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Study of candidate Be stars in the Magellanic Clouds using near-infrared photometry and optical spectroscopy

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ABSTRACT

Mennickent et al. and Sabogal et al. identified a large number of classical Be (CBe) candidates (∼3500) in the Large and Small Magellanic Clouds (LMC and SMC) based on their photometric variability using the OGLE II data base. They classified these stars into four different groups based on the appearance of their variability. In order to refine and understand the nature of this large number of stars, we studied the infrared properties of the sample and the spectroscopic properties of a subsample. We cross-correlated the optical sample with the IRSF-MCPS catalogue to obtain the J, H, K_s magnitudes of all the four types of stars (∼2500) in the LMC and SMC. Spectra of 120 stars belonging to the types 1, 2 and 3 were analysed to study their spectral properties. Among the four types, the type 4 stars are the dominant group, with ∼60 and ∼65 per cent of the total sample in the LMC and SMC, respectively. The near-infrared (NIR) colour–colour diagrams suggest that the type 4 stars in the LMC have a subclass, which is not found in our Galaxy or in the SMC. This subclass is ∼18 per cent of the type 4 sample. The main type 4 sample which is ∼49 per cent of the total sample has NIR properties similar to the Galactic CBe stars and the SMC type 4 stars. Though the new subclass of type 4 stars have high $E(B-V) \sim 0.75$, they are not located close to regions with high reddening. The type 3 stars (∼6 per cent and 7.3 per cent in the LMC and SMC) are found to have large Hα equivalent width (EW) in the SMC and some are found to have large NIR excess. This small fraction of stars are unlikely to be CBe stars. Three stars among the type 3 stars in the LMC are found to be double periodic variables. The type 2 stars are found in larger fraction in the SMC (∼14.5 per cent), when compared to the LMC (∼6 per cent). The spectroscopic and the NIR properties suggest that these could be CBe stars. The type 1 stars are relatively more in the LMC (∼24 per cent) when compared to the SMC (∼13 per cent). The SMC type 1 stars have relatively large Hα EW and this class has properties similar to CBe stars. The spectroscopic sample of type 1 stars which show Hα in emission and are confirmed as CBe stars are more abundant in the SMC by a factor of 2.6. If the effect of metallicity is to cause more CBe stars in the SMC, when compared to the LMC, then type 1, type 2 and type 4 stars follow this rule, with an enhancement of 2.6, 2.4 and 1.3, respectively.

Key words: techniques: spectroscopic – circumstellar matter – stars: emission-line, Be – Magellanic Clouds.

1 INTRODUCTION

Be stars are B-type stars with luminosity class III–V that show or have shown emission in Balmer lines such as Hα, which originate in a circumstellar disc. They occupy a region on or near the main sequence in the Hertzsprung–Russell (HR) diagram, implying that

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they are still burning hydrogen in their core. These stars are rapid rotators and show both photometric and spectroscopic variability. Detailed studies of Be stars in environments with different metallicities, such as the Magellanic Clouds (MCs), have been performed in the recent past (Keller, Wood & Bessell 1999; Mennickent et al. 2002; de Wit et al. 2003; Sabogal et al. 2005; Martayan, Baade & Fabregat 2010).

Mennickent et al. (2002) presented a catalogue of 1056 Be star candidates in the Small Magellanic Cloud (SMC) by studying light-curve variations using the OGLE II data base (Udalski et al. 1998, 2000). They classified these Be star candidates of the SMC in four categories: type 1 stars showing outbursts (139 stars); type 2 stars showing sudden luminosity jumps (154 stars); type 3 stars showing periodic or near-periodic variations (78 stars); type 4 stars showing light curves similar to Galactic Be stars (658 stars). They also classified type 1 stars with luminosity jumps in their light curves as type 1/type 2 stars (18 stars). They suggested that type 4 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. Spectroscopy is needed to confirm the suggestion that some of these stars are Be stars. Also, more studies, especially in the near-infrared (NIR) are required to confirm the pre-main-sequence hypothesis. On the other hand, they suggested that type 3 stars should not be linked to the Be star phenomenon at all.

Based on a similar inspection of OGLE II data, Sabogal et al. (2005) classified Be candidates in the Large Magellanic Cloud (LMC) also as type 1 (581 stars), type 2 (150 stars), type 3 (149 stars), type 4 (1468 stars) and type 1/type 2 (98 stars). However, many of the type 4 stars in the LMC are found to be reddened and located parallel to the main sequence; this feature was not found in the same diagrams of the SMC. The photometric properties of type 1 and type 3 stars on the LMC are very different from those of the SMC. Thus, the various types of stars identified based on variability seem to differ between the LMC and the SMC.

The above studies identified a large number of candidate Be stars which can be used to derive the parameters that are responsible for the Be-phenomenon as these types of stars in the MCs are metal poor when compared to the Galactic Be stars. The above classification was based only on photometric variability. It is desirable to get some more properties such as their NIR magnitudes and colours to understand these stars. The aim of this paper is to study the NIR properties of various types of Be star candidates in the LMC and SMC by cross-matching IRSF (NIR) and OGLE II (optical) catalogues. We also present results from a spectroscopic study of 70 stars from types 1, 2 and 3 in the SMC and 49 stars belonging to type 1 and type 3 in the LMC. The spectral features are used to identify their spectral class and to see whether they show some properties of Be stars. The paper is arranged as follows. Details of the NIR photometric data as well as the spectroscopic data are presented in Section 2. The results of the cross-correlation between the optical and NIR properties as well as the spectral classification are presented in Sections 3 and 4. The results are presented in Section 5. A discussion and conclusions are presented in Sections 6 and 7, respectively.

2 PHOTOMETRIC DATA AND SPECTROSCOPIC OBSERVATIONS

Catalogues of Be star candidates in the SMC and the LMC as identified by Mennickent et al. (2002) (∼1000 stars) and Sabogal et al. (2005) (2446 stars), respectively, were used. In order to obtain their NIR properties, we used the NIR IRSF catalogue (Kato et al. 2007; http://pasj.asj.or.jp/v59/n3/590315) which has JHK_s photometric data for about 15 million point sources spread over a 40 deg^2 area of the LMC and 2.7 million sources spread over a 11 deg^2 area of the SMC. The 10σ limiting magnitudes of the above catalogue are 18.8, 17.8 and 16.6 mag at J, H and K_s, respectively. This catalogue has better spatial resolution than the Two Micron All Sky Survey (2MASS) catalogue. The optically identified stars were cross-matched with the NIR IRSF catalogue to confirm candidature in the IRSF. Matches between both catalogues were found by comparing the right ascension and declination co-ordinates in both the catalogues. We considered the closest candidates as NIR counterpart, with an upper limit of $0\overset{\circ}{.}001$ (3.6 arcsec) for separation. We could cross-identify the NIR counterpart of 1640 stars among the 2348 candidate Be stars in the LMC (excluding the type 1/2 candidates) and 839 stars from the sample of 1029 stars in the SMC. Hence the cross-identification is 70 per cent successful in the LMC and 80 per cent in the SMC. Due to crowding we could not cross-identify the rest of the stars. These stars were used to study the NIR properties of the various types.

Optical spectra were obtained for 120 candidate stars in the LMC and the SMC. Spectroscopic observations were conducted at the Cerro Tololo Inter-American Observatory (CTIO) and the Las Campanas Observatory (LCO) during four nights of 2002 October and four nights of 2003 November, respectively. At the CTIO we used the 1.5-m telescope with the Cassegrain Spectrograph and the Loral 1-K detector. The spectrograph details are available at the web page http://www.ctio.noao.edu/spectrographs/60spec/60spec.html. We obtained 57 blue spectra with the grating no. 26 tilted at $16\overset{\circ}{.}2$ and a slit width of 1.5 arcsec, yielding a wavelength range of 3700−5500 Å. Fifty-two red spectra were obtained with grating no. 36 tilted at $28\overset{\circ}{.}7$, resulting in a wavelength range of 5700−7000 Å. In both cases the resolution was about 3.7 Å. The spectra were reduced with standard IRAF routines, such as apall and doslit, including bad pixel rejection, spectroscopic flat fielding, 1D extraction and wavelength calibration. The typical error in the wavelength calibration is 5 km s^{-1} in Hα.

In addition, 48 spectra were obtained at LCO with the Modular Spectrograph and the SiTe2 detector. Technical details for this spectrograph can be found at the web page of the LCO observatory.[1] The combination of grating no. 600 blazed at 5000 Å with a slit width of 1.5 arcsec yielded a spectral range of 3870–6100 Å, and a resolution of 2.5 Å. The log of observations is given in Tables A1 and A2. The spectra were reduced and wavelength calibrated using the standard IRAF tasks. The typical error in the wavelength calibration is 12 km s^{-1} in Hβ. These spectra were used to identify the spectral lines, determine spectral types and measure equivalent width (EW).

3 ANALYSIS OF NIR COLOURS

We cross-correlated 1640 stars (70 per cent) identified by Sabogal et al. (2005) with the IRSF data in the LMC. Among these, 399 are type 1 stars, 92 are type 2 stars, 91 are type 3 stars and 989 stars are type 4 stars. The SMC sample contains 839 stars, of which 89 are type 1 stars, 131 are type 2 stars, 65 are type 3 stars and 554 are type 4 stars.

[1] http://www.lco.cl

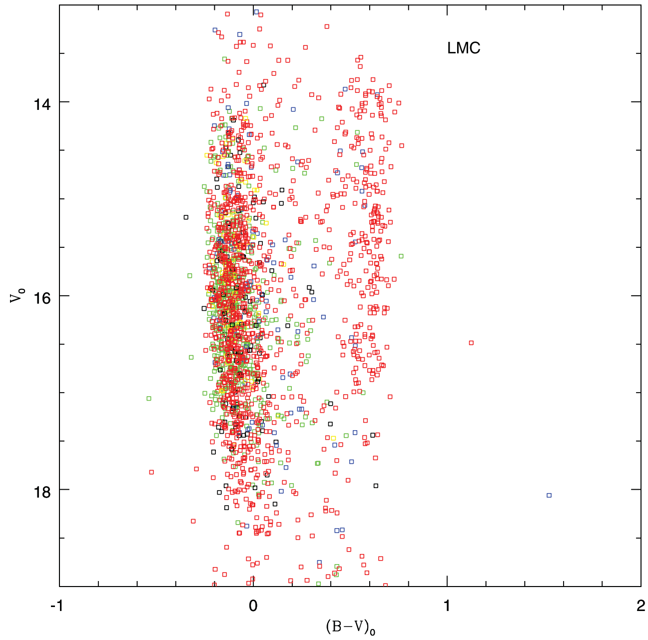

Figure 1. V_0 versus $(B-V)_0$ diagram of the total sample (type 1 in green colour, type 2 in black, type 3 in blue and type 4 in red) of the cross-correlated stars in the LMC.

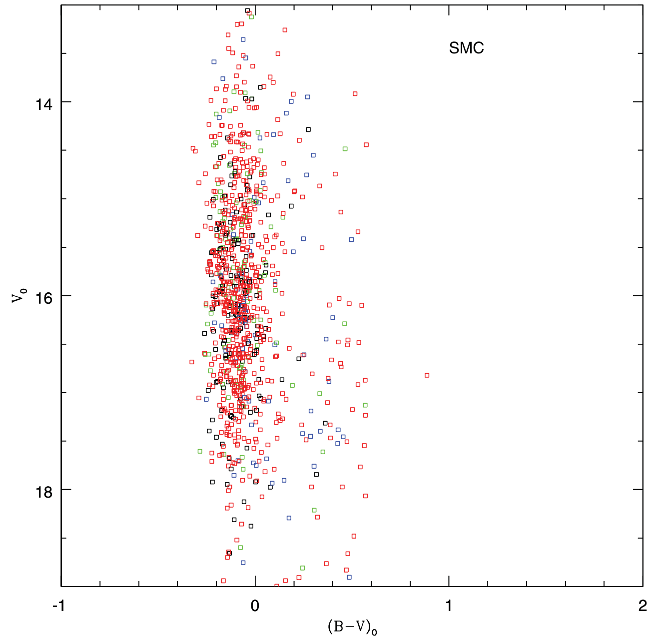

Figure 2. V_0 versus $(B-V)_0$ diagram of the total sample (type 1 in green colour, type 2 in black, type 3 in blue and type 4 in red) of the cross-correlated stars in the SMC.

Adopting an average value of $E(B-V) = 0.1$ and $R = A_V/E(B-V) = 3.1$, on the basis of previously published values, colour–magnitude diagrams (CMDs) with $(B-V)_0$ versus V_0 were plotted. Figs 1 and 2 show V_0 versus $(B-V)_0$ CMDs for the cross-matched stars (type 1 to type 4 shown in different colours) for the LMC and the SMC, respectively. These figures show the location of all the types in the CMD, which indicates that the cross-identified stars span the full range of loci similar to the optically identified sample [in comparison with the figures given in Sabogal et al. (2005) and Mennickent et al. (2002)]. We note the red sequence of type 4 stars located parallel to the main sequence in the range of $(B-V) = 0.4$–0.7 mag, in Fig. 1 (LMC), which is absent in Fig. 2 (SMC). This feature was noted by Sabogal et al. (2005). This shows that the cross-correlated sample contains these peculiar stars also. In order to quantify and thus verify whether we have evenly sampled all the types in both the galaxies, we estimated the fractions of various types.

