Simulations of accretion in binaries formed by an OB star plus a compact object

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in collaboration with
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in accretion sims
and many more in B1259-63 sims

Massive binaries with an accreting compact object

High Mass X-ray Binaries

- Supergiant X-ray binaries (including supergiant fast X-ray transients)
  a blue supergiant + a NS or BH
- Be/X-ray binaries
  a Be star + a NS or BH

Majority of total population

TeV binaries

- All are massive binaries
- 4 (including 1 candidate) show periodic/ persistent TeV emisison
- Among these 4 systems
  - 1 is O star + compact object (LS 5039)
  - 3 have a Be star (B1259-63, LS I+61 303, HESS J0632+057)

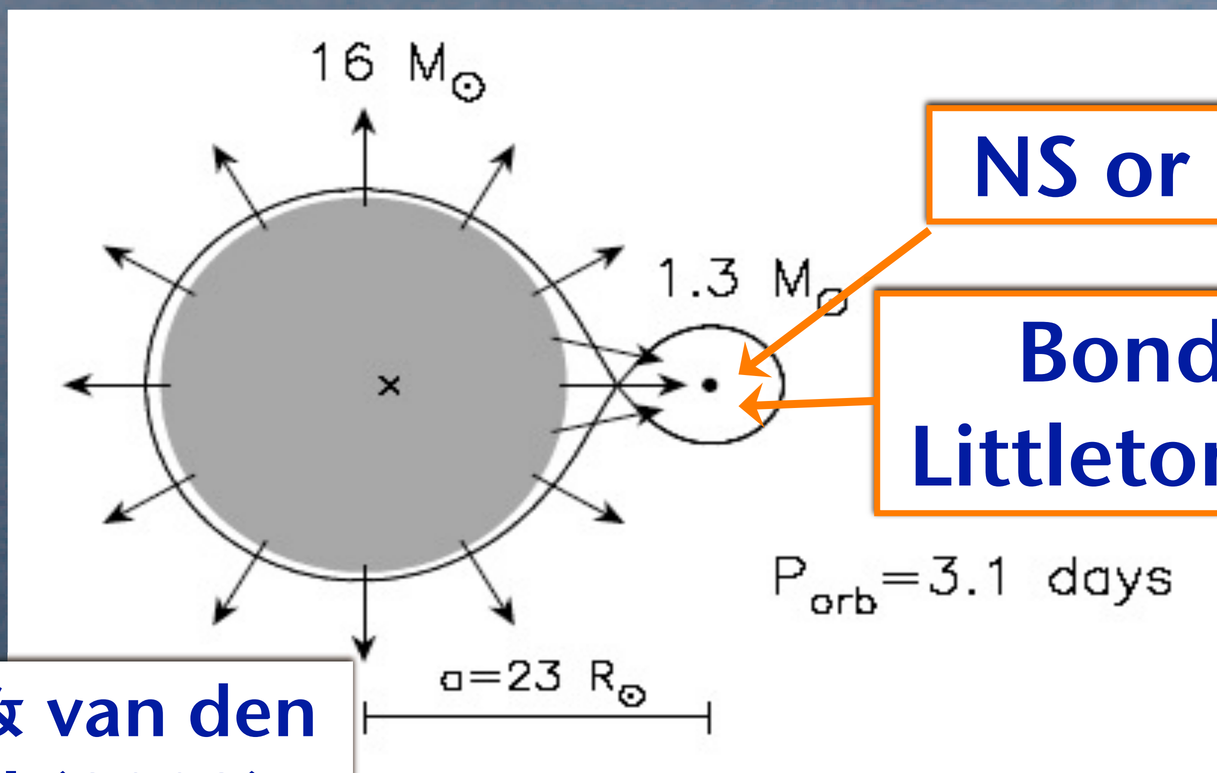
Mass transfer mode in massive binaries with an accreting compact object

Donor	Mass transfer
O stars, B stars	*stellar wind*
blue supergiants	*stellar wind* or Roche-lobe overflow
Be stars	overflow from *Be disk*

