Gouttebroze, P. and Labrosse, N. and Heinzel, P. and Vial, J.-C. (2002) *Prediction of line intensity ratios in solar prominences.* In: Sawaya-Lacoste, H. (ed.) SOLMAG 2002: Proceedings of the Magnetic Coupling of the Solar Atmosphere Euroconference and IAU Colloquium 188, 11-15 June 2002, Santorini, Greece. ESA Special Publication (505). ESA Publications Division, Noordwijk, The Netherlands, pp. 421-424. ISBN 9789290928157

PREDICTION OF LINE INTENSITY RATIOS IN SOLAR PROMINENCES

P. Gouttebroze[(1)], N. Labrosse[(2)], P. Heinzel[(3)], and J.-C. Vial[(1)]

[(1)]Institut d'Astrophysique Spatiale, Bat. 121, Université Paris XI, 91405 Orsay Cedex, France, E-mail: goutte@ias.u-psud.fr, vial@medoc-ias.u-psud.fr

[(2)]Department of Physics, The University of Wales, Aberystwyth, Ceredigion SY23 3BZ, UK, E-mail: nll@aber.ac.uk

[(3)]Astronomical Institute, Academy of Sciences of the Czech Republic, CZ-25165, Ondřejov, Czech Republic, E-mail: pheinzel@asu.cas.cz

ABSTRACT

Solar prominences are made of relatively cool and dense plasma imbedded in the solar corona, supported and structured by the magnetic field. Since this plasma is definitely out of LTE, the diagnosis of physical conditions in prominences needs the use of specific radiative transfer (RT) codes to predict the spectrum emitted by models and compare it to observations. For optically thin lines, the solution of RT equations in the transition itself is not required, but the emitted intensities depend, via the statistical equilibrium equations, on RT in other transitions which are optically thick.

We use two different sets of models. The first one contains monolithic models defined by 5 parameters: temperature, pressure, thickness, microturbulent velocity and altitude above the solar surface. For each parameter, we assume a range of variation. For each model, the values of the 5 parameters are randomly chosen within the corresponding range of variation. The second set contains composite models made of multiple layers, in order to simulate the penetration of radiation into inhomogeneous prominences. We use NLTE radiative transfer codes to compute the intensities of the lines of hydrogen, helium and calcium emitted by each model. So, for any couple of lines, we may obtain their intensity ratio as a function of the 5 parameters. We discuss the behaviour of some of these intensity ratios as a function of the principal parameters and construct distribution diagrams, which are compared to different published observations.

Key words: prominences; spectra; radiative transfer.

1. USE OF STATISTICAL MODELS

We define as *statistical model* a set of *individual models* whose properties are randomly chosen according to specified probability distributions. In the present case, the *individual* models consist of plane-parallel, isothermal and isobaric slabs standing vertically above the solar surface. Each individual model produces its own spectrum. In general, we record the frequency-integrated intensity, or "energy" E, for a set of relatively strong lines (strong enough to be commonly observed). In this way, we obtain a distribution of intensity for each line, which may be compared to observations.

Table 1. Variation ranges for physical parameters (monolithic models).

quantity	minimum	maximum
T	4 000 K	20 000 K
P	10^{-3} dyn cm^{-2}	1 dyn cm^{-2}
D	100 km	5 000 km
ξ	2 km/s	8 km/s
H	3 000 km	30 000 km

We consider here two different statistical models:

(1) a set "M" of 2000 monolithic slabs depending on 5 parameters: temperature (T), gas pressure (P), total thickness (D), microturbulent velocity (ξ) and altitude above the Sun (H). The probability density for each parameter is uniform in logarithm, between two limits, which are indicated in Table 1.