The fractions of the four types of stars in the original sample and in the cross-correlated sample are given in Table 1. The first column indicates the types, followed by the number of stars identified in the optical and then the cross-correlated sample for both the galaxies. The last two columns give the ratio of stars in the two galaxies (ratio = LMC/SMC). The fractions of optically identified type 1 to type 4 stars are similar to the fraction in the cross-correlated sample. This suggests that the cross-identification has sampled all the types similarly and this subset can be used to study the properties of various types in the NIR. Later in the discussion we will use this table to compare the relative populations of the four types in the LMC and SMC. We compared the magnitude distribution of stars identified in the NIR with the original optical sample, in order to estimate how much stars are missed due to the limiting magnitude of the NIR photometry. Since the SMC is more distant compared to the LMC, there is a possibility that relatively more fainter stars are missed out in the SMC. We compared the distribution in both the galaxies and we find that the number of stars missed in the fainter limit is similar in both the galaxies. Hence the NIR+optical sample discussed here is not biased to brighter stars in the SMC.

We estimated the dereddened $(J-H)_0$ and $(H-K)_0$ values of the cross-matched sources (1640 stars in the LMC and 839 stars in the SMC) using the IRSF data. We assumed an average reddening of $E(B-V) = 0.1$ mag, which is basically the median of reddening estimated by Indu & Subramaniam (2011) using the bright main-sequence stars. Although the bar region of the LMC does not show large reddening, some of the individual stars could show reddening different from the above value. Since we do not derive any quantities for various types, the above assumption is justified. Reddening corrections were made using the following formulae (Bessell & Brett 1988) by taking $E(B-V) = 0.1$ mag:

$$(J-H)_0 = (J-H) - E(J-H)$$

$$(H-K)_0 = (H-K) - E(H-K)$$

$$E(J-H) = 0.37 \times E(B-V)$$

$$E(H-K) = 0.19 \times E(B-V).$$

Colour–colour diagrams (CCDm), were plotted with $(H-K)_0$ versus $(J-H)_0$ for all the types (type 1, 2, 3 and 4) of stars. Figs 3 and 4 show CCDm for the LMC and the SMC, respectively, for all types. In order to identify the location of the stars we overplotted the main sequence, the reddening vectors and the region of T Tauri stars. The location of T Tauri stars is shown as the dashed straight line (Meyer, Calvet & Hillenbrand 1997). The location of Be stars is taken from Dougherty et al. (1994) and the location of Herbig Ae/Be stars is taken from Hernández et al. (2005).

The figure for the LMC (Fig. 3) shows that most of the stars are populated near $(J-H)_0 \sim 0.0$, with a small range in $(H-K)_0$, in a more or less horizontal band. We do also notice that some stars occupy a location above this band, on the main sequence (MS), giving rise to a clumpy appearance. The stars in this clump are

Table 1. Number of various types of stars identified in the optical and infrared in the LMC and the SMC. Relative fractions of various types are indicated in the parentheses. Columns 6 and 7 represent the ratio of various types of stars in the LMC to the SMC.

	LMC		SMC		LMC/SMC	
Type	Optical	Optical + IR	Optical	Optical + IR	Optical	Optical + IR
1	581(0.24)	399(0.24)	139(0.13)	89(0.10)	4.17	4.48
2	150(0.06)	92(0.056)	154(0.15)	131(0.156)	0.97	0.7
3	149(0.06)	91(0.055)	78(0.07)	65(0.077)	1.9	1.4
4	1468(0.60)	989(0.60)	685(0.65)	554(0.66)	2.14	1.76
1/2	98(0.04)	69(0.042)	–	–	–	–
Total	2446	1640	1056	839	2.3	1.95

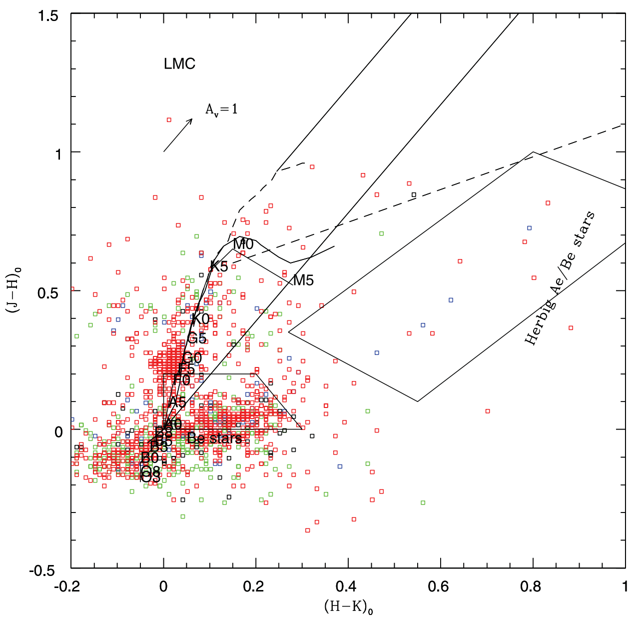

Figure 3. NIR colour–colour diagram of the Be candidates in the LMC (same colour code as in Fig. 1). The location of the MS and the T Tauri stars and reddening vectors are also shown. The reddening vector indicates $A_v = 1$.

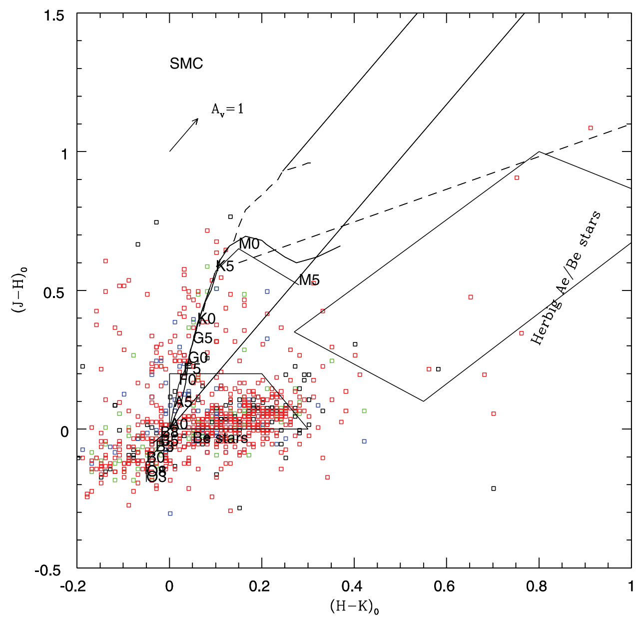

Figure 4. NIR colour–colour diagram of the Be candidates in the SMC (same colour code as in Fig. 1), rest same as Fig. 3.

mostly type 4 stars. Apart from these two prominent features, some stars are found to be scattered in the diagram. The SMC figure (Fig. 4) also shows the horizontal band like distribution, but the clumpy population is not found in the SMC. Some amount of scatter is also noted similar to the LMC. Thus, the NIR analysis suggests a different subpopulation among the type 4 stars in the LMC, which is not found in the SMC. We shall explore these stars further in the next section. We identify some sources with large NIR excess in the LMC, belonging to type 3 and type 4. The SMC has fewer sources with NIR excess. The distributions of the four types of stars along the NIR colours, $(J-H)_0$ and $(H-K)_0$, are shown for the LMC and SMC in Fig. 5. We compare the four types between the two galaxies using these histograms. The histograms not only show the distribution, but also compare the relative number of stars in various types in the two galaxies. We discuss the properties of various types and compare them between the LMC and the SMC in the following sections.

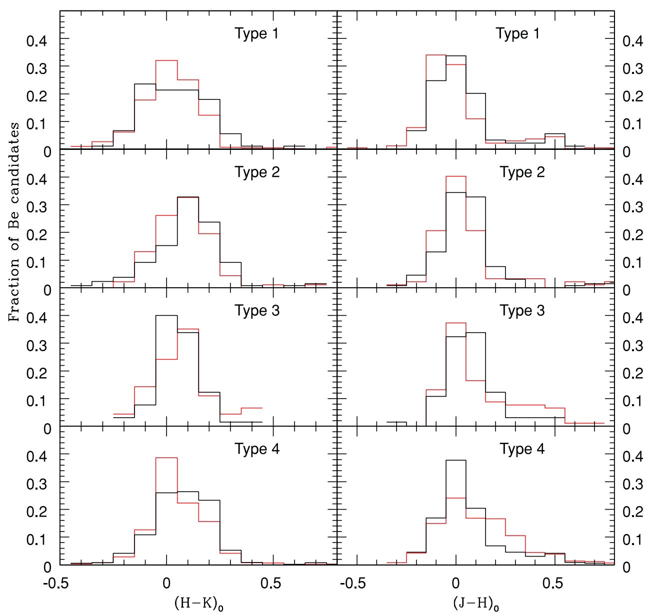

Figure 5. Histograms of $(H-K)_0$ and $(J-H)_0$ colours of 1640 Be candidates in the LMC (shown in red) and 839 Be candidates in the SMC (shown in black) divided into various types (type1 to type 4).

4 SPECTROSCOPIC ANALYSIS

Our spectroscopic sample contains 44 spectra in the SMC (17 type 1, 12 type 2 and 15 type 3) and 13 spectra in the LMC (one type 1, 12 type 3) in the blue region, and 42 spectra in the SMC (15 type 1, eight type 2 and 19 type 3) and 20 spectra in the LMC (eight type 1, three type 2 and nine type 3) in the red region. The reason for studying spectroscopically only type 1, type 2 and type 3, omitting type 4 stars at this stage, was that the type 4 stars were very likely Be stars. On the other hand, due to their atypical photometric variability, the nature of type 1, type 2 and type 3 stars was not so obvious. A preliminary study of spectra of type 4 stars in the SMC obtained with the ESO UVES spectrograph was presented in Sabogal, García-Varela & Mennickent (2011), where the spectra showed Hα lines in emission. The detailed paper (Sabogal et al., in preparation) based on the UVES spectra of type 4 LMC/SMC Be stars is in preparation. These two studies suggest that the type 4 stars are likely to be classical Be (CBe) stars.

The EW of the spectral lines were estimated using routines in IRAF. For spectroscopic classification, we compared the spectra of the Be candidate stars with those of the standard stars from Jacoby, Hunter & Christian (1984) in the interval 3700–7000 Å. The classification was done by comparing the intensity of H I and He I absorption lines of the candidate star in the 3800−4500 Å region with the library spectra. The lines used for classification are H I 3835, 3970, 4101, 4340 Å and He I 4026, 4121, 4143, 4388, 4471 Å. It is known that the spectral lines will be affected by emission components. Hence we have preferred the blue end of the spectrum which is least affected by contamination. Our idea was to derive a broad picture about the spectral type rather than being accurate about the subclass. The derived spectral types are listed in Tables 2–7. We are only able to estimate a range of spectral type. The luminosity classification is less accurate such that we could not classify them as V or III. For B type stars, we estimated the spectral types from the EW of the He I lines assuming that our sample is composed of dwarf stars. For most of the spectroscopic sample Hα is detected in emission. In the case of type 3 stars in the SMC, Mennickent et al. (2006) have classified these stars using spectra of better resolution and we have shown both the classifications. It can be seen that in most of the cases, the spectral types are very similar and this validates our method of classification. We have estimated radial velocity for most of the stars with spectra. The estimated radial velocities were corrected for heliocentric velocities. These estimated velocities are also tabulated in Tables 2–7 (except Table 5), along with the error in the velocity and the number of lines used for estimation. Wherever any previous measurement is available, they are also compared and discussed. These radial velocity measurements can be used to trace whether they are variables, which could point to their binary nature.

For stars with spectra, $(J-H)$ and $(H-K)$ colours were dereddened using the $E(B-V)$ values estimated based on their locations in the LMC and the SMC. The reddenings towards these stars were taken from a reddening map estimated using the main-sequence stars (Indu & Subramaniam 2011, map-B, fig. 3). These authors estimated an average reddening map for stars located near the turn-off stars in that region. This reddening map is ideal for early type stars located on the MS. Since it is known that the reddening in the LMC depends on the tracer used, a reddening map appropriate for the population studied is used.

5 RESULTS

Our results of the NIR analysis and the spectral analysis are presented for the four types of stars. We do not have spectra for type 4 stars, and hence the results and conclusions for this class are based only on the NIR and optical photometric properties.

