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Preliminary analysis of an extreme helium sdO star: BD+25 4655

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Abstract.
Preliminary analysis of CCD spectra obtained by the 6m SAO telescope is presented. We have used simple H-He NLTE model atmospheres computed by TLUSTY to derive the basic parameters of the star.

1. Introduction

BD+25 4655 (SAO 90153, HIP108578, IS Peg) is an interesting object known today as a variable O subdwarf, suspected binary and spectrophotometric standard at the same time. It was mentioned as an sdO star in Greenstein (1960) already. First detail analysis of this star using LTE approach was accomplished by Peterson (1970). He derived the following basic parameters: $T_{eff} = 43000K, \log g = 6.7, Y/X = 49, \log L/L_{\odot} = 1.3, M/M_{\odot} = 1.2$ (see also Richter 1971). Greenstein & Sargent (1974) list equivalent widths of some lines and $T_{eff} = 42000K, \log g = 6.7, M_V = 6.0$. Some spectroscopic data were published also in an atlas of spectra of He-rich stars of Kaufmann & Theil (1980) covering 3700-4600ÅÅ. Bartolini et al. (1982) searched for variability in hydrogen poor stars and although they failed to find regular periodicities for this star they did find variations in UBV with a period of $P = 0.009368^d$ and amplitude of $\Delta m = 0.03^m$ in two nights. At the same time, they suggested long term variations on a time scale of several months and amplitude of $\Delta V = 0.07^m$. Dworetsky et al. (1982) measured the star in UBV system and obtained: V=9.69, B-V=-0.26, U-B=-1.16, E(B-V)=0.06. They classified it as O4:. Later on Colina

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& Bohlin (1994) obtained V=9.656, B-V=-0.305. Tobin (1985) obtained uvbyβ photometry. Bartkevicius & Lazauskaite (1996) classified the star in the Vilnius photometric system as: sdO6, He, and estimated $E(Y-V)=0, M_V=4.0$. Diplas & Savage (1994) set an upper limit for interstellar HI column number density in front of the star: $logN(HI)=19.94$ per cm^{-2}. The star is a HST optical and UV spectrophotometric standard and Oke (1990) measured its absolute spectral energy distribution in the range 3200-9200 ÅÅ while Bohlin et al. (1990) obtained absolute UV flux from IUE data. HIPPARCOS gives the parallax $\pi=8.99\pm1.20$ mas (ESA 1997) and labels the star as constant. Above parallax corresponds to the distance of 111 pc. Elkin (1998) attempted to measure the magnetic field but could set only an upper limit of about 300 G and concluded that there is no field within the precision of his measurements. Ulla & Thejll (1998) did IR photometry and obtained: $J=10.39, H=10.52, K=10.58$. They found an excess in JHK fluxes of about $\Delta J=0.1^m$ and interpreted it as due to the binary companion of the sp. type earlier than B8. They also put the following upper limit for the reddening $E(B-V)<0.025^m$.

Main aim of the paper is to present a preliminary analysis of this star based on high resolution, high signal to noise spectra using pure NLTE H-He model atmospheres as well as to compile other available data from the literature for a more elaborated study. Similar NLTE analysis of sdO stars were recently carried by Lanz et al. (1997) (using line blanketed NLTE models) and Thejll et al. (1994). Recent review on sdO stars can be found in Heber (1992).

2. Observations

The high resolution spectra were obtained at 6-m telescope of SAO RAS using Main stellar spectrograph located in Nasmith 2 platform of the telescope. Spectral resolution of spectra obtained in blue and red regions are 0.3 Å and 0.45 Å, respectively. For both observations and subsequent data reduction we used MIDAS package and also DECH20 code (Galazutginov 1992). The low resolution spectra were obtained at 1-m telescope with UAGS spectrograph. Spectral resolution of this spectrum is about 6 Å. Here the data reduction were done using the software written by Vlasyuk (1993) and DECH20 of Galazutginov (1992).

