High-mass X-ray Binaries: Illuminating the Passage from Massive Binaries to Merging Compact Objects
Proceedings IAU Symposium No. 346, 2019
L. M. Oskinova, E. Bozzo, T. Bulik & D. Gies, eds.

doi:10.1017/S1743921319002217

Detection of the progenitors of Be X-ray Binaries

Douglas Gies[1], Luqian Wang[1] and Geraldine Peters[2]

[1]CHARA, Dept. of Physics & Astronomy, Georgia State University, P.O. Box 5060, Atlanta, GA 30302-5060, USA
emails: gies@chara.gsu.edu, lwang@chara.gsu.edu

[2]Space Sciences Center, University of Southern California, Los Angeles, CA 90089-1341, USA
email: gpeters@usc.edu

Abstract. A recent survey of the far-ultraviolet spectra of 264 B-emission line stars has revealed 16 systems with hot companions that are the stripped down remains of a former mass donor star. Some of these will probably become Be + neutron star X-ray binaries in the future. The actual numbers of such systems may be large, because the detected systems have companions that occupy the brief and bright, He-shell burning stage of evolution.

Keywords. binaries: spectroscopic, stars: emission-line Be, stars: evolution

1. Binary Origin of Be Stars

Be stars are rapidly rotating, B-type stars that eject equatorial disks, which are detected through their line and continuum emission (Rivinius *et al.* 2013). The origin of their rapid rotation may be related to mass and angular momentum accretion in an interacting binary (Pols *et al.* 1991). Depending on the original masses of the two component stars, Roche lobe overflow can strip the outer envelope of the mass donor star, while the gainer star increases in both mass and spin. The outcomes include Be + neutron star systems (observed as Be X-ray Binaries = BeXRBs; Reig 2011), Be + helium burning cores, and Be + white dwarf remnants. Some of the immediate progenitors of BeXRBs may consist of a Be star and He star remnant with a mass greater than the Chandrasekhar limit, and these remnants will explode as H-deficient supernovae.

It is important to search for such BeXRB progenitors among Be stars with stripped He star companions. However, it is difficult to detect such faint companions because they are lost in the glare of the much brighter Be stars. However, the hot companions do contribute relatively more flux at shorter wavelengths, and their line spectra are particularly rich in the far-ultraviolet, so the few detections thus far have resulted from analysis of their ultraviolet spectra (although some are detected through line emission from hot gas in the vicinity the He star: see the case of HD 55606 by Chojnowski *et al.* 2018). The detections from UV spectroscopy include ϕ Per (Mourard *et al.* 2015), FY CMa (Peters *et al.* 2008), 59 Cyg (Peters *et al.* 2013), 60 Cyg (Wang *et al.* 2017), and HR 2142 (Peters *et al.* 2016). All of these systems were known to be spectroscopic binaries in advance of their companion detection in the ultraviolet. However, successful detection of hot companions should be possible in favorable cases even if the system is not a known binary. This report summarizes a survey made by Wang *et al.* (2018) to find new cases of Be + He star binaries.

2. IUE Survey of Be stars

Wang *et al.* (2018) gathered all the available ultraviolet spectra from the archive of the International Ultraviolet Explorer Satellite for a sample of 264 Be stars from the catalog of Yudin (2001). These are Short Wavelength Prime camera observations made with the high dispersion grating (yielding a spectral resolving power of ≈ 10000). Each of the spectra were cross-correlated with a model spectrum appropriate for a He star with an effective temperature of $T_{\rm eff} = 45000$ K. All of the known He star companions have spectra with very sharp lines indicative of a small projected rotational velocity, so the presence of a hot companion is revealed by a sharp peak in the cross-correlation function (CCF). All of the CCFs were tested for the presence of a narrow peak that attained a CCF maximum greater than three times the standard deviation of the scatter in the extreme velocity parts of the CCF. The analysis led to the confirmation of detections for ϕ Per, FY CMa, 59 Cyg, and 60 Cyg, plus twelve new candidate Be + He star systems, effectively increasing the known sample by a factor of three.

Although none of the twelve candidate systems are known binaries, there was a sufficient number of archival spectra for eight of them to demonstrate the Doppler shifts and orbital motion of the He star companion. New spectroscopic observations are now underway at Apache Point Observatory and Cerro Tololo Interamerican Observatory to measure the small orbital motion of the Be star and to search for any optical band spectral features from the He star. The He star companions are relatively faint and generally contribute less than 5% of the combined monochromatic flux in the ultraviolet spectrum, but a new program of Hubble Space Telescope observations in Cycle 26 will provide the ultraviolet spectroscopy needed to characterize the orbital and physical parameters for these binaries.

3. Are there other stripped-down companions?

Mass estimates are only known for six systems with full orbital solutions, and of these only the He star companion of 60 Cygni has a mass greater than the Chandrasekhar limit ($M(\text{He star}) = 1.7 M_{\odot}$; Wang *et al.* 2017). Thus, the He star in 60 Cygni may be a future supernova candidate, and the binary may be a progenitor BeXRB system. All the Be + He systems discovered to date have relatively hot and massive Be primaries, and 12% of B0-B3 types in the survey have detected companions (Fig. 1). Schootemeijer *et al.* (2018) studied the evolutionary state of the He stars in ϕ Per and several other systems, and they argue that these stars are in a luminous and short-lived stage of He-shell burning that occurs after the longer duration He-core burning stage. If so, then there probably exists a much larger population of systems in this He-core burning stage with He stars that are too faint to detect by current means. For He stars like that in ϕ Per, Schootemeijer *et al.* (2018) estimate that the He-shell burning phase lasts only about 3% of the total lifetime, so that the total number of Be + He star systems should be about 30 times greater than the detected number. With a 12% detection rate among the early Be stars, this would suggest that all Be stars have stripped down companions.

