Modeling the Formation and Evolution of Wind-Capture Disks In Binary Systems

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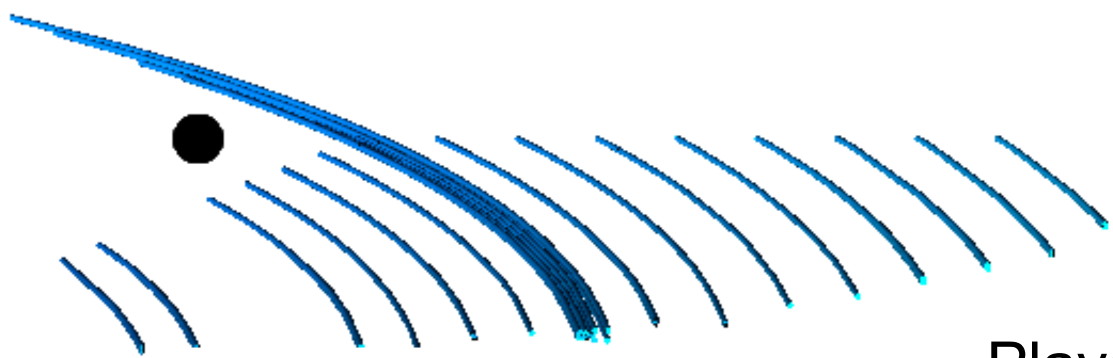
University of Rochester NY

