Simulations of Common Envelope Evolution with AstroBEAR: First Results

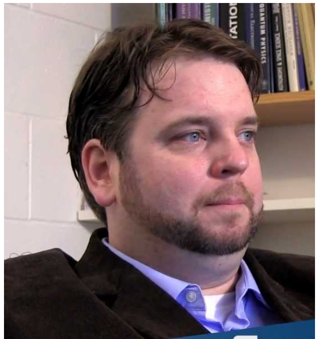
Luke Chamandy

University of Rochester, NY, USA

Adam Frank

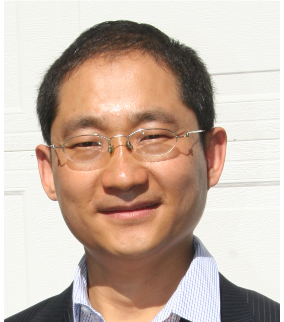
Eric Blackman

Jonathan Carroll-Nellenback



Zhuo Chen

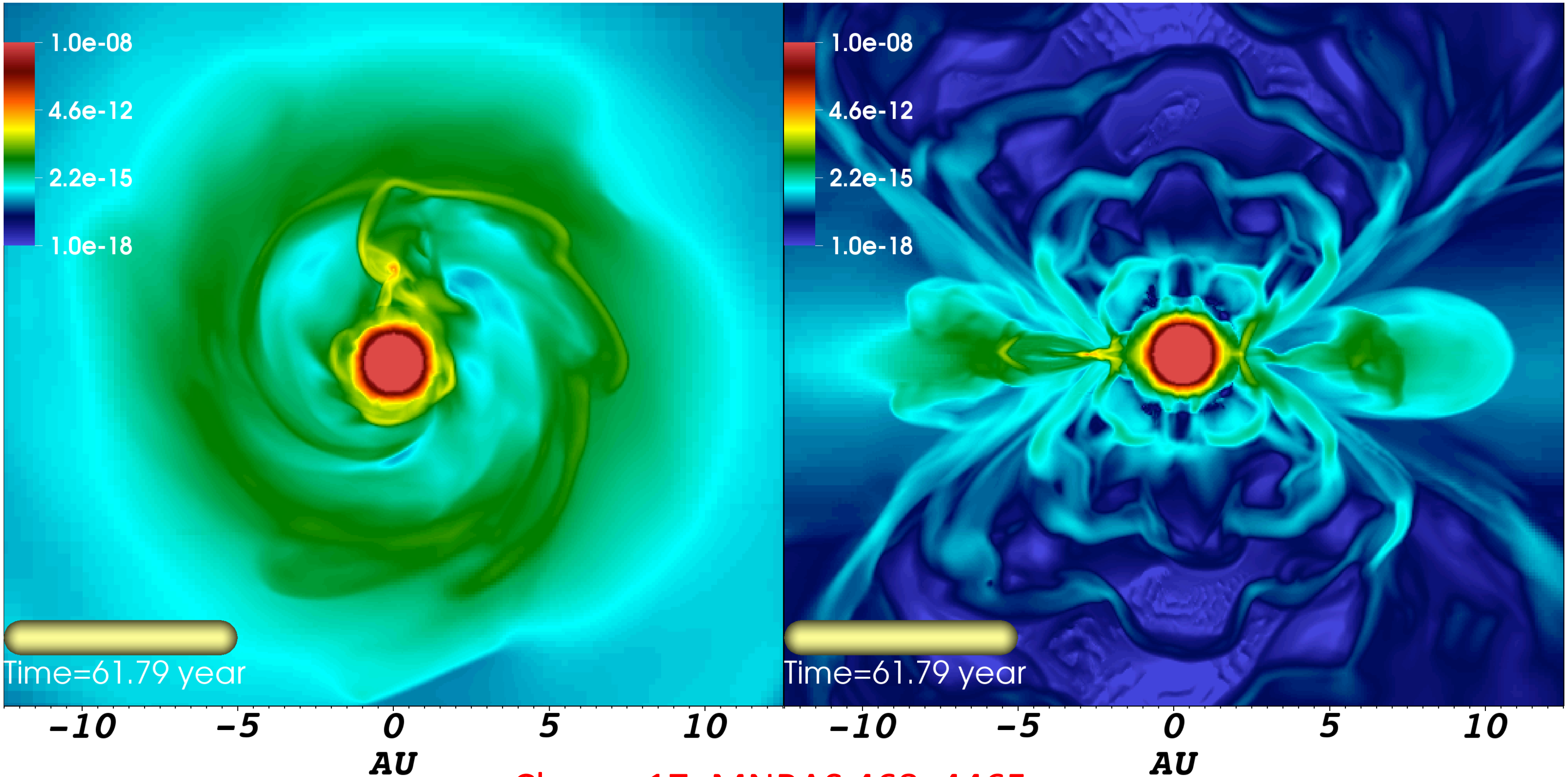
Baowei Liu



Jason Nordhaus

