Binaries Among Be Stars

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Abstract:

Binarity as an explanation of some observed properties of Be stars, such as the fast rotation and the presence of circumstellar disks, was suggested nearly 40 years ago. Although not well accepted initially because of the lack of supporting data, this hypothesis gained solid grounds with the advent of high resolution spectroscopy. Many bright Be stars have been recognized as primary components of binary systems over the last two decades. I will review the current binary statistics among Be stars, discuss methods of detecting binaries, and briefly present recent results on newly found binary systems.

Keywords: Astronomy | Binary stars | Be stars

Article:

1. Introduction

The first star with emission lines in its spectrum, γ Cassiopeae, was discovered by means of visual spectroscopy nearly 150 years ago. A few dozen other bright stars were found to show both bright and dark lines by the end of the 19–th century (Campbell 1895). Initially, the presence of line emission was the only property that distinguished them from other stars. These stars formed a separate class of Be stars (Merrill et al. 1925). These authors published a list of 90 hot emission-lined stars which contained several O-type stars and B-type supergiants. Later it was found that many of them have a nearly main-sequence luminosity and a rapid rotation. With time, it also became clear that a Be star is a B-type star surrounded by a gaseous disk (e.g., Struve 1931). The majority of Be stars was assumed to be single, and a possibility of their binarity was not considered until 1970's. Since it is believed now that most massive and hot stars are born in at least pairs (e.g., Preibisch et al. 2000), it is natural to expect that a noticeable fraction of Be stars can be members of binary systems. Below I will attempt to review what is known about Be binaries. I will only cover binaries with a Be primary and a non-degenerate secondary companion.

2. The Binary Hypothesis and Its Observational Support

A hypothesis to explain the fast rotation of Be stars by mass transfer between components in binary systems was proposed by Křiž & Harmanec (1975). The spin-up mechanism involved transfer of angular momentum the component that is later observed as a Be star. Not long after the hypothesis was suggested, Polls et al. (1991) theoretically showed that only 5–30% of all Be stars could be explained by this scenario. There is also a possibility that some Be stars might have been spun-up during the time of their formation.

Let me now consider observational data about Galactic Be stars and Be binaries in particular. Nearly 30 years ago a catalog of 1159 Be star candidates from the brightest to as faint as ∼13 mag. was compiled by Jaschek & Egret (1982). Recently I examined this catalog and found that over a half of its content is either represented by emission-line stars of other classes (e.g., supergiants andWolf-Rayet stars) or objects with line profiles that are not good enough to conclude of their Be status (Miroshnichenko 2011). As a by-product of this study, I compiled a list of ∼340 brightest Be stars ($V \leq 8.3$ mag), collected recent photometric, spectroscopic, polarimetric, and interferometric data for them, and investigated a binary population of this selection.

Before describing the results of this study, I briefly mention published lists which contained Be binaries. Pavlovski et al. (1997) reported 16 spectroscopically revealed binary Be stars, three of which were interacting. Gies (2000) presented a list of 40 binaries, binary of 13 of which was not confirmed. At the same time, Harmanec (2000) compiled a list of nearly 160 binaries, 28 of which were single-line spectroscopic Be binaries (two unconfirmed cases). Most recently, Chini et al. (2012) took high-resolution spectra of several hundreds of hot stars and found 17 double-lined unreported spectroscopic Be binaries. The latter cases need further confirmation, because binary was concluded mostly from the presence of any observed spectral line variability.

Analyzing all these lists and searching through publications on other Be stars, I found

that there are 13 binaries among the Be stars brighter than the visual magnitude $V = 4$, and 67 binaries among 245 Be stars brighter than $V = 8$ mag. (see also Miroshnichenko 2011, for a graphic representation of this statistics). Not every Be binary has a measured orbital period. Some of them are visual binaries, some others were detected interferometrically (e.g., Mason et al. 2009). Spectroscopic periods of some reported binaries need to be re-examined. One of such cases, β CMi, is described by Folsom (2014). Information about the brightest Be binaries is presented in Table 1. Nevertheless, the main conclusion from this statistics is that since over 50% of the brightest Be stars are binaries, there is no reason to think that this fraction is lower for fainter stars.