5.1 Type 4 stars

The type 4 stars are found to be the largest among the sample in both the Clouds. Their fractions are 60 and 65 per cent in the LMC and the SMC, respectively, suggesting that the fractions are similar in these two galaxies. Thus more than half of the total sample fall in this group, making it the single most important type among the four types studied. Mennickent et al. (2002) suggested that the type 4 stars are likely to be CBe stars, since they show rather irregular photometric variation similar to the Galactic counterparts. Therefore, in order to confirm the above, we compared the NIR properties of the Galactic Be stars along with the LMC and the SMC type 4 stars. We used data of the Galactic Be star candidates from Mathew, Subramaniam & Bhatt (2008). The NIR photometric magnitudes for all these candidate stars are taken from the 2MASS data base. The $(J-H)$ and $(H-K)$ colours obtained were transformed to the Koornneef (1983) system using the transformation equations by Carpenter (2001). The colours were dereddened. The $(J-H)_0$ and $(H-K)_0$ colours obtained for the Galactic Be stars were overplotted in the CCDm of the LMC and the SMC type 4 stars (Fig. 6). It can be seen that the Galactic Be stars occupy the region which coincides with a horizontal band. Thus, the type 4 stars which are located in this region are similar to the Galactic Be stars, with respect to their NIR colours. A clumpy distribution of type 4 stars located above the band like distribution is found in the LMC. This group does not have any counterpart in our Galaxy, or in the SMC. The histograms shown in Fig. 5 suggest that more type 4 stars in the LMC have redder $(J-H)_0$ colours, compared to the SMC, and this is due to the population which appears as a clump in the NIR CCDm. The distribution along $(H-K)_0$ colour suggests that the LMC type 4 has a bluer component within the range observed and this component is the contribution from the new subgroup which appears as a clump. The colour ranges populated by the type 4 stars are similar in both the galaxies. Thus, we can summarize that type 4 stars in the LMC fall in two groups, one with NIR properties similar to those of the Galactic Be stars, and a new subclass with different NIR properties. This new subgroup does not have any NIR excess. Their location in the NIR diagram suggests that these may be A–F type stars located on the MS, or highly reddened OB stars. The type 4 stars in the SMC have NIR properties similar to the Galactic Be stars. Bonanos et al. (2010) identified a similar red sequence among Be stars in the SMC, derived from a very different sample. They found these stars to be redder than the MS stars by about 0.7 mag. It is not clear whether these stars are similar to those we have identified in the LMC.

It will be interesting to find the location of stars in the new subgroup in the optical CMD. Fig. 7 shows the V_0 versus $(B-V)_0$ CMD of type 4 stars which appear as a clump in the NIR CCDm. These stars occupy the reddened parallel sequence in the optical CMD. Among the 1468 type 4 stars, about 265 stars (∼18 per cent) show this property. In the cross-correlated sample, we find that among the 989 stars, 216 stars (21.8 per cent) appear as a separate group. Thus the cross-correlated sample also has a similar fraction of the new subgroup. In the LMC, nearly 22 per cent of the type 4 stars appear as a separate group and hence only 47 per cent of the cross-correlated sample are type 4 stars having properties similar to Galactic Be stars. On the other hand, the SMC has about 65 per cent of the cross-correlated type 4 stars which are similar to Galactic Be stars. The fraction of type 4 stars, similar to the Galactic Be stars, is relatively more abundant in the SMC. The enhancement is found to be 1.3 times in the SMC, with respect to the LMC, as estimated from the optically identified sample. Since

Table 2. Type 3 stars in the SMC present in our sample along with optical and infrared magnitude and colours. Spectral type determined in this study is given in column 7 and spectral type determined by Mennickent & Smith (2010) for the star smc3-1 and Mennickent et al. (2006) for the rest of the stars is given in column 8. Our determination of radial velocity and the radial velocity determined by Mennickent et al. (2006) are also given. N is the number of lines averaged for radial velocity determination.

Star	OGLE name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	Sp. type (this study)	Sp. class Mennickent et al. (2006)	$E(B-V)$	$v \pm \sigma_v$ (this study)	N	$v \pm \sigma_v$ Mennickent et al. (2006)	N
	Spectra from 1.5-m CTIO											
smc3-1	OGLE004336.91−732637.7	−0.19	13.04	0.13	0.02	A3-A5	A+B	0.37	117 ± 32	6	114 ± 31	15
smc3-2	OGLE004454.66−730802.9	−0.16	13.44	−0.01	0.15	B8-A1	B7-9IIIe	0.44	130 ± 36	7	137 ± 26	7
smc3-3	OGLE004554.14−731404.3	0.39	15.09	0.04	0.25	A7-F0	F0Ib-II	0.13	164 ± 37	5	174 ± 23	7
smc3-5	OGLE004750.14−731316.4	0.07	14.85	0.05	0.06	B8	B7-8III	0.20	167 ± 69	6	139 ± 5	7
smc3-6	OGLE004921.41−725844.9	0.20	14.23	0.06	0.16	A7-F0	A5 II	0.12	199 ± 30	8	191 ± 23	13
smc3-7	OGLE005025.64−725807.1	0.17	13.63	0.01	0.19	A7-F0	F4IV	0.12	150 ± 29	7	127 ± 15	10
smc3-8	OGLE005043.44−732705.3	−0.24	13.51	0.13	0.04	–	WR	0.05	192 ± 58	3	179 ± 26	4
smc3-9	OGLE005100.18−725303.9	−0.15	13.23	0.12	0.53	B5-B8	B1II-IIIe	0.12	170 ± 77	4	172 ± 32	12
smc3-12	OGLE005359.22−723508.9	−0.25	13.27	−0.01	0.04		A3III	0.36	66 ± 23	7	54 ± 17	12
smc3-15	OGLE005745.25−723532.1	−0.27	13.43	−0.05	−0.09	B2-B5	B1II-III	0.13	220 ± 23	7	195 ± 37	22
smc3-18	OGLE010000.78−725522.9	−0.32	13.10	0.02	−0.11		B8-9IIIe	0.37	240 ± 24	6	222 ± 32	14
smc3-20	OGLE010451.21−724646.9	−0.09	13.29	0.15	0.08	B5-B8	B1Ib-IIe	0.04	172 ± 9	8	179 ± 32	16
smc3-21	OGLE010452.99−715918.8	−0.21	14.09	0.09	0.04	B2-B5	B2IIIe	0.04	132 ± 33	5	143 ± 24	15
smc3-14	OGLE005520.27−723710.1	0.77	12.75			A0-A3	A0Ibe	0.61	122 ± 37	5	141 ± 16	2
smc3-16	OGLE005812.58−723048.5	−0.42	14.62			B8-A0	B0IIIe	0.20	166 ± 40	4	164 ± 24	4
	Spectra from 2.5-m LCO											
smc3-30	OGLE005710.71−722550.2	0.17	15.48	0.09	0.17			0.04				
smc3-31	OGLE005617.49−730005.1	−0.55	14.44	0.00	−0.12			0.53				
smc3-32	OGLE004652.17−731409.2	−0.27	15.36	0.20	0.01			0.20				
smc3-33	OGLE005059.66−725648.3	−0.13	15.22	0.15	0.03			0.12				
smc3-35	OGLE005217.74−725627.9	−0.11	16.15	0.13	0.03			0.04				

Table 3. Type 3 stars in the LMC present in our sample along with our determinations for spectral type, magnitude, colour and radial velocity. *N* is the number of lines averaged for radial velocity determination.

Star	OGLE name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	Sp. type	$E(B-V)$	$v \pm \sigma_v$	N
	Spectra obtained from 1.5-m CTIO								
lmc3-1	OGLE05005236−685803.7	0.61	13.84	0.05	0.31	F9	0.05	149 ± 2	2
lmc3-5	OGLE05030370−690615.0	0.10	13.75	0.03	0.07	A9-F0	0.13	193 ± 33	8
lmc3-20	OGLE05141821−691235.0	0.42	14.43	0.59	0.43	F6	0.04	226 ± 20	5
lmc3-23	OGLE05164754−694415.2	0.47	14.74	0.10	0.35	F3	0.12	264 ± 33	7
lmc3-24	OGLE05174442−692033.3	−0.09	12.75	−0.03	−0.01	B8-A1	0.12	301 ± 13	10
lmc3-30	OGLE05194782−693912.3	0.21	13.05	0.05	0.07	F6	0.29	166 ± 43	4
lmc3-33	OGLE05203226−694224.2	0.14	13.61	0.04	0.09	F6	0.44	262 ± 20	6
lmc3-37	OGLE05225847−692621.0	0.17	13.91	0.02	0.23	F6	0.28	250 ± 99	4
lmc3-39	OGLE05240201−694920.5	−0.78	11.45	−0.03	0.24	B2-B3	0.60	245 ± 22	8
lmc3-44	OGLE05265249−693317.2	−0.10	14.62	0.15	0.08	–	0.05	–	–
lmc3-12	OGLE05084863−684315.6	−0.22	14.31			A6	0.21	192 ± 21	9
lmc3-49	OGLE05293898−693448.0	−0.78	14.30			B2-B3	0.60	266 ± 22	9

Table 4. Type 2 stars in the SMC present in our sample along with our determinations for spectral type, magnitude, colour and radial velocity. *N* is the number of lines averaged for radial velocity determination.

Star	OGLE name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	Sp. type	$E(B-V)$	$v \pm \sigma_v$	N
	Spectra obtained from 1.5-m CTIO								
smc2-4	OGLE004721.86−730650.1	−0.31	13.15	0.16	0.04	B0-B2	0.28	188 ± 11	4
smc2-6	OGLE004848.83−730620.1	−0.08	14.25	0.22	0.12	B0-B2	0.04	160 ± 15	2
smc2-8	OGLE004849.49−724800.0	−0.15	14.79	0.15	0.09	B0-B2	0.04	187 ± 26	5
smc2-12	OGLE005224.40−724038.6	−0.04	13.90	0.12	0.08	B0-B2	0.04	115 ± 24	6
smc2-14	OGLE005251.97−723508.5	−0.20	14.50	0.16	0.09	B0-B3	0.04	218 ± 32	5
smc2-19	OGLE005614.45−724053.2	0.17	13.96	0.03	0.16	A5-A7	0.13	131 ± 16	8
smc2-23	OGLE005806.05−723544.5	−0.21	14.21	0.18	0.07	B0-B3	0.20	192 ± 18	5
smc2-27	OGLE010025.10−724632.2	−0.15	14.57	−0.11	−0.10	B0-B2	0.04	205 ± 19	5
smc2-9	OGLE004938.01−730610.0	−0.17	14.30			B0-B3	0.04	149 ± 20	3
smc2-20	OGLE005618.51−722645.2	−0.40	13.77			A0-A3	0.45	108 ± 35	7
smc2-29	OGLE010401.11−723311.1	−0.06	12.98			B0-B3	0.04	167 ± 25	8
smc2-32	OGLE010447.25−722559.4	−0.08	14.65			B0-B2	0.04	85 ± 37	6
	Spectra obtained from 2.5-m LCO								
smc2-38	OGLE004236.69−733033.1	−0.27	15.60	0.09	0.04		0.12		
smc2-39	OGLE004304.50−730206.3	−0.34	14.92	0.13	0.02		0.37		
smc2-40	OGLE004327.71−731653.9	−0.42	15.26	0.27	−0.05		0.37		
smc2-45	OGLE004521.57−731717.7	−0.55	14.53	−0.19	−0.26		0.44		

Table 5. Type 2 stars in the LMC present in our sample along with our determinations of magnitude and colours.

Star	OGLE name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	$E(B-V)$
	Spectra obtained from 2.5-m LCO					
lmc2-1	OGLE050017.58−692749.9	−0.11	14.71	–	0.59	0.13
lmc2-2	OGLE050039.16−692003.9	−0.16	15.02	−0.02	–	0.13
lmc2-3	OGLE050053.02−692011.5	−0.15	13.84	−0.02	–	0.13
lmc2-4	OGLE050103.77−691746.7	−0.15	14.50	0.14	0.65	0.13
lmc2-5	OGLE050116.74−692027.7	−0.25	14.66	0.08	0.46	0.13
lmc2-6	OGLE050306.60−691807.5	−0.13	14.89	−0.02	–	0.13
lmc2-7	OGLE050340.10−691530.9	−0.13	13.96	–	0.30	0.13
lmc2-8	OGLE050350.56−690223.0	−0.19	14.63	0.15	0.57	0.13
lmc2-9	OGLE050412.28−685021.7	−0.18	14.99	−0.02	–	0.13

Table 6. Type 1 stars in the SMC present in our sample along with our determinations for spectral type, magnitude, colour and radial velocity. N is the number of lines averaged for radial velocity determination.

