Investigating Mass Transfer in Symbiotic Stars Using the CHARA Optical Interferometry Array

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Abstract

Symbiotic star systems are a type of interacting stellar binary in which a red giant star is closely orbited by a white dwarf (WD) or other compact object. These systems are characterized by a long orbital period, wide binary separation, and a dense circumstellar medium produced by mass transfer from giant to WD. The nature and mechanisms of mass transfer within symbiotic systems are currently poorly understood. Research suggests that the best way to test mass transfer models is to measure the Roche Lobe radius of the giant star using an optical interferometer. However, few studies have attempted these measurements and none have used CHARA. The high resolution of CHARA presents an opportunity to measure the geometry of symbiotic giants in unprecedented detail. In preparation for the observation of several symbiotic systems using the CHARA Optical Interferometer, we present the scientific case for our observations and the pre-observation modeling performed. Detailed imaging of the giant will be used to determine the Roche-filling factor of the giants and better constrain mass transfer present in the system.

Science Justification

Symbiotic stars (Figure 1) are a type of interacting binary system consisting of a red giant star (spectral type M or K) and a companion white dwarf (WD) or other compact object. We wish to learn more about mass transfer from red giant to compact object in these systems.

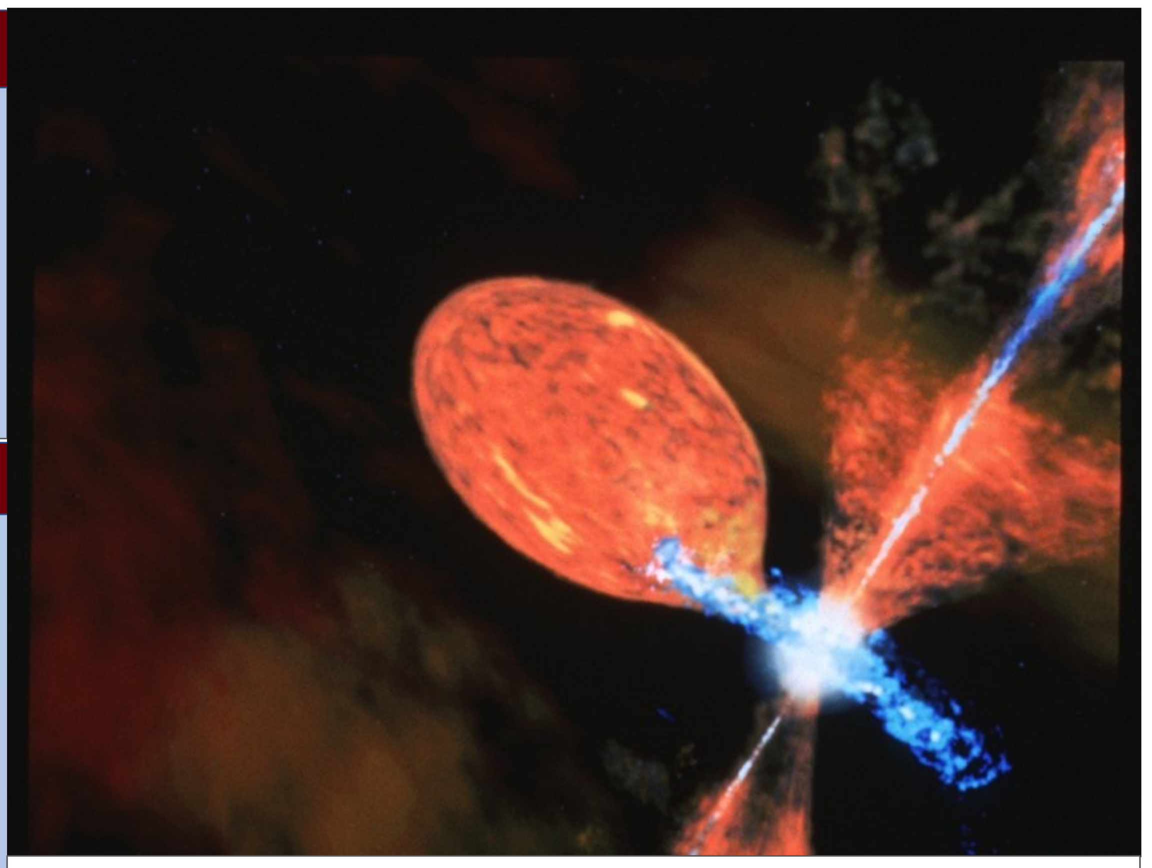

Figure 1. An artist's representation[1] of symbiotic star system RR Aurigae. Here we see mass being transferred from the red giant to the WD which is emitting X-rays through jets.