Table 1. Brightest Be binaries

Name	**MK**	**V**	**EW (Hα)**	**Period**	**Sep.**	**Ref.**
α Eri	B3 V	0.5	~3	15 years	≤150	1
δ Sco	B0.3 IV	1.6-2.3	0-25	10.8 years	6-200	2
γ Cas	B0 IV	2.1-2.8	20-30	203.5 days	9.0	3
δ Cen	B2 IV	2.6	~40		68.7	4
η Tau	B7 III	2.9	~6	4.2 days		5

α Ara	B2 V	2.95	33	74 days		6
ζ Tau	B4 III	2.9-3.0	5-20	132.9 days	9.1	7
μ Cen	B2 V	3.0-3.5	weak	IR-companion	4637	8
η Ori	B1 V	3.4	weak	triple		9
O And	B6 III	3.6	weak	33.1 days	1.6	10
17 Tau	B6 III	3.6	weak	4.3 days		5
β Mon A	B3 V	3.8	~20	visual	3000	11
k Dra	B6 III	3.9	~20	61.55 days		12

Column information: 1 – Name of the star, 2 – MK type, 3 – visual brightness, 4 – equivalent width of the Hα line, 5 – orbital period, 6 – companion separation in milliarcseconds, 7 – reference to a most recent paper on binary of the star.

Reference mentioned in column 7: 1 – Kervella et al. (2008) 2 – Miroshnichenko et al. (2013), 3 – Nemravová et al. (2012), 4 – Meilland et al. (2008), 5 – Jarad et al. (1989), 6 – Chesneau et al. (2005), 7 – Harmanec (1984), 8 – Shatsky & Tokovinin (2002), 9 – Mason et al. (1997), 10 – Harmanec et al. (1987), 11 – Hartkopf et al. (2012), 12 – Juza et al. (1991)

β CMi (V=2.9 mag) is not included in this list since its orbital period is not confirmed.

Another statistical result from my study of the brightest Be stars is that there is a trend toward a larger binary fraction for objects with stronger Hα lines (see Fig. 1 in Miroshnichenko 2011). Although this result is derived from a small number statistics, it may indicate that binarity is responsible for Be stars with the strongest emission-line spectra. It may also suggest targets to search for signs of binarity. At the same time, weak-lined Be stars may be both single and binary. No explanation of how binarity makes emission-line spectra stronger is suggested, but a long-term monitoring of objects with strong emission lines is definitely worthwhile.

The sparse data on orbital periods of the Be binaries also allows certain conclusions. A plot of maximum equivalent widths of the Hα line in the spectra of Be binaries versus orbital periods is shown in Fig. 1. In this plot, objects of early B-types show a similar dependence as Be/Xray binaries (Reig et al. 1997). The latter typically have an O-type or an early B-type primary companion. Be stars of late B-type (B5–B8) show a similar dependence but with weaker Hα lines for the same orbital periods. This might be due to inability of cooler stars to ionize the entire circumstellar disk. Using these relationships, one could roughly estimate possible orbital period. For instance, the preliminary period found from the V/R variations of the Hα line in β CMi (Folsom 2014) is consistent with the relationship for late B-type objects and its average Hα equivalent width of ∼10 Å.

Qualitatively this relationships can be explained by a larger volume available for the disk in wider pairs. Objects on long-period eccentric orbits (e.g., δ Sco) would not fit in this picture, because the mass loss from the primary stars in them may be enhanced during very close periastron passages. Additionally, the disk may be severely disturbed at the time around periastron (see Miroshnichenko et al. 2013).

3. Methods and Problems of Revealing Be Binary Systems

Several methods are currently being used to reveal Be binaries. Regular photometric variations are observed in eclipsing systems, but such Be binaries are very rare. Spectroscopically they can be recognized if the following phenomena are observed:

1. regular radial velocity variations of emission or absorption lines. Examples: ζ Tau, γ Cas (Nemravová et al. 2012), _ Aqr (Bjorkman et al. 2002).

