Finding the Observability Fraction of Double Degenerate Binary Systems Using Monte Carlo Simulations

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Abstract

Double degenerate systems are binary systems consisting of two white dwarf stars. Many double degenerates are identified inside planetary nebulae where their physical conditions make them easier to detect and study. Planetary nebulae are made up of giant clouds of gas that glow due to the intense heat from a dying central star which ionizes the gas within the shell. We would like to determine what fraction of double degenerates are detectable using standard search methods, and how different physical parameters of the double degenerate system affect that fraction. Due to the small existing dataset for double degenerate systems, a Monte Carlo simulation code was used to create a statistically significant synthetic sample of double degenerate systems. In order to create accurate input for the Monte Carlo code, possible probability distributions for central star mass, companion star mass, age of the planetary nebulae, and orbital period had to be varied and compared to the available observational data. The resulting binary observability fraction is presented and discussed here. In addition, a brief discussion is included on how the results of this study also provide information on the occurrence of type Ia supernovae, an important class of events in our understanding the size and expansion of the Universe.

Background and Importance

- Estimated that roughly half of all stars are binary stars
  - ~30% of those binaries will have at least one white dwarf[1]
- ~10% of all binary systems with a white dwarf will be a system where both are white dwarfs, called Double Degenerate Systems (DD)
- Very hard systems to detect, but incredibly important systems
  - Help to shape Planetary Nebulae (PN), play a role in stellar evolution, background noise for gravitational waves
- What we are focusing on
  - Type Ia Supernovae (SN Ia), their rate of formation, and how often they happen
- SN Ia are incredibly important transient objects

Figure 1: A picture of the Southern Ring Nebula, a planetary nebula, recently taken by the James Webb Space Telescope NASA/STScI JWST

Monte Carlo Simulations

- Very few measurements of ***central star mass, companion star mass, orbital period, and age***
  - Require a simulation to increase the sample size
- Code chooses random values for each parameter from distributions
  - Distributions show the probability of a double degenerate system having a specific value
  - The random values for each parameter create an individual double degenerate system
  - Must find which distributions best fit the data we have
- Used to find the fraction of double degenerate systems that are observable (change in brightness at a level that can be detected by current telescopes)

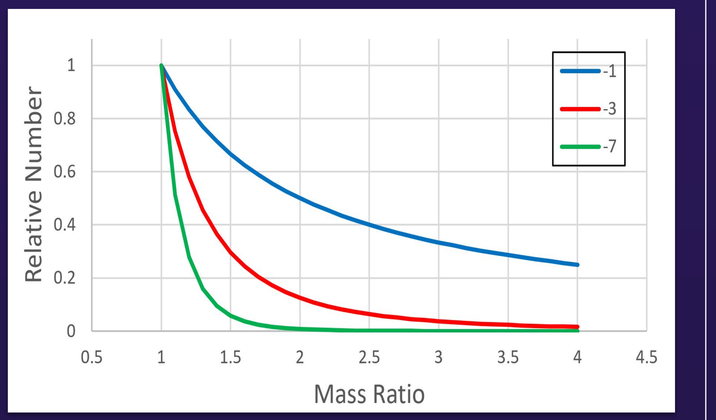

Figure 2: An example of a power law distribution where the higher the graph on the y-axis, the more probable the value on the x-axis is. The power law distribution is later used for the companion star mass.

Reference

1. J B Holberg 2009 J. Phys.: Conf. Ser. 172 012022

Companion Star Mass Distribution

- Appears to be relationship between central star mass and companion star mass
  - Based on other binary systems, believed to follow a power law distribution

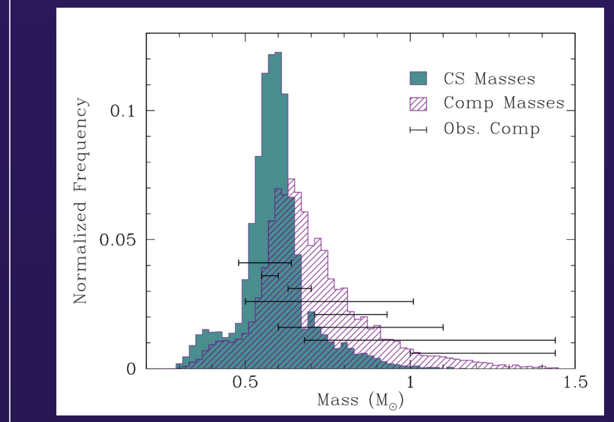

Figure 3: A distribution where the companion star mass has a power law value of -7.

