MODELING THE OPTICAL SPECTRUM OF ROMANO‘S STAR IN MINIMUM BRIGHTNESS

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ABSTRACT. V532, known as Romano‘s star, is an interesting variable star located in the M33 galaxy. We study its spectral variability and the optical spectrum in minimum brightness. Using the non-LTE radiative transfer code CMFGEN we model the structure of its expanding atmosphere and stellar wind. The calculations show that all the observed properties of the object are well described by a late WN star model with high hydrogen abundance. We find that the luminosity of the object is $L = (0.8 \pm 0.2) \cdot 10^6 L_{\odot}$, its mass loss rate is $(4.5 \pm 0.5) \cdot 10^{-5} M_{\odot}$/year and the terminal wind velocity is 400 ± 100 km/s. We also find that H/He is $1.3 \div 1.8$.

Key words: stars: individual:Romano’s star (M33); stars: Wolf-Rayet

1. Introduction

Luminous Blue Variables (LBVs) are broadly accepted as very massive and energetic stars emitting close to the Eddington limit, evolving from Of towards Wolf-Rayet stars. But the links between LBV, nitrogen-rich Wolf-Rayet (WN) and hydrogen-rich WN (WNH) stars are uncertain. Studying LBVs in nearby galaxies is very important for understanding stellar evolution and mass loss in different environments.

Romano’s star is named after italian scientist Giuliano Romano who was the first to notice its irregular variability (Romano, 1978). This object ($\alpha = 01^h35^m09.^s71$, $\delta = +30^o41'57.''1$, epoch 2000) is located in the outer spiral arm of the M33 galaxy. Now V532 is classified as an LBV star because it demonstrates both photometric and spectral variability (Kurtev et al. (2001), Viotti et al. (2007), Maryeva & Abolmasov (2010)).

In this article we study the spectral changes of V532 using archival data. We investigate the optical spectrum in minimum brightness using the non-LTE radiative transfer code CMFGEN. We describe the data and data reduction process in the next section. Spectral variability is presented in section 3, results of modeling in section 4. In section 5 we make the conclusions.

2. Observations and Data Reduction

We use archival data from the 6m telescope of the Special Astrophysical Observatory (SAO) of Russian Academy of Sciences (RAS) and the SUBARU telescope. The 6m telescope data were obtained with the Multi Pupil Fiber Spectrograph (MPFS) (Afanasiev et al., 2001) and with the SCORPIO multi-mode focal reducer in the long-slit mode (Afanasiev & Moiseev, 2005). The data from SUBARU were obtained with the Faint Object Camera (FOCAS) (Kashikawa et al., 2002) in the Cassegrain focus.

All the spectra were reduced using IDL-based software. The reduction process includes all the standard reduction steps.

3.Spectral Evolution

Figure 1 shows all the spectra of V532 in the blue range (4000-5500 ÅÅ) analysed in this work, obtained between 2002 and 2007 at different spectral resolutions. It also shows a spectrum obtained by Szeifert (Szeifert, 1996) at Calar Alto with TWIN in 1992.

All the spectra obtained between 2002 and 2008 were classified using the classification of Smith, Crowther & Prinja (1994) for WN6-11 stars based primarily on relative strengths of NV $\lambda\lambda 4604-20$, NIV $\lambda 4058$, NIII $\lambda\lambda 4634-41$ and NII $\lambda 3995$ emission lines. The method has low dependence on elemental abundances, because only helium and nitrogen lines (preferably, ratios of the lines of one element) are used. The results of spectral classification are given in table 1.

We classified the spectra obtained in maximum of optical brightness (2004-2005) as WN11. From the middle of 2005 Romano star evolves along the sequence of late WN stars. The spectra in the minimum in 2007-2008 are classified as WN8. Combined with the data published by Szeifert, our results show that the object changes from a B emission-line supergiant in the photometrical maximum (1992), through Ofpe/WN

