Abstract

Classical OBe stars are rapidly rotating OB stars with emission lines produced in a decretion disk. The origins of the fast rotation and subsequent disk are not yet well understood. In this work we add to the growing evidence that OBe stars form from massive binary systems. The model proposes that OBe stars gain angular momentum if their massive companion evolves to fill its Roche lobe. These close binary interactions should result in OBe stars residing farther into the field on average than OB stars, because mass transfer can prolong the life of the OBe star, allowing it to drift farther in the field, as the companion losses mass. Supernova progenitors can impart a runaway velocity on the OBe star. To test for this effect we compare the distributions between OBe stars and their nearest O stars in the Small Magellanic Cloud. These distances serve as an effective measure of how far into the field each star resides. We find that OBe stars reside at a median distance of 36 ± 3 pc into the field vs 22 ± 1.8 pc for OB stars, consistent with the expectation that post-mass-transfer objects are more isolated. Furthermore, the Oe and Be populations themselves are equally isolated in the field, with Oe stars residing at 34 ± 1.4 pc into the field and 39 ± 5.0 for Be stars. This is to be expected if their birth masses are obscured by mass transfer. We note that OBe stars and high-mass X-ray binaries (HMXBs) are closely related, with 39/45 HMXBs in the sample being OBe stars. These HMXBs have a median distance of 48 ± 6.5 pc, which further supports the scenario that most OBe stars are post-binary supernova objects released into the field. Finally, we show that supergiant OBe stars, which are known to not have formed via binary interactions, have a spatial distribution consistent with OB supergiants rather than non-supergiant OBe stars. Our analysis therefore finds multiple lines of evidence supporting the binary formation model of OBe stars, which has implications ranging from binary population models to gravitational wave astronomy.

Background

Classical OBe stars are non-supergiant OB stars that exhibit Balmer emission lines in their spectra, first observed in 1830. The emission lines result from circumstellar disks that are expelled by near-critical stellar rotation (e.g., Rivinius et al., 2013), and how the stars obtained their fast rotation is not well understood.

The focus of this research is to test the model that these circumstellar disks form from the transfer of mass and angular momentum in massive binaries (KZ & Hamann, 1975). In the binary model, the Be star transfers mass to its Roche-lobe-filling companion which becomes a donor to the Be star and becomes a mass donor to the companion. By doing so, the mass donor increases the mass gainer’s angular momentum enough to generate the decretion disk. Massive donors later explode as supernovae, accelerating the mass gainers and often unbinding them from star clusters in a binary supernova ejection (e.g., Blaauw 1961).

If OBe stars form in binary systems as described above, their enhanced transversal velocities would cause them to be more isolated than OB stars not in similar binary star models for the OBe phenomenon. The work presented here confirms that OBe stars in the Small Magellanic Cloud (SMC) are more isolated than non-OB stars, strongly supporting this model.

Results

Figure 1 below plots the cumulative distribution function (CDF) of the projected separations between different types of massive stars in the SMC and their nearest O stars that are not Oe, HMXB or supergiant. Figure 2 – Cumulative distribution functions of distances to the nearest O-type star for different star populations. The top and bottom axes show separation in pc and degree, respectively. The upper right panel of Figure 2 represents the estimated cumulative CDFs for 47 Oe stars. We note that the CDF for the Oe stars tends to increase more gradually than that of the Be stars, implying that the Be stars are more isolated from other massive stars, whereas the Oe stars tend to cluster together more closely.

The main results from this plot are:

- OBe stars reside consistently further into the field than both OB stars and evolved OB supergiants.
- The Oe population and the Be populations CDFs reside in the same loci. OBe stars approach the high-mass X-ray binaries (HMXBs), a known post-OB binary population, in degree of separation.
- OBe supergiants are found at the same distances as OB supergiants and not with the Oe stars. This is consistent with an evolved population that has a second origin for the emission lines, which are believed to be formed in the stellar winds rather than a decretion disk (Puls et al., 2008).

These trends are supported by Mann-Whitney statistics, which test for difference in location of distributions.

- The p-values for comparing the Late O vs Oe and B vs Be CDFs are 0.089 and 0.005, respectively. In contrast, p > 0.5 for both Late O vs B, and Oe vs Be.
- The p-value comparing both the Be and Oe Be CDFs with the Late O population is 0.007, whereas the p-value comparing OBe supergiants to OB supergiants is 0.33, compared to 0.05 when comparing OBe supergiants to regular OB stars.

Methodology

We numerically observe the trends present in Figure 2, showing that the OBe stars are more isolated compared to the OB stars. Furthermore, if OBe stars are binary supernova-ejected objects, then their CDF should reside at a locus similar to that of other known binary supernova-ejected populations. Figure 2 and Table 1 indeed show that the Oe and Be populations approach a similar degree of isolation as the HMXBs in our sample, which are known post-SN objects. We do see that 39 of the 49 are confirmed OBe stars, thus the comparison is not independent, but this demonstrates a close link between OBe stars and HMXBs.

Implications

Binary mass transfer is increasingly seen as the mechanism for spinning up classical OBe stars, enabling formation of their high-mass X-ray binaries (HMXBs). The isolation of OBe stars is consistent with a high frequency of SN events, as expected from the binary formation model of OBe stars. On average, Be stars do not drift further into the field than Oe stars, contrary to expectations based on the relative lifespans of O and Be stars. This can be readily explained if the masses of the gainers are obscured by mass transfer.

We now consider the implications of OBe stars being binary supernova progenitors. Our results show that the isolation of OBe stars is consistent with a high frequency of SN events, as expected from the binary formation model of OBe stars. On average, Be stars do not drift further into the field than Oe stars, contrary to expectations based on the relative lifespans of O and Be stars. This can be readily explained if the masses of the gainers are obscured by mass transfer.

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