Modeling the Future Evolution of a Blue Straggler Star-White Dwarf Binary System

Leah English, Emily Leiner, Alina Hussain

Department of Physics, Illinois Institute of Technology

Abstract

Blue straggler stars are stars that appear to be younger and more luminous than expected. These stars are suspected to have been formed from a collision or mass transfer from a binary companion. WOCS 5379 is a binary star system in the NGC 188 star cluster that consists of a blue straggler star and a Helium white dwarf star orbiting each other. Using the stellar evolution code Modules for Experiments in Stellar Astrophysics (MESA) (Jermyn et al. 2023) , we model a 6 Gyr star system consisting of a blue straggler star of mass 1.2 solar masses and a white dwarf with a mass of 0.42 solar masses and a temperature of 15,500K in a 120 day orbit, matching the observed parameters of the real WOCS 5379 system (Gosnell et al. 2019). We model the future evolutionary trajectories of this binary using two different models: conservative mass transfer, meaning the mass lost by the blue straggler star is fully accreted onto the white dwarf, and non conservative mass transfer, meaning some percentage of mass lost by the blue straggler is lost from the system and the rest is accreted onto the white dwarf. Fully conservative mass transfer leads to unstable mass transfer and causes a common envelope to form. Most non-conservative mass transfer led to the same conclusion, ending with a double white dwarf binary or double white dwarf merger. Highly non-conservative mass transfer in which 90% of the mass is lost from the donor via a wind, and only 10% is accreted to the white dwarf does lead to stable mass transfer, and yields a model that looks broadly consistent with observed characteristics of symbiotic binaries. These results are interesting because the future evolution of blue straggler-white dwarf binary systems has not yet been modeled in detail, but they may ultimately form interesting systems such as symbiotics or double white dwarf mergers.

Mass transfer efficiency can significantly impact the course of binary evolution

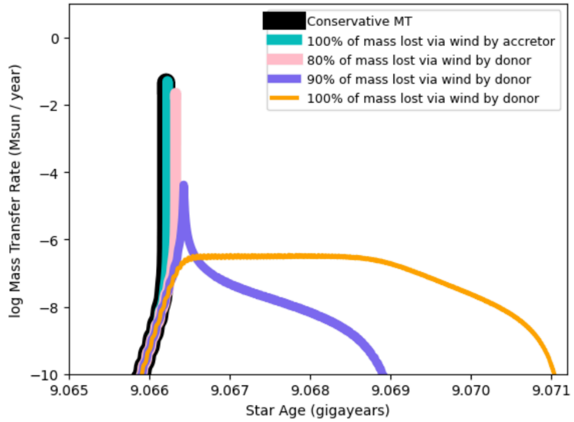


Figure 1: The mass transfer rates for WOCS 5379 system over time is shown and the legend depicts what type of mass transfer the system is undergoing. The rates that go to infinity lead to unstable mass transfer and go into a common envelope, while the rates that peak and come back down show stable mass transfer. Stable mass transfer is found to only be possible under extremely nonconservative conditions, meaning most of the mass is lost (at least 90%) from the system and only when it's lost from system via wind by the donor star.

Stable, non-conservative mass transfer can lead to a long period double white dwarf binary. Unstable mass transfer leads to a common envelope, and the formation of a short period double white dwarf binary

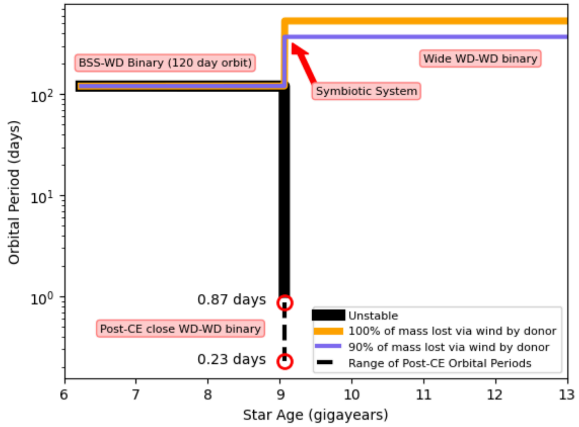
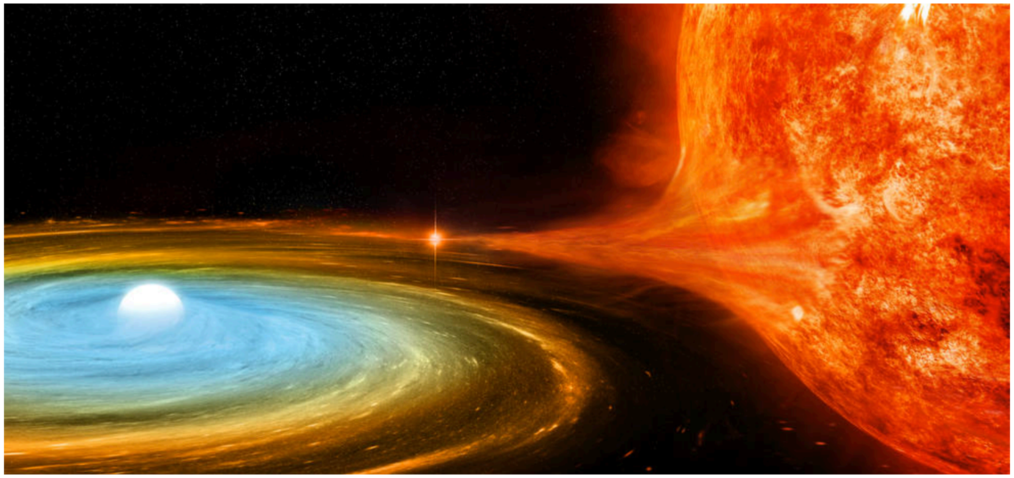


