Modeling Accretion Disk Formation In Binary Systems

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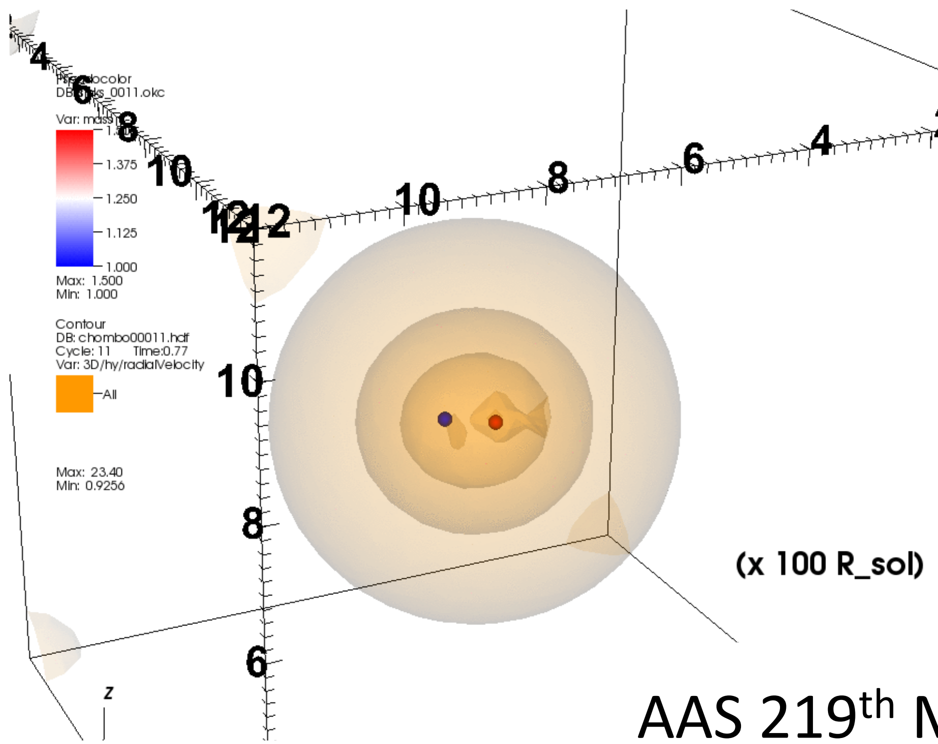

AAS 219th Meeting, Austin Texas, January 12 2012

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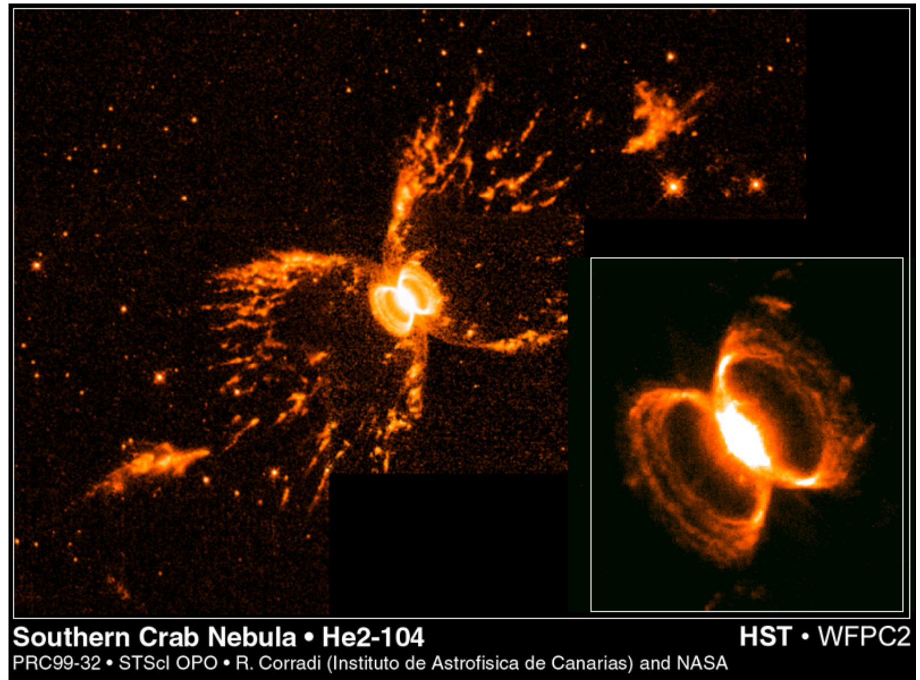
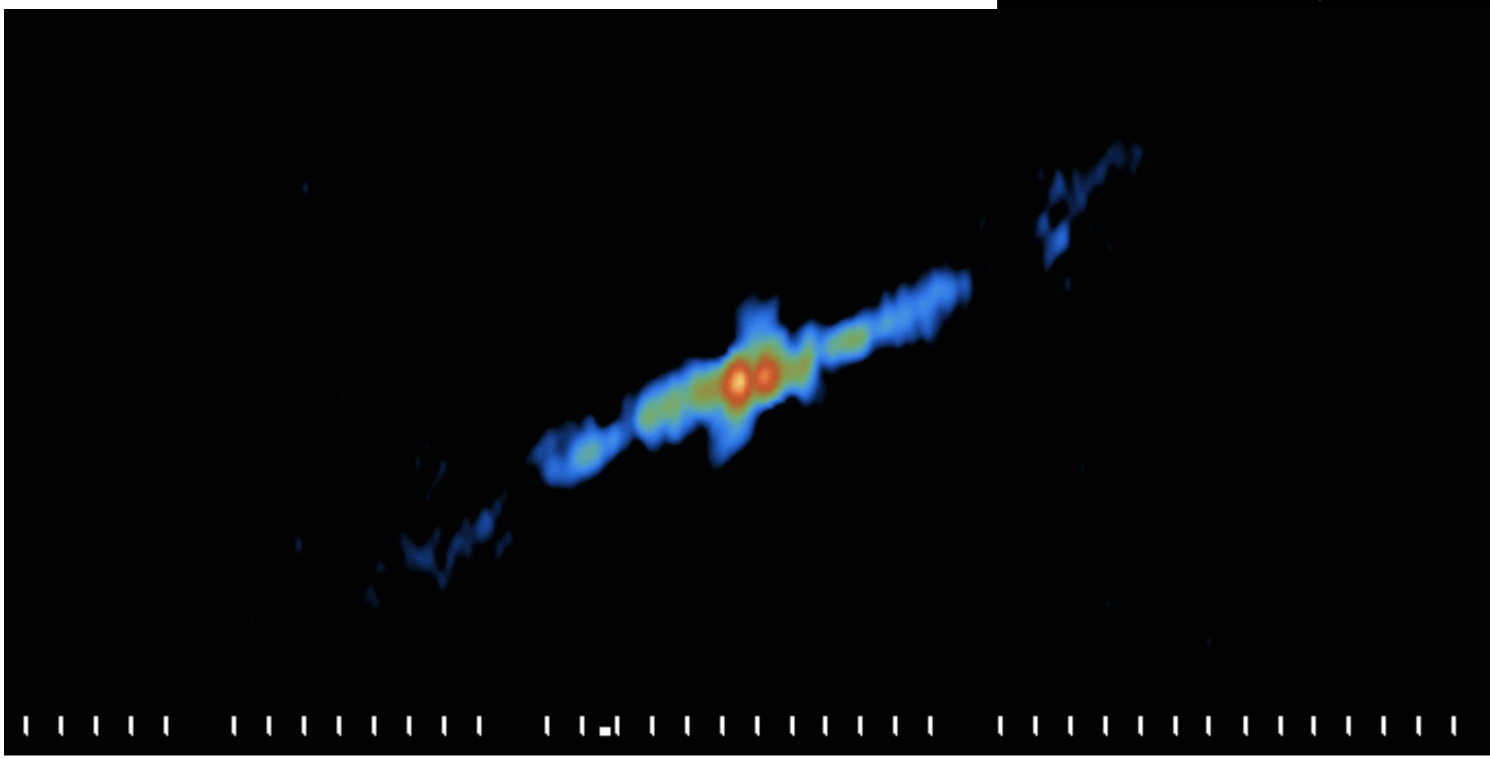
Motivation

