Mem. S.A.It. Vol. 7, 164

Memorie della
Supplementi

Heights of formation of Mn I spectral lines broadened by hyperfine structure

N. Vitas

Department of Astronomy, Faculty of Mathematics, Studentski trg 16, 11 000 Belgrade, Serbia and Montenegro
e-mail: nikola@matf.bg.ac.yu

Abstract. This paper considers the influence of hyperfine broadening on heights of formation of some Mn I spectral lines in Solar spectrum. The comprehensive model atom of neutral manganese is constructed with 64 bound energy levels and continuum and 161 bound-bound transitions. Preliminary results of spectrum synthesis for this model and atmospheric models for quiet Sun and plage are obtained by using program MULTI. It is shown that hyperfine structure decreases the height of formation and narrows down the line formation region.

Key words. Sun: photosphere – Line: formation

1. Introduction

Lines of neutral manganese in solar spectrum are broadened by hyperfine structure (hfs) as it is shown by Abt (1952). Elste & Teske (1978) suggested that equivalent widths of these lines can be used as good indicators for temperature, independent of velocity and magnetic field. Livingston & Wallace (1987) have reported unusually high variability of line Mn I 539.4 nm on the basis of full-disk observations at Kitt Peak during the period 1979-1985. The same line was included in "Belgrade Program for Monitoring of Activity-sensitive Spectral Lines of the Sun as a Star" (Vince et al. 1988). Various authors analyzed these two data sets and found different values for parameter variations. For example, (Danilović & Vince 2004) found that the relative variation of the equivalent width during the increasing part of solar activity cycle is 1.4%, while the variation of the central depth is 2.3%. For a photospheric line these values are exceptionally high.

For the explanation of the MnI 539.4 nm line behavior several hypotheses were proposed. Doyle et al. (2001) proposed optical pumping of Mn I ground level by photons emitted in the emission core of Mg II k line as a mechanism responsible for observed variation of resonant line Mn I 539.4 nm. Recently, Vince et al. (2005) shown that the variation of the MnI 539.4 nm spectral line in solar flux with the activity cycle could be explained by the variation of solar surface coverage with plages. Here we present preliminary results of NLTE synthesis of this line in two atmospheric models for quiet Sun and plage. Besides, we determined the layer responsible for line Mn I 539.4 nm formation and effect of including of hyperfine structure on the position and wideness of this layer.

Send offprint requests to: N. Vitas

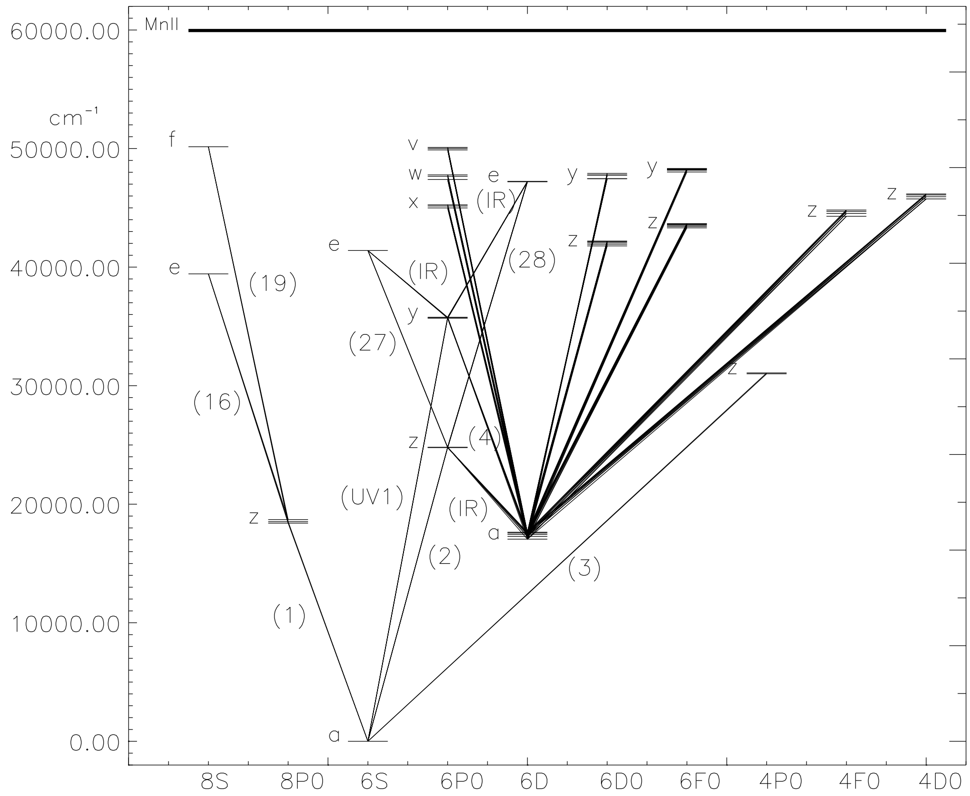

Fig. 1. Term diagram of comprehensive Mn I model atom. Numbers in parentheses mark various multiplets included in the model.

