Study of Be-Stars - Impact on the Evolutionary Stage Understanding

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Abstract

New achievements in the understanding of the Be phenomenon are discussed in the present review. One of the oldest problems of the stellar astrophysics has now surprising and some times paradox developments. They are based on new results obtained from the study of composition and evolutionary status of open stellar clusters members. New knowledge for binary and multiple stars with Be star as one of the components and implementation of the modern technology achievements also improves our understanding of the rather complicated evidences of Be phenomenon.

1 Introduction

Research of the Be-stars and connected with them evidences of the Be-phenomenon are of special interest for the contemporary stellar astrophysics. Despite significant efforts continuing already 134 years there is still no definite understanding of the processes of formation and dissipation of Be-stars circumstellar envelopes. What is more, there is no clear understanding of what the central star is. Scientists are still arguing about the influence of fast rotation, variability of stellar atmosphere patterns, phase changes and presence of hot and cool envelopes.

2 Some History

Just by chance Be-stars were among the first spectroscopicaly distinguished classes of stars. In the middle of XIX century Father Angelo Secchi in Rome, who first discovered Be phenomenon. When he inspected visually the spectrum of two bright blue stars β Lyr and γ Cas he found the line Fraunhofer F (now known as Hβ line of the Balmer series of the hydrogen) to be in emission. He described in 1866 volume of the Comptes rendus of the French Academy of Sciences his discovery . Officially name of Be stars was given by the creators of Henry Draper catalogue in the beginning of XXth century. It simply denoted that the star is from the spectral class B and in addition exhibits emission lines in its spectra. This definition was loose enough and astronomers from the fist half of the century started to use it for several groups of variable stars, sometimes quite different in origin and appearance. Under the name of Be-stars were united:

- pequliar B-type stars, showing presence of rare gas around the star.
- Herbig Ae/Be stars connected with early stages of stellar evolution.
- Oe and Ae type stars, connected with well known groups of Of and chemical peculiar stars.
- β Cep pulsating stars.
- B type super and hyper giants.
- some planetary nebula.

3 Definition for a classical Be star

In his classical review paper J. Dachs (1986) defined Be-stars as "non-supergiant, early type stars whose spectrum shows or has shown at some time, hydrogen lines in emission". This definition is based on recommendations of the IAU Working Group of Be-stars leaded by C.Jaschek (1981).

It is generally accepted that Be-stars share at least one of the following general properties (Dachs, 1986):

1. The underlying (central) early type star on average are among the fastest known rotators. This was first noted by Struve (1931) and confirmed by many other astronomers.

2. There are emission lines in the optical and near infrared spectra. They indicate presence of cool dense envelopes of circumstellar envelope. Conditions in the envelopes are assumed to be like follows: electron temperatures 104 K(or less than the photospheric temperatures) and electron density 1011 to 1012 electrons.cm-3.

3. Profiles of resonance absorption lines in the UV spectra of early- type Be-stars usually reveal variable stellar wind with typical velocities of 500 to 1000 km.s-1 and electron temperatures exceeding effective temperatures of the stars.

4. Virtually all Be-stars show strong irregular variations in their visual spectra and optical brightness on various time-scales.

5. Appearance of emission lines in the spectrum of an early type Be- star represents a transient phase in the life of the star; transitions from normal B phase of the central star with a pure absorption spectrum to a Be-phase of usually limited duration are common phenomenon.

As seen from Fig.1 relative proportion of Be stars to normal stars is in strong dependence from the spectral type (Balona, 2000). One of the explanations is found in the frames of magneto-centrifugal acceleration mechanism. According to it the low number of Be stars earlyer than B1 class is caused by very effective radiatively driven wind which destroys the circumstellar disk. For Be stars of late subclasses there is different reason which influent formation of the envelope. For this group of stars ionization radius decreases. Than it is necessary central star to rotate with velocity closer to the critical value in order that co-rotational radius will cover the ionization one. Obviously there are not so many so fast rotating Be-stars and their relative number decreases with the effective temperature of the stars.

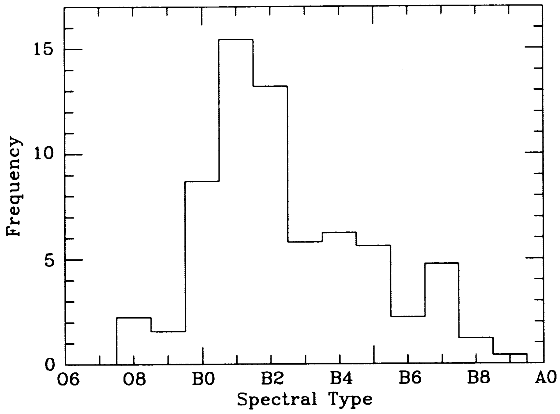

Figure 1: Distribution of the known Be starts as a portion of all stars of spectral class B (from L.Balona, 2000).

