A CHALLENGING PROJECT: MODELING MASS TRANSFER IN BINARY SYSTEMS

KITP Graduate Student Afternoon

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Outline of Talk

Why model mass transfer in binary systems?

How do we plan on modeling such systems?

Problems encountered so far… and still not solved

Why model mass transfer?

To investigate one of the formation scenarios for blue stragglers!

- Thought to be formed either through stellar collisions or binary mass transfer (either primordial or dynamically formed)

- Collisional scenario has been extensively investigated (e.g. Lombardi et al. 1995, Sills et al. 1997, 2001)

- Observations seem to suggest that BSS are mainly found/formed in binary systems (e.g. Knigge et al. 2009, Geller et al. 2008. See also Ferraro et al. 2006)

- To better understand how matter is deposited onto the accretor and how the properties of the accretor are modified (e.g. mass, luminosity, etc)

What's so challenging about it?

It can be computationally expensive and tricky

- Mass transfer rates can be fairly low ($\sim 10^{-3}$-10^{-6} $M_\odot$/yr) which imply secular evolution of the system

- The need for a high spatial resolution (e.g. number of particles) in order to resolve the stream of matter and the accretion process

- Some authors do not even model the accreting star but rather use point masses or sink particles

Our Tool: SPH

Discretization of a fluid into smoothed particles which are subject to pressure gradients and gravity

- Density is calculated using a weighted summation over each particle's neighbors:

$$\rho_i = \Sigma\, m_j\, W_{ij}(r,h)$$

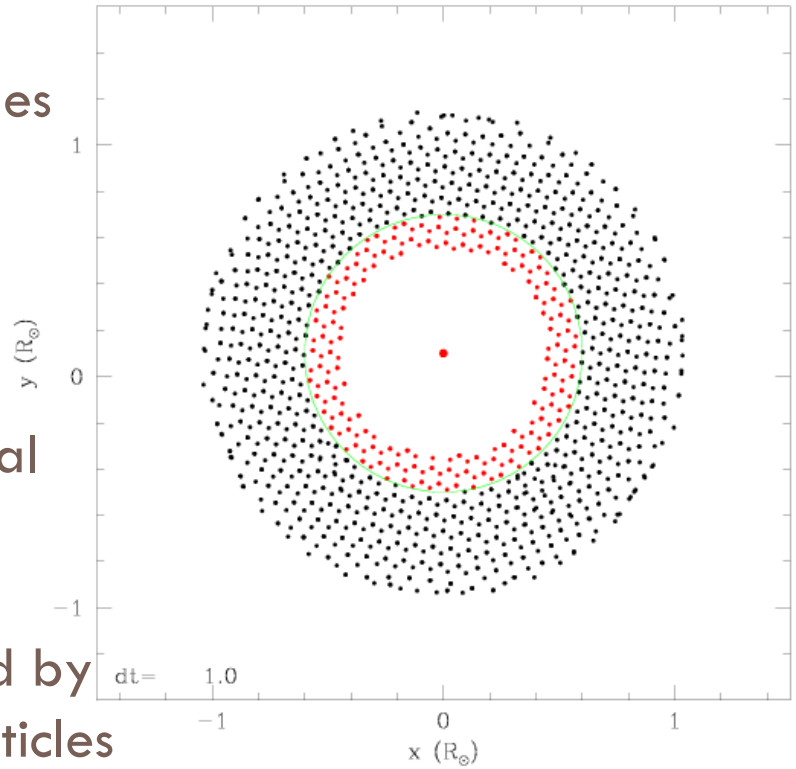
- $W_{ij}(r,h)$ is the smoothing kernel and "*h*" is the smoothing length