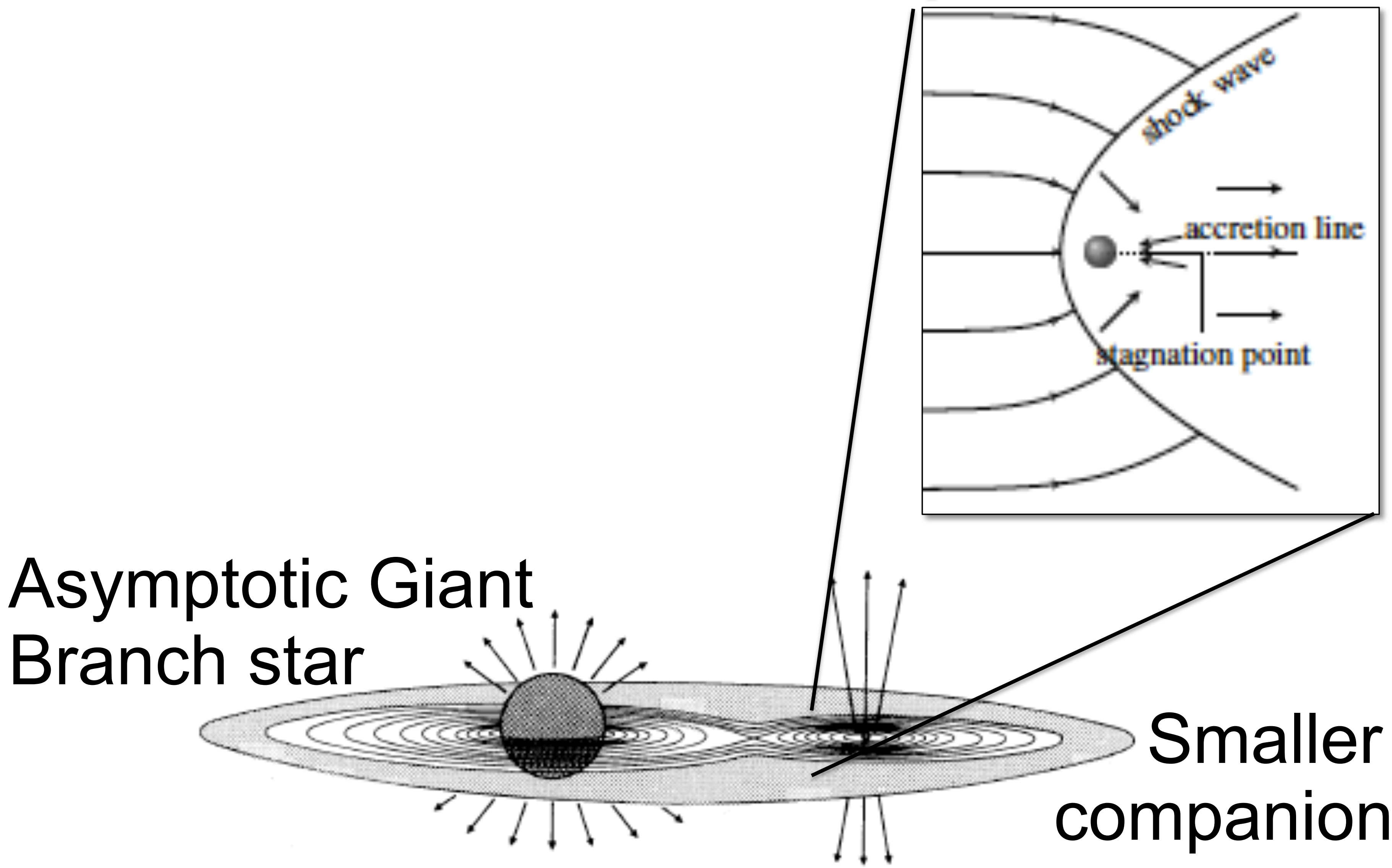


APN VI,
5 Nov 2013
Playa del Carmen
México

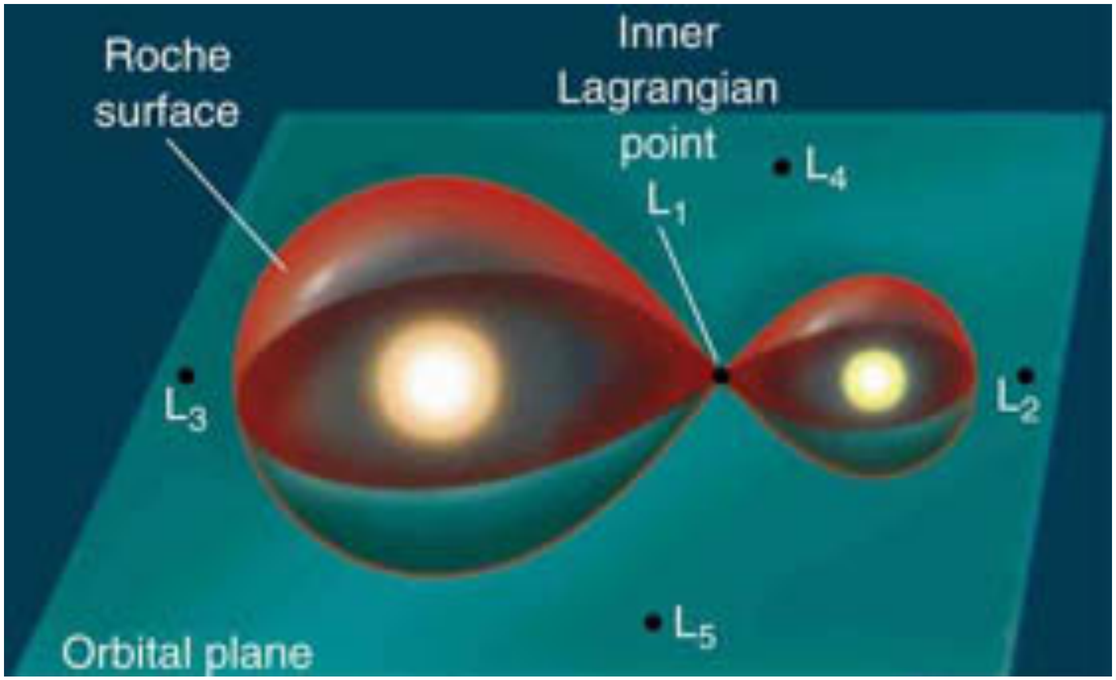
Outline

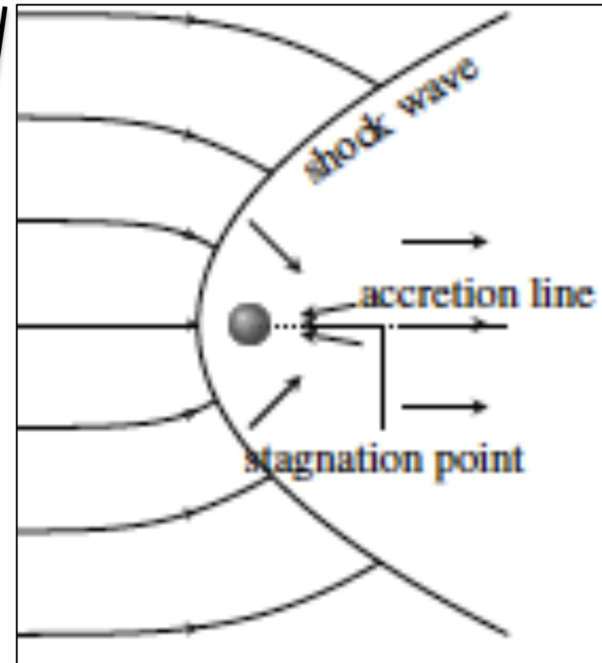
1. Introduction,
2. Previous models (apologies if I don’t mention yours),
3. Our model: conditions and results,
4. Summary and final comments.

System:
Disks in common envelope binaries

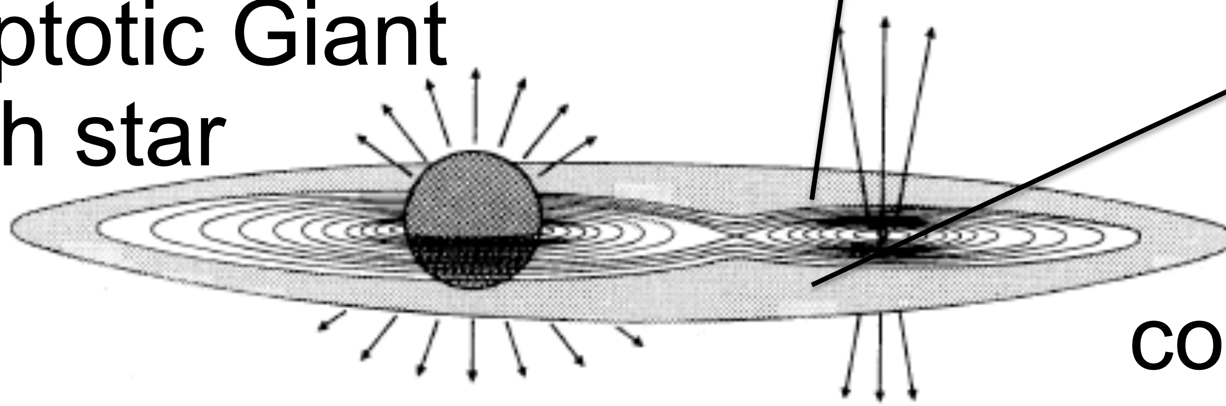


System:
Disks in common envelope binaries





Asymptotic Giant
Branch star



Smaller
companion

Physics: Disk Formation Condition in Planetary Nebulae

(Soker & Rapport 2000)

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

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.

Physics: Wind Accretion in Binaries

Not many numerical studies

Old questions:

1. What is the limit of disk accretion?
   Binary separation, 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

Previous numerical studies

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

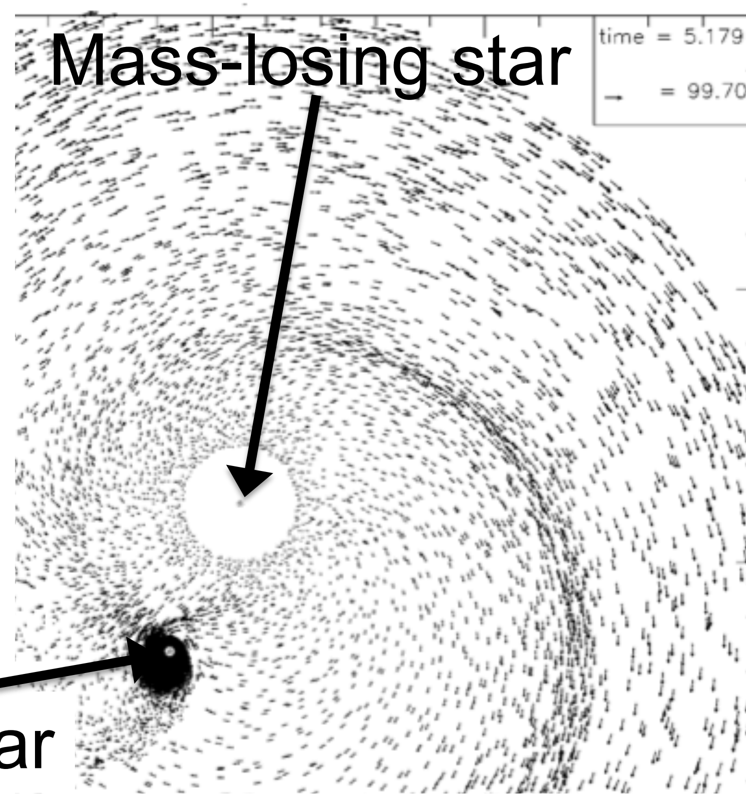
BIPOLAR PREPLANETARY NEBULAE: HYDRODYNAMICS OF DUSTY WINDS IN BINARY SYSTEMS. I. FORMATION OF ACCRETION DISKS

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 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.



