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The Quasi-WR Star HD 45166 Revisited

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Abstract. We studied the wind of the quasi Wolf-Rayet (qWR) star HD 45166. As a first step we modeled the observed UV spectra of this star by means of the state-of-the-art Potsdam Wolf-Rayet (`PoWR`) atmosphere code. We inferred the wind parameters and compared them with previous findings.

1. Introduction

HD 45166 is a binary star consisting of a qWR (quasi Wolf-Rayet) star and a B7V companion (Willis & Stickland 1983). First observations of HD 45166 from 1922 as a peculiar variable O star were reported by Anger (1933). The binary system was later studied in detail by Steiner & Oliveira (2005), who also changed the spectral type of the secondary to B7V.

The optical spectrum of HD 45166 shows: a) much narrower lines than for WR stars, b) long-term spectral variability, c) emission lines of both C and N, d) much lower mass and luminosity, e) apparently a normal H/He ratio. The narrow emission lines are formed in a highly variable wind around the qWR. The surface gravity of the qWR star is lower than for sdO stars. The orbit is eccentric, and the Roche lobe increases and decreases as a function of the orbital phase. There is also a small sized envelope that mimics the environment of a WR envelope. Groh et al. (2008) showed the wind parameters to be unusual compared to O-type or WR stars. They also concluded that a wind compression zone is present (the equatorial wind density is higher than the polar wind).

Götberg et al. (2018) believe that qWR stars are the stripped remnant of an initially more massive stars. Also the wind speed is low and the wind is optically thin in the continuum, contrary to what is the case in WR stars ($\dot{M}$ is about 1000 times smaller in HD 45166). Steiner & Oliveira (2005) included the object as a candidate V Sge star. HD 45166 is possibly a link between hot subdwarfs and Wolf-Rayet stars.

2. UV observations

A low-resolution near-ultraviolet (NUV) spectra (λ = 1200 − 3200 Å) taken with the IUE satellite were downloaded from the INES Archive Data Server[1]. Data sets are: SWP18009 (UT 1982-09-19) and LWR09705 (UT 1981-01-14). The spectral region λ = 920 − 1180 Å was covered by high-resolution observations with the FUSE satellite, which we retrieved from the MAST[2] archive data set P2240101000 taken at UT 2001-03-05.

3. Potsdam Wolf-Rayet code

The code solves non-LTE radiative transfer equation in a spherically expanding atmosphere simultaneously with the statistical equilibrium equations, and it accounts for energy conservation. The non-LTE radiative transfer is solved in the co-moving frame. It is used for the spectroscopic analysis of any type of hot stars with winds. Detailed model atoms of the most relevant elements (H, He, C, N, O, Si and P) are taken into account. Line blanketing is also taken into account, with the iron-group elements treated in the super-level approach. Mass-loss rate and wind velocity are among the free parameters of the models. For more details see, e.g., Hamann & Gräfener (2004).

4. Modeling spectra

Stellar and wind parameters of the star obtained by Groh et al. (2008) served as a starting point for our PoWR model. We varied them to obtain a better fit with the UV observations we used. Table 1 presents these parameters with changed mass-loss rate, temperature, luminosity, and added phosphorus.

Table 1. The stellar and wind parameters of HD 45166 used in this work. They differ from the Groh et al. (2008) values by the effective temperature, luminosity, and mass-loss rate, which were $T_{\rm eff}$ = 70 kK, log $[L_*/L_\odot]$ = 3.75, and log $\dot{M}$ $[M_\odot/{\rm yr}]$ = −6.66, respectively in their paper. Additionally, we added the phosphorus in the PoWR model calculations.

Parameter	Value	Element	Mass fraction
$T_{\rm eff}$ [kK]	80	Hydrogen	0.33
log $[L_*/L_\odot]$	4.78	Helium	0.65
log $\dot{M}$ $[M_\odot/{\rm yr}]$	−7.18	Carbon	$5.9 \cdot 10^{-3}$
M_* $[M_\odot]$	4.2	Nitrogen	$4.6 \cdot 10^{-3}$
v_∞ [km/s]	425	Oxygen	$3.9 \cdot 10^{-3}$
β	4.0	Silicon	$3.6 \cdot 10^{-4}$
		Phosphorus	$5.8 \cdot 10^{-6}$

