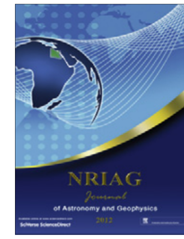
NRIAG Journal of Astronomy and Geophysics (2012) **1**, 106–109

National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag



LTE synthetic and observed profiles of Ca II IR triplet lines in photosphere and faculae

M.A. Semeida *, A.A. Galal, R.H. Hamid, B.A. Marzoke

National Research Institute of Astronomy and Geophysics, Helwan, Cairo, Egypt

Received 15 October 2012; accepted 9 December 2012
Available online 19 February 2013

Abstract A new NLTE photospheric and facular physical models are applied to calculate synthetic profiles of Ca II IR triplet lines (8498.023 Å, 8542.091 Å and 8662.141 Å) in solar photosphere and faculae at angular distances 0.75 and 0.30 from the center of the solar disk. A reasonable congruency of calculated and observed contours of the lines is achieved in the wings and outer shoulders of the lines. Evident deviations are noted in the line cores. These results confirm the previous conclusions about the NLTE effects in the higher sub solar layers where the cores of the lines are formed, as indicated by the temperature curves of the electronic and excitation temperatures of our models. Values of Ca II abundance are deduced in the course of calculations, and compared with other values.

Introduction

The observed emergent intensities at different displacements from the centers of Ca II IR triplet lines in the solar photosphere recorded by De Jager and Neven (1967) and in solar faculae by Galal (1977) are used to compute solar profiles of the lines according to the LTE synthetic method (Semeida, 1998). The synthetic method consists mainly of the comparison of the observed spectrum around the considered line with the calculated spectrum (Ross et al. 1968).

In the LTE synthetic approaches, the total source function (line + continuum) is considered to be identical with Planck's function and can be defined directly from the temperature curve of the reassigned model of the solar atmosphere (Semeida, 1998).

Synthetic analyses generally depend on the assumption of atmospheric parameters and suitable mechanisms of spectral line formation. For spectroscopic determination of photospheric abundance, the simplified assumption of LTE is commonly made, implying that the source function equals the Planck function.

In the present work NLTE values of the abundance of Ca II element are determined in observed photosphere and faculae and compared with another studies.

Method of analysis

Assuming LTE condition, we may write the limb darkening formula of the emergent intensity at certain wavelength in spectral line can be written as follows:

* Corresponding author. Tel.: +2 02 25560046.
E-mail address: m_semeida@yahoo.com (M.A. Semeida).

Peer review under responsibility of National Research Institute of Astronomy and Geophysics.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.nrjag.2012.12.005

Table 1 Spectroscopic Parameters of Ca II Infrared Triplet Lines in photosphere and faculae.

Transition	λ (Å)	J–J	Log (gf)			L.E.P. (ev)	U.E.P. (ev)
			(1)	(2)	(3)		
$3d^2D_{5/2}$–$4p^2P_{3/2}$	8542.09	5/2–3/2	−1.29	−0.51	−0.362	1.70	3.14
$3d^2D_{3/2}$–$4p^2P_{1/2}$	8662.14	3/2–1/2	−1.56	−0.77	−0.623	1.69	3.11
$3d^2D_{3/2}$–$4p^2P_{3/2}$	8498.02	3/2–3/2	−2.22	−1.46	−1.312	1.69	3.14

(1) Corliss and Bozman (1962), (2) Biemont and Grevesse (1973), (3) Kurucz Atomic line data base (1995).

$$I_\lambda(0,\mu) = \int_0^\infty B_\lambda(\tau_\lambda)e^{-\tau_\lambda}\frac{d\tau}{\mu} \tag{1}$$

where B_λ (τ_λ): is the Planck's function , τ_λ is the total optical depth.