Star	OGLE name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	Sp. type	$E(B-V)$	$v \pm \sigma_v$	N
	Spectra obtained from 1.5-m CTIO								
smc1-7	OGLE005059.21−724357.3	−0.06	14.67	0.19	0.34	B0-B2	0.04	205 ± 2	2
smc1-10	OGLE005224.40−724038.6	−0.04	13.90	0.12	0.09	B0-B3	0.04	149 ± 30	6
smc1-11	OGLE005227.51−732001.2	−0.28	12.30	−0.03	−0.09	B0-B2	0.28	200 ± 13	8
smc1-17	OGLE005504.55−724637.3	−0.31	13.53	−0.09	−0.12	B0-B3	0.20	163 ± 24	5
smc1-18	OGLE005614.63−723755.1	−0.08	14.18	0.19	0.07	B0-B3	0.13	247 ± 38	5
smc1-19	OGLE005641.86−724425.4	−0.24	14.33	0.44	0.09	B0-B3	0.13	167 ± 28	6
smc1-21	OGLE005916.06−722100.3	−0.24	13.88	0.22	0.07	B0-B3	0.20	223 ± 51	3
smc1-26	OGLE010058.69−723049.9	−0.13	13.82	0.17	0.11	B0-B3	0.04	158 ± 23	7
smc1-28	OGLE010213.80−722213.0	−0.01	14.24	0.21	0.11	B0-B3	0.04	176 ± 18	3
smc1-31	OGLE010542.57−722747.3	0.09	14.91	0.18	0.15	B0-B3	−0.04	170 ± 28	5
smc1-36	OGLE010807.38−721932.6	−0.23	14.04	0.19	0.54	B0-B2	0.05	179 ± 24	9
smc1-37	OGLE010809.52−721556.8	−0.23	14.34	0.07	0.02	B0-B3	0.05	167 ± 32	7
smc1-38	OGLE010825.82−722327.2	−0.08	13.82	0.27	0.13	B0-B3	0.05	228 ± 10	2
smc1-2	OGLE003918.20−733656.6	0.20	13.66			F0	0.29	200 ± 16	5
smc1-23	OGLE010041.93−723028.6	−0.63	14.59			B0-B2	0.45	238 ± 35	7
smc1-24	OGLE010043.94−722604.8	−0.64	14.37			B0-B3	0.45	188 ± 14	5
smc1-39	OGLE005235.60−723751.7	–	–			B0-B2	–	188 ± 19	5
	Spectra obtained from 2.5-m LCO								
smc1-40	OGLE003631.42−733917.8	−0.36	15.76	−0.02	−0.05		0.13		
smc1-44	OGLE004225.27−731718.2	−0.52	14.83	−0.07	−0.16		0.37		
smc1-47	OGLE004626.57−731929.3	−0.13	15.22	−0.09	−0.03		0.20		
smc1-50	OGLE004701.71−731041.9	−0.39	14.64	−0.09	−0.14		0.28		
smc1-52	OGLE004801.80−731057.0	−0.32	14.84	−0.08	−0.10		0.28		
smc1-53	OGLE004803.29−730722.2	−0.27	16.22	0.19	0.07		0.04		
smc1-56	OGLE004916.20−724941.2	−0.05	15.34	−0.12	−0.03		0.12		
smc1-57	OGLE004930.81−731236.5	−0.16	15.39	−0.04	−0.04		0.12		
smc1-59	OGLE004958.39−725750.8	−0.08	15.49	0.18	0.08		0.12		
smc1-60	OGLE005018.69−725524.3	0.00	15.62	0.29	0.17		0.12		

Table 7. Type 1 stars in the LMC present in our sample along with our determinations for magnitude, colour and radial velocity. N is the number of lines averaged for radial velocity determination.

Star	OGLE-name	$(B-V)_0$	V_0	$(H-K)_0$	$(J-H)_0$	$E(B-V)$	$v \pm \sigma_v$	N
	Spectra obtained from 1.5-m CTIO							
lmc1-55	OGLE051747.85−690908.6	−0.23	13.31	0.11	0.13	0.36	287 ± 38	7
	Spectra obtained from 2.5-m LCO							
lmc1-1	OGLE050122.35−690004.9	−0.10	15.07	–	0.80	0.05		
lmc1-2	OGLE050131.42−684251.0	0.32	14.09	0.07	0.18	0.05	107 ± 22	3
lmc1-3	OGLE050132.69−692845.8	−0.25	14.67	0.05	−0.09	0.13	263 ± 31	2
lmc1-4	OGLE050147.90−692424.1	0.43	13.99	0.02	0.22	0.13		
lmc1-5	OGLE050151.04−692109.6	0.11	13.94	0.04	0.08	0.13	117 ± 38	2
lmc1-6	OGLE050158.32−684315.5	0.29	15.34	0.09	0.52	0.05		
lmc1-7	OGLE050221.24−690451.6	−0.21	14.38	−0.04	−0.04	0.13	203 ± 32	2
lmc1-9	OGLE050127.92−685947.7	0.42	14.31	0.03	0.23	0.13		
lmc1-10	OGLE050234.22−683939.8	−0.05	14.14	−0.02	–	0.13		
lmc1-11	OGLE050320.42−685315.7	−0.35	14.25	0.18	0.19	0.28	254 ± 28	2
lmc1-12	OGLE050438.96−691624.6	−0.26	13.61	0.16	0.36	0.13	242 ± 2	2
lmc1-13	OGLE050426.31−690714.4	−0.32	14.29	–	−0.21	0.36		
lmc1-15	OGLE050447.46−690552.3	−0.15	14.24	−0.07	–	0.36		
lmc1-114	OGLE050151.61−690152.8	−0.36	15.68	0.21	0.05	0.37		
lmc1-115	OGLE050428.01−690927.5	−0.03	15.85	−0.07	–	0.36		
lmc1-116	OGLE050521.34−691550.1	−0.35	14.48	−0.07	–	0.36		
lmc1-117	OGLE053319.88−701213.1	−0.01	16.39	0.07	0.02	0.05		

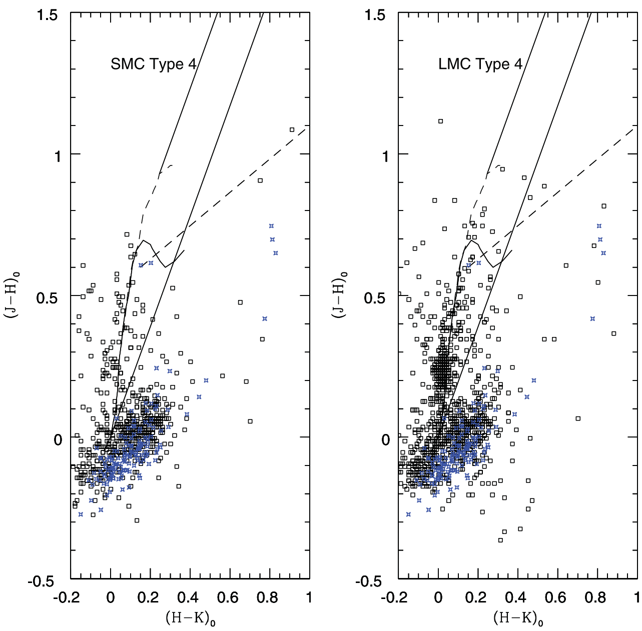

Figure 6. NIR CCDm of the type 4 Be candidates in the SMC and the LMC. The Galactic Be stars are shown as blue points.

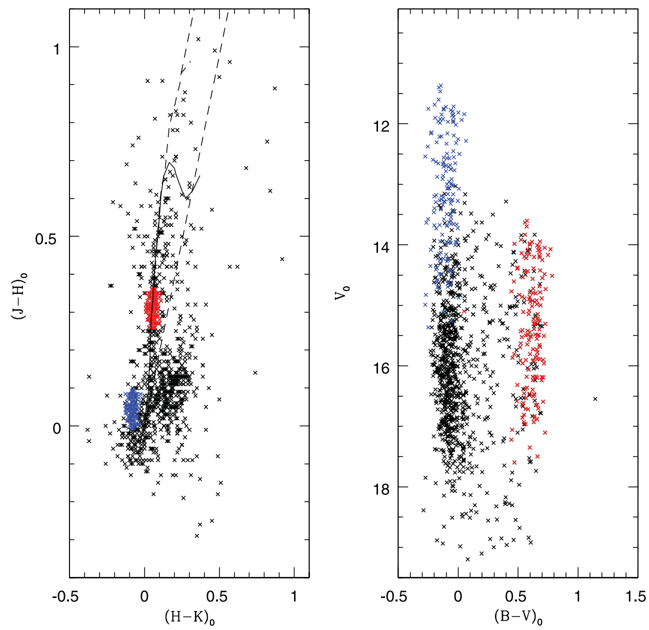

Figure 8. CMD and CCDm showing all types of stars. The type 4 stars in reddened parallel sequence are shown in red colour along with all other types (shown in black colour). If the type 4 stars forming the parallel sequence are dereddened, they will occupy the position shown with blue points.

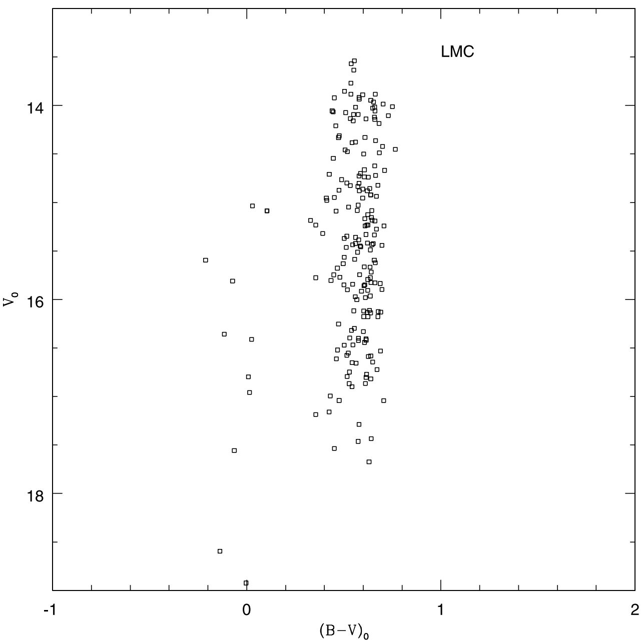

Figure 7. The V_0 versus $(B-V)_0$ CMD of type 4 stars which appear as a clump in the NIR CCDm.

the Be phenomenon is enhanced in the low metallicity environment of the SMC, when compared to the LMC or our Galaxy as found by Martayan et al. (2006, 2007), the larger fraction of type 4 stars found in the SMC falls in line with the above argument.

It will be interesting to decipher the nature of the new subgroup. One possibility is that this new group of stars could be highly reddened OB stars. We checked whether the reddening in the optical CMD required to create the parallel sequence is consistent with the reddening required in the NIR to create the clump like distribution. We estimated that the parallel sequence has a reddening of $E(B-V) \sim 0.75$ mag more than the MS counterparts. This corresponds to $E(J-H) \sim 0.266$ and $E(H-K) \sim 0.137$ mag. A plot showing the unreddened parallel sequence in the optical and NIR is shown in Fig. 8, assuming the above reddening values. It can be seen that the estimated reddening in the optical bands more or less fits the NIR reddening also, since the unreddened sequence falls almost along the horizontal sequence of likely Be stars. In the optical CMD, after correcting for the extinction, the parallel sequence is found to occupy the brighter part of the MS. This as well as the unreddened location in the NIR diagram suggests that these stars could be more massive than the normal type 4 stars. We estimated the average reddening of the location in which these stars are located by comparing their locations in the extinction map estimated by Harris & Zaritsky (2004) which provides reddening to individual stars. Fig. 9 shows the histogram of $A_{\rm v}$ around the reddened type 4 stars. The average value we obtained is around 0.5 mag, suggesting that the $E(B-V)$ around these stars is less than 0.2 mag. The reddening required to make these stars fall back on the MS is 0.75 mag. For the $E(B-V)$ to be 0.75, $A_{\rm v}$ should be more than 2.0, and the locations do not have such large extinction. Thus these stars are not likely to be associated with regions of high reddening. On the other hand, these stars could be individually highly reddened due to large mass loss, in which case it is highly unlikely that all the stars should have the same high reddening, instead of a range in reddening. In either case, these stars are highly interesting and might turn out to be a new class of objects. Thus, it is necessary to obtain spectra of normal and the new group of type 4 stars to understand their nature.

5.2 Type 3 stars

This class of stars is one of the most poorly populated classes among the four classes identified. They are classified as showing periodic or quasi-periodic photometric variations. The fractions of stars identified are 6 per cent in the LMC (149 out of 2446) and 7.3 per cent in the SMC (78 out of 1056). Our cross-identified sample

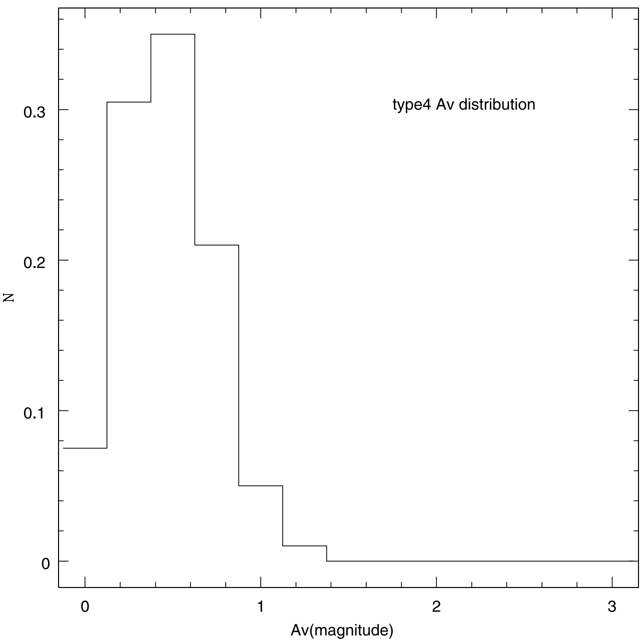

Figure 9. Histogram showing extinction $A_{\rm V}$ around the reddened type 4 stars.

