POPULATION OF THE Be STARS IN THE YOUNG OPEN CLUSTERS

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ABSTRACT. Both high and medium resolution spectroscopy of the Be stars and binary stellar systems in the young open clusters (e.g., NGC 869 & 884, NGC 6913, NGC 6871, NGC 7160 and NGC 7419) were carried out. High resolution spectroscopy of 100 stars in the Hα region and 42 stars in the region of 4400–4960 Å with the medium resolution were obtained. The spectra of 52 B and 48 Be stars were studied. T_{eff}, $log\, g$ and $V \sin i$ were determined by using the medium resolution spectra. One new Be star was found, one star showed complex variability of the Hα line profile, which is characterized as a close binary system. A few demonstrate long - term V/R variability of the emission peaks that can be easy described by the one arm oscillations in theirs envelopes. Our clusters survey approved that classical Be stars mostly appeared at age of 10 Myr, and reached the maximum abundance in the age of interval 12-20 Myr.

Key words: Clusters: yuong open clusters: individual clusters: NGC 869 & 884, NGC 6913, NGC 6871, NGC 7160 and NGC 7419; Stars: Be stars.

1. Introduction

The phenomenon of Be stars has been known for over a century. The fact that at least 20% of B stars have an emission spectrum supports that the definition that this phenomenon is not special but it is rather typical from a large group of objects at a certain stage of evolution. The vagueness of the concept of the Be phenomenon suggests that this definition encompasses a broad group of objects near the main sequence that includes binary systems with different rate of mass exchange. Thus, the hypothesis that all Be stars are the consequence of the evolution of binary systems is still current. On the other hand, most classical Be stars are probably individual objects and the formation, at rotational velocities far from critical of the disks surrounding them requires a separate explanation.

One way of solving this problem might be to study the properties of Be stars in young open stellar clusters. In the 1980's a number of photometric (Mermilliod, 1982) and spectral (Slettebak, 1985) studies were undertaken which showed that clusters with ages of 14-25 millions years contain the maximum number of Be stars. Fabregat et. al (2000) interpreted their results in a sense that the Be phenomenon is an evolutionary effect and proposed that it could be related to the main the structural changes that had been happing at this evolutionary phase.

In this paper we study and compare population of Be stars in some young open stellar clusters (e.g., NGC 869 & NGC 884, NGC 6871, NGC 6913, NGC 7160 and NGC 7419), which have differentness but have similarities because of close age. The goal of this work is to find new Be stars with a faint emission in the Hα line and a binary star in these clusters. To study long-term spectral variability of the emission spectrum of the Be stars and possible binary some of them, was used the high resolution spectroscopic observations.

2. Observation

Spectral observations of the B and the Be stars in all of the open stellar clusters were carried out at the Crimean Astrophysical Observatory from 1997 to 2007 by using the Coudé focus of the 2.6-m ZTSh telescope. The spectral resolution was about 30000. The signal-to-noise ratio for most of the spectra was about 100. A total of 125 spectra were obtained for 52 B and 48 Be stars in the Hα line region from six young open stellar clusters (e.g., NGC 869 & 884, NGC 6871, NGC 6913, NGC 7160 and NGC 7419).

In 2000 - 2002 years spectral observations of the B and Be stars were made over wavelengths of 4400-4960 Å , in addition to the Hα observations. These spectra were obtained at the Nesmith focus of the 2.6-m ZTSh telescope with a moderate resolution of 2.5 Å and a signal/noise ratio of about 100. The Hβ line, a number of the HeI lines, and several metal lines lie within this spectral range. In all, 32 spectra were obtained for 27 Be stars and 15 spectra for 12 B stars in the region of

4400-4960 Å .

3. h/χ Per

The binary open cluster h/χ Per (NGC 869 and NGC 884) has been well studied by many authors. The distance to the cluster is about 2.3 kpc with a distance modulus of $11^m.4$ - $12^m.0$. Strömgren photometry yields different estimates for the ages of h and χ Per, *logt* = 7.0 and 7.3, respectively, which slightly differe from ages of the clusters remains an open question to this day. The clusters are rich in Be stars, context of Be stars in young clusters are variously estimated form 25 to 50% of the overall number of B stars (Fabregat et. al 2000).

