A NLTE model atmosphere analysis of the pulsating sdO star SDSS J1600+0748

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Abstract We started a program to construct several grids of suitable model atmospheres and synthetic spectra for hot subdwarf O stars computed, for comparative purposes, in LTE, NLTE, with and without metals. For the moment, we use our grids to perform fits on our spectrum of SDSS J160043.6+074802.9 (J1600+0748 for short), this unique pulsating sdO star. Our best fit is currently obtained with NLTE model atmospheres including carbon, nitrogen and oxygen in solar abundances, which leads to the following parameters for SDSS J1600+0748: $T_{\text{eff}} = 69,060 \pm 2080$ K, $\log g = 6.00 \pm 0.09$ and $\log N(\text{He})/N(\text{H}) = -0.61 \pm 0.06$. Improvements are needed, however, particularly for fitting the available He II lines. It is hoped that the inclusion of Fe will help remedy the situation.

Keywords hot subdwarfs stars; model atmospheres; SDSS J160043.6+074802.9

1 Introduction

SDSS J1600+0748 is this unique hot subdwarf O star showing short-period p-mode instabilities (Woudt et al. 2006). Because this star is likely to contain its fair share of metals (currently in unknown abundances and proportions), we felt that it was important to assess the role of such metals on its derived atmospheric parameters and pin down better its position in the surface gravity-effective temperature plane. This is particularly important for constraining an eventual seismic model (see Fontaine et al. 2008). So, with this idea in mind, we have started the construction of several grids of model atmospheres and synthetic spectra suitable for the analysis of the optical spectrum that we gathered for this star.

2 Observational data

Figure 1 shows our high-sensitivity ($S/N \sim 300$), low-resolution (8.7 Å) optical spectrum of the SDSS J1600+0748 system (upper curve) obtained at the Steward Observatory 2.3-m telescope over four nights for a total exposure time of 12.23 h. Doppler shifts due to orbital or proper motions of the star are corrected during the reduction procedure. Note that this spectrum has also been presented in Fontaine et al. 2008. As first pointed out by Woudt et al. (2006), and as can be seen here, this spectrum is obviously contaminated by the light of a cool star showing the Ca II K and H doublet at 3964-3968 Å, the G band around 4305 Å and the Mg I complex at 5167-5184 Å as its most conspicuous features. One of us (E.M.G.) went to considerable efforts to determine the most probable spectral type of that cool companion, converging, at the end of the process, to a G0V star (see Fontaine et al. 2008). A template G0V spectrum obtained with the same experimental setup, and normalized properly in flux, is shown by the lower curve. The resulting spectrum, obtained from the subtraction of those two, is shown by the middle curve in red. It is this “cleansed” spectrum that forms the observational basis of our study. It turns out, however, that the atmospheric parameters
derived from the analyses of the polluted spectrum (upper curve) and the cleansed spectrum (middle curve) are not hugely different.

3 Grids of model atmospheres and synthetic spectra

Only a few spectral analyses of hot subdwarf O stars including both deviations from local thermodynamic equilibrium (NLTE) and metal line blanketing have been done in the past (e.g., Lanz, Hubeny & Heap 1997; Deetjen 2000). This is essentially because calculating such model atmospheres is very time consuming, especially when one includes iron-peak elements. Thus, to compute our grids of NLTE model atmospheres with metals, we have adapted the public codes TLUSTY and SYNSPEC of Ivan Hubeny and Thierry Lanz to run in parallel on CALYS, our small cluster of dedicated PCs at the Université de Montréal, currently made up of 80 fast processors. This considerable effort was carried out by one of us (P.B.).

At this time, we have two grids of NLTE models: one with H and He, and a second one with these two elements as well as carbon, nitrogen and oxygen (CNO for short) in solar abundances. In LTE, only the H and He grid is now complete. Each grid is defined in terms of the effective temperature (from 60 000 K to 80 000 K in steps of 2 000 K), the surface gravity (log \( g \) of 4.8 to 6.4 in steps of 0.2 dex), and the helium-to-hydrogen number ratio (log \( N(\text{He})/N(\text{H}) \) from −4.0 to 0.0 in steps of 0.5 dex). Our model atmospheres include model atoms available on TLUSTY web site\(^1\). We include the following ions in our models: C II to C V, N II to N VI and O II to O VI. For each ion there are a few models available with different number of levels and superlevels. In our grids, we took those used in the BSTAR2006 grid from Lanz & Hubeny (2006). Among the sdO stars, there’s no “standard” chemical abundance unlike the trend observed in sdB stars (Blanchette et al. 2008). Specifically for SDSS J1600+0748 there’s no hint, in currently available spectra, on which elements (heavier than helium) could be present in its atmosphere and even less on their abundance. Because of this lack of information, we used in our model a typical solar abundance for CNO. We are aware that these abundances are probably not the real ones and that further observations are necessary to get more information about the atomic species present in this star. Thus, we planned to get visible spectrum at 1 Å resolution and a UV spectrum with the COS spectrograph on HST.

\(^1\)http://nova.astro.umd.edu/Tlusty2002/tlusty-frames-data.html

Fig. 1 Observed spectrum of the SDSS J1600+0748 system (top curve); template spectrum of the G0V companion (bottom curve); cleansed spectrum (middle curve, in red).