2. Input data

2.1. Atomic data

Our Mn I model atom contains 64 bound levels and continuum. The term structure is presented at Fig. 1. Excitation energies are taken from Corliss & Sugar (1977). For 161 radiative bound-bound transitions the oscillator strengths are from Corliss & Sugar (1977) and Kurucz (1995). Cross-sections for photoionization and collisional transitions have been calculated according to various formulae known in the literature.

Hyperfine structure is taken into account for 37 lines from multiplets marked in Fig 1. Measurements of hfs constants A and B are from various sources. Particularly, for the ground level very precise values are found in Davis et al. (1971). For level z^8P^o, the upper term of multiplete (1), the most reliable measurements are given by Brodzinski et al. (1987).

2.2. Atmospheric models

We have used standard semi-empirical atmospheric models for quiet Sun (FWFAKC) and bright plage (FWFAKP) constructed by Fontenla et al. (1999). Figure 2 shows the temperature stratification of these models as a function of height above the level $\tau_{500} = 1$.

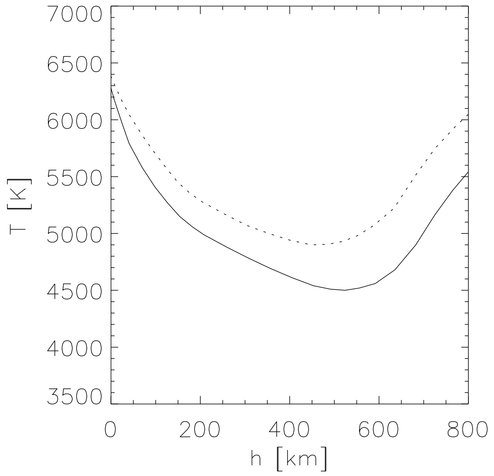

Fig. 2. Temperature stratification in atmospheric models for the quiet Sun (solid line) and plage (dotted line), Fontenla et al. (1999).

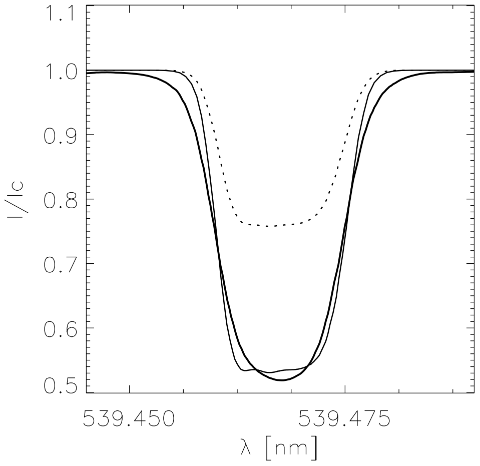

Fig. 3. Profiles of Mn I 539.4 nm calculated in atmospheric models for the quiet Sun (solid line) and plage (dotted line), and observed profile from Delbouille et al. (1981) (thick solid line).

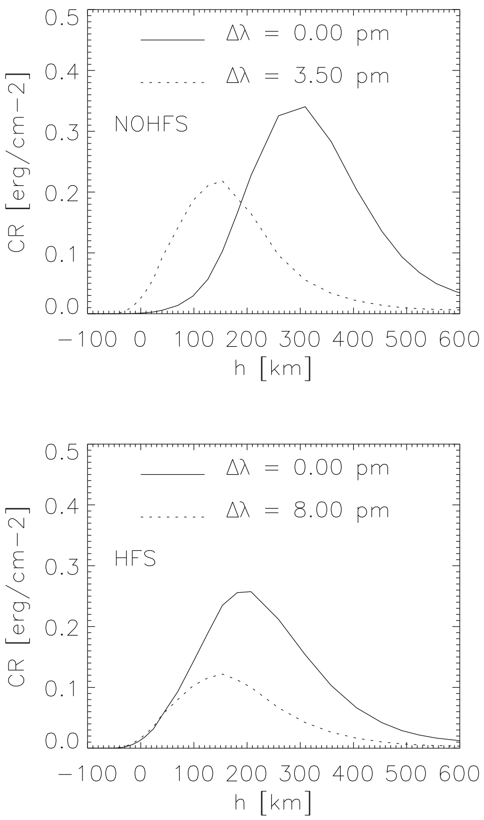

Fig. 4. Contribution functions *CR* for line Mn I 539.4 nm in two cases: without hfs (upper) and with hfs (lower). The core (solid line) is formed in higher layer than the wing (dotted line).

