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NIR properties of Be stars in star clusters in the Magellanic Clouds

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HIGHLIGHTS

- We studied the NIR properties of Be star candidates in clusters in the LMC and SMC.
- New diagnostic area is suggested in the CCD for the Classical Be stars in the MCs.
- We found 14 Be stars with high NIR excess suspected to be in HAeBe or sgB[e] phase.

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ABSTRACT

Magellanic Clouds are the nearby galaxies which are ideal to study the properties of metal poor stellar population. In this study, we explore the near-IR properties of optically identified classical Be stars in 19 star clusters in the Magellanic Clouds. From an optically identified sample of 835 Be stars we obtained the *J, H, K* magnitudes of 389 stars from the IRSF MCPS catalog. Among these, 247 stars (36.4%) are found in 9 clusters in the Large Magellanic Cloud and 142 stars (55.5%) in 10 clusters in the Small Magellanic Cloud. After correcting for reddening, we studied their NIR properties in the $(H - K)_0$ vs $(J - H)_0$ diagram. We identified 14 stars with abnormally large near IR excesses, which were removed from the analysis, there by restricting our study to 355 classical Be stars. We propose an extended area in the near-IR $(H - K)_0$ vs $(J - H)_0$ diagram as the diagnostic location of Classical Be stars in the Magellanic Clouds. We identified 14 stars to have near-IR excess, higher than those seen in classical Be stars. From the analysis based on spectral energy distribution and luminosity estimate, we found that 8 candidate Be stars may be Herbig Ae/Be stars. We identified a new sample of 6 sgB[e] stars, which when added to the sparse existing sample of 15 sgB[e] stars in the Magellanic Clouds can provide insight to understand the evolutionary link between sgB[e] stars and Luminous Blue variables.

1. Introduction

Classical Be stars (CBe) are non-supergiant B-type stars that show or have shown, Balmer emission lines in their spectra at least once in their lifetime (Porter and Rivinius, 2003; Rivinius et al., 2013). The term classical has been used to distinguish them from Herbig Ae/Be (HAeBe) stars, which are intermediate mass pre-main sequence (PMS) candidates with circumstellar accretion disk. From here onwards, we denote CBe/Be to represent classical Be stars. CBe stars are characterised by their rapid rotation and decretion disks (see Rivinius et al. (2013) for a recent review). There are several ways to identify Be stars. The first possibility is to use the photometric techniques. Combining different color/color diagrams (CCDs) or color/magnitude diagrams (CMDs) would help to pre-classify the stars and detect potential Be star candidates. Wisniewski and Bjorkman (2006) studied the B, V, R, and Hα photometry of clusters in the SMC, the LMC, the MW and use CCDs to identify candidate Be star populations in these clusters. Keller et al. (1999) provide examples of CMDs with given thresholds above which the Be stars could fall. They also show that Be stars tend to form a redder sequence than normal B stars. Dachs et al. (1988) have shown that the infrared excess is related to the circumstellar disk of Be stars. It is also linked to the Hα equivalent width.

In the Galaxy, there are different surveys to find Be stars, including the photometric survey by McSwain and Gies (2005) and the slitless spectroscopic survey by Mathew et al. (2008). Slitless spectroscopic survey of the SMC by Meyssonnier and Azzopardi (1993), Martayan et al. (2010) and Martayan et al. (2008) are also examples of surveys to find Be stars. Spectroscopic survey of massive stars particularly, of B and Be stars in the Galaxy and

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the MCs using the Fibre Large Array Multi-Element Spectrograph (FLAMES) instrument at the Very Large Telescope (VLT) were performed (Evans et al., 2005; Martayan et al., 2006; 2007). Some Be stars were found in the SMC/LMC using polarimetry, (Wisniewski et al., 2007; Wisniewski and Bjorkman, 2006), and with FORS2 in the galaxy, IC1613 (Bresolin et al., 2007), which correspond to the farthest Be stars detected.

Another approach to identify Be stars is related to their photometric variability. Microlensing projects (OGLE, MACHO and EROS) have monitored millions of stars in the MCs and Galactic bulge for variability. The resulting photometric databases are very well studied not only for microlensing studies but also for many other issues in modern astrophysics. In particular the OGLE II project has provided accurate BVI measurements for about 6.5 million stars from central parts of the Magellanic Clouds (Udalski et al., 1998). Mennickent et al. (2002) and Sabogal et al. (2005) used these catalogs for finding Be stars by studying the behaviour and the variation of light curves. Some of these candidates were studied spectroscopically by Paul et al. (2012). The Be phenomenon is transient, as a consequence stellar flux would vary depending on the amount of circumstellar matter. Moreover, Be stars often show outbursts. These characteristics were used by them to prepare a catalog of Be star candidates in the MCs. Using the above method, Be stars can be found in open clusters and in fields.