Common envelope Evolution in PN, symbiotic stars, X-Ray binaries, etc. A good deal of observations (see poster sessions).

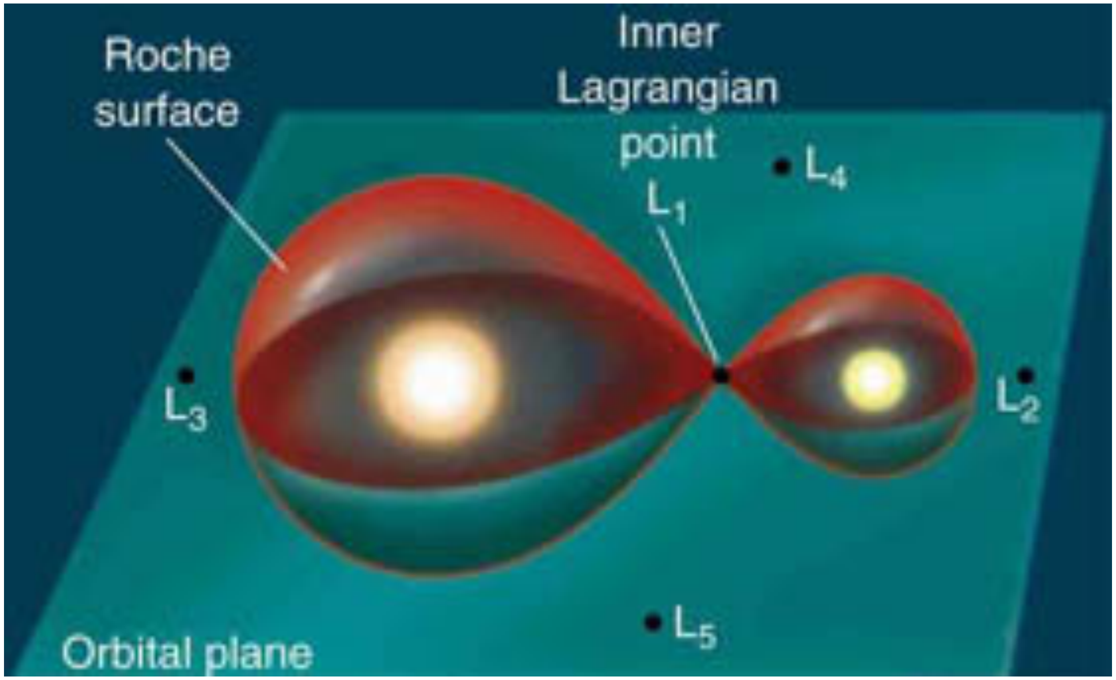




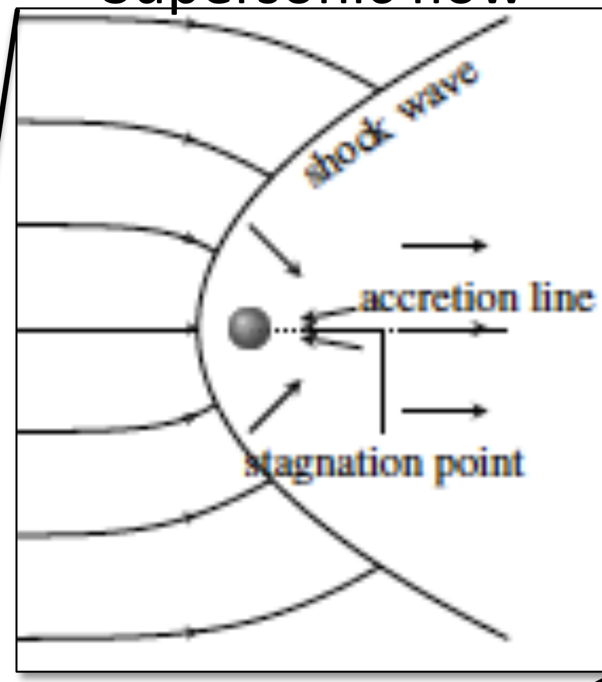
Outline

- Physics
- Previous numerical studies
- Model
- Preliminary results
- Summary and questions

