Stars and their variability observed from space
C. Neiner, W. W. Weiss, D. Baade, R. E. Griffin, C. C. Lovekin, A. F. J. Moffat (eds)

CEPHEID SPHERES OF INFLUENCE

N. R. Evans[1], H. M. Günther[2], H. E. Bond[3], G. H. Schaefer[4], B. D. Mason[5], M. Karovska[1], E. Tingle[1], S. Wolk[1], S. Engle[6], E. Guinan[6], I. Pillitteri[7], C. Proffitt[8], P. Kervella[9] and A. Gallenne[10]

Abstract. Satellite data from *HST*, *Chandra*, *XMM*, *IUE*, and *Gaia* have provided important information for multiple systems containing Cepheids in order to supplement ground-based light and velocity studies. Since systems containing massive stars frequently have multiple components, many approaches are needed to derive the parameters of the components. The distribution of separations and mass ratios are of particular interest here. The final segment of the *HST* WFC3 survey (companions between 0.5 and 5.0$''$) identifies companions between 100 and 2000 AU. They have the unusual property that *all* have an inner binary as well. This is in contrast to the overall Cepheid population in which 29% are spectroscopic binaries, suggesting that the dynamical evolution of these triple systems plays a part in setting the configuration.

Keywords: Stars: Cepheids, companions, star formation, massive stars

1 Introduction

Like many stars with intermediate or large masses, Cepheids (typically 5 $M_\odot$ stars) are frequently found in binary and multiple systems. Multiple systems such as these provide observational input for investigating many topics:

1. Star formation: the formation of multiple components involves processes such as core fragmentation and disk fragmentation; the resulting properties are functions of the total mass of the system and the separation between components.

2. Dynamical evolution: dynamical interaction between components can occur either before the system settles into an hierarchical configuration or through the Kozai-Lidov mechanism.

3. Mergers: Cepheid progenitors (B stars) include a high fraction of binaries with periods as short as a few days. Post-red-giant Cepheids do not have orbits shorter than one year, implying that shorter orbits have undergone Roche Lobe overflow (RLOF) after their main-sequence phases, and many have merged.

4. Exotic end stage objects: Cepheids are destined to become compact objects, many in multiple systems. Multiple systems containing a compact object (a white dwarf in the case of a Cepheid) give rise to objects such as high-mass X-ray binaries, cataclysmic variables and (in more massive systems) supernovæ. The properties of Cepheid multiple systems furnish the ingredients for these outcomes.

2 Surveys

Studies in recent years have provided detailed information about the components of Cepheid multiple systems. We now have surveys (each containing an average of 70 stars) of spectroscopic binaries (Evans et al. 2015), hot companions observed with *IUE* (Evans 1992), resolved companions (Evans et al. 2016a) and *Gaia* proper motions (Kervella et al. 2019), plus a number of close systems resolved by interferometry (Gallenne et al. 2018).

[1] Smithsonian Astrophysical Observatory, MS 4, 60 Garden St., Cambridge MA, 02138 USA
[2] MIT, 77 Massachusetts Avenue, NE83-557,Cambridge, MA 02139 USA
[3] Dept. Astronomy and Astrophysics, Pennsylvania State Univ., University Park, PA, 16802, USA
[4] The CHARA Array, Georgia State University, P.O. Box 3965, Atlanta GA 30302-3965, USA
[5] US Naval Observatory, 3450 Massachusetts Ave., NW, Washington, D.C. 20392-5420, USA
[6] Department of Astronomy and Astrophysics, Villanova University, 800 Lancaster Ave., Villanova, PA, 19085, USA
[7] INAF-Osservatorio di Palermo, Piazza del Parlamento 1,I-90134 Palermo, Italy
[8] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[9] LESIA, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Univ. Paris Diderot, Sorbonne Paris Cité, 5 place Jules Janssen, 92195 Meudon, France
[10] Université Cote d'Azur, OCA, CNRS, Lagrange, Parc Valrose, Bat. Fizeau, 06108 Nice Cedex 02, France

This suite of programmes has provided coverage of parameter space wider than the orbital destruction limit of one year and mass ratios M_2/M_1 down to 0.4. The *IUE* survey, for instance, identified companions with no separation-dependent bias.