From 1997 to 2002 we obtained 90 spectra for 48 stars in the early spectral class B0-B3 which are members of the h/χ Per cluster. We found no traces of emission in the Hα line in the spectra of 28 of the stars. Several objects which were previously identified as or suspected of being Be stars showed no traces of the emission in the Hα line profile during our observations. These include the stars Oo146, Oo566, Oo717, Oo922, and Oo1268. (Here and in the following the numbers stars for the h/χ Per follow the Oosterhoff catalog (1937).)

An emission Hα line profile was obtained for 20 stars in the h/χ Per cluster. In addition, one new Be star, Oo2296, was observed and it is possible that Oo992 also has a faint emission in the wings of the absorption profile (fig. 1). It can be seen there that faint emission is definitely present in the wings of the photospheric Hα line of Oo2296. The presence of the faint emission in the Hα line is less evident in Oo992 as can be seen in Fig. 1, the Hα line profile for this star is asymmetric and varies in time.

Three Be stars, Oo1161, Oo2242, and Oo2371, manifested significant variability in the emission profile of the Hα line during the time of our observations. The variability in the Hα profile for Oo1161 (fig. 2) and Oo2242 are similar and show up as a change in both the intensities of the blue and red emission components with a characteristic time of hundreds of days and in slow variations in the equivalent width of the line. This type of variability in the emission spectrum is fairly widespread among Be stars and is customarily explained by the one arm oscillations in the circumstellar disk.

Oo2371 (BD $+58^0578$, V622 Per) was observed in more details during 1997-2002 the spectra revealed a regular variability in the Hα line profile (fig. 3). This variability indicates that the star is a binary with an orbital period of about 5.2 days. Both components can be seen in their spectrum. This star appears to have passed through the phase of active mass exchange and little emission in the Hα line wich is been currently

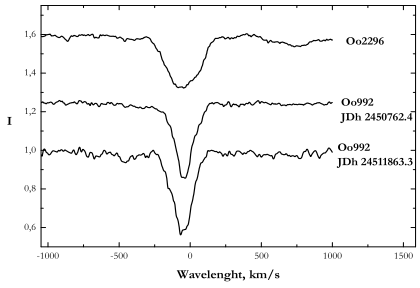

Figure 1: Profiles of the Hα line for the stars Oo2296 and Oo992, from the cluster h/χ per. (The Julian date of the observation is indicated for each star.)

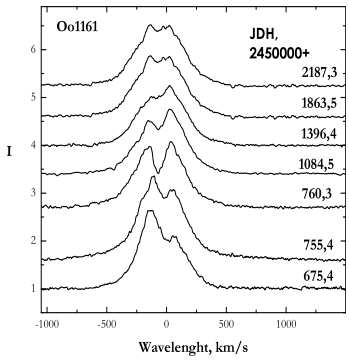

Figure 2: The variability in the Hα profile for Oo1161, member of the cluster h/χ Per.

observing.

In addition to the spectral observations of the Hα line, the moderate resolution spectra were obtained in the range of 4400-4960 Å for a number of the B and Be stars. The Hβ line falls in this range together with the Hα line it manifests signs of emission in most Be stars. In some of the Be stars that were observed the Hβ line profile is in absorption (e.g., Oo1268, Oo2262, Oo2371, and Oo2649). Other stars manifested a weak emission in the Hβ line, e.g., Oo2402, Oo2242, Oo2088, Oo2138, or a bright single component structure (e.g., Oo309, Oo1261, Oo1926, Oo2284, Oo2563). Probably, the last group of objects has more extended and optically thicker disks, unlike the first group, which disks are optically thin, so that emission does not show up in the Hβ line.

