System Parameters of Binary Central Stars of Planetary Nebulae

Todd C. Hillwig

Valparaiso University, Valparaiso, IN USA 46383

ABSTRACT

An important step in understanding the influence of binary star systems on the shaping and formation of planetary nebulae is determining the system parameters of known binary central stars of planetary nebulae. I will summarize properties of both the central stars and their companions. In addition I will relate those parameters to existing evolutionary models and complimentary data (e.g. nebular expansion ages). Finally, I will discuss the relationship between known close binary central stars and their surrounding planetary nebula.

1. Introduction

A number of searches have been undertaken in an effort to identify close binary central stars of planetary nebulae (CSPNe). Here the term "close" means generally those systems with orbital periods of less than about 13 days in which photometric variability might be expected due to eclipses, irradiation of a cool companion, or ellipsoidal variability due to one or both stars nearly filling their Roche lobes. A summary of many of these systems can be found in De Marco et al. (2008) and Miszalski et al. (2009), though there are a number of more recent papers with additional discoveries. A complete listing of the systems, papers, and known parameters is beyond the scope of this paper, which provides a general summary.

At present about 45 CSPNe have been found to show either photometric or radial velocity variability indicative of a close binary system. Only about half of those systems have spectroscopic confirmation of a binary system. The remainder have only photometric observations so cannot be confirmed as binaries even though the likelihood is high that they are. Of the 45, there are sixteen with strong identification of the companion in the system and only twelve with full binary model calculations.

The binary models are needed to determine a full set of system parameters including stellar mass, radius, and temperatures as well as binary inclination. However, these systems provide a host of difficulties in system modeling due to the often bright nebulosity which effects the observed variability amplitude of not properly removed. The large possible range in physical parameters also makes the model parameter space very large. For example, since the binaries often include both a main sequence (MS) star and a pre-white dwarf, the expected stellar radii can vary from a few hundredths to a few solar radii. Likewise masses and temperatures can vary over large ranges. Producing a good binary model in CSPNe requires a great deal of information to reduce the parameter space and remove local minima in the modeling.

2. Companions to Central Stars

Of the sample of known binary CSPNe with well-sampled light curves, approximately 20 – 25% of them have variability dominated by ellipsoidal effects or have two visible eclipses. Because of the high temperatures of the CSs in these systems, a MS companion will show irradiation effects much stronger than any ellipsoidal variabilitiy. So those systems dominated by ellipsoidal effects are highly likely to be double-degenerate (DD) systems (a CS with a WD or pre-WD companion). Similarly, due to the large difference in temperatures a hot CS and MS star, systems with two visible eclipses will often be DDs where both stars will have more similar temperatures. As a caveat, this is not exclusively true because in the optical we observe the Rayleigh tail of the blackbody for many CSs so the eclipse depths do not provide as clear a ratio of stellar temperatures as for MS binaries.

Considering the above, we find that roughly one-quarter of all binary CSPNe discovered through photometric variability are DD systems. However, the photometric variability described above will only occur when the CS is still large. As the CS contracts, eclipses will become less likely to be observed and the star will move farther from filling its Roche lobe, so ellipsoidal variability will decrease and, quickly in the contraction process, disappear completely. Thus the observed systems represent some fraction of the existing systems. Preliminary calculations for CSs of 0.56 $M_\odot$ suggest that ellipsoidal variability will be observable for approximately 25% of the lifetime of the PN. From this we can then estimate that we observe a similar fraction of the existing DD CSPNe. If this is true, then there may be just as many binary CSPNe with a compact companion as those with a MS companion–roughly 15%, the same fraction as DD systems among WDs found by the SPY survey (Napiwotzki et al. 2003).

Of the 16 systems with identified companions 6 are DD systems (though only 4 of these show ellipsoidal variability or eclipses, the other two were discovered using other methods). The remaining 10 systems have MS companions, seven of which are *M* spectral type, 1 *K* star, and 2 *G* stars. Of those ten MS companions all but one have radii too large for MS stars of their mass and all are too hot for MS stars of their mass. These are well-known behaviors among post-common envelope binaries with a MS companion.

3. The Central Stars in Close Binary Systems

Of the modeled CSs themselves, all fall in the mass range 0.51 – 1 $M_\odot$ with temperatures and radii typical of CSPNe (roughly 38 – 200 kK and 0.04 – 1.1 $R_\odot$). There are two specific conclusions that can be made based on these results. First, none of the CSs appear to be the result of post-RGB evolution. There are no low-mass, He WDs in the sample. The absence of these CSs is interesting because a number of population synthesis papers predict that common envelope evolution will result in a large fraction of post-RGB CSs. Second, for the individual CSs with values for mass, radius, temperature, and age (based on nebular age), the values are consistent with existing evolutionary models of, e.g. Schönberner (1983), Vassiliadis & Wood (1994), and Blöcker (1995). However, the values are not precise enough to discern between the models were differences exist. More precise system values can be obtained for eclipsing binary systems, making it important to discover and study more eclipsing binary CSPNe.

4. Connections Between the Central Binary and the PN

Based on the known system parameters for binary CSPNe there are clear correlations between the binaries and the surrounding PN with one exception: binary inclination. In every system for which both the binary inclination and the nebular inclination are known, the two values agree with one another. The central binary is aligned with the major axis of the PN. For more discussion of these values see the paper in this proceedings by Jones et al. (2014).

There exists one other clear relationship between binary CSPNe and PN morphology not related to binary system parameters. There are no known binary CSs in a spherical PN. A current photometric survey is underway based on David Frew's 2 kpc sample of PNe. To date approximately 75% of the PNe in this sample have been monitored photometrically. The current binary fraction (of close binaries from photometric variability) of the sample is about 12% and none of the CSs of spherical PNe show evidence of variability. In addition, none of the known binary CSPNe *not* included in this sample occur in a spherical PN.

5. Conclusion

From the current system parameters of binary CSPNe we find four general conclusions:

- There may be as many binary CSPNe with a hot compact companion as a MS companion.
- There are no known post-RGB stars in the current sample of bCSPNe.
- Current CS parameters are consistent with evolutionary models but we need more eclipsing systems with well studied nebulae to confirm this.
- There are no known binary CSs in a spherical PN.

Studies of additional systems are underway with binary models being produced for 3 more systems. At least two newly discovered variable CSPNe are being followed up to confirm binary as the most likely source. With the growing number of binary CSPNe and further studies, more specific, quantitative conclusions will be possible and potential new links between binary and PN ejection and morphology may be found.

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