Supergiant X-ray binaries

Strong wind → high energy emission

accretion



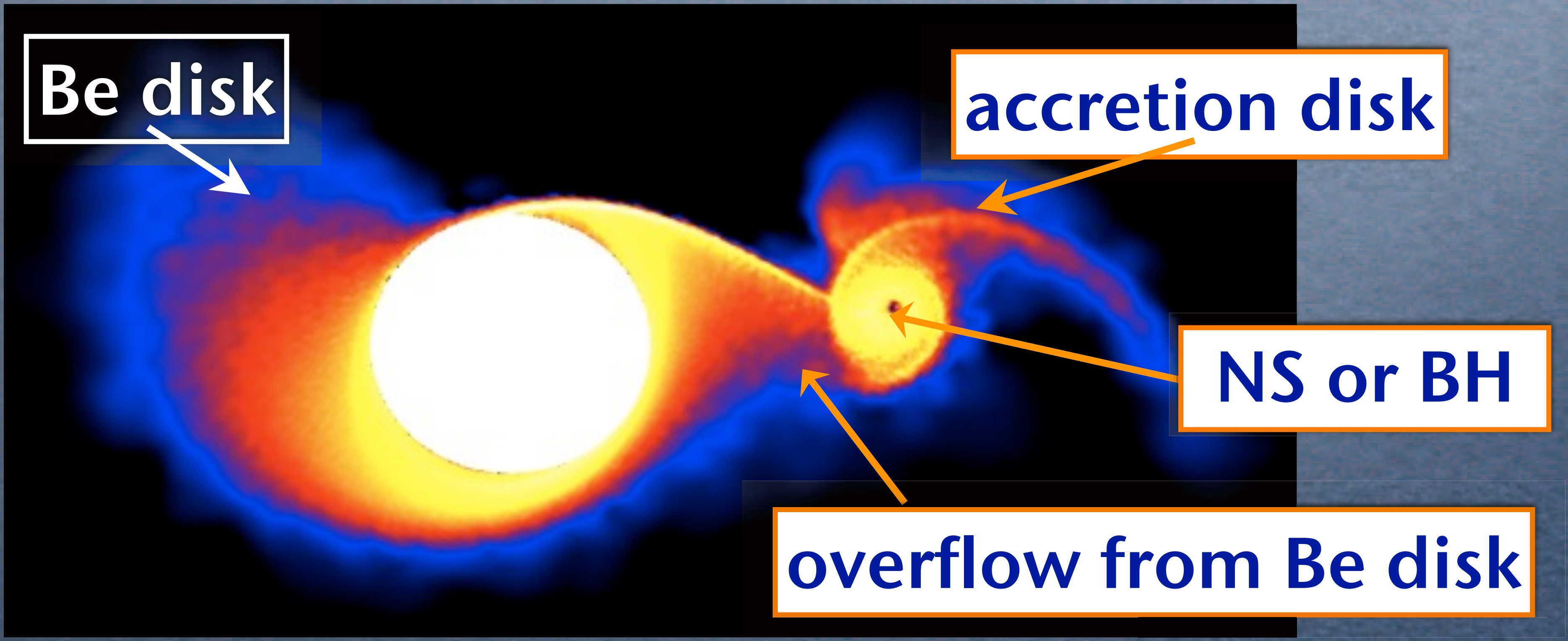
NS or BH

Bondi-Hoyle-Littleton accretion

(Edgar 2004)

Tauris & van den Heuvel (2003)

Be/X-ray binaries



⇩ accretion

high energy emission

Circumstellar disks around Be stars

(Porter & Rivinius 2003 for a review)

