Mon. Not. R. Astron. Soc. **361,** 1055–1062 (2005) doi:10.1111/j.1365-2966.2005.09261.x

Be star candidates in the Large Magellanic Cloud: the catalogue and comparison with the Small Magellanic Cloud sample

B. E. Sabogal,[1] R. E. Mennickent,[1★] G. Pietrzyński[1,2] and W. Gieren[1]

[1] *Universidad de Concepción, Departamento de Física, Casilla 160-C, Concepción, Chile*
[2] *Warsaw University Observatory, Al. Ujazdowskie 4,00-478, Warsaw, Poland*

Accepted 2005 May 24. Received 2005 May 11; in original form 2005 February 22

ABSTRACT

We present a catalogue with coordinates and photometric data of 2446 Be star candidates in the Large Magellanic Cloud (LMC), based on a search of the OGLE II data base. The *I*-band light curves of these stars show outbursts in 24 per cent of the sample (Type-1 stars), high and low states in 10 per cent, periodic variations in 6 per cent (Type-3 stars), and stochastic variations in 60 per cent of the cases. We report on the result of the statistical study of light curves of Type-1 and Type-3 stars in the LMC, and the comparison with the previously reported results of the Small Magellanic Cloud (SMC) sample. We find a statistically significant difference between amplitude, duration and asymmetry distributions of outbursts in both galaxies. Outbursts of SMC Type-1 stars are usually brighter, longer and with a slower decline. We find a bimodal distribution of periods of Type-3 stars in both galaxies, probably related to the recently discovered double periodic blue variables. We find also period and amplitude distributions of Type-3 LMC stars statistically different from those of the SMC stars. Our findings above suggest that the mechanisms causing the observed photometric variability of Type-1 and Type-3 stars could depend on metallicity. Moreover, they suggest that the outbursts are not primarily caused by stellar winds.

Key words: stars: emission-line, Be – Magellanic Clouds.

1 INTRODUCTION

Be stars are B-type stars with luminosity class III to V that show, or have shown, emission in H_α originated in a circumstellar gaseous disc. In order to understand the formation mechanisms of these discs, detailed studies of Be stars in environments with different metallicities, such as the Magellanic Clouds, have been performed in recent years (Keller, Wood & Bessell 1999; De Wit et al. 2003).

Mennickent et al. (2002, hereafter M1) presented a catalogue with a total of 1056 Be star candidates in the Small Magellanic Cloud (SMC) as a result of a rigorous inspection of the OGLE II data base (Zebrun et al. 2001). In several cases, the light curves of those stars showed variations never observed in the Galactic Be stars.

Based on the appearance of the light curves, the authors classified Be star candidates of the SMC in four types: Type-1 stars, showing outbursts; Type-2 stars, showing sudden luminosity jumps (i.e. high and low states); Type-3 stars, showing periodic or near-periodic variations; Type-4 stars, showing light curves similar to Galactic Be stars. M1 also classified those Type-1 stars with luminosity jumps in their light curves as Type-1/Type-2 stars. In particular, Type-1 stars can show either sharp outbursts with sudden rises of luminosity followed by gradual declines and durations of tens of days, or hump-like outbursts with similar rising and declining time-scales and durations of hundreds of days. Afterwards, some of the Type-3 stars were catalogued as double periodic stars, with two types of variability, one of short period and small amplitude, and another showing long-period sinusoidal oscillations (Mennickent et al. 2003b). M1 suggested that Type-4 stars could be Be stars. They also proposed that some of the Type-1 and Type-2 stars might be Be stars with accreting white dwarfs in a Be + WD binary, or they could be blue pre-main-sequence stars showing accretion disc thermal instabilities. On the other hand, M1 suggested that Type-3 stars should not be linked to the Be star phenomenon at all.

Keller et al. (2002, hereafter K1) also presented photometric properties of 1279 blue variables in the Large Magellanic Cloud (LMC), which were selected from the MACHO data base. K1 reported a variety of light-curve morphologies including bumper and flicker events, which are similar to Type-1 hump-like and Type-1 sharp outbursts, respectively. Keller et al. found that stars with flicker events have significantly lower luminosities than those with bumper events. They also reported that 91 per cent of a spectroscopic subsample (102 of the 1279 stars) exhibited Balmer emission lines in at least one epoch. They concluded that the variability observed in their sample is consistent with the establishment and maintenance of the Be phenomenon.

★E-mail: rmennick@astro-udec.cl

Mennickent, Pietrzinsky & Gieren (2003a, hereafter M2) reported on a statistical study of the light curves of Type-1, Type-2 and Type-3 stars in the SMC, including only 30 per cent of the total sample in the case of Type-1 stars. One of the results of this study was that Type-3 stars showed a bimodal period distribution, and only low-luminosity Type-3 stars show large amplitude oscillations. Another result reported by M2 was that the asymmetry, duration and amplitude distributions of Type-1 stars outbursts suggested smooth transitions between hump-like and sharp outbursts.

In this paper we present the results of a search of Be star candidates in the LMC, based on a similar inspection of the OGLE II data base to that described in M1. Then we show the comparison between the statistical analysis of the I-band photometric properties of the entire sample of Type-1 and Type-3 stars in the SMC and LMC. Our goal is to help to clarify the nature and evolutionary status of the variables and the origin of their variability.