The *HST* imaging survey is just being completed. Data were observed with Wide Field Camera 3 (WFC3) in two filters which transform to V and I. The first segment (Evans et al. 2016a) covered companions more than 5" from the much brighter Cepheid. That was followed with *XMM* X-ray observations of 14 out of 39 Cepheids with resolved companion candidates to identify X-ray activity in stars young enough to be Cepheid companions, as opposed to old field stars (Evans et al. 2016b). In that sample, one young star (R Cru) was identified has having a separation of 7.6". S Nor was noted as a system whose young companion was at the greatest separation (14.6"), but since it is in a cluster, the companion could be another cluster member rather than a gravitationally bound companion. Closer companions require careful point spread function (psf) correction. Fig. 1 illustrates that for V659 Cen. Full details are to be given in (Evans, et al, 2020 in preparation), and will concentrate on systems whose companions are found within 5" of the Cepheid.

3 Results

The most surprising result concerned the 7 systems systems which have resolved companions within 2" (roughly 500 au) of the Cepheid. Each of the 7 systems with a resolved companion also has an inner spectroscopic binary. This is in sharp contrast to the result from the sample of 70 Cepheids (Evans et al. 2015), where less than one third occur in spectroscopic binaries. There are two possibilities that could explain how this unusual property in the sample with resolved companions might arise.

One possibility is star formation itself; the other is dynamic evolution within these multiple star systems. A number of complex processes which are involved in these intermediate-mass multiple systems are mentioned above: star formation, dynamical evolution within the system, or possibly that some of the components had undergone RLOF that resulted in mergers in some cases. Is it possible to disentangle these complex processes? The finding that wide companions seem to require an inner binary provides a clue to a dominant process. In a model of sequential star formation, outer components are formed first, and inner components form subsequently through disk fragmentation. This sequence seems unlikely to produce wide components *only* if an inner binary is going to be formed, since the outer components will not be able to anticipate that there will in the future be an inner binary formed. On the other hand, dynamical evolution of the system seems consistent with other systems that contain both a resolved companion and a spectroscopic binary, i.e., three stars were formed but the ultimate location of the components was set by interactions among the components of a triple system.

4 Conclusions

Observations have provided good distributions of the separations and mass ratios in Cepheids. As with other systems containing reasonably massive stars, the components can be tricky to disentangle, particularly since many systems contain more than two stars. However the Cepheid studies from *HST*, *Chandra*, *XMM*, *IUE* and *Gaia* are providing data on the distributions of separations and mass ratios. In particular, they provide clues to star formation, yieldibng the implication that the dynamical evolution of the systems is important.

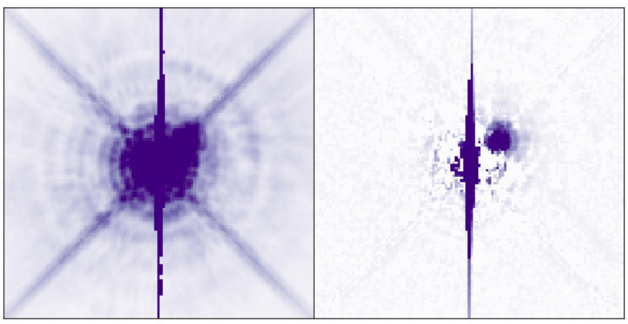

Fig. 1. Left: *HST* image of V659 Cen, showing a square of ∼6" around the Cepheid. The companion is visible, but the image is very complicated. **Right:** The remaining image after point-spread-function correction. The companion is now seen clearly.

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