Physics: Binary stellar systems

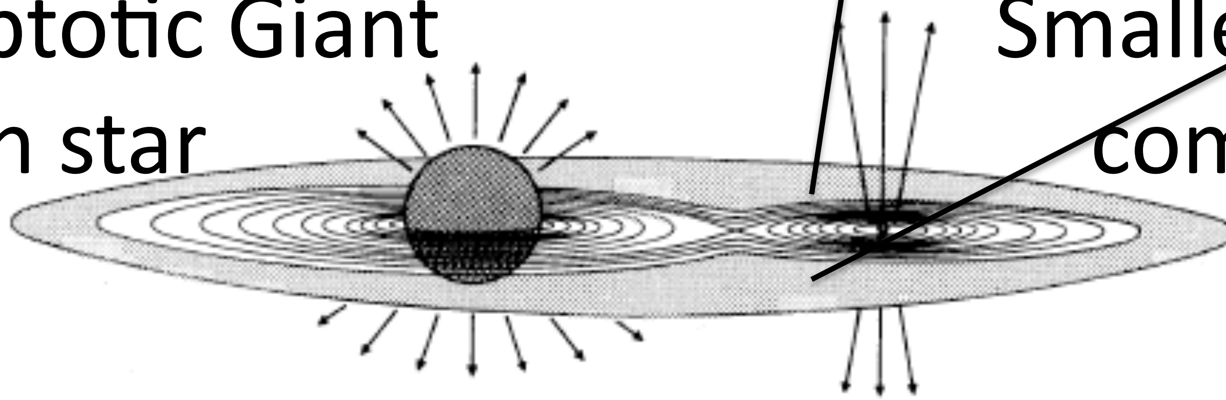


Supersonic flow



Asymptotic Giant Branch star

Smaller companion



Physics: Wind Accretion in PN Binaries

Old question: Few numerical studies

1. What is limit of disk accretion?
   a = 20 AU, 30 AU, 40 AU?

2. What is the accretion rate?
   = Bondi-Hoyle
   > Bondi-Hoyle
   < Bondi-Hoyle

$$R_a = 2GM_2/v_r^2$$

Bondi-Hoyle Accretion

Disk Formation Condition in bipolar PN, Soker & Rapport 2000

$$\frac{J_a}{J_c} = f\left(\frac{M_{AGB} + M_c}{1.2M_\odot}\right)^{1/2}\left(\frac{M_c}{0.6M_\odot}\right)^{3/2}\left(\frac{R_c}{.01R_\odot}\right)^{-1/2}\left(\frac{a}{10au}\right)^{-3/2}\left(\frac{V_r}{15km/s}\right)^{-4}$$

where:

J_a and J_c are the specific angular momenta of the accreted material and that of a particle in Keplerian orbit at the equator of an accreting star of radius R_c, respectively

a is the distance between the center of the stars; the separation

V_r is the relative velocity of the wind and the accretor.

