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Be Stars in the Magellanic Clouds

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Abstract.
We present the results of our studies of Be stars within the Magellanic Clouds. We have studied the Be population within four young populous clusters, NGC 330 in the SMC, NGC 1818, 2004 and 2100 in the LMC as well as the field population around NGC 2004. The Be fraction within each cluster is seen to peak towards the luminosity of the main sequence turnoff. The field, which exhibits a large spread of ages, has a Be fraction more uniformly distributed in luminosity. We interpret this difference as evidence for an evolutionary enhancement of the Be phenomenon that occurs towards the end of the main sequence lifetime.

1. Introduction

The young populous clusters of the Magellanic Clouds present the largest fraction and number of Be stars seen in any observed stellar association. Our study focuses on four such clusters; NGC 330 in the SMC and NGC 1818, 2004 and 2100 in the LMC. It was shown by Grebel et al. (1992) and Keller et al. (1998) that the clusters contain a large fraction of Be stars. The Be stars of the Magellanic Clouds offer a statistically significant sample with which to probe evolutionary and metallicity effects in a way which is not possible with our galaxy. In the present work we construct a volume limited study of Be stars in the LMC field. Such a task is almost impossible in the galaxy due to large depth and reddening effects but is easily conducted in the disk-like LMC which is seen at low inclination.

2. HST/WFPC2 Observations

The four clusters have been imaged by the HST/WFPC2 in F555W, broadband analogue of V, F160BW, a wideband UV filter ($\Delta\lambda$=446Å, λ_e=1491Å) with negligible red-leak, and F656N a narrow-band filter ($\Delta\lambda$=22Å) centred on the Hα line. More details are to be found in Keller et al (1999).

Be stars are distinguished through the use of F555W-F656N, F160BW-F555W colour-colour diagram (see Figure 1a). Stars with strong Hα emission should appear to have a more positive F555W-F656N colour than their non-emission counterparts at similar F160BW-F555W colour. Main sequence (MS)

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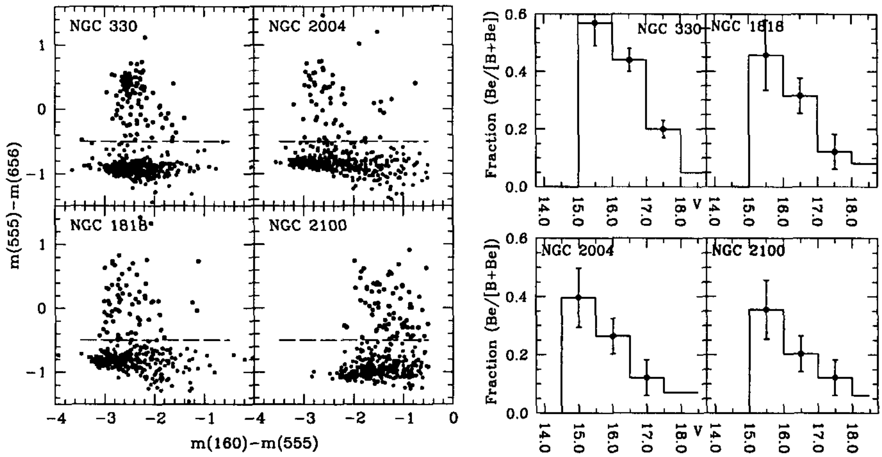

Figure 1. a. (left) Diagnostic F160BW-F555W, F6565N-F555W diagrams for the four MC clusters. b. (right) Histogram of the Be fraction within the four clusters. $\sqrt{n}$ error bars are shown.

stars lie in a tight, almost horizontal band. Above this band are a group of stars that clearly show significant Hα emission: these are Be stars.

3. Observations of the Be Population in the LMC field

In order to investigate the Be population within the LMC field we obtained *VRI*, Hα photometry for 4×20′ square fields in the vicinity of NGC 2004 in the LMC. This photometry was obtained using the MSSSO 40″ telescope. The resulting CMD and distribution of the Be fraction is shown in Figure 2a.

A feature of the field CMD is the presence of an extended branch of red supergiants (RSGs) covering a large range of absolute magnitudes. This is consistent with a large age spread within the field population in this locality. Because our data is saturated above V=13 we are not able to determine the youngest population within the field, however from the study of Will et al. (1995) of the nearby field of NGC 1948 ages as young as 5 Myrs have been found. The oldest population may be estimated from our data from the faintest RSGs, seen here at around V=16. Isochrones of Bertelli et al. (1994) indicate an age on the order of 160 Myrs. Whilst the peak in RSGs at V=13.5 indicates a period of active star formation at 20 Myrs, it is clear that the region has been a site of ongoing star formation since around 160 Myrs or more. Such an age range spans the lifetime of stars to a spectral type of B7 (Bertelli et al. 1994). That is to say the majority of the B spectral range is represented in the field sample by a stars of a range of evolutionary phases, essentially from the zero age MS to the end of core H-burning.

