CATEGORY: ASTRONOMY & ASTROPHYSICS - AA03

POSTER P6197

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GPU TECHNOLOGY CONFERENCE

N-body Simulation of Binary Star Mass Transfer Using NVIDIA GPUs

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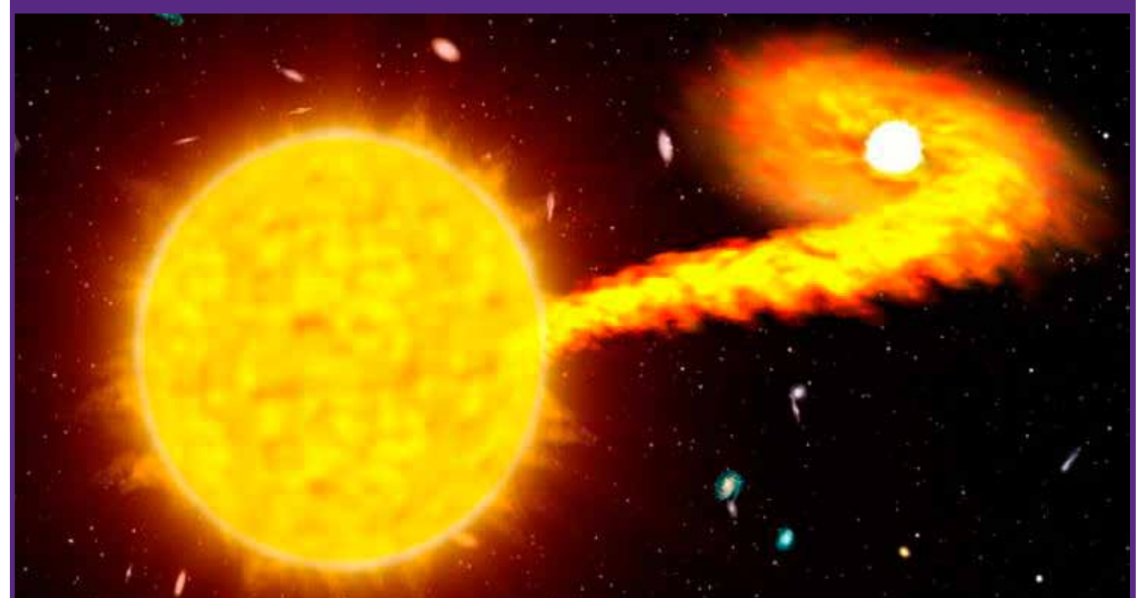
Introduction



Over 70% of the stars in our galaxy are binary systems, two stars that orbit around a common center of mass [1]. The masses of the individual stars can be found using Newton's and Kepler's Laws. This allows astronomers to use these systems as astrophysical laboratories to study properties and processes of stars and galaxies. Among the many types of binary stars observed, the dynamics of contact systems are the most interesting because they exhibit mass transfer, which changes the composition and function of both stars. The process by which this mass exchange takes place is not well understood. The lack of extensive mass transfer analysis, inadequate theoretical models, and the large time scale of this process are reasons for our limited understanding. In this work, a model was made to give astronomers a method for gaining a deeper knowledge and visual intuition of how the mass transfer between binary stars takes place.

Our Model

Our model uses a Discrete Element Method (DEM) based off of Eiland's work on late lunar-forming impacts [2]. The DEM results in a large N-body system that is integrated through time using the Leapfrog formulas [3]. Each body in the system has enough independence that it can be efficiently parallelized, which is well suited to run on affordable, modern GPUs. We chose to use NVIDIA-brand GPUs to power our simulations because of the simplicity of CUDA. Traditionally, this type of computing required near-unaffordable super computers. Now, anyone with an NVIDIA CUDA-enabled GPU can tackle meaningful, computation-heavy problems such as ours.

Hardware

The Tarleton HPC Lab consists of several workstations, all equipped with dual GPUs. Our model ran on two workstations, one with Tesla C2070s donated by NVIDIA and another with dual 680 GTX GPUs.