Be stars

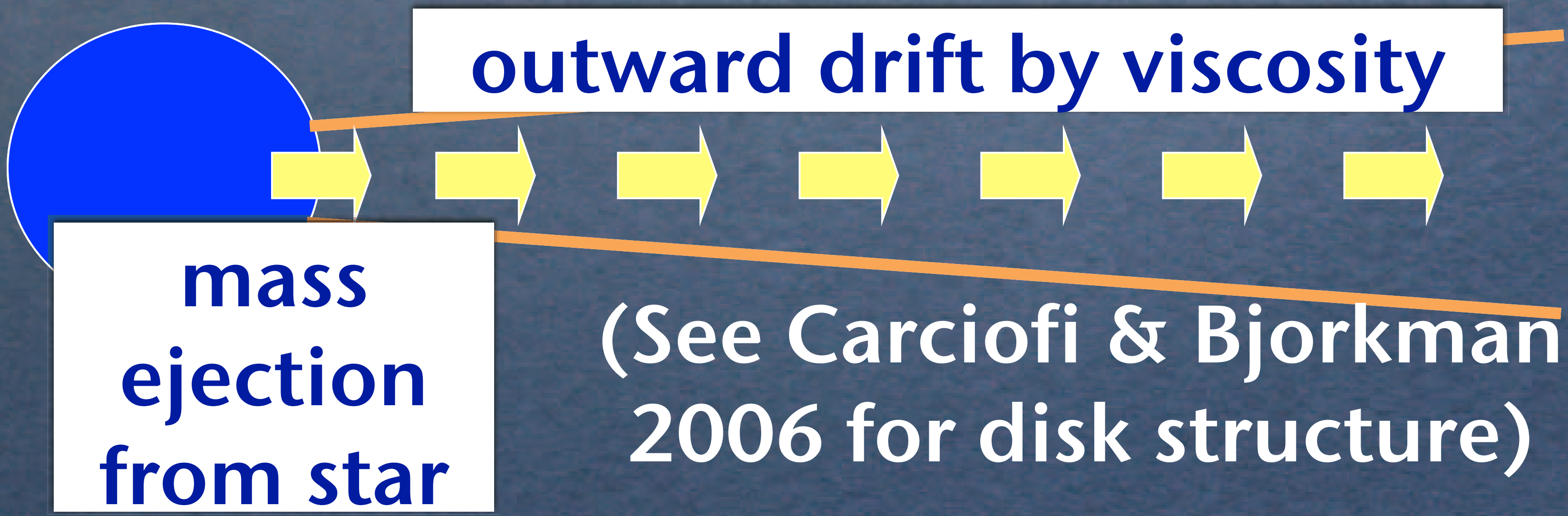
- Non-supergiant B-type stars with Balmer lines in emission (“e” is for emission).
- Two circumstellar components: a polar wind and an equatorial disk.
- Rapid rotators (rotation close to critical).

Circumstellar disks around Be stars

(Porter & Rivinius 2003 for a review)

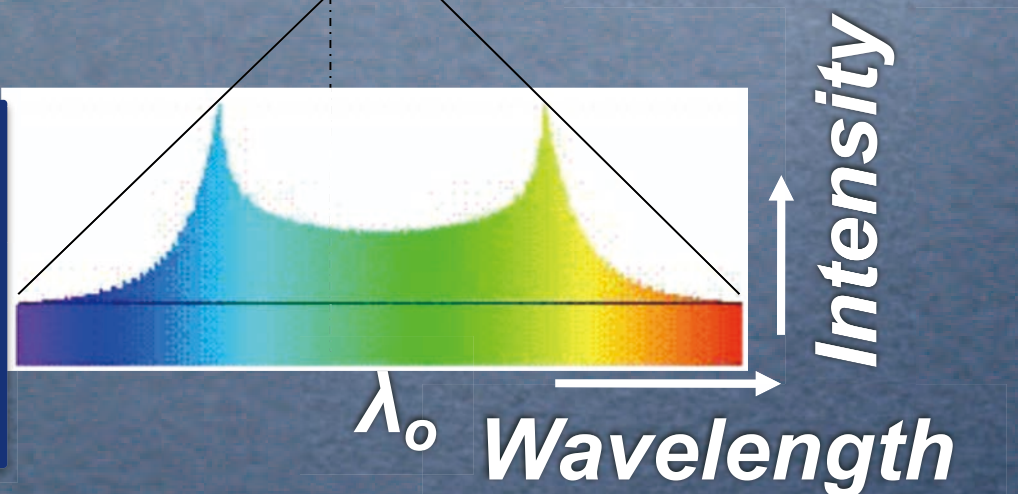
Be disks

- Viscous decretion disks (Lee et al. 1991)
- Keplerian (radial velocity <<1 km/s)