Previous numerical studies

THE ASTROPHYSICAL JOURNAL, 497:303–329, 1998 April 10

BIPOLAR PREPLANETARY NEBULAE: HYDRODYNAMICS OF DUSTY WINDS IN BINARY SYSTEMS. I. FORMATION OF ACCRETION DISKS

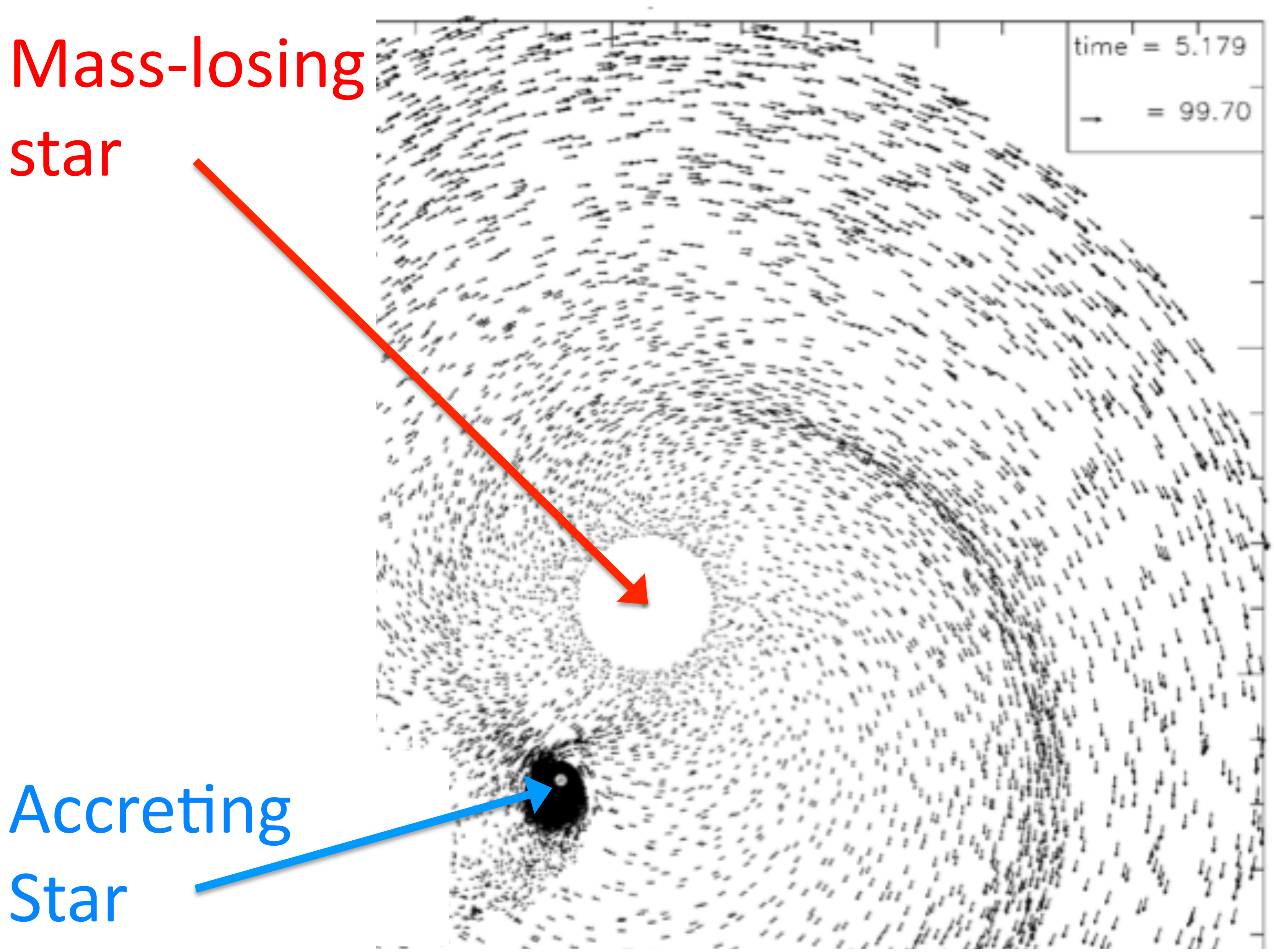
NIKOS MASTRODEMOS AND MARK MORRIS

Model: 3D, **SPH**, dusty wind models, accretion disks formation about the binary companion to the mass-losing giant of asymmetric and bipolar PN.

Free parameters: wind velocity, binary separation and rotation of the mass-loosing star

Results: Stable thin accretion disks form around the companion. Their equilibrium structure has elliptical streamlines with a range of eccentricities. Such disks may be **susceptible to tilt or warping instabilities**. Wind accretion in such binaries is stable, displaying no evidence for any type of flip-flop instability.

Slice through the orbital plane



Mon. Not. R. Astron. Soc. 316, 906–916 (2000)

Two- and three-dimensional numerical simulations of accretion discs in a close binary system

Makoto Makita,[★†] Kenji Miyawaki and Takuya Matsuda[★]

Model: 2D and 3D, accretion disc in a close binaries, flux vector splitting (SFS) finite volume method. **They do not follow the orbital motion of the binaries.**

Free parameters: ϒ= 1.01; 1.05, 1.1 and 1.2,
M(mass-losing star)/M(mass-accreting star) =1.

Results: Spiral shocks form on the accretion disc in all cases. This is due to tidal interaction. The smaller Y, the more tightly the spiral winds. $\mathrm{Mach}_{\mathrm{disk}}$ <=10 ; lower than in observed accretion discs in close binaries. The pitch angle of the spirals in 3D is not so markedly correlated with g as in the 2D cases

2D

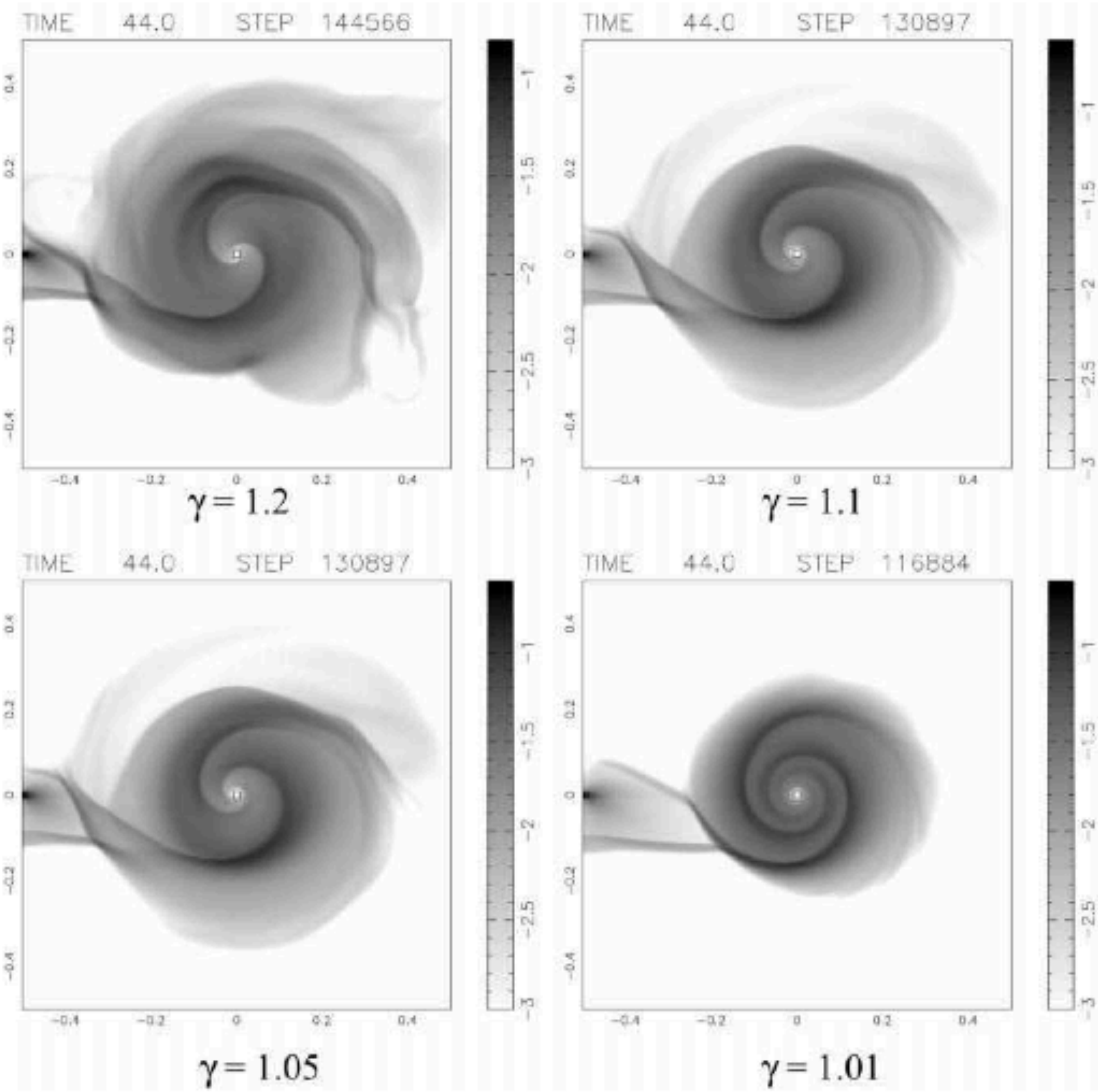


Figure 3. Grey-scale of the density distribution with a logarithmic scale after seven periods of revolution in the 2D calculations. The bar in the right-hand side shows the scale range.