3D radiation hydrodynamic simulations of AGB binary systems

Close binaries may have circumbinary disc

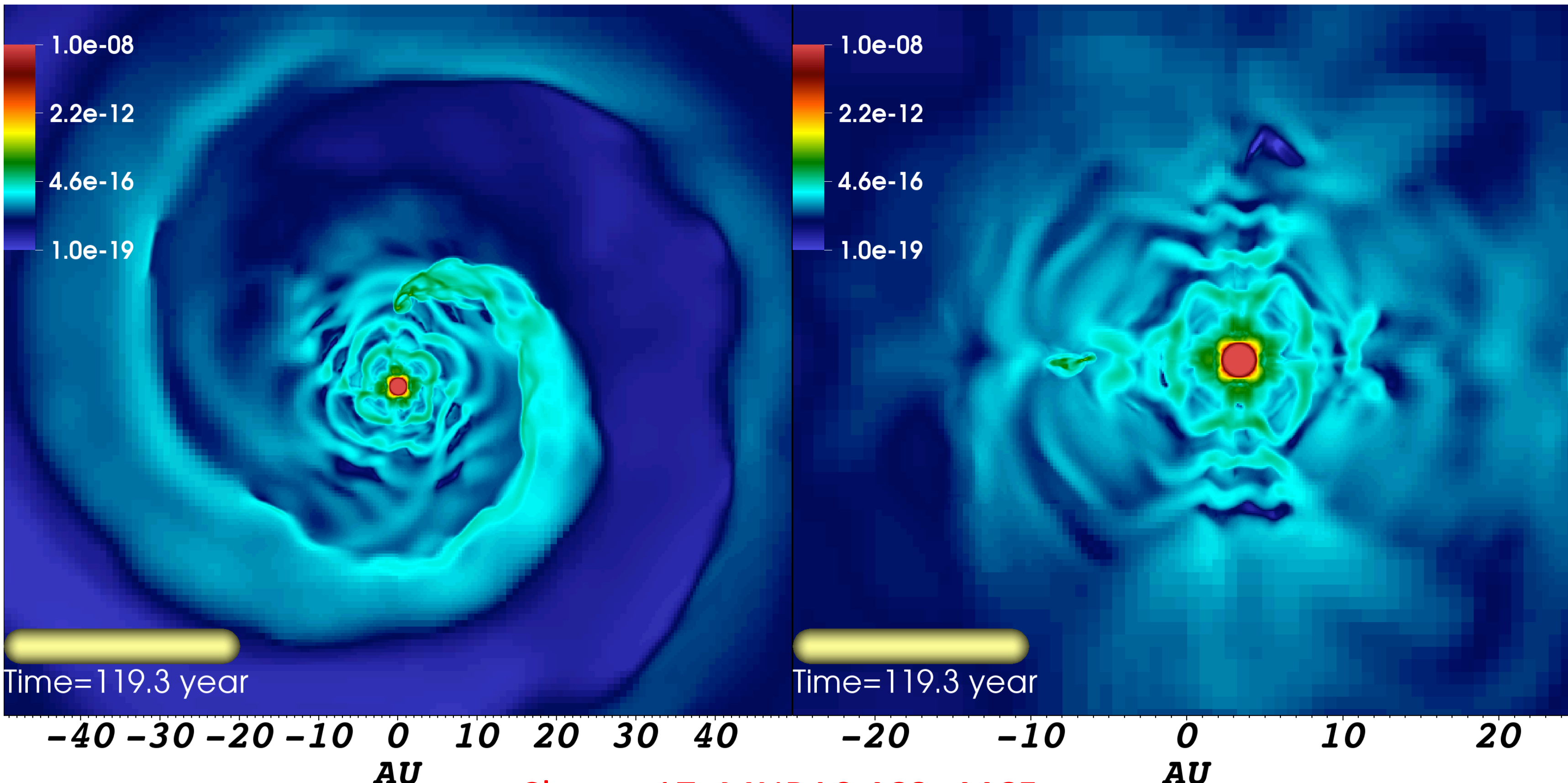


Chen++17, MNRAS 468, 4465

Figure: $M_{AGB}=1\ M_{\odot}$, $M_{companion}=0.1\ M_{\odot}$. Separation is 3au. We can clearly see the gap between the binaries and the circumbinary disc.

