The Be star content of young open clusters

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Abstract. We present a photometric survey aimed to characterize the Be star population of young open clusters. It is found that in these clusters early-type Be stars are more frequent than in the galactic field, and late-type Be stars are scarce or inexistent. We interpret this result as evidence for an evolutionary enhancement of the Be phenomenon towards the end of the main sequence lifetime.

1. Introduction

The study of the frequencies of Be stars in open clusters of different ages and their distribution as a function of the spectral subtype are key issues in the discussion on the evolutionary status of Be stars.

The clusters NGC 663, NGC 869 and NGC 884 are known to be among the galactic clusters with a higher Be star content. Lists of Be stars in these clusters with information on spectral types are presented by Mermilliod (1982) and Slettebak (1985). From these lists it is remarkable that all Be stars are of early spectral types: earlier than B3 in NGC 869 and 884 and earlier than B5 in NGC 663. This fact contrasts with the distribution of the galactic Be star population. About 20% of B stars are Be, along the B0-B8 range (Zorec & Briot 1997).

A possible explanation of this discrepancy is observational bias. Most of the known Be stars in open clusters have been identified within the framework of large surveys for emission line stars in the Milky Way, which are magnitude limited. For most clusters only the brightest stars have been searched for line emission, and hence the derived frequencies are only lower limits, restricted to the earliest spectral types.

The aim of this work is to study the complete B star sequence of the young open clusters with a high Be star content referred to above, and to analyze the Be star frequency for the different spectral subtypes. To detect emission line stars we have used CCD imaging photometry through interference filters centered in the Hα and Hβ Balmer lines.
2. Observations and reduction procedure

Observations were done during two runs in December 1995 and November 1998 at the Calar Alto Observatory (Almería, Spain). The first run was performed with the 1.23m telescope of the Centro Astronómico Hispano Alemán, and the second one with the 1.52m telescope of the Observatorio Astronómico Nacional. In each telescope we used two pairs of interference filters centered on H\(\alpha\) and H\(\beta\) Balmer lines. Each pair consisted of a wide and a narrow filter.

The data have been reduced using the standard procedures in IRAF. For each frame we have obtained the instrumental magnitudes of the stars. We have transformed the instrumental magnitudes into the \(\alpha\) and \(\beta\) indices by subtracting the magnitude in the wide filter from the magnitude in the narrow one.

We have transformed our instrumental \(\beta\) indices into the standard Crawford & Mander (1966) system. As there is not a widely accepted H\(\alpha\) photometric system, we have worked with the instrumental indices obtained in our observations. Note that the instrumental \(\alpha\) systems are different in the two runs, which explain the different scales in Figure 1.

There is a good correlation between the \(\alpha\) and \(\beta\) indices for B stars, and hence in the plot of the two indices for objects without emission a well-defined sequence is apparent. For emission-line stars, since emission in H\(\alpha\) is much stronger than in H\(\beta\), such objects appear significantly above the sequence. In
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Figure 1 we have represented the photometric $\alpha - \beta$ plane for the observed clusters in two epochs. Be stars are represented with a different symbol.

In the 1998 run Strömgren $uvby$ photometry was also obtained, and has been published elsewhere (Capilla & Fabregat 2002a,b). The $uvby$ photometric diagrams show that our survey is complete through all the B-type main sequence in the three observed clusters.

3. Discussion

From the $uvby$ and H$\beta$ photometry we have obtained the reddening and intrinsic colours and indices for the stars observed (see Capilla & Fabregat 2002a,b for details). Photometric spectral types were derived from the $c_0$ index, by using the mean $c_0$–spectral-type relation presented in Table II in Crawford (1978). For Be stars, of which the $c_0$ index is anomalous due to circumstellar emission in the Balmer continuum, spectral types have been assigned following the precepts in Fabregat & Torrejón (1998). The photometric spectral types derived in this way are coincident with spectroscopic MK types presented by Slettebak (1985) for the stars in common, within one spectral subtype in all cases.

From the $\alpha$ and $\beta$ photometry we have detected as emission line stars most of the previously known Be stars, and we have made three new detections. All but one are of spectral types earlier than B5. In NGC 869 and 884 we have obtained photometry for 168 stars in the range B4-A0, and none of them presented line emission. In NGC 663 we observed 132 stars in the interval B5-A0, and only one Be star was found (star NGC 663 51, of spectral type B6). This proves that the lack of late-type Be stars in the surveyed clusters is a real feature and not observational bias.