[1] http://sdc.cab.inta-csic.es

[2] http://archive.stsci.edu

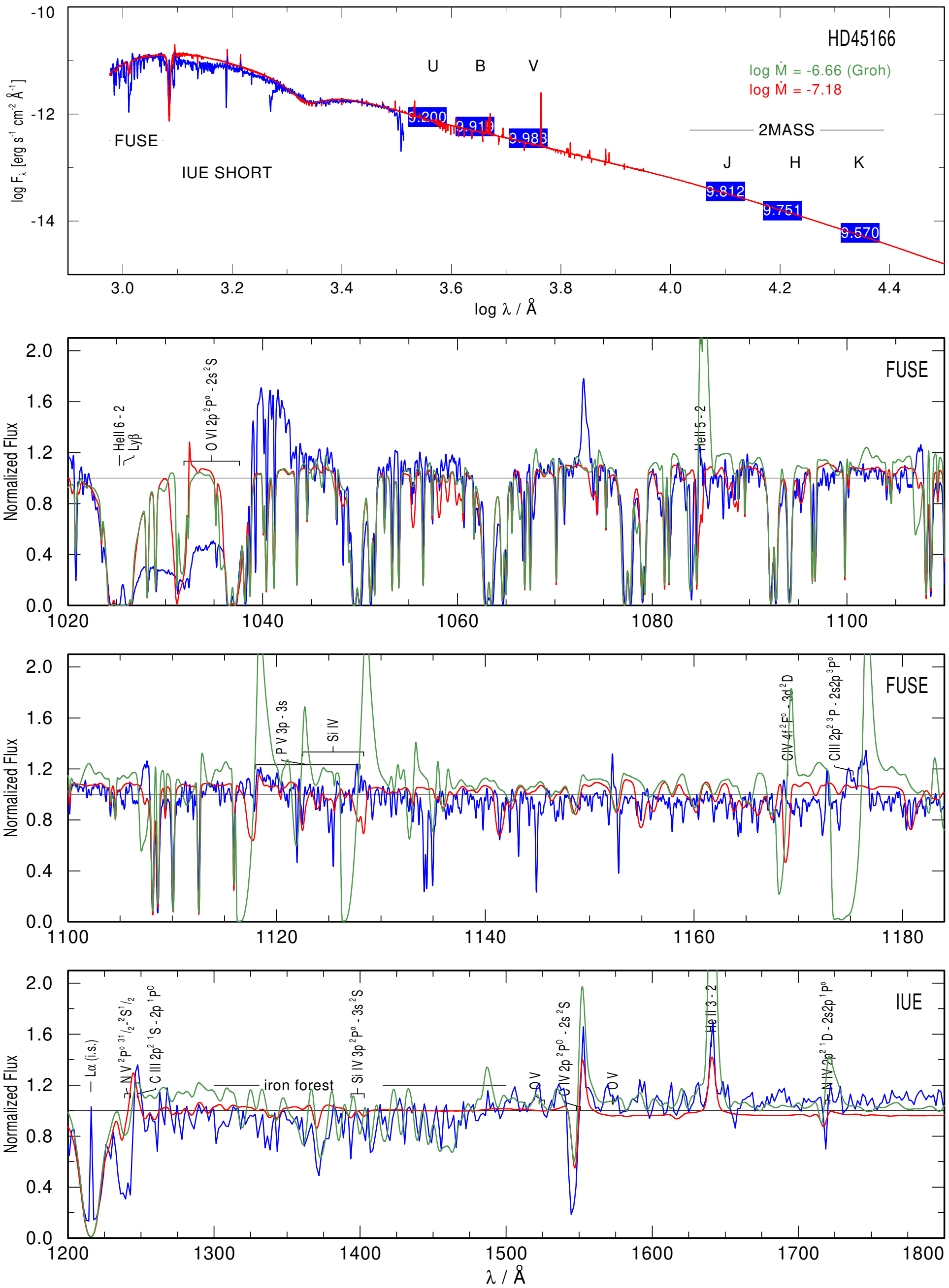

Figure 1. Observed spectrum of HD 45166 (blue lines) vs. PoWR models with the parameters from Groh et al. (2008) (green lines), and our model specified in Table 1 (red lines). Blue labels with numbers in the uppermost panel are *UBVJHK* magnitudes.

The spectrum of the corresponding model is shown in Fig. 1 (red lines). The spectrum obtained with the original Groh et al. parameters is shown as well (green lines).

The synthetic spectra are corrected for interstellar H_2 and Lyman line absorption. The blue lines represent the observation of HD 45166 normalized by the model continuum. The spectral energy distribution (the uppermost panel of Fig. 1) was obtained with a color excess of $E(B-V) = 0.29$ mag and $R_V = 4.5$ (Cardelli et al. 1989). The Gaia distance of $d = 1.488$ kpc was used.

5. Conclusions

Our PoWR model with $T_{\mathrm{eff}} = 80$ kK and $\log \dot{M}\,[M_\odot/\mathrm{yr}] = -7.18$ gives a better fit with the UV observations of HD 45166 than the model of Groh et al. (2008), which had lower effective temperature ($T_{\mathrm{eff}} = 70$ kK) and a higher mass-loss rate ($\log \dot{M}\,[M_\odot/\mathrm{yr}] = -6.66$) and was based on the optical spectra. We prefer higher T_{eff} to suppress C III and P V resonance lines in the FUSE observation. Inferred lower mass-loss rate is in better agreement with the mass-loss rate prediction by Vink (2017). Simultaneous modeling of both the optical and the UV spectra is needed for more reliable determination of stellar and wind parameters.

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