CATEGORY: COMPUTATIONAL PHYSICS - 01

POSTER
P21883

CONTACT NAME
Mason McCallum: masonamccallum@gmail.com

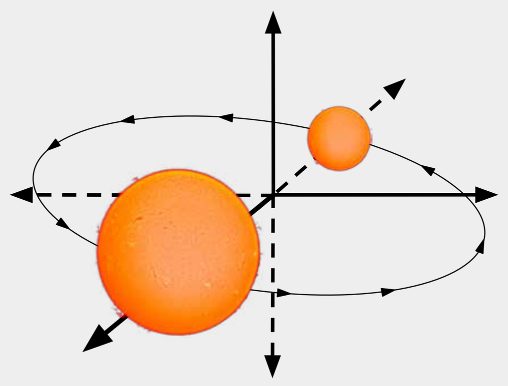
NVIDIA GTC GPU TECHNOLOGY CONFERENCE

N-body Simulation of Binary Star Mass Transfer

Mason McCallum, Dr. Bryant Wyatt, Dr. Shaukat Goderya

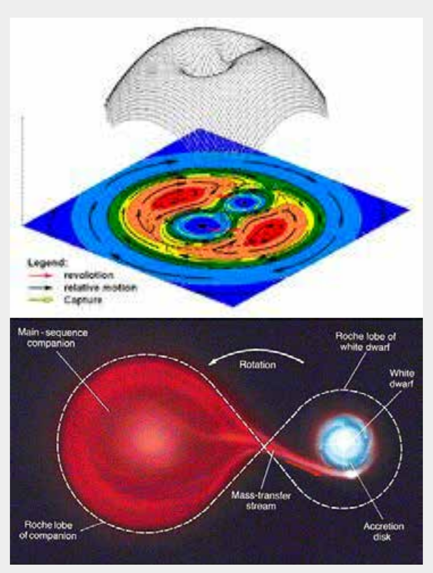
Department of Mathematics at Tarleton State University

Introduction



Binary star systems are a pair of stars orbiting around a common center of mass. Due to their abundance and unique characteristics, such systems are invaluable sources of astrophysical data. In this study we are concerned with contact binary systems: a pair of stars in physical contact sharing a common envelope. Due to mass transfer between the stars, the structure and evolution of these systems differ greatly from solitary stars (like our Sun). Here we develop an N-body model that simulates evolving contact binary star systems. With this, we study the evolution of contact binaries, in particular the role mass transfer between stars plays in this process.

Roche Lobe

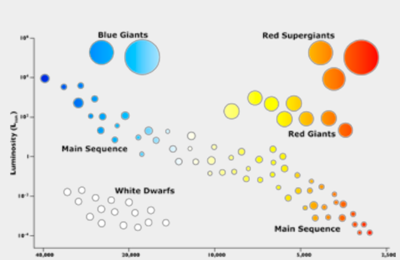


Chief among the unique properties of binary systems is their ability to transfer mass when the system is in a contact or semi-detached state. This mass transfer can happen in a multitude of ways, the most prevalent being the case where one star fills its Roche lobe and mass is leeched to the companion star through the L1 Lagrangian point, which is known as Roche lobe overflow (RLOF)[1]. The Roche lobe is the equipotential surface of the two stars that passes through L1. This equipotential surface satisfies the equation

$$\psi = \frac{-G \cdot m_{star1}}{r_1} - \frac{G \cdot m_{star2}}{r_2} - \frac{1}{2}\omega^2 \rho^2$$

where G is the gravitational constant, ω is the orbital velocity at periastron, and $\frac{1}{2}\omega^2\rho^2$ is an overall centrifugal term[2]. This is the most common form of mass transfer, and as such it is the most thoroughly studied and classified.

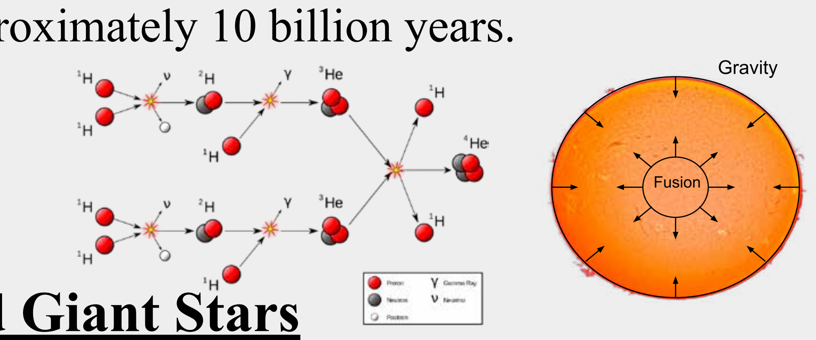
Stars Life Cycle



A Stars Classification (main sequence, red giant, etc.) can be found on The HR diagram. The life Cycle of a star is largely driven by its total mass. The HR diagram is used to organize phases of a stars life. Stars will move across the HR diagram as they age.