3. NLTE calculations

For the calculation of NLTE atmosphere models and level populations of explicit ions we used the TLUSTY195 code described in more detail in Hubeny (1988), Hubeny & Lanz (1992) and Hubeny & Lanz (1995). Table 2 lists which ions and how many levels were treated explicitly what means that their level populations were calculated in NLTE and their opacity was considered. Model of atoms were constructed using and IDL interface tool MODION developed by Varosi et al.(1995) from the Opacity Project Data. Other elements up to $Z=30$ were allowed to contribute to the particle and electron number density in LTE. Synthetic spectra were calculated with the SYNSPEC42 code Hubeny et al. (1995). Atomic data for line transitions were taken from Kurucz (1990) but VALD data base was also consulted (Kupka et al. 1999).

Table 1. Log of observations: spectrum identifier, date [ddmmyyyy], time [hhmm], exposure [m], JD-2400000 of the middle of the exposure, wavelength interval covered [ÅÅ], resolution [Å], heliocentric correction [km/s] and radial velocity [km/s]. Note: the second spectrum is not suitable for RV measurements and first spectrum has rather large error.

Sp.	date	UT	E	JD	λ	R	h.c.	RV
1	13 07 1997	21 54	30	50643.423	6489-6732	0.45	+18.1	-37.2±2.3
2	15 09 1997	20 05	30	50707.347	4352-4514	0.3	–	–
3	18 09 1997	18 12	30	50710.269	4352-4514	0.3	-5.6	-30.6±0.3
4	07 09 1998	19 38	30	51064.328	4320-4482	0.3	-1.1	-31.7±1.0
5	08 06 2001	01 43	5	52069.406	3738-5441	6		

Table 2. Number of explicit levels considered in particular explicit elements/ions; abundances estimated.

element/ion	I	II	III	IV	V	A
H	9					1
He	14	14				40

4. Discussion

The spectrum of this star is hard to fit and understand. We will describe various interesting observed features relatively to a H-He NLTE model with $T_{eff} = 38000K, \log g = 5.3, A(He) = N(He/H) = 40$. This model is a certain preliminary compromise to reproduce different spectral lines. The following problems arise if one tries to fit our observations with pure H-He NLTE model. HeII 4686 and HeII 4541 lines are very strong while some HeI lines like HeI 3867-71,3926 are almost absent (see Fig.1) and one needs temperatures above 40000K to improve the fit significantly. On the other hand, red part of our spectra contains strong HeI but weak HeII 4338 line of Pickering series and weak HeII 6527 (see Figs. 2, 3, 4) what strongly favors temperatures below 36000K. Strong HeI lines have generally narrower wings and would prefer $\log g \approx 5.$ while $H\gamma$ is broader and best reproduced with $\log g \approx 5.5$. Also it seems that our model predict generally weaker Balmer and HeI lines with increasing wavelength. $H\alpha$ exhibits a central emission reversal (see Fig.4), which is a well-know NLTE effects found at hot white dwarfs and subdwarfs (e.g. Lanz & Hubeny 1995; Lanz et al. 1997). The absorption profile of $H\alpha$ is asymmetric, with the blue wing being much deeper. This could be a signature of a stellar wind. Asymmetry in the HeI 4471 and 4388 seems to be qualitatively reproduced by the atomic line broadening data. NIII/NII ionization balance speaks in favor of higher temperatures. Nitrogen is very abundant and would certainly be important opacity source.

Perhaps, an atmosphere model with much steeper temperature gradient due to, for instance, line blanketing could enhance HeII 4686 and HeI 4471 lines simultaneously and suppress some temperature inconsistencies. Also weak Pickering line HeII 4338 might be understood as it forms on the background of hydrogen opacity and consequently would originate from higher and cooler layers. Blue-red discrepancies in Balmer and some HeI lines lines could be caused bye wrong correction on the stimulated emission resulting from the inappropriate model of the atmosphere as mentioned by Lanz et al. (1997). More sophisticated line blanketed model atmospheres are called for.