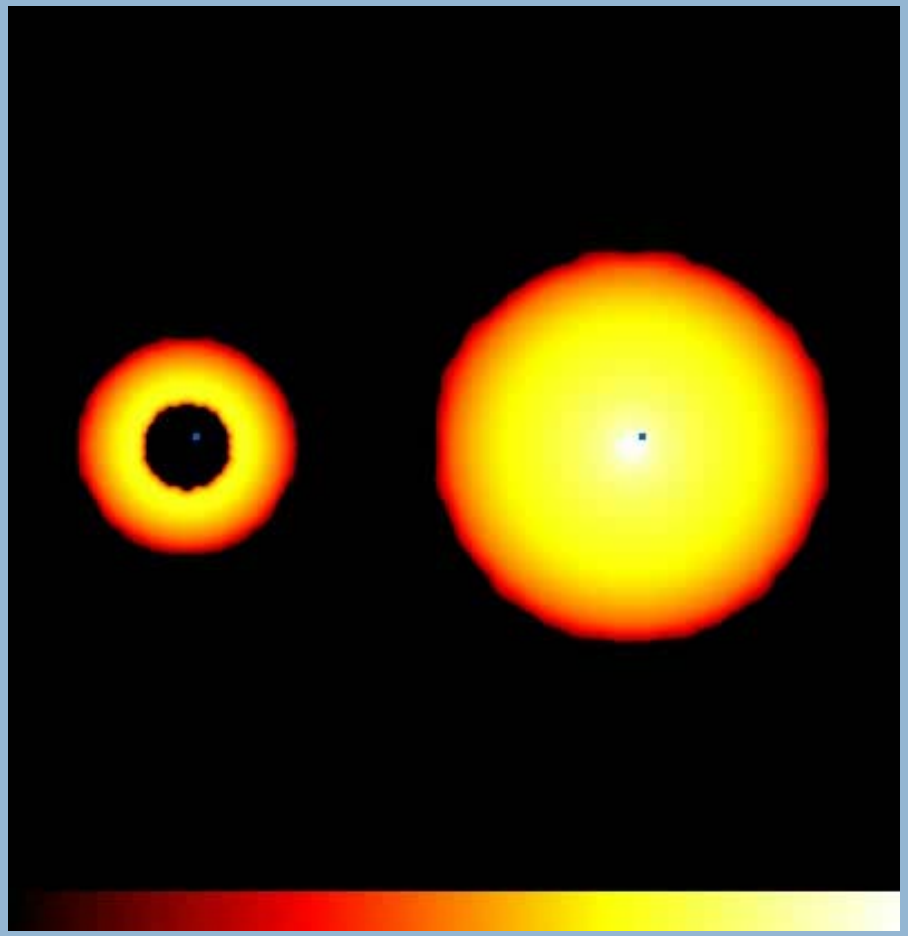
- By construction, SPH conserves energy as well as linear and angular momenta, although the use of a (binary) tree might alter these properties

Our Strategy

Only model the outer part of the stars, i.e. where all the action is happening

- Boundary conditions are implemented using ghost particles:
  - Ghosts are not evolved like SPH particles
  - Density of ghosts is scaled to match the theoretical profile of full star
  - Total inner mass is replaced by a central point mass
  - Drift of point mass significantly reduced by including the back reaction of SPH particles on ghosts/point mass