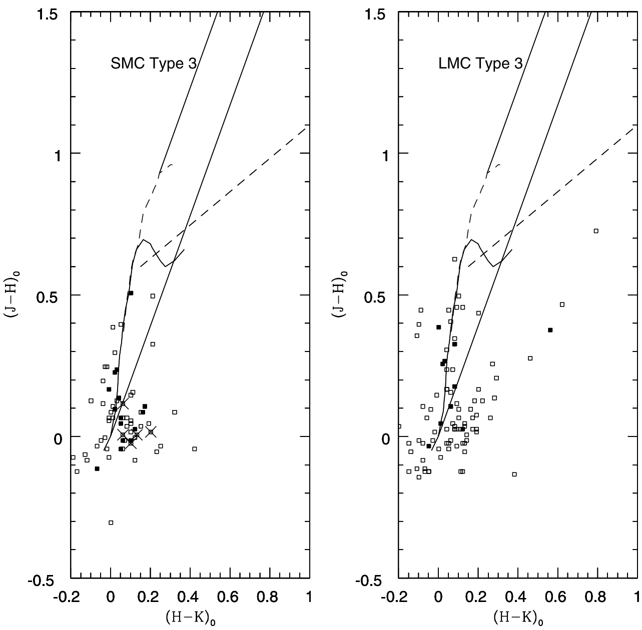

Figure 10. NIR CCDm of the type 3 stars in the SMC and the LMC. Shaded points represent the stars with spectra from the 1.5-m CTIO and points shown with crosses represent stars with spectra from the 2.5-m LCO.

has 5.5 per cent in the LMC and 7.7 per cent in the SMC. This type of stars is found similarly populated in the LMC and SMC as indicated by the above fractions. The optical CMDs (Figs 1 and 2) show that these stars occupy a similar location in the CMD and hence they are likely to have similar evolutionary status in both the Clouds. The NIR CCDm for the type 3 stars in the LMC and the SMC are shown in Fig. 10. In the NIR diagram, the type 3 stars are not located as a homogeneous group. Some stars can be found in the Be location and some stars are found along the MS. They are more scattered in the LMC, when compared to the SMC. Some stars in the LMC also show large NIR excess. The histograms in Fig. 5 show that the type 3 stars occupy a larger range of $(J-H)_0$ in the LMC. This is due to the presence of a few stars located close to the the MS in the NIR CCDm. The distribution in $(H-K)_0$ suggests that the LMC stars have a larger range of $(H-K)_0$ values when compared to the SMC sample. The contribution comes from the blue stars located in the Be location as well as the stars with large NIR excess. The fact that they are not found in a coherent location may support the conclusion drawn by Mennickent et al. (2002, 2006) that these stars should not be linked to the Be phenomenon at all. Sabogal et al. (2005) found that type 3 stars have bimodal period distribution and that double periodic variables (DPVs) are a small subgroup of type 3 stars. Mennickent et al. (2006) studied some long period variables in the SMC and some of these are type 3 stars. They suggested that the type 3 stars are a mix of different kinds of stars. Their sample did not have any Herbig Ae/Be type stars, but has a number of binaries. Mennickent & Smith (2010) studied one of the type 3 stars from the above sample using high resolution spectra and suggested that this star (smc3-1) could be a prototype of a small group of MC wind-interacting A + B binaries. Mennickent & Smith (2010) studied the photometric variability of smc3-1 and found a primary period of 238.1 d along with a complicated waveform suggesting ellipsoidal variability influenced by an eccentric orbit. This star also shows a secondary variability with an unstable periodicity that has a mean value of 15.3 d. Mennickent & Smith (2010) suggested that this could be associated with non-radial pulsations.

We have spectra of type 3 candidates in both the LMC and the SMC. Spectra of 20 type 3 stars in the SMC were obtained; the details of these stars are tabulated in Table 2. We have also tabulated the spectral type estimation of Mennickent et al. (2006) and Mennickent & Smith (2010) (for smc3-1) as their spectra are of better resolution. We have tabulated the OGLE II number, optical magnitudes and NIR colours, reddening and radial velocity estimates by us and also by Mennickent et al. (2006) in Table 2.

We analysed 15 spectra (blue) of type 3 stars in the SMC. The spectral line details of these stars are tabulated in Table 8. Balmer lines Hγ, Hδ, Hξ are present as absorption lines. In a few cases, Hβ is found in absorption. In eight cases, Hβ is seen in emission. Lines of hydrogen (H13, H12, H10, H9 and H8) are also present in absorption. He I lines (4026, 4471 Å) are present in a few cases. We have 12 spectra in the red region. The Hα line is present in emission with varying EW in all the spectra except in three cases where we can see emission in the absorption line. The Hα EW ranges between −82 and +10 Å, where the positive EW might suggest a filled in absorption. Among these stars, smc3-1 has the highest Hα EW of −82 Å, followed by smc3-20 and smc3-8, with Hα EW of −37 and −33 Å, respectively. These stars are also found to have large values of $(H-K)_0$ as seen from Table 2. The star smc3-1 is found to be an interacting binary with a circumbinary disc. It can be seen that the Hα EW somewhat correlates with the $(H-K)_0$ magnitude. If we assume the large $(H-K)_0$ values indicate NIR excess, then the above correlation might suggest the presence of circumstellar dust for these stars. The reddening estimated towards these stars has a range between $E(B-V) = 0.04$ and 0.61 mag. The reddening values do not correlate with either the $(H-K)_0$ values or the Hα EW. The large reddening values observed in some stars might suggest association or proximity to star forming regions. The radial velocity estimates are comparable to those estimated by Mennickent et al. (2006), suggesting that we do not detect any significant radial velocity variation. The star smc3-12 shows low radial velocity in both the measurements and hence is likely to be a member of the Galactic halo.

Table 8. List of spectral lines observed in the sample of Be candidate stars in the SMC [type 1, 2 and 3 as defined by Mennickent et al. (2006)] considered in the present study along with their EWs in Å. '#' indicates that there are no spectra available for these stars in the red region. '##' indicates that there are no spectra available for these stars in the blue region. 'ea' indicates emission in absorption line in Hα. Numbers in the brackets indicate the number of spectra in the red region for that particular star.

Star	Ca II	Hε	He I	Hδ	Hγ	He I	He I	Hβ	Hα	Comment
smc1-2	8.27	6.97	–	2.34	2.84	–	–	–	–	
smc1-7	–	–	1.16	1.01	–	–	0.34	−4.57	−32.83	
smc1-10	0.67	1.64	0.62	1.67	2.27	0.88	0.69	–	−8.23	
smc1-11	0.70	2.71	0.63	1.65	1.83	0.57	0.72	1.8		#
smc1-16									−8.95	##
smc1-17	0.30	2.28	0.65	1.27	1.85	0.43	0.29	–		#
smc1-18	–	0.90	0.7	1.17	–	–	ea	−2.91	−30.66	
smc1-19	–	1.92	0.58	1.22	–	–	0.4	–		#
smc1-21	0.50	2.77	0.87	1.91	1.89	0.46	0.73	1.85	−31.28	
smc1-23	0.89	2.89	0.9	2.49	2.36	0.27	1.13	2.153		#
smc1-24	0.48	1.9	0.63	1.21	1.27	–	0.28	–		#
smc1-25									−24.28	## (4)
smc1-26	–	1.50	0.82	0.90	–	0.34	0.45	−2.23	−16.64	
smc1-28	–	2.09	0.63	0.842	–	0.55	0.38	−2.91	−23.42	
smc1-31	0.70	1.85	0.81	1.24	–	–	–	−3.70		#
smc1-36	–	3.12	0.94	2.18	2.58	0.58	0.82	2.24	−0.94	
smc1-37	0.31	2.25	0.82	1.95	1.60	–	0.49	−1.40	−12.56	
smc1-38	–	–	0.40	–	−1.03	–	–	−4.27	−31.74	
smc1-39	0.48	3.92	1.10	2.20	2.36	0.51	0.40	0.19	−8.96	
smc2-4	0.44	1.34	0.50	1.41	–	–	0.34	−3.53	−33.84	
smc2-6	–	1.26	–	–	–	–	–	−2.86	−21.08	
smc2-8	0.74	3.15	1.4	2.07	1.9	–	0.87	–	ea	
smc2-9	–	–	0.86	1.14	1.85	–	0.46	–	−13.87	
smc2-12	0.30	2.50	0.4	1.76	1.71	0.32	ea	ea		#
smc2-14	0.58	1.45	0.50	–	–	0.32	0.85	−2.59	−17.91	
smc2-19	3.98	7.96	–	4.87	5.97	–	–	4.79		#
smc2-20	1.32	7.05	0.09	6.10	6.88	–	0.08	6.32		#
smc2-23	–	2.06	0.72	1.47	1.93	0.33	085	0.93		#
smc2-27	0.88	4.25	1.32	3.01	3.31	0.62	1.09	2.74	1.31	
smc2-29	0.99	1.99	0.66	1.36	−0.45	0.35	0.63	−2.90	−24.29	
smc2-32	0.12	1.49	1.0	1.23	−0.12	0.13	0.91	−3.08	−25.67	
smc3-1	2.38	4.54	–	–	–	–	–	−8.00	−82.36	
smc3-2	0.8	6.25	–	3.28	3.4	0.7	–	–	−5.95	(2)
smc3-3	5.65	6.63	–	4.55	3.16	0.55	–	6.09	1.64	(3)
smc3-4									9.90	## (3)
smc3-5	–	7.28	–	5.30	9.24	–	ea	6.01		#
smc3-6	5.19	8.96	–	6.93	5.44	–	–	5.72		#
smc3-7	5.52	8.36	–	5.69	5.54	–	–	6.37		#
smc3-8	0.77	0.73	–	−2.09	−1.76	–	–	−7.22	−33.28	(3)
smc3-9	–	0.72	0.57	−0.34	–	0.34	0.5	−2.12	−13.83	
smc3-10									4.68	##
smc3-12	2.74	6.28	0.5	5.31	4.54	–	0.5	4.43		#
smc3-14	0.81	2.49	–	2.23	1.99	0.30	0.07	−0.57	−13.67	
smc3-15	0.79	2.64	0.91	1.55	2.21	0.46	0.75	1.52		#
smc3-16	0.59	0.65	0.63	ea	–	–	0.4	−2.17	−10.37	
smc3-17									−6.20	##
smc3-18	1.20	3.38	–	2.67	1.76	–	–	−2.43		#
smc3-20	0.65	1.85	0.25	0.82	−0.24	0.52	0.63	−3.27	−37.26	
smc3-21	–	2.24	0.77	1.72	2.60	–	0.94	−0.59	−9.87	

We analysed 12 spectra in the blue region and nine spectra in the red region for LMC type 3 stars. Balmer lines Hγ, Hδ and Hξ are present as absorption lines. In seven cases Hβ is seen in absorption. In one case Hβ is seen in emission. Lines of hydrogen (H13, H12, H10, H9 and H8) are also present in absorption. He I lines (4026, 4471 Å) are present and one star shows He I 4026 Å in emission. The spectral types along with other details are tabulated in Table 3.

The spectral line details of these stars are tabulated in Table 9. The Hα line is present in emission with varying EW in five stars. Three stars show Hα in absorption; it may also be partially filled. One star has a relatively high EW of ∼−30 Å, whereas the rest have EW less than −10 Å. We find that the type 3 stars in the LMC have relatively lower Hα EW, when compared to those in the SMC, keeping in mind that we only have a limited number of stars. We

Table 9. List of spectral lines observed in the sample of Be candidate stars in the LMC [type 1, 2 and 3 as defined by Mennickent et al. (2006)] considered in the present study along with their EWs in Å. '#' indicates that there are no spectra available for these stars in the red region. '##' indicates that there are no spectra available for these stars in the blue region. 'ae' indicates absorption in emission line in Hα.

Star	Ca II	Hϵ	He I	Hδ	Hγ	He I	He I	Hβ	Hα	Comment
lmc1-8									3.60	##
lmc1-12									−16.12	##
lmc1-52									−11.33	##
lmc1-55	0.44	2.98	0.65	0.38	0.34	0.13	0.72	−1.64	−13.27	
lmc1-60									2.43	##
lmc1-106									1.73	##
lmc1-109									2.06	##
lmc1-112									1.76	##
lmc2-16									ae	##
lmc2-31									−6.80	##
lmc2-43									−26.57	##
lmc3-1	10.96	8.10	0.87	1.91	1.92	0.82	–	1.65	1.59	
lmc3-5	5.34	8.32	0.12	6.17	7.39	–	–	7.49	4.56	
lmc3-12	2.63	10.55	–	8.08	7.99	–	–	6.64	3.10	
lmc3-20	5.32	6.13	–	2.25	2.32	–	–	–	−3.96	
lmc3-23	5.10	4.78	−1.17	2.52	–	–	–	–	−2.65	
lmc3-24	0.91	3.73	–	3.43	3.35	–	–	3.00		#
lmc3-30	9.28	8.05	–	4.92	3.75	–	–	–	−30.69	
lmc3-33	7.24	7.69	–	3.36	3.39	–	–	2.71		#
lmc3-37	2.71	4.24	–	–	–	–	–	1.98		
lmc3-39	–	2.03	0.73	1.39	2.43	–	0.69	–		#
lmc3-44	–	0.68	–	–	–	–	–	−1.13	−7.78	
lmc3-49	0.42	3.68	1.24	3.17	3.75	–	0.84	1.80	−8.41	

have a spectrum of one star with large NIR excess, lmc3-20. This does not show any other emission than the Hα line. These stars do not show any correlation between $(H - K)_0$ values and Hα EW. The reddening range estimated for these stars is similar to those in the SMC, that is $E(B - V) = 0.05$–0.60 mag. Thus, some stars might be located near star forming regions.

Spectra of five type 3 stars in the SMC and one type 3 star in the LMC obtained from LCO100 are also analysed. The spectral line details of these stars are tabulated in Table 10. In the SMC, Hβ is found to be in absorption for four stars and in emission for one star. The Hγ line is also seen in most cases as absorption. He I lines 4471 Å and 4922 Å are seen in absorption in four spectra.