Another, solution of some of the mentioned inconsistencies could be proposed. The spectrum could be a composite of two different spectra one having the temperature in excess of 40000K the other below about 36000K. This seems to be in accordance with Ulla & Thejll (1998) who suggested that this star is a binary candidate based on its JHK excess. On the other hand, their excess was found comparing the observed data with Kurucz line blanketed models with normal He abundance. We collected low resolution IUE, ground based spectrophotometric and UBVJHK photometric data from the sources mentioned in the Sec.1. and compare it with our model atmosphere in Fig.5. UBV data were calibrated using an average A0V star as a comparison and JHK filters were calibrated on Vega. Comparison object absolute fluxes were taken from Cox (2000). Table 3 lists the calibration constants derived to get I_λ $[erg\,cm^{-2}\,s^{-1}\,\mathring{A}^{-1}]$ from m_λ – magnitude in the particular filter using the following equation:

$$\log I_\lambda = -0.4 m_\lambda - q \tag{1}$$

Although there might be a J excess of about 0.1^m it seems rather questionable as it is almost within the error comparable to the possible photometric variability of this star and precision of such calibrations indicated in the figure by the radius of the open circles. Radial velocities (see Table 1) of our spectra are constant within the precision of our measurements and do not exhibit potential orbital motion. Moreover, this hypothesis would not, probably, be able to account fully for some strong observed HeI lines not would it help to get rid fully of strong synthetic HeII 4338... and could only partially improve the situation. Fig. 5 also reveals that effective temperature adopted for this star is not bad although it could be slightly higher. Detailed synthetic spectra in the IUE region would help to locate the continuum here.

Similar effects of a two component model atmosphere could be expected if there is a convection resulting in some kind of solar like granulation with hotter granules and cooler inter-granules. However, Groth et al. (1985) found that convection - when present - is a very ineffective energy transport mechanism in the atmospheres of such type of stars.

From absolute fluxes and parallax we can determine stellar parameters of the star as well. The slope of the Paschen continuum or B-V color index are not very sensitive to the temperature of such hot stars because they are in the Rayleigh-Jeans region of the Planck function and $F_\lambda \sim T_{eff}$. Absolute flux observed on the Earth is $f_\lambda = (R/D)^2 F_\lambda$ and one could determine reliable radius R of the star if he knows the distance D and compares absolute and theoretical

Table 3. Photometry and calibration of absolute fluxes. Calibration comparison standards used, their magnitudes and calibration constants derived are listed.

filter	calib	mag.	q
U	A0V	-0.04	8.391
B	A0V	-0.02	8.202
V	A0V	0.00	8.426
R	A0V	-0.02	8.765
I	A0V	0.00	9.076
J	Vega	0.02	9.472
H	Vega	0.02	9.931
K	Vega	0.02	10.375

fluxes F_λ. As

$$\frac{R}{R_\odot} = 4.433 \times 10^7 \sqrt{\frac{f_\lambda}{F_\lambda}} \frac{1}{\pi"} \tag{2}$$

$$\frac{dR}{R} = \frac{df_\lambda}{2f_\lambda} - \frac{dT_{eff}}{2T_{eff}} - \frac{d\pi"}{\pi"} \tag{3}$$

generally a 10% error in T_{eff} results in about 5% error in the stellar radius and parallax puts most severe constraints on the precision of this method (Muthsam & Weiss 1978). We tried to fit the observed absolute data in Fig.5 with our preliminary model and found $f_\lambda/F_\lambda = 10^{-21.04\pm0.1}$. Assuming $D = 111$ pc it results in $R = 0.15(\pm0.04)R_\odot$. Now, assuming $\log g = 5.3$ we get an extremely low mass,

$$\frac{M}{M_\odot} = \frac{g}{2.74 \times 10^4} \frac{R^2}{R_\odot^2} = 0.16. \tag{4}$$

This mass is lower than the lower limit for the core He burning, $M = 0.3M_\odot$ (Heber 1992). Nevertheless it is easily possible that the gravity is higher(lower) by a factor of 2-3 due to above mentioned uncertainties in determining $\log g$ from H and He line profiles.

The actual luminosity of the star is:

$$L = 4\pi R^2 \sigma T_e^4 = 4.2 \times 10^1 L_\odot. \tag{5}$$

Consequently, absolute bolometric and visual magnitudes of the star are:

$$M_{bol} = -2.5 \log L/L_\odot + 4.74 = +0.7^m \tag{6}$$

$$M_V = m_V - 5(\log D[pc] - 1) = +4.43^m \tag{7}$$

Finally, high resolution spectra enabled us to set a rather low limit on the rotation of the star. Assuming zero microturbulence and Gaussian instrumental profile with FWHM=0.3Å we obtained $vsini = 15km/s$. On the other hand microturbulence itself cannot be higher than the same value.