Figure 2: The orbital periods show that after stable mass transfer, a wide binary is formed. On the other hand, unstable mass transfer leads to orbital decay and formation of a very close binary with an orbital period less than one day. The red circles bracket the range of orbital period that result from common envelope evolution



Background

This photo from NASA depicts mass transfer between a red giant star losing mass that's being accreted onto a white dwarf. Mass transfer occurs when a star fills its roche lobe radius, meaning the mass is outside the region of the star where orbiting material is gravitationally bound to the star. With the material of the star no longer being gravitationally bound to the donor star, the companion star is able to accrete, or attract the material via gravity. Mass transfer is considered conservative if all of the mass is accreted onto the companion, while nonconservative mass transfer would require some of the mass to be lost from the binary system. Stable mass transfer occurs when the mass transfer rate is slow enough for the accretor to slowly accrete the material and mass transfer is able to stabilize and decrease after it peaks. Unstable mass transfer, however, happens when the mass transfer rate is fast and the donor loses its envelope quickly. The donors radius grows, causing it to exceed its roche lobe radius more and more and the mass transfer rate increases. At this point, a common envelope forms and the orbit decays, where the common envelope is a stellar atmosphere composed of gas that's shared between the two stars in the binary system.

Common envelope ejection efficiencies of <0.40 result in double helium white dwarf mergers within a Hubble time

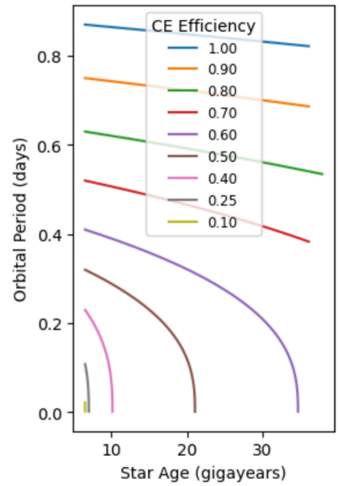


Figure 3: This graph shows the orbital evolution of WOCS 5379 system after common envelope. Depending on the common envelope efficiency, which is the fraction of orbital energy used to unbind the common envelope, there will be different orbital periods at the end of the common envelope phase. Lower common envelope efficiencies result in shorter period orbits. After the common envelope, the orbit continues to shrink via gravitational wave radiation. Orbital periods smaller than 0.32 days, or a common envelope efficiency less than 0.50, leads to a gravitational wave driven merger within the age of our universe (14 gigayears). The others merge in a time that's older than our Universe, or didn't merge at all within the time the model was run (over 30 gigayears). Merging white dwarfs cause explosions, which will be interesting to look more into in the future!

Conclusions and Next Steps

While most simulations assume mass transfer is conservative, exploring non-conservative mass transfer opens new possibilities for what this type of system could evolve into. The main conclusions of these models show how conservative and non-conservative mass transfer lead to very different outcomes. Some of the outcomes are:

- The stable, non-conservative case might create a type of X-ray binary system called a symbiotic nova consisting of a red giant and a white dwarf. This system could potentially evolve into a wide binary white dwarf-white dwarf binary system.
- The unstable, conservative case could form merging dwarfs that may be gravitational wave sources or observable as explosive events in space.

Future models could be explored to see how these systems continue to evolve and continue looking into the different physical properties that might affect their evolutions.

Sources

Jermyn, A., et al., 2023, ApJS, 265, 1

Gosnell, N., Leiner, E., et al., 2019, ApJ, 885, 45