3D radiation hydrodynamic simulations of AGB binary systems

Wide binaries may have spiral structure

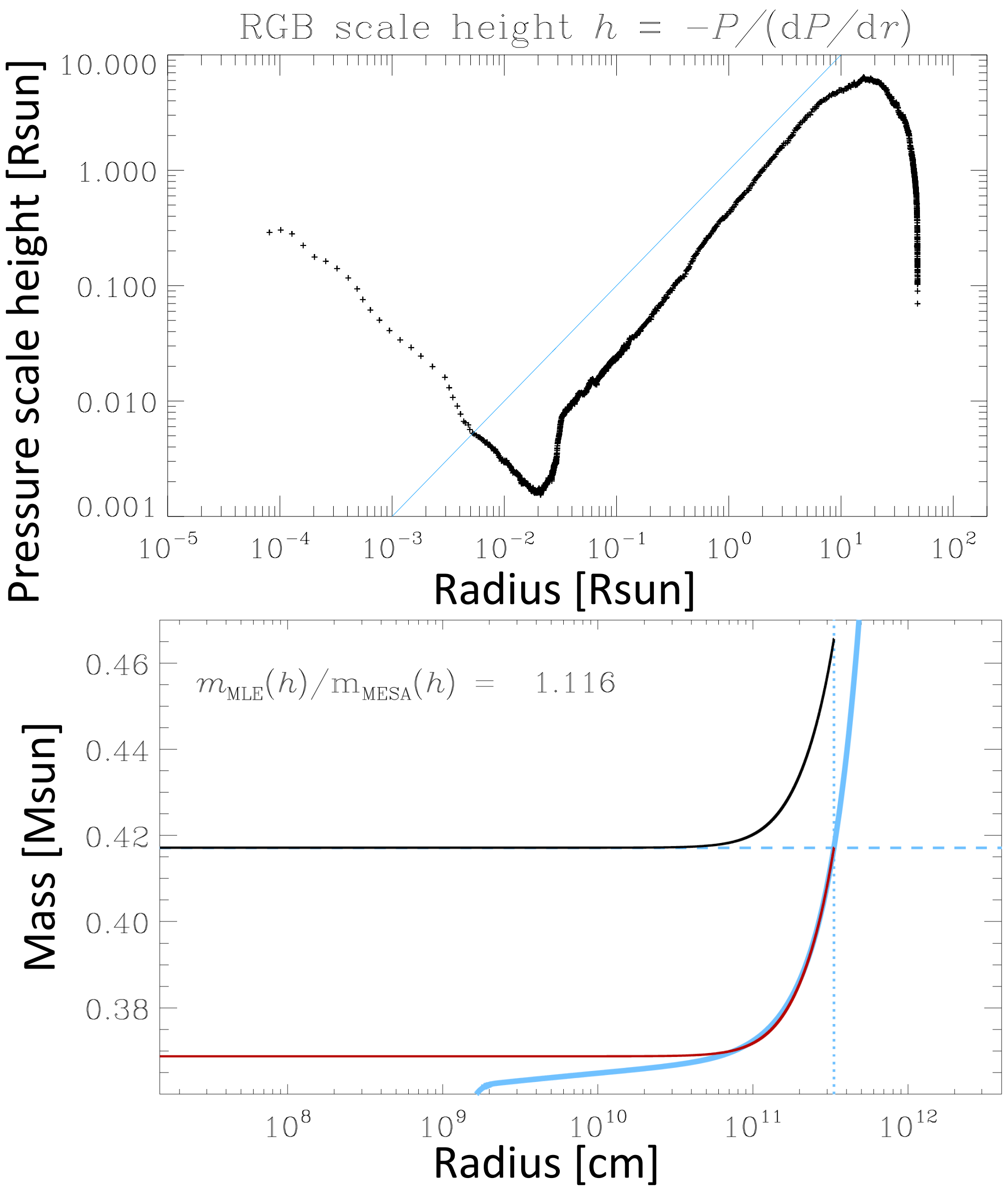


Chen++17, MNRAS 468, 4465

Figure: M_{AGB}=1 $M_\odot$, $M_{companion}$=0.5 $M_\odot$. Separation is 10au. The companion focuses gas to its tail and produces spiral structure.

Dealing with the Core of the Giant

- Use MESA to obtain RGB profile.
- Choose cutoff radius and replace core with point particle.
- Spline function (Springel 2010) for gravity, with softening length = cutoff radius.