2 THE DATA

During the course of the OGLE II project (Udalski, Kubiak & Szymanski 1997; Udalski et al. 2000), *BVI* maps for 4.5 million stars of the LMC were obtained. From these maps, we looked for stars with absolute V-band magnitudes between −6 and 0, in order to select stars with the same luminosities as the Galactic Be stars (Wegner 2000) and the extremely luminous Be stars discovered in the Magellanic Clouds by Garmany & Humphreys (1985). Assuming a distance modulus for the LMC of 18.5 ± 0.1 mag and a visual extinction of 0.3 mag (Gieren, Fouqué & Gómez 1998; Freedman et al. 2001), and the typical amplitude of the photometric variations of Be stars of 0.2 mag, we obtained apparent magnitudes between 13.0 and 19.2. We also restricted the range of colours of the selected stars to those typical of Galactic Be stars, therefore we searched for stars with $-0.4 < B\text{–}V < 0.8$ and $-0.35 < V\text{–}I < 0.8$. We then extracted and inspected the I-band light curves of the obtained sample and rejected other than Be variable stars (e.g. Cepheids, eclipsing binaries, etc.).

3 RESULTS

3.1 Catalogue of Be star candidates in the LMC

The final result of our search in the OGLE II LMC *BVI* maps was a list of 2446 stars, from which 1468 show light curves similar to the Galactic Be star light curves. The 978 remaining stars show light curves similar to those reported by M1 for the stars in the SMC. For this reason, we classified the Be star candidates of the LMC in the four types defined by M1.

For the LMC we report 581 Type-1 stars (24 per cent of the sample), 150 Type-2 stars (6 per cent of the sample), 149 Type-3 stars (6 per cent of the sample), 1468 Type-4 stars (60 per cent of the sample), and 98 Type-1/Type-2 stars (4 per cent of the sample). Tables 1–5 give the OGLE name, distance (in arcsec) to the nearest star detected with DOPHOT, V magnitude, B–V and V–I colours, and scatter of I-band magnitudes of these stars (complete tables are available in electronic form). In Figs 1 and 2 we show V versus B–V and V–I versus B–V diagrams for these 2446 stars. Reddening corrections were applied to the data of Figs 1 and 2. To achieve this step, we used the combined Milky Way and internal reddening $E(B\text{–}V) = 0.12 \pm 0.10$ mag value for the LMC derived by Dutra et al. (2001), and the average extinction law $A(I)/A(V)$ and the R_V value from Cardelli, Clayton & Mathis (1989). The location of the different kinds of stars (Type-1 to Type-4 stars) is similar to that observed in the respective diagrams for the SMC (M1). However, an important difference of these diagrams is the presence of a second clump of stars, mostly Type-4 stars, parallel to the main sequence, in the range of $B\text{–}V \approx 0.4\text{–}0.7$ mag, $V\text{–}I \approx 0.5\text{–}0.7$ mag and $V \approx 13\text{–}17$ mag, which was not observed in the same diagrams for SMC stars. Fig. 3 shows normalized V–I colour distributions for Type-4 stars of the SMC and LMC. The second structure appears only in the colour distribution for the LMC stars, indicating that it is not due to the greater number of data of the LMC. In order to have a statistical confirmation of the existence of this second group of stars in the LMC, we applied a t-test to the data. The P value of $P = 3 \times 10^{-12}$ obtained by the test was much less than the significance level of 0.05. This indicates a significant difference between the

Table 1. Photometric information for Type-1 stars (this is a sample: the complete table, in 5 parts, is available in the online version of this paper). $\Delta\Phi$ is the distance (in arcsec) to the nearest star detected with DOPHOT.

Star	$\Delta\Phi$	V	B–V	V–I	rms
OGLE04595836-6925494	0.164	15.949	0.007	0.185	0.068
OGLE05013017-6908270	0.045	16.058	−0.028	0.126	0.080
OGLE05064631-6843094	1.460	17.666	−0.043	−0.040	0.026
OGLE05064687-6842250	0.291	16.337	−0.117	−0.114	0.028
OGLE05064836-6837230	0.162	15.573	−0.015	0.145	0.052
OGLE05065094-7000527	0.119	16.110	−0.085	−0.067	0.013
OGLE05065274-6834374	0.026	15.698	−0.016	0.158	0.081
OGLE05070209-6829173	0.394	16.488	−0.094	−0.078	0.026
OGLE05070440-6842256	0.126	16.465	−0.037	0.113	0.094
OGLE05070447-6847599	4.334	18.654	0.072	0.088	0.085
OGLE05070900-7001007	0.054	16.673	−0.117	−0.032	0.031
OGLE05070987-6915153	0.062	16.306	−0.037	0.070	0.047
OGLE05013061-6838567	0.124	16.346	0.012	−0.028	0.052
OGLE05071018-6910538	0.128	16.899	−0.074	0.006	0.028
OGLE05071020-6910538	0.177	16.888	−0.069	−0.005	0.026
OGLE05071953-6845149	0.218	14.733	−0.190	−0.168	0.013
OGLE05071955-6857378	0.159	15.563	−0.072	0.001	0.071
OGLE05071986-6907387	0.439	17.185	−0.094	0.009	0.019
OGLE05072469-6912225	0.049	16.476	−0.076	0.015	0.027
OGLE05072497-6858222	0.114	16.418	0.024	0.017	0.020

Table 2. Same as Table 1 for Type-1/Type-2 stars.