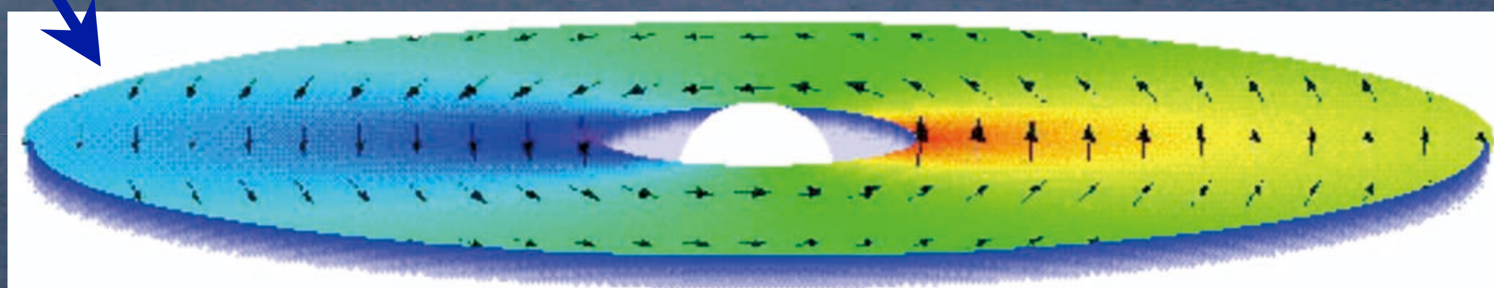
(See Carciofi & Bjorkman 2006 for disk structure)

Be stars



Viscous decretion disk

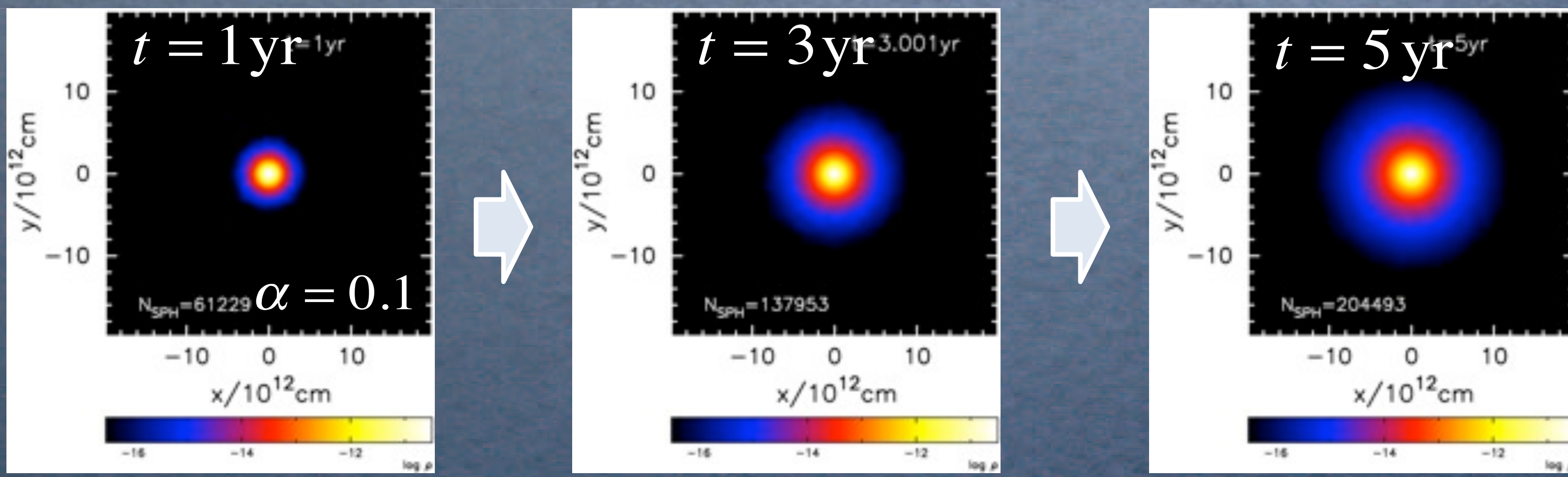
- Keplerian
- $v_r \ll c_s$



Courtesy of Stan Owocki

Equatorial disk ≠ Equatorial wind!