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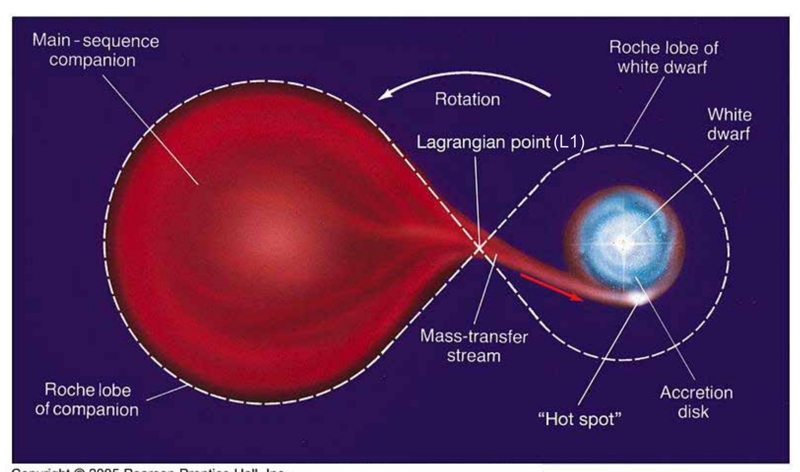
Roche Lobe

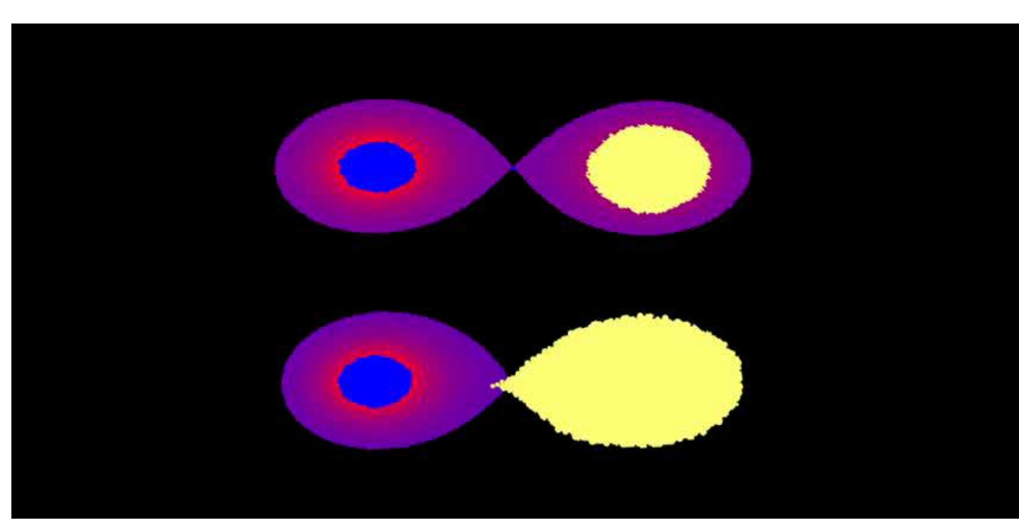
One of the methods in which our model was validated was by comparing the shape of the star as it grew to the Roche Lobe. The Roche Lobe is the region around a star in a binary system within which orbiting material is gravitationally bound to the star. The shape produced from this model assumes that the surface can be defined by its state of hydrostatic equilibrium. Thus, at the surface, the centrifugal force apparent to a single particle is equal to the sum of the force from internal pressure and the gravitational force from both stars. Matter will attempt to fall into gaps in order to find its location with the lowest possible potential. This surface is then defined by constant pressure, density, and potential. Hence, the star's physical shape can be represented as an equipotential function that satisfies the conditions of hydrostatic equilibrium.

$$\Psi = -\frac{G \cdot m_{Star1}}{Distance\ to\ Star1} - \frac{G \cdot m_{Star2}}{Distance\ to\ Star2} - \frac{1}{2}\omega^2 \rho'^2$$

The equipotential surface that crosses L1, the Lagrange point directly between the two stars, contains the region known as the Roche Lobe. This surface is the volume limit of each star. If one star fills its Roche Lobe, it will begin to transfer matter to the other star. L1 becomes a "faucet" for material to travel through.