5. Conclusions

We can conclude that H-He NLTE model cannot provide a satisfactory description of the complex spectral features of this star. Despite of this fact some parameters of the star and its atmosphere such as its radius are rather insensitive to the uncertainty in the effective temperature and could be estimated. Another parameters, for instance, gravity, seems quite different from the value mentioned in the literature.

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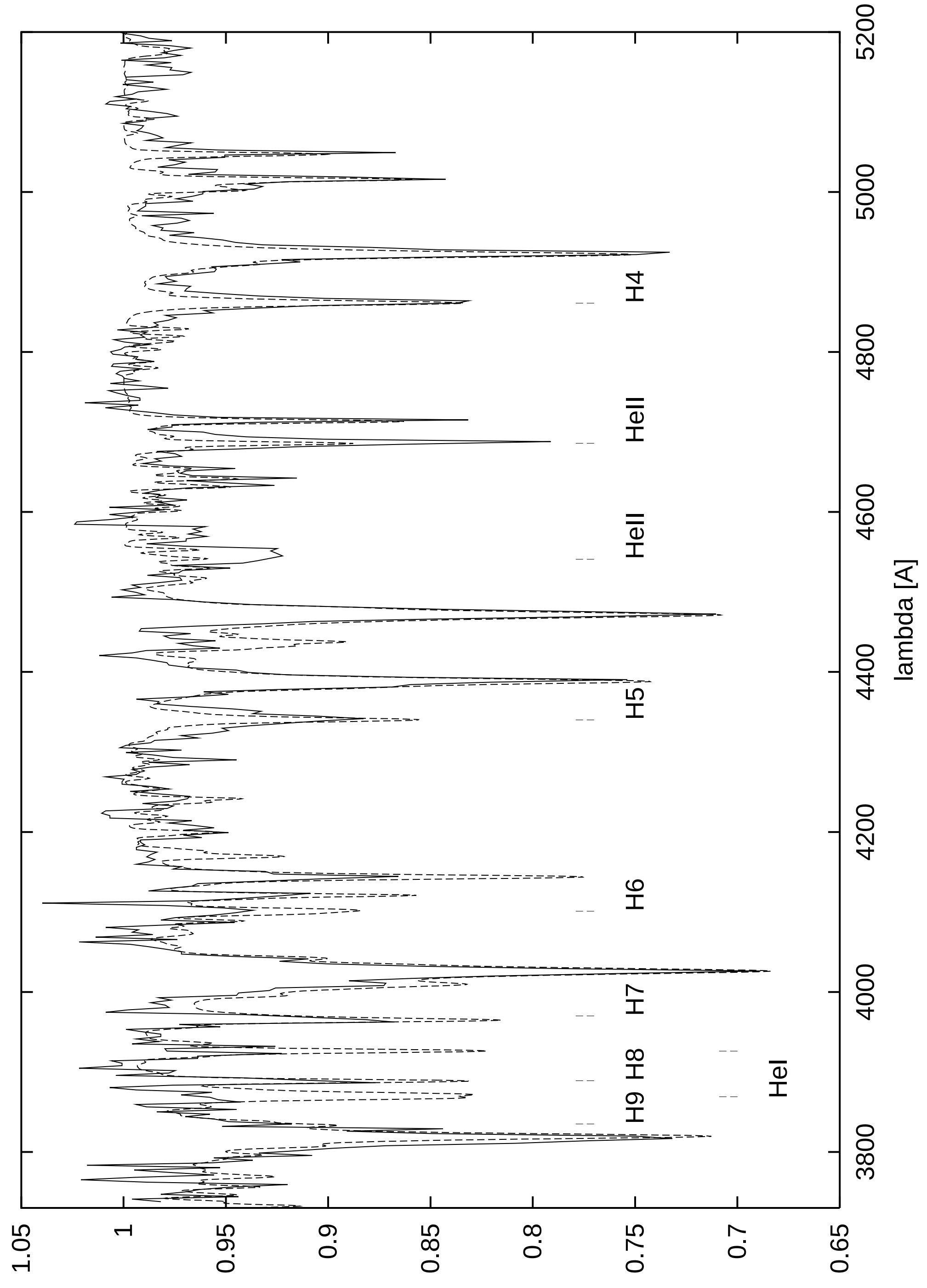

Figure 1. Relative intensity of the low resolution spectrum of BD+254655. Solid line - observations, dashes -synthetic spectrum for $T_{eff} = 38000; \log g = 5.3; N(He/H) = 40$.

