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Photometric variability of LBV-candidate stars and Hubble-Sandage variables A, B, C and 2 in M 33

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Abstract. We present the photometric history of some Luminous Blue Variable candidate stars in M 33. The search for outbursts was made in photographic plates taken in the B band of the galaxy M 33 and cover an eight year period, 1982–1990. Twenty five plates, separated into seven groups, have been used. CCD UBV magnitudes of the star UIT003 are presented also. Only one (of 12) of the LBV candidates (UIT003) presents clear variability above the noise. The combination of photometric variability and a typical LBV spectrum make it a new LBV.

We present also the light curves of Hubble-Sandage Variables A, B, C and 2.

Key words: stars: early-type – stars: variables: general – galaxies: individual: M 33

1. Introduction

Luminous Blue Variables (LBV) are a group of irregular variables characterized by their high intrinsic luminosities, their photometric behavior and their related spectroscopic changes. Members of this group are known not only in the Milky Way but in nearby galaxies as well. LBV is a term coined by Conti (1984) that covers the S Dor variables, the Hubble-Sandage variables and the P Cygni variable stars. Recent reviews of LBV can be found in Humphreys & Davidson (1994) and in Bohannan (1997). The variabilities shown by the LBVs are of different amplitudes and time scales. Giant eruptions, with amplitudes greater than 2 mag, are very rare. Normal outbursts, with amplitudes of 1 or 2 mag in the optical bands, have time scales of years or tens of years and are the 'finger-prints' of the group. It is possible that an LBV lasts several years (centuries?) without showing any outburst (e.g. P Cyg, since the outburst of 1600 has been in quiescent phase, Lammers & de Groot 1992).

The LBV members of M 33 were found by Hubble & Sandage (1953), in a photometric search of variables on plates of the Mount Willson telescope that covered observations from 1920 to 1953. It is possible that some LBV members of M 33 have not been classified as such, because they did not show variability in this search.

Some stars with the same, or at least related, spectroscopic characteristics of the LBV, but without any variation in historical times, are known as LBV-candidates.

Massey et al. (1996) from a catalog of bright UV sources in M 33 found 11 objects with spectroscopic resemblance with the classic LBV, five with spectra similar to Var B and six Ofpe/WN9 "slash" stars. Corral (1996) observed some of the Hα emission objects of M 33 found by Spiller (1992) and found 5 LBVc. Herrero et al. (1994) reported that the star M 33-B 324 showed a spectrum that resembles a classical LBV, later Monteverde et al. (1996) reported that there were significant spectral variations, strongly suggesting the LBV nature of this star.

It is interesting to see if these stars have shown any outbursts in the optical bands in order to classify them as LBVs and study the distribution and frequency of these stars in an environment with different metallicities than those of the Galaxy or the Magellanic Clouds.

We present a photometric search based on plates of M 33 from the collection of the Bulgarian National Astronomical Observatory (BNAO). We are looking for variability on the LBV candidates and Ofpe/WN9 "slash" stars presented by Massey et al. (1996), excepting UIT301 and UIT236, all the LBV candidates found by Corral (1996), and the LBV candidate of Herrero et al. (1994). There is an overlap between these sets of objects. The cross-identifications are given in Table 1. Later in the text we use mostly cross-identifications are given in Table 1. Later in the text we use mostly the designation of Massey et al. (1996).

The time distribution of the data and quality of the plate material allow us to look only for outbursts.

In this paper we present also the photometry of Hubble-Sandage variables in M 33. The original paper of Hubble & Sandage (1953) included four stars in M 33 (Vars. A, B, C and 2).

The observational material and the photometric measurement techniques are presented in Sect. 2. In Sect. 3 we present the light curves of LBV-candidates UIT003 and UIT 247 and the Hubble-Sandage variables. In Sect. 4 a short discussion is given and the conclusions of this work are presented in Sect. 5.