4. NGC 6913

This young open cluster in the Cyg OB1 association, is also know as M29, contains a large number of luminous stars with spectral types around B0. An extreme variation of extinction is found by Wang et. al (2000) across the young open cluster NGC 6913, extinction in

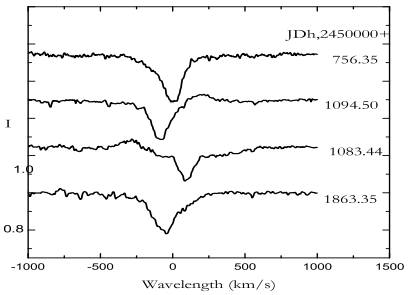

Figure 3: Selected Hα profiles for the Be star Oo2371, the member of the cluster h/χ per.

the cluster center is relatively homogeneous, but very large. The north and south of this cluster have the largest extinction. The eastern and western parts are seem to be low reddening region. The average value of the E(B-V) is 0.71±1.82. A mean distance modulus of 10.17±0.14 mag is derived for the cluster by Wang et. al (2000), which corresponds to a distance of 1.08 kpc. From the UBV photoelectric photometry, Joshi et. at (1983) obtained distance modulus as 10.85±0.15 mag. The estimated ages of a stars in the cluster span from 0.3 - 1.75 Myr (Joshi et.al, 1983) and 10 Myr.

We observed 10 spectra for 7 B stars and one known Be star in the blue region. The spectra of the two stars (1 and 9 (named from Hoag A.A. et. al 1961)) have characteristically the profiles of a more cool star and probably they do not the members of the cluster, but Boeche (2004) these stars found as binaries. For the Be star V1322Cyg (HD 229221) obtain tree spectra in the Hα region. The star has a stronger emission in the Hα and Hβ lines, there are some variability of the profiles from the Hα line. Two spectra in the Hα region were taken for the B star HD 229227, which was determined as a possible Be star; however there are no traces of an emission in the Hα line in time of the our observations.

5. NGC 6871

NGC 6871 is a rather extended open cluster, which boundaries are not well defined. It is believed to be the core of the Cyg OB3 association. The estimates of its distance and age vary relatively from the large amounts to different authors. From isochrone fitting by Massey et. all (1995) was derived from ages of 2-5 Myr for the stars with M $\leq$ 25M$_\odot$, Reimann (1989) estimated an age of 12 Myr and distance modulus 11.9 mag. The difference between two ages suggests that a large age spreads among the cluster numbers, the contamination of the nearby stars in the local spiral arm, or the large uncertainties in the ages approximately derived from optical photometry. Massey et. al (1995) notes that the cluster contains 15M$_\odot$ stars with main sequence of the lifetimes of 11 Myr.

The brightest star in the cluster is the O9.5I+WN4 binary HD190918. Recent searches of emission - line stars by Bernabei et. al (2001) and Balog et. al (2002) detected several faint Be stars and some pre-main-sequence objects. In the period from 1998 to 2002 years were observed a 11 spectra for 7 B stars and 6 spectra for two Be stars in the region of the line Hα. It was also observed a binary V1676Cyg (HD190918). HD 227611 is known as a Be star with strong emission in the Hα line, from period of the our observation profiles of the Hα, it was not shown a variability. The second Be star, which had been obtained, BD +35^{0}3956 has changed from the single absorption to the duplicity emission profile of the Hα line in about 10 days (fig.4). For the stars HD227586 and HD227621 were obtained some spectra, but profile changes of the Hα did not found (see fig.4). Other stars have the clear absorption profiles.

The moderate resolution spectra were obtained in the region 4400-4960 Å for 5 the B and 2 Be stars. The Be star V1676Cyg has a strong emission in the Hβ line and in the other lines such as HeI4471 Å and HeI4712 Å. Line profile of the Hβ for BD +35^{0}3956 is absorption, all lines from this region for the star are broad and this is likely to be group due to the fast rotation. However, the shape of the metallic lines strongly suggests that it is a double-lined spectroscopy binary star (Negueruela, 2008). The star HD 227630 from this region, which is also as in the region of the Hα line, has typically the spectra for cool stars and it is not a member of the cluster.

6. NGC 7419

NGC 7419 is a small, young open cluster in the Cepheus, with unusual presence of gigant and super giants. Form a photometric observation by Bhatt et. al (1993) was found a differential reddening of 1.54 to 1.88 mag with a mean value of 1.71 mag, a cluster distance of 2.0 kpc and the age about 40 Myr. Beauchamp (1994) estimated a younger age of 14±2 Myr and a distance of 2.3 ± 0.3 kps.

