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The LBV nature of Romano's star (GR 290) in M 33*

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Abstract. We report the first spectroscopic study of the LBV candidate GR 290 in M 33 ("Romano's star") taken in February 2003, showing, besides prominent hydrogen and He I emission lines, the 4630–60 Å blend and weak He II 4686 Å emission typical of Of stars. Our broad–band photometry shows that the star was observed during a phase of minimum optical luminosity, with $B = 17.91 \pm 0.03$, and a slightly positive colour index, which we tentatively attribute to an anomalous continuum energy distribution. We argue that GR 290 is indeed an LBV star presently in a high temperature phase, that should be followed – also in a short time – by ample spectroscopic and associated photometric variations.

Key words. stars: evolution – stars: emission-lines, Be – stars: individual: GR 290 – stars: mass-loss – galaxies: individual: M 33

Since the discovery of a small number of blue, intrinsically bright variable stars in M 31 and M 33 by Hubble & Sandage (1953), the LBV phenomenon has represented an evolutionary problem which still seems far from solution. Extensive descriptions of LBVs and in general of the S Dor type stars can be found in several review papers (e.g., Humphreys & Davidson 1994; van Genderen 2001, and reference therein). We recall briefly that to be defined as an LBV, a star must fulfil a number of photometric and spectroscopic observational conditions. It must be – or should have been in the far past – subject to sporadic violent events of photometric variability as well as to minor eruptions. These instability phases are confirmed by associated deep spectroscopic changes, with signatures of strong mass loss episodes. At minimum in the visual LBVs exhibit a blue colour and a hotter spectrum; in some cases an Of/WN spectrum has been observed. During the high luminosity phases they present a cooler continuum and display a lower excitation emission line spectrum. The variations seem to occur at constant bolometric luminosity, but in some cases light fading was caused by the formation of opaque dust shells.

With these characteristics, the identification of a star as an LBV requires a long monitoring, and, in spite of the enormous progress in observational technologys since the first work of Hubble & Sandage, the population numbers are still very low. So far the total estimated number of confirmed and candidate LBVs is 21, 4, and 21 in the Milky Way, SMC and LMC, respectively (van Genderen 2001). As far as the Local Group galaxies are concerned, the richest is M 33, where a total of about ten LBVs have so far been recognised, although their total number may be underestimated due to their possible low photometric quiescent phase (Massey et al. 1996).

The suggested evolutionary status of the LBVs is that of evolved objects. Their emission spectra are enriched in He and N and poor in oxygen, indicating that their winds and ejecta are supplying the local environment with CNO processed material. In this regard, it would be important to investigate the role of LBVs in the chemical evolution of galaxies. Many of the LBVs in the Milky Way and in the Magellanic Clouds are surrunded by circumstellar nebulae, which are gas and/or dust signatures of previous mass loss episodes and of interaction of a fast moving wind with slower gas, possibly ejected during a previous RSG phase. There is a consensus that LBVs represent a quite short-lived phase, contiguous to the WN evolutionary phases of very massive stars, although the temporal sequences are still under debate.

The poor LBV statistics and the irregular spectrophotometric behaviour of the individual objects does not lead one to favour any of the presently existing models for massive star evolution, or to provide clues for new models. In this situation the identification or the confirmation of a candidate is important for shedding light on the problem.

The LBV candidate GR 290 (the *Romano* star) is located in M 33, a member of the Local Group that has been successfully searched for LBVs and LBV candidates

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* Based on observations collected at 1.52 m Cassini telescope of the Loiano Observing Station, Bologna Astronomical Observatory.

Table 1. Log of the GR 290 observations.

Date	Object	Exp. (s)	UT beg (hh:mm:ss)
2003 February 2	*R* image	30	18:38:41
2003 February 2	Spectrum	1800	18:43:29
2003 February 2	*V* image	60	19:21:53
2003 February 2	*B* image	300	19:25:34

(Humphreys & Davidson 1994; Corral 1996; Massey et al. 1996). Giuliano Romano first derived the light curve of GR 290 from the examination of a series of photographic plates of M 33 obtained at the Asiago Observatory and covering a period of 17 years (Romano 1978). He found that the *B* magnitude presents long-term variations between 16.7 and 18.1, on a time scale of many years, and classified GR 290 as a variable of the Hubble-Sandage type. Later, Humphreys & Davidson (1994) on the basis of its light variation only, classified the star as an LBV candidate. More recently, Kurtev et al. (2001) have confirmed the large amplitude photometric variability of GR 290, on the basis of long–term (1982–1990) photographic monitoring and of a shorter survey (June 1999) performed by means of CCD photometry in the Johnson *B*–band. Although these previous observations have clearly identified the conspicuous light variability of GR 290, neither multicolour photometry nor spectroscopic observations have been so far reported in the literature, which could confirm (or disprove) the classification of GR 290 as a Luminous Blue Variable.