- Hydrostatic core profile obtained by solving a modified Lane-Emden equation, iteration to satisfy BCs (Ohlmann+ +2017).



Stabilizing the Giant

- Ambient pressure
- Velocity damping (Pakmor++ 2012)
- Boundary conditions
- Refinement

$$\dot{\boldsymbol{v}} = -\frac{1}{\tau}\boldsymbol{v}.$$

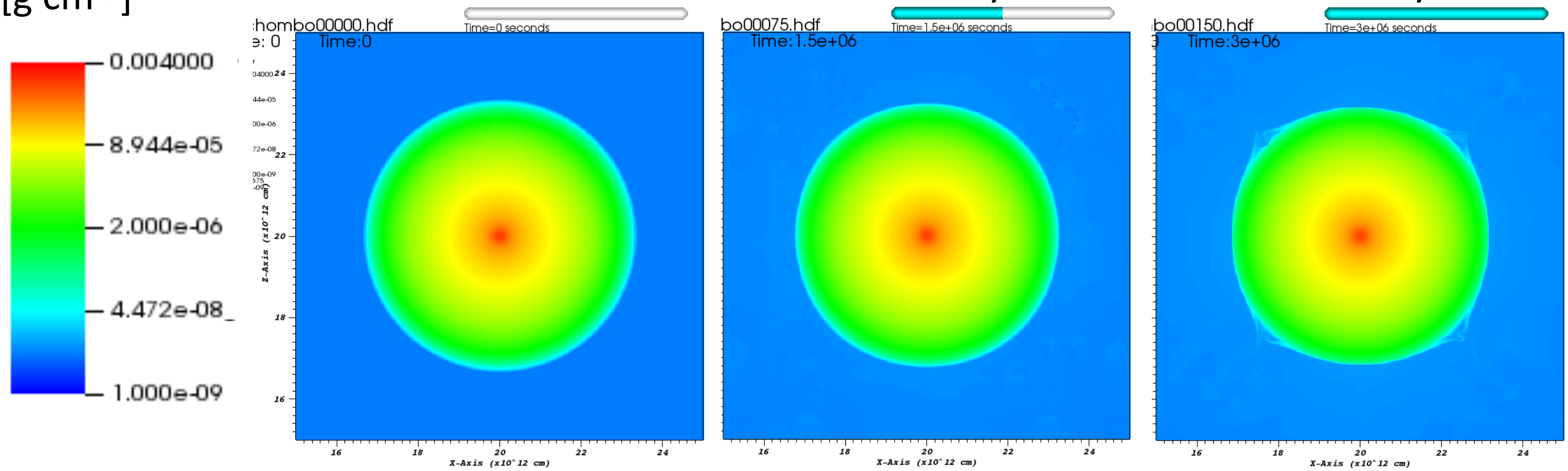
$$\tau(t) = \begin{cases} \tau_1, & t < 2t_{\mathrm{dyn}} \\ \tau_1 \left(\frac{\tau_2}{\tau_1}\right)^{\frac{t-2t_{\mathrm{dyn}}}{3t_{\mathrm{dyn}}}}, & 2t_{\mathrm{dyn}} < t < 5t_{\mathrm{dyn}} \\ \infty, & t > 5t_{\mathrm{dyn}}. \end{cases}$$