Star	$\Delta\Phi$	V	B–V	V–I	rms
OGLE05021562-6907372	0.037	16.468	0.058	0.161	0.086
OGLE05071650-7004029	0.037	16.205	−0.011	0.145	0.050
OGLE05073372-6912162	0.128	15.284	−0.018	0.137	0.059
OGLE05073373-6912164	0.028	15.242	0.001	0.084	0.051
OGLE05083007-6857415	0.125	15.668	−0.052	0.050	0.056
OGLE05090874-6915415	0.060	16.948	−0.047	0.007	0.084
OGLE05103144-6858362	0.020	16.636	−0.051	0.009	0.068
OGLE05104327-6909357	0.080	14.875	−0.030	0.008	0.107
OGLE05104605-6923239	0.198	15.498	−0.119	0.106	0.076
OGLE05105470-6932144	0.083	16.317	−0.045	0.033	0.064
OGLE05110464-6911406	0.065	16.013	−0.207	−0.010	0.131
OGLE05033286-6859052	0.036	15.867	−0.133	−0.038	0.041
OGLE05110466-6909012	0.091	14.972	0.025	0.181	0.072
OGLE05113368-6852310	0.090	16.209	−0.121	−0.018	0.088
OGLE05175213-6927051	0.024	15.542	−0.042	−0.084	0.112
OGLE05185481-6936357	0.079	15.579	−0.061	0.096	0.069
OGLE05193746-6929483	0.166	17.604	−0.080	−0.084	0.061
OGLE05225686-6940259	0.177	16.683	−0.121	−0.082	0.022
OGLE05230154-6927079	0.051	15.225	−0.080	−0.145	0.205
OGLE05335372-6951457	0.052	17.013	0.015	0.165	0.164

Table 3. Same as Table 1 for Type-2 stars.

Star	$\Delta\Phi$	V	B–V	V–I	rms
OGLE05001401-6927396	0.169	15.104	0.020	0.139	0.049
OGLE05034647-6902019	0.066	15.027	−0.064	0.016	0.119
OGLE05240754-6951231	0.119	16.314	−0.122	−0.019	0.120
OGLE05241489-6947022	0.068	15.870	−0.054	0.159	0.114
OGLE05251361-6931526	0.047	16.052	−0.135	−0.084	0.141
OGLE05251547-6930430	0.268	15.497	−0.055	0.138	0.022
OGLE05252746-6946082	0.038	16.182	−0.085	0.097	0.126
OGLE05254452-6930185	0.016	15.500	−0.149	−0.136	0.043
OGLE05254643-7015259	0.130	17.417	−0.072	0.083	0.139
OGLE05260510-6946111	0.141	15.361	−0.106	−0.014	0.033
OGLE05263636-6932003	0.147	15.120	−0.098	0.038	0.044
OGLE05040655-6920141	0.078	17.499	−0.075	−0.021	0.029
OGLE05263783-6944266	0.179	15.664	−0.030	0.167	0.025
OGLE05264286-6951079	0.827	17.102	0.099	0.039	0.129
OGLE05264475-6943075	0.118	16.646	−0.047	−0.073	0.053
OGLE05265275-6928508	0.039	15.683	−0.151	−0.145	0.014
OGLE05270980-6936356	0.095	15.702	−0.167	−0.075	0.088
OGLE05272879-6958124	0.070	17.859	0.008	−0.087	0.146

colour distributions of the SMC Type-4 stars and LMC Type-4 stars. An inspection of the light curves of the second group of the LMC Type-4 stars showed that all of these stars have photometric variations with amplitudes less than 0.1 mag, and have usually ascending or descending shapes, unlike the first group of stars, whose photometric variations have different shapes and typical amplitudes of 0.2 mag. We therefore conclude that they are slowly variable stars whose nature should be established after future spectroscopic studies.

3.2 Statistical analysis of light curves

3.2.1 Type-1 star outbursts

In order to complete the statistical study reported by M2, we have studied the properties in the I-band of the entire sample of Type-1 stars of the SMC (139 stars) and the LMC (581 stars). In particular, we have measured amplitude (A), duration (ΔT) and asymmetry (δ) for each outburst in the light curves, according to the definitions given by M2 and shown in Fig. 4. The idea is to reveal whether the visual suggestion of two types of outbursts, hump-like and sharp, is consistent with the data, or, alternatively, whether there is a continuum of outburst shapes between these two prototypes.

From asymmetry distributions (Fig. 5, upper panels) we observe that only 22 per cent of the SMC sample and 21 per cent of the LMC sample have outbursts with $\delta < 1$ (slower rising than declines). The modes of the distributions occur about $\delta = 1.1$ for both galaxies. However, a bimodal behaviour is observed in the SMC asymmetry distribution. This distribution is well fitted by the superposition of two Lorentz functions (better than with only one Lorentz function), each one given by $F = (2A/\pi) * \{w/[4(x - x_c)^2 + w^2]\}$, where A is amplitude, w is half-width and x_c is the centroid of the distribution. The first concentration of stars is centred in $x_c = 1.06 \pm 0.03$ and contains 52.9 per cent of the entire sample. The second group of stars is centred in $x_c = 2.4 \pm 0.2$ and contains 47.1 per cent of the total sample. In the case of the LMC stars, we fitted a similar function to the asymmetry distribution of the LMC Type-1 stars. The first group of stars has asymmetries centred in $x_c = 1.04 \pm 0.02$ and contains 35.7 per cent of the entire sample. The second group is centred in $x_c = 1.8 \pm 0.1$ and contains 64.3 per cent of the total sample. These results could suggest a separation between the two types of outbursts, hump-like outbursts with $\delta \sim 1$ and sharp outbursts with $\delta > 1$. In addition, the second group of outbursts in the SMC has usually greater asymmetries and has a smaller concentration of outbursts than the same group in the LMC. It is important to note that the LMC asymmetry distribution can also be fitted by a single Lorentz function, although the quality of the fit is not the best.

Duration distributions (ΔT, Fig. 5, central panels) show that 87 per cent of the outbursts in the SMC and 90 per cent in the LMC last less than 200 d. The centroids of the distributions are 28.6 d for the LMC and 38 d for the SMC.