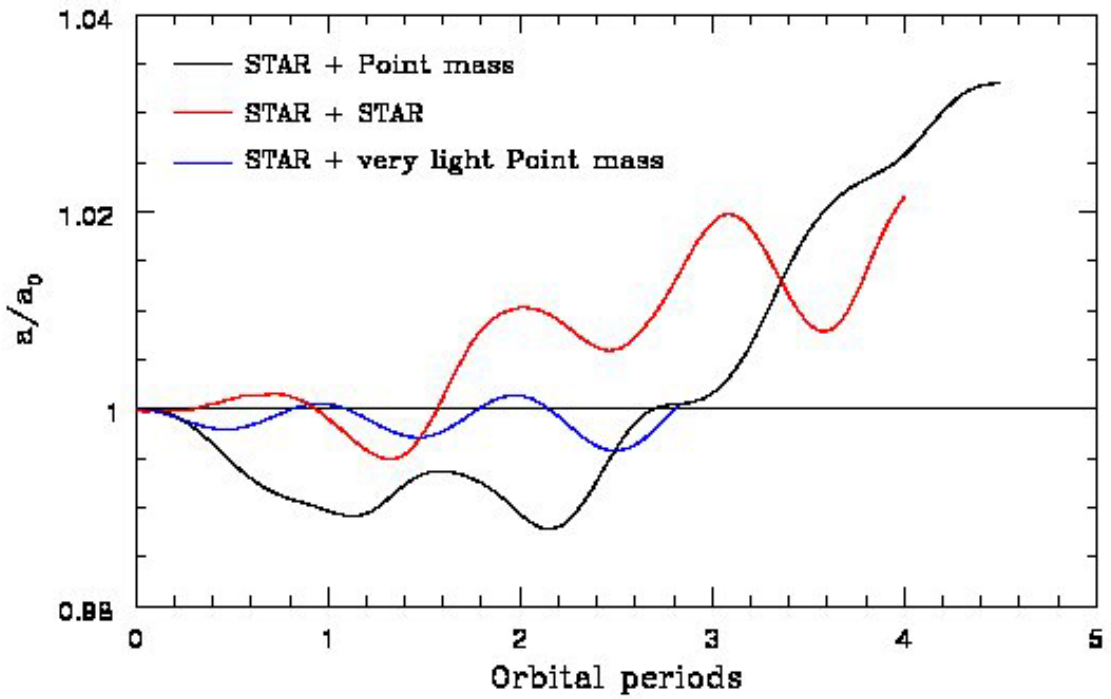
A preview of what's to come…

0.8 $M_\odot$ MS + 0.8 $M_\odot$ RG at a separation of 4 solar radii

Initially unstable

But problem with stability of orbits…

We need to make sure our code can evolve a binary on a circular orbit for many periods



➢We looked at many different things (individual time-steps, force calculations, binary tree accuracy, initial conditions!)