(2) a set "C" of 1000 composite models. In this case, each individual model is composed of a series of parallel identical slabs, perpendicular to the line of sight. The number n of these slabs is such as:

$$D = nd$$

where D is the total thickness of matter along the line of sight (without including interslab spaces), while d is the thickness of one basic slab. D is chosen randomly between 200 and 5 000 km, and d between 1

Proc. 'SOLMAG: Magnetic Coupling of the Solar Atmosphere Euroconference and IAU Colloquium 188' Santorini, Greece, 11-15 June 2002 (ESA SP-505, October 2002)

Table 2. Simultaneous observations of E(8542) and E(Hβ)

Reference	$E(8542)/E(\mathrm{H}\beta)$ (average value)
Landman and Illing (1977)	0.375
de Boer et al. (1998)	0.425
Stellmacher and Wiehr (2000)	0.63 (faint prominence) 0.28 (bright prominence)

and 10 km. The other parameters are the same as in case (1), except for the temperature which is chosen between 4 000 and 30 000 K. Each slab is supposed to be directly irradiated by the Sun (mutual radiative interaction is neglected).

2. THE (Hα/Hβ) RATIO

The $E(\mathrm{H}\alpha)/E(\mathrm{H}\beta)$ ratio is generally decreasing with $E(\mathrm{H}\beta)$, for monolithic models as well as for composite models. However, composite models produce a larger dispersion. The slope of variation is steeper at low temperatures, which may be considered as an effect of the optical thickness in Hα.

On Fig. 1, the $E(\mathrm{H}\alpha)/E(\mathrm{H}\beta)$ ratio is represented in the (pressure, temperature) plane. This ratio appears to be principally a pressure indicator. Ratios larger than 10 are almost inexistent for monolithic models, while they are present in observations. On the contrary, for composite models, such large ratios are common at low pressures ($P < 0.02$ dyn cm^{-2}). For comparison with observations, see in particular Stellmacher and Wiehr (2000, their figure 5).

3. CA II λ 8542 VS. Hβ

The formation of lines of ionized calcium has been recently revisited by Gouttebroze and Heinzel (2002). For monolithic models, the $E(8542)/E(\mathrm{H}\beta)$ ratio is mostly in the range [0.2,0.4] at low pressures. At higher pressures, this ratio tends to increase if the temperature is low, and to decrease if the temperature is high (an effect of Ca II to Ca III ionization). For composite models (made of small elements), the strong increase of $E(8542)/E(\mathrm{H}\beta)$ towards high pressures (for cool elements) disappears.

The $E(8542)/E(\mathrm{H}\beta)$ ratio has been measured by different authors. A (very partial) summary is given in Table 2.

For instance, the observation of Stellmacher and Wiehr for the bright prominence is compatible with any pressure, while the ratio observed for the faint prominence would imply a relatively high pressure and a low temperature, and favors monolithic models.