- Be disk (viscous decretion disk) is Keplerian.
- Outflow velocity is so low that only upper limit (1km/s) is obtained observationally.



Stop using the equatorial disk model of Waters (1986). It's obsolete for >10yr!

Constructing 3-D dynamical models is essential to understand:

- Nature of the system

  A colliding wind binary or a microquasar?

- Details of the interaction
  - Accretion rate etc. in accreting systems
  - Structure and dynamics of interaction region in colliding wind binaries

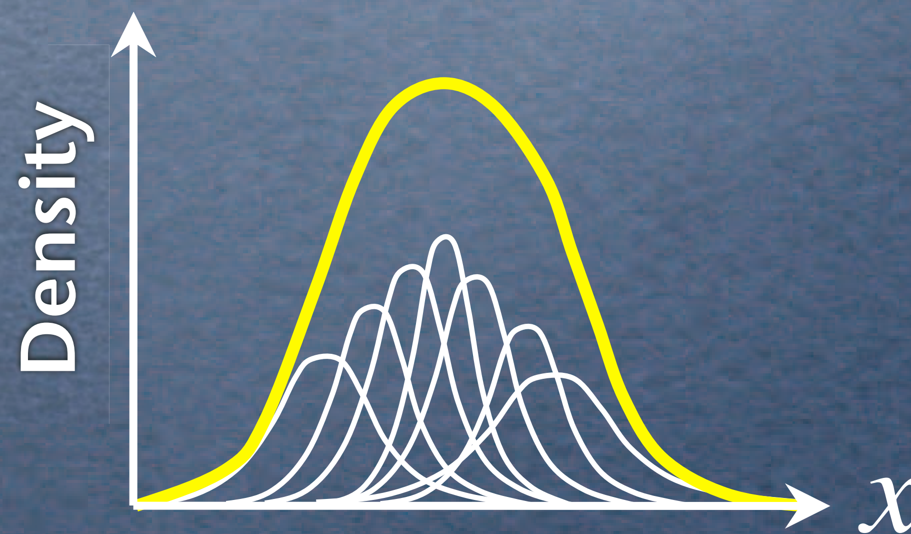
3-D hydodynamical simulations of TeV gamma-ray binaries

System	Model
B 1259-63: B2Ve(?) + NS; P_{orb}= 3.4 yr, e = 0.87	CWB **Poster**
LS 5039: O6.5V + NS or BH; P_{orb}= 3.9 d, e = 0.24	CWB or MQ? **This talk**
LS I +61 303: B0Ve + NS or BH; P_{orb}= 26.5 d, e= 0.24	CWB or MQ? **This talk**

Numerical Modeling of Interactions in Massive Binaries with SPH

SPH (Smoothed Particle Hydrodynamics)

A particle method that divides fluid into a set of discrete "fluid elements" (=particle)



Some Features of the SPH Method

- Automatic adaptation of spatial resolution.
- Can handle various configurations easily.
- Derivatives apply only to the kernel.
- Not a best method for problems with strong shocks.

Simulations of stellar wind accretion: LS 5039

(Owocki, Okazaki, Romero 2010, arXiv:1010.0355)