In Figure 2 we present the histogram of the Be star frequencies for NGC 663 and 884. NGC 869 was not analyzed due to the small number of Be stars in the surveyed area. The solid line and shadowed area in Fig. 2 represent the frequencies for the galactic field population, as given by Zorec & Briot (1997).
is apparent that the frequencies in the open clusters and in the field population are significantly different. In both clusters, the frequency of early-type Be stars is similar or greater than in the galactic field. Conversely, both clusters almost completely lack late-type Be stars, which have a frequency of about 20% in the galactic field.

In order to check the validity of this result for a larger cluster sample, we have analyzed in a similar way four open clusters in the Magellanic Clouds (hereafter referred to as MC). We have used the data presented by Keller, Bessell, & Da Costa (2000). Spectral types have been derived from the V magnitudes given by these authors.

The Be star frequencies in Keller et al. (2000) have been derived from a single epoch photometric survey. It is well known that these surveys lose a significant fraction of the actual number of Be stars, due to the episodic lost of emission lines in many Be stars and the inability of the photometric technique to detect faint emitters. Conversely, the study on NGC 663 and 884 is based on all Be stars detected in more than 80 years of spectroscopic and photometric surveys. To make both samples comparable, we have estimated the ratio be-
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| Spectral type | N(Be) / N(B+Be) |
|---------------|-----------------|
| B0            | 0.0             |
| B1            | 0.2             |
| B2            | 0.4             |
| B3            | 0.6             |
| B4            | 0.0             |
| B5            | 0.2             |
| B6            | 0.4             |
| B7            | 0.6             |
| B8            | 0.0             |
| B9            | 0.2             |

Figure 3. Relation between Be star frequencies and spectral subtypes for MC fields. Bars, solid line and shadowed area as in Fig. 3.

Figure 4. Relation between Be star frequencies and spectral subtypes for MC fields. Bars, solid line and shadowed area as in Fig. 3.

tween the actual number of Be stars and the number detected in a single epoch photometric survey. We have considered as complete samples all the known Be stars in NGC 663, 869 and 884, and we have used the detections in our 1995 and 1998 data, and the observations by Goderya & Schmidt (1994) as single epoch surveys. We obtained that the ratio between the stars detected and the actual content is around two thirds.

Results are presented in Figure 3. Each subtype bin is represented by two bars in the histogram. The shorter one is the Be star frequency detected by Keller et al. (2000), and the larger one is this number corrected by the detection efficiency parameter derived in the above paragraph. As in the galactic clusters, the frequency of early-type Be stars in the MC clusters is much higher than in the Milky Way field, while late-type Be stars are significantly less abundant.

We conclude that the Be star population in young open clusters is significantly different, and hence not representative, of the mean population in the Galaxy. We interpret this fact in the context of the evolutionary hypothesis for the Be phenomenon proposed by Fabregat & Torrejón (2000), in which the Be star phase would appear during the second half of the main sequence lifetime of a B star. In the age range of the analyzed clusters, early B stars are close to the end of their main sequence lifetime, and hence the Be phenomenon is much more frequent than in a mixed age field sample. Late-type B stars are at the beginning of the main sequence, where the Be phase would be scarce or inexistent.

Maeder, Grebel & Mermilliod (1999) have recently proposed that the Be phenomenon is related to the metal abundance, being enhanced in a low metallicity environment. They based their conclusions on the study of the Be frequencies in several young clusters in the inner and outer Galaxy and the MC. The fact that the Be population in young clusters is not representative of their host galaxy casts doubts on this conclusion. In order to ascertain this issue we have also compared the Be star frequencies in the LMC and SMC fields with those of the Galaxy field. Result are presented in Figure 4.

The data used are from Keller, Wood and Bessell (1999). Their survey of several MC fields around open clusters only reach the early B range, and the
comparison has to be restricted to this range. It is apparent, however, that the frequencies in the MC fields are compatible, within errors, with those of the Milky Way field. To ascertain the reality of the metallicity dependence of the Be phenomenon a more complete survey of the LMC and SMC field population has to be done.

4. Conclusions

We have shown that the Be star content of young open clusters is significantly different that the content of the mean galactic population. This is an evidence for the evolutionary enhancement of the Be phenomenon during the second half of the main sequence lifetime.

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