2. regular variations of the peak intensity ratios (V/R variations) in the emission lines (typically in the Hα line). Examples: π Aqr (Zharikov et al. 2013), 4 Her (Koubsky et al. 1997), and β CMi (Folsom 2014).

3. composite spectra (rare). Examples: AXMon.

So far 4 Her and π Aqr are the only Be binaries for which the orbital period has been detected by two independent spectroscopic methods. Although periodic V/R variations are observed in a number of Be stars, they seem to be locked with the orbital phase only for weaklined objects. Strong-lined ones (e.g., γ Cas and ζ Tau) show much longer periods of the V/R variations compared to the orbital periods. This effect may be due to different types of perturbations induced by the tidal interaction between the components.

Difficulties in application of the spectroscopic methods include low-amplitude radial velocity variations (e.g., $\sim$7 km s^{-1} for γ Cas Nemravová et al. 2012), long-term aperiodic trends in the mid-point of the radial velocity curve (γ-velocity), the presence of more than two components (known triple Be stars are o Cas and 66 Oph, while o And is a quadruple system), and possible interference of the orbital period and the V/R period (if they are different). Not many Be stars have been observed long and frequently enough to make a conclusive use of these methods. For some objects long-term V/R variations have been detected (e.g., 48 Lib), but binarity has not been confirmed.

Be binaries have been also discovered or confirmed by interferometry. Examples include δ Sco, 66 Oph, o Cas. Objects with large eccentric orbits or with comparable companion brightness are better targets for interferometry than short-period binaries with large brightness ratios.

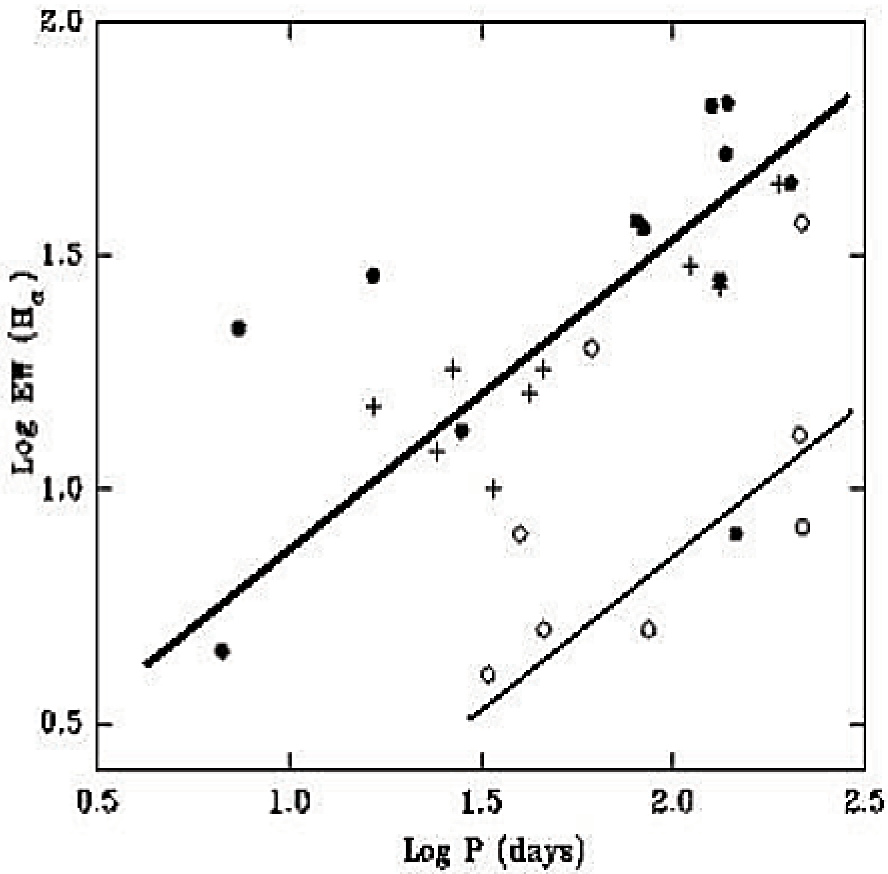

Figure 1. Relationships between the maximum observed equivalent width of the Hα line and the orbital period for known Be binaries. Be stars with spectral types between B0 and B4 are shown by filled circles, those between B5 and B9 are shown by open circles. Crosses represent Be/X-ray binaries from Reig et al. (1997). Some of the orbital periods used for this plot need re-examination (e.g., that of χ Oph, see Sect. 4)

