Modeling of Spectral Variability of Romano's Star

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The variable star GR 290 (M33/V532, Romano's Star) in the M 33 galaxy has been suggested to be a very massive star in the post-luminous blue variable (LBV) phase. In order to investigate links between this object, the LBV category and the Wolf-Rayet stars of the nitrogen sequence (WN), we have derived its basic stellar parameters and their temporal evolution. We confirm that the bolometric luminosity of the star has not been constant, it changes synchronously with stellar magnitude, being 50% larger during visual light maxima. Presently, GR 290 falls in the H-R diagram close to WN8h stars, being probably younger than them. In the light of current evolutionary models of very massive stars, we find that GR 290 has evolved from a 60 $M_\odot$ progenitor star and has an age of about 4 million years. From its physical characteristics, we argue that GR 290 has left the LBV stage and is presently moving from the LBV stage to a Wolf-Rayet stage of a late nitrogen spectral type.

1 Introduction

GR 290 was discovered as a variable star in 1978 by Giuliano Romano [1] and later classified by him as a Hubble–Sandage variable [2]. Peter Conti in 1984 merged Hubble-Sandage variables with S Dor variables in a united class – Luminous Blue Variables (LBVs), and GR 290 became a candidate LBV [3, 4]. Arguments for changing the class of GR 290 from candidate LBV to LBV were given in [5, 6, 7]. More detailed history of spectral and photometric investigations of GR 290 was described in [8].

However, in 2011 Polcaro et al. [9] suggested that, because of its very high luminosity and its extremely hot spectrum at the 2008 visual minimum (WN8h), GR 290 is probably not too far from the end of the LBV phase and may be evolving towards a late-WN-type star. In 2014 Humphreys et al. [10] also noticed that in recent years (2004–2010) GR 290 has shown large photometric variability of 1.5 mag in the blue, but no spectroscopic transition from a hot star spectrum (at the visual minimum) to the cool optically thick wind one at the visual maximum resembling an A to F-type supergiant that is typical of the LBV/S-Dor phenomenon. On the contrary, the spectrum of GR 290 varied from WN8h

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at minimum to WN11h at the recent visual maxima and to B, probably late type at its highest recorded maximum. In this regard, Humphreys et al. [10] speculate on whether GR 290 is a hot star in transition to the LBV stage (as suggested by Smith and Conti [11], for the WNh stars) or it may be in a post-LBV state.

Maryeva and Abolmasov [12] investigated the optical spectra of Romano's star in two different states: the brightness minimum of 2008 ($B = 18.5 \pm 0.05$ mag) and a moderate brightening in 2005 ($B = 17.1 \pm 0.03$ mag). Main result of the work [12] is that the bolometric luminosities (L_{bol}) of GR 290 were different in 2005 and 2008. L_{bol} of GR 290 in 2005 is 1.5 times higher, that is not typical of LBVs. This result confirms the suggestion of [9]. However, to refine the evolutionary status of the star, a more detailed investigation of intermediate states was also necessary, and in the present work we report on the results of such investigation.

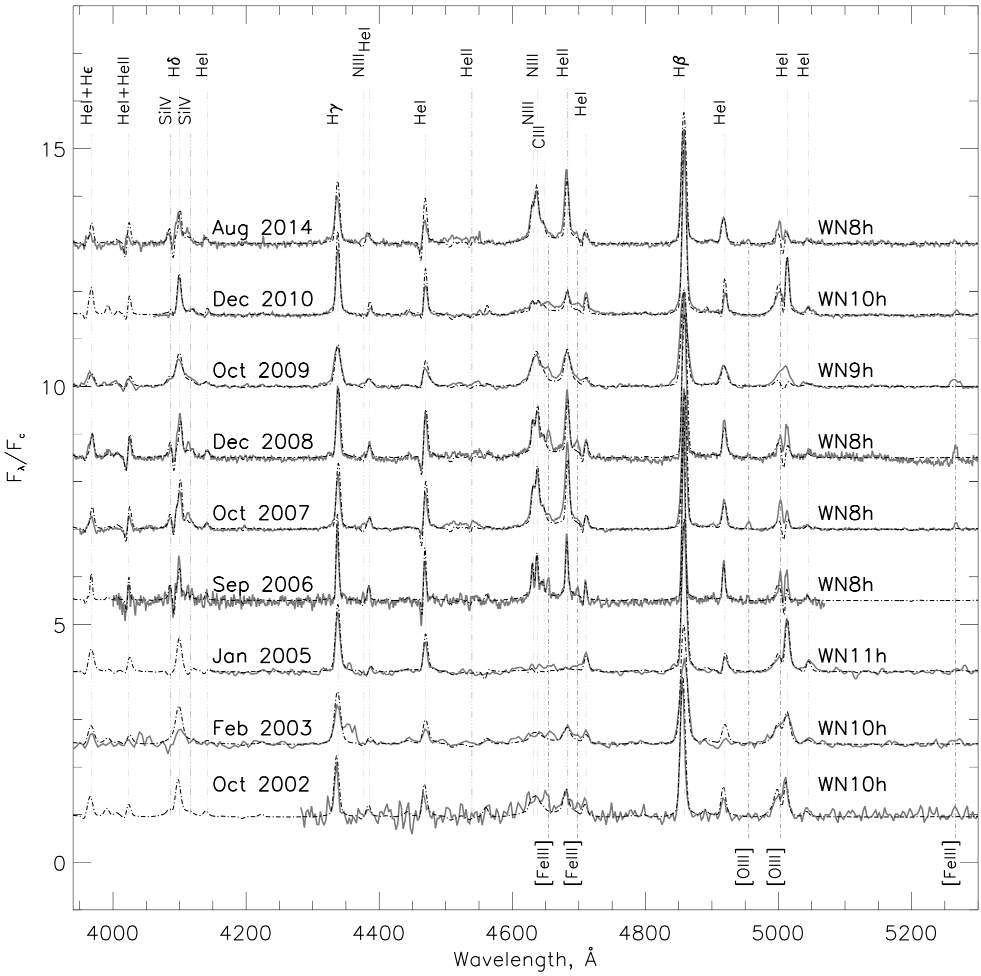

Figure 1: Normalized optical spectra of GR 290 compared with the best-fit CMFGEN models (dash-dotted line). The model spectra are convolved with a Gaussian instrumental profile.