Amplitude distributions (Fig. 5, lower panels) reveal that 93 per cent of the sample in the SMC shows amplitudes less than 0.325 mag, and the same percentage in the LMC has amplitudes less than 0.28 mag. Amplitude distributions for the SMC and LMC have centroids of 0.091 and 0.082 mag, respectively.

Table 4. Same as Table 1 for Type-3 stars. Periods (in the case of double periodic variables the two periods are given) and comments are shown in columns 7 and 8. LA means low amplitude; ART means after removing trend; VA means variable amplitude; DPV means double periodic variable; MA means multiple aliases; doubtful indicates that star could be a Type-1 or Type-3 star.

Star	$\Delta\Phi$	V	B–V	V–I	rms	Period (d)	Error (d)	Notes
OGLE05005236-6858037	0.224	13.987	0.660	0.765	0.013	173	13	LA
OGLE05033872-6901217	0.538	15.929	−0.004	0.220	0.031	391	65	
OGLE05231239-6936476	0.134	15.627	−0.168	−0.147	0.053	232	18	VA ART doubtful
OGLE05233650-6939347	0.094	15.309	−0.043	0.141	0.047	33.7	0.5	ART VA
OGLE05240201-6949205	0.233	13.320	−0.178	−0.132	0.022	7.5	0.1	strange phase curve
OGLE05241647-6928518	0.499	14.123	−0.110	0.005	0.024	350	21	VA doubtful
OGLE05242597-6944522	0.237	18.813	0.361	0.488	0.098	41.5	0.8	
OGLE05245244-6927149	0.021	16.281	−0.047	0.142	0.090	29.6	0.1	ART VA LA
OGLE05250621-6944374	0.462	18.477	0.479	0.798	0.078	23.4	0.2	VA
OGLE05252306-6924062	0.264	17.474	−0.053	−0.033	0.047	3.39	0.04	eclipsing
OGLE05253845-6942341	3.299	18.439	−0.014	−0.004	0.048	443	2	
OGLE05034017-6901424	0.079	16.230	−0.057	0.062	0.089	264	45	doubtful
OGLE05260516-6954534	0.088	16.462	0.060	0.252	0.061	233–3.632	15–0.003	DPV
OGLE05262451-6949311	0.128	14.996	−0.101	0.008	0.052	22.17	0.03	ART VA LA
OGLE05265249-6933172	0.053	14.762	−0.053	0.131	0.050	30.7	0.3	ART VA doubtful
OGLE05272914-6940207	0.253	15.873	0.214	0.478	0.025	32.2	0.3	long-term oscillation LA
OGLE05274332-6950556	0.077	15.918	0.007	0.164	0.030	227–7.320	20–0.011	DPV

Table 5. Same as Table 1 for Type-4 stars.

Star	ΔΦ	*V*	*B–V*	*V–I*	rms
OGLE04595824-6929009	0.513	16.618	−0.113	−0.026	0.041
OGLE05001695-6906086	0.226	13.165	0.058	0.153	0.024
OGLE05045870-6910069	0.211	16.546	0.043	0.292	0.051
OGLE05261048-6933284	1.189	13.952	0.617	0.698	0.011
OGLE05261090-7010161	3.036	15.345	0.699	0.734	0.027
OGLE05261191-6947540	1.375	15.245	0.666	0.772	0.023
OGLE05261368-6934266	1.476	15.046	−0.058	0.031	0.014
OGLE05261517-6952086	0.149	14.508	−0.050	0.151	0.088
OGLE05261583-6946582	0.074	15.098	0.050	0.311	0.039
OGLE05261611-6952228	0.107	16.774	−0.173	−0.056	0.032
OGLE05261814-6958283	0.018	16.155	−0.149	−0.156	0.048
OGLE05261860-6927448	0.786	16.322	−0.167	−0.178	0.013
OGLE05262013-6950270	0.969	15.553	−0.068	0.061	0.014
OGLE05262020-7013251	1.373	15.454	−0.058	0.101	0.053
OGLE05262166-6954435	0.159	17.021	0.034	0.187	0.027
OGLE05262167-6923019	1.432	15.230	0.628	0.768	0.010
OGLE05262269-6927098	1.383	15.613	−0.205	−0.208	0.014
OGLE05262302-7008082	1.328	15.212	0.641	0.789	0.030
OGLE05262720-7002537	1.026	15.113	0.236	0.381	0.011

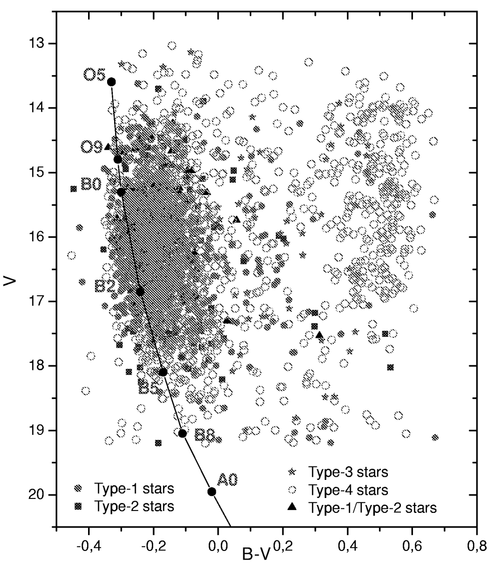

Figure 1. *V* versus *B–V* diagram for the total sample of stars of the LMC. The track of the main sequence (Allen 2000) is shown for reference.

It is important to note that duration and amplitude distributions do not show a clear separation between sharp and hump-like outbursts. We tried to fit bimodal functions to these distributions and we found that the duration distribution of the LMC outbursts and the amplitude distribution of the SMC outbursts are not well fitted by bimodal distributions. The other two distributions can be modelled by bimodal distributions but are better fitted by single Lorentz functions. We also made plots of duration and amplitude versus asymmetry, which did not show a clear separation between sharp and hump-like outbursts.