It was discovered already by O.Struve in the beginning of XX century that Be-stars are among the fastest rotators among the stellar population in our Galaxy. He also was the first who concluded that rotation could be the mean reason for outflow of mass from equatorial regions of the rotating central star. However later observations did not prove the existence of Be-stars rotating faster than the critical velocity, when centrifugal force compensates the gravitational potential. As we can see from Fig.2 mean observed rotational velocity do not reach critical values, calculated for corresponding spectral subclasses. The difference is larger for the group of BO-B4 subclasses and diminishes to less than 100 km/s for late subclasses. This fact was first reported and discussed by Sletteback (1966, 1976) and statistically proved by many other authors. It is remarkable also that observed maximal rotational velocities are about 350 km/s for all range of B type subclasses.

4 Role of binaries systems in Be-star research

In IAU Symposium 72 'Be Stars' Kriz and Harmanec defend the hypothesis that all Be-stars are members of binary systems. Most important for the characteristics of the Be-phenomenon are 1. The orbital period that determines the dimensions of Rosche lobes; and 2. Intensity of mass transfer. In the frames of this hypothesis the role of fast rotation is not so decisive. Harmanec has shown also that many of the typical for Be phenomenon evidences could find their natural explanation in the frames of supposed binarity. Despite strong argumentation the idea was not accepted at least not for all individual cases. Nevertheless binary Be-stars supply us with powerful instruments to study the

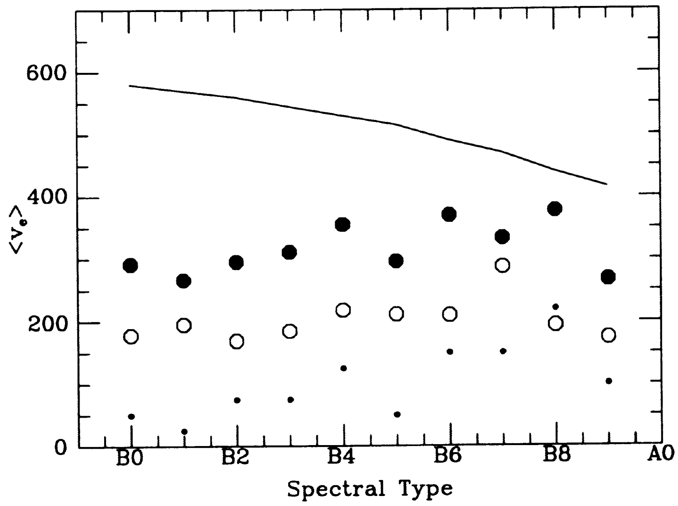

Figure 2: Mean observed rotational velocities compared to the calculated critical rotational velocity for the corresponding spectral subclass. (from L.Balona, 2000).

central stars and detached circumstellar envelopes. One recent field of very intensive work is search for forced oscillations in Be-star binaries. It is aimed to find cause(s) of rapid line-profile changes observed in the visual spectrum of many Be-stars. There are several competing interpretations of this feature, which are inferred by many authors to have decisive role for the mechanism of formation of detached envelopes of Be-stars. Among them we have to mention at least co-rotating structures at the surface or in the circumstellar material, free non-radial pulsation and forced non-radial pulsations. The idea that the duplicity could either trigger or at least modify stellar pulsation was developed in late 60-s in connection with the study of β Cep stars when astronomers realized how many of them are members of binary systems. It is supposed that periodic variations of the gravitational potential caused by binary companion, which is caused by motion on eccentric orbit or by lack of synchronization between rotation of the components, could excite and support observed short period pulsations in one of the components (primary most often). Our own result from the study of Hβ and He I profiles in the spectrum of AR Cas proved the existence of expected LPV and show that they probably have much shorter time-scale than expected: of the order of several tens of minutes.

An interesting possibility to study directly the physical properties and conditions in the circumstellar envelopes of Be-stars, which are members of binary systems, was reported first by Iliev (1994). He found evidences for connection of the variability of some shell spectral patterns with the orbital phase for V923 Aql (Fig.3). The idea was further developed by Arias, Cidale and Ringuelet (1999), who perform deep spectral analisys of the spectrum of the same star.

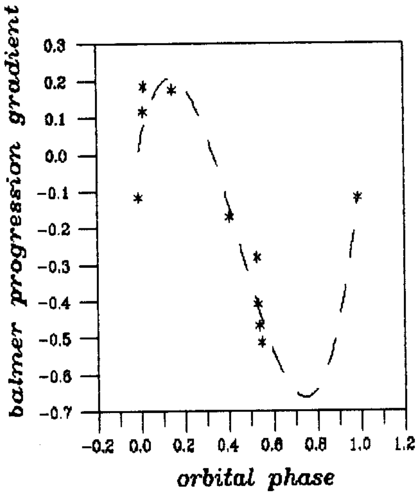

Figure 3: Period dependent changes of the Balmer progression decrement in V923 Aql.