$$\tau_\lambda = \int (k_{l\lambda} + k_{c\lambda})\rho dx \tag{2}$$

where $k_{l\lambda}$ and $k_{c\lambda}$ is the line and continuum absorption coefficients respectively, ρ is the density of solar material , dx is the geometrical depth.The line absorption coefficient k_l is related to atomic absorption coefficient (α_l^λ) by the following relation:

$$k_l^\lambda = \frac{N_{s,i}}{\rho}\cdot \alpha_l^\lambda \tag{3}$$

where $N_{s,i}$ is the number of atoms per cubic centimeter of the absorbing element in the excited level i and the ionization state s, the line absorption coefficient (per atom) for combined Doppler, neutral and pressure at the wavelength λ is given by:

$$\alpha_l^\lambda = \alpha_0 H(a,v)\left[1 - e^{-hc/\lambda kT}\right] \tag{4}$$

where,

$$\alpha_0 = \frac{\sqrt{\pi\varepsilon^2}}{m_e c^2} f \frac{\lambda_0^2}{\Delta\lambda_D} \tag{5}$$

f is the oscillator strength, and $\Delta\lambda_D$ is the Doppler broadening, it is given by:

$$\Delta\lambda_D = \frac{\lambda_0}{c}\sqrt{\frac{2kT}{M} + \xi^2} \tag{6}$$

where T is the local temperature λ_0 is the central line wavelength M is the atomic mass of the absorbing element ζ is the micro turbulent velocity. The element abundance is the summation of N_{si},

$$N_{el} = \sum N_{s,i} \tag{7}$$

where $A_{el} = \frac{N_{el}}{N_H}$ is the abundance of the element relative to hydrogen atom and N_{si} is defined as:

$$N_{s,i} = N_{s,i}\frac{N_{el}N_H}{\sum_{s,i}N_{s,i}N_H} = \frac{N_{s,i}}{\sum_{s,i}N_{s,i}}N_H A_{el} \tag{8}$$

where: N_H is the number of hydrogen atoms in cubic centimeter, and $\frac{N_{s,i}}{\sum_{s,i}N_{s,i}}$ is computed according to Boltzman and Saha formulae. The density ρ is determined by:

$$\rho = \sum_a N_a M_a = m_H \sum N_a A_a = m_H N_H \mu_0 \tag{9}$$

where N_a is the number of atoms or ions per cm^3, A_a is the atomic weight of the element a, m_H is the atomic mass of hydrogen, μ_0 is the mean atomic weight relative to hydrogen we can write the line absorption coefficient $k_{l\lambda}$ as:

$$K_{l\lambda} = \frac{\sqrt{\pi\varepsilon^2}}{m_e c m_H \mu_0} f\lambda A_{el}\frac{N_{s,i}}{\sum_{s,i}N_{s,i}}\frac{H(a,v)}{\sqrt{(2kT/Am_H + \xi^2)}}(1 - e^{-hc/\lambda kT}) \tag{10}$$

LTE synthetic method is applied using a modified version of the computer program developed by Grevesse (1982), the empirical photospheric model of Semeida (1998) and the facular temperature model of Marzoke (2007) are used in the calculations of Ca II infrared triplet lines.

The ionization potential is taken from Moore (1972). The partition functions calculated by Van Diest (1982). The Spectroscopic Parameters of these lines are shown in Table 1.

Results and discussions

The values of Ca II IR triplet lines abundance, enhancement factors, and microturbulent velocities are given in Table 2.

In the present work the abundance of Ca II element is determined in observed photosphere and faculae and compared with another studies.

Smith and Drake (1987) confirmed that the relative abundance of calcium is consistent with the metallicity of the model atmosphere, the absorption becomes more sensitive to metallicity with increasing effective temperature.

Lambert and Luck, 1978 have studied the abundance of the elements in the solar photosphere, and found the mean abundance of the Calcium element (12 Ca II lines) equal 6.38 ± 0.08.

Grevesse and Sauval (1998) studied the chemical composition of the sun, and found the Ca II abundance in the photosphere is 6.36 ± 0.02, which is comparable with the value in meteorites 6.35 ± 0.01.

