BE STARS IN YOUNG CLUSTERS IN THE MAGELLANIC CLOUDS *

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Abstract.
A substantial fraction (typically 10%) of Galactic B stars consists of Be stars. While Galactic Be stars have been fairly well investigated, very little is known about the Be star content of the Magellanic Clouds (MCs). We present a refined method of Be star identification by CCD photometry and apply it to four young clusters and associations in the MCs. We find NGC 330 in the SMC to be exceptionally rich in Be stars, while the fraction is clearly lower in the similarly aged LMC clusters NGC 2004 and NGC 1818. NGC 2044, a very young region in the LMC, contains almost no Be stars. Among very early–type B stars in the investigated MC clusters we find the largest number of Be stars, while in the Milky Way this is shifted to somewhat later types. In the LMC, there may be a second frequency peak around B6.

Key words: Stars: Be – Clusters: NGC 330, NGC 2004, NGC 1818, NGC 2044 – Magellanic Clouds

1. Photometric Identification

Be stars are non-supergiant B stars that show (or once have shown) Balmer emission lines. Therefore, currently active Be stars can be detected by using (Grebel et al., 1992)

– an Hα filter to detect Hα emission,
– an R–like filter for the continuum,
– and another broadband filter to use the information about colour and temperature of a colour–magnitude diagram (CMD) to distinguish between non-supergiant B stars and others.

CCD imaging with two broadband filters and an Hα filter is an efficient tool to identify Be stars and makes crowded regions, such as clusters (Grebel et al., 1992), accessible. From the definition of a Be star it is clear that all current detections establish only a lower limit to the true number of Be stars.

* Based on observations obtained at the 2.2m MPIA telescope at ESO, La Silla, Chile, partly on time granted by the MPIA, Heidelberg.


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2. Calibration of the Hα luminosity

The Bessell R filter is an adequate continuum filter for a measurement of the Hα flux to 30% accuracy or better. The energy flux per unit wavelength outside the atmosphere at R=0 is \( \log (f_R) = -7.76 \) in erg cm\(^{-2}\) nm\(^{-1}\) (Allen 1972). In the following, \( f \) denotes flux, \( L \) luminosity, \( D \) distance in kpc, and \( P \) power. Since the ratio of our \( r \) and \( h\alpha \) instrumental passbands is 40 (=4 mag), the Hα luminosity of any star is given by

\[
\log \left( \frac{L_{H\alpha}}{L_\odot} \right) = 2 \log (D/\text{kpc}) + 10.5 + \log (P_{H\alpha}), \quad \text{where}
\]

\[
P_{H\alpha} = (3.5 \text{nm}) f_{H\alpha} = 3.5 \times 10^{-0.4R} \times 10^{0.4(r - h\alpha + 4.0)},
\]

so that

\[
\log \left( \frac{L_{H\alpha}}{L_\odot} \right) = 2 \log (D/\text{kpc}) + 3.4 + 0.4([r - h\alpha] - R) \quad \text{with}
\]

\[
[r - h\alpha] \equiv (r - h\alpha + 4.0).
\]

3. Results for our program clusters.

Fig. 1a shows (B–R) vs. our passband-corrected Hα index for NGC 330, a young blue cluster in the SMC. The clump at (B–R) = −0.2, \([r - h\alpha] \leq 0\) comprises blue supergiants and blue MS stars without Hα emission. The corresponding area redwards of (B–R) ≥ 0.5 consists of red supergiants and giants. Above the blue clump, a band of blue stars bright in Hα can be seen. As a criterion for Be stars, we chose \([r - h\alpha] \geq 0.2\). That this is a reasonable distinction was confirmed for NGC 330 using spectroscopic classifications by Feast (1972) and an unpublished grism survey by M. Azzopardi (see Meyssonier & Azzopardi 1991).

In the dereddened CMD of NGC 330 (Fig. 1b) Be stars are marked by filled triangles. Most of them lie redwards of the upper main-sequence (MS) and they clearly contribute to the apparent width of the MS. The colour index (B–R) makes the effect more dramatic than (B–V) or (V–I). Using our synthetic isochrones based on tracks of the Geneva group, Kurucz model atmospheres, and standard filter passbands (Roberts & Grebel, this conference), we obtain the best fit for 20 Myr and \([\text{Fe/H}] = -0.7 \) dex. The derived age automatically constrains the evolutionary status of the Be stars in NGC 330 and indicates that they are MS stars.

The young LMC cluster NGC 2004 (age 20 Myr, \([\text{Fe/H}] \approx -0.4 \) dex) contains many fewer Be stars (Fig. 1c) and shows weaker Hα emission. In the CMD of NGC 2004 (Fig. 1d), a first group of Be stars is concentrated around 15 mag, while a second group can be found at 18 mag.

For the LMC cluster NGC 1818 (age about 25 Myr, \([\text{Fe/H}]= -0.8 \) (Richtler et al., 1989)), again we find only relatively few Be stars, and again we see two apparent concentrations.

In Fig. 2, we compare Be star fractions by spectral type with the Galactic values. The numbers of Galactic Be stars were taken from Jaszek & Jaszek (1983). In the MC clusters, the highest percentages of Be stars can be found among B0–B1, while in the Milky Way the frequency peak is in the range B1–
Fig. 1. (a–d) Two-colour identification diagram for Be stars in NGC 330 (Fig. 1a) and NGC 2004 (Fig. 1c) and colour-magnitude diagrams with Be stars (filled triangles) in NGC 330 (Fig. 1b) and NGC 2004 (Fig. 1d). See sect. 3 for more explanation.

Fig. 2. Comparison between Be star fractions by spectral type in the Milky Way, NGC 330, and NGC 1818. Note the different frequency peaks.
B3. In addition, two of the LMC clusters show indications of a second frequency peak at later B types (B6-B7). In the Milky Way, such a peak may be present, too. The distributions are significantly different.

The LMC OB association NGC 2044 contains four very young clusters (ages \( \leq 10 \) Myr, Grebel & Melnick, in prep.). Though very rich in B stars, we find only up to 3 Be stars per cluster. In comparison with the other clusters this may indicate a lower age limit for Be stars, possibly associated with an evolutionary spin-up of young B stars leading to the Be phenomenon (Bessell & Wood 1993).

4. Discussion

With its large number of Be stars, NGC 330 is an exception among the MC clusters studied thus far. Balona (1992) found that a number of the Be stars in this cluster are \( \lambda \) Eri variables. Of the three suspected \( \lambda \) Eri candidates he discovered in NGC 2004 (1993), which we found to be not very rich in Be stars, we confirm only one as a Be star. Are \( \lambda \) Eri variables a clue to the Be star phenomenon in the MCs? – In Galactic open clusters, the presence of \( \lambda \) Eri variables seems to exclude the presence of \( \beta \) Ceps and vice versa. Does this hold also in young MC clusters?

As can be seen in Fig. 1b, Be stars can broaden the MS considerably which must be taken into account for isochrone fitting. A possible reason for such red excess could be free-free emission from circumstellar material.

More precise spectral classifications and a determination of the rotational velocities would disclose more about the nature of the MC Be stars. How can theory account for the different frequency peaks in the MCs? Are high rotational velocities a general property of young MC clusters rich in Be stars? In NGC 330 in particular, high \( v \sin i \) values might be expected.

Obviously, we are only beginning to understand the Be stars in the MCs.

References