Fig. 2 Resulting fit of the spectrum of SDSS J1600+0748 with NLTE model atmospheres including H and He (top) and with CNO (bottom)
Table 1 Results of our fitting procedure

| Grid                  | $T_{\text{eff}}$ | $\log g$ | $\log N(\text{He})/N(\text{H})$ | Spectrum |
|-----------------------|------------------|----------|---------------------------------|----------|
| LTE, H + He           | 51 056 ± 1 400   | 6.04 ± 0.08 | −0.71 ± 0.06                  | cleansed |
| NLTE, H + He          | 67 632 ± 2 048   | 5.92 ± 0.09 | −0.60 ± 0.06                  | cleansed |
| NLTE, H + He + CNO    | 69 059 ± 2 076   | 6.00 ± 0.09 | −0.61 ± 0.06                  | cleansed |
| NLTE, H + He + CNO    | 70 681 ± 3 523   | 5.87 ± 0.12 | −0.84 ± 0.07                  | polluted |

4 Atmospheric parameters for SDSS J1600+0748

We performed a simultaneous fit of the available Balmer lines and helium lines in our observed spectrum using our different grids of synthetic spectra. This was done using the standard line fitting method of Bergeron et al. (1992). Results are summarized in Table 1, with errors given on the parameters corresponding only to formal errors of the fit. As mentioned before, we notice that the parameters obtained with the polluted spectrum and the cleansed one are not that different. This is reassuring. As for LTE model atmospheres, the quality of the fit is very poor, leading to an effective temperature that is definitely too small. Note that this result is quite uncertain as the temperature predicted with such models is below the inferior limit of the grid. But this experiment underlines the huge NLTE effects on the solution, particularly on the effective temperature. On the other hand, inclusion of CNO in solar abundances in NTLE models increases only slightly the effective temperature and surface gravity obtained by the fitting procedure. These two results are illustrated in Figure 2. The fits to Hβ and He ii (5412 Å) lines are improved by the inclusion of CNO, but the two strongest He ii lines still remain poorly fitted, showing a flux deficit compared to our best-fit model.

5 Effects of CNO line blanketing on our NLTE model atmospheres

In stellar atmospheres, line blanketing of metal usually produce a drop of temperature in the outermost layers (see, e.g., Bergeron, Saumon, & Wesemael 1997). This effect is easily seen in Figure 3 where the red and blue curves represent the temperature as a function of depth for model atmospheres with and without CNO, respectively. We picked models in our grids with parameters similar to those determined for J1600+0748. This figure also features another interesting characteristic of our model atmospheres with CNO, namely, the depth in the atmosphere where the optical depth is equal to 2/3 as a function of the wavelength. With the help of this curve, we can figure out where in the atmosphere Fig. 3 Temperature and optical depth $\tau_\nu = 2/3$ as functions of depth, where $m$ is the column density, in the atmospheres of NLTE models with $T_{\text{eff}} = 70 000$ K, $\log g = 6.0$ and $\log N(\text{He})/N(\text{H}) = -0.5$.

Fig. 4 Results of the fitting procedure of our synthetic spectra with CNO using our grid of synthetic spectra with H and He only. See more details in the text.
are formed the Balmer and He II lines as well as the temperature at which these lines are formed.

We also carried out a detailed comparison between some of our synthetic spectra characterized by a value of \( \log \frac{N(\text{He})}{N(\text{H})} = -1.0 \) and a resolution of 8.7 Å obtained by convolution to mimic observational data. We considered our model spectra with CNO as “observed” spectra (represented by dots in Fig. 4) and performed a fit on each model with our grid of synthetic spectra computed with models including H and He only. We used the same fitting technique as for J1600+0748, but this time the value of \( \log \frac{N(\text{He})}{N(\text{H})} \) was fixed to -1.0, and searched for an optimal solution in terms of temperature and gravity. The end of each line segment in Figure 4 gives the result of the fitting procedure. We observe that the inclusion of CNO in NLTE model atmospheres tends to increase the resulting effective temperature and surface gravity, at least in our range of temperature, with a larger effect at high \( T_{\text{eff}} \). Interestingly, our results seem to point toward an inverted temperature trend at \( T_{\text{eff}} \) smaller than 60 000 K, a result that also depends on the He abundance.

6 What is left to do

The next planned stage in the construction of our grids of model atmospheres is the inclusion of iron in NLTE models. We expect that a fit of J1600+0748 with this new grid will result in a (slightly?) larger effective temperature as iron adds an important source of opacity. We hope being able to improve the fit to the He II lines with the inclusion of iron in our models. Since He II 5412 line is a transition starting at the fourth energy level, while the three other strong HeII lines start at the third level, an increase of the effective temperature should raise the population of the fourth level and maybe cause a drop of flux in our predicted He II 5412 line. Our ultimate goal is to provide a convincing fit to the observed spectrum of SDSS J1600+0748 and, thus, reliable estimates of its atmospheric parameters. This is of clear importance in the context of the future seismic exploration of the properties of SDSS J1600+0748, as spectroscopic constraints (especially on the effective temperature) have proven to be essential during the course of asteroseismological studies of pulsating hot subdwarf stars (see, e.g., Charpinet et al. 2005).

References

Bergeron, P., Saumon, D., & Wesemael, F., 1995, Astrophys. J., 443, 764

Bergeron, P., Saffer, R.A., & Liebert, J. 1992, Astrophys. J., 394, 228

Blanchette, J.-P., Fontaine, G., Wesemael, F. et al. 2008, Astrophys. J., 678, 1329

Charpinet, S., Fontaine, G., Brassard, P. et al. 2005, Astron. Astrophys., 443, 251

Deetjen, J. L., 2000, Astron. Astrophys., 360, 281

Fontaine, G., Brassard, P., Green, E. M., Chayer, P., Charpinet, S., Andersen, M., & Portouw, J., 2008, Astron. Astrophys., 486, L39

Lanz, T. & Hubeny, I., 2007, Astrophys. J. Suppl. Ser., 169, 38

Lanz, T., Hubeny, I., & Heap, S. R., 1997, Astrophys. J., 680, 1042

Woudt, P. A., Kilkenny, D., Zietsman, E. et al. 2006, Mon. Not. R. Astron. Soc., 371, 1497