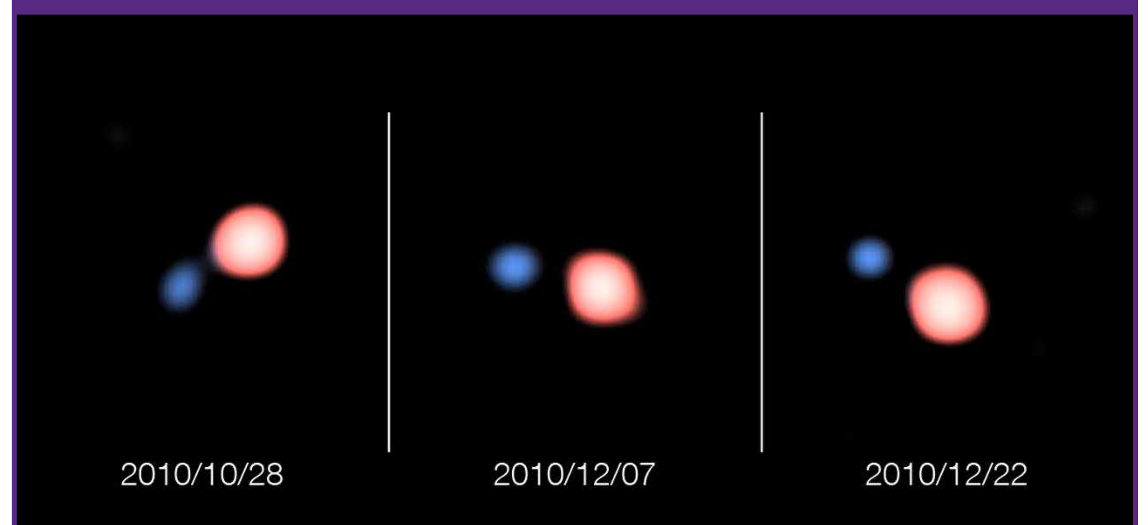
The Roche Lobe, in our model, is generated by looking at specific points in a grid around the center of mass. The potential is calculated at each point of the grid, creating a gradient of the potential field around the stars. Each grid point is independent from the others, making this process "embarrassingly" parallelizable. From this gradient, we isolate the Roche Lobe by displaying only those points with a potential value less than L1 [4].



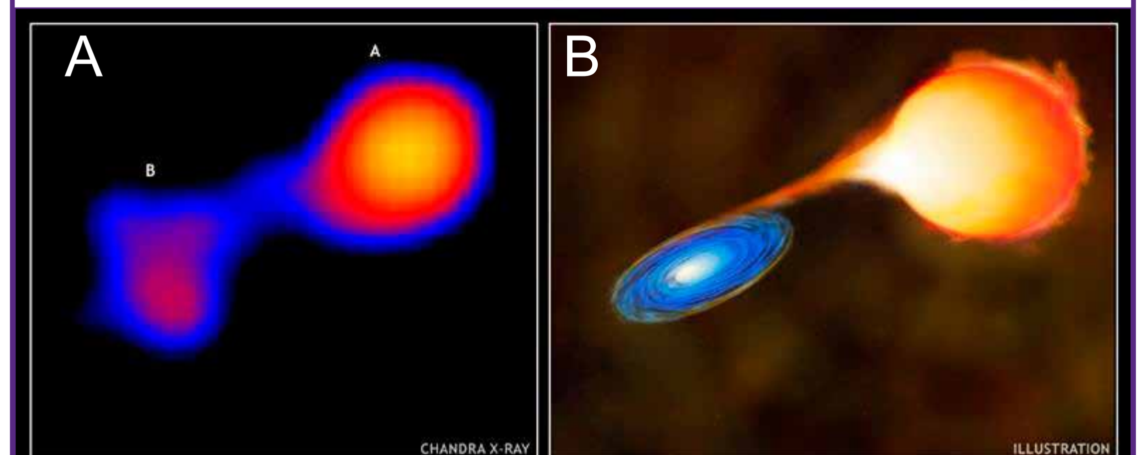
Visual representation of the Roche Lobe with the yellow star filling its Roche Lobe and beginning to transfer mass to the blue star.

Having a visual representation of the Roche Lobe, we can now determine if the model is both properly filling the bounding limit and transferring mass across L1. Our model obeyed both of these conditions, giving it further validation.

