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Search for vertical helium abundance in He-rich star

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Abstract. Based on high-resolution spectra the helium vertical stratification in He-r stars was studied. Fully consistent NLTE and LTE models altogether with available photometry were used to derive basic stellar parameters as well as the relation for stellar luminosity. Study of the helium 402.6 nm transition long ward-wing revealed several candidates for the stratification amongst 1 standard and 5 He-r stars. The search gives the support to helium settlement within narrow interval of depth-mass-variable above local continuum forming region, and helium enlargement according to line central depth in several cases. The HeI 400.9 nm transition deserves up-date profile tables in the temperature-pressure plane.

Key words. Stars: abundances – Stars: atmospheres – Stars: helium stratification

1. Introduction

Of chemically peculiar (CP) stars the He-rich stars are the most massive, typically with the spectral type B2 and belonging to the main sequence. Their abundance anomalies are interpreted as the result of a diffusion mechanism involving a competition between the radiative and gravitational forces in the atmosphere and in the presence of wind (Vauclair 1975, Vauclair et al. 1991). A number of He-rich stars are magnetic and possessing signatures of light and spectral variabilities. Other properties worth investigation are their projected rotational velocities, helium age dependence and certainly the vertical helium abundances. One of the first studies (but not first) concerning the vertical helium stratification is the paper of Farthmann et al. (1994). They studied the 447.1 nm line profile in HD 49333 and announced the vertical stratification in the atmosphere. Later on, Leone and Lanzafame (1997) found on a sample of He-weak and He-rich stars the stratification as based on contribution functions of red spectral transitions (667.8, 706.5, 728.1 nm etc.). Importantly, in the first case the helium abundance increases with the optical depth in contrast with sample of Leone & Lanzafame. An extensive dataset (both high and low resolution spectra) was obtained at ESO, La Silla, Chile during several periods with aim to study the helium abundances and projected rotational velocities. The gross helium abundance was determined from several transitions and their equivalent widths.

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2. Observations

As far as first dataset concerns, a number of spectra for 14 stars in two spectral ranges were obtained using CAT tele-

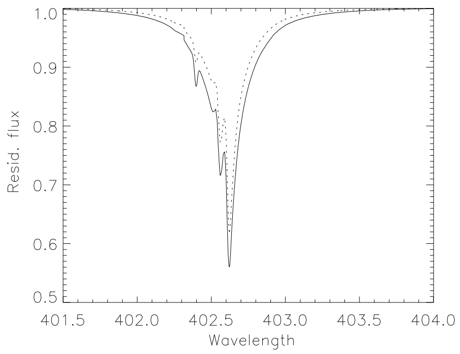

Fig. 1. The HeI 402.6 nm profile: **solid** line-LTE (Kurucz) model 15000, 4.0, n(He)=0.1, **dotted** line-NLTE model 15000, 4.0 and n(He)=0.1.

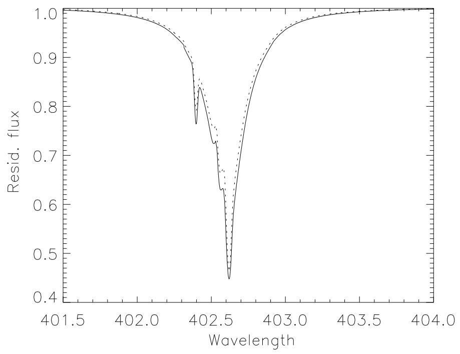

Fig. 2. The HeI 402.6 nm profile: **solid** line-LTE model 20000, 4.0, n(He)=0.1, **dotted** line-NLTE model 20000, 4.0 and n(He)=0.1.

scope and the CES spectrograph at European Southern Observatory, La Silla, Chile. The resolving power of the data is R=30 000 and the spectral ranges are 400.0-403.5 nm and 423.5-427.0 nm. Every sample star was observed in two nights. The data were reduced in a standard way using the IHAP software package (Zboril, Glagolevskij & North 1994). Similarly, low resolution spectra with resolution R=4150 were obtained using 1.5m spectrographic telescope and Boller & Chivens spectrograph later at ESO. The spectral range stands for 395.2 - 493.8 nm. The raw data were reduced using TACOS software package developed at Geneva Observatory (Zboril et al. 1997).