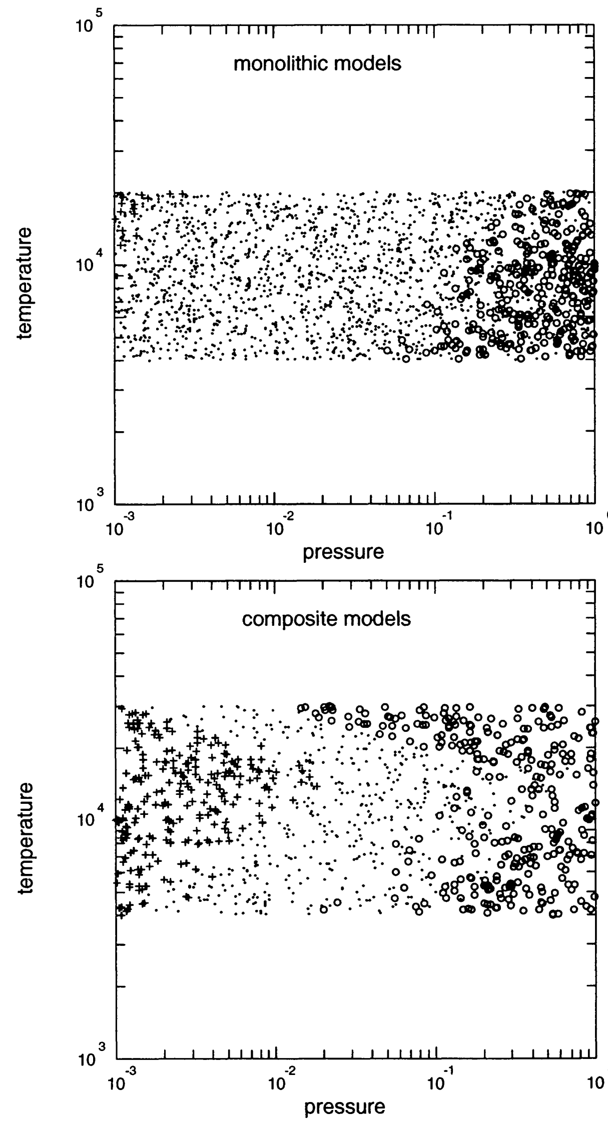

Figure 1. The $E(H\alpha)/E(H\beta)$ ratio in the (pressure, temperature) plane. Ratios lower than 7 are represented by circles, ratios greater than 10 by "+". Intermediate ratios are indicated by points. Upper panel: monolithic models. Lower panel: composite models. Temperatures are in kelvins and gas pressures in dyn cm^{-2}.