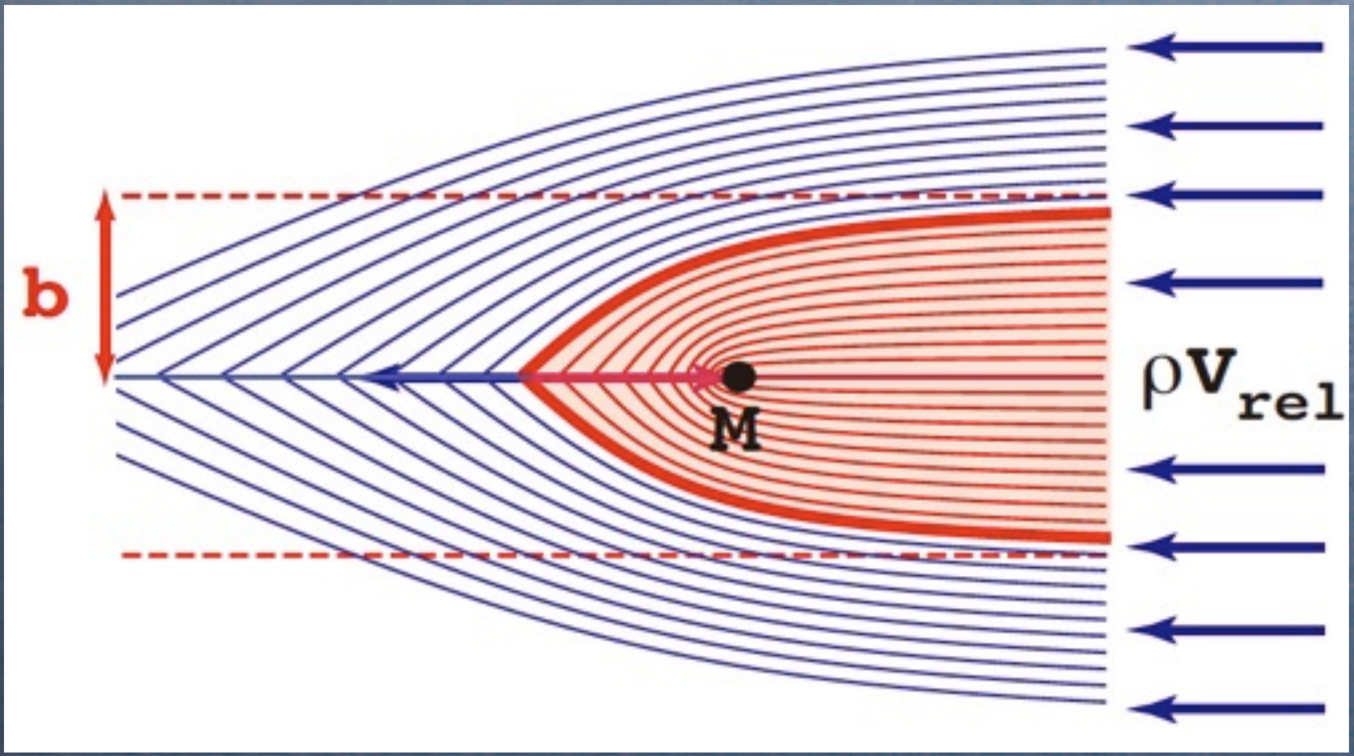
Numerical model

- Isothermal O-star wind w/ beta=1 velocity law:

$$v_{\mathrm{w}} = v_{\infty}(1 - R / r)^{\beta}$$

- Wind particles ejected in a narrow cone toward BH.
- Fix BH accretion radius << Bondi-Hoyle accretion radius at periastron.

Bondi-Hoyle-Lyttleton (BHL) Accretion



(Owocki+ 2010)