Table 1: Derived properties of Romano's star. $R_{2/3}$ is the radius where the Rosseland optical depth is equal to 2/3, T_{eff} is the effective temperature at $R_{2/3}$, $\dot{M}_{cl}$ is the mass loss rate. For all models, we included clumping with the filling factor 0.15. For all dates, uncertainty of T_{eff} is 1 kK.

Date	V [mag]	Sp. type	T_{eff} [kK]	$R_{2/3}$ [$R_\odot$]	L_*, 10^5 [$L_\odot$]	$\dot{M}_{cl}$, 10^{-5} [$M_\odot$yr^{-1}]	v_∞ [km/s]
Oct 2002	17.98	WN10h	28	39	8 ± 0.5	2.4 ± 0.3	250 ± 100
Feb 2003	17.70	WN10.5h	27.5	44	10.2 ± 0.7	2.6 ± 0.3	250 ± 50
Jan 2005	17.24	WN11h	23.5	61	$10.5^{+1.5}_{-3}$	4.0 ± 0.3	250 ± 50
Sep 2006	18.4	WN8h	31	28	6.7 ± 0.5	1.5 ± 0.3	250 ± 100
Oct 2007	18.6	WN8h	33.3	23.8	6.3 ± 0.5	1.9 ± 0.3	370 ± 50
Dec 2008	18.31	WN8h	31.5	28.5	7.2 ± 0.5	2.3 ± 0.3	370 ± 50
Oct 2009	18.36	WN9h	32	28.4	7.5 ± 0.5	2.0 ± 0.3	300 ± 100
Dec 2010	17.95	WN10h	26.7	42	8 ± 0.5	2.6 ± 0.3	250 ± 100
Aug 2014	18.74	WN8h	33	22.5	5.3 ± 0.5	1.7 ± 0.3	400 ± 100

2 Modeling

In order to see how the parameters of GR 290 changed with time, we modeled the most representative spectra with best quality obtained during October 2002 – December 2014, when the star displayed an ample range of variation in visual luminosity. This time interval covers two brightness maxima and three minima. For modeling we used CMFGEN atmospheric code [13] and constructed nine models (Fig. 1). We can see from Table 1 that the nature of the stellar wind significantly changes, being much denser and slower during the eruption in 2005, while during the minimum of brightness wind structure is fairly similar to the one of typical WN8h (non variable) stars.

The main result of this analysis is that the bolometric luminosity of GR 290 is variable, it is higher during the phases of greater optical brightness. The present model fitting of a large sample of spectra obtained during two successive luminosity cycles allows us to trace the recent path of the star in the Hertzsprung–Russell (H-R) diagram (Fig. 2).

3 Results

Combining the results of numerical modeling with data of photometric and spectral monitoring, we may conclude that we observed GR 290 in very rare evolutionary phase – post-LBV. The initial mass of GR 290 is near 60 $M_\odot$ and age is about 4 Myr. Probably, the changes of L_{bol} are due to the hydrogen mixing in the core generating a burst of nuclear energy: presently, such repeated nuclear events should be the extra-energy input to increase the bolometric luminosity of GR 290 during its last outbursts. They will end when the hydrogen percentage in the envelope will become too low to be mixed in the core.

More details are published in [14].

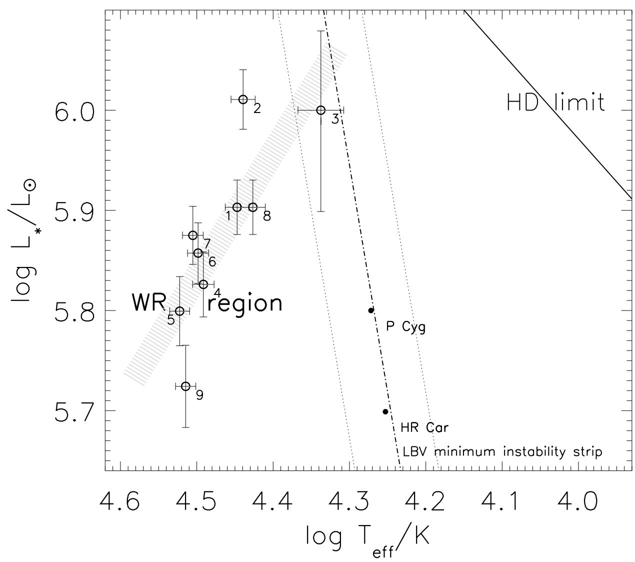

Figure 2: Position of GR 290 in the H-R diagram. HD limit line shows the Humphreys–Davidson limit [3]. 1 – Oct. 2002; 2 – Feb. 2003; 3 – Jan. 2005; 4 – Sep. 2006; 5 – Oct. 2007; 6 – Dec. 2008; 7 – Oct. 2009; 8 – Dec. 2010; 9 – Aug. 2014.

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