The Astrophysical Journal, 700:1148–1160, 2009 August 1 doi:10.1088/0004-637X/700/2/1148

NUMERICAL SIMULATIONS OF WIND ACCRETION IN SYMBIOTIC BINARIES

M. de Val-Borro[1], M. Karovska, and D. Sasselov

Model: symbiotic binaries, **2D**, no self-gravity, large separations, relevant for Mira AB (Karovska et al. 2005).

Free parameters: mass-loss rate, wind temperature depends on the distance from the mass losing star and its companion, orbital separation.

Results: Flow pattern similar to **a Roche lobe overflow** with accretion rates of 10% of the mass loss from the primary**. Stable Keplerian thin disks,** exponential density profiles, $M \sim 10^{-4} M_{sun}$. Tidal streams and disks form and show a dependence with AGB mass loss. The evolution of **the binary system**, and its independent components, is **affected by mass transfer** through focused winds.

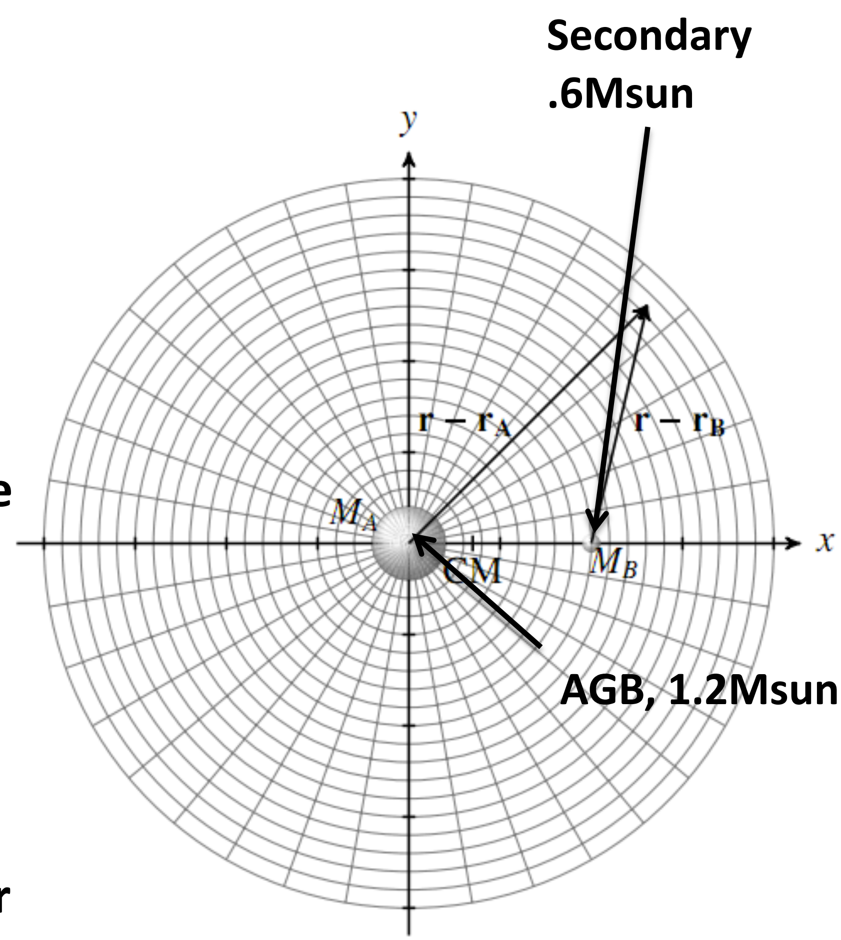
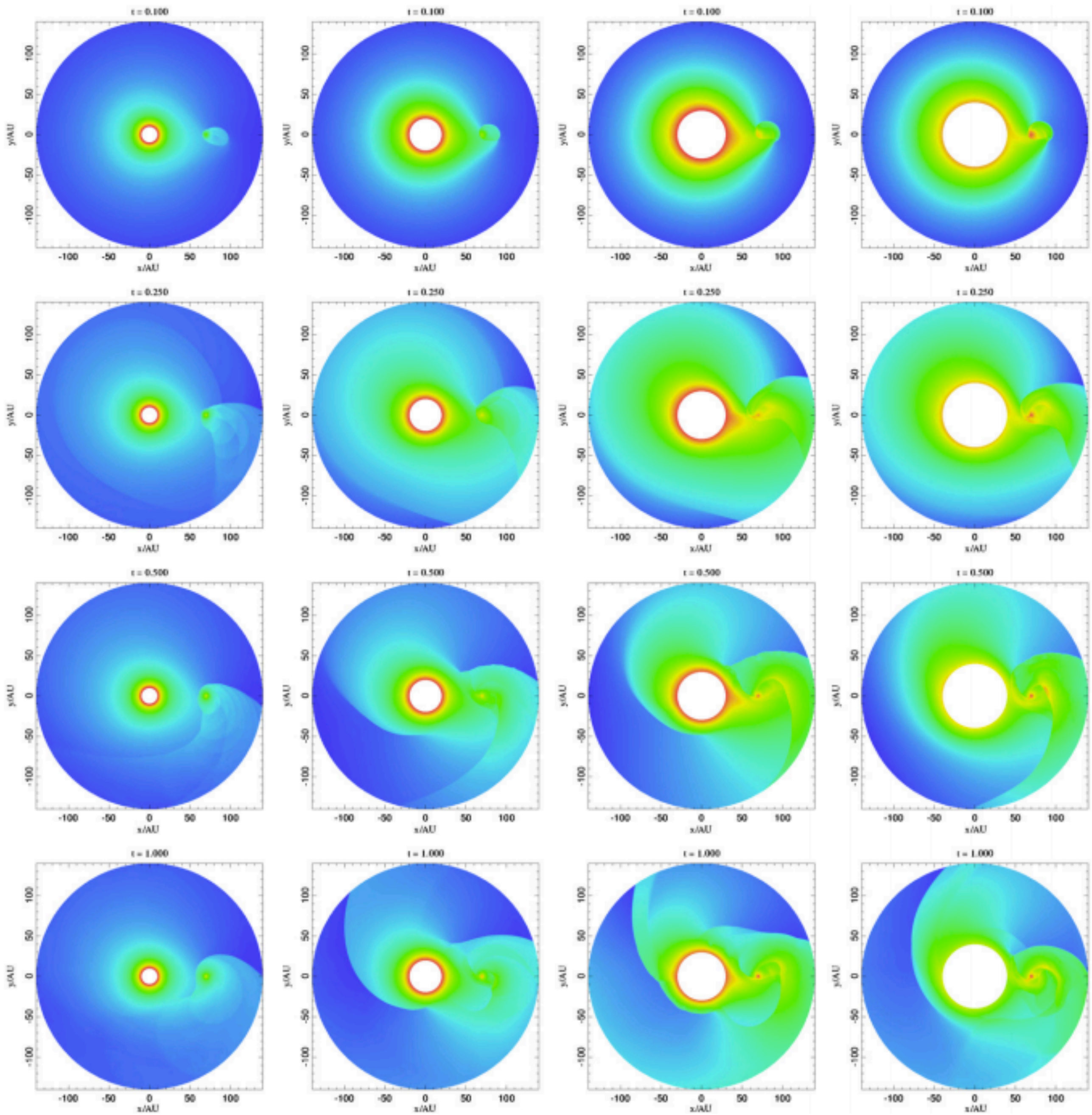