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.

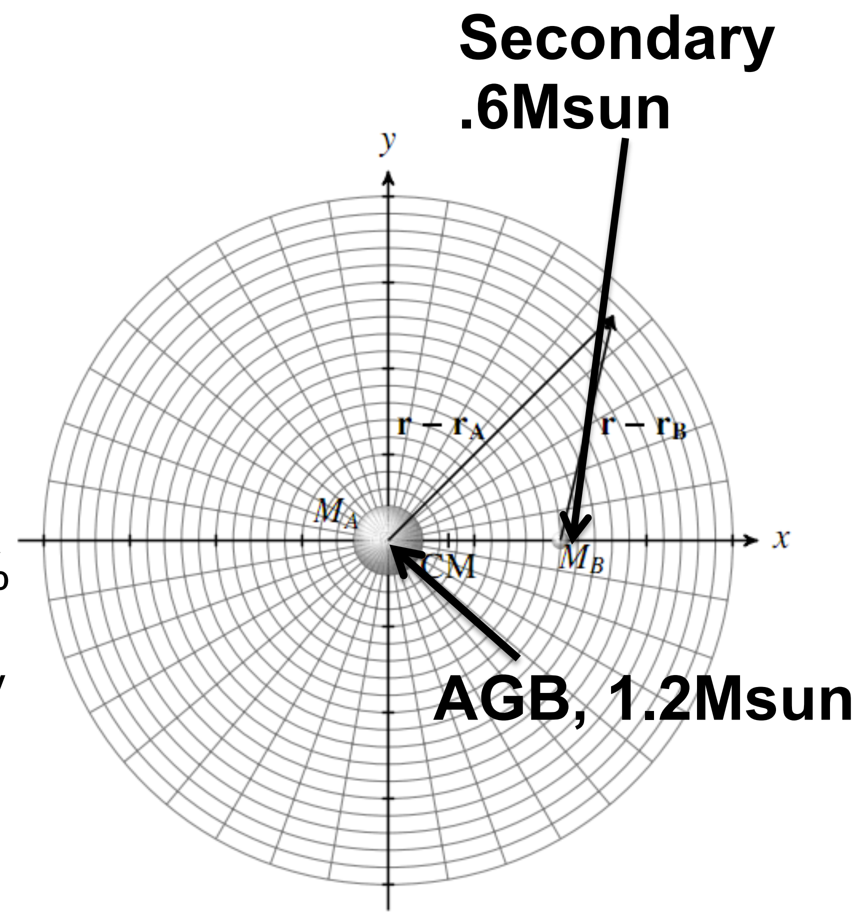
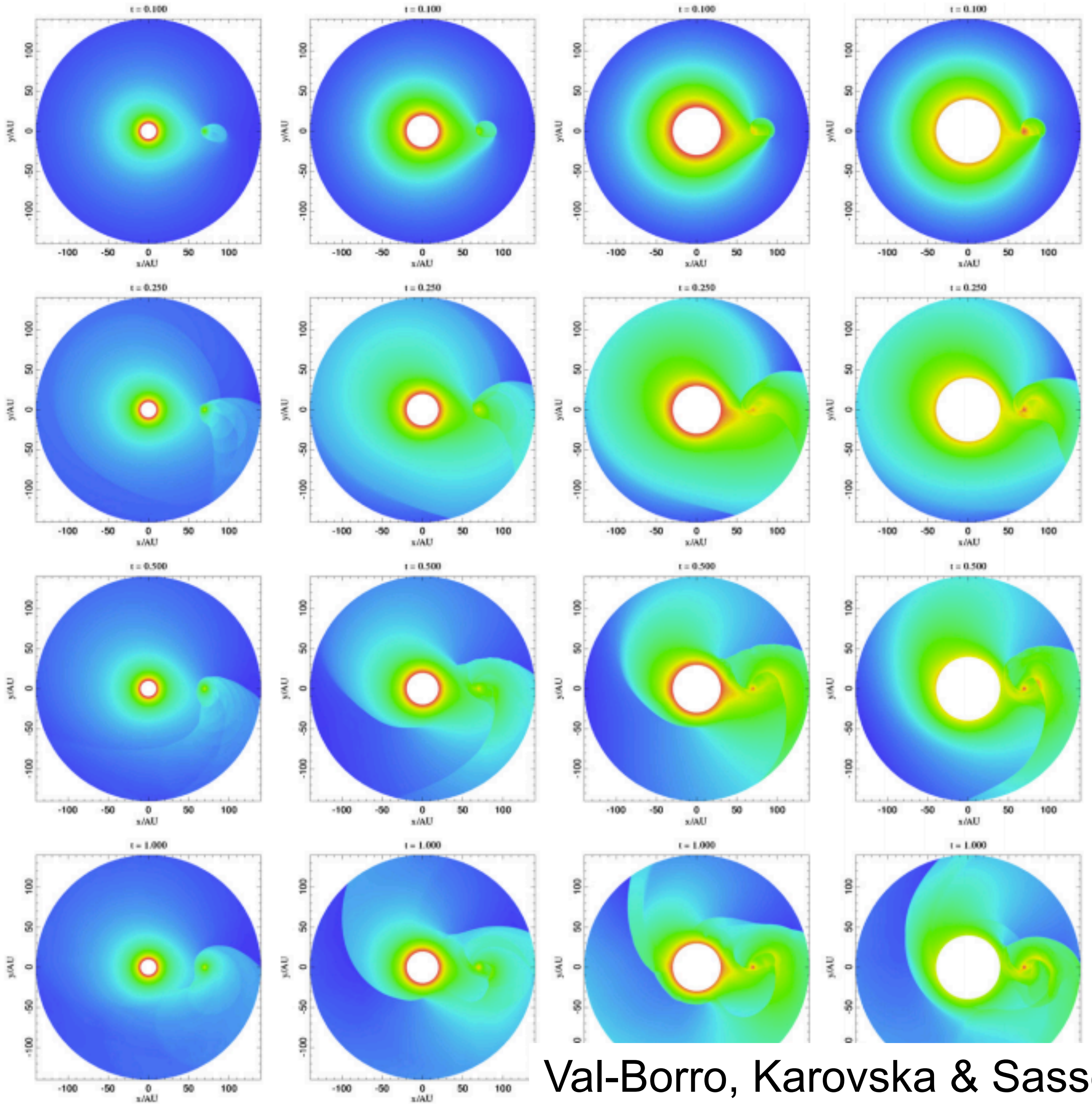


Figure 7. Schematic representation of the grid geometry in the polar coordinates. The physical quantities are defined in the center of the cells. The system is centered on the primary and rotating in clockwise direction.