It is known from the theory of stellar evolution and stellar atmospheres that there are significant changes in the stellar properties and parameters at low metallicity. These are observationally apparent in the metal poor MCs which are the nearby laboratories to study massive stars. Several photometric studies (Grebel et al., 1992; Grebel, 1997; Maeder et al., 1999; Keller et al., 1999) have suggested that the Be phenomenon may be more prevalent in low-metallicity environments, based on comparisons of the apparent fractional Be populations of Galactic, LMC and SMC clusters. During the last decade, detailed studies of Be stars in environments with different metallicities, such as MCs, have been performed (Keller, 2004; de Wit et al., 2003; Mennickent et al., 2002; Sabogal et al., 2005; Martayan et al., 2006; 2007). International Ultraviolet Explorer (IUE), Hubble Space Telescope (HST), and Far-Ultraviolet Spectroscopic Explorer (FUSE) observations show that stars tend to have lower wind velocities in metal-poor environments (Garmany and Conti, 1985; Bianchi et al., 1996; Fullerton et al., 2000). Maeder et al. (1999) suggest that the increase in the frequency of Be stars in low-metallicity environments is related to the presence of a greater number of rapidly rotating stars in these locations. Feast (1972) found that about 50% of B stars in the SMC cluster NGC 330 show Be phenomenon. This is a high fraction compared to 10–20% in the MW (Grebel et al., 1992). These studies suggest that there may be a higher fraction of Be stars in the MCs possibly pointing to a low metallicity influence for a star to become a Be star. Wisniewski and Bjorkman (2006) performed the B, V, R, and Hα photometry of eight clusters in the SMC, five in the LMC, and three Galactic clusters and used CCDs to identify candidate Be star populations in these clusters. They found evidence that the Be phenomenon is enhanced in low-metallicity environments. Spectroscopic observations of hot stars belonging to LMC cluster NGC 2004 and SMC cluster NGC 330 were obtained by Martayan et al. (2006); 2007) with the VLT-GIRAFFE facilities in MEDUSA mode. They find that B and Be stars rotate faster in the SMC than in the LMC, and in the LMC than in the MW; they also find that at a given metallicity, Be stars begin their main sequence life with a higher initial rotational velocity than B stars. Consequently, only that fraction of B stars that reach the ZAMS with a sufficiently high initial rotational velocity can become Be stars. According to their findings the distributions of initial rotational velocities at the ZAMS for Be stars in the SMC, LMC and MW are mass and metallicity dependent. The angular velocities of B and Be stars are higher in the SMC than in the LMC and MW. Iqbal and Keller (2013) identified Be stars in 11 clusters in LMC and 14 clusters in SMC using narrow band Hα filter and find that low metallicity environment such as the SMC hosts a larger fraction of Be stars than a higher metallicity environment. Their study show that young clusters are more likely to host a larger fraction of Be stars.

Mennickent et al. (2002) presented a catalog of 1056 Be star candidates in the SMC by studying light curve variations using OGLE II photometric data base. 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. Similarly, Sabogal et al. (2005) carried out similar study of Be candidates in the LMC. Paul et al. (2012) studied the NIR properties of all the four types in the L&SMC and found that type 1, type 2 and type 3 stars have more or less similar NIR properties in the LMC and in the SMC. On the other hand, type 4 stars, which are highly probable Be candidates, 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 most brightest and massive stars in the sample. Detailed spectroscopic studies are needed to understand these enigmatic candidates. This new subclass is $\sim$ 18% of the type 4 sample. The main type 4 sample is $\sim$ 49% of the total sample, whereas the SMC has $\sim$ 65% type 4 stars. The properties as well as the characteristics of this new type, which is not found in our Galaxy or the SMC, need to be studied in detail. In this paper we study the NIR properties of classical Be stars in the star clusters of the LMC &SMC. We aim to compare the NIR properties of field and cluster CBe stars in these galaxies and Milky Way. Paul et al. (2012) noticed that the CBe stars have relatively bluer $(H-K)_0$ colors when compared to the Galactic counter parts. One of the aims of this study is to compare the NIR colors of CBe stars in the MCs with their counter parts in the Galaxy. The disk properties of the CBe stars could be dependent on the stellar environment. We would like to see whether the new sub class identified in the LMC by Paul et al. (2012) is present among the LMC cluster CBe stars.

CBe stars for the present study are taken from two separate photometric studies of Be stars (Wisniewski and Bjorkman, 2006; Keller et al., 1999). CBe stars were identified by comparing the R band and narrow-band Hα CCD images. Keller et al. (1999) studied CBe stars in six fields centered on young clusters. They found that the fraction of Be stars to normal B stars within each cluster vary significantly although the average ratio is similar to the average Be to B star ratio found in the Galaxy. Wisniewski and Bjorkman (2006) studied the B, V, R, and Hα photometry of eight clusters in the SMC, five in the LMC, and three Galactic clusters and use two-color diagrams (2-CDs) to identify candidate Be star populations in these clusters. They found evidence that the Be phenomenon is enhanced in low-metallicity environments, based on the observed fractional early-type candidate Be star content of clusters of age