Using the photometric and the spectroscopic analysis of type 3 stars, we propose the following. These stars do not seem to have a specific location in the NIR diagrams, supporting that these stars are unlikely to belong to one stellar population, or CBe stars. The fact that most of the stars show emission lines in the spectra (either Hβ or Hα) suggests that they have circumstellar material. Most of the stars with the spectra are found to belong to A and F types, suggesting that the majority among type 3 are unlikely to be CBe stars. The fact that they correlate with the $(H - K)_0$ magnitude for some of the SMC candidates suggests the presence of dust in the disc. Some of the stars in the SMC are long periodic variables and one is found to be an interacting binary. Three stars in the LMC are found to belong to DPVs studied by Mennickent et al. (2005). Thus, type 3 stars are likely to be a heterogeneous mix of stars belonging to various types of stars.

5.3 Type 2 stars

The NIR CCDm for the type 2 stars in the LMC and the SMC are shown in Fig. 11. Relatively more type 2 stars exist in the SMC (14.5 per cent) when compared to the LMC (6 per cent). The cross-identified sample also shows the overpopulation in the SMC (15.6 per cent) when compared to the LMC (5.6 per cent). It is clear that the SMC has a larger fraction of this type when compared to the LMC. Thus, the identification of the nature of these stars might provide some insight into the reason for the above difference. This type is also one of the poorly populated samples among the four types of Be candidates. The majority of these stars show NIR excess similar to the Galactic Be stars. There is no significant difference in the NIR properties between the LMC and the SMC type 2 stars. There are a few stars which are located along the MS. This scatter is relatively more in the LMC than in the SMC. The histograms presented in Fig. 5 show that the type 2 stars in the SMC are slightly redder in $(J - H)_0$ than those in the LMC, whereas the colour distribution in $(H - K)_0$ is very similar in both the galaxies. None of the type 2 stars shows significant NIR excess, which is typical for pre-MS stars. Mennickent et al. (2002) suggested that type 2 stars could be Be + WD binary stars or accreting pre-MS stars, based on the light-curve analysis of these stars. The NIR properties suggest that most of the LMC type 2 stars and probably all the SMC type 2 stars are similar to the Galactic Be stars. They do not show the NIR properties typical of the pre-MS stars.

We obtained spectra of 20 type 2 stars in the SMC (12 in the blue region and eight in the red region) and the spectral classification suggests that most of them are early type stars. Stars observed are tabulated in Table 4 along with their identification number, optical magnitudes, NIR colours and the estimated spectral types. The identified spectral lines and the EW of the prominent lines are tabulated in Table 8.

Balmer lines Hγ, Hδ and lines of hydrogen (H13, H12, H10, H9, H8) are present in absorption. He I lines (4009, 4026, 4471, 4390 Å) are present in a few cases and five out of 12 stars show Hβ emission. Four spectra show no emission or absorption corresponding to Hβ, probably due to filled up absorption. In one case there is absorption

Table 10. List of spectral lines observed in the sample of Be candidate stars (spectra obtained from the 2.5-m LCO) considered in the present study along with their EWs.

Star	Hδ 4101	Hγ 4340	He I 4387	He I 4471	Fe II 4629	He I 4713	Hβ 4861	He I 4922	He I 5015	Si II 5052	Fe II 5169
lmc1-1	0.52	1.23	–	1.57	–	–	−1.61	–	0.22	–	–
lmc1-2	2.61	3.49	–	–	0.31	0.14	3.88	0.91	0.29	0.27	1.16
lmc1-3	–	3.16	−0.68	1.17	0.19	0.6	2.49	0.72	0.6	–	–
lmc1-4	0.62	2.34	–	–	–	0.07	2.48	0.87	0.23	0.45	1.55
lmc1-5	1.57	2.95	0.21	0.27	–	0.33	6.74	0.15	–	–	1.05
lmc1-6	1.52	5.63	1.49	–	–	–	6.73	–	–	–	0.52
lmc1-7	–	2.27	1.43	0.82	–	0.37	2.4	0.81	0.99	0.53	0.11
lmc1-9	–	3.39	–	0.45	–	–	3.36	2.48	–	–	1.4
lmc1-10	3.98	5.24	0.45	0.23	–	–	5.87	0.15	0.24	–	–
lmc1-11	–	1.61	1.05	0.54	–	–	2.31	0.61	–	–	–
lmc1-12	–	1.42	0.71	1.15	–	0.49	0.77	0.67	0.43	0.27	0.11
lmc1-15	–	10.7	1.63	–	–	–	7.78	–	–	–	–
lmc1-114	5.34	6.52	–	–	–	–	5.95	–	–	–	–
lmc1-115	–	5.13	0.97	2.64	–	1.16	2.13	–	–	–	1.96
lmc1-116	–	1.32	–	–	–	–	−0.41	0.6	–	–	–
lmc1-117	0.55	0.42	–	0.14	−0.23	−0.13	−1.53	−0.22	−0.3	–	–
smc1-40	2.19	1.75	–	1.12	1.56	0.34	3.69	1.39	0.66	0.39	−0.26
smc1-42	–	1.32	–	–	–	–	−2.82	–	0.88	0.26	−0.75
smc1-44	–	2.76	0.95	0.98	–	–	0.45	2.97	2.11	−0.35	–
smc1-47	–	2.11	2.75	1.13	–	–	3.18	–	–	–	–
smc1-50	3.74	1.16	1.82	1.87	−0.61	0.13	4.58	0.89	–	0.45	−2.27
smc1-52	–	3.48	–	–	–	0.27	2.62	0.84	0.66	–	−0.11
smc1-53	–	−6.29	–	–	–	–	−8.51	–	–	–	–
smc1-56	–	–	–	–	–	–	–	–	–	–	–
smc1-57	–	0.56	–	–	–	–	1.47	0.61	–	–	–
smc1-58	–	–	–	–	–	–	−2.01	–	–	–	–
smc1-59	–	–	1.22	–	–	–	−2.95	–	–	–	–
smc1-60	–	−3.36	–	–	–	–	−9.27	–	–	–	–
lmc2-1	–	1.55	0.58	0.69	0.18	0.76	1.7	0.6	0.21	–	–
lmc2-2	–	–	–	–	–	–	0.58	0.38	−1.36	−0.85	3.56
lmc2-3	–	0.97	0.6	0.86	–	0.13	−1.95	0.52	–	0.31	−0.31
lmc2-4	–	–	–	–	–	–	−2.97	–	–	–	–
lmc2-5	–	0.59	–	–	–	–	−1.89	0.46	–	–	–
lmc2-6	–	0.46	–	0.32	–	–	–	0.48	–	–	–
lmc2-7	–	0.97	0.27	0.39	–	0.19	−0.34	0.36	–	–	–
lmc2-8	–	−0.66	–	–	–	–	−2.72	–	−0.62	–	–
lmc2-9	–	1.37	0.56	0.88	–	0.15	0.47	0.85	0.47	–	–
lmc3-6	–	5.24	7.19	7.04	5.28	7.10	7.47	–	–	–	–
smc2-38	5.25	8.22	–	0.31	–	–	6.52	0.61	0.29	−0.54	0.83
smc2-39	–	1.3	1.32	1.21	1.28	–	−5.01	0.63	–	–	−0.33
smc2-40	–	1.79	0.86	0.73	0.17	0.51	2.41	0.69	0.22	–	−0.29
smc2-45	–	–	–	–	–	0.32	1.48	1.17	0.33	1.23	–
smc3-30	0.14	1.47	0.55	0.69	–	–	1.81	1.13	0.13	–	–
smc3-31	4.28	5.21	–	–	–	–	4.78	0.26	–	–	–
smc3-32	2.96	3.92	1.73	1.84	–	1.2	0.88	–	0.75	–	–
smc3-33	–	–	–	–	–	–	0.2	0.21	−0.34	–	–
smc3-35	–	–	–	0.91	–	–	−3.86	0.37	–	0.44	–

corresponding to Hβ. Among the eight red spectra, the Hα line is present in emission with varying EW (−34 Å to +1.3 Å) in seven spectra. Martayan et al. (2007) also found a range of Hα EW among the CBe stars in the LMC. Of the 12 stars, therefore, we find that emission lines are present in at least seven stars. Thus, most of the stars have circumstellar material and these are early type stars. Spectra of nine stars in the LMC and four stars in the SMC obtained from LCO100 are also analysed. The spectral types along with other details are tabulated in Tables 4 and 5. The spectral line details of these stars are tabulated in Table 10. In the LMC, five stars show Hβ in emission. He I 4922 Å is found in absorption in seven stars. In the SMC Hβ is found in absorption in two stars and emission in two stars.

The reddening values for these stars show that about half of them have very low reddening of $E(B - V) = 0.04$ and the half have values ranging up to 0.45 mag. They are unlikely to be pre-MS stars due to lack of large NIR excess. Among the 12 stars classified, 10 stars belong to early B-type. The difference in the variability might give clues to their nature, as these stars show sudden luminosity jumps. This type of star is found more in the SMC than in the LMC. Their location in the NIR CCDm suggests that these stars in the SMC appear like a homogeneous group, whereas the LMC stars do

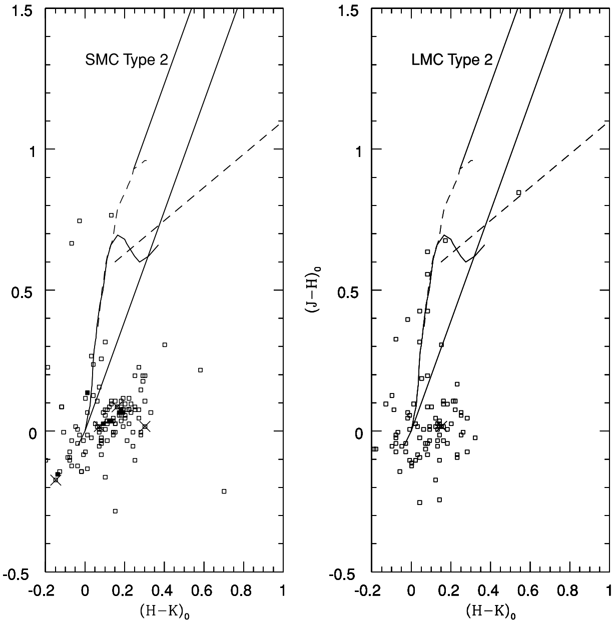

Figure 11. NIR CCDm of the type 2 Be candidates in the LMC and the SMC. Shaded points represent the stars with spectra from the 1.5-m CTIO and points shown with crosses represent stars with spectra taken from the 2.5-m LCO.

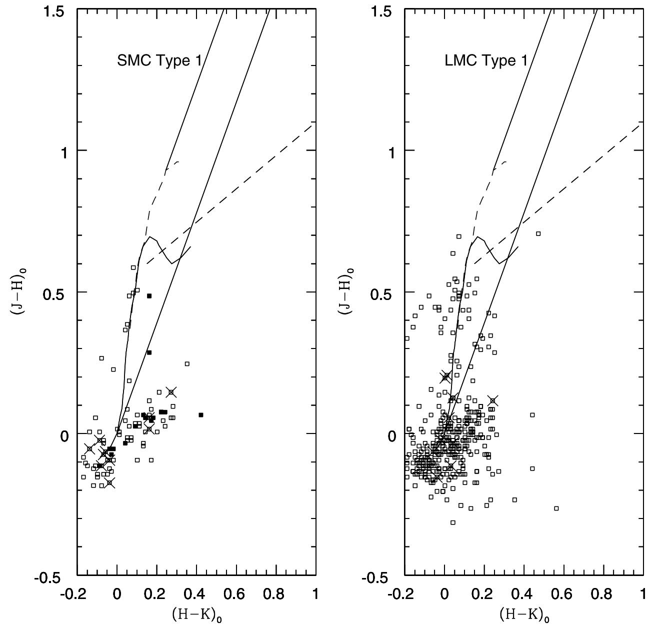

Figure 12. NIR CCDm of the type 1 stars in the LMC and the SMC. Shaded points represent the stars with spectra from the 1.5-m CTIO and points shown with crosses represent stars with spectra from the 2.5-m LCO.

not appear as a homogeneous group. The locations of these stars in the optical CMDs are similar for the LMC and the SMC. If these are early type stars, then it might appear that the SMC sample might have a larger fraction of the more massive Be stars when compared to the LMC as reported by Martayan et al. (2010) and Bonanos et al. (2010) for early Be and Oe stars. This could happen due to the lower metallicity of the SMC. These stars could be very young Be stars, or could be Be stars in binaries as suggested by Mennickent et al. (2002). Therefore, it will be interesting to study these type 2 stars in detail in the LMC also, in order to compare them with the SMC.