Figure 7. Schematic representation of the grid geometry in the polar coordinates. The physical quantities are defined in the center of the cells. The system is centered on the primary and rotating in clockwise direction.

The wind is accelerated at 10, 20, 30, and 40 AU, from left to right.

Orbital period



Model: We use the AstroBear code

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 182:519–542, 2009 June doi:10.1088/0067-0049/182/2/519

SIMULATING MAGNETOHYDRODYNAMICAL FLOW WITH CONSTRAINED TRANSPORT AND ADAPTIVE MESH REFINEMENT: ALGORITHMS AND TESTS OF THE AstroBEAR CODE

ANDREW J. CUNNINGHAM[1], ADAM FRANK[1], PEGGY VARNIÈRE[1,2], SORIN MITRAN[3], AND THOMAS W. JONES[4]

- Solve hyperbolic PDE with elliptic constraints: **MHD**
- Source terms for energy loss/gain, **ionization dynamics**
- Operator splitting: **gravity, heat conduction** (*HYPRE*)

$$\frac{\partial}{\partial t}\begin{bmatrix}\rho\\ \rho v_x\\ \rho v_y\\ \rho v_z\\ \mathcal{E}\\ B_x\\ B_y\\ B_z\end{bmatrix} + \frac{\partial}{\partial x}\begin{bmatrix}\rho v_x\\ \rho v_x^2+P+B^2/2-B_x^2\\ \rho v_y v_x\\ \rho v_z v_x\\ (\mathcal{E}+P+\boldsymbol{B}^2/2)v_x - B_x(\boldsymbol{B}\cdot\boldsymbol{v})\\ 0\\ -E_z\\ E_y\end{bmatrix} +$$

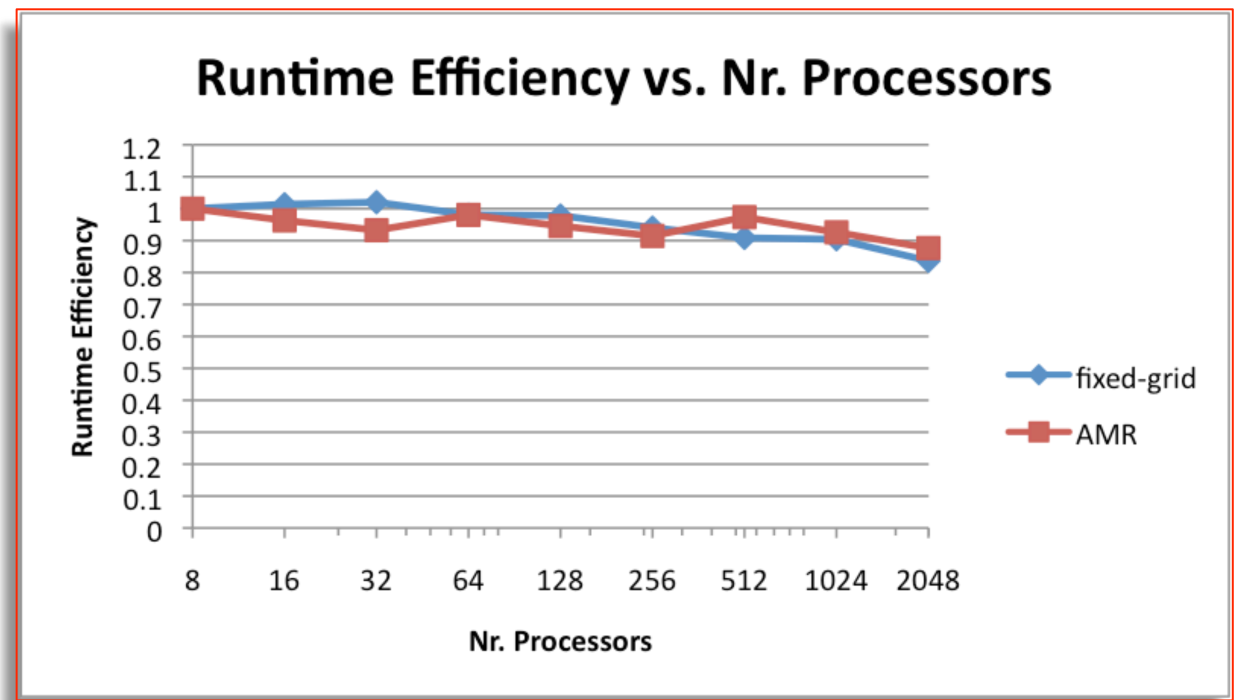
$$\frac{\partial}{\partial y}\begin{bmatrix}\rho v_y\\ \rho v_x v_y\\ \rho v_y^2+P+B^2/2-B_y^2\\ \rho v_z v_y\\ (\mathcal{E}+P+\boldsymbol{B}^2/2)v_y - B_y(\boldsymbol{B}\cdot\boldsymbol{v})\\ E_z\\ 0\\ -E_x\end{bmatrix} + \frac{\partial}{\partial z}\begin{bmatrix}\rho v_z\\ \rho v_x v_z\\ \rho v_y v_z\\ \rho v_z^2+P+B^2/2-B_z^2\\ (\mathcal{E}+P+\boldsymbol{B}^2/2)v_y - B_z(\boldsymbol{B}\cdot\boldsymbol{v})\\ -E_y\\ E_x\\ 0\end{bmatrix} = \boldsymbol{S}$$