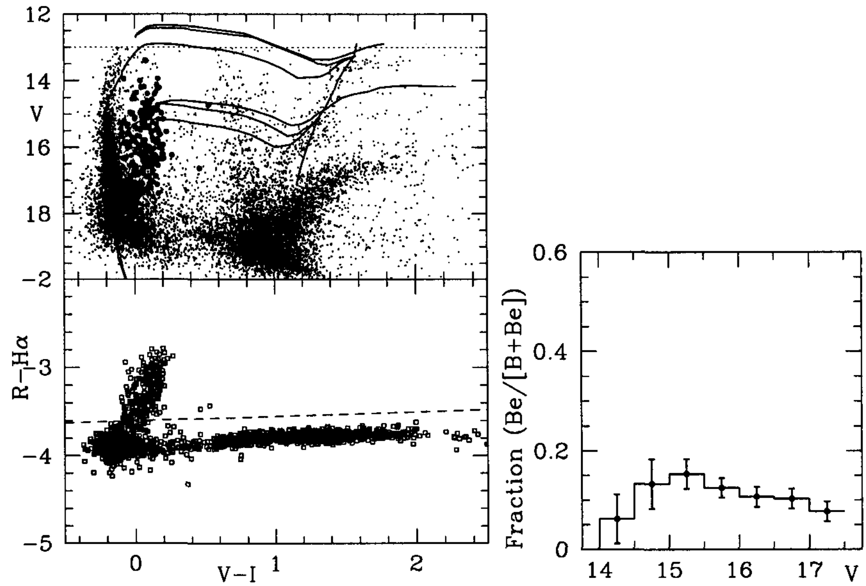

Figure 2. a. (left) V,I CMD for the field population. Be stars are indicated as filled circles. Isochrones from Bertelli et al. (1994) are for 16 and 160 Myrs. b.(right) The histogram of the Be fraction within the field population.

4. Discussion

Our results show that the Be fraction within the LMC field is comparable with that seen in the Galactic field (Zorec and Briot 1997). In Figures 1b and 2b we see a clear difference between the distribution of the Be fraction within NGC 2004 and the field. In each cluster the Be fraction within the cluster population is significantly greater than the field population. This overabundance is seen to diminish down the MS and becomes relatively insignificant at V=17.0. A Kolmogorov-Smirnov test between the two populations rates the probability of the two resulting from an identical parent population at 2%.

4.1. Evidence for an Evolutionary Enhancement in Be Fraction

Our scenario of evolutionary enhancement makes use of the one clear difference between the cluster and field populations: the spread of ages in each population. Whilst the field population contains a large spread of ages, the age spread within the cluster population is only on the order of 10% the cluster age. The mechanism of evolutionary enhancement may result from the evolution of an initially rotating population. The angular momentum evolution of rotating stars has been examined by Endal and Sofia (1979) and Endal (1982). These models explicitly follow the radial exchange of angular momentum throughout MS evolution. They find that slowly rotating stars remain slow rotators throughout the MS lifetime. Initially rapidly rotating stars (~60% critical velocity) attain critical velocities over a moderate fraction of the MS lifetime. This preferential

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"boosting" of the rotational velocities of more rapidly rotating stars towards the end of the MS presents an enhancement mechanism.

Consider an enhancement in the Be fraction that occurs towards the end of the MS lifetime. Near the MS terminus, the small age spread within the cluster population means that the majority of stars lie within the enhancement age range. A peak in the Be fraction results here and diminishes at lower luminosities as fewer stars reside in the age range of enhancement. At lower luminosities a population of rapid rotators accounts for the ambient Be fraction seen at $V \sim 17$. Within the field we see the time-average of the proportion of Be stars. This is consequently lower than that seen in the cluster and more-or-less uniform with luminosity.

4.2. Consequences for Studies of the Be Fraction

The study of Maeder et al. (1999) presents evidence that the Be fraction increases in lower metallicity environments. In reaching this conclusion Maeder et al. have studied young clusters. As we have seen above, the fraction of Be stars within clusters is enhanced above that of the surrounding field due to an evolutionary effect. By taking a cluster-based sample there appears to be a systematic trend to greater Be fractions at lower metallicities, which Maeder et al. have suggested is due to an increase in the average rotational velocity of the population. However since a larger Be fraction is not seen in the field population, we suggest that rotational velocities are similar in both environments. Rather, we propose that the magnitude of the evolutionary enhancement is increased at lower metallicities. The test of such a claim awaits the acquistion of a significant sample of rotational velocities within the Magellanic Clouds.

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References

Bertelli, G., Bressan, A., Chiosi, C., Fagotto, F., Nasi, E., A&AS 106, 275

Bessell, M.S., Wood, P.R., 1992, in New Aspects of Magellanic Cloud Research, Baschek, B., Klare, G., Lequeux, J. (eds.). Springer: Berlin, p271

Endal, A.S., Sofia, S., 1978, ApJ 232, 531

Endal, A.S., 1982, in IAU Symposium 98, Be Stars, Jaschek, M, Groth, H.-G. (eds.). Reidel: Dordrecht, p. 299

Grebel, E.K., Richtler, T., de Boer, K.S., 1992, A&A 254, L5

Keller, S.C., Bessell, M.S., DaCosta, G.S., AJ, submitted

Keller, S.C., Wood, P.R., Bessell, M.S., A&AS 134, 489

Maeder, A., Grebel, E., Mermilloid, 1999, A&A 346, 459

Will, J-M., Bomans, D.J., de Boer, K.S., 1993, A&A 119, 91

Zorec, J., Briot, D., 1997, A&A 318, 443