We have obtained Johnson *B*, *V* and *R* images of a field centred on GR 290[1] at the Loiano 1.52 m Telescope equipped with the Bologna Faint Objects Spectrometer and Camera (*BFOSC*, Gualandi & Merighi 1994), and an EEV D129915 CCD (1300 × 1340 pixels). In addition, we secured a spectrogram of GR 290, in the 3800–8000 Å range with a resolution of $\Delta\lambda = 4.0$ Å. An exposure time of 1800 s has provided a signal-to-noise ratio for the continuum generally ranging between 10–20 and reaching ∼50 at the Hα emission peak. A logbook of the observations is reported in Table 1.

The photometric and spectral data were analysed by means of standard IRAF[2] procedures.

Due to the variable sky condition on the night of the observations, it was impossible to take photometric calibration fields. The photometric images were therefore calibrated by using other objects in the stellar field of GR 290. The *B* image was reduced using the standard stars in the field listed by Kurtev et al. (2001). We discarded stars A and L since in the cross calibration they give systematic errors of +0.5 and −0.8 mag, respectively. We derive for GR 290 a *B* magnitude of 17.91 ± 0.03. This value is close to the minimum B flux measured by Romano (1978) and by Kurtev et al. (2001). The *V* and *R* images were reduced using the *V* and *R* photometry of stars in the field of M 33 listed in SIMBAD, and the *R*1 and *R*2 photometry of field stars derived from the USNO-B catalogue (Monet et al. 2003). We obtain in this way magnitudes for the star $V = 17.5 \pm 0.2$ and $R = 17.7 \pm 0.3$. By convolving the observed spectrum with the *B*, *V* and *R* photometric curve, we have found that the emission lines contribute by about 10%, 4%, and 10% to the *B*, *V* and *R* bands, respectively. This implies that a −0.05 mag correction should be applied to $V - R$, while $B - R$ is not affected. Therefore, although the measurement errors in *V* and in *R* are too large to give a precise colour evaluation of GR 290, we estimate that the $B - V$ index is at least +0.2. A positive colour index implies either an interstellar/circumstellar extinction in excess of that towards M 33 (about $E_{B-V} = 0.04$, e.g. Kim et al. 2002), and/or an intrinsic continuum energy distribution flatter than a hot star's typical continuum, for instance with a substantial contribution from a massive ionised wind.

The spectral image was reduced using the standard procedures of the IRAF packages. After the correction for the bias, the monodimensional spectrum was extracted and the sky emissions subtracted. The correction for the CCD response needed particular care in the red part of the spectrum where high frequency fringes appear and the signal-to-noise ratio goes down. Since the nominal spectral range extends to 8700 Å we intended to look for the possible presence of the emissions in the near infrared such as of O I and He I, and the Ca II red triplet. Better than by using the halogen lamp, the fringes were eliminated by dividing our spectrum by that of the featureless BL Lac object ON231, taken on the same night and with similar zenithal distance. At any rate, no reliable identification was possible beyond the telluric absorption band at 7600 Å and the only detectable emissions were the residuals of the sky lines. The final spectrum normalised to the continuum is presented in Fig. 1. The line identification is reported in Table 2.

GR 290 presents a prominent emission line spectrum, with strong hydrogen and neutral helium lines. The spectrum also displays the broad N II + N III blend near 4630–50 Å and the He II 4686 Å line, that are typical of Of stars. These features have also been observed in the LBVs R127 and AG Car during their Of/WN phases.