$$\nabla\cdot\boldsymbol{B} = 0.$$

AstroBear2.0
Parallel AMR Performance

Rebuild load balance algorithm across AMR grid hierarchy

(Carroll-Nellenback et al. 2011, astro-ph:1112.1710)



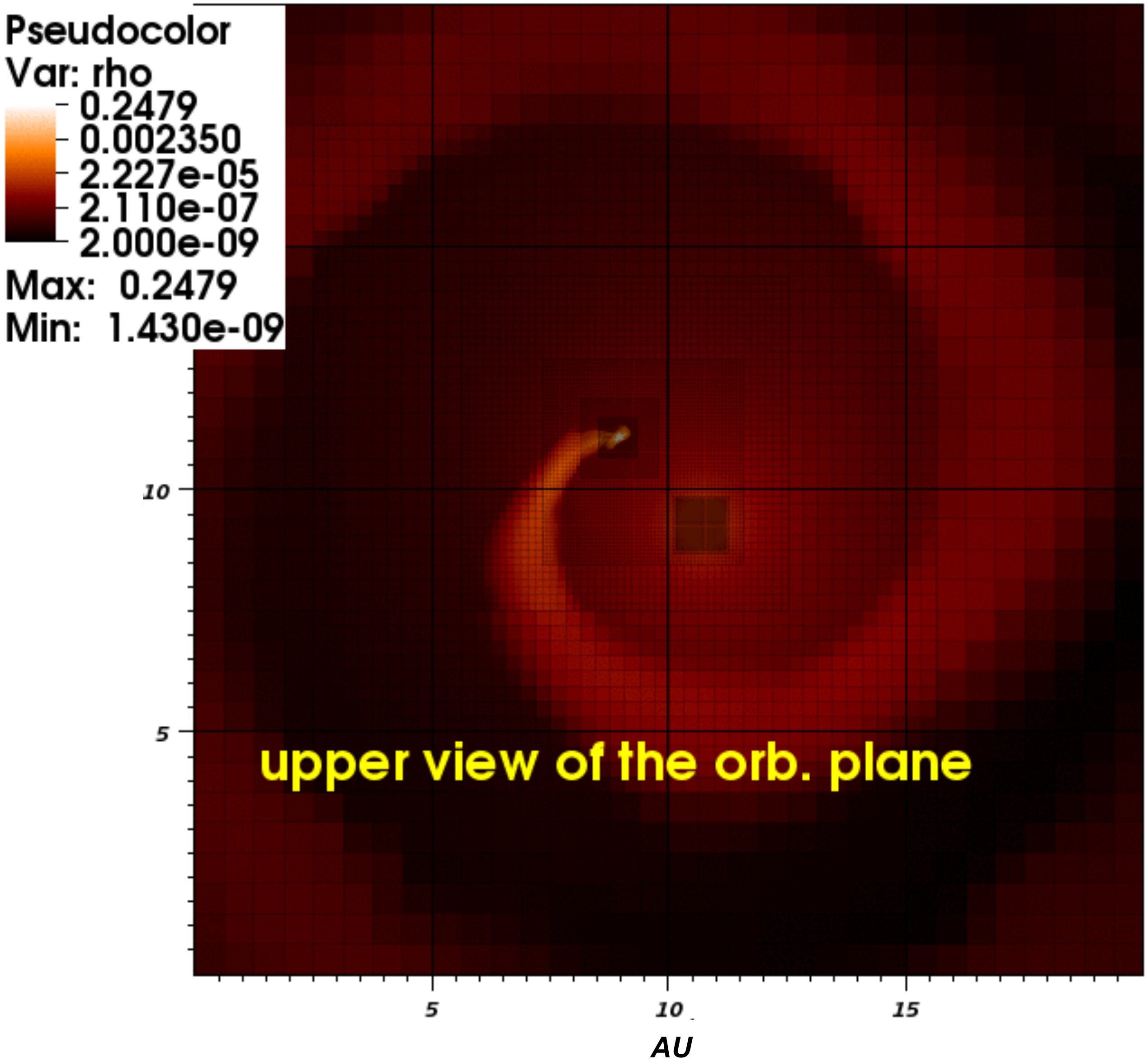
https://clover.pas.rochester.edu/trac/astrobear

Model: Grid and initial conditions

- 3D, cubic grid with Cartesian coordinates
- Outflow boundary conditions
- The two stars move in bound circular orbits, center of mass at the origin
  - Primary: AGB with spherical wind (v~20km/s, mass-loss($r_{injection}$)~$10^{-5}M_{sun}$/yr) and M_1=1.5M_{sun}
  - Secondary: accretor with M_2=M_{sun}
- Separations within 5-25AU
- gamma=1.001; isothermal (like M&M ’98)