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

Orbital period

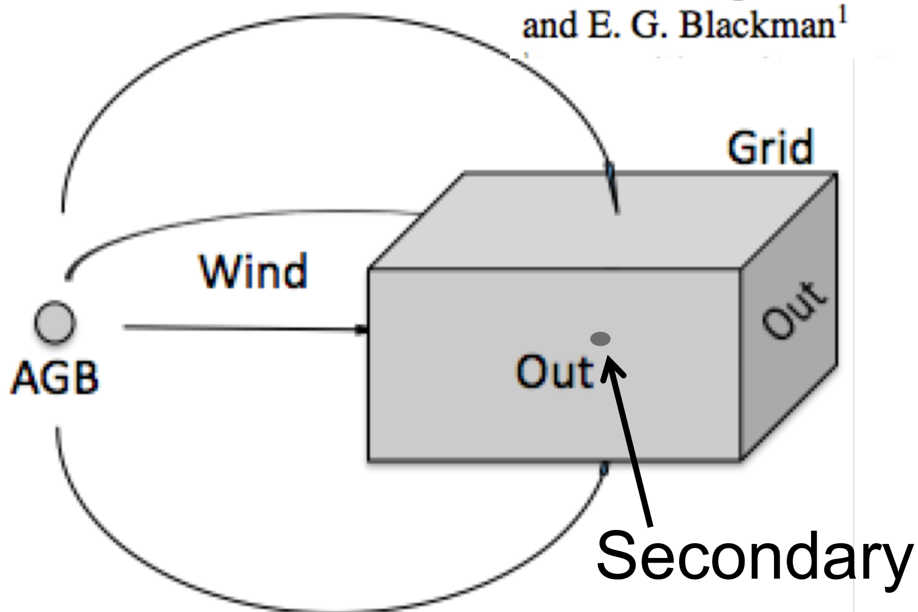


Val-Borro, Karovska & Sasselov, 2009

MNRAS 433, 295–306 (2013)
Advance Access publication 2013 May 29
doi:10.1093/mnras/stt725

Our model: The formation and evolution of wind-capture discs in binary systems

M. Huarte-Espinosa,[1★] J. Carroll-Nellenback,[1] J. Nordhaus,[1,2,3†] A. Frank[1]
and E. G. Blackman[1]



Code: AstroBear, *Adam's talk*

Grid & initial conditions

- Co-rotating frame of reference, nested grid
- Circular orbits

MNRAS 433, 295–306 (2013)
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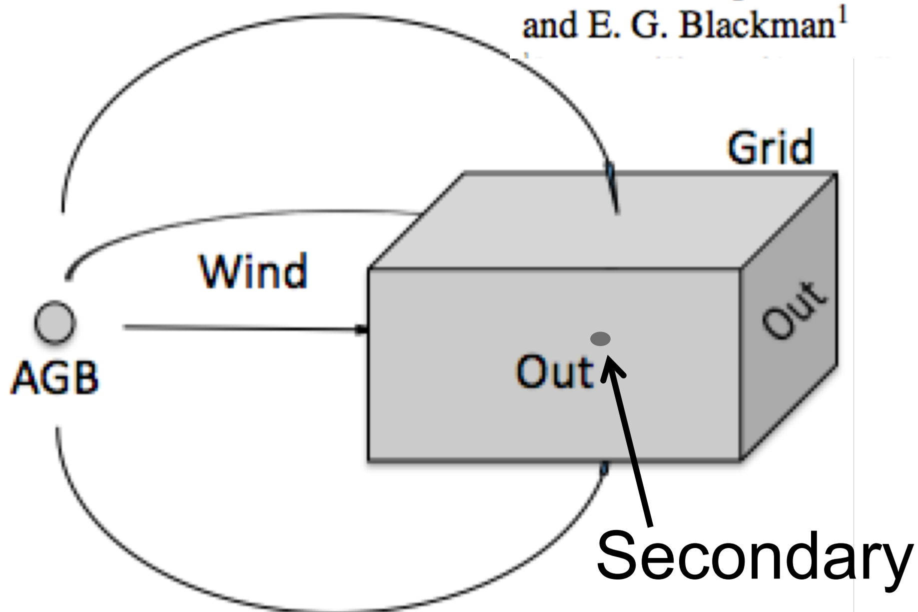


