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Spectroscopic survey of emission line stars in open clusters

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Summary. We summarize a study of emission-line stars in young open clusters. The study was done in two phases. The first phase was the survey, where the emission stars in young open clusters were identified using the slitless spectral images. The identified emission stars were then studied in detail using their slit spectra in the 3700–9000 A range. The results of the study suggest that there could be two mechanisms responsible for the Be phenomenon. The early type B stars are likely to become Be stars in the second half of their MS lifetime, whereas the late type B stars are likely to be born as Be stars.

1 Introduction

Open clusters are dynamically associated system of stars, which are presumed to be formed from giant molecular clouds through bursts of star formation. Apart from the coeval nature of the stars, they are assumed to be at the same distance and have the same chemical composition. Hence it is a perfect place to study emission stars since we do not have a hold on these parameters in the field. Young open clusters are found to contain emission stars since the emission stars undergo evolution over a time scale of less than 100 Myr. Early type emission stars are broadly classified as Classical Be (CBe) stars and Herbig Be (HBe) stars. A Be star is defined as a non-super giant B-type star whose spectrum has, or had at some time, one or more Balmer lines in emission (Collins 1987). CBe stars are fast rotators (70−80% of the critical velocity) whose circumstellar disk is formed through decretion mechanism (wind/outflow) (Porter & Rivinius 2003). Jaschek & Jaschek (1983) has identified 12% of the stars in the Bright Star Catalogue as Be stars. Herbig Ae/Be (HAeBe) stars are intermediate mass pre-main sequence (PMS) stars, found to possess a natal accretion disk which is a remnant of star formation (Hillenbrand et al. 1992). Maeder et al. (1999) suggested the influence of metallicity in Be star formation by indicating a higher fraction of Be stars in low-metallicity clusters. Mermilliod (1982) studied 94 Be stars in 34 open clusters. He found that the distribution of Be stars peaked at spectral type B1−B2 and B7−B8, confirming earlier results. He also found that the Be stars occupy the whole main sequence (MS) band and are not confined to the region of termination of the MS. Recently, Mcswain & Gies (2005) conducted

a photometric survey of 55 southern open clusters and identified 52 definite Be stars and 129 probable candidates. They also reported that the spin-up effect at the end of the MS phase cannot explain the observed distribution of Be stars.
The Be mechanism still is not well understood and also its dependence on the stellar mass and age. Be stars found in open clusters are ideal targets to understand the above. These are probably the only targets to understand the evolution of the decretion disk, its properties including the angular momentum, radius and density with age. In order to address the above, a slitless spectroscopic survey of 207 clusters were performed. This is a major survey considering the number of surveyed clusters and the emission stars detected. Some of the results obtained in this survey are presented here.

2 Slit-less spectroscopic survey

Emission-line stars in young open clusters are identified to study their properties, as a function of age, spectral type and evolutionary state. 207 open star clusters were observed using slitless spectroscopy method using the 2-m Himalayan Chandra Telescope (HCT), located in Hanle and operated by IIA. In this survey, 157 emission stars were identified in 42 clusters. The result of this survey was published by Mathew et al. (2008). They found 54 new emission-line stars in 24 open clusters, of which 19 clusters were found to house emission stars for the first time. Rich clusters like NGC 7419, NGC 663, NGC 2345, NGC 6649, h Persei, χ Persei are also rich in emission-line stars (25, 22, 12, 7, 6 and 6 emission stars respectively). We classify rich clusters as those with 6 or more emission stars. The detailed table is given in Mathew et al. (2008). About 20% clusters harbour emission stars. The optical colour magnitude diagram (CMD) along with Near-IR Colour-Colour diagram (NIR CCDm) and nebulosity was used to classify the emission stars into CBe and HAeBe category. **Most of the emission stars in the survey belong to CBe class (∼ 92%) while ∼ 6.3% is HBe and remaining ∼1.7% is HAe.** The youngest clusters to have CBe stars are IC 1590, NGC 637 and NGC 1624 (all 4 Myr old) while NGC 6756 (125-150 Myr) is the oldest cluster to have CBe stars. The CBe stars are located all along the MS in the optical CMDs of clusters of all ages, which indicates that the Be phenomenon is unlikely due to core contraction near the turn-off.