We also notice that stars showing sharp outbursts have *V* magnitudes between 14 and 17.5 mag. This indicates that these stars also have higher luminosities, and therefore a significant tendency of these stars to have lower luminosities than stars showing hump-like

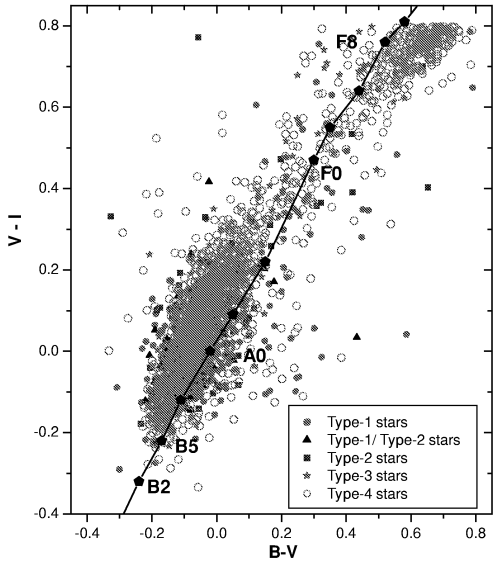

Figure 2. *V–I* versus *B–V* diagram for the entire sample of stars of the LMC. The track of the main sequence (Allen 2000) is shown for reference.

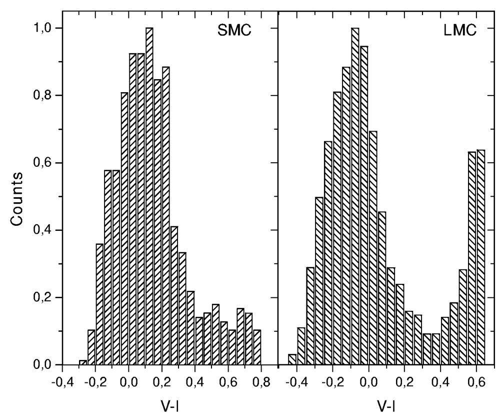

Figure 3. *V–I* distribution for Type-4 stars of the SMC (left) and LMC (right).

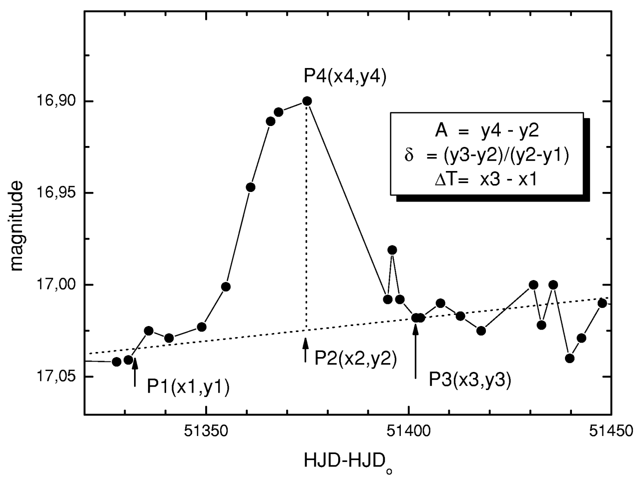

Figure 4. Definition of amplitude (A), duration (ΔT) and asymmetry (δ) for Type-1 star outbursts.

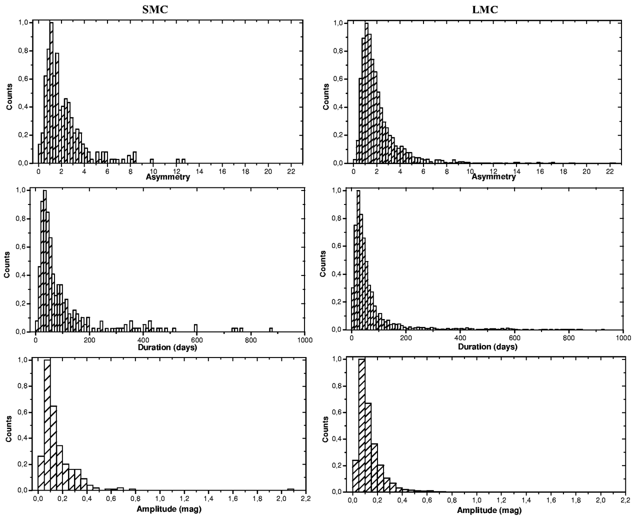

Figure 5. Normalized amplitude (A), duration (ΔT) and asymmetry (δ) distributions for Type-1 star outbursts in the SMC (left) and LMC (right).

Table 6. Results of the KS test applied to photometric distributions for Type-1 stars in the LMC and the SMC. The number of data was 3545 for the LMC and 295 for the SMC.

Parameter	Discrepancy	Significance (per cent)
Amplitude	0.09	3.11
Duration	0.19	0.00
Asymmetry	0.09	2.80

outbursts is not observed. Plots of duration, amplitude and asymmetry versus apparent magnitude do not show correlations between these parameters.

In order to determine if the photometric distributions are statistically different for both galaxies, we applied a Kolmogorov–Smirnov (KS) test to the amplitude, duration and asymmetry distributions of the outbursts of Type-1 stars. We had a total number of data (equal to the total number of outbursts in all light curves) of 3545 for the LMC and 295 for the SMC. Dividing the number of data by the number of stars, we conclude that many more outbursts occur in Type-1 stars in the LMC than in the SMC. Outburst number per star in the LMC is 2.9 times the SMC value, possibly implying that the mechanisms causing the outbursts are more efficient in the LMC than in the SMC. The results of the KS test are shown in Table 6, where the second column is the maximum absolute discrepancy between the two distributions and the third column is the probability (in percentage) that the two distributions match.