They obtain information about electronic temperature and dimensions, which allows them to build semi-empirical model for the structure of the extended envelope.

5 Physical properties of Be-stars

In his late survey Torrejon (1999) tried to establish strong dependencies between observed properties of Be-stars members of open clusters and physical conditions in their central stars atmospheres. In general terms he separates the contribution of the spectrum of the central star from that of the circumstellar envelope. In open clusters there are ideal conditions to perform this. Be-stars there are of similar age and composition and on the Teff - L diagram their position is presented by a izohrone line. Torrejon presented results of combination of uvbyβ photometry and spectroscopy. The following results were obtained:

- On (b - v) - Mv plane Be-stars are shifted to redder positions in comparison with "normal" B stars. This fact reflects additional reddening caused by hydrogen free-free transitions in the envelope, which changed the slope of the Paschen continuum.

- On c_0 - Mv plane there are two distinguished groups of Be-stars. For Be stars belonging to classes earlier than B5V - c_0 values are smaller (bluer) because of the free-bound transitions in the envelope. For later type Be stars show regular or large values of c_0 indicating additional absorption in the Balmer discontinuity with an origin in the detached envelope.

When the intrinsic photometric indexes were obtained one can use standard calibrations and obtain the physical parameters of the central star e.g. Teff and log g . To study other parameters of the Central stars Torreyon used decrement plots of D_{34} to D_{54}. For high emission envelopes he obtain electron densities of $N_e \cong 10^{11}$ - 10^{13} . For smaller envelopes he obtained higher electron densities, which could be understood in terms of luminosity conservation in the envelope (Torreyon and Fabregat, 1999).

General conclusions of the study of Be-stars in open clusters that concern evolutionary stage of this stars could be summarized as follows: Be-stars do need some minimal time and "hence Be-stars could not be very young objects". Torreyon invoked terms of binary system evolution to fulfill this time limit.

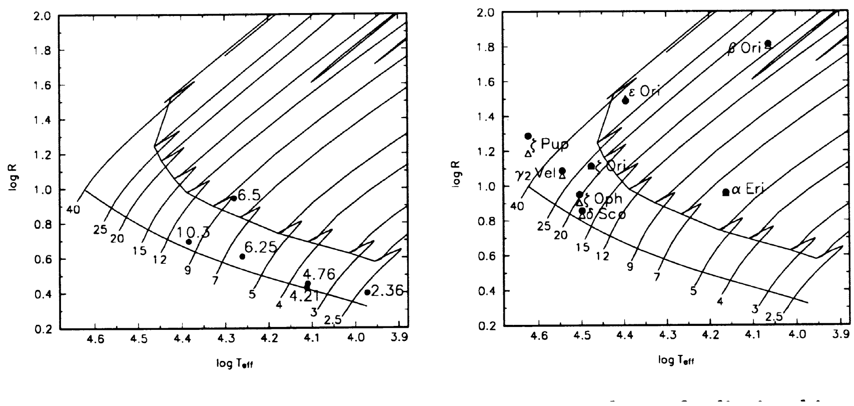

Figure 4: L_{eff} and R_* obtained from orbital parameters of known binary systems. (from P.Harmanec, 2000).

6 Be-stars in open clusters

Large number of studies of Be star population in open clusters resulted in development of new basic for models of Be-phenomenon.

- Sletteback (1975) was the fist who made systematic study of Be- stars in open clusters. He came to the conclusion that Be-stars could exist at different evolutionary stages pointing that the unevolved stage near the zero- age main sequence have to be included as well.

- Already at IAU Symposium 72 of Be-stars Schild and Romanishin (1976) reported results from Hα spectroscopy of 566 stars from total 29 young galactic open clusters. They inferred ages and intrinsic (B-V) colors to perform first thorough study of the evolutionary state of Be-stars. Their conclusion were that fast rotating star could become Be-star in the early stage of hydrogen burning when the stars evolve away from the main sequence. Fraction of stars showing hydrogen line emission as well as the distribution of emission strength are nearly constant during first 80post main sequence evolution. However when the gravitational core contraction starts both the fraction of emission stars and the emission strength showed increase of up to 4 times. Results of Schild and Romanishin show also that many Be-stars in the core contraction phase show an intrinsic (B-V) excess of up to 0.15 amplitude because of the effect of free-bound continuum radiation of H-1. Results from this study were put at the grounds of many of the latest modeling of Be-stars.