Qualitative Verification

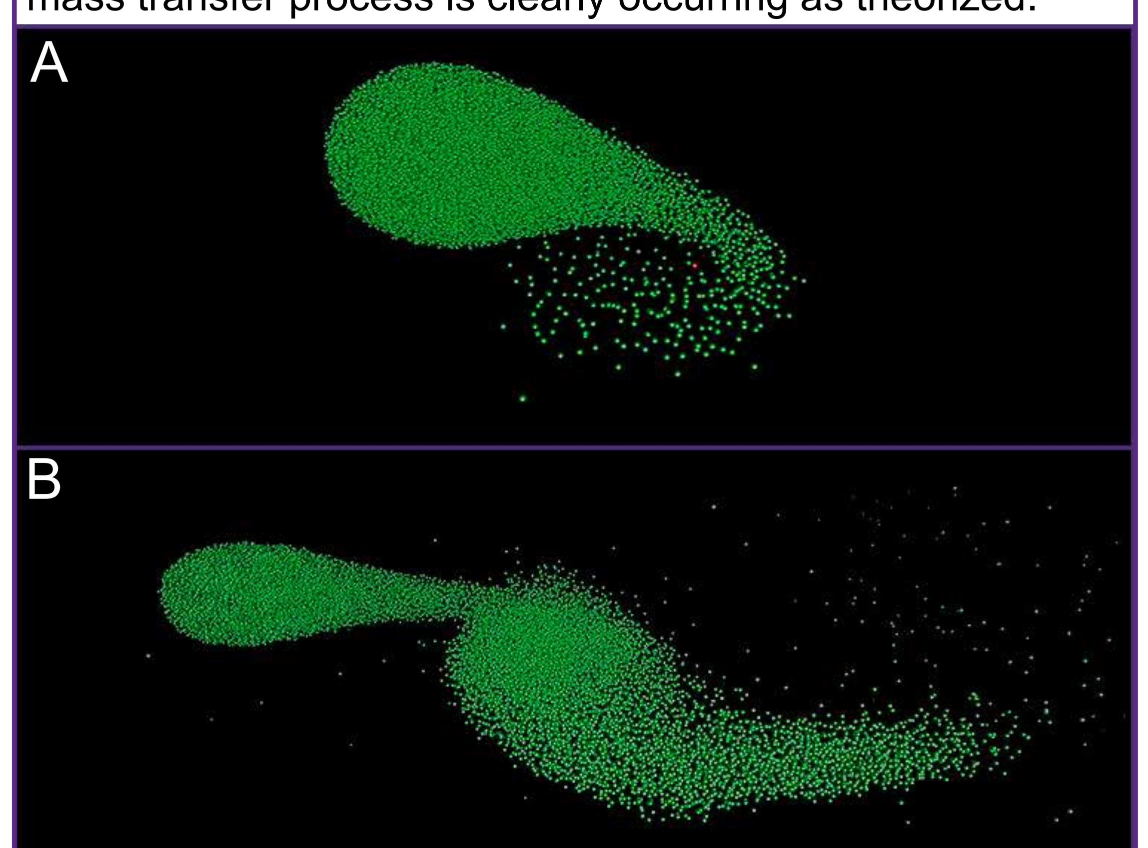


The pictures above are photos of the binary system SS Leporis. These photos are some of the best images ever captured of a star transferring mass to its companion. [5]



Picture A is an X-ray photograph of the binary system, Beta Lyrae [6]. Picture B is an artist's rendition of Beta Lyrae.

Even with the best observations available from X-ray imaging, it is hard to analyze the mass transfer between two stars. To visually and qualitatively represent theory, physicists must rely on artist renditions of these systems. Our model bridges the gap between observation and visual representation. As can be seen in our model below, the mass transfer process is clearly occurring as theorized.



Picture A is the beginning of the mass transfer in our model. Picture B shows the model after a large quantity of the mass has been transferred.

The results are comparable to what has been observed. Below, is an artist rendition of a high-mass X-ray binary star.

The system consists of a neutron star and a blue supergiant star. The neutron star sucks mass from the supergiant, causing a large tail to be formed, like observed in our model.

Binary system IGR J17252-3616 [7]

Conclusions

A model of the mass transfer was produced. Our straightforward code is very intuitive which makes it easy to understand how to model specific systems. The model renders in "real time", which allows the user to make changes and quickly receive feedback. This model, though preliminary, has closely matched what astronomers have observed. It is interesting, that while not rigorously including thermodynamics and electromagnetism, the filling of the Roche Lobe and mass transfer works very well, if not perfectly, in our model. This shows that the binary star mass transfer is mostly a gravitational phenomenon. From this, we can focus on how to further improve our model.

Want to see a simulation? Copy the link or follow the QR-code.

YouTube Channel: **http://tinyurl.com/tsuparticle**

Roche Lobe Video

Simulation Video

Future Works

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—without user input. From this, nuclear processes can be incorporated, which will allow the binary system in the model to evolve through normal evolutionary processes.

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.

Acknowledgments

We would like to thank:
NVIDIA, for donating us two GPU's
The Tarleton High Performance Computing Lab

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