2.1 Frequency distribution of emission star clusters with age

Since the ages of most of the clusters which house the emission star are known, the appearance of emission stars as a function of age can be studied. Among the surveyed 207 open clusters, 140 were younger than 100 Myr, 39 clusters were older than 100 Myr while the ages of 28 clusters are unknown. Out of the total number of clusters surveyed 20.28 % has been found to have emission stars. The fraction of clusters which have emission stars with respect to the total surveyed clusters as a function of age is shown as histogram in Fig. 1. **We found 48 clusters fall in the age bin 0−10 Myr, of which 18 have emission stars. Similarly 8 out of 29 clusters have e-stars in 10−20 Myr age bin while 4 out of 10 clusters have e-stars in 20−30 Myr age bin.** The maximum fraction of clusters which house CBe stars were found to fall in the age bin 0−10 Myr and 20−30 Myr ($\sim$ 40%). There seems to be a dip in the fraction of CBe clusters in the 10−20 Myr age bin. For older clusters, the estimated fraction ranges between 10−25%. The reduction in the fraction from 0−10 Myr age bin to 10−20 Myr age bin could be due to evolutionary effects and also due to the MS evolution of the probable HBe stars. There seems to be an enhancement in the cluster fraction with Be stars in the 20−30 Myr age bin bin. This is suggestive of an enhancement in the Be fraction in this age bin indicating a possible evolutionary effect on the angular momentum of mostly early type stars.

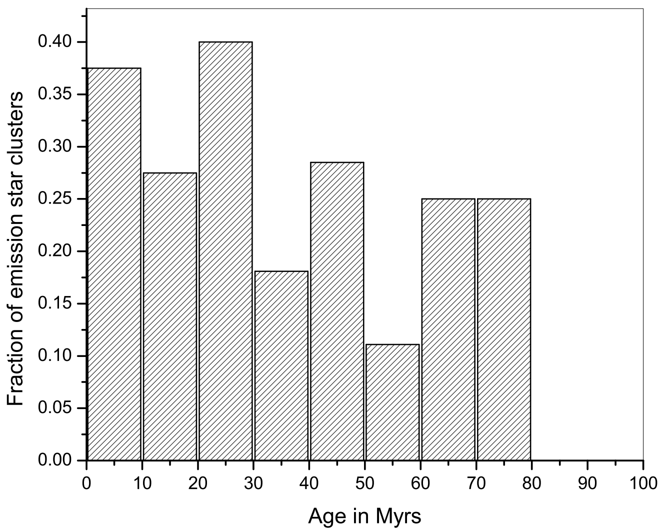

Fig. 1. Fraction of clusters which have emission line stars with respect to the total number of clusters surveyed in each bin.

We find that CBe phenomenon is pretty much prevalent in clusters younger than 10 Myr, $\sim$ 40% of clusters house CBe stars and about 20% CBe stars are about 10 Myr. Mcswain & Gies (2005) also find a good fraction of clusters to have CBe stars in this age bin. Thus, these CBe stars are born as CBe stars, rather than being evolved to become CBe stars. Since we do not find any CBe stars earlier than B1 in clusters of this age range, our results mildly suggest that this happens mainly for spectral types later than B1.

We also find that the fraction of clusters with CBe stars significantly increases in the age range 20−30 Myr, similar to that found by Wisniewski & Bjorkman (2006) (10−25 Myr) and Mcswain & Gies (2005) (10−20 Myr). All these results put together indicate that there is an enhancement in the 10−30 Myr age range. These suggest that stars in these clusters evolve to become CBe stars. Thus, there could be two mechanisms responsible for the Be phenomenon. Rapid rotation is generally considered as the reason for the CBe phenomenon. The first mechanism, being rapid rotation, is where the stars start off as CBe stars early in their lifetime, as indicated by CBe stars in very young clusters. These probably are born fast-rotators. These type of stars are found in all age groups of clusters. These types of stars are likely to be later than B1, as indicated by the paucity of very early type CBe stars in young clusters. The second mechanism is responsible for the enhanced appearance of Be stars in the 10−30 Myr age group clusters. This is likely to be an evolutionary effect. The 10−30 Myr age range has a large number of CBe stars with spectral types earlier than B1. This component is probably due to the structural or rotational changes in the early B-type stars, in their second half of the MS life time.

3 Spectroscopic properties of emission stars

The spectroscopic observations of the identified individual emission stars in clusters were obtained using HFOSC instrument mounted on HCT. A comparative analysis of the spectral lines of 157 surveyed emission-line stars is presented in Mathew & Subramaniam (2009).