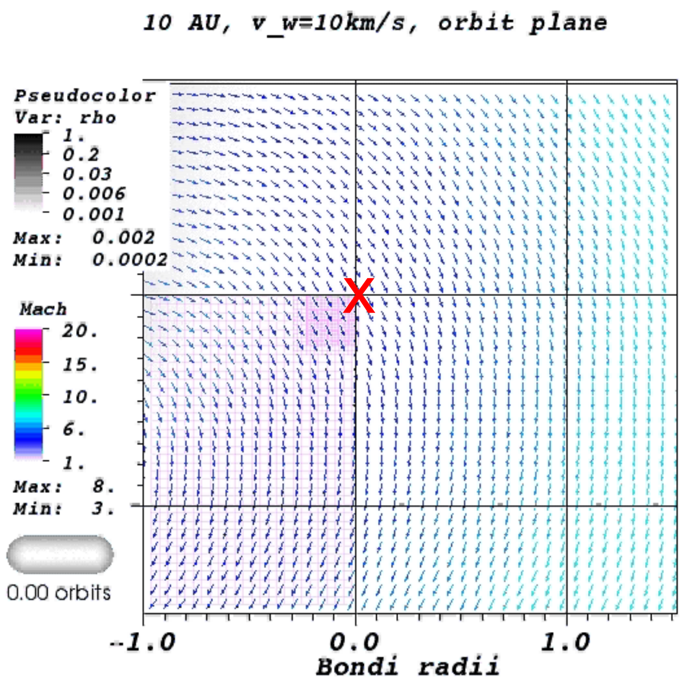
Code: AstroBear, *Adam's talk*

Grid & initial conditions

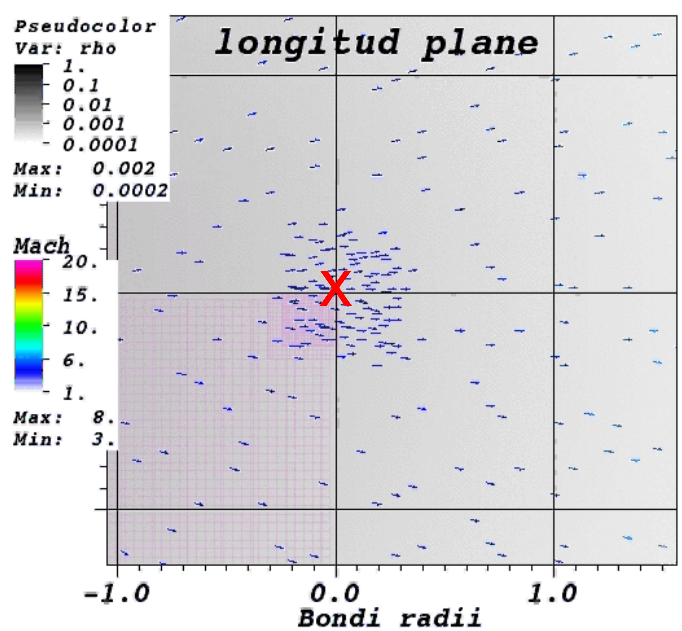
- Co-rotating frame of reference, nested grid
- Circular orbits

- Primary: AGB with spherical wind (v=10km/s, mass-loss($r_{injection}$)~$10^{-5}M_{sun}$/yr) and M_1=1.5M_{sun}
- Secondary: accretor with M_2=M_{sun}
- Separations =10,15 and 20AU
- γ=1.001; isothermal (like M&M '98)

E V O L U T I O N

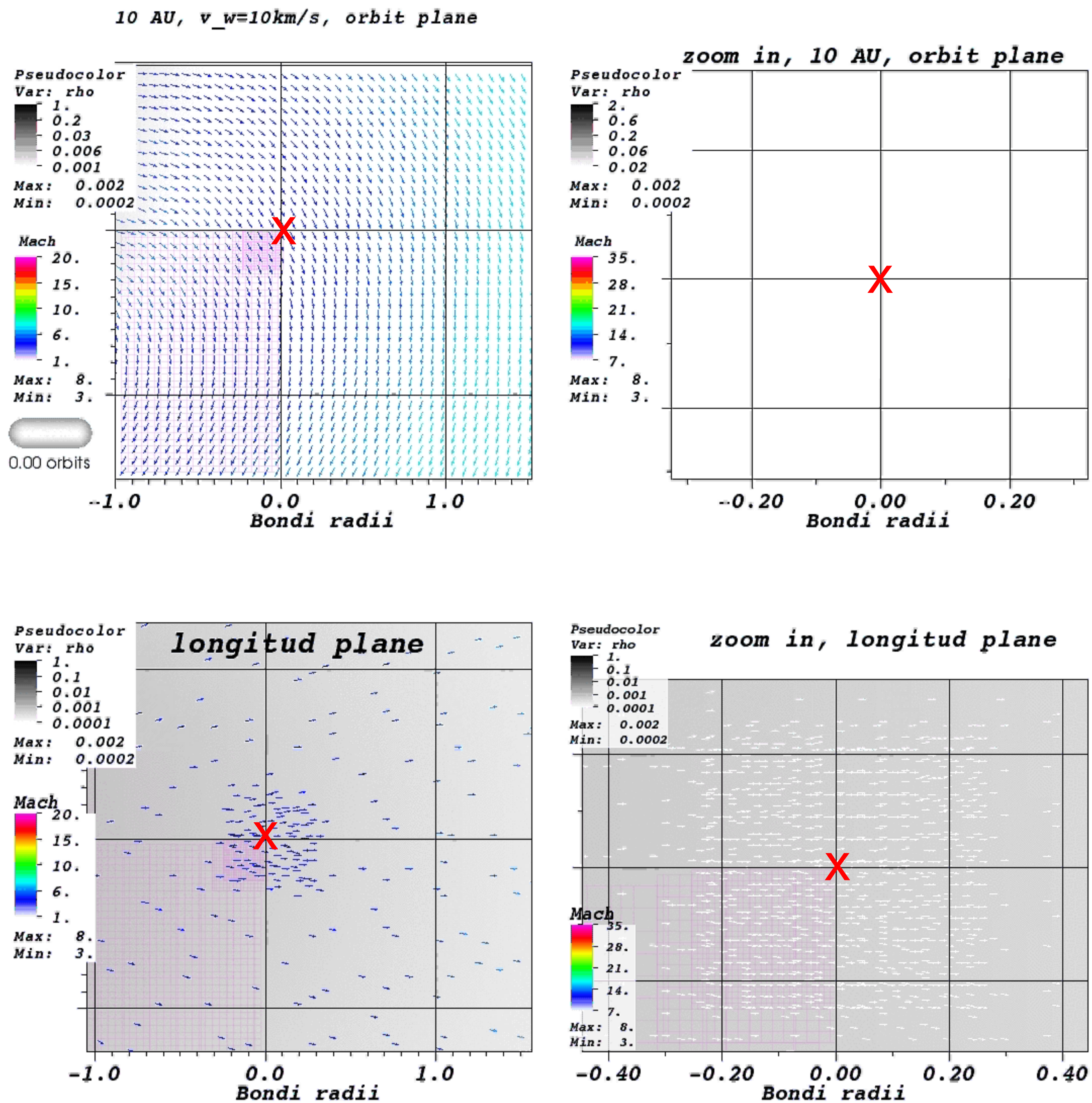


10 AU, v_w=10km/s, orbit plane
Pseudocolor
Var: rho
1.
0.2
0.03
0.006
0.001
Max: 0.002
Min: 0.0002
Mach
20.
15.
10.
6.
1.
Max: 8.
Min: 3.
0.00 orbits
-1.0
0.0
1.0
Bondi radii