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Table 1. Cross-identifications between different designations of LBV-candidates and some Ofpe/WN9 “slash” stars in M 33. * M refers to Massey et al. (1996); S refers to Spiller(1992) and HS refers to Humphreys & Sandage (1980)

UIT003	UIT008	UIT026	UIT045	UIT104	UIT154		UIT212	UIT247		UIT341	UIT349	M*
H235					S193	S204	S95	S220	H108			S*
B5	B7	B43						B324	B517			HS*

Table 2. Photometry in B of LBV candidates and Hubble-Sandage variables

JD	Date	UIT3	UIT8	UIT26	UIT45	UIT104	UIT154	S204	UIT212	UIT247	B517	UIT341	UIT349	VarA	VarB	VarC	Var2	StX	St15	σ
45286	12.XI.82	16.24	17.25	17.81	17.87	17.77	17.37	17.79	17.01	15.31	18.03	16.19	18.19	20.78	17.79	17.47	17.89	15.74	17.47	0.15
45295	21.XI.82	16.17	17.08	17.72	17.79	17.72	17.3	17.78	16.89	15.45	17.96	16.42	17.99		17.87	17.43	17.94		17.41	0.15
45296	22.XI.82			17.65	17.78	17.72	17.28	17.62	16.98	15.12	17.96	16.38	17.94		17.97	17.32	18.05	15.86	17.53	0.23
45297	23.XI.82	16.1	16.9	17.69	17.71	17.67	17.16	17.64	16.7		17.99	16.6	17.85		17.72	17.39	17.98	15.54	17.35	0.25
45588	9.X.83	17.27	17.25	17.86	17.81	17.78	17.09	17.69	16.93	14.61	17.77	16.5	18.03	20.61	16.53	15.74	17.66	15.84	17.39	0.23
45588	9.X.83	17.06	16.9	17.73	17.78	17.67	16.99	17.79	17.04		17.98	16.34	17.88	20.64	16.79	16.04	17.58	15.57	17.33	0.31
45590	11.X.83	17.3	17.19	17.85	17.74	17.73	17.07	17.65	16.77	14.88	17.79	16.21	18	20.26	16.62	15.94	17.66	15.66	17.38	0.2
45591	12.X.83	17.03	16.88	17.77	17.9	17.65	16.97	17.58	16.85	14.74	17.81	16.53	18.24	20.72	16.85	15.69	17.72	15.79	17.48	0.16
45623	14.X.83	17.13	17.23	17.89	17.68	17.63	16.95	17.62	16.9		17.85	16.35	18.33	20.59	16.58	15.72	17.69	15.52		0.23
45625	16.X.83	17	17.08	17.71	17.91	17.83	16.97	17.7	16.86	15.16	17.66	16.72	18.31	20.31	16.7	15.9	17.67	15.65	17.18	0.16
45702	2.I.84	17.11	17	17.7	17.79	17.77	17.31	17.73	16.73	15.21	17.98	16.48	17.95	20.15	16.32	15.6	17.67	15.71	17.41	0.08
45929	14.IX.84	17.11	16.91	17.75	17.79	17.61	17.23	17.74	16.9	15.29	18.05	16.53	18.05	20.21	16.26	15.55	17.88	15.82	17.33	0.08
45968	23.X.84	17.27	17.19	17.89	17.78	17.67	17.38	17.78	16.85	15.27	17.91	16.51	18.3	20.13	16.41	15.41	17.74	15.59	17.43	0.09
46435	3.I.86	17.29	17.17	17.77	17.89	17.72	17.2	17.8	16.71	15.12	17.85	16.55	17.92		16.36	15.47	17.96	15.66	17.4	0.08
46707	2.X.86	17.1	17.1	17.62	17.76	17.74	17.41	17.55	16.78	14.89	17.83	16.47	17.79		16.02	15.64	17.72	15.76	17.36	0.16
46707	2.X.86	17.11	16.87	17.69	17.95	17.7	17.48	17.68	16.78	15.17	17.85	16.36	17.74		16.03	15.46	17.82	15.59	17.42	0.16
46708	3.X.86	17.1	16.93	17.64	17.83	17.72	17.47	17.76	16.78	15.33	17.78	16.42	17.85		16	15.51	17.74	15.74	17.48	0.07
46708	3.X.86	17.14	17.06	17.81	17.77	17.74	17.51	17.68	16.75	15.17	17.81	16.46	17.98		15.93	15.4	17.78	15.67	17.4	0.1
46709	4.X.86	17.17	17.05	17.79	17.92	17.65	17.53	17.71	16.8	15.28	17.99	16.44	18.18		16.06	15.58	17.86	15.84	17.45	0.08
46738	2.XI.86	17.33	17.21	17.75	17.87	17.73	17.26	17.66	16.93	15.38	17.94	16.53	18.27	20.09	16.18	15.66	17.8	15.66	17.35	0.11
46738	2.XI.86	17.32	17.26	17.68	17.85	17.7	17.31	17.81	17.01	14.99	17.87	16.23	18.19	20.05	15.73	15.4	17.78	15.7	17.39	0.17
48177	12.X.90	17.19	17.1	17.73	17.72	17.72	17.38	17.64	17.04	15.07	17.65	16.55	18.01	20.79	15.48	16.36	17.67	15.74	17.45	0.18
48180	15.X.90	17.24	17.2	17.64	17.8	17.65	17.36	17.73	16.91	14.88	17.78	16.36	17.94		15.42	16.22	17.73	15.57	17.32	0.17
48180	15.X.90	17.22	17.14	17.7	17.8	17.69	17.37	17.74	16.89	15.3	17.69	16.4	18		15.68	16.22	17.76	15.69	17.34	0.13
48180	15.X.90	17.19	16.96	17.71	17.76	17.74	17.37	17.69	16.8	14.91	17.67	16.65	18.09	20.51	15.63	16.42	17.77	15.86	17.34	0.12