3. Analysis

The high resolution dataset consists of 14 star (amongst them 3 standards and 10 He-r stars) and subsequently low resolution dataset described in Zboril et al. (1997) consists of 24 stars (5 standards and 19 He-r stars). Importantly, 7 stars overlap (2 standards and 5 He-r stars) and this dataset is subject of detailed analysis here. Preliminary light element abundances were also estimated from 423.5 - 427.0 nm frame.

3.1. Hydrogen line shape modelling

The low resolution data are going to be subject of hydrogen profile analysis to re-estimate basic atmospheric parameters such as the effective temperature and surface gravity. Several theoretical modelling approaches have to be certainly examined. First, standard VCS broadening theory for hydrogen transitions was used and NLTE effect were checked and microturbulent velocities as well. Second, both consistent helium rich NLTE models and LTE (Kurucz) models were used to match hydrogen profiles Hβ, Hγ and Hδ by means of least squares. This allows us to estimate basic atmospheric properties. Typically all hydrogen transitions converge to the same values for the temperature and surface gravity. Third, available photometry was used to derive atmospheric parameters. Fourth, the estimates were further checked with well-known relation for stellar radius (therefore surface gravity), namely

$$L = 4\pi R^2 T_{eff}^4 \quad (1)$$

and

$$\log(R/R_{ZAMS}) = \frac{1}{2}(\log g_{ZAMS} - \log g) \quad (2)$$

where the luminosity is derived from the absolute magnitude. The value $\log g_{ZAMS}$=4.26 was derived from theoretical models. In practice, NLTE effect and microturbulence were found of little effect on profiles. We used 10

Table 1. Helium abundances for He-r stars

Star	low-res data	Zboril et al. ('94)	relation (2)	He abundance	Note	vsini
hd122980	20500, 3.8	19500, 4.0	3.5	0.10 strat?	core	20 km/s
hd133518	20500, 3.5	19700, 4.0	3.9	0.12 strat. ?	core,wing	0.0
hd96446	24000, 3.5	23400, 4.0	3.7	~0.80 strat. ?	wing?	0.0
hd92938	15000, 3.5	15500, 4.0	3.5	0.20strat?	core	120.0
-46^o 4639	23000, 3.5	22000, 4.0	—	0.30	—	80.0
hd66522	20000, 3.5	21000, 4.0	3.9	~ 0.15 strat. ?	core, wing	0.0

level atom for hydrogen, 14 level atom for neutral helium (merging close energy levels of singlets and triplets) and 14 levels for singly ionized helium.

3.2. Helium line shape modelling

Given the atmospheric parameters the detailed line shapes 400.9 and 402.6 nm were generated for a variety of helium abundances and finally the LTE profiles were applied. Specifically, long ward-wing of 402.6 nm transition was used for the inspection in wavelength domain. The value for microturbulence 5 km/s was used being the same value found for normal B type stars. Another step was to use the projected rotational velocity and instrumental profile. This value was already determined in earlier paper from CII 426.7 nm and was verified again in this study. Theoretical helium profiles were subsequently convolved with these values. A specific broadening mechanism has to be applied to the helium profiles and therefore the tables of Shamey (1969) were used for helium profiles. CCP7 library NLTE codes (Tlusty, Synspec) were used for modelling the atmospheres and theoretical hydrogen and helium profiles where all relevant atomic data for hydrogen and helium are already coded. Both radiative and collisional rates for the transitions were linearized.