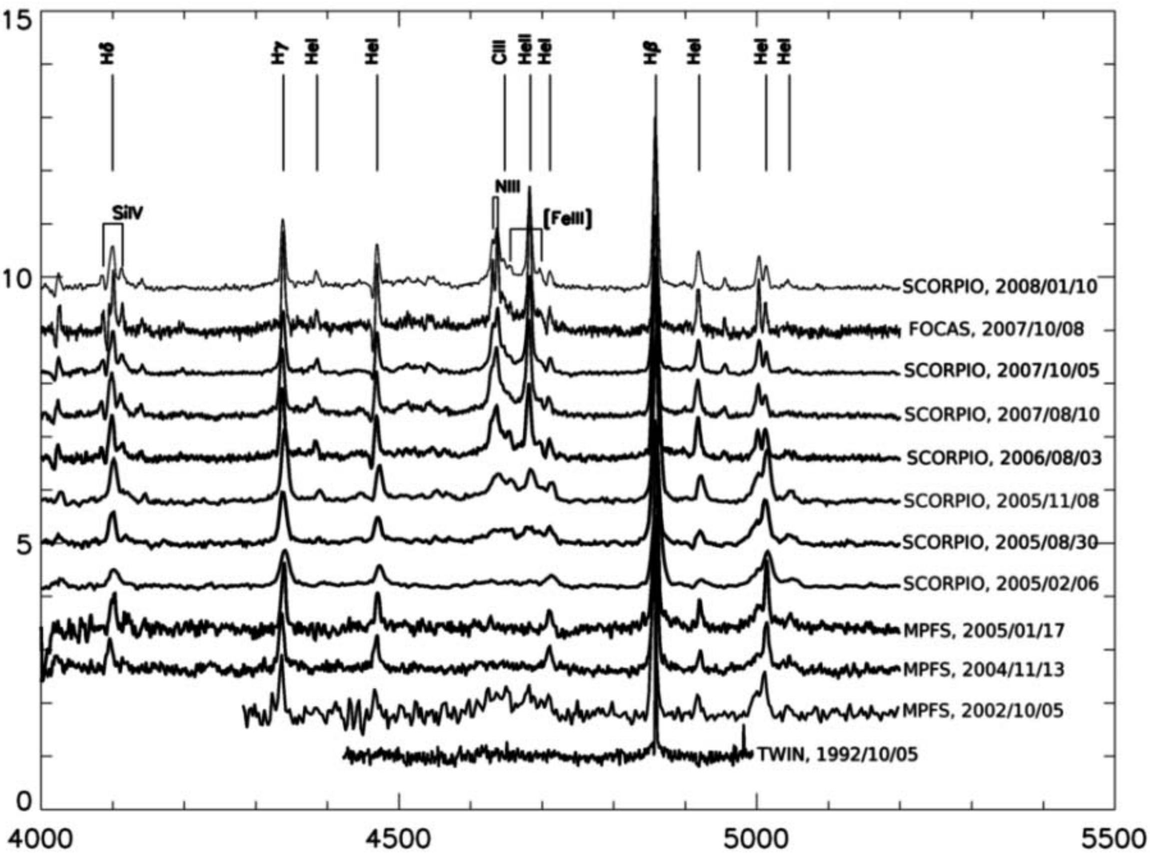

Figure 1: Optical spectrum evolution in the blue spectral range (4000÷5200ÅÅ). Spectra are normalized by the local continuum level and vertically shifted for clarity.

(WN10,WN11) to WN9 and further towards a WN8 star in deep minimum. We classify the observed evolution of the object as S Dor variability cycle (Maryeva & Abolmasov, 2010).

4. Modeling

To analyze the spectra of V532, we used the non-LTE radiative transfer code CMFGEN (Hillier & Miller, 1998). CMFGEN solves the radiative transfer equation in a spherically symmetric expanding outflow simultaneously with the statistical and radiative equilibrium equations. Each model is defined by the hydrostatic stellar radius R_*, the luminosity L_*, the mass-loss rate $\dot{M}$, the wind terminal velocity v_∞, the stellar mass M, and by the abundances Z_i of included species.

CMFGEN allows for clumping within the wind using a volume-filling factor ($f = f(v)$) approach. In all models of this work we assume that the volume-filling factor at infinity $f_\infty = 0.1$. The velocity law used was a simple β-law with $\beta = 1$. The photospheric velocity was set to 100 km/s and the terminal velocity is 400 km/s for all our models. Profile fitting of the triplet lines of HeI (such as $\lambda 3889, 4025, 4471$) allows to estimate the terminal velocity as ~ 400 km s^{-1} (Maryeva & Abolmasov, 2010).

We calculate a number of models (about 130) with different parameters (luminosity, mass-loss rate, mass, elementary abundances) in order to reproduce the spectrum of V532 obtained in October 2007 with FOCAS, while the object was in a deep minimum. Luminosity was varied in the range $(0.6 \div 2) \times 10^6 L_\odot$ constrained by the optical photometrical data ($B = 18^{\rm m}.5$ and $B - V \sim 0$).