- Only 8 measurements for companion star mass, some with large errors
  - Required a code to test agreement between different values for power law distribution and the known measurements

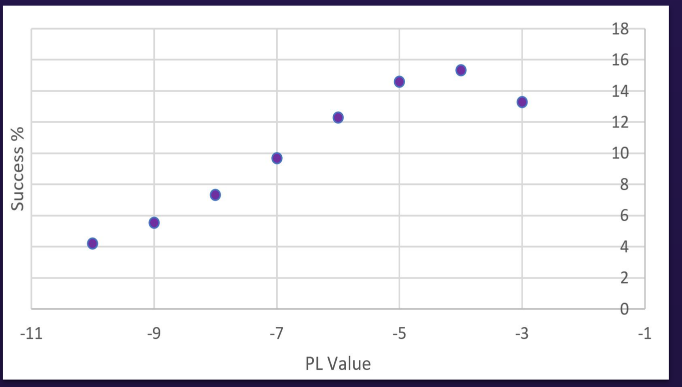

Figure 4: A graph showing the power law values vs. the success percentages when run through the code.

Changing Distributions

- Three parameter set distributions to change
  - Companion Star Mass Distribution
  - PNe Max Age
  - Orbital Period Distribution
- Best Companion Star Mass Power Law determined statistically by Brook, which is a power of -4
- PNe Max Age is determined by current understanding of PNe formation and evolution
- Orbital Period Distribution is determined by fitting multiple different distributions to data of orbital periods and determining which one best fits the data
  - Fit using a Planck Style Function or a Pearson IV function

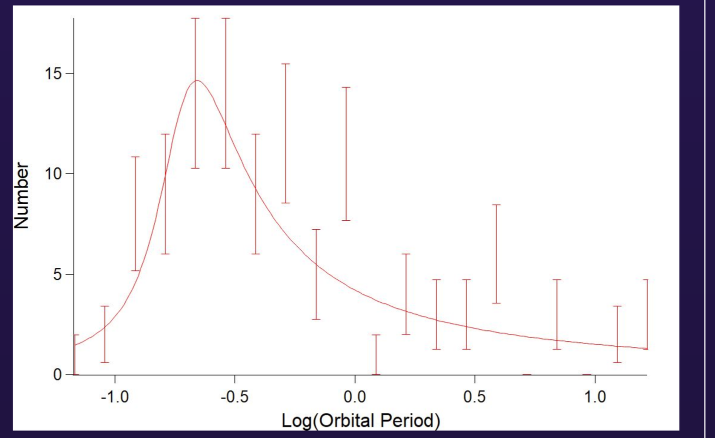

Figure 5: The Pearson IV Distribution for Orbital Period.

Conclusion

- ***Observability Fraction***: 27.1% +/- 1.8%
- ***SN Ia Progenitor Fraction***: 25.2% +/- 5.2%
- This means only ~27% of DD central stars of PNe are detectable and ~25% of DD will merge within the age of the universe and be over 1.44 $M_{\odot}$ (The maximum mass of a WD)

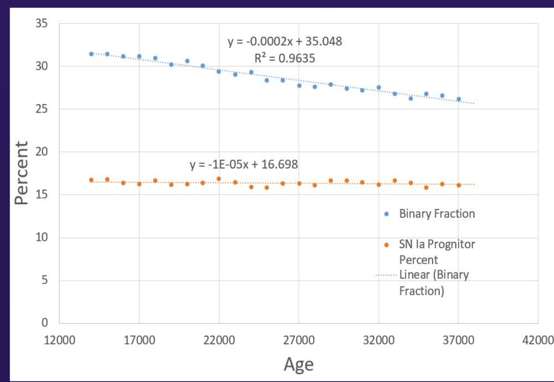

Figure 6: A plot of Age vs. Binary Fraction Percent (blue) and Age vs. SN Ia Progenitor Percent (red).

- Literature search in progress for star formation rate and PN birthrate in the Milky Way Galaxy
- Start a second program that calculates SN Ia rates based on PN birthrates and our results as shown above
- Simulate the Milky Way Galaxy with DDs using our results and star formation rates and compare to the present day Milky Way

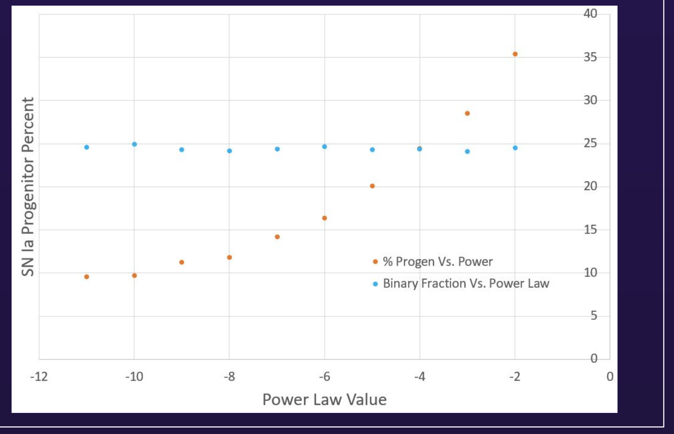

Figure 7: A plot of Power Law Value vs. SN Ia Progenitor Percent (blue) and Age vs. Binary Fraction Percent (red).