Wurz et al. (2003) determined the abundance of Ca II lines in the solar wind and the photosphere, where the abundance of

Table 2 CLV of Ca II IR triplet lines abundance (A_{el}), microturbulence (v_t) and enhancement factors (E).

Lines	μ Parameters	Photosphere		Faculae	
		0.75	0.3	0.75	0.3
8542.091 Å	A_{el}	6.37	6.33	5.10	4.70
	E	1.80	2.00	1.70	1.70
	v_t	1.00	1.40	0.85	0.90
8662.141 Å	A_{el}	6.35	6.31	5.47	5.15
	E	2.00	2.00	1.85	1.70
	v_t	1.00	1.40	1.00	1.10
8498.023 Å	A_{el}	6.37	6.31	5.80	5.55
	E	2.00	2.00	1.75	1.80
	v_t	1.00	1.40	1.00	1.40

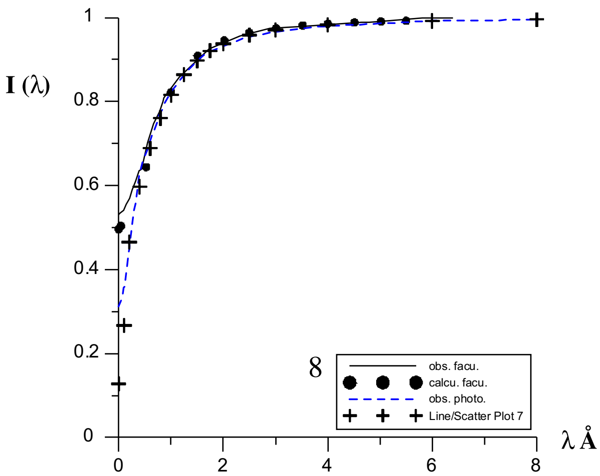


Fig. 1a Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.75$ and 8498.023 Å.

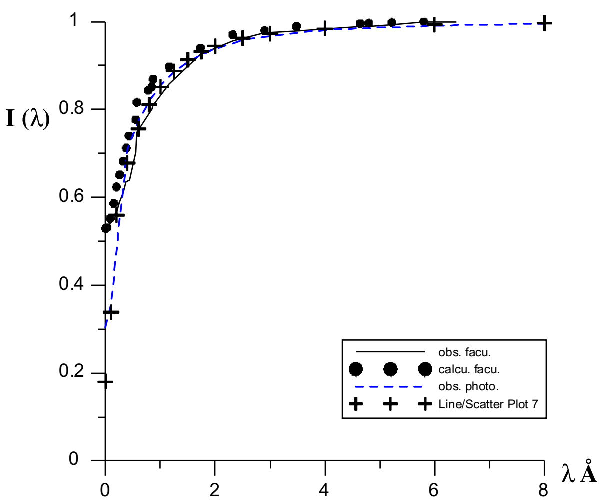


Fig. 1b Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.3$ and 8498.023 Å.

Ca II/H is found to be $A_{Ca} = 6.63 \pm 0.05$ and $A_{Ca} = 6.21 \pm 0.10$ for slow and fast solar wind respectively. In these connections the given photospheric Ca II abundance is $A_{Ca} = 6.36 \pm 0.02$.

Mashonkina et al. (2007) calculated the average of the absolute solar Ca I (from 23 lines) and Ca II (from 8 lines) abundance, it is found to be $A_{Ca} = 6.38 \pm 0.06$.

The mean abundances derived from our sample of lines (8498.023, 8542.091, 8662.141 Å) range from $A_{Ca} = 5.8$ to $A_{Ca} = 4.7$.

By comparing the abundance values of the photosphere, we see that the abundance values in the solar faculae are lower than that in the solar photosphere, because the lines are weaker in faculae.