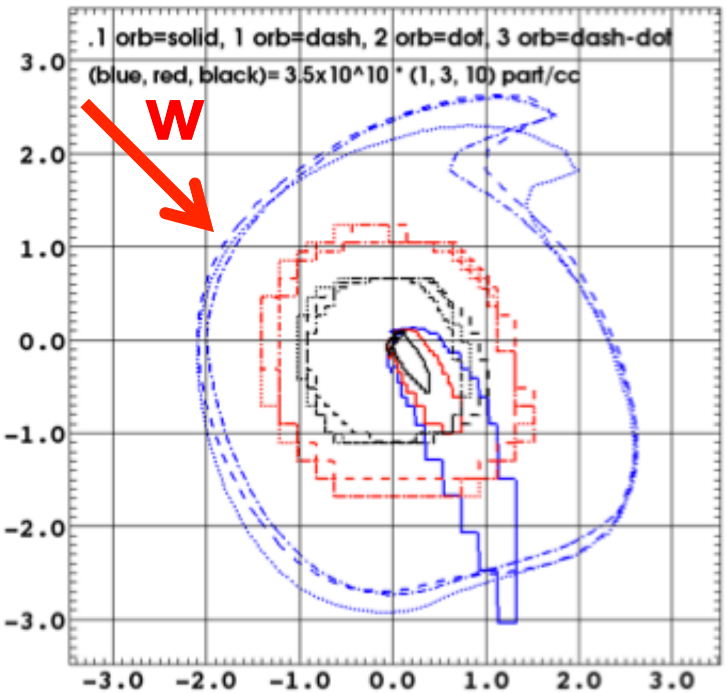
longitud plane
Pseudocolor
Var: rho
1.
0.1
0.01
0.001
0.0001
Max: 0.002
Min: 0.0002
Mach
20.
15.
10.
6.
1.
Max: 8.
Min: 3.
-1.0
0.0
1.0
Bondi radii

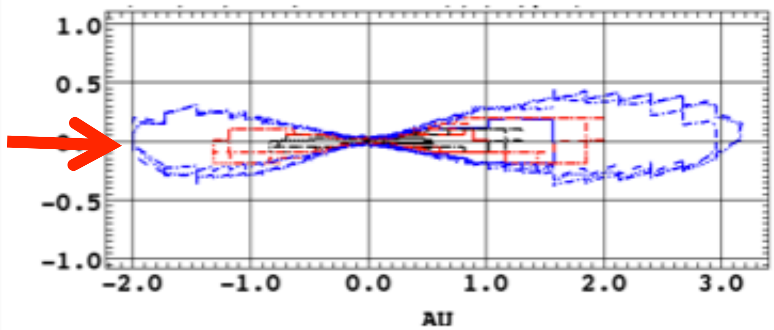
EVOLUTION



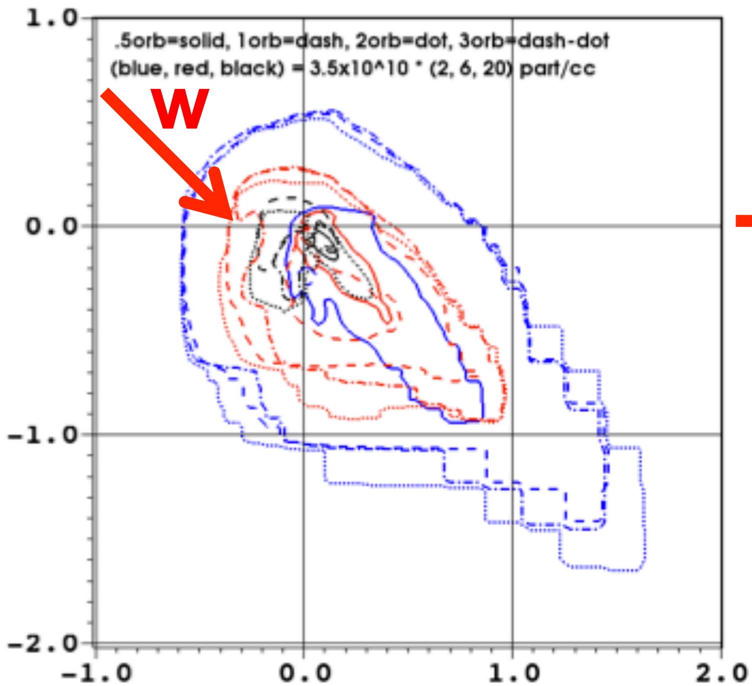
10 AU, v_w=10km/s, orbit plane
Pseudocolor
Var: rho
1.
0.2
0.03
0.006
0.001
Max: 0.002
Min: 0.0002
Mach
20.
15.
10.
6.
1.
Max: 8.
Min: 3.
0.00 orbits
-1.0
0.0
1.0
Bondi radii
zoom in, 10 AU, orbit plane
Pseudocolor
Var: rho
2.
0.6
0.2
0.06
0.02
Max: 0.002
Min: 0.0002
Mach
35.
28.
21.
14.
7.
Max: 8.
Min: 3.
-0.20
0.00
0.20
Bondi radii
longitud plane
Pseudocolor
Var: rho
1.
0.1
0.01
0.001
0.0001
Max: 0.002
Min: 0.0002
Mach
20.
15.
10.
6.
1.
Max: 8.
Min: 3.
-1.0
0.0
1.0
Bondi radii
zoom in, longitud plane
Pseudocolor
Var: rho
1.
0.1
0.01
0.001
0.0001
Max: 0.002
Min: 0.0002
Mach
35.
28.
21.
14.
7.
Max: 8.
Min: 3.
-0.40
-0.20
0.00
0.20
0.40
Bondi radii

