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Study of emission line stars in young open clusters

Blesson Mathew[1]* and Annapurni Subramaniam[1]†
[1]*Indian Institute of Astrophysics, Bangalore 560034, India*

Abstract. 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 the slitless spectroscopy method and 157 emission stars were identified in 42 clusters. We have found 54 new emission-line stars in 24 open clusters, out of which 19 clusters are found to house emission stars for the first time. The Classical Be (CBe) stars are located all along the main sequence (MS) in the optical colour magnitude diagram (CMD) of clusters of all ages, which indicates that the Be phenomenon is unlikely only due to core contraction near the turn-off. A spectroscopic study of 152 CBe stars in 42 young open clusters was performed using medium resolution spectra in 3700−9000 Å range, to understand the Be phenomenon. Stars in the B0−B2 spectral bin are found be spun up towards the end of their MS life time, suggesting that early type stars evolve to become Be stars. Similar variation in properties were not found for stars in the later spectral types (B4−A0), suggesting that the Be phenomenon differs in early type and late type stars. Spectroscopic studies were done for the identified Herbig Ae/Be (HAeBe) stars. The star formation history of the hosting cluster was estimated by identifying pre-MS stars. The ages of HAeBe stars were estimated. The duration of star formation in the hosting cluster were found to be about 10 Myr.

Keywords : stars: formation – stars: emission-line, Be – stars: pre-main sequence – : (Galaxy:) open clusters and associations: general – surveys

*Current address: Astronomy and Astrophysics Division, Physical Research Laboratory, Navrangapura, Ahmedabad 380009, Gujarat, India, email: blesson@prl.res.in
†email: purni@iiap.res.in

1. Introduction

An open cluster is a system of dynamically associated stars which are found to have been 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 for the field stars.

Early type emission stars (e-stars) are broadly classified as Classical Be (CBe) stars and Herbig Ae/Be (HAeBe) stars. CBe stars are fast rotators whose circumstellar disk is formed through decretion mechanism (wind/outflow) (Porter & Rivinius 2003). HAeBe stars are intermediate mass pre-main sequence (pre-MS) stars, found to possess a natal accretion disk which is a remnant of star formation (Hillenbrand et al. 1992). CBe stars and HAeBe stars are emission-line stars in different evolutionary phases. Both these stars are found to possess a circumstellar disk from which we can see emission lines over the photospheric spectrum. The emission is found to come from this equatorial disk as recombination radiation, mainly in Balmer lines like Hα and Hβ. The circumstellar equatorial disk in HAeBe stars is a remnant of the star formation activity, which has been formed by accretion mechanism. The production of disk in CBe stars is still a mystery and majority of the studies point towards an equatorial disk formed by channeling of matter from the star through wind, rotation and magnetic field (Porter & Rivinius (2003) and references therein).

2. Outline of the Thesis

We have done a survey to search for e-stars in northern open clusters, belonging to different parts of the Galactic disk. The sample of 157 stars in 42 clusters has been used to derive conclusion about the role of environment and mechanisms for the formation of Be stars (Mathew, Subramaniam & Bhatt 2008). We used slitless spectroscopy to find e-stars in clusters, which is quite an innovative concept for a survey of this magnitude. From photometric and spectroscopic studies we propose a bimodal distribution in Be star population. The early subtype (B0−B2) evolve to become Be stars while others (B2−A0) are born in Be phase. The detailed description of the studies given in each chapter is summarized below.

In Chapter 1, we have given an introduction to Be stars. We have explained Be phenomenon in CBe stars and the efforts underway to resolve the puzzle. Rapid rotation, stellar wind, non-radial pulsation, magnetic field and binary interaction are the proposed mechanisms to resolve Be phenomenon in Be stars. We have explored the theoretical aspects of each of these mechanisms with the observational developments on each front. Be stars are studied in various bands in the electromagnetic spectrum, to understand the nature of the star with the formation and evolution of circumstellar disk.

Figure 1. The slitless spectral image of NGC 7419.

The details of the survey to search for e-stars in young open clusters using slitless spectroscopy is explained in chapter 2. The spectroscopic and the R band imaging observations of the clusters were obtained using the HFOSC instrument, available with the 2 m Himalayan Chandra Telescope (HCT), located at Hanle and operated by the Indian Institute of Astrophysics. The broad band R filter (7100 Å , BW=2200 Å) and Grism 5 (5200−10300 Å , low resolution) of HFOSC CCD system were used in combination without any slit. A sample spectral image of the cluster NGC 7419 obtained by this method is shown in Fig. 1. The bead like enhancements over the continuum correspond to emission in Hα. This dispersed image is cross-matched with R band image to identify e-stars.

We found 157 e-stars in 42 open clusters, most of which are less than 100 Myr. The properties of these e-stars are discussed in the context of the clusters which harbour them. 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. A detailed description of the studies conducted in each of these 42 clusters is given in this chapter. The optical V vs (B−V) colour magnitude diagram (CMD) along with near Infrared (J−H) vs (H−K_s) colour-colour diagram (near-IR CCDm) are used to classify CBe stars from HAeBe stars in terms of near-IR excess. The slit spectra of 157 e-stars taken using HFOSC in wavelength range 3700–9000 Å are presented in this chapter, with an effective resolution of 10 Å around Hβ and 7 Å around Hα spectral region.

The photometric analysis of the collective sample of 157 e-stars is done in chapter 3. The optical photometric data are taken from the references listed in WEBDA database while near-IR data are taken from 2MASS catalogue. 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 only due to core contraction near the turn-off. The spectral distribution shows bimodal peaking in B1−B2 and B6−B7 spectral bins. Rich clusters like NGC 7419, NGC 2345, NGC 663 and h & χ Persei are found to favour the formation of early-type Be stars. Our survey is more or less complete in northern sky since it covers various star forming regions in Galaxy like Perseus, Monoceros and Cygnus (Mathew, Subramaniam & Bhatt 2008).

From the spectroscopic survey of 152 CBe stars, various spectral and evolutionary properties of stars and their disks are studied in chapter 4. Apart from the Balmer lines in emission, spectra of most of the stars show FeII, Paschen and OI lines in emission while HeI is seen in absorption. Majority of surveyed stars (76%) may have optically thick disks, identified by the presence of large Balmer decrement, high Hα equivalent width, metallic lines and high $(H-K)_0$ values. Our analysis suggests that Be phenomenon differs in early and late type Be stars.

In chapter 5 we have identified sure HAeBe candidates from optical, near-IR photometry, Spectral Energy Distribution (SED) and spectroscopy. We found 3 HBe and 2 HAe candidates from a sample of 157 e-stars. The ages of these HAeBe stars, estimated using pre-MS isochrones, were found to range between 0.25–3 Myr. We combined the optical and near-IR photometry to estimate the duration of star formation in clusters Bochum 6, IC 1590, NGC 6823 and NGC 7380. We found ongoing star formation in all these clusters, with an appreciable number of pre-MS stars. All the four clusters were found to be forming stars for the last 10 Myr (Mathew, Subramaniam & Bhavya 2010).

3. Impact of this work

The survey and analysis presented here is the first of its kind to understand Be phenomenon in CBe stars in open clusters. Our sample of 152 CBe stars was combined with the dataset of CBe stars in southern clusters (McSwain & Gies 2005) to get a complete picture of the formation and evolution of CBe stars in Galaxy (Martayan et al. 2010). The method of slitless spectra to identify CBe stars was used by Martayan, Baade & Fabregat (2009), to study CBe stars in the SMC clusters.

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