles are shown in Fig. 2.

With each background profile, cloud-model fitting was applied to the observed Hα profile at all 1.74×10^5 pixels in the IBIS field of view. We rejected the pixels with resulting values $S > 0.8 I_c$ (in units of continuum intensity) and also the pixels giving $\tau_0 > 5$. In addition, the cloud model routine did not converge or did not yield physically acceptable values for 0.04%, 7.47% and 23.19% of the total when we used the Kurucz, FAL-C, and observed mean profile, respectively. Figure 3 displays the remaining distributions of the cloud model parameters for each background profile. It shows that using the Kurucz profile permits a

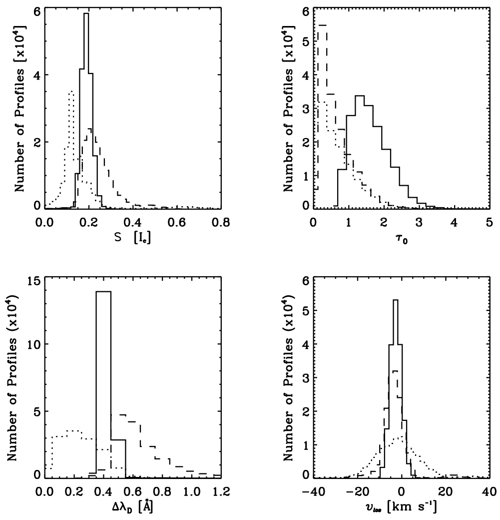

Fig. 3. Occurrence distributions of the cloud parameters. Clockwise source function S, optical thickness at line center τ_0, Doppler width $\Delta\lambda_D$, and line-of-sight velocity υ_{LOS}. *Solid*: Kurucz background profile. *Dashed*: FAL-C background profile. *Dotted*: observed mean profile used as background profile.

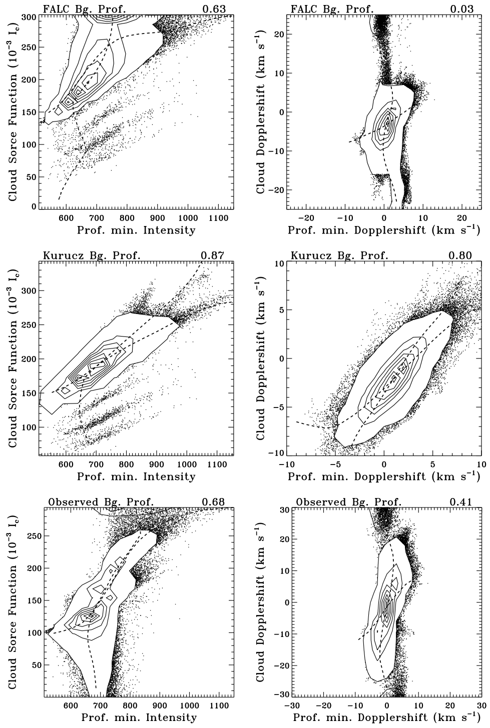

Fig. 4. Scatter plots. *Left column*: Hα source function S against the observed profile-minimum intensity, respectively with the FAL-C background profile (top), the Kurucz background profile (middle), and the observed mean profile as background profile (bottom). *Right column*: idem for the fitted line-of-sight cloud velocity υ_{LOS} against the observed profile-minimum Dopplershift. The numbers at the upper-right corners specify the overall Pearson correlation coefficient.

solution for many more Hα profiles, with narrower parameter distributions.

Figure 4 shows scatter plots for the resulting values of S and υ_{LOS} against the observed profile-minimum intensity and Dopplershift, respectively, when using the three different background profiles. The best correlations between these cloud parameters and profile-minimum measurements are found when the Kurucz synthetic profile is used.

These comparisons suggest that the synthetic Kurucz profile is the best choice as background profile for cloud modeling of these Hα observations. The spread between these tests

Table 1. Comparison of the observed parameters with the values inferred from VAL-C atmosphere models.

Physical Parameter	Quiet Chromosphere	
	Observational	*VAL-C*
S (I_c)	0.19 ± 0.02	–
τ_0	1.50 ± 0.46	–
$\Delta\lambda_D$ (Å)	0.46 ± 0.04	–
υ_{LOS} (km s^{-1})	−1.74 ± 3.37	–
N_1 (10^{10} cm^{-3})	2.21 ± 0.42	1.24
N_2 (10^4 cm^{-3})	2.54 ± 0.88	2.88
N_e (10^{10} cm^{-3})	5.13 ± 0.94	3.54
N_H (10^{10} cm^{-3})	8.02 ± 1.47	4.67
T (10^4 K)	1.43 ± 0.40	1.07
P (dyn cm^{-2})	0.27 ± 0.09	0.13
M (10^{-5} gr cm^{-2})	3.61 ± 0.55	0.62
ρ (10^{-13} gr cm^{-3})	1.75 ± 0.28	1.09
χ_H	0.63 ± 0.01	–

confirms that the issue of the selection of a background profile is key in chromospheric cloud modeling.

3.3. Physical parameters

We then applied cloud model fitting using the Kurucz background profile to all 192 spectral scans in the 50-min time series. We then converted the resulting cloud parameters into more physical parameters with the method of Tsiropoula & Schmieder (1997). The resulting mean values and standard deviations are given in Table 1. For comparison the values of the VAL-C atmosphere model of (Vernazza et al. 1981) at the height where its N_2 population is close to the mean value in the cloud determinations are also listed. Table 1 shows good agreement between the cloud model and VAL-C values.

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