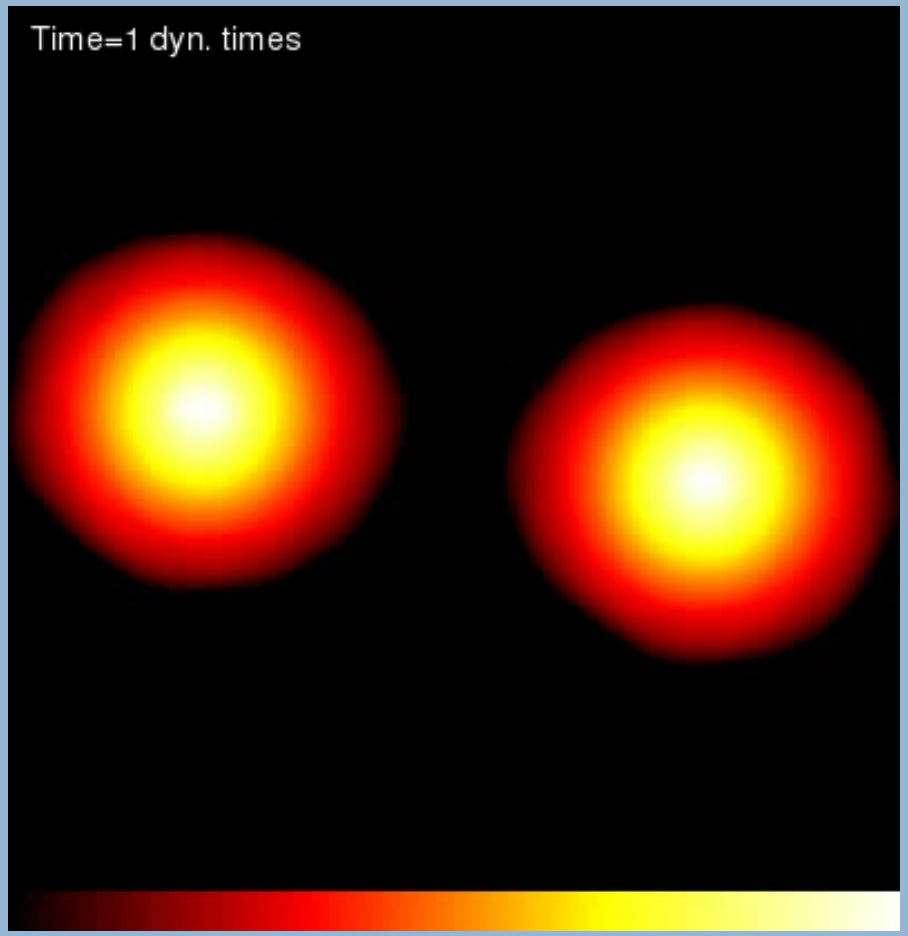
Need for better initial conditions

Relaxation of both stars in co-rotating frame to take into account tidal and centrifugal forces

- e.g. Rosswog et al. (2004) and Lombardi et al. (2009; in prep.)

  - Calculate the acceleration of both centres of mass
  - Find the centrifugal acceleration that counterbalances the pull from the companion
  - Reset positions of both stars to desired separation

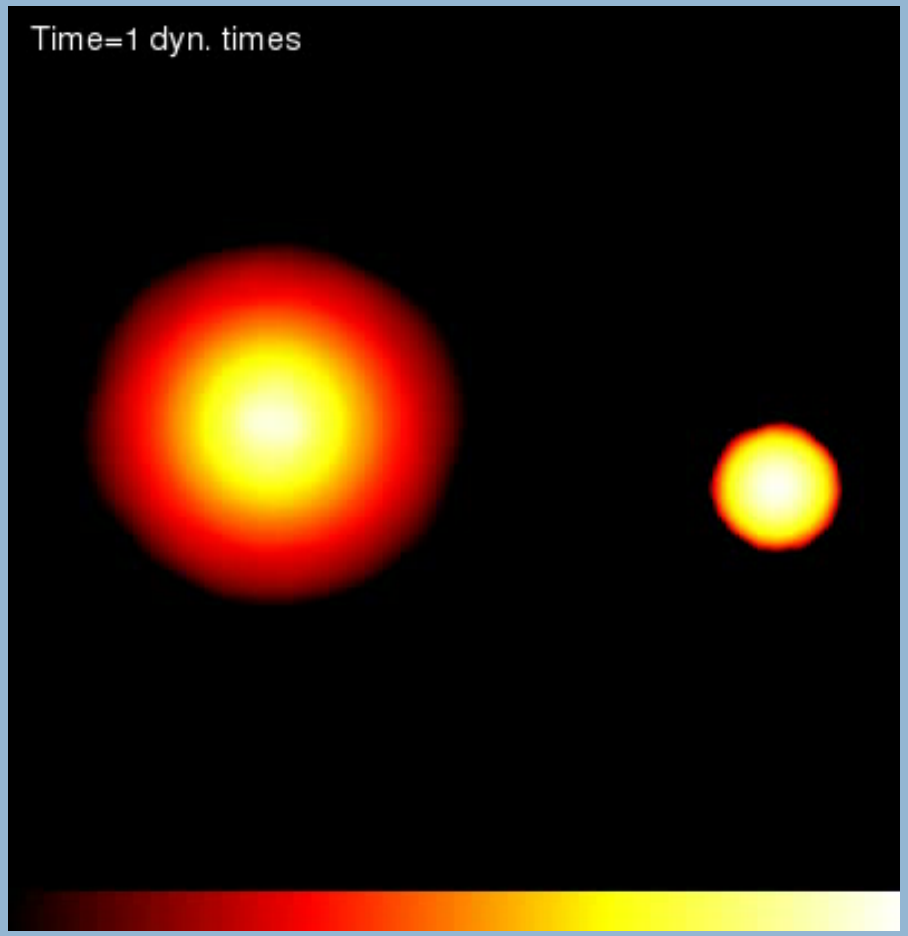
- This way we make sure the binary is fully relaxed and synchronous