In Figs. 1a, 1b a comparison is given between synthetic and observed contours of the weakest line ($\lambda = 8498.023$ Å) at $\mu = 0.75$; 0.28 respectively, while Figs. 2a, 2b show calculated and observed contours of the strongest line ($\lambda = 8542.091$ Å) at $\mu = 0.75$; 0.28 respectively, and Figs. 3a, 3b demonstrates the comparison between synthetic and observed contours for

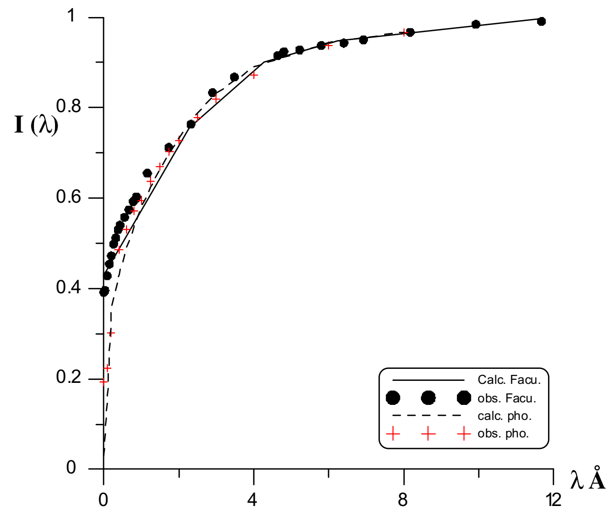


Fig. 2a Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.75$ and 8542.091 Å.

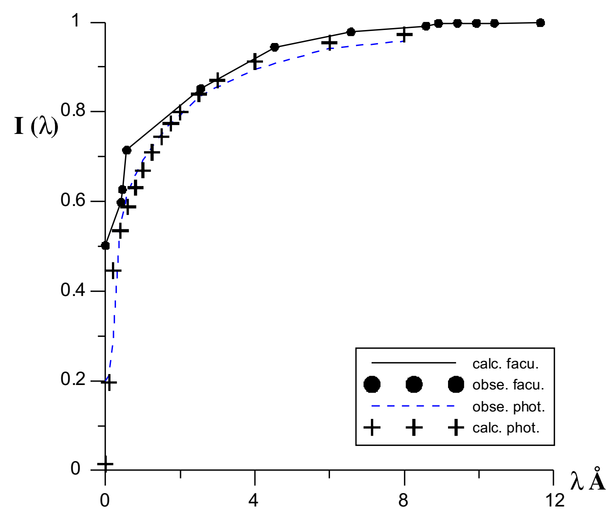


Fig. 2b Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.3$ and 8542.091 Å.

the moderate line ($\lambda = 8662.141$ Å) at $\mu = 0.75$; 0.28 respectively.

Good coincidence (Ca II line $\lambda = 8498.023$ Å) between calculated and observed profiles is seen at heliocentric distance ($\mu = 0.75$) and ($\mu = 0.28$), while the profiles of the strongest Ca II line $\lambda = 8542.091$ Å have a good coincidence in wing spectrum only at the center and the limb of the solar disk. Good congruency of calculated and observed profiles of the moderate Ca II line $\lambda = 8662.141$ Å is achieved especially at the wing.

Conclusions

- N LTE synthetic analysis of Ca II IR triplet lines lead to a good agreement between calculated and observed spectrum of the lines at the center and the limb of the solar disk in photosphere and faculae.

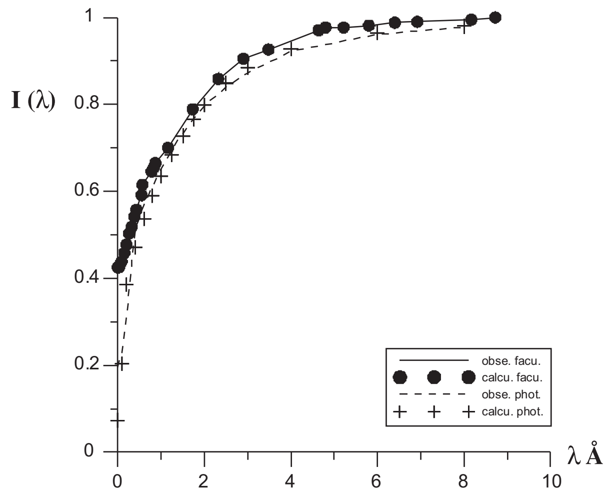


Fig. 3a Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.75$ and 8662.141 Å.

