NLTE-EFFECTS IN PROFILES OF PASCHEN AND BRACKETT LINES OF AN A0IV STAR γ GEM

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Abstract Profiles of the hydrogen Paβ, Paγ and Brγ lines of an A0IV star γ Gem were obtained at a high resolution to investigate at what degree the hydrogen IR lines can be useful for fine tests of the NLTE model atmospheres. All three lines show a deep and narrow absorption core in a good qualitative agreement with the predictions of the available NLTE models for B stars, thus proving that the NLTE effects are important for A stars as well. New NLTE models were computed to extend the grid down to 9500 °K and to include 8 discrete levels of H atom into the energy balance. However, further theoretical work is necessary to compare the observed profiles and the theory.

1. Introduction. About 20 years ago it has been realized that the departures from LTE in atmospheres of O and B main sequence stars change dramatically the temperature profile near the stellar surface (Strom and Kalkofen, 1966; Auer and Mihalas, 1969a). The subsequently built NLTE model atmospheres for the hot stars were tested by using observations obtained in the visible (Strom and Kalkofen, 1967; Auer and Mihalas, 1970). Auer and Mihalas (1969b) also suggested to undertake spectroscopy in the near IR. Namely, they pointed out that the profile of the hydrogen Brα 4.05 μm line should be very sensitive to the departures from LTE and have a narrow emission core in the spectra of B stars. However, high resolution spectroscopy of this line is difficult because of the strong thermal background at these wavelengths. In the present study we wish to adress two questions. First, whether a high resolution spectroscopy of other hydrogen lines in the near IR ($\lambda\lambda$ 1-2.5 μm), where the thermal background is negligible, could be useful in testing model atmospheres, and second, if the NLTE effects are still important for A stars. We selected γ Gem (A0IV, T_{eff} = 9500°K) which is a slow rotator, v·sin i = 7 km·s^{-1} (Boesgaard and Praderie, 1981)

2. Observations. The Fourier transform spectrometer at the 3.6 m CFH telescope on Mauna Kea (Hawaii) was used to obtain the spectrum of the star from 1 to 2.5 μm at the resolution of 1 cm^{-1}. The instrument was described by Maillard and Michel (1982). The hydrogen lines of interest in this spectral range are Paβ 1.2818 μm, Paγ 1.0938 μm and Brγ 2.1655 μm. Their observed profiles are displayed in Fig. 1.

3. Discussion and model atmosphere computations. All three lines show broad wings and a deep and narrow absorption core which is particularly conspicious in the profile of Paβ. Such a core was predicted by Auer and Mihalas (1970) and is due to departures from LTE. However, the lowest effective temperature they considered in

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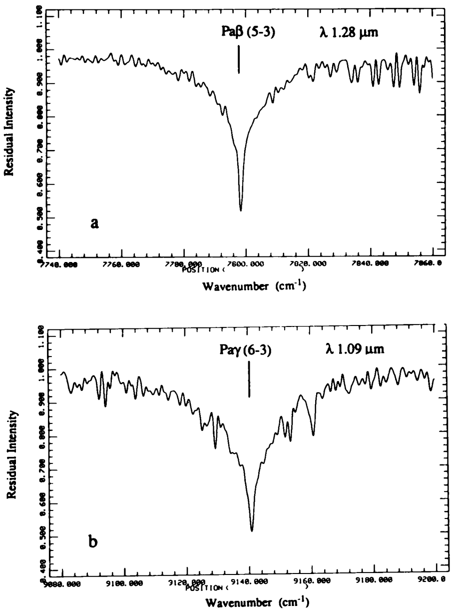

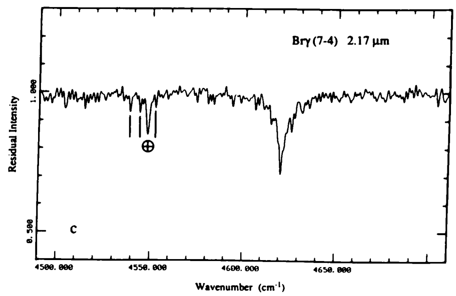

Fig. 1 *The observed profiles of the hydrogen lines in the near IR spectrum of γGem (A0IV) :* ***a*** *- Paβ;* ***b*** *- Paγ;* ***c*** *- Brγ.*