4. Results

Table 1 offers the results of modelling. The "strat" remark stands for vertical helium stratification candidate. The star hd110879 was eventually ruled out. The object turned to be binary with close spectral types and separation about 1.09" (Davis & North 2001) and deserves different mode of modelling. The results suggest the expected interval for surface gravities and radii. Helium modelling therefore was performed for limiting cases of surface gravities, namely log$g$=3.5 and 4.0 (1.5, 2.0 in SI units) respectively. Given the helium line shapes for the stars in sample, the vertical helium stratification is naturally suggested if tables for 402.6 nm transition are valid. The process already operates close to the depth of continuum forming region (at optical depth corresponding to 400.0 nm) where the temperature is roughly equal to the effective temperature. The forming region was derived from monochromatic optical depth equal to 2/3 at helium transition wavelengths. The star hd96446 is extremely helium rich stars and the line profiles cover full spectral frame and due to the rectification the helium abundance may be lower limit only. Preliminary analysis gives the support earlier Farthmann et al. (1994) results for increase the helium with optical depth and is in agreement with theoretical calculations as well in some cases as far as the transition central depth is concerned.

5. Summary

The analysis supports the idea of vertical helium stratification in the atmosphere as based on red-wing of HeI 402.6 nm transition. Since more He-r stars wait for detailed analysis, new

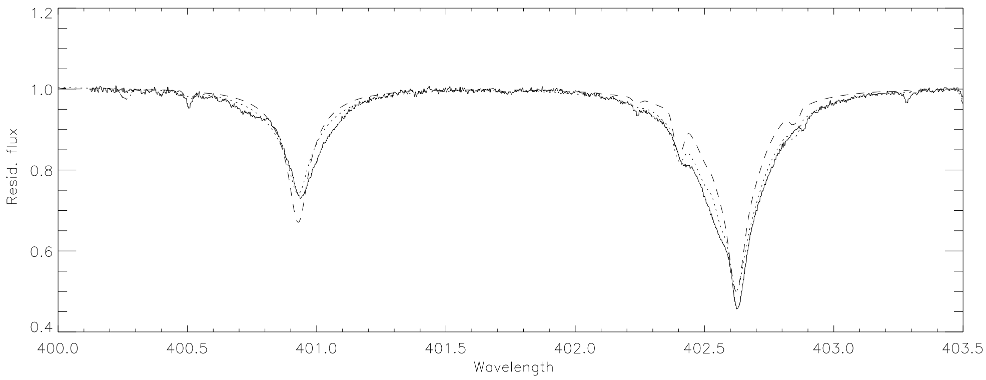

Fig. 3. The helium LTE profiles for standard hd122980. The transition 400.9 nm was put aside from analysis. **Solid** line-observed spectrum, **dotted** line-model with 20500K, 4.0 and n(He)=0.1, **dashed** line-20500, 3.5, n(He)=0.1.

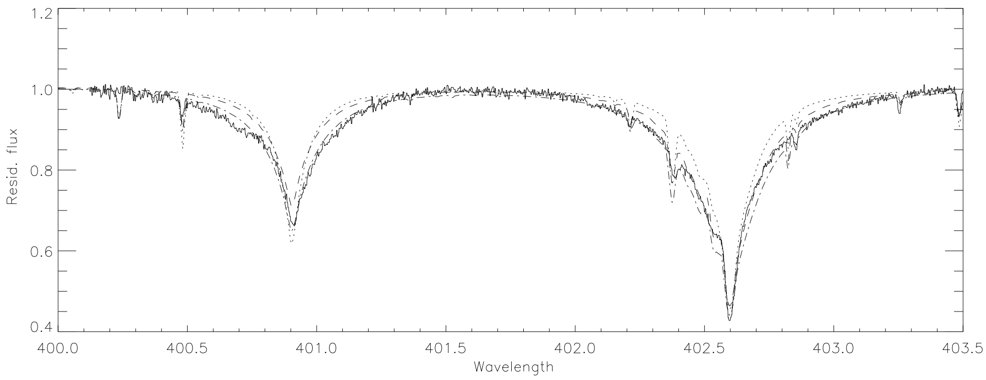

Fig. 4. The profiles for hd133518. **Dotted** line-model with 20000K, 3.5 and n(He)=0.12, **dashed** line-20000, 4.0, n(He)=0.12, **dash-dot** line-20000, 4.0, n(He)=0.20.

results and some cut-off conclusions will appear in forthcoming paper.

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