Bondi radius

$$b = \frac{GM_{\mathrm{BH}}}{V_{\mathrm{rel}}^2 / 2}$$

BHL accretion rate

$$\dot{M}_{\mathrm{BHL}} = \rho V_{\mathrm{rel}} \pi b^2$$

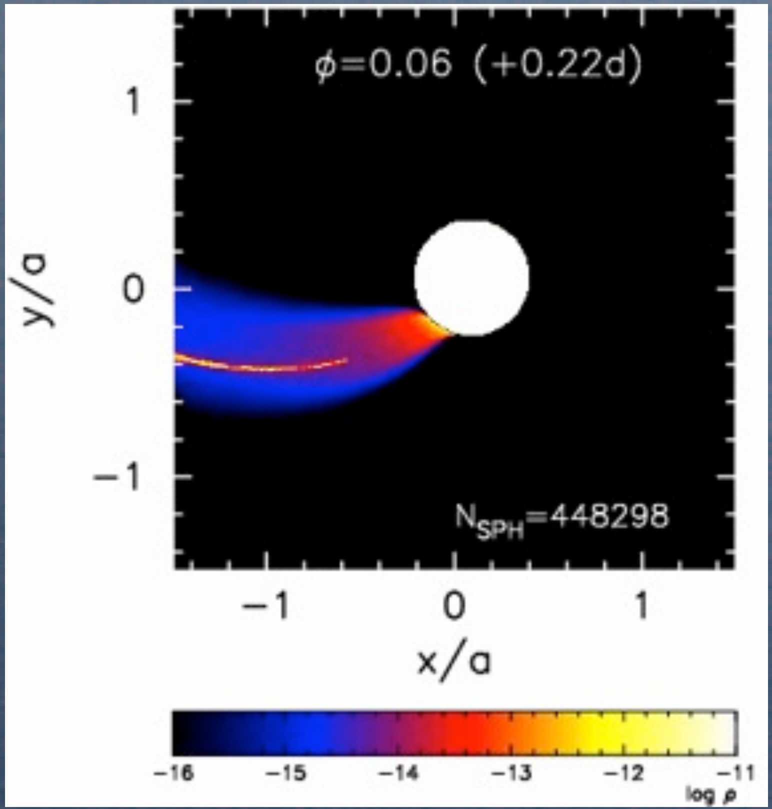
$$= \frac{G^2 M_{\mathrm{BH}}^2 \dot{M}_{\mathrm{w}}}{V_{\mathrm{rel}}^3 V_{\mathrm{w}} d^2}$$

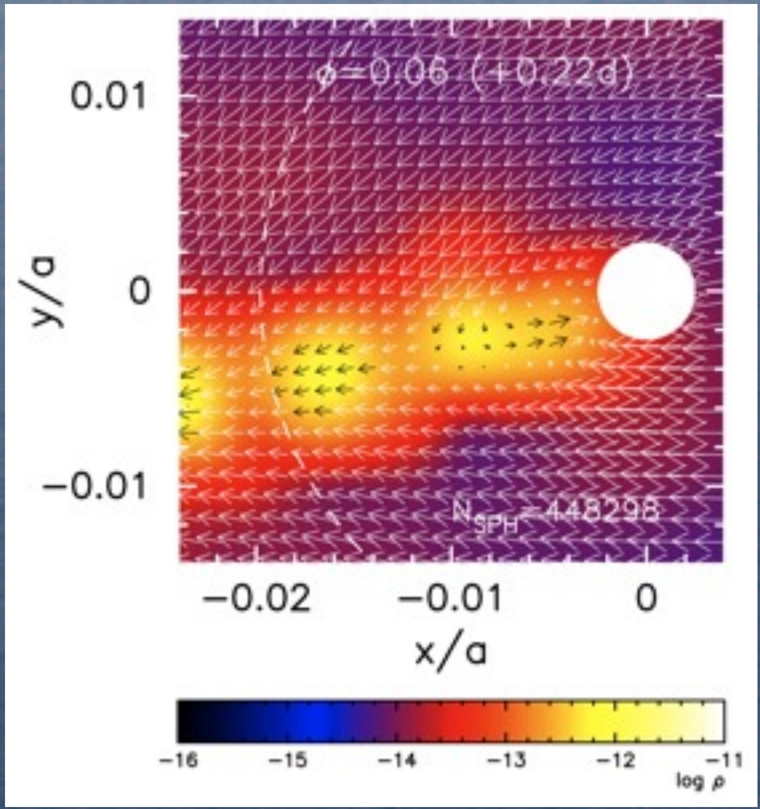
The stellar, wind, and orbital parameters for LS 5039 simulations

	Primary	Secondary
Spectral Type	O6.5V	BH
Mass	22.9Msun	3.7Msun
Radius	9.3Rsun	2.5×10^{-3}a
Vinf	2,440 km/s	---
T_{wind}	39,000 K	---
Mdot	5×10^{-7}Msun/yr	---
Porb	3.9060 days	
Eccentricity	0.24	