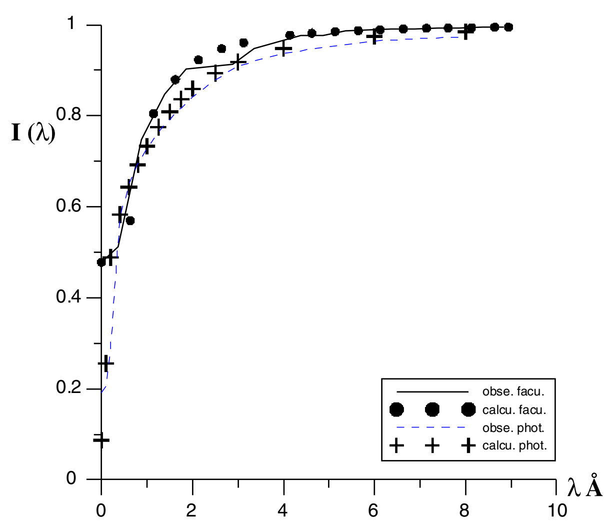


Fig. 3b Observed and calculated synthetic profiles of solar Faculae and photosphere at $\mu = 0.3$ and 8662.141 Å.

- For the weakest Ca II line $\lambda = 8498.023$ Å, a good coincidence between calculated and observed profiles is achieved at the center of the solar disk ($\mu = 0.75$) and the solar limb ($\mu = 0.28$),
- For the strongest Ca II line $\lambda = 8542.091$ Å, we achieved a good coincidence between calculated and observed wings at the center and the limb of the solar disk.
- For the moderate Ca II line $\lambda = 8662.141$ Å, we have a good agreement between the calculated and observed profiles especially at wings.
- The variation of the solar calcium abundance from the center of the solar disk to the limb is defined. The abundance values are found to increase from the center to the limb of the solar disk.
- The determined average value of Ca II IR triplet lines abundance was found to be $A_{Ca} = 5.3$ in faculae, while the determined average value of Ca II IR triplet lines abundance in the photosphere was found to be $A_{Ca} = 6.34$. The reason for the average values of calcium abundance in faculae lower than in photosphere is due to the fact that the lines are relatively weaker in solar faculae.

References

Lambert, David L., Luck, Earle R., 1978. Mon. Not. R. Astr. Soc. 183, 79–100.

Galal, A.A., 1977. Soln. Dann 8, 99 (Russian).

Grevesse, N. 1982. Private Commun.

Grevesse, N., Sauval, A.J., 1998. Space Sci. Rev. 85, 161–174.

Kurucz atomic line data base, 1995. <http://www.pmp.uni-hannover.de/cgi-bin/ssi/test/kurucz/sekur.html>.

Mashonkina, L., Korn, A.J., Przybilla, N., 2007. A&A J. 461, 261–275.

Moor, C.E., 1972. Private Commun.

Ross, J.E., Aller, L.H., Mohler, O.C., 1968. Proc. Natl. Acad. Sci. USA 59, 1.

Smith, G., Drake, J.J., 1987. Astron. & Astrophys. 181, 103–111.

Van Diest, 1982. Private Commun.

Wurz, P., Bochsler, P., Paquetter, J.A., Ipavich, F.M., 2003. Astrophys. J. 583, 489–495.

De Jager, C., Neven, L., 1967. Bull. astr. Inst. Netherlands Suppl., Vol. 1, No. 8.

Semeida, M.A., 1998. M.Sc. Thesis, Astronomy Department, Faculty of. Science, Cairo University.

Marzoke, B.A., 2007. M.Sc. Thesis, Astronomy Department, Faculty of. Science, Al-Azhar University.

Corliss, C.H. and Bozman, W.R., 1962. Nat. Bur. Stand. Monograph 53.