Based on a CCD photometric observation of 327 stars in UBV passabands Subramaniam et. al (2006) estimated the cluster parameters as a reddening (E(B-V)) = 1.65 ± 0.15 mag and the distance 2.9 kpc. The turn-off age of the cluster was estimated as 25 ± 5Myr by using isochrones fits. The isochrones fits to pre-MS stars in the optical color-magnitude diagram showed that the turn-on age of the cluster is 0.3 - 3 Myr. This indicates that there has been a recent episode of star formation in the vicinity of the cluster.

From CCD photometry in narrow Hα band, R and I filters, were identified 31 Be stars, that constitute 36 ± 7 % (Pigulski et. al, 2000). With Nesmith

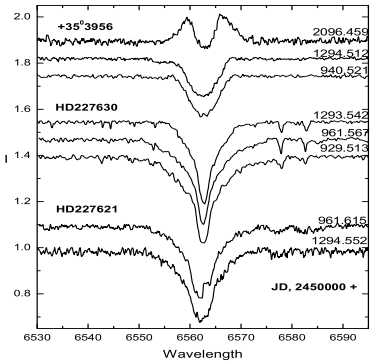

Figure 4: Profiles of the Hα line for the Be and two B stars in the NGC 6871

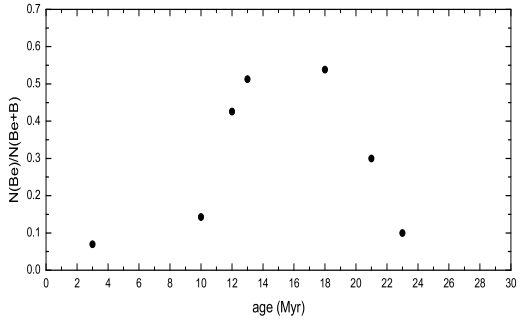

Figure 5: Dustribution of the Be stars as a function of age

spectrograph were observed 30 spectra for 25 Be stars and 11 spectra for 10 B stars in the Hα region. All spectra were taken with a low resolution (about 6-8 Å). The four stars (e.g., 290, 318, 451, 458 and 967, numerous for the stars from NCG 7419 as in Beauchamp et. al (1994)), which previously identified as Be stars, showed weak emission in the profile of the Hα line or absorption profiles of the Hα line during our observations. In the blue region were taken 11 spectra for ten Be stars and one for B star. In the same nights spectra for 7 stars were obtained in both regions. It allows us to see the spectra into the region 3700 - 7850 Å, and to study the emission in the Hα, Hβ and for few stars in the Hγ lines.

7. Results and conclusion

In total, we studied about 140 profiles of the Hα line and 47 spectra in the region of the Hβ for more than 100 stars in the young open stellar clusters. One (possibly two) new Be stars were discovered by mean of the high resolution spectra. The finding of the study especially a small number of new Be stars with faint emission, was unexpected. Given that, up to now this clusters has been observed with a much lower resolution. Some stars manifested a significant long-term variability in the Hα line. It was found that the binary Be star V622Per, which previously had been suspected of being a Be star, is indeed that, with an orbital period of 5.2 days.

The Hα and Hβ lines demonstrated a weak emission or a bright single component structure for the Be stars and a completely absorption profile for some of them.

We used data from the both our observations and literature in order to determine the distribution of the relative fraction of a Be stars in a clusters with an age. This distribution has been show on the fig.5. Data for the clusters, which we studied are marked on fig.5. We can conclude, that the classical Be stars appear in the clusters with age 10 Myr and they are absent or appear very rare in the clusters with age more than 100 Myr. As it seens from fig.5 the maximum content of Be stars are in clusters with age 12-20 Myr. The decrease of the Be abundance with the age after 25 Myr is underlined the dependence of the Be stars abundance from the spectral type. Zorec et. al (1997) found that the maximum abundance occurs in the spectral type of B1-B2. Clusters that are older than 25 Myr have their turnoff at type B3 or late.

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