- Investigating the evolution of symbiotic stars is crucial to improving understanding of the later stages of stellar evolution. Symbiotic stars are connected to the evolution of important stellar objects such as cataclysmic variable stars.
- The key to understanding the evolution of symbiotic stars is investigating the mechanism and rate of mass transfer from giant to companion.
  - Evidence of mass transfer is visible in the form of a teardrop-shaped deformation of the giant star's radius, called its Roche lobe.
  - We can measure the asymmetrical Roche lobe of the giant by imaging the star with an optical interferometer.
  - We can calculate the rate of mass transfer from the asymmetry of the Roche lobe using equations such as those found in Liu et al.[3]
- Very Large Telescope Interferometer (VLTI)'s PIONEER instrument has been used before to image symbiotic stars (Figure 2). We will use the Center for High Resolution Astronomy (CHARA) array to perform similar observations.
  - VLTI has fewer telescopes and shorter baselines than CHARA.
  - CHARA is capable of higher resolution and can achieve better measurement and images.
  - No published observations have used CHARA for this purpose.

Simulation Methodology

In order to be prepared for the fall semester observation sessions, two modeling processes must be run using software built in the Julia programming language for each object:

Roche Lobe System Models – ROTIR

- Currently under development by collaborators at Georgia State University. It is used to create a model of the expected Roche lobe radius for a binary system.
- Simplifying assumptions made: simple limb darkening law, circular orbit, rotation period of red giant equal to binary orbital period.
- Computes the Roche lobe geometry and a 2D-temperature map using binary and stellar parameters and then plots the temperature map.

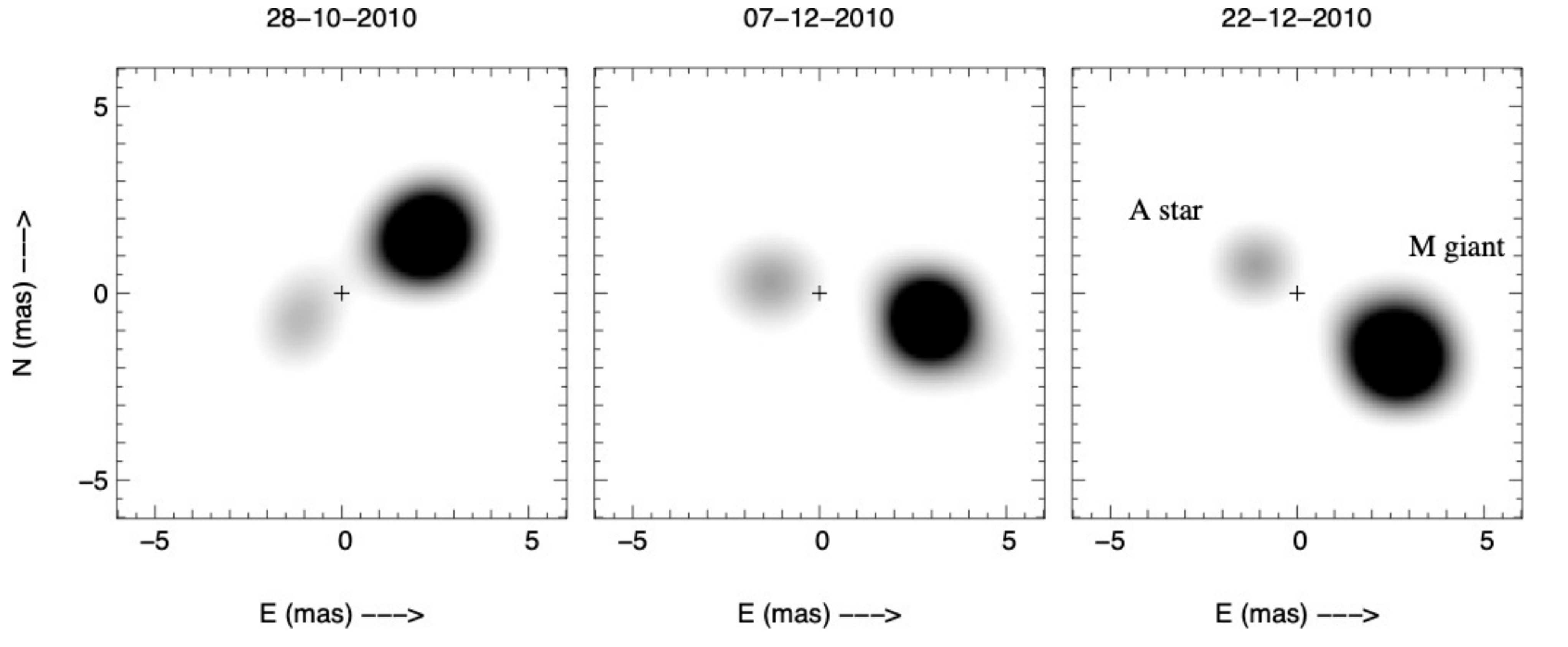

Figure 2. The highest resolution image yet taken of a symbiotic star using an optical interferometer. Instead of a white dwarf, this symbiotic star has an A-type companion to the giant. This image shows three separate observations of SS Lep with the PIONEER Instrument on the VLTI on three separate dates. The axes show the angular size of the stars. From Blind et. al. 2011[2].