3.2.2 Type-3 Stars

Periods for Type-3 stars were obtained through several period searching algorithms similar to those used by M1. We found periodicities between 17 and 935 d.

In order to obtain the amplitudes of the oscillations, we fitted the phase curves of these stars with sine functions. Then we compared the behaviour of the light curves of Type-3 stars in the LMC with that reported by M2 for the SMC. We made this comparison by confronting the period distributions of Type-3 stars of both galaxies and comparing the tendencies showed by the amplitude distribution with luminosity and period.

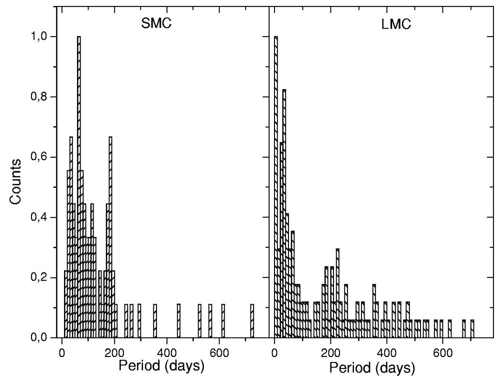

Figure 6. Normalized period distributions for Type-3 SMC stars (left) and LMC stars (right).

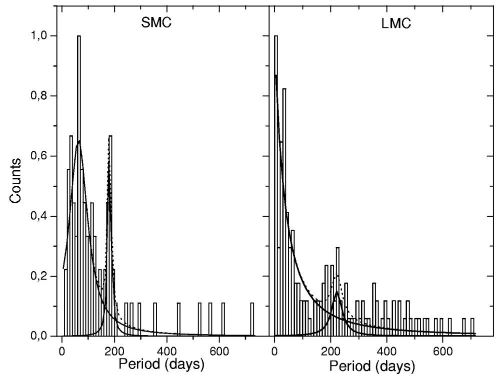

Figure 7. Normalized period distributions showing the Lorentz functions (lines) fitted for Type-3 SMC stars (left) and LMC stars (right). The dashed function is the superposition of the two Lorentz functions.

For both, LMC and SMC stars, we observe bimodal period distributions (Fig. 6), which can be modelled by the superposition of two Lorentz functions similar to that used in the case of Type-1 stars (Fig. 7). There is a first broad group of stars in the case of the SMC, that is centred on 63 d. It contains 82.4 per cent of the total sample and includes periods usually less than 147 d. The second narrow group of stars is centred on 182 d. It contains only 17.6 per cent of the sample and has periods usually between 156 and 208 d. For the LMC, the first group includes 72 per cent of the sample and usually has periods less than 100 d. The second group of stars contains 28 per cent of the sample and includes periods usually between 147 and 297 d. Modes of these distributions are 5 and 225 d, respectively. It is important to note the existence of a gap in the period distributions of Type-3 stars of both galaxies. This gap includes periods between 126 and 149 d in the case of the SMC. For the LMC, there is a lack of periods between 118 and 141 d. Another notable fact is that the deficit of stars with periods less than 150 d is larger in the LMC than in the SMC.

Double periodic blue variables (DPVs) are a small subgroup of Type-3 stars recently discovered in the Magellanic Clouds by Mennickent et al. (2003b). They apparently are close binary systems consisting of two B-type stars where the primary, more luminous component shows ellipsoidal variations (Mennickent et al. 2005). These authors pointed out that many of the Type-3 stars could be double periodic variables not well resolved photometrically. In order

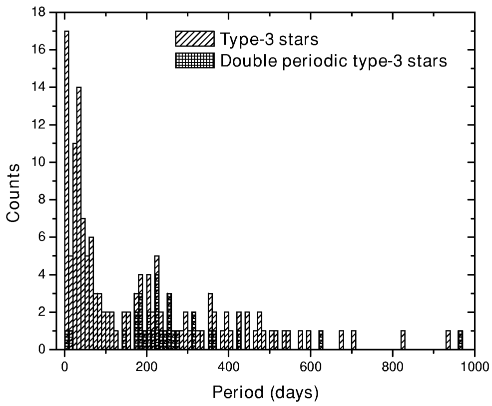

Figure 8. Normalized period distributions for Type-3 stars and double periodic Type-3 stars in the LMC.

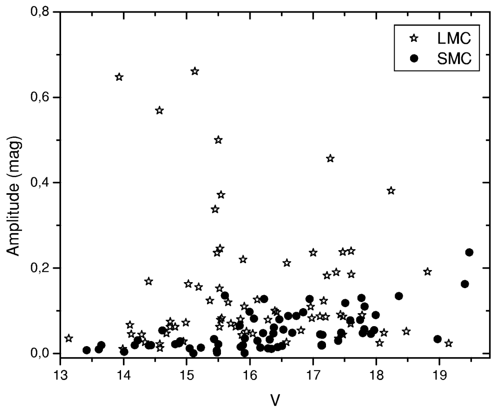

Figure 9. Amplitude–magnitude diagram for Type-3 stars in the LMC (stars) and the SMC (dots).

to check if the bimodal distribution observed in Fig. 6 reveals the subsample of DPVs, we show in Fig. 8 the superposition of the period histogram for Type-3 stars in the LMC and the position of the LMC DPVs. This figure reveals that double periodic stars significantly contribute to the second group of the bimodal distribution, suggesting that they could be causing the bimodal observed behaviour.