EQUAL-MASS BINARY

0.66 $M_\odot$ + 0.66 $M_\odot$ at a separation of 4 solar radii

Followed for up to 5 orbits



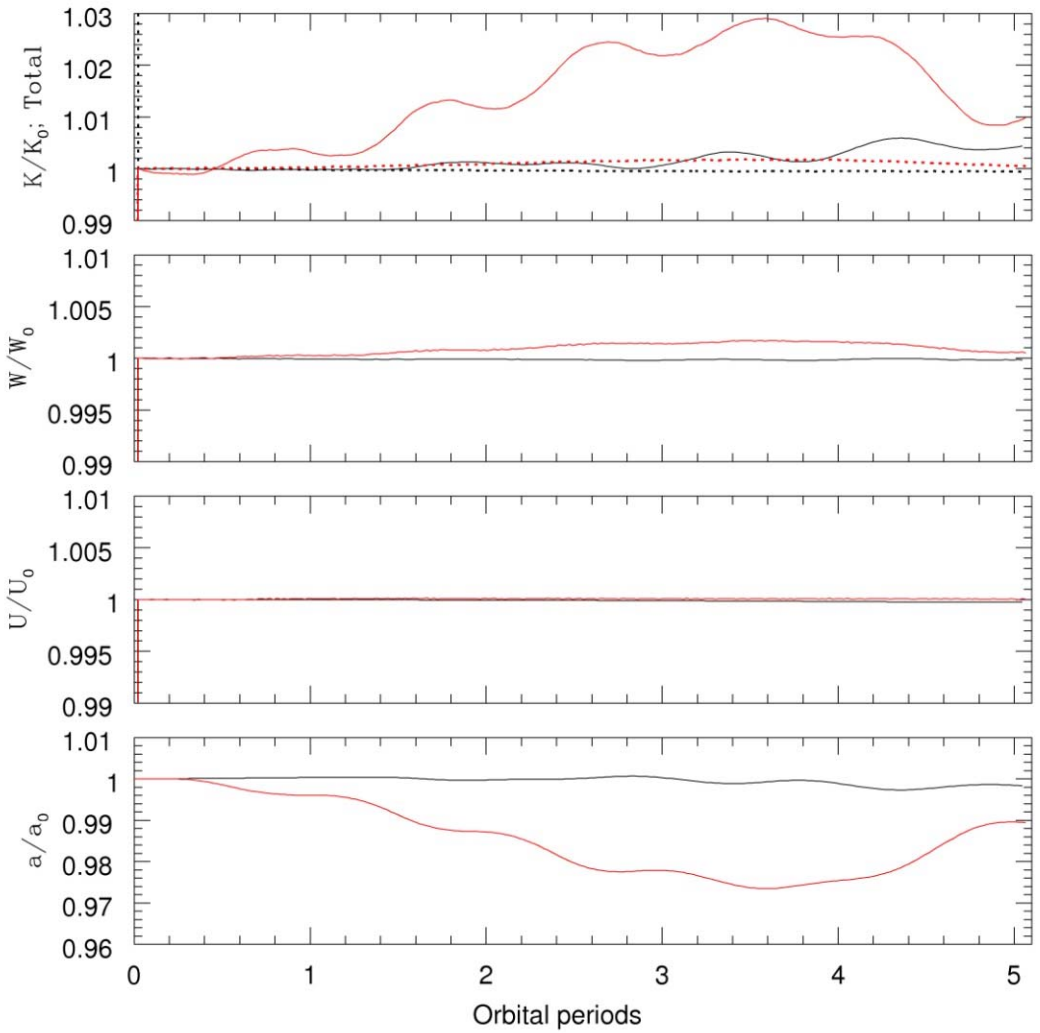
UNEQUAL-MASS BINARY

0.66 $M_\odot$ + 0.37 $M_\odot$ at a separation of 4 solar radii

Followed for up to 5 orbits

Equal- vs Unequal-Mass Binaries

Conservation of energy and orbital separation



Kinetic & Total (dashed)

Gravitational

Thermal

Orbital Separation

Unequal-Mass Binaries

We are still investigating why unequal-mass binaries behave like they do

- Individual/different time-steps?
- Initial conditions?
- Accuracy/Force calculations with a binary tree?
- Any ideas or suggestions?