4. Objects to Look for Binarity or Re-Examine It

As it was mentioned above (see Sect. 2), strong-lined Be stars may be good candidates to search for binarity. A short list of such binary candidates was presented in Miroshnichenko (2011). A more complete list of Be stars whose binarity has not been revealed and whose Hα emission line has been detected to have an equivalent width that exceeded 40 Å includes the following objects: ψ Per, V742 Mon, V764 Cas, EWLac, V777 Cas, NVPup, V659 Mon, MWC19, MWC376, HD60006, V795 Cen, MWC381, and MWC724. Weak-lined Be stars, especially those of late B-types, can be probed for periodic V/R variations. This method of revealing binarity needs to be tested on more objects. Many bright stars can now be easily observed spectroscopically with small telescopes, and it is worth monitoring them to search for periodicities. As mentioned above, 13 out of 24 Be stars brighter than $V = 4$ mag are recognized binaries. The remaining 11 still need to be monitored. There are only 16 recognized binaries out of 45 Be stars with brightness between $V = 4$ and 5 mag, while the other 29 have not been studied enough to conclude on their binarity. Harmanec (2000) called for re-examination of the orbital periods of some Be stars found by Jarad et al. (1989). These objects are η Tau, 48 Per, β CMi, ν Gem, and χ Oph. Binaries discovered by interferometry with no measured orbital periods also need to be observed spectroscopically to search for periodic variations. Some examples of such objects are FV CMa, 8 Lac, θ Cir, MWC604, and ϕ And.

5. Conclusions

My analysis of published photometric, spectroscopic, and interferometric data for 340 Be stars brighter than $V \sim 8$ mag shows that the binary fraction for this class of objects should be over 50% based on the statistics for the brightest and most well-studied ones. There is also a tendency for strong-lined Be stars to be primary components in binary (or multiple) systems. A list of the strongest Hα emitters is suggested to be checked for binarity.

Provisional relationships between the H_ line equivalent width and orbital period are presented for the early (B0–B4) and late (B5-B9) Be stars. The relationship for the early B-type objects is very similar to that found for Be/X-ray binaries by Reig et al. (1997). Late B-type objects show a similar slope of the relationship, but their Hα lines are weaker for the same orbital periods probably due to a lower ability of the central stars to ionize the circumstellar disk.

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Questions and comments

(K. Bjorkman) You have pointed out the critical requirement for long-term monitoring of bright Be stars at moderate resolution. I know that you have been working with the amateur astronomy

community members who are now doing spectroscopic monitoring at low to medium resolution. Would you care to comment on the importance of that resource for these kinds of studies?

(A. Miroshnichenko) Now there are hundreds of spectra in the BeSS database. This is a good source for spectroscopic studies of Be stars. Although the data reduction need to be carefully checked, amateur spectroscopy has already made an important contribution to studies of emission-line stars and to studies of Be stars in particular.

(D. Baade) For Anatoly Miroshnichenko: “How many Be stars are Be stars because they are not single?”

(A. Miroshnichenko) I think all stars which we see as Be stars at some point (because they may loose disks) and which do not develop large disks can be single, but not necessarily single.

(D. Baade) For Anatoly Miroshnichenko: “How does the distribution of orbital periods of Be binaries compare to this distribution for “normal” B stars?"

(A. Miroshnichenko) I have not studied the distribution of orbital periods of “normal” B stars, but am planning on doing that.

(D. Baade) Anatoly Misroshnichenko (comment after a question by him to Leandro Rocha Rimulo): "Bumpers were often found by MACHO as false positives of gravitational lensing events because the selection criteria included low color variation and a roughly symmetric rise and fall of the light curve."