their NLTE computations was 12500 °K, therefore the agreement with their results is only qualitative. The grid of the NLTE model atmospheres had to be extended to temperatures lower than 12500 °K. At these temperatures, the ionisation front of hydrogen is situated in the atmosphere, which leads to instability of iterations. Further, the statistical equilibrium equations in the models of Auer and Mihalas include the first 5 discrete levels of the H atom while to have a correct source function of Brγ (transition 4-7) one must consider at least 8 discrete levels. As the starting point we used the code described by Mihalas *et al.* (1975). It makes use of the complete linearisation method. The code was modified to include 8 discrete levels (in total, 21 transitions were considered; the Lyman transitions are assumed to be in the detailed balance). A great care was taken to handle instability problems due to lower T_{eff}. The code underwent additional modifications to be used on VAX mini- and micro-computers. A grid of NLTE model atmospheres was thus obtained for log g = 4 and for T_{eff} ranging from 9500°K to 15000°K with the step of 250°K. For each model, the profiles of temperature in the atmosphere, of the hydrogen ionisation and of populations of the first 8 levels of H atom were computed in a *self-consistent* manner. It was found that including 8 levels in the energy balance leads to the outward temperature rise up to about *1000 °K more* than in the models where only 5 discrete levels were considered (Borsenberger and Gros, 1978) . As an example, the temperature profile obtained for T_{eff}=9500°K is displayed in Fig. 2. (There, we also indicated the depths in the atmosphere where the hydrogen lines of interest reach the unity optical depth. One can see that the Brackett and Paschen lines probe the region of the temperature minimum). Another result to be mentioned is the emission core predicted in the Brα 4.05 μm line at T_{eff} as low as 9500°K. A more detailed description of the model computations and the results will be given elsewhere (Borsenberger, in preparation).

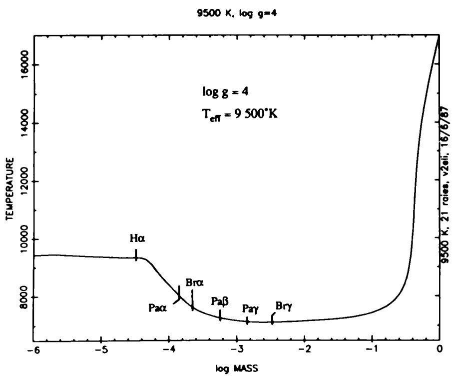

Fig.2 *The temperature profile of the NLTE model atmosphere at T_{eff}=9500 °K. The energy balance accounts for 8 discrete levels of hydrogen and the continuum. We also indicated the depths where different hydrogen lines become optically thick.*

So far, only a progress report can be done on the computations of the hydrogen IR line profiles. The source functions are NLTE and frequency independent. The optical depths and the source functions are fully consistent with the models. The line broadening includes the thermal one and the Stark broadening. The quasi-static approximation was used for ions (Edmonds *et al.*, 1967). The electron broadening was treated quasistatically in the wings and using the impact approximation in the line center (Hoang-Binh,1982). The resulting computed profiles turned out to have too narrow wings and do not match the observed profiles. After analysis, we noted that for a large part of the higher series H line profiles neither the impact approximation nor the quasi-static one can be used. Unfortunately, laboratory profiles of those lines or theoretical profiles computed in the unified or quantum theory are lacking. Further work on improving the line broadening computations is necessary before we could produce a comparison between the observed profiles and the theory.

4. Conclusions. The reported study shows that the profiles of the hydrogen lines in the 1-2.5 μm spectral range, arising deeper in the atmosphere than the Balmer lines, are useful as a fine test of the model atmospheres. In A-type stars, the IR lines probe the region of the temperature minimum. The observed profiles demonstrate that the NLTE effects are important for T_{eff} as low as 9500 °K. A new grid of plane-parallel NLTE model atmospheres was computed from 9500°K to 15000 °K. The energy balance takes into account 8 discrete levels of H atom and the continuum level. The outward temperature rise was found to be up to 1000°K more than in the models where only 5 discrete levels and the continuum one were considered. The models predict an emission core in the Brα 4.05 μm line for T_{eff} as low as 9500 °K. Further work is in progress to obtain theoretical profiles of the IR lines.

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DISCUSSION

NISSEN How long integration times did you need to obtain these FTS spectra for γGem ?

CHALABAEV About 30 minutes. This is a bright star and the passband is very large so that one has a "multiplex disadvantage" with respect to a conventional spectrograph + mosaic detector. However, the comparison is not so straightforward. The total number of spectral elements was 8000 (although only a part of them can be considered as useful). How many settings one needs to obtain the same spectrum by a conventional spectrograph ? Further, there is no need in calibration exposures (flat-fields, comparison spectra, etc.), so that the telescope time is used efficiently.
(See also review by J.P. Mailllard in this volume).