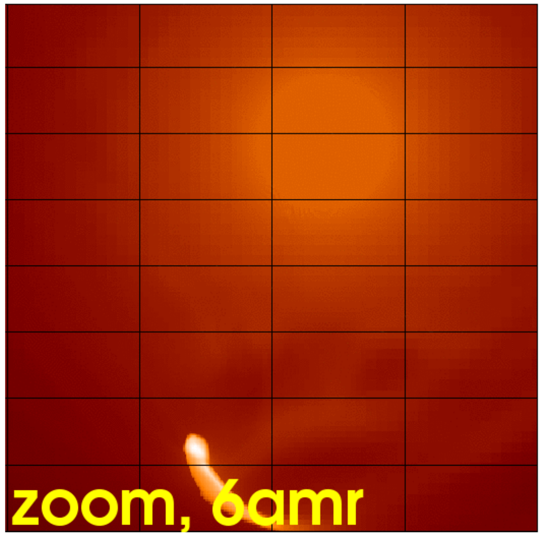
Preliminary results

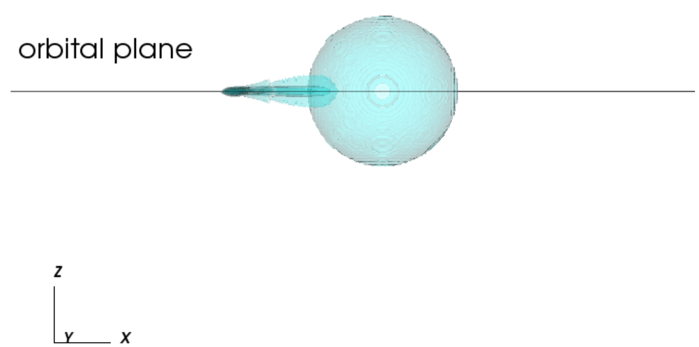
Comp. units



Slice through the orbital plane

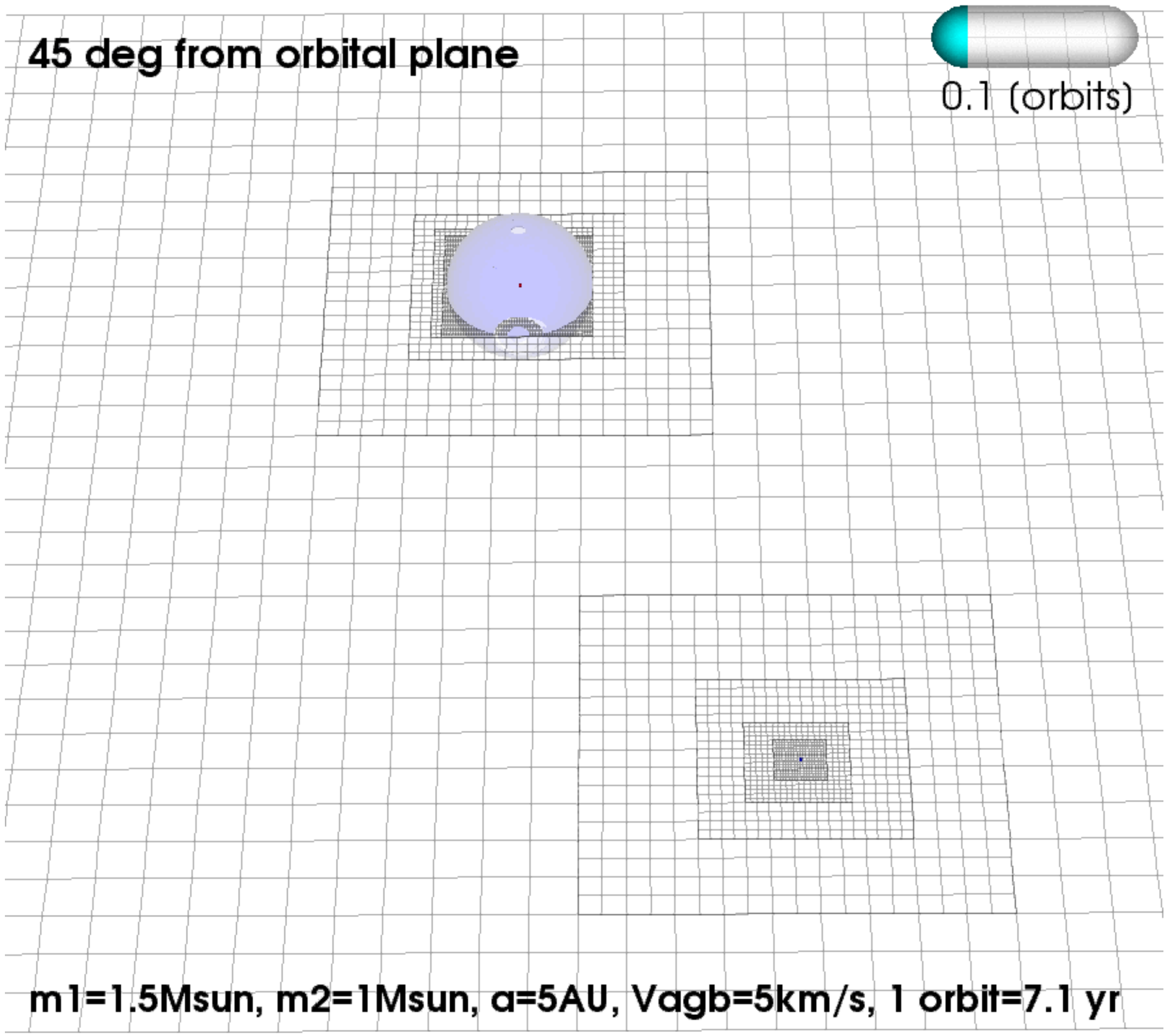
Preliminary results





Preliminary results

Complex 3D flow. Initial Pseudo-disk



Summary and questions

- We see the formation of accretion disks in 3D for large separations ~25AU
- Disks form properly after ~2.5 orbits
- Evidence of wrapping and tilting instabilities (further investigation)
- We can follow the mass, geometry, angular momentum and accretion rate of the disks, as well as the distribution of the wind
- Disk formation depends on: the "thermal radius", GM/c_s^2; the gravity softening radius; gamma; AGB wind velocity, density and temperature; grid resolution
- Future: finish the work! then elliptical orbits, add jets, magnetic fields.

More details soon in Huarte-Espinosa, Frank, Blackman, Carroll-Nellenback & Nordhaus 2012b, in prep.

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Thanks!

Find this talk at: http://www.pas.rochester.edu/~martinhe/talks.html