Binary Star Systems in Planetary Nebulae and their Relationship to Stellar Evolution: Modeling Two New Binary Systems

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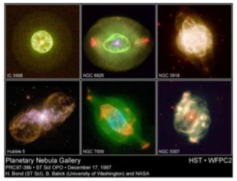
Abstract

The aim of this research was to learn more about close binary star systems and how they influence the formation of planetary nebulae at the end of a star's life. These systems are produced by a common envelope phase where they share the same atmosphere and spiral closer together, causing stronger interactions between the stars. Properties of these systems can be used to better understand Type 1A supernovae, cataclysmic variable stars, and gravitational waves. There are 70 of these close binary star systems known, of which fewer than 20 have been modeled. This summer, models were generated for two of these systems, the central stars of Lo 16 and PHR 1510-6754. The parameters determined were masses, radii, temperatures, inclination, and separation of the stars. displaying a small eclipse. Possible solutions for both systems have been found, and at this time, the models indicate stellar parameters that are consistent with the expected ranges for these systems. Further work will aim for a more complete range of all possible parameters. Knowing the specific combination of parameters will lead to a better understanding of how these systems form, how they impact the shaping of the planetary nebula, and how they will continue to evolve in the future.

Background

Planetary nebulae (PNe) result from stars 0.8 to 8 times our sun's mass when their core runs out of fuel and the outer layers of its atmosphere begin to expand. The core shrinks to a white dwarf--hot, dense star--and eventually the gases of the atmosphere are ionized by the star and begin to glow. This ionized gas is the colorful part we see in PNe.

The nebula itself can take on many diverse shapes, as seen on the right in Fig. 1. A current hypothesis is that binary systems have a strong influence on the shaping of the nebula.



A phase of evolution binary stars may go through is called the common envelope phase. The stars begin to share an atmosphere when one star swallows the other.

Background (continued)

They begin spiraling together, which creates a closer binary system than before. Most, if not all, close binary systems with a white dwarf came from this process. This is important for the formation of PNe because the energy from this common envelope interaction can easily go into creating various outflows of gas, like the jets or other unique formations we see in PNe.

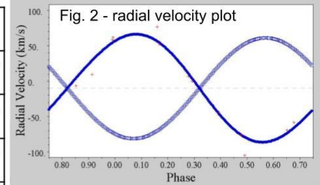
PHR 1510-6754

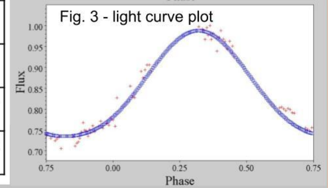
PHR 1510-6754 is a system that is highly irradiated, with the hot central star heating up the facing side of the cool companion. This creates a constant gradual change in flux in the light curve, as shown below. This system does not display an eclipse in the current data, though we lack full data at the minimum of the light curve, so there may be a small eclipse there. Data for only one star is available for the radial velocity plot, which gives a wider range of mass ratios possible for the system. Parameter sets are being found in visible, blue, red, and infrared filters.

Fig. 2 - 3 below: the radial velocity (top) and light curve (bottom). Red dots are the data, blue lines are the model.

Central Star Mass (solar masses)	0.534 - 0.989
Companion Mass (solar masses)	0.534 - 0.865
Central Star Radius (solar radii)	0.470 - 0.845
Companion Radius (solar radii)	0.936 - 1.148
Central Star Temperature (kK)	100
Companion Star Temperature (kK)	5.75
Inclination (degrees)	45 - 70
Separation (solar radii)	6.513 - 7.827

Table 1: current ranges for this system



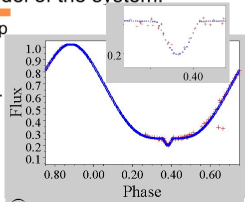


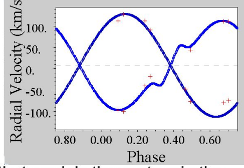
Lo 16

Lo 16 is a binary system consisting of a hot central star and a cooler main sequence companion. The data display a strong irradiation effect resulting from the hotter star heating up one side of the cooler star. It also displays an eclipse, which can be used to determine the temperatures, radii, and inclination of the stars in the system. The radial velocity curve also shows interesting behavior such as a deviation for the central star from the characteristic sine curve shape.

Parameter sets that fit the data in the infrared, red, and visible filter are being found. The maximum and minimum possible value of each parameter are required to describe the full range of solutions for a model of the system.

Figures 3-4: The light curve plot on the top shows brightness vs. time in the infrared filter, while the radial velocity plot on the bottom shows the velocity of each star vs. time in the visible filter. The model is shown in blue and the data are in red.





Central Star Mass (solar masses)	0.655
Companion Mass (solar masses)	0.801
Central Star Radius (solar radii)	0.156
Companion Radius (solar radii)	0.934
Central Star Temperature (kK)	90
Companion Star Temperature (kK)	3.5
Inclination (degrees)	70.95
Separation (solar radii)	2.947

Table 2: One possible set of parameters that models the system in the infrared filter. The full range of parameters that fit the data will likely be within roughly 15% of these values.

Conclusions

Possible models have been developed for both Lo 16 and PHR 1510-6754. Moving forwards, work is being done to find the full range of possible solutions for all parameters for each system. This work is important because of the 70 known close binaries, fewer than 20 have been fully modeled. Having models of close binary systems helps complete the picture of how binary systems affect the evolution of stars and planetary nebula. This has further applications in understanding Type 1A supernovae, cataclysmic variable stars, and gravitational waves.

Acknowledgements and References

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