From the analysis of optical, Near-IR photometry and nebulosity we found that star 1 belongs to HBe category while 2 and 3 are HAe and CBe respectively (Mathew et al. (2008)). From UBV CCD photometry star IC 1590-1 was estimated to belong to B8.5 spectral type while stars 2 and 3 were found to be A0 and B2 respectively. The spectral features of these emission stars are given below. All the Balmer lines except H_α and H_β are found in absorption (Fig. 2). The emission profile of H_α shows P-Cygni nature for star 2 and double-peak for star 3 while it is normal single peak profile for star 1. The P-Cygni profile indicates that the H_α line might be formed in wind/outflow, which is a characteristic of HAeBe star. The double-peak H_α profile is usually indicative of the CBe stars. H_β is found to have an asymmetric emission in absorption profile for stars 1 and 2 while it is in absorption for star 3. As seen in Fig. 1, quite a number of FeII lines (4549 A, 4584 A, 4924 A, 5018 A, 5169 A, 5235 A, 5276 A, 5316 A, 5363 A) are found in emission for the stars 1 and 2 while no such nature is seen for star 3. The 5018 A Fe II profile is found to show P-Cygni feature for stars 1 and 2, which is a signature of wind/outflow associated with the star. In the red region of the spectrum, calcium II (CaII) triplet (8498 A, 8542 A, 8662 A) is found in emission along with the Paschen lines (8467(P17), 8598(P14), 8750(P12), 8862(P11)) for stars 1 and 2 while they are found to be in absorption for star 3. The helium lines (4026 A, 4471 A, 5876 A, 6678 A, 7065 A) are found to be visibly present in star 3 which matches with the spectral type estimated earlier from photometry. OI 8446 A spectral line shows intense emission for stars 1 and 2 while it is absent in 3. Hence the spectral line features confirms our prediction from optical and Near-IR photometry that stars 1 and 2 are pre-main sequence HAeBe stars.

3.1 Main results from the survey

The main results of the survey can be summarized as:

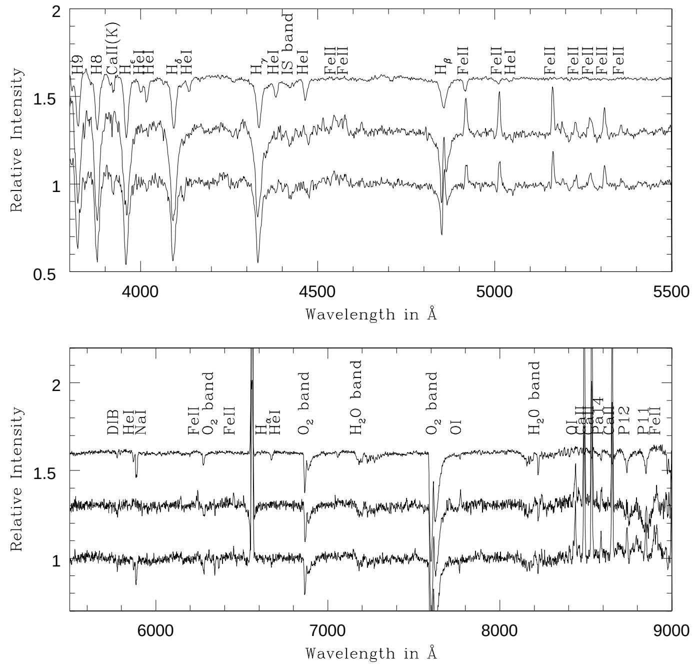

Fig. 2. The spectra of the emission stars in the cluster IC 1590 in the wavelength range 3800 – 9000A. The emission stars are numbered 1, 2, 3 from bottom to top.

1. From photometric analysis we deduced that early B-type stars may be evolved to CBe phase while those belonging to late B are born as CBe stars.

2. The Balmer decrement (D_{34}) of Be stars is found to range from 1.5 and 6.5 with a mean value of 3.5, unlike the typical nebular value of 2.7. The distribution of D_{34} with age, spectral type and Near-IR excess seems to confirm the bimodal origin of Be stars predicted from photometric analysis.

3. About 83% of the surveyed emission stars show FeII lines in their spectra. We found Lyman *beta* fluorescence as the mechanism for the production of 8446A line in 25% of the surveyed stars.

4. The emission region for H_α profile is found to be around 15 stellar radius, with a range of 7–30, assuming the circumstellar disk to be Keplerian.

5. The rotational velocity of candidate stars is found to be in the range 100–300 km/s, which matches with the values of field CBe stars. From the spectral line width analysis it is found that the circumstellar disk lags behind the star.

References

Collins, G. W. II., 1987, pbes.coll, 3
Hillenbrand, L. A., Strom, S. E., Vrba, F. J., Keene, J., 1992, ApJ, 397, 613
Jaschek, C., Jaschek, M. 1983, A&A, 117, 357
Maeder, A., Grebel, E. K., Mermilliod, J. C. 1999, A&A, 346, 459
Mathew, B., Subramaniam, A., Bhatt, B. C. 2008, MNRAS, 388, 1879
Mathew, B., Subramaniam, A. 2009, BASI, in preparation
Mcswain, M. V., Gies. D. R. 2005, ApJS, 161, 118
Mermilliod, J. C., 1982, A&A, 109, 48
Porter, J. M., Rivinius, T. 2003, PASP, 115, 1153
Wisniewski, J. P., Bjorkman, K. S., 2006, ApJ, 652, 458