Cloud modeling of bright and dark features in Hα

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ABSTRACT

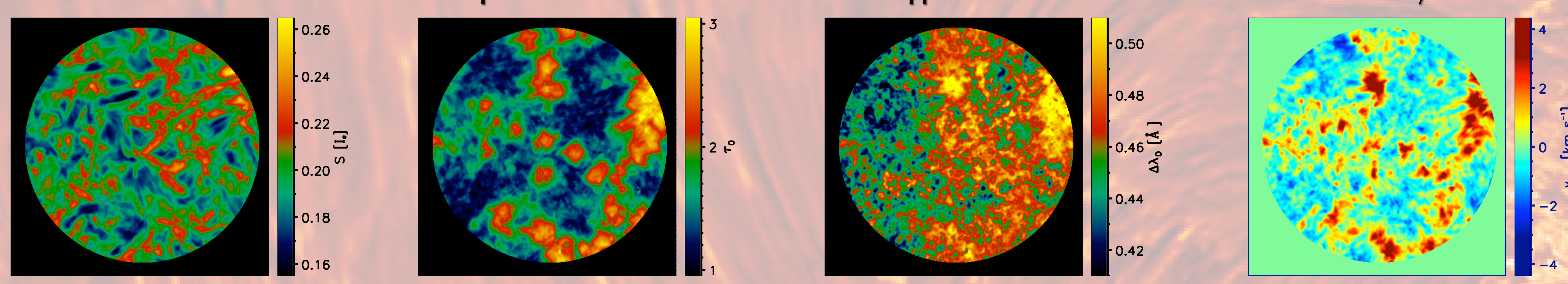
Chromospheric network when viewed in Hα shows bright and dark structures like fibrils. These fine structures usually called mottles are the key to understand the topology and energy balance of this solar regime. Bright and dark mottles form into two kind of groups, named rosette and chain. The mottles in a rosette spread radially outwards from a bright center while in a chain they all point in the same direction.

In this work, we study the physical properties of bright and dark mottles in network, using Hα profile-scanning images taken with IBIS at the DST. Cloud modeling was applied to derive estimates of the mottle optical thickness, source function, Doppler width, and line of sight velocity. With these estimates more intrinsic parameters were determined: the number density of hydrogen atoms in levels 1 and 2, total particle density, electron density, temperature, gas pressure, mass density. We compare the results with those obtained by various authors. It is concluded that dark and bright network mottles have similar nature.

Time averaged parameter maps of Hα observations of quiet-sun region obtained with IBIS

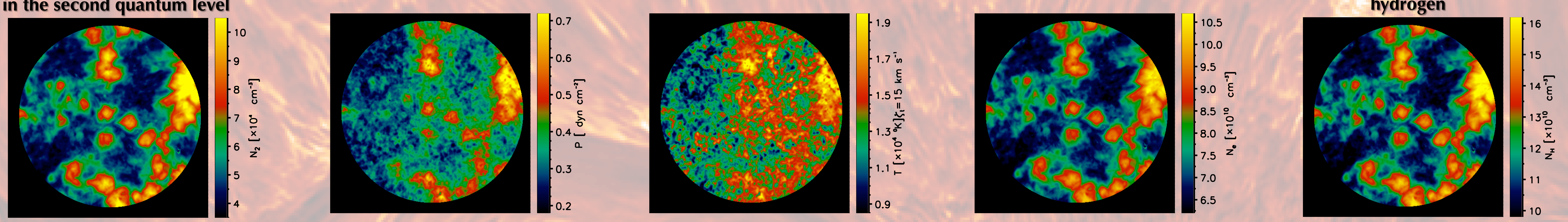
Cloud parameters

Source Function — Optical Thickness — Doppler Width — Velocity



Physical parameters

Number density of hydrogen atoms in the second quantum level — Pressure — Temperature — Electron Density — Total particle density of hydrogen



Model

Cloud modeling considers a feature as due to a cloud above a uniform atmosphere described by a reference background profile. The approach works well for optically thin structures and delivers estimates of the cloud source function S, optical thickness at the line center τ_0, Doppler width $\Delta\lambda_D$, and line-of-sight velocity v_{LOS}, all assumed constant within the cloud along the line of sight. The observed contrast profiles are matched with theoretical contrast profiles [Beckers 1964]:

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

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

where $I(\lambda)$ is the local profile, $I_0(\lambda)$ the reference background profile computed from Kurucz model, and $\tau(\lambda)$ the optical thickness with τ_0 the optical thickness at line center, λ_c the line-center wavelength and c the speed of light.