5.4 Type 1 stars

The NIR CCDm for the type 1 stars in the LMC and the SMC are shown in Fig. 12. Type 1 stars are relatively more numerous in the LMC (24 per cent), when compared to the SMC (13 per cent). The cross-correlated sample has 24 per cent in the LMC and 10 per cent in the SMC. We have cross-identified a smaller sample of this type in the SMC. Type 1 stars are the second largest population among the four types and forms one fourth of the identified sample in the LMC. These stars are populated more in the LMC, when compared to the SMC, and the ratio is almost a factor of 2. Thus, it will be interesting to find the reason for their overabundance in the LMC or their underabundance in the SMC. The majority of type 1 stars occupy similar locations to Galactic Be stars in the NIR CCDm. These stars do not have large NIR excess. The histograms shown in Fig. 5 suggest that the distributions in $(J-H)_0$ as well as $(H-K)_0$ are very similar in LMC and SMC, except for the large number present in the LMC. Thus, these stars are found to have similar NIR properties in the LMC and the SMC. Mennickent et al. (2002) had stated that the type 1 could be similar to Galactic Be stars.

In the SMC type 1 stars, we have analysed 17 spectra in the blue region and 13 spectra in the red region. The spectral line details of these stars are tabulated in Table 8. Balmer lines Hβ, Hγ, Hδ and lines of hydrogen (H13, H12, H10, H9, H8) are present in absorption. He I lines (4009, 4026, 4471, 4390 Å) are present with varying intensities in absorption. Seven (stars 7, 18, 26, 28, 31, 37 and 38) out of 17 stars show Hβ emission. A filled in profile is seen in Hδ in a few cases. The Hα line is present in emission with varying EW in all the spectra. The estimated range is between −33.8 and −0.94 Å. The spectral types along with other details are tabulated in Table 6. These stars are found to belong to early B type stars, which is consistent with their location in the brighter part of the optical CMD (Fig. 2). lmc1-55 is the only type 1 star in the LMC for which we could estimate the spectral type, and it is found to belong to B0–B2.

Spectra of 17 stars in the LMC and 12 stars in the SMC obtained from LCO100 are also analysed (Tables 6 and 7). In the LMC, Balmer lines Hγ and Hβ are found in absorption for 14 stars in our sample while in three stars they are seen as emission lines. As tabulated in Table 10, quite a number of He I lines (4387, 4471, 4713, 4922 Å) are present in absorption in many cases. Eight stars are found to have the 5169 Å Fe II line in absorption. In the SMC out of 12 spectra, six show Hβ in absorption and five in emission. He I lines are also present in the majority of the cases in absorption. Fe II 5169 Å is found in emission in four stars. Our analysis shows that these stars are B-type stars though we are unable to identify the exact spectral subclass. Many of these stars are found to lie in the CBe location in the CCDm and a few are found on the MS above the CBe location. Since Hβ is found in emission for five stars, it can be assumed that Hα also will be in emission. Hence we conclude that half the stars show Hα in emission.

Most of the type 1 stars in the SMC are found to show emission features, whereas the LMC stars do not show clear emission features. We could not estimate the spectral type of these stars in the LMC because of poor signal-to-noise ratio. Their location in the optical CMD (Fig. 1) suggests that the majority could belong to later spectral types. Hence it is probable that type 1 stars in the LMC and the SMC may belong to different spectral types, but with properties similar to CBe stars.

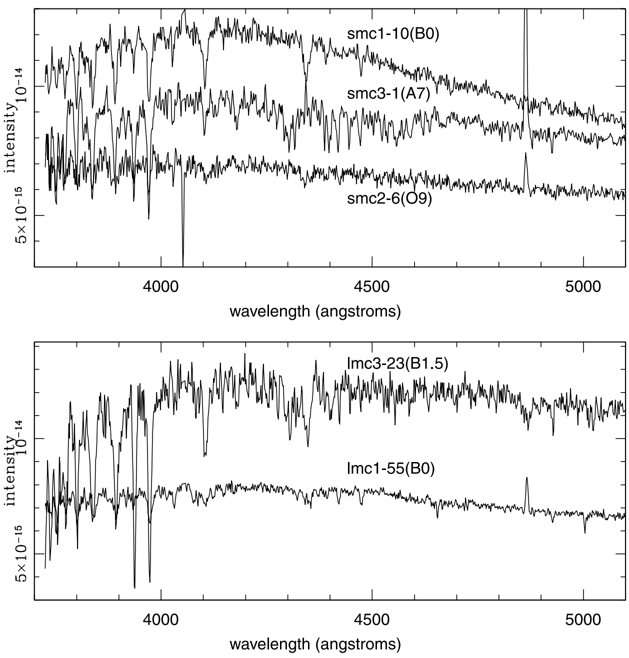

Figure 13. Representative sample of spectra of Be candidate stars in the LMC and the SMC, in the blue region.

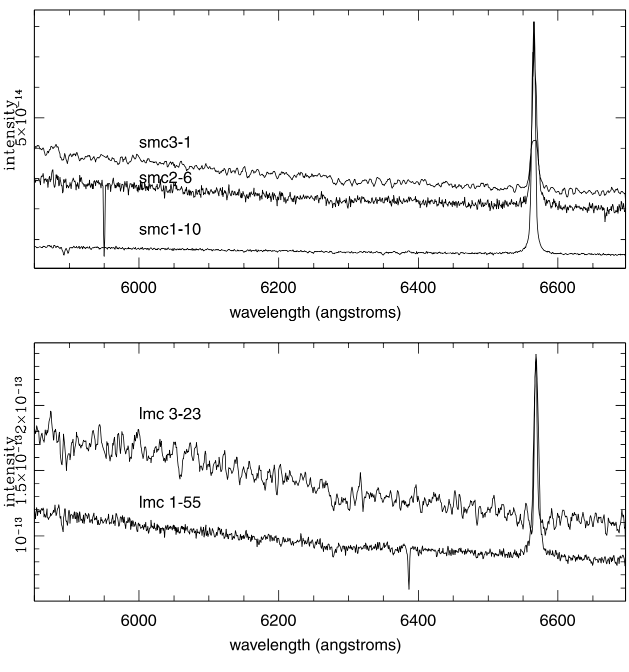

Figure 14. Representative sample of spectra of Be candidate stars in the LMC and the SMC, in the red region.

6 DISCUSSION – COMPARISON BETWEEN THE CLOUDS

We studied the NIR properties of Be star candidates in the LMC and the SMC by combining the optical and the NIR magnitudes of a sample of 1640 stars in the LMC and 839 stars in the SMC. We also used spectra of 109 of the type 1, type 2 and type 3 stars to understand their nature. Figs 13 and 14 show the representative spectra of Be candidates (types 1, 2 and 3 in the SMC and types 1 and 3 in the LMC) in the blue and red regions. In the discussion below, we derive the fraction of various types of stars, which are candidate CBe stars, in the two galaxies studied. The CBe mechanism is expected to be more efficient in the SMC due to its lower metallicity, when compared to the LMC. On the other hand, at low metallicity the kappa mechanism should be less efficient than at higher metallicity (Salmon et al. 2009; Miglio, Montalbán & Dupret 2007). Also, the CBe stars show variability in Hα emission. These factors can affect the ratios discussed below.

Within the area surveyed, the LMC and the SMC have varying fractions of various types of stars. The relative fractions of the four types were found to be different. In both the galaxies, type 4 is the dominant type, with more than half of the stars belonging to this group. In the case of the LMC, type 1 stars form one quarter of the population and type 2 and 3 are the least populated group. In the SMC, the second dominant group is the type 2 stars, followed by type 1 and type 3 stars. This trend is also seen if we estimate the ratio of the LMC/SMC for various types. If we take the total sample, the LMC/SMC fraction is 2.3. Now, we can compare this fraction for various types and see how they deviate from the average. These values are tabulated in Table 1. The fractions of stars in the cross-correlated sample are also given in the same table. Both the values are similar suggesting that the cross-correlated sample has similar fractions of the four types of stars. It can be seen that the type 4 stars have a similar fraction (2.14) to the average. Thus, the type 4 stars are similarly populated in the LMC and the SMC. The fractions of the type 3 stars are slightly less than the average, but can be considered to be similarly populated in the LMC and the SMC. The type 2 stars are found to have a low value of the fraction (0.97), which suggests that these stars are more populated (more than twice) in the SMC, when compared to the LMC. On the other hand, the value of the fraction for type 1 stars is very high (4.17), when compared to the average. This suggests that the type 1 stars are more populated in the LMC, when compared to the SMC. To summarize, we find that the types 3 and 4 are equally abundant in both the Clouds. Type 1 stars are almost twice as abundant in the LMC, whereas type 2 stars are twice as abundant in the SMC.

After combining the optical and the NIR properties, we find that the type 4 stars have a new subgroup of stars with slightly different photometric properties. The new group is found to be about one fifth of the type 4 population and they could be highly reddened O,B type stars. This new group does not have any NIR excess. This group is not found among the SMC type 4 stars. We have found that the type 4 stars are similarly populated in both the galaxies. Hence if it exists, the new group should have been identified in the SMC as well. Thus it is likely that this group exists only in the LMC. It is important to study this group of stars in detail using spectroscopy to understand their nature. If we remove this subgroup from the type 4 sample, then the type 4 stars are overabundant in the SMC, by about 1.3.

The spectroscopic analysis suggests that most of the stars studied here show emission features and suggests that they have circumstellar material. The majority of the type 1 and type 2 stars are found to belong to early B type whereas type 3 stars were found to belong to A-F type. The spectroscopic analysis supports the photometric result that most of the stars studied here belong to early type stars, with emission supporting circumstellar material. The type 3 stars are found to belong to a mix of various types of stars and are unlikely to be CBe stars. Our analysis finds that the type 2 stars are likely to be CBe stars. They are unlikely to be pre-MS stars. The interesting fact is that their number is found to be twice as high in the SMC when compared to the LMC. Type 1 stars are also found to be similar to the CBe stars. It is known that due to the lower metallicity of the SMC, the fraction of CBe stars is expected to be higher in the SMC. Martayan et al. (2010) found that the CBe phenomenon is about three to five times enhanced in the SMC, when compared to the Galaxy. Maeder, Grebel & Mermilliod (1999) found that the Be/B fraction in the SMC is about 2.4 times that in our Galaxy. Thus, the true CBe stars should be more populated in the SMC than in the LMC. The enhancement from the LMC to the SMC is expected to be less than the above range. The type 2 stars follow this trend, with a enhancement of 2.4, and it is quite likely that the type 2 candidates are similar to the Galactic Be stars. This argument is simply based on the metallicity difference and nothing else, and we find that the full photometric sample of type 1 does not follow the metallicity trend. If we consider only stars with Hα emission among the type 1 stars (which can be confirmed as CBe stars because of emission), we estimate a ratio of $6/22 = 26$ per cent in the LMC and $22/31 = 71$ per cent in the SMC. Therefore, the CBe stars among the type 1 are more in the SMC by 2.6 times. This enhancement is in agreement with Bonanos et al. (2010) and Martayan et al. (2010). The above ratio could be affected by the variability in Hα emission of CBe stars, as seen in LMC1-12. Therefore, the ratio derived above could be a lower estimate for the LMC, as well as for the SMC. The fact that only a fraction of the type 1 stars show emission lines in the spectra suggests that the type 1 could be a heterogeneous group, consisting of CBe stars and other variables, which do not show Hα emission. In the case of type 4 stars similar to CBe stars (without the new subclass in the LMC), we find an enhancement of 1.4 times in the SMC.

In order to check whether any of the stars studied here are part of star clusters, we performed a cross-correlation between all the four types and the star clusters in both the galaxies. We used the catalogue of Pietrzynski et al. (1998, 1999) for the SMC and LMC clusters, respectively. We searched for stars located within the radius of the cluster. We found that about 13 per cent of the stars, mostly type 4, are probably located in the SMC clusters, and 1 per cent could belong to the candidate clusters. In the case of the LMC, 22 per cent of the stars are probably located in the LMC clusters. Thus the majority of the candidate Be stars in both the galaxies are probably located in the field.

This study points to the fact that the photometric variability is a very effective and efficient tool to identify large numbers of candidate Be stars as well as a variety of binaries in the LMC and SMC. Mennickent et al. (2002) and Sabogal et al. (2005) identified these stars using the OGLE II variability data and followed up with IR photometry and spectral analysis. The next generation OGLE III scans cover a much larger area of the LMC and the SMC and the photometric variability data are also available. We suggest that similar studies based on data bases such as OGLE III will be very useful for comparative studies of CBe candidates and binaries in these two galaxies.

7 CONCLUSIONS

The conclusions are summarized as follows.

(i) We combined the optically identified sample of candidate Be stars with the IRSF catalogue to obtain the B, V, J, H and K_s magnitudes of all the four types of stars in the LMC (with ~70 per cent cross-identification) and the SMC (~80 per cent). The majority of the sample shows NIR properties similar to the Galactic Be stars.

(ii) Spectra of 120 stars belonging to the types 1, 2 and 3 were analysed to study their spectral properties. The majority of the stars showed emission lines in the spectra suggesting the presence of circumstellar material and were found to belong to early spectral type.

(iii) The above two results indicate that the photometric variability is a very effective and efficient tool to identify a large number of candidate Be stars and binaries in the LMC and SMC.

(iv) We find that type 1, type 2 and type 3 stars have more or less similar spectral and NIR properties in the LMC and in the SMC. On the other hand, type 4 stars are found to have a subgroup in the LMC, with different optical and NIR properties. This subgroup is not found in the SMC or in our Galaxy. These stars do not have NIR excess, show large reddening, but are not located in regions with high reddening. The reddening corrected magnitudes make them the brightest and most massive stars in the sample. Detailed spectroscopic studies are needed to understand these enigmatic candidates. This new subclass is ~18 per cent of the type 4 sample. The main type 4 sample is ~49 per cent of the total sample, whereas the SMC has ~65 per cent type 4 stars.