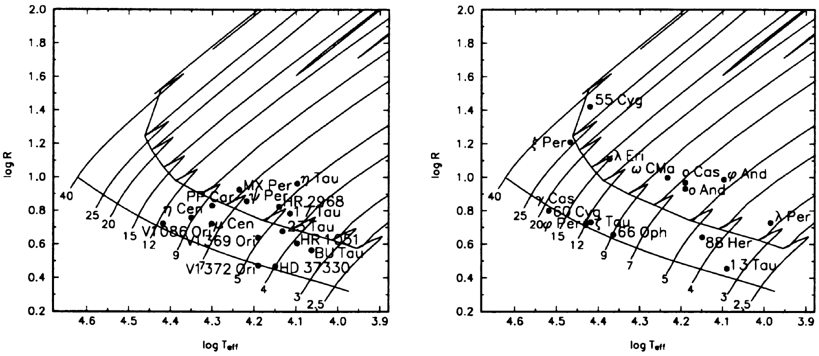

Figure 5: L_{eff} and R_* obtained from Hipparcos observations. (from P.Harmanec, 2000)

- Recently Steele, Neguerella and Clark (1999) used powerful instruments and newest results for stellar atmosphere modeling to study again distribution of Be-starts. They confirmed that there is no difference in distribution between "normal" B class stars and Be-stars. This should be regarded in favor of the conclusion that all normal stars of spectral class B are potential candidates to became Be-stars.

Results from open clusters members and comparison with the data from Hipparcos were performed recently by Harmanec (1999). With the aim to obtain systematic observational information about Be stars, Harmanec studied the widest possible sample of B type emission stars of all luminosity classes. He derived on first place values of the radii and masses for Be stars known to be members of eclipsing binaries. For those of them with sure orbital elements it is possible to obtain directly values of their radii and masses. Results are shown on left panel of Fig.4. Evolutionary tracks were taken from Schaller et al. (1992) for comparison. On the right panel of the same figure are plotted results for individual Be stars obtained from astrometric measurements of Hipparcos satellite. Harmanec systematized also the data for Be stars from open stellar clusters (Fig. 5). On both figures the terminal Main Sequence is also plotted. It is clearly seen that Be stars included into this representative sample have already started their evolution away from the MS stage.

- In his study he collected results for Be-stars which are members of open clusters and associations and have good Hipparcos measurements of their paralaxes and radii. He added as well Be-stars from the galactic field with reliable individually measured paralaxes. Harmanec compiled also observed properties of all known Oe and Be stars and compared them with results from cases of detached binaries Harmanec (1988). Comparison was made with the evolutionary tracks calculated by Geneva group (Schaller et all. 1992). In this set of tracks new values of opacities were used and for Z was chosen value of 0.02.

Interesting and important detail for the study of Be-stars was that mass loss was included in calculation of the tracks. Harmanec also compared radii of Be-stars members of open clusters and for which Hipparcos paralaxes could be used with radii obtained from research of Be stars belonging to the field.

Two conclusions were emphasized by Harmanec: - Although there are some Be-stars having masses and radii similar to normal B stars, no stars close to the ZAMS were found. This results is in support of conclusions of Fabregat and Torrejon (1999) that Be phenomenon could occur dominantly during the second half of main-sequence stage of B type stars. - In half of the eclipsing binaries there is significant discrepancy between directly derived mass and the evolutionary mass. This should be consequence of significant mass exchange in the systems.

Harmanes also calls attention on new studies of the fraction distribution of the Be stars as a function of spectral subclasses. He found indications that the distribution has different maxima in different clusters. There exists not only one maximum at B2-3 as pointed in the work of Slettebak (1976) but also at B8 although not so prominent.

Recently new results concerning Be stars evolutionary status were widely discussed. In their work Maeder et al. (1999) studied early B type emission-line stars from globular clusters in our Galaxy, as well as in Large and Small Magellanic Clouds. They found that the fraction of Be among normal B stars increases with the metallicity Z. The conclusion the authors do is that higher rotational velocity must be in connection with low metallicity and with chemical composition in general. Although in the studied sample of stars the fraction of Be stars in the phase of strong emission is higher than the average, the fact still need to be embraced by the theory of Be-phenomenon.

Conclusion

Coming to the final part of our review let us try to see the themes of the continuing saga of Be stars research from a different, more distant point of view. Let us try to imagine what could be expected in a near future from a research of this group of very close to our Sun stars, stars that form large part of the stellar population in nearby regions of the Galaxy and also stars that are among the brightest visible on our sky? After recent results in the research of Be-stars in open clusters and binary systems that changed deeply our understanding of their evolutionary stage, astronomers pointed their attention again to the problems of formation and dissipation of the circumstellar material that forms the detached envelopes. Observations with very high accuracy of individual objects (as by good chance Be stars are close enough to allow this) perhaps will lead us toward final solution of one of the oldest problems in the stellar astrophysics.

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