Measuring the Physical Properties

We also applied the method of Tsiropoula & Schmieder (1997) to estimate more intrinsic state parameters from the four cloud parameter values per sample in the following manner:

If we assume the geometric width of the structures d=1000 km and microturbulent velocity ξ_t=15 km s^{-1}, we can deduce the number density of the second level in hydrogen N_2, and the temperature T:

$$N_2 = 7.26\ 10^7\ \frac{\tau_0 \Delta\lambda_D}{d} \qquad \Delta\lambda_D = \frac{\lambda_0}{c}\sqrt{\xi_t^2 + \frac{2kT}{m}}$$

we can have estimations of electron density N_e, and the total particle density of hydrogen N_H from the value of N_2:

$$N_e = 3.2\ 10^8\ \sqrt{N_2} \qquad N_H = 5\ 10^8\ 10^{0.5\ \log N_2}$$

Thus the hydrogen ground-level population, N_1 is:

$$N_1 = \frac{\lfloor N_t - (2+\alpha)\ N_e \rfloor}{1+\alpha}$$

where Nt is the total particle number density and α is the abundance ratio of helium to hydrogen (~0.0851).

The total column mass m, gas the pressure p, the mass density ρ, and the degree of hydrogen ionization χ_H, are then:

$$m = (N_H m_H + 0.0851\ N_H \times\ 3.97\ m_H)$$

$$p = k\ (N_e + 1.0851\ N_H)\ T$$

$$\rho = \frac{m}{d} \qquad \chi_H = \frac{N_e}{N_H}$$

Observations

In March 2007 a quiet-sun network near disk center was observed in Hα with IBIS at the Dunn Solar Telescope at NSO/Sacramento Peak. The line was sampled at 24 spectral positions at step intervals of 90 mÅ in Hα 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 arcsec).

Table 1 : Cloud parameters for dark mottles derived by various authors and our work.

Authors	S (I_c)	τ_0	$\Delta\lambda_D$ (Å)	v_{LOS} (*km s^{-1}*)
Beckers (1968)	0.12	1.4	0.5	-
Bray (1973)	0.13 to 0.16	1.0	0.5	-9 to 7
Grossman-Doerth & von Uexküll (1977)	0.13	1.1	0.45	-8 to 8
Tsiropoula et al. (1993)	0.16 ± 0.01	1.8±1.1	0.37±0.1	-0.26±6.6
Lee et al. (2000)	0.16	2.2±0.5	0.55	-2.8
Tziotziou et al. (2003)	0.15	0.9	0.35	-0.1
Al et al. (2004)	0.14	1.58	0.44	0.18
This work	**0.17±0.01**	**1.86±0.64**	**0.46±0.03**	**-1.94±3.13**

Table 2 : Cloud parameters for bright mottles derived by various authors and our work.

Authors	S (I_c)	τ_0	$\Delta\lambda_D$ (Å)	v_{LOS} (*km s^{-1}*)
Beckers (1968)	> 0.16			
Bray (1973)	0.28-0.65	0.35-1.0	0.5-0.6	2 - 9
This work	**0.25±0.01**	**2.38±0.59**	**0.48±0.04**	**0.25±3.49**

Table 4: Comparison of the observed parameters with the values inferred from VAL-D and VAL-F atmosphere models.

Physical Parameters	Dark Mottles		Bright Mottles	
	Observational	VAL-D	Observational	VAL-F
N_1 (cm^{-3})	(2.37±0.43) 10^{10}	1.24 10^{10}	(2.83±0.42) 10^{10}	2.43 10^{10}
N_2 (cm^{-3})	(2.84±1.08) 10^4	2.88 10^4	(4.08±1.21) 10^4	3.82 10^4
N_e (cm^{-3})	(5.38±0.99) 10^{10}	4.03 10^{10}	(6.42±0.96) 10^{10}	6.43 10^{10}
N_H (cm^{-3})	(8.02±1.47) 10^{10}	4.85 10^{10}	(10.16±1.47) 10^{10}	7.42 10^{10}
T (K)	(1.34±0.36) 10^4	1.30 10^4	(1.69±0.44) 10^4	1.35 10^4
P (dyn cm^{-2})	0.27±0.09	0.17	0.41±0.13	0.27
M (gr cm^{-2})	(3.91±0.60) 10^{-5}	0.77 10^{-5}	(4.58±0.67) 10^{-5}	1.23 10^{-5}
ρ (gr cm^{-3})	(2.10±0.30) 10^{-13}	1.13 10^{-13}	(2.24±0.34) 10^{-13}	1.7 10^{-13}
x_H	0.63±0.01		0.63±0.01	