2. Observations and reductions

The observational basis of our study was a sample of photographic plates of M 33 from BNAO’s collection. All plates were taken with the 2 m RCC f/8 Rozhen Telescope.

We used 25 B-plates(103aO, IIaO and ORWO ZU 21 emulsions, GG 385 glass filter) with dimensions of 30 $\times$ 30 cm. The plates were taken from November, 1982 to October, 1990. The plate scale is 12.8 arcsec mm^{-1} and the area covered is $1^\circ \times 1^\circ$. The whole image of M 33 fits in each plate.

The measurements have been made with a MF-4 densitometer with a constant diaphragm in the Astronomical Observatory of the Sofia University. At least four estimations of sky background for each star were obtained and then the averaged value was used. To minimize errors due to variable sky background the sky measurements were made always at the same places around each star. These places were chosen after careful inspection on deeper plates in order to avoid faint neighbors. The calibration curves have been constructed using the photoelectric sequence of Sandage & Johnson (1974). For some deeper plates, to flatten the saturation zone of the calibration curve, Becker’s densities

$$D = \log\left(10^{\frac{\langle T_{\rm sky}\rangle}{T_\star}} - 1\right)$$

have been used, where $T_\star$ is the transmission through the diaphragm centered on the star and $\langle T_{\rm sky}\rangle$ is the averaged transmission of the local sky background through the same diaphragm. A variety of functions have been used to obtain the best fit of the data. For each plate the standard deviations of the measurements are presented in Table 2.

We present also CCD UBV magnitudes of UIT003. The data were obtained on Oct 1, 1997 with a 1024$\times$1024 CCD Photometric camera on the 2-m Rozhen telescope. The plate scale was 0.33 arcsec/pixel, resulting in a field size of about 5.6$\times$5.6 arcmin. The night was no photometric and the seeing was poor. Fortunately there is a photoelectric standard star in the field of view (standard 1, Sandage & Johnson (1974)). We took 3 U and 3 B frames, each with an exposure time of 90 sec, and 3 V frames each with an exposure time of 60 sec. Photometry of the program frames were carried out by PSF-fitting using DAOPHOT.

3. Results

The results of our photometry are given in Table 2. The light curves of UIT003, UIT247 and the photometric behavior of two standard stars, X and 19 from the photoelectric sequence of, Sandage & Johnson (1974) showing the intrinsic variability of the observations, are presented in Fig. 1. In Fig. 2 the light curves of Variables A, B, C and 2 are shown.