Setup: Relaxation Run

Parameter	Ohlmann++2016a	Chamandy++ (test run)
Code	AREPO (moving adaptive mesh)	AstroBEAR (Eulerian AMR)
Hydro BCs	Periodic	Extrapolated
Poisson solver	Tree method	Multipole expansion
$L_{\rm box}$	$192\,{\rm R}_\odot$ $(=4R_*)$	$575\,{\rm R}_\odot$
Smallest resolution element	$0.14\,{\rm R}_\odot$	$0.29\,{\rm R}_\odot$
Primary	ZAMS $2\,{\rm M}_\odot$ $\rightarrow$ RG (MESA)	ZAMS $2\,{\rm M}_\odot$ $\rightarrow$ RG (MESA)
Primary core	Point particle, spline	Point particle, spline
Cutoff radius = softening length	$2.8\,{\rm R}_\odot$	$4.8\,{\rm R}_\odot$
Core profile	Modified Lane-Emden with $n=3$	Modified Lane-Emden with $n=3$
Primary mass	$1.98\,{\rm M}_\odot$	$1.956\,{\rm M}_\odot$
Primary core mass	$0.38\,{\rm M}_\odot$	$0.369\,{\rm M}_\odot$
$\rho_{\rm ambient}$	$\sim 2\times10^{-10}\,{\rm g\,cm^{-3}}$	$6.7\times10^{-9}\,{\rm g\,cm^{-3}}$
$P_{\rm ambient}$	Comparable to surface of star	$10^6\,{\rm dyn\,cm^{-2}}$
Damping τ	$9.4\,{\rm d}$	$3.5\,{\rm d}$
Total relaxation time	$94\,{\rm d}$	$17.4\,{\rm d}$

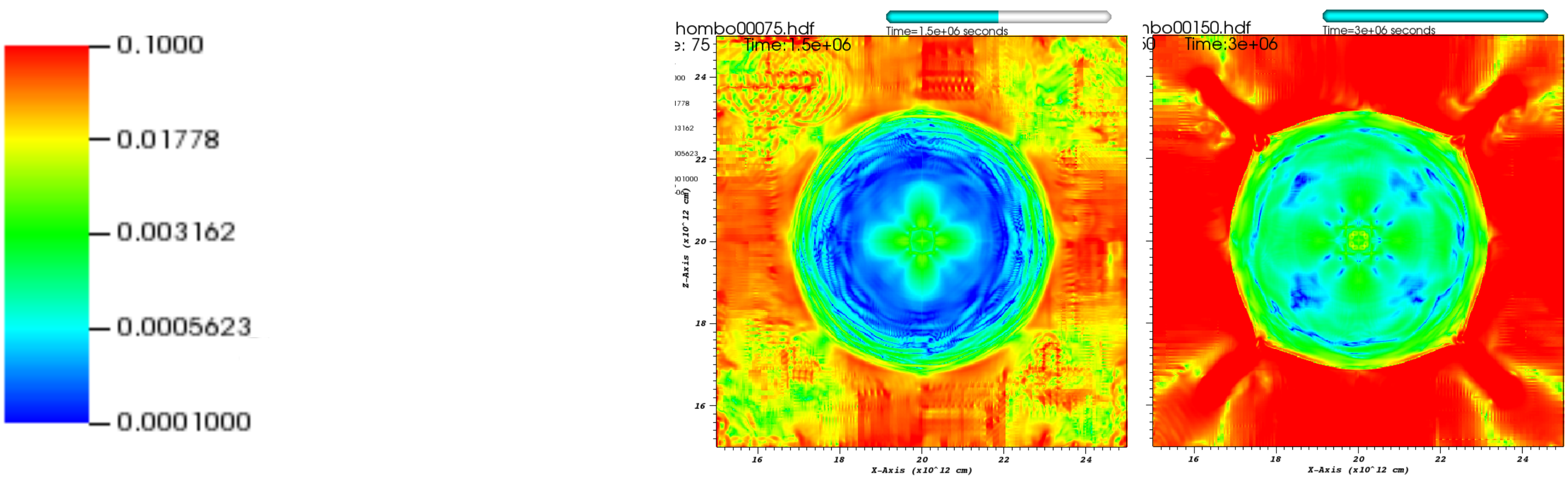
Density [g cm^{-3}]