Table 5 : Physical parameters of dark mottles published by other authors

Physical Parameters	Tsiropoula & Schmieder (1997)	Tsiropoula & Tziotziou (2004)
N_1 (cm^{-3})	(1.6±0.8) 10^{10}	
N_2 (cm^{-3})	(1.4±1.1) 10^4	(4.2±2.0) 10^4
N_e (cm^{-3})	(3.4±1.5) 10^{10}	(6.4±1.6) 10^{10}
N_H (cm^{-3})	(5.1±2.1) 10^{10}	(9.9±2.5) 10^{10}
T (K)	(1.0±0.8) 10^4	(1.0±0.3) 10^4
P (dyn cm^{-2})	0.15±0.1	0.24±0.1
M (gr cm^{-2})	(2.2±0.9) 10^{-5}	(2.2±0.6) 10^{-5}
ρ (gr cm^{-3})	(1.1±0.5) 10^{-13}	(2.2±0.6) 10^{-13}
x_H	0.65±0.10	0.65

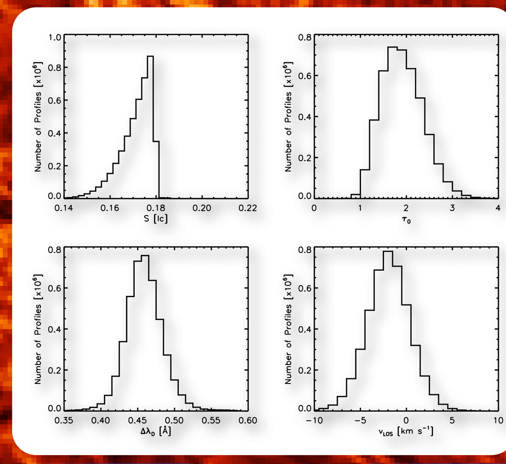


Figure 2a The distribution of cloud parameters for dark mottles.

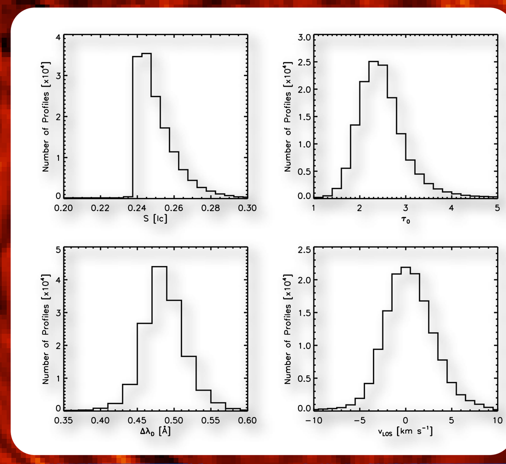


Figure 2b The distribution of cloud parameters for bright mottles.

Results and Conclusion

The model parameters were determined by an iterative least square fitting procedure. For the selection of bright and dark features in network, masks were used for each spectral scan. Fig. 2 displays histograms of cloud parameters for bright and dark mottles. Table 1 and 2 represent the mean values of the parameters with the standard deviations and the results of various authors. It can be seen from these tables there is an agreement between our work and the others except the optical thickness of bright structures. The reason can be that Bray (1973) used 5 spectral profiles of bright mottles to estimate these parameters, whereas we used ~10^5 profile.

Different physical parameters such as N_1, N_2, N_e, N_H, T, and P can be calculated by using cloud results. Fig. 3 shows the images of time-averaged physical parameters when taking into account all pixels in which the cloud model iteration converged. The mean values of parameters for bright and dark mottles are given in Table 3. We also determined the same parameters from VAL-D and VAL-F atmosphere models (Vernezza et al., 1981) by using the averaged N2 value calculated from observations (see Table 3). We gave results of Tsiropoula and Schmieder (1997) and Tsiropoula and Tziotziou (2004) in Table 4 to compare our results with them for dark mottles.

Furthermore, we found pressures of 0.27 and 0.41 dyn cm^{-2} for dark and bright mottles, respectively. Heinzel and Schmieder (1994) using non-LTE models have concluded that for low pressure structures (< 0.5 dyn cm^{-2}) one can easily apply the classical cloud model assuming a constant source function and rather low opacity, while the higher pressure solution gives much higher opacity and strongly non-constant source function. Same authors concluded that there is no principal difference between the dark and bright structures; their pressure and contrast probably depend on the amount of material injected into the flux tube and on the pressure-balance conditions inside it. As it can be clearly seen from our results of physical conditions inside the dark and bright features, given in Table 3, we also find no major difference between them.

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