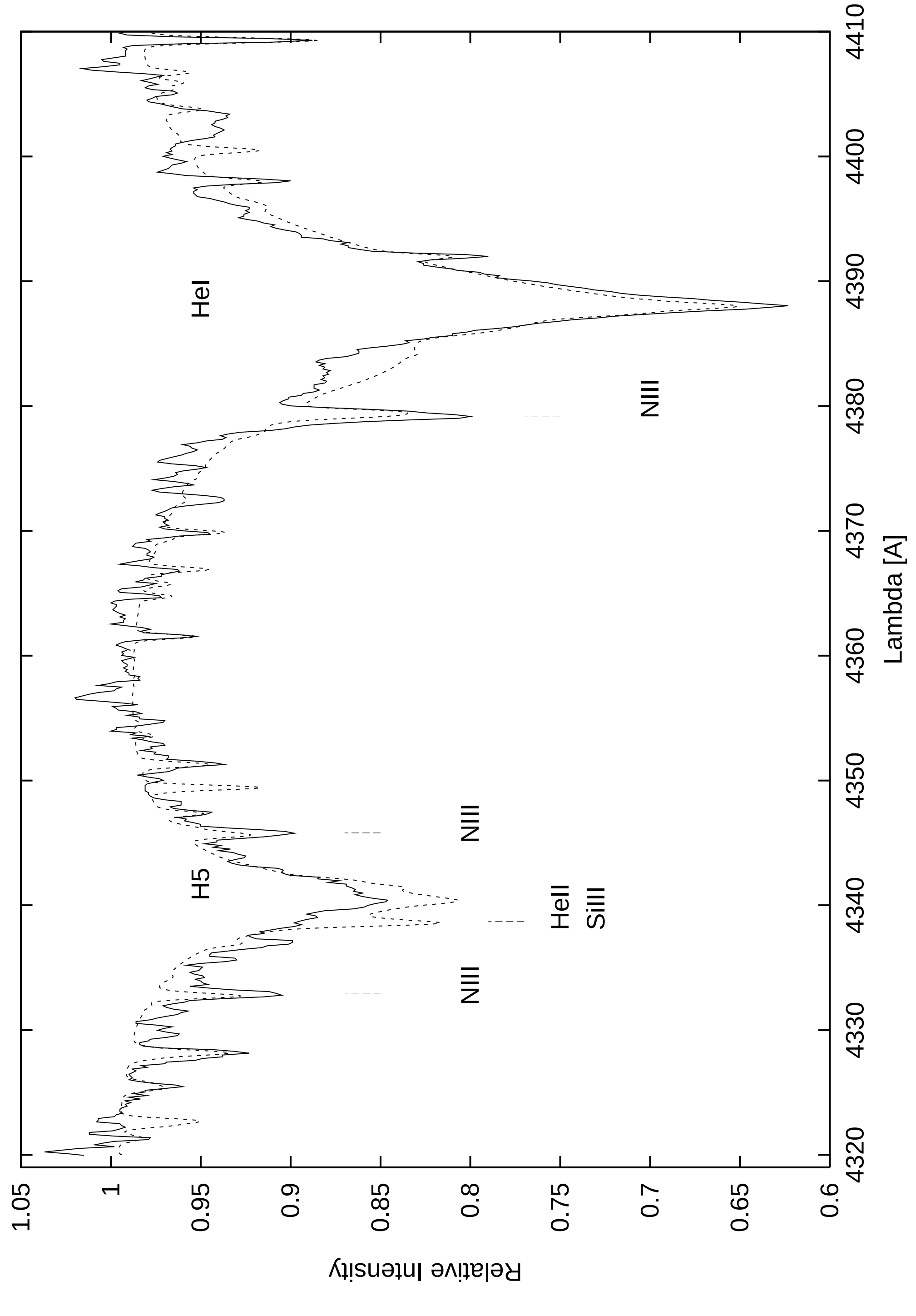

Figure 2. High resolution spectrum of BD+254655. Solid line - observations, dashes -synthetic spectrum for $T_{eff} = 38000; \log g = 5.3; N(He/H) = 40$.

