PRESSURE BROADENING AND SOLAR SPECTRAL LINE BISECTORS

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ABSTRACT. In order to show that pressure broadening (atomic collisional processes) may have an important contribution to the spectral line asymmetries in some cases, what is of interest especially for the solar granulation studies, bisectors for NaI 3s^2 S-np^2 P^2 solar lines have been calculated for different positions on the solar disk. Our numerical results clearly demonstrate that in the case of the examined spectral series the influence of pressure broadening has not a negligible role for the convective layer diagnostic.

1. INTRODUCTION

The study of line shapes and shifts is a powerful tool for the investigation of a number of problems in solar and stellar spectra (e.g. the line shift as function of the distance from the center of the apparent solar disk, commonly known as limb effect) may be studied using the line profiles analysis. Often (e.g. Dravins et al., 1981), line shape asymmetries are described by bisectors. The line bisector is formed by the loci of points midway between equal-intensity points on either side of the line profile dividing thus, the absorption line into two halves of equal equivalent widths. It shows the apparent radial velocity at each depth in the line what is of the special interest for solar granulation research. Such investigation does not require spatially resolved spectra and can be applied also in stellar studies.

In such research, the influence of collisions between the absorber and surrounding particles is usually neglected (e.g. Dravins et al., 1981). However, Hart (1974) and Vince et al. (1985, 1987) are demonstrated that the influence of collisions may be significant for some spectral line shifts.

The aim of our investigation is to show that pressure broadening (collision processes) may have an important


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contribution to the spectral line asymmetries in some cases and might not always be neglected in precise analysis. In order to demonstrate this, we performed an analysis of the influence of collisional processes on bisectors of some sodium atom spectral lines at different positions on solar disk.

2. THEORY

In order to investigate the influence of collision processes on the convective zone outer layer (observed as the granulation on solar surface) study, by using Fraunhofer lines bisectors, synthetic bisectors due to collisions with atomic hydrogen, electrons and protons have been calculated for NaI $3s^2S$-$np^2P^0$ lines ($n=3, 4, 5, 6$).

The synthetic spectral line profile is determined from the equation of radiative transfer (e.g. Mihalas, 1972)

$$I_\lambda(0, \mu) = \int_0^\infty S(\tau_\lambda) e^{-\tau_\lambda/\mu} d\tau_\lambda/\mu$$

where $I_\lambda(0, \mu)$ is the emergent intensity, $S(\tau_\lambda)$ is the source function, $\tau_\lambda$ is the optical depth and $\mu$ is the cosine of heliocentric angle. The optical depth is a function of absorption coefficient, we assume that the absorption coefficient have Voigt profile which is defined by the following dimensionless parameters

$$a = 2w/\Delta \lambda_D \quad \text{and} \quad v = (\lambda - \lambda_0 + d)/\Delta \lambda_D,$$

there, $\Delta \lambda_D$ is the Doppler width, $\lambda_0$ is the wavelength of the unshifted line core. In the case of the solar atmosphere the impact approximation is valid. The profile for constant plasma conditions is then lorentzian and is defined with full width at half maximum (FWHM) $2w$ and shift $d$. Since a Fraunhofer line is formed in a wide layer of solar atmosphere where temperature, perturber density and other relevant parameters are functions of position and time, the emergent spectral line bisectors have been calculated using the VALC model (Vernazza et al., 1981) of the solar atmosphere.

The broadening and shift of spectral lines due to collisions with neutral perturbers has been calculated for NaI $3s^2S$-$np^2P^0$ ($n=4, 5, 6$) lines using the Smirnov-Roueff exchange potential, which takes into account the overlap at intermediate absorber-perturber distances of the electronic orbitals (Roueff, 1972, 1975, 1976). In the case of $3s^2S$-$3p^2P^0$ line, results of Monteiro et al. (1985) have been used.
Monteiro et al. (1985) used semiclassical impact-parameter method (see e.g. Lewis et al., 1971) which should be satisfactory at the temperatures of interest (∼5000 K). Moreover, they used improved interatomic potentials.

For the electron- and proton-impact contribution, data by Dimitrijević and Sahal-Bréchot (1985), obtained with the semiclassical-perturbation formalism, have been used.

3. RESULTS AND DISCUSSION

Center to limb variation of NaI 3s2S-np2P0 (n=3-6) synthetic line asymmetries, i.e. bisectors, are shown in Fig.1 for five values of cosine of heliocentric angle. In laboratory conditions, it is expected that the variation of pressure broadening parameters within a spectral series is regular (see e.g. Dimitrijević and Sahal-Bréchot, 1985; Dimitrijević and Peach, 1987). However, we can see in Fig.1 that in the case of the examined bisectors the situation is not so simple.

The calculated bisectors depend on electron- proton- and neutral hydrogen atom-impacts. In spite of the fact that electron-impact broadening dominate in most cases, H- and p-impacts are also important and each contribution has a different trend within a spectral series. Moreover, the region of line formation as a function of the heliocentric angle changes within the spectral series examined becoming narrower when cosine of heliocentric angle tends to 1 for higher series number. Those changes are more important for the line wings than for the peaks which is clearly seen in Fig.1 for 3s2S-6p2P0 transition. In this case line wings are formed in the lower regions of solar atmosphere and are more sensitive to the particle density and temperature variations with heliocentric angle. On the other hand line peaks are formed in the higher part of solar atmosphere where the influence of collisional processes on the line shapes is smaller. Consequently, even the large variations in the height of line peak formation have not significant influence on examined bisectors.

We might conclude that our numerical results clearly demonstrate that in the case of choosen sodium spectral lines the influence of pressure broadening has not a negligible role for the convective layer diagnostic. Moreover, the influence of collisional processes become more significant for higher series members as clearly seen in Fig.1. In order to understand better the behaviour of Fraunhofer lines bisectors within a spectral series it is interesting to perform an analysis of the influence of various atomic processes contributions to line asymmetries (bisectors) within a spectral series.
Fig. 1. Bisectors of NaI $3s^2S-3p^2P^\circ$ (a), $3s^2S-4p^2P^\circ$ (b), $3s^2S-5p^2P^\circ$ (c) and $3s^2S-6p^2P^\circ$ (d) spectral lines for $\mu=1$ (———), $\mu=0.8$ (——_), $\mu=0.6$ (———), $\mu=0.4$ (———_) and $\mu=0.2$ (·····)
4. REFERENCES

Dimitrijević, M.S. and Sahal-Bréchet, S.: 1985, JQSRT, 24, 149.
Part 2
Observations