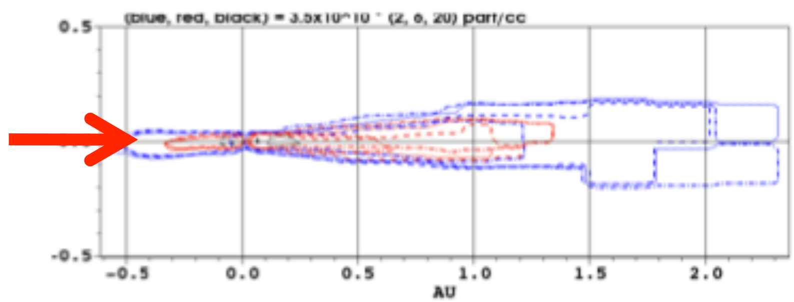
Disk structure





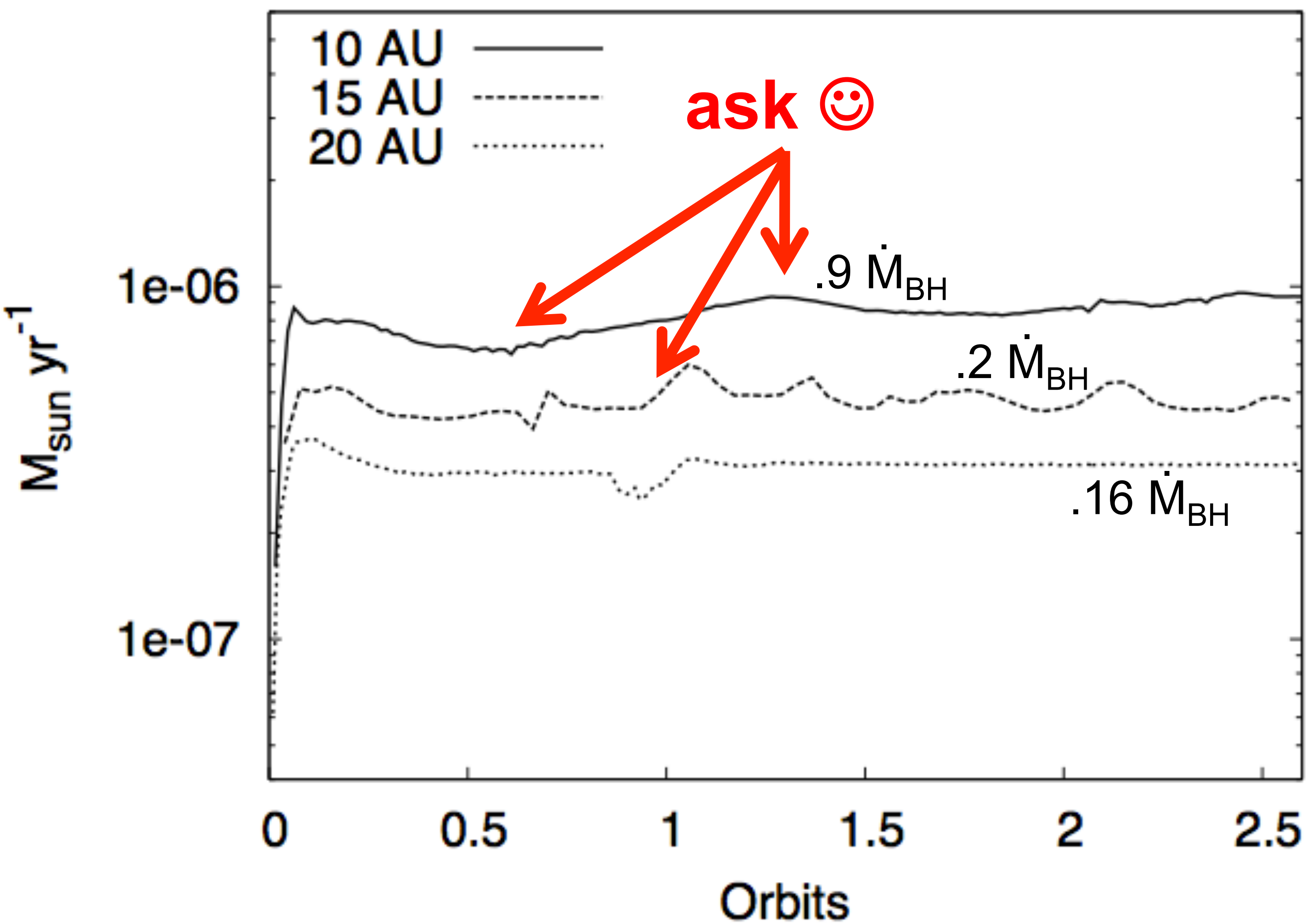
a=15 AU





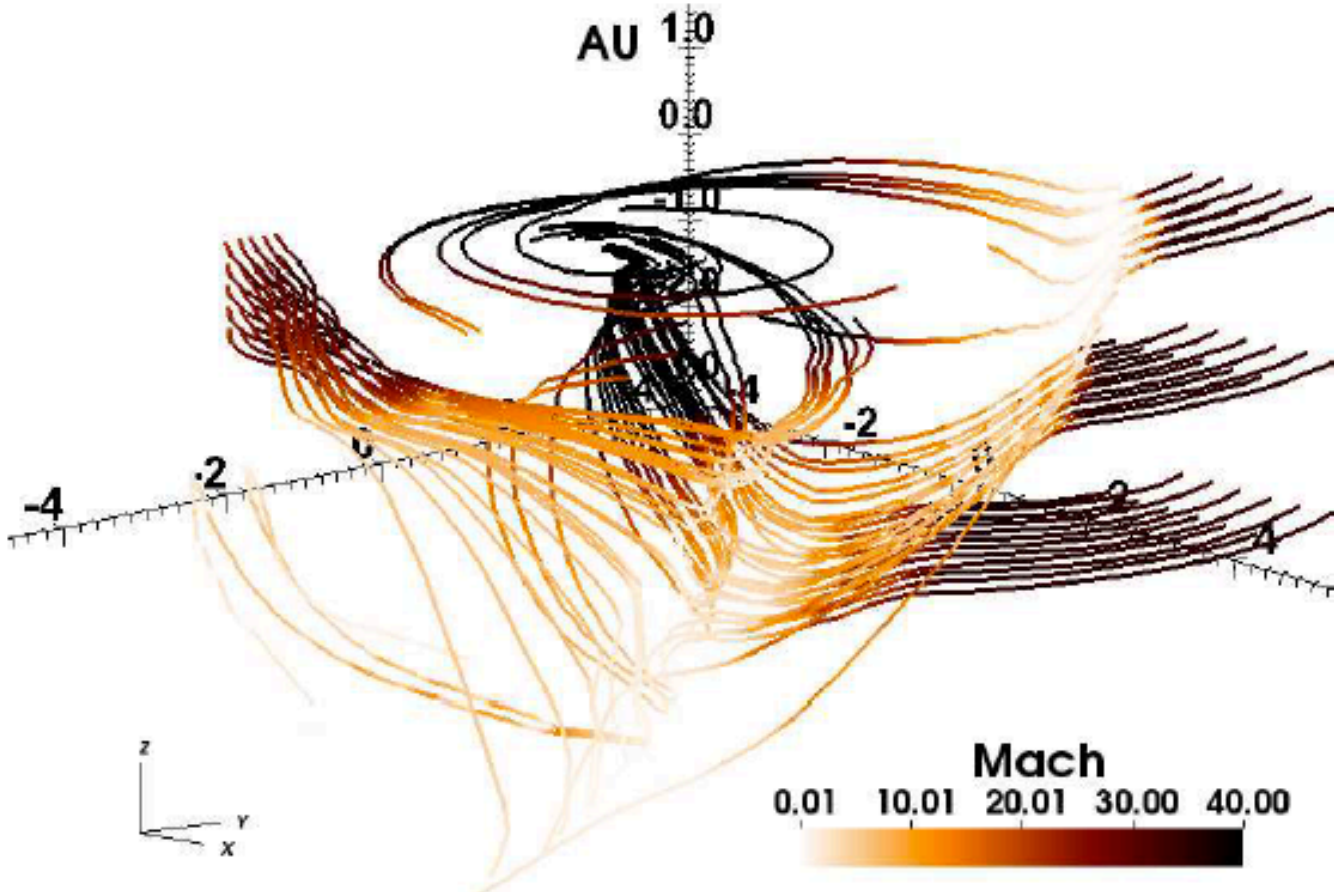
a=20 AU

Accretion: rate onto the secondary

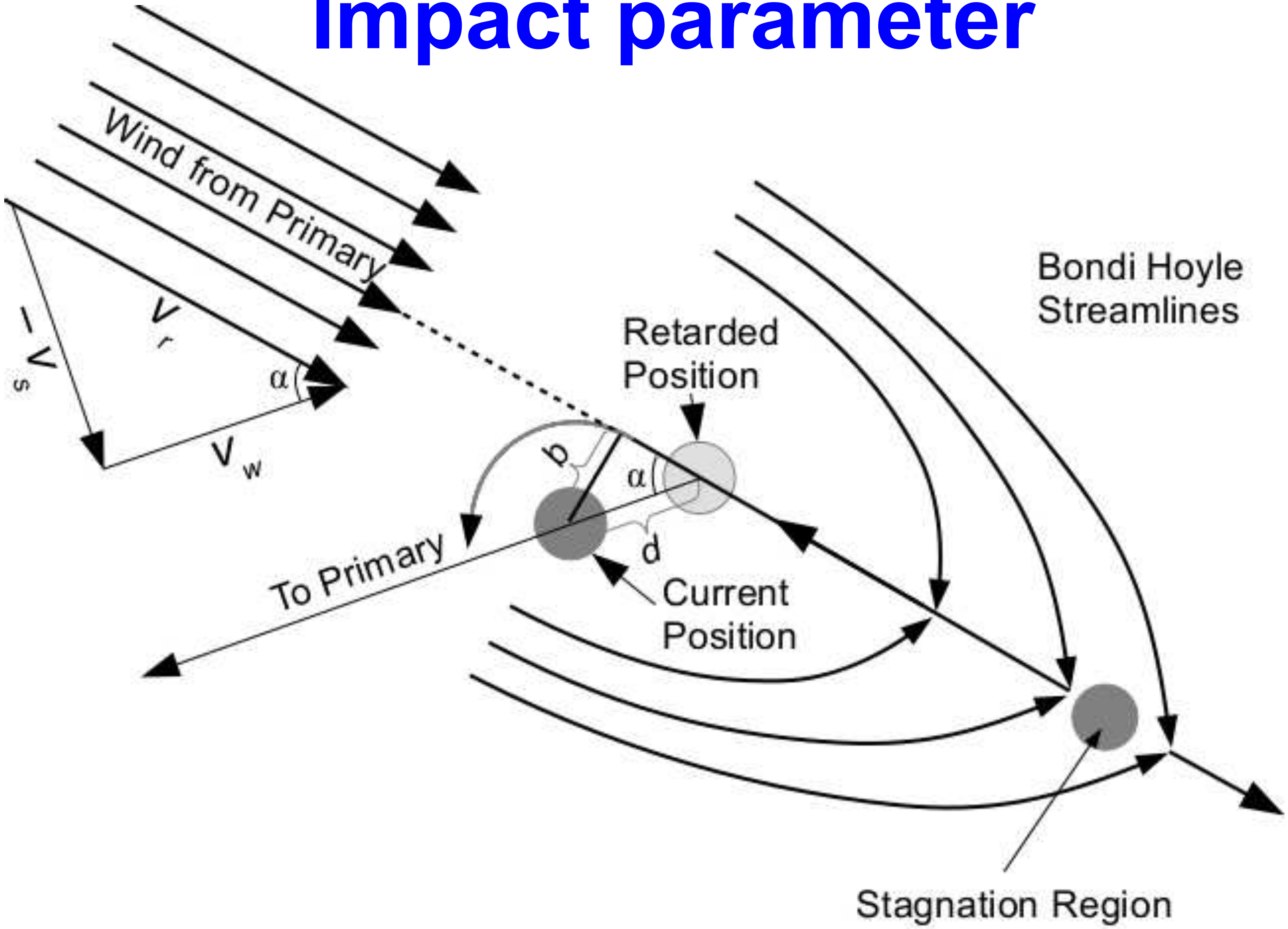


Accretion: flow structure

The accreted wind component has a vortex tube-like structure, rather than a column-like one as it was previously thought.



Impact parameter



The accretion stream falls towards a retarded point in the secondary's orbit as the secondary is pulled towards the primary relative to the stream, Blackman, Carroll-Nellenback, Frank, Huarte-Espinosa & Nordhaus, 2013, MNRAS, 2281

Summary & Discussion

- The disks' radii and height are inversely proportional to *a,*

- We see disks forming up to 20 AU in 3D,

- Disks' material orbits are a function of *a,*

- The impact parameter! Its resolution is key to follow the formation of disks in these kind of models,

    - Discs will form at larger radii from the secondary than traditional estimates (see Blackman, Carroll-Nellenback, Frank, Huarte-Espinosa & Nordhaus, 2013, MNRAS, 2281),

-Energetic arguments suggest that $\dot{M}_{secondary}$ form our models are insufficient to account for the launch of jets in post-AGB stars (pre-PN; see Blackman & Nordhaus, 2007, who have estimated jet mass losses ~ 5×10^{-4} $M_\odot\ yr^{-1}$).

10 au (black) vs. 20 au (red), disk orbit streamlines comparison at 3 times: 1orb=thin; 2orb=thicker; 3orb=thickest, orbital plane view.