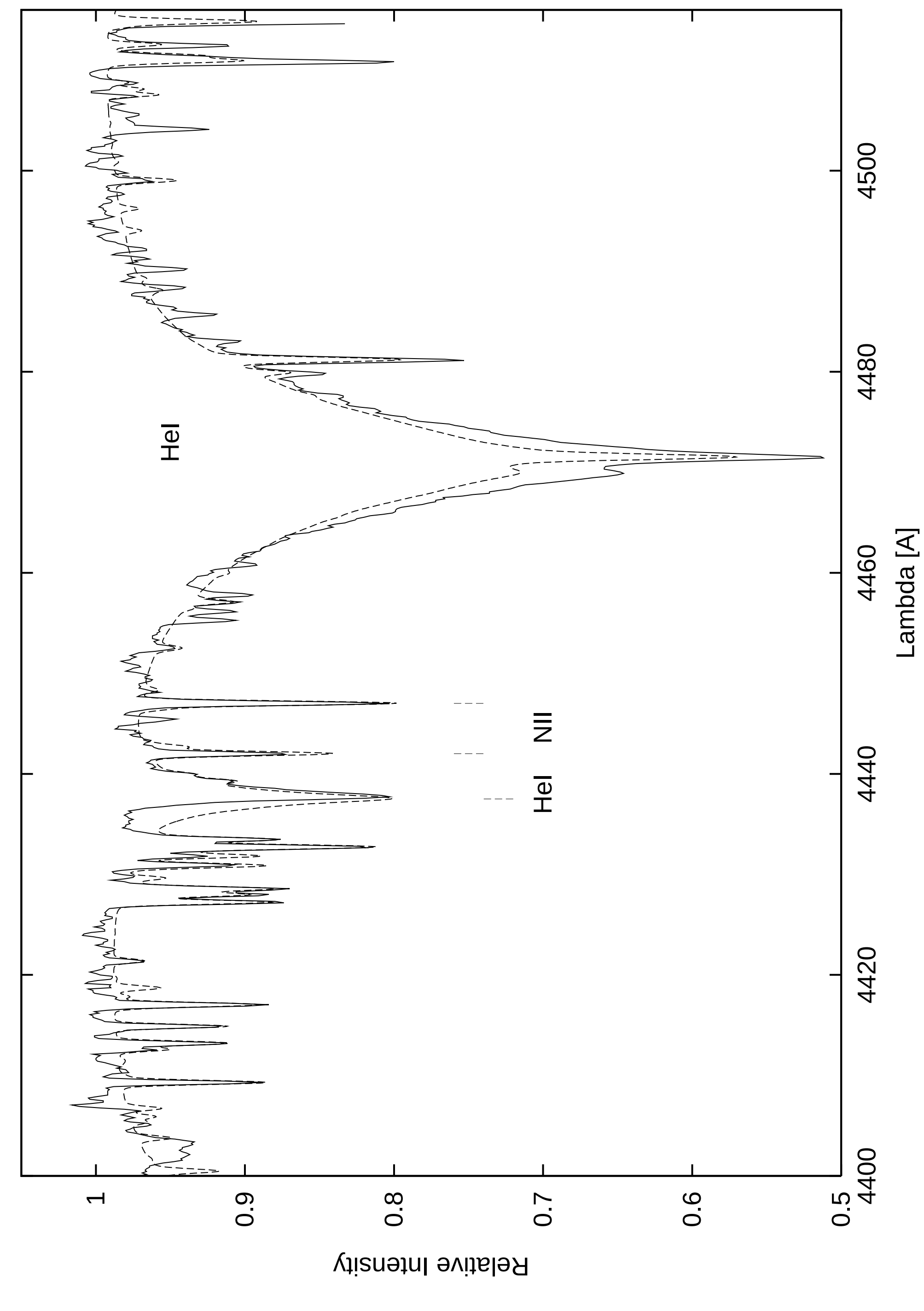

Figure 3. High resolution spectrum of BD+254655. Solid line - observations, dashes -synthetic spectrum for $T_{eff} = 38000; \log g = 5.3; N(He/H) = 40$.