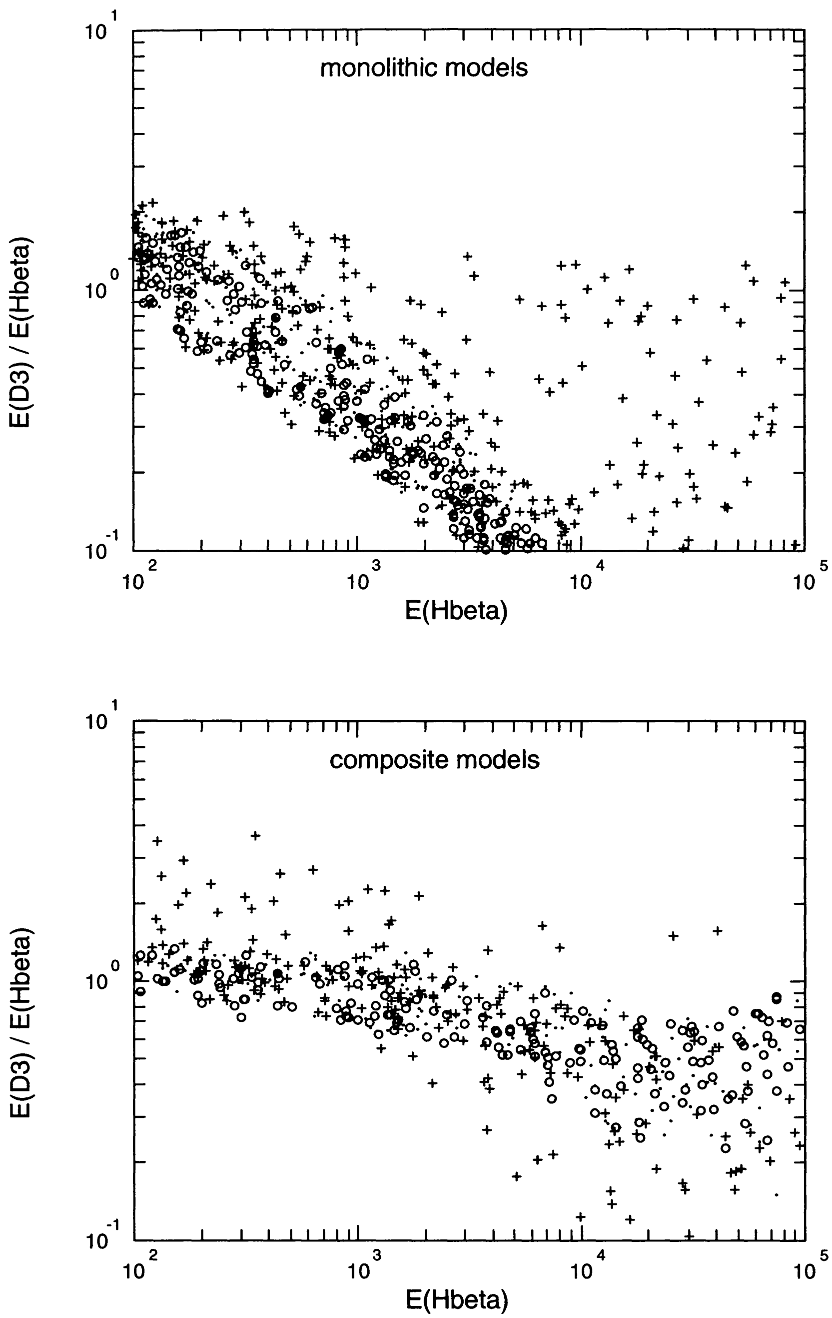

Figure 2. The $E(H\alpha)/E(H\beta)$ ratio as a funtion of $E(H\beta)$. Symbols correspond to different temperature ranges: circles from 4000 to 6500 K, points from 6500 to 10000 K, and "+" from 10000 to 20000 K. Upper panel: monolithic models. Lower panel: composite models.

4. HE I λ 5876 (D3) VS. Hβ

Using a set of monolithic slabs, Labrosse and Gouttebroze (2001) have recently computed the intensities of helium lines emitted by model solar prominences. For these monolithic models, the $E(\mathrm{D3})/E(\mathrm{H}\beta)$ ratio is highly dispersed and generally decreasing with pressure. For composite models, the dispersion of results is much smaller, and there are practically no ratio lower than 0.1 . This difference between monolithic and composite models is probably due to the fact that the helium line is formed near the boundaries of the slab, where UV radiation penetrates, so that the internal parts of monolithic models are inactive for this line. On the contrary, the internal parts of the monolithic slabs contribute to Hβ emission.

On Fig. 2, the $E(\mathrm{D3})/E(\mathrm{H}\beta)$ ratio is represented as a function of $E(\mathrm{H}\beta)$, in order to compare with similar observed diagrams. Such diagrams may be found, for instance, in Landman and Illing (1976, their figures 4 and 5). See also de Boer et al. (1998, their figure 6).

If we compare our Fig.2 with the figure 5 of Landman and Illing (1976), it appears that the general slope obtained with composite models better corresponds to observations than that of monolithic models.

5. CONCLUSION

Concerning the ratios $E(\mathrm{H}\alpha)/E(\mathrm{H}\beta)$ and $E(\mathrm{D3})/E(\mathrm{H}\beta)$, the use of composite models instead of monolithic models allows a better fit of observations. In particular, $E(\mathrm{H}\alpha)/E(\mathrm{H}\beta)$ ratios larger than 10 may be obtained at low pressures with composite models. Concerning the helium D3 line, the slope of the curve $E(\mathrm{D3})/E(\mathrm{H}\beta)$ vs. $E(\mathrm{H}\beta)$ seems also much more realistic with composite models. However, concerning calcium lines, there is no evidence for any advantage of composite models. In the future, we plan to investigate more realistic statistical models, with several elements of different pressure, temperature, etc., along each line of sight.

ACKNOWLEDGEMENTS

The computations were performed at IDRIS (Institut du Développement et des Ressources en Informatique Scientifique) and MEDOC (Multi-Experiment Data Operation Centre for SOHO).

REFERENCES

de Boer C. R., Stellmacher G., Wiehr E., 1998, A&A 334, 280

Labrosse N., Gouttebroze P., 2001, A&A 380, 323

Gouttebroze P., Heinzel P., 2002, A&A 385, 273

Landman D. A., Illing R.M.E., 1976, A&A 49, 277

Landman D. A., Illing R.M.E., 1977, A&A 55, 103

Stellmacher, G., Wiehr, E., 2000, Solar Phys. 196, 357