Some weak features, such as the N II emission lines near 4447 Å and 6340 Å, were identified by comparison with the optical spectrum of known LBVs, in particular AG Car during its hot phase (e.g. Viotti et al. 1993), binned to the same resolution. N II most probably contributes to the 5015 Å line, which appears too strong and broad to be attributed solely to He I 5015.7 Å; the forbidden [N II] lines are present in the Hα wings. A few absorptions are attributed to the interstellar Na I lines and to the DIB at 6278 Å, both formed in our Galaxy. The comparison with the 1990 hot phase spectrum of AG Car shows also that the He I emission lines are a factor 2–4 stronger in GR 290 and the He II 4686 line is much stronger than that. We were unable to identify more He I lines and other permitted or forbidden transitions, which are observed in some LBV spectra, or shifted P Cygni absorption lines. This is not surprising at these relatively low signal-to-noise levels. Of special interest are the equivalent widths of the hydrogen and neutral helium emission lines, that appear quite large and compare better with the ones in the spectrum of the very luminous star

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[1] Notice that the star's coordinates reported in the *SIMBAD* database are wrong. The J2000 coordinates are: RA = $01^{h}\ 35^{m}\ 10^{s}$, Decl = +30° 41′ 54″ (see the finding chart in Kurtev et al. 2001).

[2] IRAF is distributed by the NOAO, which is operated by AURA, under contract with NSF.

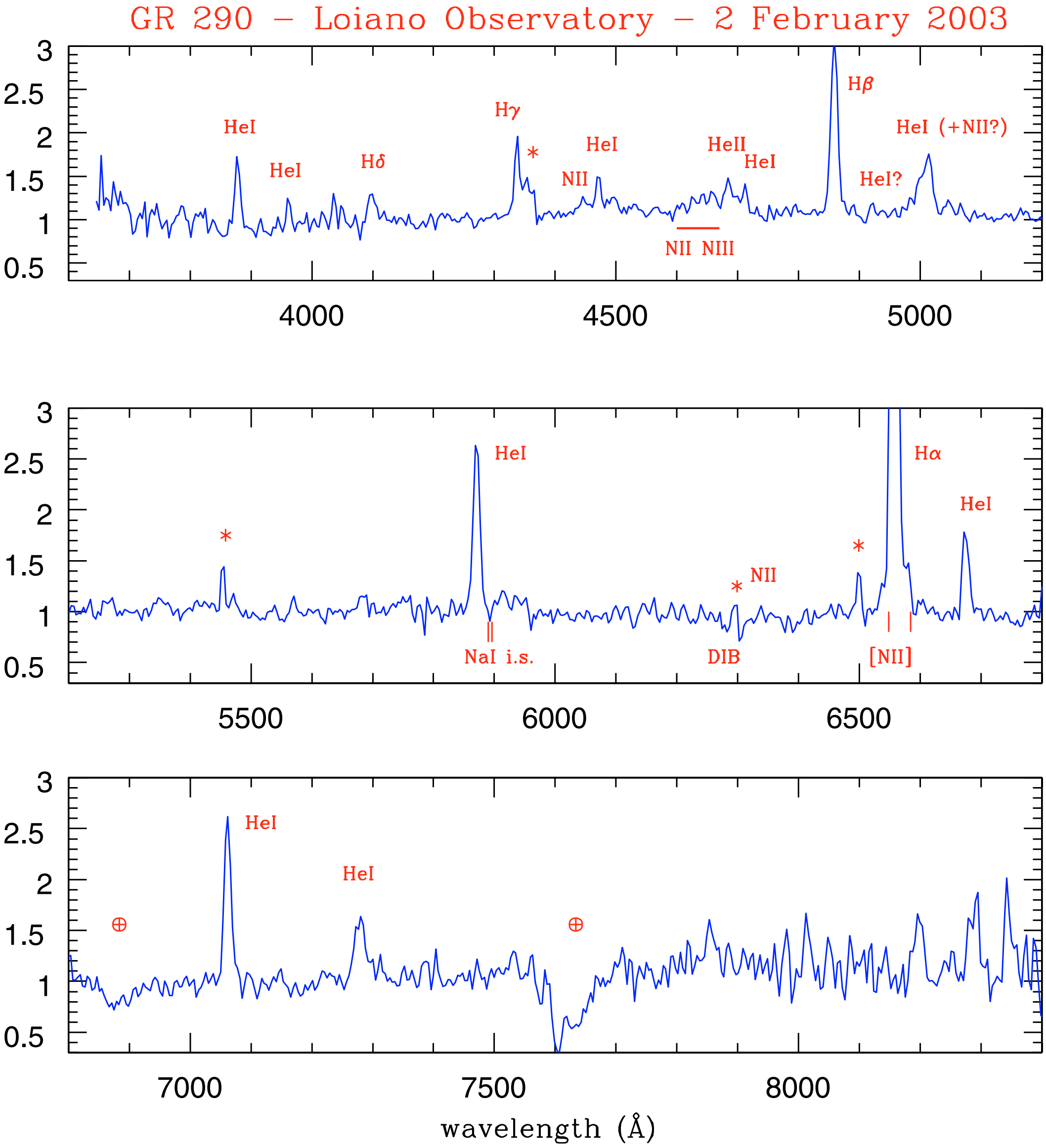

Fig. 1. The rectified spectrum of GR 290. Spectral artifacts are indicated by asterisks, the telluric absorptions by ⊕. The redder part of the spectrum is affected by residual sky emission lines.