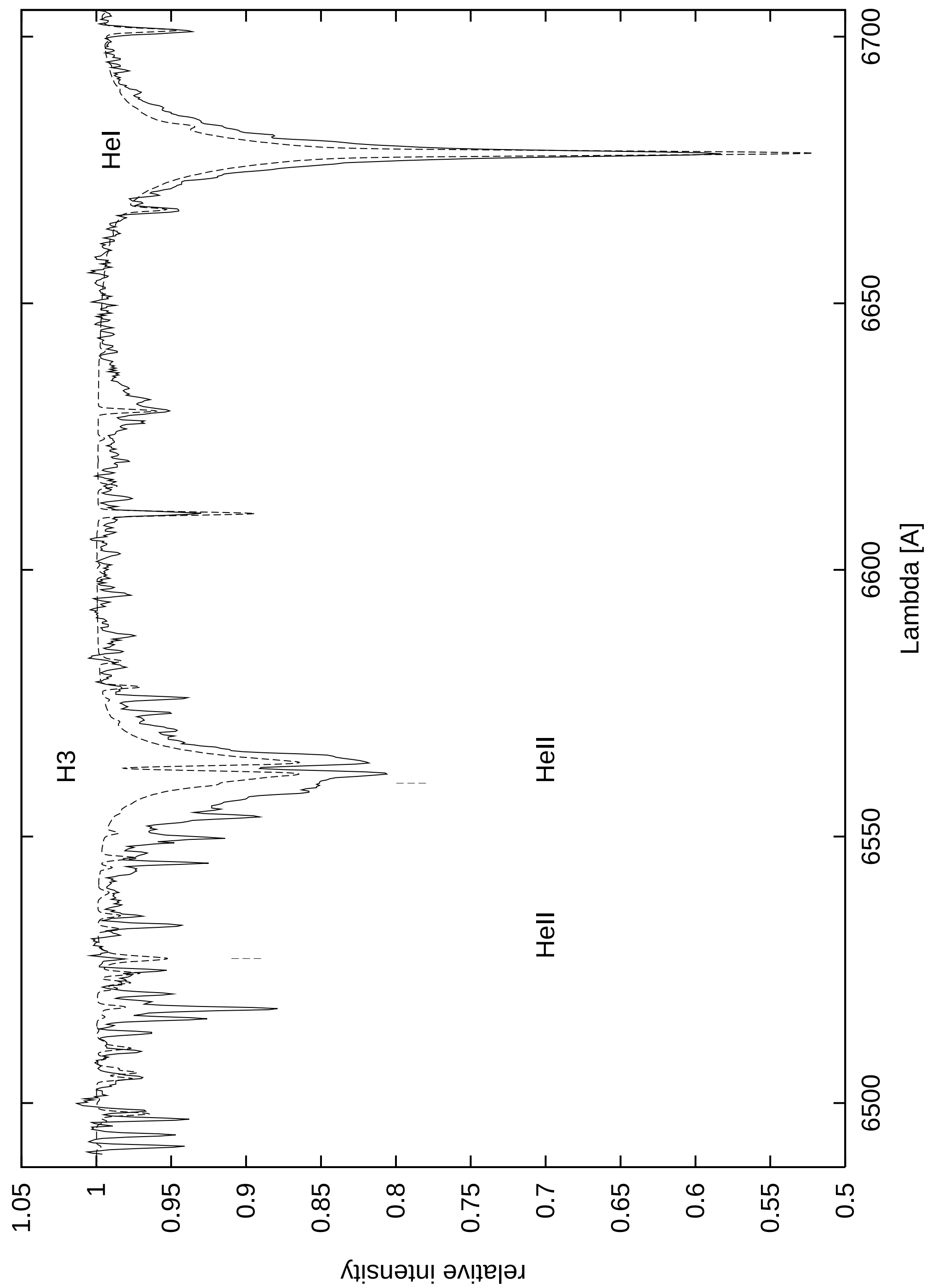

Figure 4. High resolution spectrum of BD+254655. Solid line - observations, dashes -synthetic spectrum for $T_{eff} = 38000; \log g = 5.3; N(He/H) = 40$.