In the case of UIT247 we found that it is too bright for the plate material, falls into the non-linear part of the calibration curves, and real errors are greater than those given in Table 2. In any case the light curves of the control stars show that the stability of the material and the stability of the measurements are good enough for a first look at the variability of these stars.

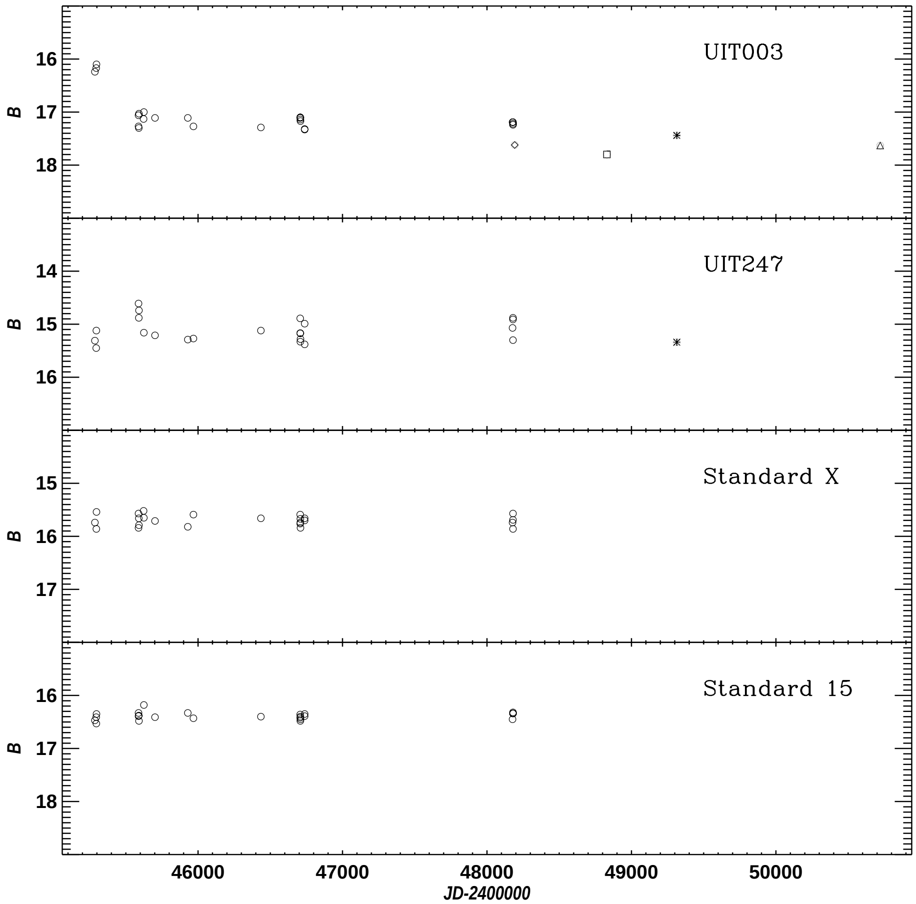

Fig. 1. Light curves of UIT003, UIT247 and photometric behavior of two standard stars, X and 19 (Sandage & Johnson 1974). The B magnitudes reported by several authors are presented also as an open diamond (Willis et al. 1992), open square (Smith et al. 1995), asterisk (Massey et al. 1996) and triangle (this work)

Table 3. Degree of variability of LBV candidates and Hubble-Sandage variables.

$\sigma_1 = 0.12$																
	UIT3	UIT8	UIT26	UIT45	UIT104	UIT154	S204	UIT212	UIT247	B517	UIT341	UIT349	VarA	VarB	VarC	Var2
σ_2	0.35	0.13	0.08	0.07	0.05	0.18	0.07	0.1	0.22	0.12	0.13	0.17	0.27	0.74	0.68	0.12
σ_2/σ_1	2.92	1.08	0.67	0.58	0.42	1.5	0.58	0.83	1.83	1	1.08	1.42	2.25	6.17	5.67	1