η Car, rather than in the classical galactic LBV stars P Cyg, AG Car and S Dor in the LMC. Finally, we notice that the emission line radial velocities are in good agreement with that of M 33.

We have measured an Hα/Hβ equivalent width ratio of about 3.65, which appears rather low, if one assumes the intrinsic stellar continuum to be hot: indeed, Hα/Hβ flux ratios lower than the case B pure radiative emission have been observed in the same AG Car hot phase spectrum (Viotti et al. 1993), as well as in some planetary nebulae (Pottasch & Acker 1989). (The intensity of Hγ in GR 290 is probably affected by a residual of the strong city light nearby emission, therefore cannot be considered here). Alternatively, we might assume the intrinsic continuum to deviate largely from that of hot supergiants, with a flatter continuum slope, as for instance observed in WR stars. A marked contribution of a nebular–type continuum is also suggested by the large equivalent widths of the hydrogen emission lines.

Assuming for M 33 a distance modulus of $m - M = 24.80$ and a foreground reddening of $E(B - V) = 0.04$ (Kim et al. 2002), the absolute visual magnitude of GR290 in February 2003 turns out to be $M_v = -7.4$. Reasonable values of the bolometric correction of at least −3 mag would therefore comfortably bring the $M_{\rm bol}$ of GR 290 in the ranges for LBVs ($M_{\rm bol} \leq\sim -10$; see, e.g., Humphreys & Davidson 1994).

Let us finally consider that in general, LBVs are identified on the basis of their "η Car–type" or "P Cyg–type" spectrum, and of their large secular photometric variability. However, in a few cases LBVs at minimum have displayed an Of/WN spectrum, as already stated. An object without previous photometric measurements, casually observed during such a phase, would not have been classified as an LBV. This is in fact the case for GR290, already known because of its large S Dor–type

Table 2. The spectrum of GR 290 in February 2003.

$\lambda_{\rm GR}$	$W^1_{\rm eq}$	Identification	RV^2	Contrib.^{3}
3877	–9.1:	He I 3888.6		[Ne III] 68.7
3962	–2.4	He I 3964.7	–204	Hϵ 70.1
4098	–4.3	Hδ 4101.7	–271	N III m.1
4338	–17.5:	Hγ 4340.5	–173	
4445	p	N II 4447.1		
4470	–5.3	He I 4471.5	–100	
4624- –4668	–8.1:	N II 4601-30 N III 4634-42		
4684	–6.4	He II 4685.7	–109	
4712	–4.9	He I 4713.1	–70	
4859	–25.5	Hβ 4861.3	–142	
4921	–0.24	He I 4921.9		uncertain
5014	–13.8:	He I 5015.7	–60	N II m.3
5870	–17.4	HeI 5875.6	–286	
5893	0.91	NaI 5890.0+96.0		interstellar
6283	0.80	DIB		interstellar
6338	p	N II 6340.7-47.1		
6537	p	[N II] 6548.1		in Hα wings
6557	–93.1	Hα 6562.8	–265	
6581	p	[N II] 6583.6		in Hα wings
6673	–8.3	He I 6678.1	–229	
7061	–19.9	He I 7065.2	–178	
7281	–10.2:	He I 7281.3		broad

Notes to the table. [1] Equivalent widths in Å, negative for emission lines. *p*: line probably present but not measurable. [2] Radial velocity in km s^{-1}. [3] Other contributors to the emission lines are indicated.

photometric variability, which in February 2003 presented a typical Of/WN spectrum when the star was in a deep minimum phase, in agreement with its LBV nature.

Since a very few LBVs have been so far observed in this very hot phase, this first spectroscopic observation needs to be urgently complemented by continued spectroscopic and multicolour photometric monitoring, to examine the present hot phase, and to detect signs of the crucial transition to another phase that might start impredictably at any time.

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[3] `http://www.bo.astro.it/~loiano/TechPage/pagine/BfoscManualTechPage/BfoscManual.htm`