An important result is shown in Fig. 9. In this figure we observe that amplitudes of oscillations increase with magnitudes for SMC Type-3 stars. Instead, we observe bright and faint Type-3 stars in the LMC with both small and large amplitudes. This suggests that the properties of the light curves of Type-3 stars could have a strong dependence on metallicity.

Fig. 10 shows the amplitude–period diagram for Type-3 stars of the LMC and the SMC. There are no observed correlations between these parameters for the SMC and LMC. However, we note that only LMC Type-3 stars have very large amplitudes. The largest amplitude of a SMC Type-3 star is 0.24 mag. We found 14 Type-3 stars in the LMC with amplitudes greater than 0.24 mag.

We also applied a KS test to the amplitude and period distributions of the photometric variations of Type-3 stars. We had a total number of data of 144 for the LMC and 78 for the SMC in the case of periods, and 74 for the LMC and 62 for the SMC in the case of amplitudes. The difference between the number of periods and amplitudes is

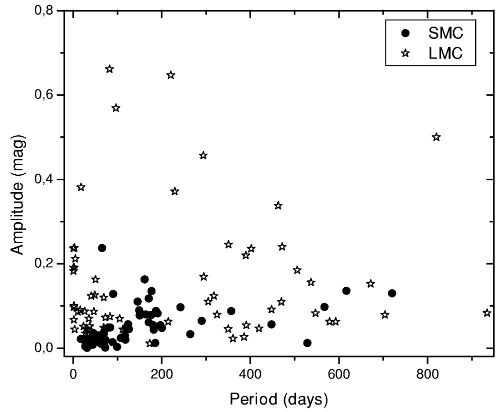

Figure 10. Amplitude–period Diagram for Type-3 stars in the LMC (stars) and the SMC (dots).

Table 7. Results of the KS test applied to photometrical parameters for Type-3 stars in the LMC and SMC.

Parameter	Discrepancy	Significance (per cent)
Amplitude	0.46	0.00
Period	0.27	0.12

due to the fact that it was not possible to fit a sine function to all phase curves to determine their amplitudes. The results are shown in Table 7, where the columns have the same parameters described for Table 6. This analysis reveals that these distributions in the LMC are statistically different from those of the SMC.

4 CONCLUSIONS

We have presented a catalogue of 2446 Be star candidates in the LMC, giving positions and photometric information. These objects show similar light curves to those found by M1 for the SMC and were consequently classified using the four types of variable stars introduced by M1.

The results of our statistical analysis show that the photometric properties of Type-1 and Type-3 stars of the LMC are very different from those of the SMC. For instance, the frequency of outbursts per star is larger in the LMC by a factor of 3, but they are, in the mean, more energetic in the SMC (longer duration and larger amplitude). On the other hand, in spite of the visual suggestion of two types of outbursts, hump-like and sharp, our analysis suggests that there is a continuum of outburst shapes, and the aforementioned types are likely the extremes of the distribution. This points to the same physical mechanism for hump-like and sharp outbursts. On the other hand, the period distribution for Type-3 stars is clearly bimodal in both galaxies. We suggest that this bimodal distribution could indicate the merging of two different stellar populations. The recently discovered double periodic variables mostly fill the longer period branch of the distribution. The nature of the stars filling the shorter period branch is at present unknown. Tables 8 and 9 summarize the principal results of our statistical comparison between LMC and SMC subsamples of Be star candidates.

Our findings for Type-1 stars could have implications on the model proposed for outbursts. If these stars correspond to Be stars as

Table 8. Summary of the results of the statistical analysis of Type-1 star outbursts in the LMC and the SMC. The range of durations is defined to include 90 per cent of the outbursts.

	LMC	SMC
Asymmetry	Bimodal distribution	Bimodal distribution
Centroid of distribution (first group)	1.04	1.06
Centroid of distribution (second group)	1.8	2.4
Percentage of the total sample (first group)	36 per cent	53 per cent
Percentage of the total sample (second group)	64 per cent	47 per cent
Centroid of duration distribution	29 d	38 d
Range of durations	0–100 d	0–125 d
Centroid of amplitude distribution	0.081 mag	0.091 mag

Table 9. Summary of the results of the statistical analysis of oscillations of Type-3 stars in the LMC and the SMC. The range of periods is defined to include 90 per cent of the objects.

	LMC	SMC
Period	Bimodal distribution	Bimodal distribution
Centroid of distribution (first group)	5 d	63 d
Centroid of distribution (second group)	222 d	182 d
Percentage of the total sample (first group)	72 per cent	82 per cent
Percentage of the total sample (second group)	28 per cent	18 per cent
Range of periods (first group)	0–330 d	0–190 d
Range of periods (second group)	150–310 d	155–225 d
Interval of lack of periods	118–141 d	126–149 d

suggested by Keller et al. (2002), then the competing mechanisms are mass loss through stellar winds, rapid rotation or non-radial pulsations, or a combination of these. These mechanisms are usually invoked for disc formation and outbursts in Be stars (see Porter & Rivinius 2003, for a review of the Be star phenomenon). In this context, it is interesting that recent work suggests that rapid rotation (and eventually rotationally induced mass loss) is favoured in low metallicity environments. Keller (2004) find that the B-type stars of the LMC are more rapid rotators than their Galactic counterparts. On the contrary, mass loss through stellar winds increases with metallicity, because the driving force is applied on a larger number of ions (Vink, de Koter & Lamers 2001; Aerts, Lamers & Molenberghs 2004). On the other hand, non-radial pulsation alone is probably not enough to account for mass ejections in Be-star photospheres, and it should be combined with fast rotation or other mechanisms to produce observable mass ejections in the form of outbursts. It is a matter of research to establish if Be stars rotate faster in the Magellanic Clouds than in our galaxy, but with this very basic ideas in mind we conjecture that our findings should favour in principle the role of rotation, probably combined with non-radial pulsations (the connection between mass-loss episodes and non-radial pulsations has been established for μ Cen by Rivinius et al. 1998), in the triggering of outbursts, rather than stellar winds. The fact that the outbursts are more pronounced in the low metallicity stars of the SMC probably indicates a reduced contribution of stellar winds to the process triggering the outbursts.