3. Computational method and preliminary results

For profile calculation in NLTE conditions we use radiative transfer code MULTI of Carlsson (1986). This code is based on operator perturbation method by Scharmer & Carlsson (1985). Contribution functions *CR* are calculated according to well known formula by Magain (1986).

Calculated profiles of line Mn I 539.4 nm are shown at Fig. 3. They are normalized to local continuum and compared with the observed profile (Delbouille et al. 1981). It is obvious that the applied method provides good fitting of theory and observation in the case of quiet Sun. Deviations between theoretical and observed profile in the line core are probably due to low resolution of used atlas in comparison to the resolution of synthesized pro-

Table 1. Heights of formation of Mn I 539.4 nm

λ [nm]	h [km]							
	FWFAKC				FWFAKP			
	NOHFS		HFS		NOHFS		HFS	
	wing	core	wing	core	wing	core	wing	core
539.467	189	324	198	244	197	259	194	213

file. Corresponding contribution functions are shown in Fig. 4.

Heights of formation of line Mn I 539.4 nm are presented in Table 1 for both used atmospheric models and two cases: when hyperfine structure is not taken into account (NOHFS) and when it is taken (HFS). Also, all results are given for the line core and a frequency point in the line wing.

4. Conclusions

It is clearly shown that including of hyperfine structure into model atom changes the results for contribution functions and height of formation of line Mn I 539.4 nm. Photospheric origin of this line is confirmed. The height of formation we found is about 14% lower than the value estimated by (Gurtovenko & Kostyk 1989). It is also shown that the layer responsible for formation of a line with pronounced hyperfine structure is narrower. Particularly, in plage this layer is less than 20 km wide.

Acknowledgements. This research is a part of my master thesis. I am very grateful to my advisors Istvan Vince and Olga Atanackovic-Vukmanovic. Also, I am indebted to Darko Jevremovic for invaluable help and assistance in using code MULTI. Ministry of Science and Environmental Protection of Serbia supported this research (project No. 1951, "Solar spectral irradiance variation").

References

Abt, H. A. 1952, ApJ, 115, 199

Brodzinski, T., Kronfeldt, H. D., Kropp, J. R., & Winkler, R. 1987, Z. Phys D, 7, 161

Carlsson, M. 1986, A Computer Program for Solving Multi-Level Non-LTE Radiative Transfer Problems in Moving or Static Atmospheres, Report No. 33, Uppsala Astronomical Observatory

Corliss, C., & Sugar, J. 1977, J. Phys. Chem. Ref. Data, 6, 4, 1256

Danilović, S., & Vince, I. 2004, Serb. Astron. J., 169, 47

Davis, S. J., Wright, J. J., & Balling, L. C. 1971, Phys. Rev. A, 3, 1220

Delbouille, L., Roland, G., Brault, J. W., & Testerman, L. 1981, Photometric Atlas of the Solar Spectrum from 1850 to 10000 cm-1 (1.85 to 10 mm), Kitt Peak Publication

Doyle, J. G., Jevremović, D., Short, C. I., Hauschildt, P. H., Livingston, W., & Vince, I. 2001, A&A, 369, L13

Elste, G., & Teske, R. G. 1978, SoPh, 59, 275

Fontenla, J. M., White, O. R., Fox, P. A., Avrett, E. H., & Kurucz, R. L. 1999, ApJ, 519, 480

Gurtovenko, E., & Kostyk, R. 1989, Fraunhofer Spectrum and System of Solar Oscillator Strengths, Naukova dumka, Kiev

Kurucz, R. L. 1995, Atomic Line Data Kurucz CD-ROM No. 23, Cambridge, Mass., Smithsonian Astrophysical Observatory

Livingston, W., & Wallace, L. 1987, ApJ, 314, 808

Magain, P. 1986, A&A, 163, 135

Scharmer, G. B., & Carlsson, M. 1985, J. Comput. Phys., 59, 56

Vince, I., Kubicela, A., & Arsenijevic, J. 1988, Bull. Obs. Astron. Belgrade, 139, 25

Vince, I., Gopasyuk, O., Gopasyuk, S., & Vince, O. 2005, Serb. Astron. J., 170, 115