Modified profile | 5 freefall times = 17 days | 10 freefall times = 35 days



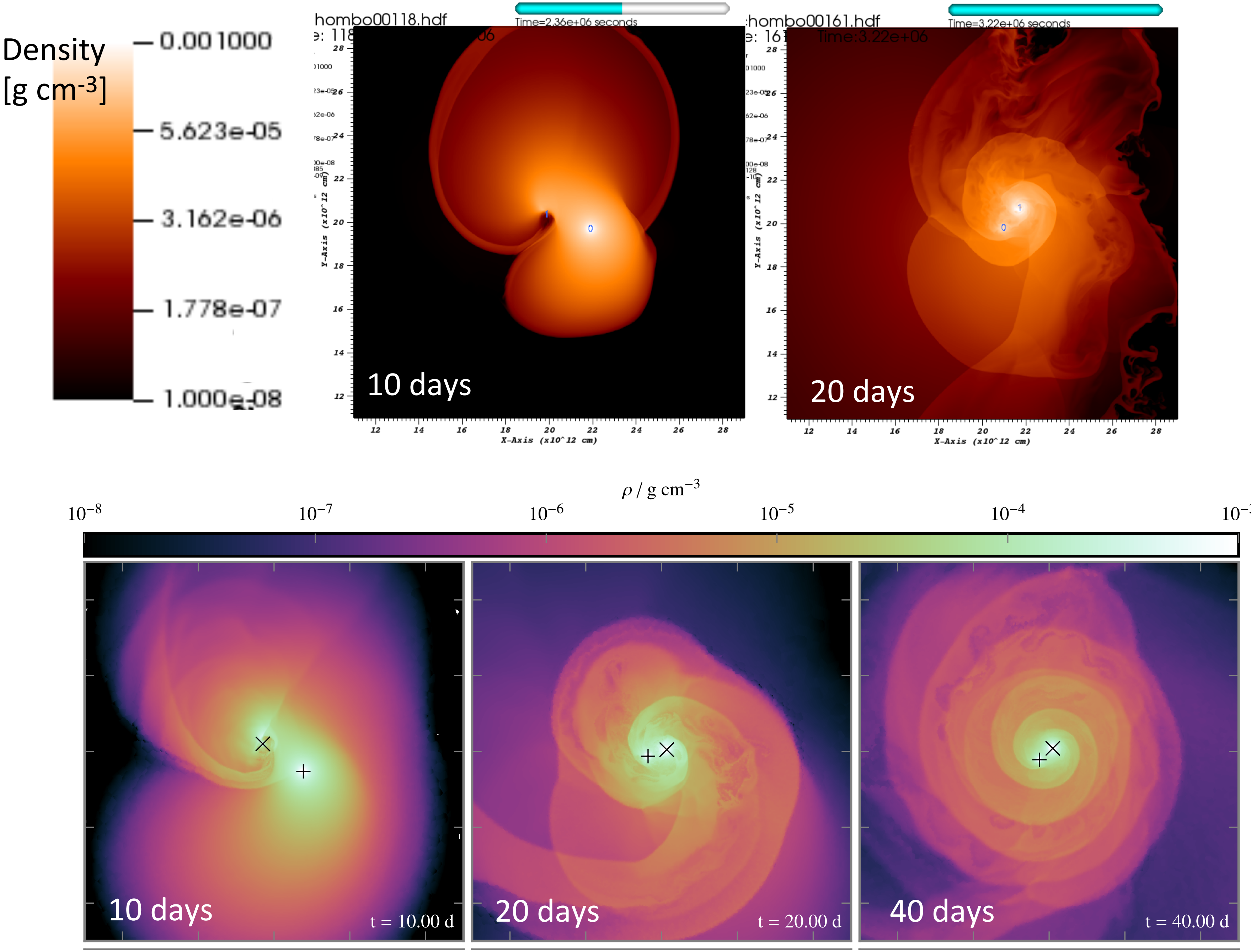
-11 % | -17 %

Mach number

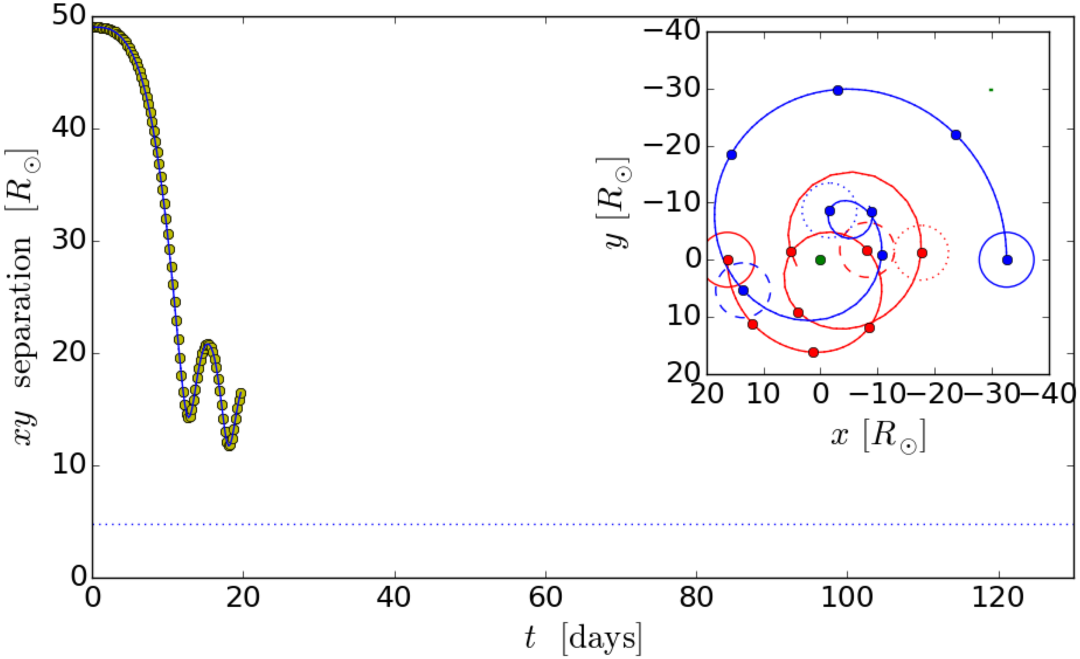


Setup: Binary Run

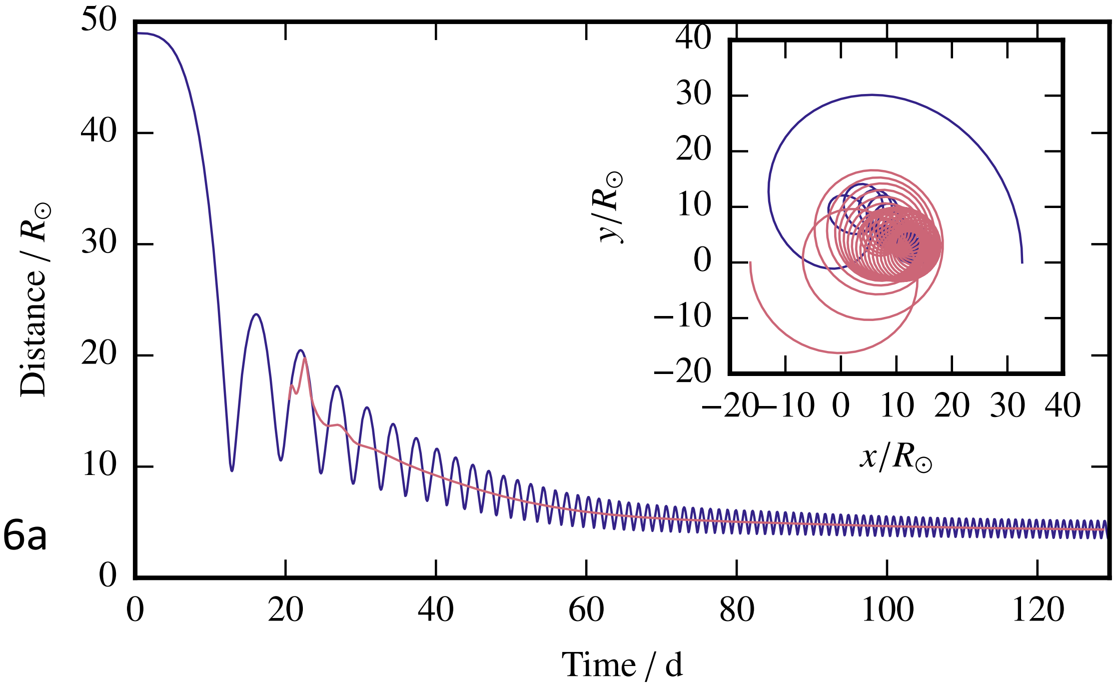
Parameter	Ohlmann++2016a	Chamandy++ (test run)
Reference frame	Centre of mass	Centre of mass
Secondary	Point particle	Point particle
Secondary mass	$0.99\,\mathrm{M}_\odot$ (half of primary)	$0.978\,\mathrm{M}_\odot$ (half of primary)
Primary/secondary softening length	$\min(2.8\,\mathrm{R}_\odot, \frac{1}{5}$separation)	$4.8\,\mathrm{R}_\odot$
L_{box}	$4700\,\mathrm{R}_\odot$	$575\,\mathrm{R}_\odot$ (same as relaxation run)