ACKNOWLEDGMENTS

We acknowledge the referee, Dr Mike Bessell, for his valuable comments on a first version of this manuscript. BS acknowledges support of MECESUP UCO0209. REM acknowledges support by Fondecyt grant 1030707. WG, GP and REM acknowledge financial support for this work from the Chilean Centre for Astrophysics FONDAP 15010003

REFERENCES

Aerts C., Lamers H. J. G. L. M., Molenberghs G., 2004, A&A, 418, 639
Allen C. W., 2000, in Cox A., ed., Allen's Astrophysical Quantities, 4th edn. Springer-Verlag, New York
Cardelli J. A., Clayton G. C., Mathis J. S., 1989, ApJ, 345, 245
De Wit W. J., Beaulieu J. P., Lamers H. J. G. L. M., Lesquoy E., Marquette J. B., 2003, A&A, 410, 199
Dutra C. M., Bica E., Clariá J. J., Piatti A. E., Ahumada A. V., 2001, A&A, 371, 895
Freedman W. J. et al., 2001, ApJ, 553, 47
Garmany C. D., Humphreys R. M., 1985, AJ, 90, 2009
Gieren W., Fouqué L., Gómez M., 1998, ApJ, 496, 17
Keller S. C., 2004, PASA, 21, 310
Keller S. C., Wood P. R., Bessell M. S., 1999, A&AS, 134, 489
Keller S. C., Bessell M. S., Cook K. H., Geha M., Syphers D., 2002, AJ, 124, 2039 (K1)
Mennickent R. E., Pietrzinsky G., Gieren W., Szewczyk O., 2002, A&A, 393, 887 (M1)
Mennickent R. E., Pietrzinsky G., Gieren W., 2003a, in Sterken C., ed., ASP Conf. Ser. Vol. 292, Interplay of Periodic, Cyclic and Stochastic Variability in Selected Areas of the H–R Diagram. Astron. Soc. Pac., San Francisco, p. 89 (M2)
Mennickent R. E., Pietrzinsky G., Díaz M., Gieren W., 2003b, A&A, 399, L47
Mennickent R. E., Cidale L., Diaz, M., Pietrzinsky G., Gieren W., Sabogal B., 2005, MNRAS, 357, 1219
Porter J. M., Rivinius T., 2003, PASP, 115, 1153
Rivinius T., Baade D., Stefl S., Stahl O., Wolf B., Kaufer A., 1998, in Kaper L., Fullerton A. W., eds, Proc. ESO Workshop, Cyclical Variability in Stellar Winds. Springer-Verlag, Berlin, p. 207
Udalski A., Kubiak M., Szymanski M., 1997, Acta Astron., 47, 319
Udalski A., Szymanski M., Kubiak M., Pietrzynski G., Soszynski I., Wozniak P., Zebrun K., 2000, Acta Astron., 50, 307
Vink J. S., de Koter A., Lamers H. J. G. L. M., 2001, A&A, 369, 574
Wegner W., 2000, MNRAS, 319, 771
Zebrun K. et al., 2001, Acta Astron., 51, 317

SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online:

Table 1, Part 1. Photometric information for Type-1 stars. $\Delta\Phi$ is the distance (in arcsec) to the nearest star detected with DOPHOT. Column 1 is the OGLE name of the star, column 2 is the distance (in arcsec) to the nearest star detected with DOPHOT, column 3 is the V-magnitude, column 4 and 5 are $B - V$ and $V - I$ colours, and column 6 is the scatter of I-band magnitude.

Table 1, Part 2. Photometric information for Type-1/Type-2 stars. Column 1 is the OGLE name of the star, column 2 is the distance (in arcsec) to the nearest star detected with DOPHOT, column 3 is the V-magnitude, column 4 and 5 are $B - V$ and $V - I$ colours, and column 6 is the scatter of I-band magnitude.

Table 1, Part 3. Photometric information for Type-2 stars. Column 1 is the OGLE name of the star, column 2 is the distance (in arcsec) to the nearest star detected with DOPHOT, column 3 is the V-magnitude, column 4 and 5 are $B - V$ and $V - I$ colours, and column 6 is the scatter of I-band magnitude.

Table 1, Part 4. Photometric information for Type-3 stars. Column 1 is the OGLE name of the star, column 2 is the distance (in arcsec) to the nearest star detected with DOPHOT, column 3 is the V-magnitude, column 4 and 5 are $B - V$ and $V - I$ colours, and column 6 is the scatter of I-band magnitude. Periods and errors (in the case of double periodic variables the two periods are given) are shown in columns 7 and 8. Column 9 shows some notes. LA means low amplitude; ART means after removing trend; VA means variable amplitude; DPV means double periodic variable; MA means multiple aliases; doubtful means that star could be a Type-1 or Type-3 star.

Table 1, Part 5. Photometric information for Type-4 stars. Column 1 is the OGLE name of the star, column 2 is the distance (in arcsec) to the nearest star detected with DOPHOT, column 3 is the V-magnitude, column 4 and 5 are $B - V$ and $V - I$ colours, and column 6 is the scatter of I-band magnitude.

This paper has been typeset from a TEX/LATEX file prepared by the author.