Wang *et al.* (2018) found no Be + He star binaries among the cooler, low mass Be stars of types B4 - B9, even though their sample of targets was more than adequate to detect such systems if they occur with a fraction similar to that of the hotter Be stars (Fig. 1). The lack of Be + He star systems among the low mass Be stars was anticipated by Pols *et al.* (1991; see their Fig. 4b), who suggested that low mass systems probably host white dwarf companions with masses too small to ignite He burning. Such Be + white dwarf binaries may be detected in cases where the inclination permits mutual occultations of the components. One tell-tale case is KOI-81 (Matson *et al.* 2015), an eclipsing binary discovered in the NASA Kepler field-of-view. The primary of KOI-81 is a rapidly rotating

https://doi.org/10.1017/S1743921319002217 Published online by Cambridge University Press

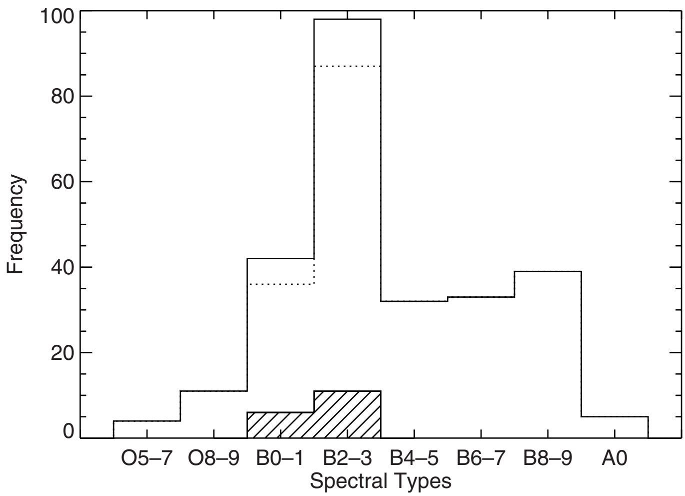

Figure 1. Histograms of the spectral type distributions of the full Be star sample (solid line), those with no detections (dotted line), and those that are known or candidate Be + He star systems (line filled) (from Wang *et al.* 2018).

B8 V star with a low mass $0.19 M_{\odot}$, hot subdwarf in a 23.9 day orbit. The cooler Be stars may be the hosts of similar kinds of remnants that are destined to become white dwarfs.

Acknowledgments

This work was supported in part by NASA grant NNX10AD60G (GJP) and by the National Science Foundation under grant AST-1411654 (DRG).

References

Chojnowski, S.D., Labadie-Bartz, J., Rivinius, T., Gies, D., Panoglou, D., Borges Fernandes, M., Wisniewski, J. P., Whelan, D. G., Mennickent, R. E., McMillan, R., Dembicky, J. M., Gray, C., Rudyk, T., Stringfellow, G. S., Lester, K., Hasselquist, S., Zharikov, S., Levenhagen, R., Souza, T., Leister, N., Stassun, K., Siverd, R. J., & Majewski, S. R. 2018 *ApJ*, 865, 76

Matson, R. A., Gies, D. R., Guo, Z., Quinn, S. N., Buchhave, L. A., Latham, D. W., Howell, S. B., & Rowe, J. F. 2015, *ApJ*, 806, 155

Mourard, D., Monnier, J. D., Meilland, A., Gies, D., Millour, F., Benisty, M., Che, X., Grundstrom, E. D., Ligi, R., Schaefer, G., Baron, F., Kraus, S., Zhao, M., Pedretti, E., Berio, P., Clausse, J. M., Nardetto, N., Perraut, K., Spang, A., Stee, P., Tallon-Bosc, I., McAlister, H., ten Brummelaar, T., Ridgway, S. T., Sturmann, J., Sturmann, L., Turner, N., & Farrington, C. 2015, *A&A*, 577, A51

Peters, G. J., Gies, D. R., Grundstrom, E. D., & McSwain, M. V. 2008, *ApJ*, 686, 1280

Peters, G. J., Pewett, T. D., Gies, D. R., Touhami, Y. N., & Grundstrom, E. D. 2013, *ApJ*, 765, 2

Peters, G. J., Wang, L., Gies, D. R., & Grundstrom, E. D. 2016, *ApJ*, 828, 47

Pols, O. R., Cote, J., Waters, L. B. F. M., & Heise, J. 1991, *A&A*, 241, 419

Reig, P. 2011, *Ap&SS*, 332, 1

Rivinius, T., Carciofi, A. C., & Martayan, C. 2013, *A&AR*, 21, 69

Schootemeijer, A., Götberg, Y., de Mink, S. E., Gies, D., & Zapartas, E. 2018, *A&A*, 615, A30

Wang, L., Gies, D. R., & Peters, G. J. 2017, *ApJ*, 843, 60

Wang, L., Gies, D. R., & Peters, G. J. 2018, *ApJ*, 853, 156

Yudin, R. V. 2001, *A&A*, 368, 912

https://doi.org/10.1017/S1743921319002217 Published online by Cambridge University Press