Every model was classified using the equivalent width (EW) ratio of $HeI\lambda5876$ and $HeII\lambda5411$ (Smith, Shara & Moffat, 1996). We construct several characteristic diagramms to compare the model spectra with the observations. Figure 2 shows one of them. Models of the different spectral class are marked by various symbols. The modeling of V532 is complicated by the nebula surrounding the object. Therefore we use the characteristic EW ratios of HeIIλ4686 to HeIλ5876

Table 1: Spectral classes identified via the scheme of Smith, Crowther and Prinja (1994)

B, mag	Spectral subtype	Date
17.5	WN10.5	2002/10/05
16.9	WN11	2004/11/13
17.1	WN11	2005/01/17
17.15	WN11	2005/02/06
17.3	WN10	2005/08/30
17.6	WN9	2005/11/08
18.3	WN8	2006/08/03
18.4	WN8	2007/08/10
18.5	WN8	2007/10/05-08
	WN8	2008/01/08-10

The photometric data were provided by Vitalij Goranskij

(these lines form both in the stellar atmosphere and in the nebula) and $HeII\lambda5411/HeI\lambda4713$, where contribution of the nebula is negligibly small.

Bright hydrogen lines are present in the spectra. Equivalent width ratios of hydrogen and helium lines are similar to those for the WN9h star BE381 (Brey 64) that has H/He $\simeq$ 2 (Crowther & Smith, 1996). Therefore we calculate models with $H/He = 0.75 \div 2.6$ that is typical for hydrogen WR stars.

5. Results and Conclusions

Our results show that the object changes from a B emission line supergiant in the optical maximum, through Ofpe/WN (WN10,WN11) to WN9 and further towards a WN8 star in deep minimum.

We model the low-luminosity state spectrum of V532 having the highest available resolution of about 1Å. Figure 3 shows the best-fit model spectrum, redshifted and diluted for the distance towards M33. The parameters of the model are: luminosity $L = 8 \cdot 10^5 L_\odot$, mass loss rate $4.2 \cdot 10^{-5} M_\odot$/year, hydrogen abundance $H/He = 1.3$, effective temperature at hydrostatic radius $T_* = 34600K$ ($R_* = 25R_\odot$) and $T_{tau=2/3} = 28200K$.

Abundance pattern is consistent with the moderately sub-solar metallicity of M33 ($[Fe/H] \sim -0.5$), but nitrogen is significantly over-abundant ($\sim$ 2.4 solar). The latter value is consistent with the existing evolutionary models and with data on other nitrogen-rich WR stars (Herald et al., 2001). Models are most sensitive to the mass-loss rate and the luminosity and practically unaffected by changes in the mass of the star. This is expected, because the density structure of the wind and optical depths are defined by the velocity law rather than by gravity, as for ordinary stars.

Increasing the number of models and refining the fitting procedure will help to better understand the physics and evolutionary status of V532.

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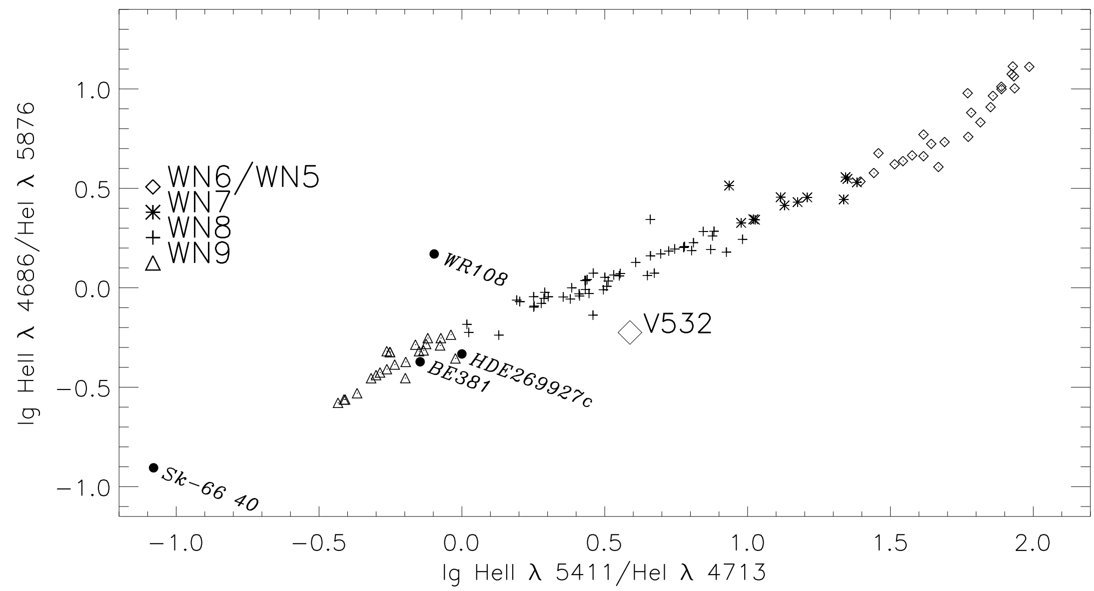