Run time t_{f}	$120\,\mathrm{d}$	$20\,\mathrm{d}$
Smallest resoln elmt at $t = 0$	$0.14\,\mathrm{R}_\odot$	$0.29\,\mathrm{R}_\odot$
Smallest resoln elmt at $t = t_{\mathrm{f}}$	$0.02\,\mathrm{R}_\odot$	$0.29\,\mathrm{R}_\odot$
ρ_{ambient}	$10^{-16}\,\mathrm{g\,cm^{-3}}$	$6.7 \times 10^{-9}\,\mathrm{g\,cm^{-3}}$ (same as relaxation run)
Initial eccentricity	0	0
Initial separation	$49\,\mathrm{R}_\odot$	$49\,\mathrm{R}_\odot$
Initial rotation of primary	$0.95\,\Omega_{\mathrm{Kepler}}$	0



Density
[g cm-3]
0.001000
5.623e-05
3.162e-06
1.778e-07
1.000e-08
hombo00118.hdf
Time=2.36e+06 seconds
10 days
X-Axis (x10^12 cm)
Y-Axis (x10^12 cm)
hombo00161.hdf
Time=3.22e+06 seconds
20 days
X-Axis (x10^12 cm)
Y-Axis (x10^12 cm)
ρ / g cm−3
10−8
10−7
10−6
10−5
10−4
10−3
10 days
t = 10.00 d
20 days
t = 20.00 d
40 days
t = 40.00 d



Our preliminary results



Ohlmann++2016a

Concluding Remarks

1st goal: reproduce first 20-40 days of Ohlmann++16a sim

- softening length (factor or 2)
- ambient density (orders of magnitude)
- resolution (factor of 2+)
- rotation (not yet implemented)
- total relaxation time (factor of 5)
- box size (factor of 8)

Then lots of interesting possibilities...

- Accretion onto secondary
- Exploration of parameter space
- Magnetic fields
- Radiation transport
- Etc.