In order to investigate the degree of variability of each of the program stars we have used the following criterion (see Bastien et al. 1988). We compare two standard deviations, for which the variances are:

$$\sigma_1^2 = N \left[\sum_{i=1}^{N} \frac{1}{\sigma_i^2} \right]^{-1}$$

and

$$\sigma_2^2 = \left[\sum_{i=1}^{N} (B_i - \langle B \rangle)^2 \right] / \, (N-1)$$

where N is the number of plates, σ_i is a fit standard error for plate i, B_i is the magnitude of program star and $\langle B \rangle$ is the unweighted average magnitude of the same star. σ_1 gives the statistical "noise" variations, due to measurement errors, variable sky background, fitting algorithm, etc ($\sigma_1 = 0.12$). σ_2 represents the real variations + noise. We suspect variability if σ_2 is significantly larger (approx. 2–3 times) than σ_1. The ratio σ_2/σ_1 of the program stars are given in Table 3.

4. Discussion

4.1. LBV-candidates

The σ_2/σ_1 ratio shows that all program stars are constant except for UIT003 that looks like it was caught in a recovery from an outburst. This star is omitted from the list of blue stars of M 33 presented by Humphreys and Sandage (1980), where is identified as star B5 from association 132.

Spiller (1992) in his catalogue reports UIT003 (H 235) with V magnitude of 16.75. Willis et al. (1992) report the discovery of the Ofpe/WN9 spectra of this star UIT003 (MCA-1-B) and they give $V = 17.5$, $B - V = 0.12$ and $U - B = -1.16$. Measured magnitudes are corrected for slit losses. Later, Smith et al. (1995), from their spectrophotometry, estimate $V = 17.7$, $B - V = 0.1$ and $U - B = -1.1$. In their opinion UIT003

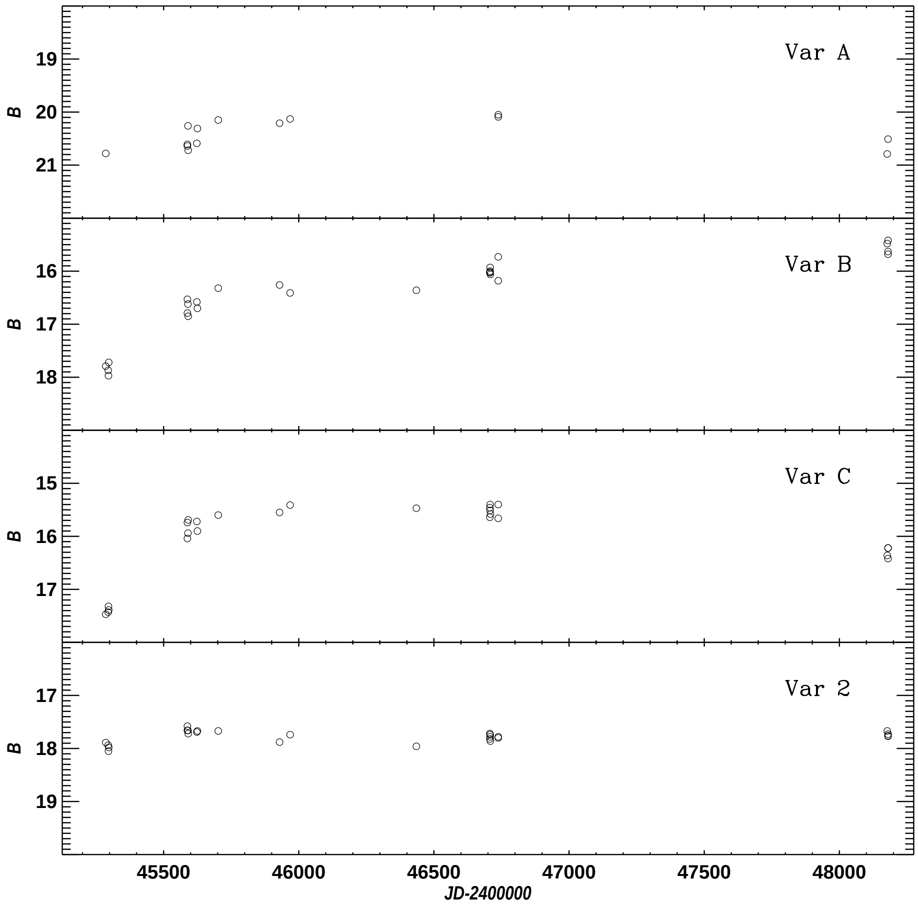

Fig. 2. Light curves of Variables A, B, C and 2.