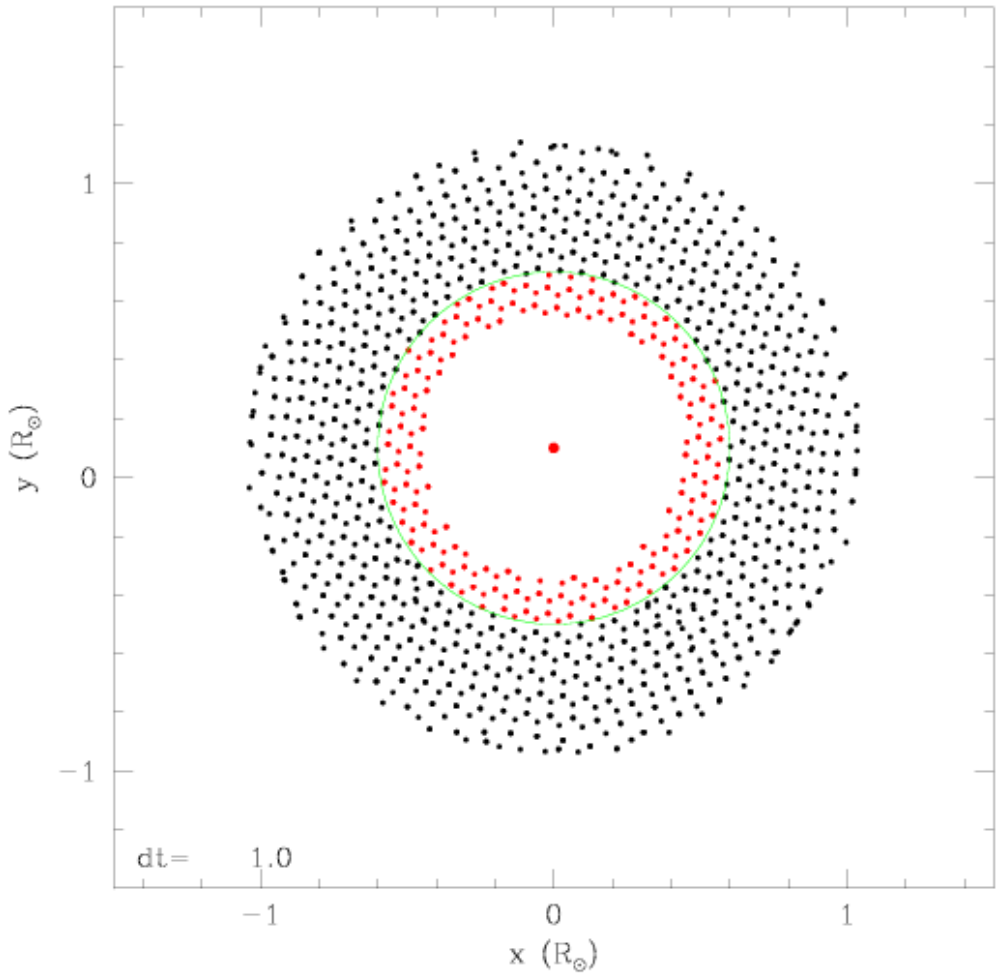
Summary

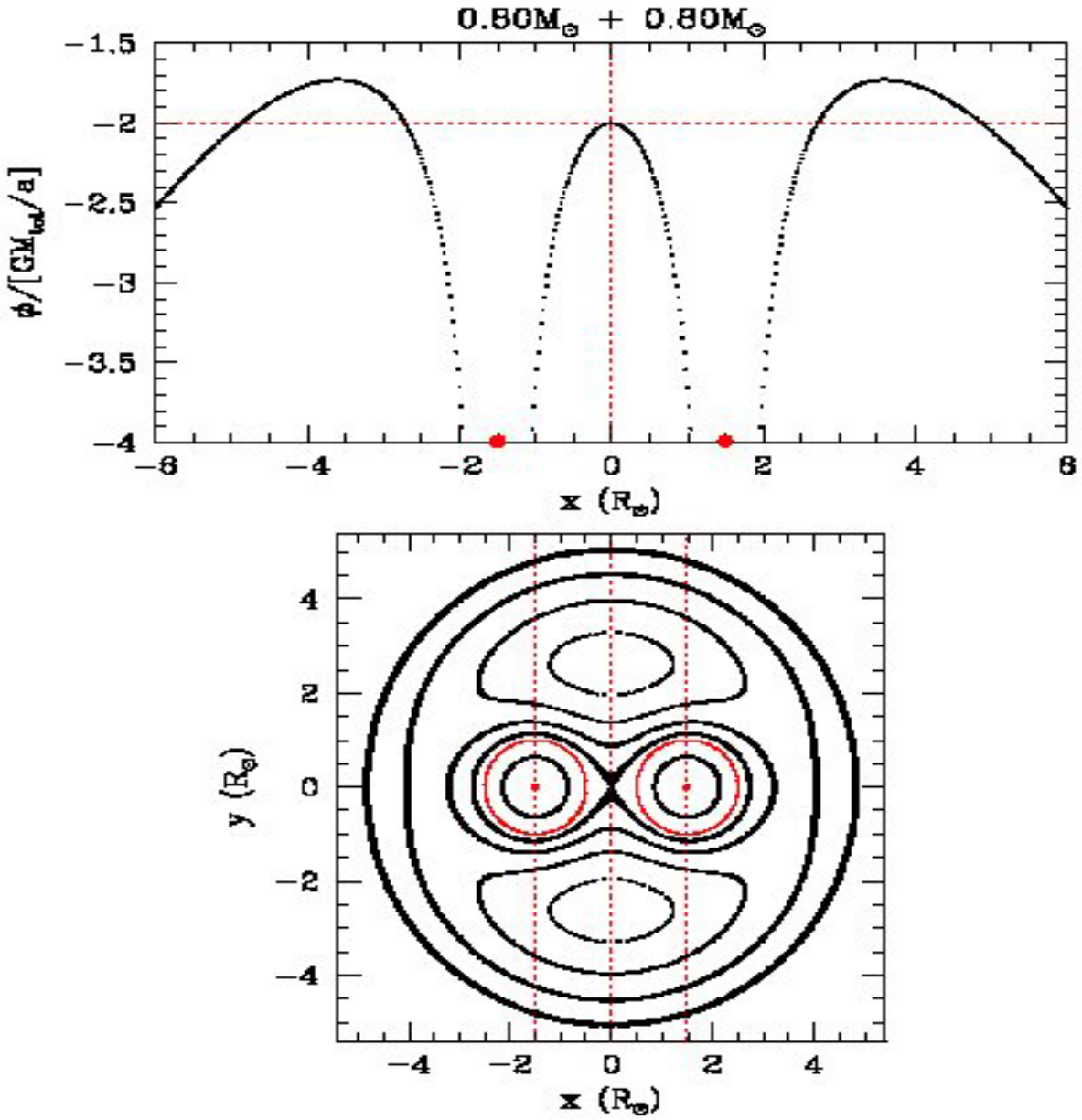
We are working on an SPH code with the idea of modeling mass transfer and investigate the formation of blue stragglers

- We plan on modeling only the outer parts of the stars with the use of boundary conditions/ghost particles
- We are having some problems with the evolution of circular binaries
- We hope to model realistic models in the next few months in order to better understand the accretion process and the structure of the accreting star

Ghost Particles

Rotation + translation with ghost particles




0.60M⊙ + 0.60M⊙
−1.5
−2
−2.5
−3
−3.5
−4
−6
−4
−2
0
2
4
6
φ/[GM_tot/a]
x (R⊙)
4
2
0
−2
−4
−4
−2
0
2
4
y (R⊙)
x (R⊙)