CHARACTERIZING BINARY PROPERTIES OF \(5 M_\odot\) STARS:
NEW APPROACHES USING CEPHEIDS

Nancy Remage Evans

Abstract. Cepheids provide approaches to determining binary parameters which are often complementary to those for main sequence massive and intermediate mass stars. Specifically, we are using high resolution imaging, radial velocities, and X-ray studies to determine binary characteristics. Among the results are that they have both a high frequency of binary systems, and also a high proportion of triple systems.

1 Introduction

Great progress has been made in recent years in determining the binary/multiple properties of massive stars. This is important input into our understanding of star formation. The recent finding (Sana, et al. 2012) that over 70\% of O stars interact with binary companions also demonstrates the importance of binary systems in determining the course of evolution and ultimate outcome of massive stars.

Cepheids (typically \(5 M_\odot\)) begin life as B stars. They have characteristics which are complementary to the more massive O stars in ascertaining their binary properties. In particular they have sharp-lined spectra and hence accurate velocities. We can also study uncontaminated spectra for both the primary and the secondary (the Cepheid in the visual region, a hot companion in the ultraviolet). There is a limitation, however, in obtaining binary properties. Cepheids are post-red giant branch stars, and hence binaries with periods shorter than 1 year have undergone Roche-lobe overflow, and are no longer found in the sample of Cepheid binaries. We have undertaken a threefold program to determine the properties of Cepheid binaries, as discussed in the three subsequent sections.

2 High Resolution Studies

We have made a snapshot survey of 69 Cepheids with the Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) in two filters which transform to V and I.
This survey can be used in several ways.

2.1 **High Mass Companions**

We surveyed 75 bright Cepheids with the International Ultraviolet Explorer satellite (IUE; Evans, 1992). From this study we can create a list of all Cepheids with companions more massive than $2 \, M_\odot$ (Evans, et al. 2013). Of the 18 stars with massive companions, 12 have orbits from which we can obtain the orbital period or separation. Three more were resolved in the WFC3 survey. Fig. 1 shows the distribution of separations from the sample. (Note that there is no detection bias at any separation range in this sample.) A comparable sample ($P < 1$ yr, mass ratio $q > 0.4$) has been created from the recent Raghavan et al. (2010) sample of solar mass stars. Fig. 1 shows that the more massive Cepheids clearly favor shorter orbital periods than the solar mass stars.

2.2 **Resolved Companions**

A second result from the WFC3 survey is $V$–$(V-I)$ color magnitude diagrams (CMD) for the field of each Cepheid (Fig. 2 for S Mus). A Zero Age Main Sequence (ZAMS) at the distance and reddening of the Cepheid is superimposed on the CMD. A list is made of all possible resolved companions (down to M0). In order to confirm that the possible companions are physically related to the Cepheid, we have made XMM-Newton X-ray observations of a number of the candidates, since a physical companion of a Cepheid will be young and much more X-ray active than a field star in a chance alignment. The XMM observation of S Mus has an X-ray source, confirming that the companion is a physical companion. Preliminary indications, however, for several other Cepheids are that the possible companions are chance alignments with field stars.
Late B stars—similar in mass to Cepheids—do not in general produce X-rays. Therefore, an X-ray source at their location is taken to be produced by a low mass companion. We (Evans, et al. 2011) have identified the locations of late B stars in a Chandra ACIS image of the cluster Tr 16 (Fig. 3 left). The fraction of X-ray detections indicates that 39% of late B stars which have a low mass companion between 1.4 and 0.5 $M_\odot$.
4  Radial Velocities

Radial velocities accurate to 1 km/sec have been obtained in large numbers for Cepheids since the advent of the CORAVEL radial velocity spectrometer, and subsequently by the Moscow University group (Gorynya, et al. 1998, and references therein). This means for some stars more than 30 years of data exist. We have formed annual means of this data after subtracting the pulsation curve using a Fourier series. Fig. 3 (right) shows an example. We expect to be able to identity stars with an orbital velocity amplitude > 1 km/s. Simple estimates show that with this data we will detect 97% of systems with the mass ratio q = 0.3 and P = 30 years and 77% of systems with q = 0.1 and 30 years. Preliminary estimates of the results for data series up to 20 years show that about 35% of the Cepheids are in spectroscopic binaries.

5  Summary

The combination of studies described here is extending the coverage of q and separation/period in Cepheid binaries. Specifically, both spectroscopic binaries and resolved companions will be surveyed down to mass ratios q = 0.1. Ultimately companions will be detected at least as close as 0.7″, and probably closer. So far the studies have found several characteristics of binary/multiple systems. The frequency of triples among well-studied binaries is at least 44%. High mass companions (q > 0.4) have smaller separations than a comparable sample of solar mass stars. Finally, the estimate of the fraction of high mass companions from an IUE survey is 34%. The fraction of low mass companions of late B stars is 39%. These fractions should be roughly additive, implying that at least three quarters of Cepheids occur in binary systems.

Acknowledgments: We are grateful for financial support from HST grant GO-12215.01-A and the Chandra X-ray Center NASA Contract NAS8-03060.

References

Evans, N. R. 1992, ApJ, 384, 220
Evans, et al. 2011, ApJS, 194, 13
Evans, N. R. et al 2013, AJ, 146, 93
Gorynya et al. 1998, AstL, 24, 815
Raghavan et al. 2010, ApJS, 190, 1
Sana., H. et al 2012, Sci., 337, 444