Simulated Observations- OITOOLS/SQUEEZE (Figure 3)

- Currently under development by partners at Georgia State University
- Takes FITS files generated using the results of ROTIR Code and simulates an observation with the CHARA Array.
- Can generate multiple types of plots that correspond to interferometry observables:
  - (u, v) coverage plot
  - Visibility squared plot
  - Closure phase plot
- Contains code to perform image reconstruction and predict what a reconstructed image may look like based on ROTIR results

Object Catalogue

Symbiotic Source	RA (J2000)	Dec (J2000)	Estimated Diamter (mas)	Potential Observing Window
SU Lyn	06 42 55.137	+55 28 27.228	1.8	October - December
BD Cam	03 42 09.328	+63 13 00.463	5.5	September-December
EG And	00 44 37.188	+40 40 45.703	1.5	August - December
V1472 Aql	19 24 33.07	+50 14 29.058	1.9	August – September

Future Work

A proposal has been submitted to the New Mexico Space Grant Consortium to fund further research into this topic. The next steps include:

- **Data Analysis:**
  - We will make use of tools developed by collaborators at Georgia State University.
  - Our aim is to reconstruct images of giants and make diameter measurements for mass transfer calculations.
- **Second Observing Run:**
  - We will apply for time to observe more symbiotic stars (up to 5 more systems) using CHARA during 2022 Spring Semester.

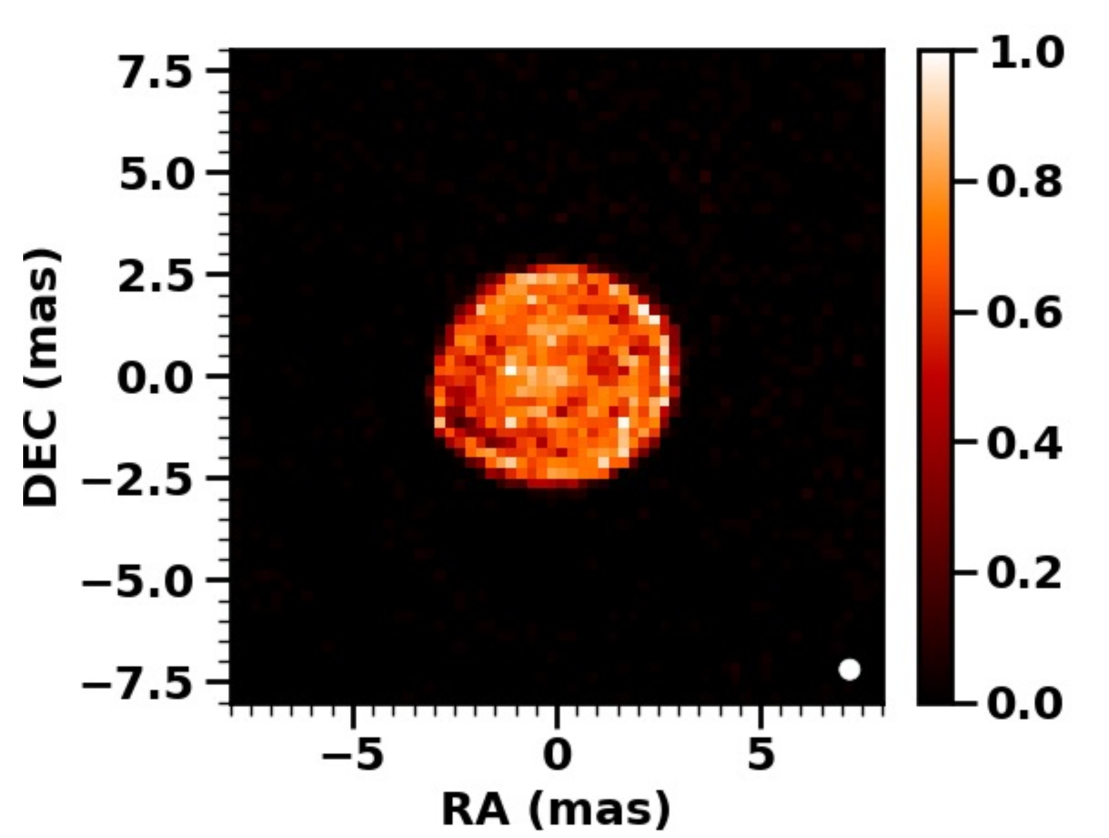

Figure 3. A reconstructed image of the symbiotic star BD Cam at its predicted orientation in November 2021. This reconstruction represents the best case scenario where the star is completely filling its Roche Lobe (fillout factor of 1.0). It was made by modeling the system using the ROTIR code package and using the results to simulate an observation using the SQUEEZE code package. Image reconstruction code is built into the OITOOLS package.

References

[1]Image Credit: NASA, ESO, D. Barry (STSci)
[2]Blind, N et al., 2011, *Astronomy & Astrophysics*, *536*, A55.
[3]Liu, D et al., 2019, *Astronomy & Astrophysics*, 622, A35

Contact Information and Acknowledgements

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