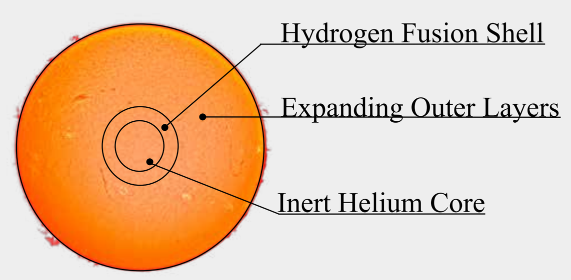
Main Sequence Stars

These stars fuse hydrogen at their core into helium. The amount of time a star remains in the main sequence phase depends on its total mass. A typical star like our Sun would remain in its main sequence phase for approximately 10 billion years.



Red Giant Stars

These stars were once main sequence stars which fused all the hydrogen in its core. When this happens the star's core contracts, upon contracting the core pressure and temperature rise and the star begins to fuse hydrogen around the core. This is known as shell fusion. This increase in energy causes the outer layer of the star to expand. Red Giants can grow many times larger than their original volume. It is the outer layer of particles which initiate the transition of mass across L1.



Physics approximations

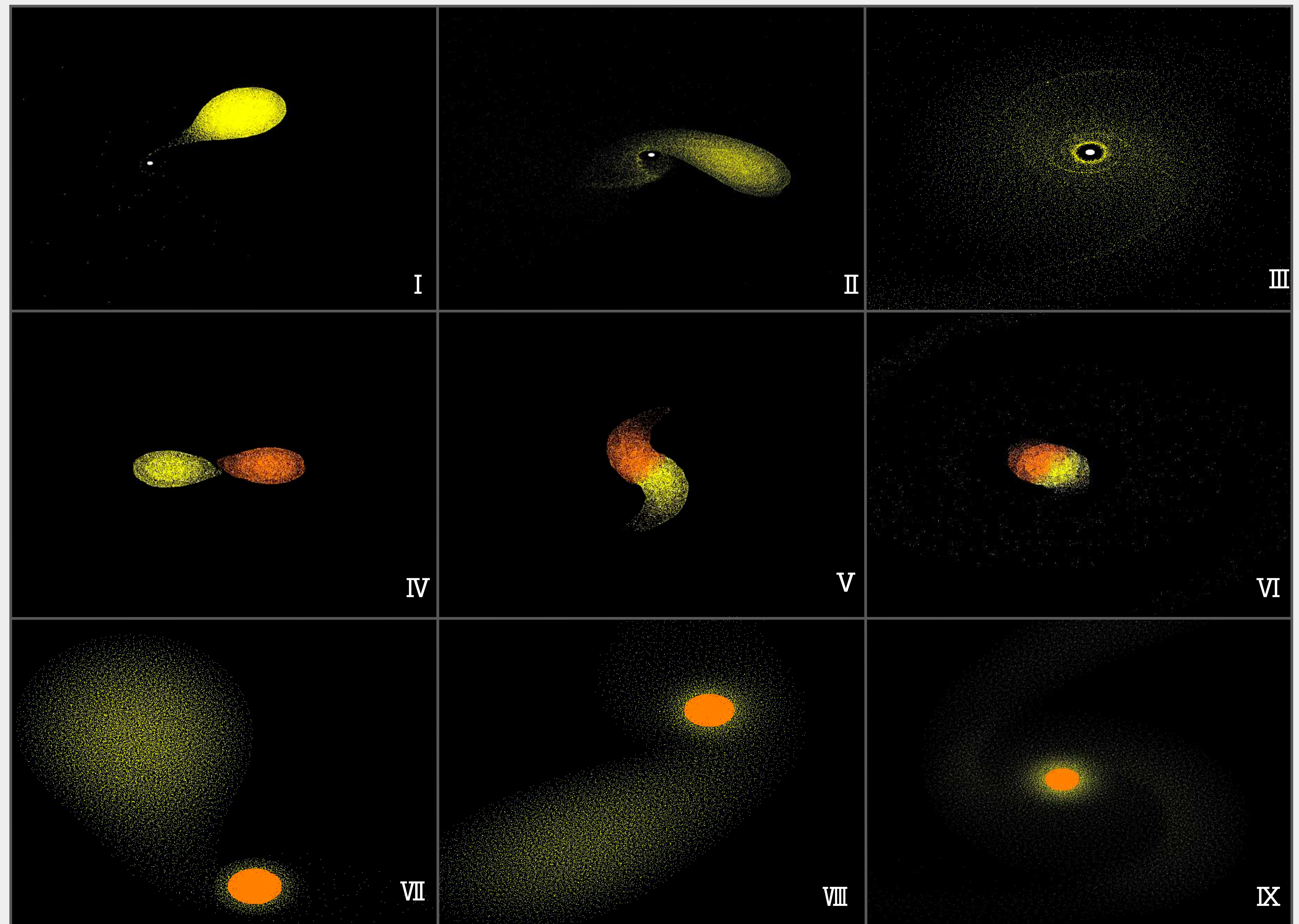
Because of the sophistication of a star's thermodynamic properties we reduced the physics to a model which resembles star like behavior. The quasi-particles repel proportionally to the volume that is displaced when they are in contact. The strength of this repulsion force (its pressure) is dynamically increased to represent the increase in heat caused by shell fusion as a main sequence star enters the red giant phase of its life.