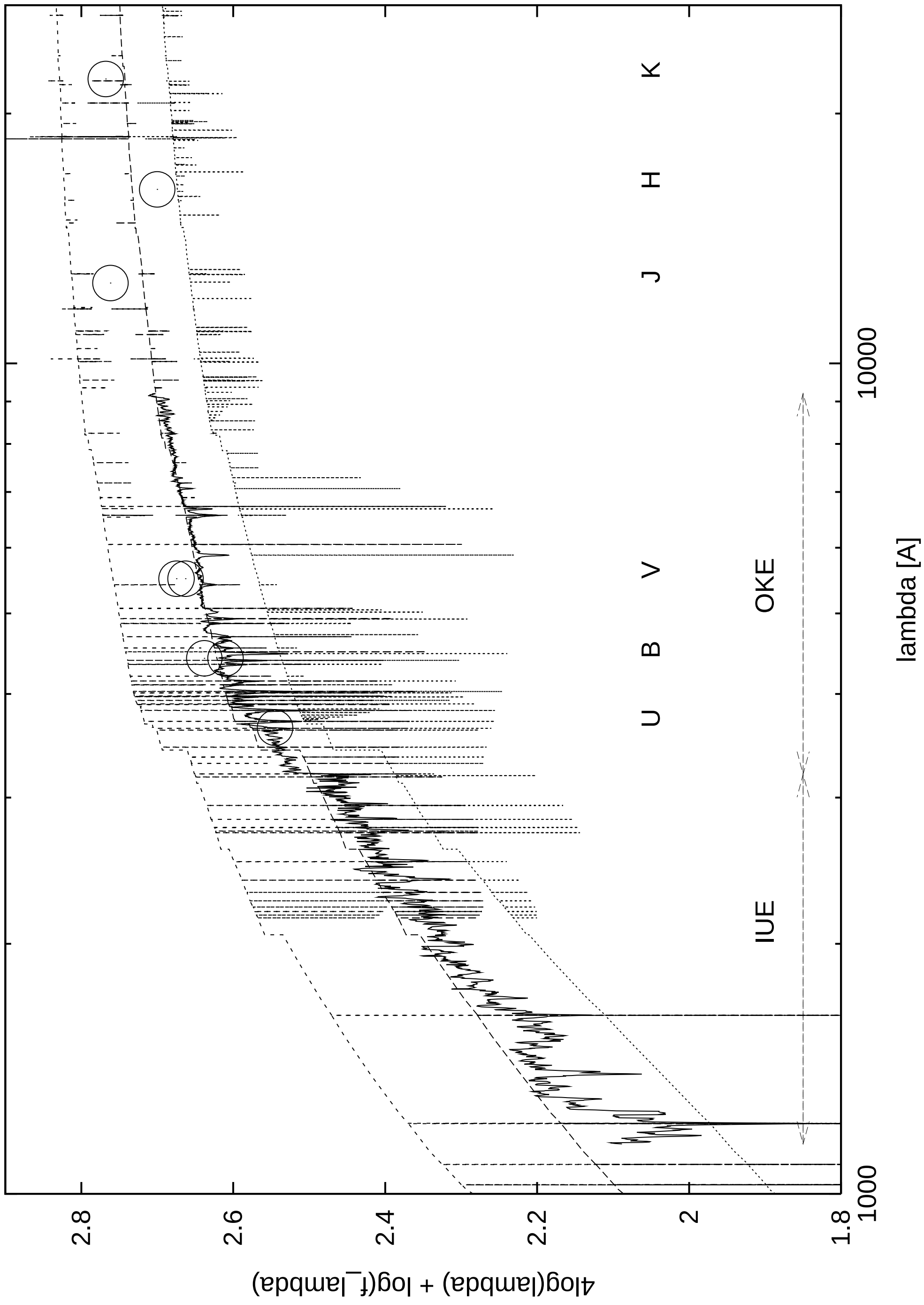

Figure 5. Observations versus absolute fluxes from three model atmospheres from the top: $T_{eff} = 43000, 38000, 34000K; \log g = 6.7, 5.3, 5.5; N(He/H) = 10, 40, 40$. Fluxes are in $erg/cm^2/s/\mathring{A}$ and are multiplied by $\lambda^4[\mathring{A}^4]$. Model fluxes are sifted bye 21.04 dex.