share the same evolutionary status with R 84 (LMC). According to Crowther et al. (1995), R 84 is either a dormant LBV or at a phase immediately after this stage. Massey et al. (1996) include UIT003 in their list of Ofpe/WN9 stars and give $V = 17.43$, $B-V = 0.01$ and $U-B = -0.98$. Our last CCD observations from October 1997 show $V = 17.67$, $B - V = -0.04$ and $U - B = -1.32$.

When all these measurements are taken into account, from the light curve given here it is possible to assume that UIT003 has presented some outburst before 1983. From the beginning of 1983 until October 1997, UIT003 was in quiescent phase. Behavior of this star is very similar to that of AG Carinae and LMC-R127, two stars that established the two-way link between LBVs and Ofpe/WN9 stars (Pasquali 1997).

Humphreys and Sandage (1980) reported $V = 15.20$ and $B - V = -0.05$ for UIT247. Massey et al. (1996) gives $V = 14.93$, $B - V = 0.41$ and $U - B = -0.03$. B magnitudes are in the range of our data. Massey et al. (1996) noted also that the spectrum of UIT247 looked very similar to the LBV Var B. Monteverde et al. (1996) showed that UIT247 changed its spectroscopic appearance over the past ten years from A-type supergiant to early F-type, which is consistent with an LBV designation. Larger photometric errors for this star however, do not allow us to fix or reject its variability. Probably there is a little "jump" in brightness at JD 2 445 588. It is clear however that UIT247 has not presented any outburst during the period of our data set.

4.2. Hubble-Sandage variables

As the whole image of M 33 fits in each of our plates, we present also the photometry of the Hubble-Sandage (H-S) variables. Not all of the original H-S variables are LBVs. Variable A has a very peculiar light curve and changes in color from blue to red. Humphreys et al. (1988) have suggested that this star is actually a cool F-hypergiant which an unstable episode of mass ejection produced a much expanded photosphere with a spectrum like that of an M star. Because of its red color, Var A is faint in B and is not presented in all plates (see Table 2). During the observational period the star varied between $B = 20.1$ and $B = 20.8$.

Variable B rose slowly in brightness since the end of 1982, when its B magnitude was about 17.8. This rise is in good agreement with photographic photometry of Sharov (1990). The star continued to brighten until the end of our observational set in autumn of 1990. It will probably reach its maximum in 1992 (Szeifert et al. 1996).

Since the beginning of this century, Variable C has presented two clear maxima, in 1947 and 1985 (Sharov 1990). The bright maximum in the 1940's lasted more than 10 years. We have complete coverage of the second one (see Fig. 2). It had a continuous plateau from 1984 until 1987. Magnitude in the maximum by our observations is $B = 15.4$. It is between the maximum values given by Sharov (1990) (15.5) and Humphreys et al. (1988) (15.3). It seems that this maximum lasted at least as long as the previous one. In the photometry of Szeifert et al. (1996), from the end of 1992, Var C has B magnitude 16.3–16.4. These values are still far from the minimum value of $B = 17$.

Variable 2 presented a strong outburst around 1925 with a maximum magnitude 15.4 in B. There was a smaller maximum in 1980. During the time of this study the star was in a quiescent phase and its magnitude was approximately constant.

5. Conclusions

All the LBV candidates of M 33, except UIT003, show variations at noise level during the time covered in this work. In particular UIT247 did not present any outbursts during the time of the reported spectrum variation made by Monteverde et al. (1996).

The Hubble-Sandage variables B and C present outbursts in the observational period. Variables A and 2 were in minimum phase.

In the case of LBV candidate UIT003, we can conclude that this star presented an outburst prior to our observations, and we could observe only the recovery to the quiescent phase. This variation plus the observation of a LBV type spectrum (Of/WN in this case) make this star a new member of the LBV group of M 33.

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