(v) Type 3 stars, the least populated type, are found to belong to B and A spectral types. These stars in the LMC have relatively lower Hα EW when compared to those in the SMC. Some stars are found to have NIR excess and the Hα EW correlates with the $(H - K)_0$ values, suggesting dust in the circumstellar material. These stars also show relatively large reddening. These stars are possibly a mix of various types of stars such as interacting binaries and DPVs, supporting the suggestion by Mennickent et al. (2002, 2006).

(vi) Type 2 stars in the LMC and the SMC show similar spectral and NIR properties. Their NIR properties are similar to the Galactic CBe stars, suggesting that they are likely to be CBe stars. These stars are found in larger fraction in the SMC (~14.5 per cent), when compared to the LMC (~6 per cent).

(vii) The type 1 stars are relatively more in the LMC (~24 per cent) when compared to the SMC (~13 per cent). The SMC type 1 stars are early type stars with large Hα EW and this class has properties similar to CBe stars. Some of the type 1 stars in the LMC do not show evidence of emission and their V_0 magnitudes suggest that they could belong to late B spectral types.

(viii) It is known that due to the lower metallicity of the SMC, the fraction of CBe stars is expected to be more in the SMC. Thus, the true CBe stars should be more populated in the SMC than in the LMC. The type 4 stars (without the subclass in the LMC) are more in the SMC by a factor of about 1.4. The type 2 stars follow a similar trend, with an enhancement of 2.4. The spectroscopic sample of type 1 stars which show Hα in emission and confirmed as CBe stars are more abundant in the SMC by a factor of 2.6.

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APPENDIX A

Table A1. Log of spectroscopic observations from the 1.5m CTIO telescope.

Star	OGLE ID	Blue spectra date of OBS	Exp. time	Red spectra date of OBS	Exp. time	Comment on Hα profile
smc1-2	OGLE003918.20−733656.6	10-10-2002	900	–	–	–
smc1-7	OGLE005059.21−724357.3	10-10-2002	900	12-10-2002	900	Strong emission
smc1-10	OGLE005224.40−724038.6	09-10-2002	900	12-10-2002	900	Weak emission
smc1-11	OGLE005227.51−732001.2	09-10-2002	900	–	–	–
smc1-16	OGLE005535.60−731029.2	–	–	11-10-2002	900	Weak emission
smc1-17	OGLE005504.55−724637.3	09-10-2002	900	–	–	–
smc1-18	OGLE005614.63−723755.1	10-10-2002	900	12-10-2002	900	Strong emission
smc1-19	OGLE005641.86−724425.4	10-10-2002	900	–	–	–
smc1-21	OGLE006916.06−722100.3	10-10-2002	900	12-10-2002	900	Strong emission
smc1-23	OGLE010041.93−723028.6	10-10-2002	900	–	–	–
smc1-24	OGLE010043.94−722604.8	10-10-2002	900	–	–	–
smc1-25	OGLE010056.79−721635.2	–	–	11-10-2002	900	Strong double emission
smc1-26	OGLE010058.69−723049.9	09-10-2002	900	11-10-2002	900	Weak emission
smc1-28	OGLE010213.80−722213.0	09-10-2002	900	11-10-2002	900	Strong emission
smc1-31	OGLE010542.57−722747.3	10-10-2002	900	–	–	–
smc1-36	OGLE010807.38−721932.6	09-10-2002	900	11-10-2002	900	Weak emission
smc1-37	OGLE010809.52−721932.6	09-10-2002	900	12-10-2002	900	Weak emission
smc1-38	OGLE010825.82−722327.2	09-10-2002	900	11-10-2002	900	Strong emission
smc1-39	OGLE005235.60−723751.7	09-10-2002	900	11-10-2002	900	Weak emission
smc2-4	OGLE004721.86−730650.1	09-10-2002	900	11-10-2002	900	Strong emission
smc2-6	OGLE004848.83−730620.1	09-10-2002	900	11-10-2002	900	Strong emission
smc2-8	OGLE004849.49−724800.0	10-10-2002	900	12-10-2002	900	Emission in absorption
smc2-9	OGLE004938.01−730610.0	09-10-2002	900	11-10-2002	900	Weak emission
smc2-12	OGLE005224.40−724038.6	09-10-2002	900	–	–	–
smc2-14	OGLE005251.97−723508.5	10-10-2002	900	12-10-2002	900	Emission

Table A1 – *continued*

Star	OGLE ID	Blue spectra date of OBS	Exp. time	Red spectra date of OBS	Exp. time	Comment on Hα profile
smc2-19	OGLE005614.45−724053.2	09-10-2002	900	–	–	–
smc2-20	OGLE005618.51−722645.2	09-10-2002	900	–	–	–
smc2-23	OGLE005806.05−723544.5	10-10-2002	900	–	–	–
smc2-27	OGLE010025.10−724632.2	10-10-2002	900	12-10-2002	900	–
smc2-29	OGLE010401.11−723311.1	09-10-2002	900	11-10-2002	900	Strong emission
smc2-32	OGLE010447.25−722559.4	10-10-2002	900	12-10-2002	900	Emission
smc3-1	OGLE004336.91−732637.7	09-10-2002	900	11-10-2002	900	Strong double emission
smc3-2	OGLE004454.66−732802.9	08-10-2002	600	11-10-2002	300	Weak emission
smc3-3	OGLE004554.14−731404.3	09-10-2002	900	12-10-2002	300	–
smc3-4	OGLE004721.86−730650.1	–	–	11-10-2002	900	Strong double emission
smc3-5	OGLE004750.14−731316.4	09-10-2002	900	–	–	–
smc3-6	OGLE004921.41−725844.9	09-10-2002	900	–	–	–
smc3-7	OGLE005025.64−725807.1	09-10-2002	900	–	–	–
smc3-8	OGLE005043.44−732705.3	09-10-2009	900	11-10-2002	300	Strong emission
smc3-9	OGLE005100.18−725303.9	09-10-2002	900	11-10-2002	900	Weak emission
smc3-10	OGLE005107.59−732636.6	–	–	11-10-2002	900	–
smc3-12	OGLE005359.22−723508.9	09-10-2002	900	–	–	–
smc3-14	OGLE005520.27-723710.1	10-10-2002	900	12-10-2002	900	Weak emission
smc3-15	OGLE005745.25-723532.1	09-10-2002	900	–	–	–
smc3-16	OGLE005812.58-723048.5	09-10-2002	900	11-10-2002	900	Weak emission
smc3-17	OGLE005822.04-725522.9	–	–	11-10-2009	900	Weak emission
smc3-18	OGLE010000.78-725522.9	09-10-2002	900	–	–	Weak emission
smc3-20	OGLE010325.11-724646.9	09-10-2002	900	11-10-2002	900	Strong emission
smc3-21	OGLE010452.99-715918.8	09-10-2002	900	11-10-2002	900	Weak emission
lmc1-8	OGLE050220.61-690240.9	–	–	12-10-2002	900	–
lmc1-12	OGLE050351.57-685300.9	–	–	12-10-2002	900	Emission
lmc1-52	OGLE051651.98-691129.5	–	–	12-10-2002	900	Emission
lmc1-55	OGLE051747.85-690908.6	10-10-2002	900	11-10-2002	900	Emission
lmc1-60	OGLE051813.34-691305.4	–	–	12-10-2002	900	–
lmc1-106	OGLE053723.19-701349.4	–	–	12-10-2002	900	–
lmc1-109	OGLE054259.85-704153.2	–	–	12-10-2002	900	–
lmc1-112	OGLE054715.07-705300.6	–	–	12-10-2002	900	–
lmc2-16	OGLE050918.50-684225.2	–	–	12-10-2002	900	–
lmc2-31	OGLE051824.53-691552.5	–	–	12-10-2002	900	Emission double peak
lmc2-43	OGLE052455.30-700706.3	–	–	12-10-2002	900	Emission
lmc3-1	OGLE050052.36−685803.7	09-10-2002	900	11-10-2002	900	–
lmc3-5	OGLE050303.70−690615.0	09-10-2002	900	11-10-2002	900	–
lmc3-12	OGLE050848.63−684315.6	10-10-2002	900	11-10-2002	900	–
lmc3-20	OGLE051418.21−691235.0	10-10-2002	900	11-10-2002	900	Weak emission
lmc3-23	OGLE051647.54−694415.2	10-10-2002	900	11-10-2002	900	Weak emission
lmc3-24	OGLE051744.42−692033.3	10-10-2002	900	–	–	–
lmc3-30	OGLE051947.82−693912.3	10-10-2002	900	11-10-2002	900	Strong double emission
lmc3-33	OGLE052032.26−694224.2	10-10-2002	900	–	–	–
lmc3-37	OGLE052258.47−692621.0	10-10-2002	900	11-10-2002	900	–
lmc3-39	OGLE052402.01−694920.5	10-10-2002	900	–	–	–
lmc3-44	OGLE052652.49−693317.2	10-10-2002	900	11-10-2002	900	Weak emission
lmc3-49	OGLE052938.98−693448.0	10-10-2002	900	11-10-2002	900	Weak emission

Table A2. Log of spectroscopic observations from the 2.5-m LCO telescope.

Star	OGLE ID	Date of Obs	Exp. time	No. of exposures	Comment on Hβ profile
lmc1-1	OGLE050122.35−690004.9	12-11-2003	300	4	Emission
lmc1-2	OGLE050131.42−684251.0	12-11-2003	300	4	
lmc1-3	OGLE050132.69−692845.8	13-11-2003	300	3	
lmc1-4	OGLE050147.90−692424.1	12-11-2003	300	4	
lmc1-5	OGLE050151.04−692109.6	12-11-2003	300	4	
lmc1-6	OGLE050158.32−684315.5	13-11-2003	300	5	
lmc1-7	OGLE050221.24−690451.6	12-11-2003	300	5	
lmc1-9	OGLE050127.92−685947.7	13-11-2003	300	3	
lmc1-10	OGLE050234.22−683939.8	13-11-2003	300	4	
lmc1-11	OGLE050320.42−685315.7	13-11-2003	300	5	
lmc1-12	OGLE050438.96−691624.6	13-11-2003	300	3	
lmc1-13	OGLE050426.31−690714.4	13-11-2003	300	5	
lmc1-15	OGLE050447.46−690552.3	13-11-2003	300	5	
lmc1-114	OGLE050151.61−690152.8	14-11-2003	300	6	
lmc1-115	OGLE050428.01−690927.5	14-11-2003	300	6	
lmc1-116	OGLE050521.34−691550.1	14-11-2003	300	5	Emission
lmc1-117	OGLE053319.88−701213.1	14-11-2003	300	4	
lmc2-1	OGLE050017.58−692749.9	15-11-2003	300	4	
lmc2-2	OGLE050039.16−692003.9	15-11-2003	300	5	
lmc2-3	OGLE050053.02−692011.5	13-11-2003	300	3	Emission
lmc2-4	OGLE050103.77−691746.7	14-11-2003	300	4	Emission
lmc2-5	OGLE050116.74−692027.7	14-11-2003	300	4	Emission
Lmc2-6	OGLE050306.60−691807.5	14-11-2003	300	5	
lmc2-7	OGLE050340.10−691530.9	15-11-2003	300	3	Emission
lmc2-8	OGLE050350.56−690223.0	15-11-2003	300	4	Emission
lmc2-9	OGLE050412.28−685021.7	15-11-2003	300	4	
lmc3-6	OGLE050343.42−685947.7	13-11-2003	300	4	
smc1-40	OGLE003631.42−733917.8	11-11-2003	300	5	
smc1-42	OGLE004045.97−732925.6	11-11-2003	300	4	Emission
smc1-44	OGLE004225.27−731718.2	11-11-2003	300	5	
smc1-47	OGLE004626.57−731929.3	13-11-2003	300	5	
smc1-50	OGLE004701.71−731041.9	12-11-2003	300	5	
smc1-52	OGLE004801.80−731057.0	13-11-2003	300	5	
smc1-53	OGLE004803.29−730722.2	14-11-2003	300	6	Emission
smc1-56	OGLE004916.20−724941.2	14-11-2003	300	5	
smc1-57	OGLE004930.81−731236.5	14-11-2003	300	5	
smc1-58	OGLE004948.88−722330.0	14-11-2003	300	4	Emission
smc1-59	OGLE004958.39−725750.8	14-11-2003	300	5	Emission
smc1-60	OGLE005018.69−725524.3	14-11-2003	300	5	Strong emission
smc2-38	OGLE004236.69−733033.1	11-11-2003	300	3	
smc2-39	OGLE004304.50−730206.3	12-11-2003	300	5	Emission
smc2-40	OGLE004327.71−731653.9	12-11-2003	300	6	
smc2-45	OGLE004521.57−731717.7	12-11-2003	300	5	
smc3-30	OGLE005710.71-722550.2	12-11-2003	300	5	
smc3-31	OGLE005617.49-730005.1	12-11-2003	300	5	
smc3-32	OGLE004652.17-731409.2	13-11-2003	300	5	
smc3-33	OGLE005059.66-725648.3	13-11-2003	300	5	
smc3-35	OGLE005217.74-725627.9	13-11-2003	300	5	Emission

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