Our model

The model is based off the work done on lunar forming impacts[3,4]. In the model large aggregates of quasi-particles[5] which are refer to as elements are grouped together to form bodies. The properties of the bodies are governed solely by the sum total of all the pairwise element to element interactions. This creates a large N-body system. N-body systems are highly parallelizable allowing the compute load to be efficiently distributed across the numerous processor on modern graphics processing units

Time scaling problem

Modeling the lifecycle of a star happens on the order of billions of years while the orbital period can be on the order of days. This creates a challenge with our numerical integrators. We chose to grow the stars unnaturally fast in order to gain insight into the qualitative behavior of mass transfer.

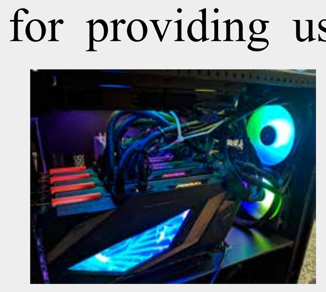


These are a series of screenshots from our simulations. The first row of screenshots (I-III) are sequential and come from a simulation of a red giant passing particles through L1 to the neighboring white dwarf. The second row of screenshots (IV-VI) are sequential and come from a simulation of two main sequence stars sharing mass through L1. The third row of screenshots (VII-IX) are sequential and come from a simulation of a red giant passing particles through L1 to the neighboring main sequence star.

Hardware and Acknowledgments

Our simulations were run on a workstation containing four water cooled Nvidia 2080TI GPUs. We would like to thank Tarleton State University's High performance computing lab for providing us resources to conduct this research.

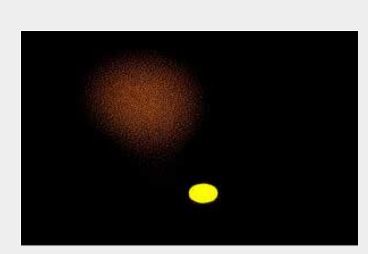
NVIDIA



Conclusions

Currently, refined thermodynamics for the particle interactions is being worked into the model. The particles will be able to grow, shrink, differentiate, and convect naturally. A huge milestone will be to add electromagnetic radiation in order to create realistic light curves. This will allow us to model the photometry a binary system would exhibit, so we can compare known binary systems to our model.

Videos



Github

References

1. Chen, X. Han, Z. Deca, J. Podsiadlowski, P. The Orbital Periods of Subdwarf b Binaries Produced by the First Stable Roche Lobe Overflow Channel, Monthly Notices of the Royal Astronomical Society 434 (1) (2013) 186–193.
2. Regos, E. Bailey, Mardling, R. Mass Transfer in Eccentric Binary Stars, Monthly Notices of the Royal Astronomical Society 358 (2) (2005) 544–550.
3. Eiland, J. Salzillo, T. Hokr, B. Highland, J. Mayfield, M. Wyatt, B. Lunar-forming Giant Impact Model Utilizing Modern Graphics Processing Units, Journal Of Astrophysics & Astronomy 35 (4) (2014) 607–618.
4. Wyatt, B. Petz, J. Sumpter, H. Turner, T. Smith, E. Fain, B. Hutyra, T. Cook, S. Gresham, J. Hibbs, M. Goderya, S. (2018). Creating an Isotopically Similar Earth-Moon System with Correct Angular Momentum from a Giant Impact. Journal of Astrophysics & Astronomy 39 (2) (2018) 26.
5. Greenspan, D. Quasimolecular Modeling, World Scientific Publising, Singapore (1991)
6. Lajoie, C. Sills, A. Mass Transfer in Binary Stars Using smoothed Particle Hydrodynamics. I. Numerical Method. The Astrophysics Journal 726 (2) (2010) 66–75.
7. Schneider, S. Arny, T. Pathways to Astronomy, McGraw Hill, New York, New York (2012)

Contact Information

masonamccallum@gmail.com