Figure 2: The plot of the EW ratio log(HeII 4686 /HeI 5876) versus the EW ratio log(HeII 5411 /HeI 4713). V532 location in October 2007 is marked by the diamond. Sk-66 40 (WN10), BE381 (WN9), HDE269927c (WN9) and WR108 (WN9-abs) are shown for comparison. Data on these objects were taken from Crowther et al. (1995).

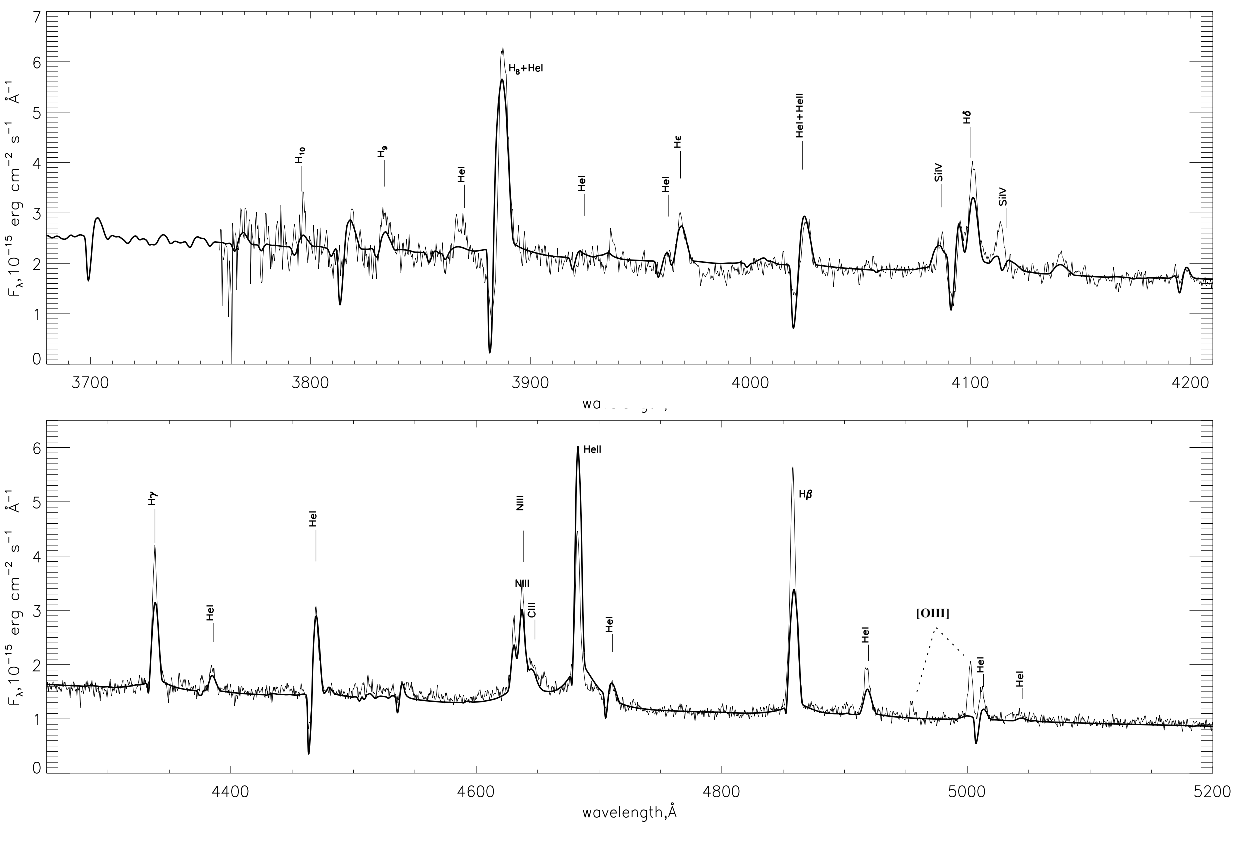

Figure 3: The optical spectrum V532 (obtained with FOCAS in Oct.2007) and our model (thick line)