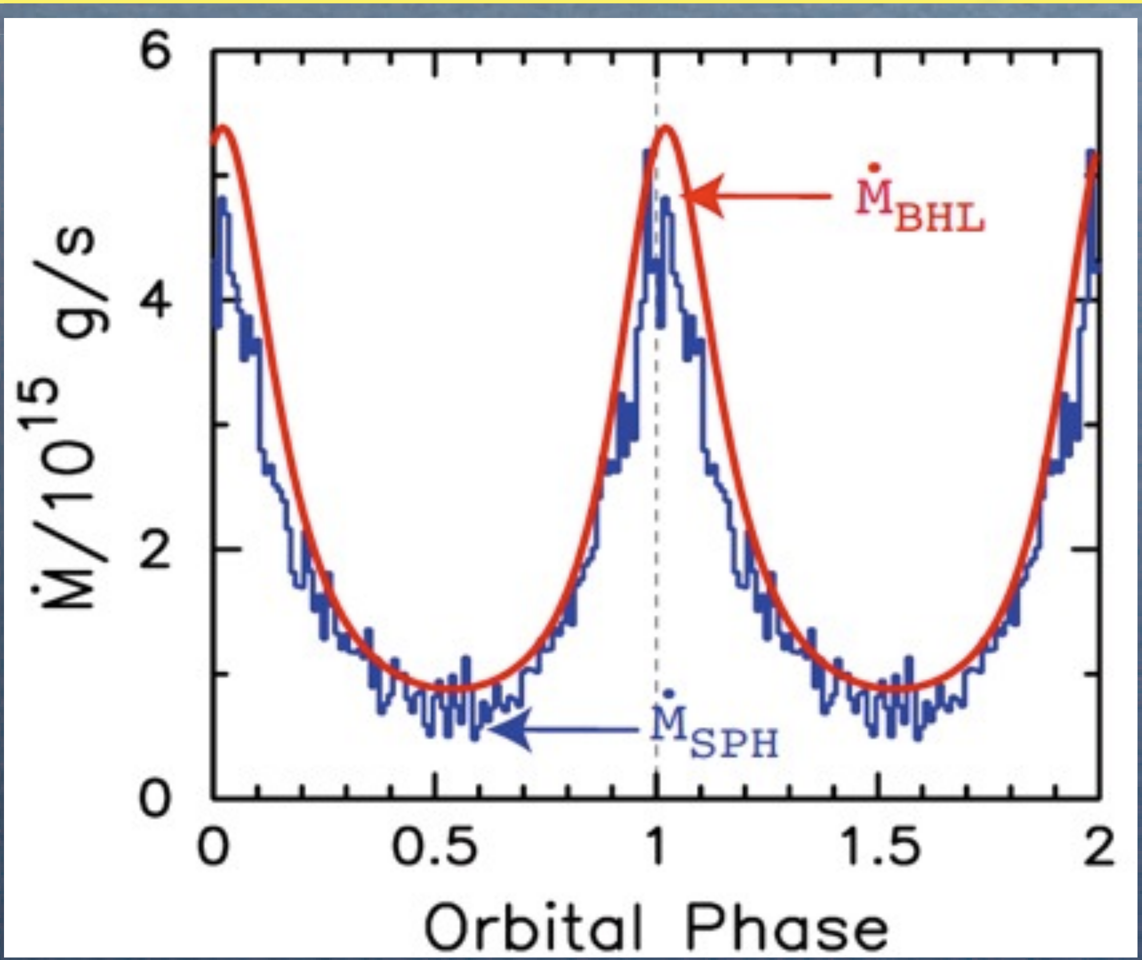
Accretion of stellar wind with beta-velocity law $v_w = v_\infty(1 - R/r)^\beta$ with $\beta = 1$

A snapshot of flow structure





KEY RESULT: SPH accretion rate closely follows Bond-Hoyle-Littleton rate



BHL accretion rate

$$\dot{M}_{BHL} = \frac{G^2 M_{BH}^2 \dot{M}_w}{V_{rel}^3 V_w d^2}$$

(Owocki+ 2010)

Summary of LS 5039 accretion sims

- SPH sims show Mdot given by BHL rate!
  - direct accretion fits Fermi light curve for 0.1-10 Gev
  - BHL emission + γ−γ abs. fits HESS light curve for E > 1 TeV
- But model does not fit Energy Spectrum: γ−γ absorption predicts hardening at minimum, whereas observations show softening at minimum

Simulations of accretion from Be disk: LS I +61 303

(Romero, Okazaki, Orellana, Owocki 2007, A&A, 474, 15, + new sims)

Numerical Model

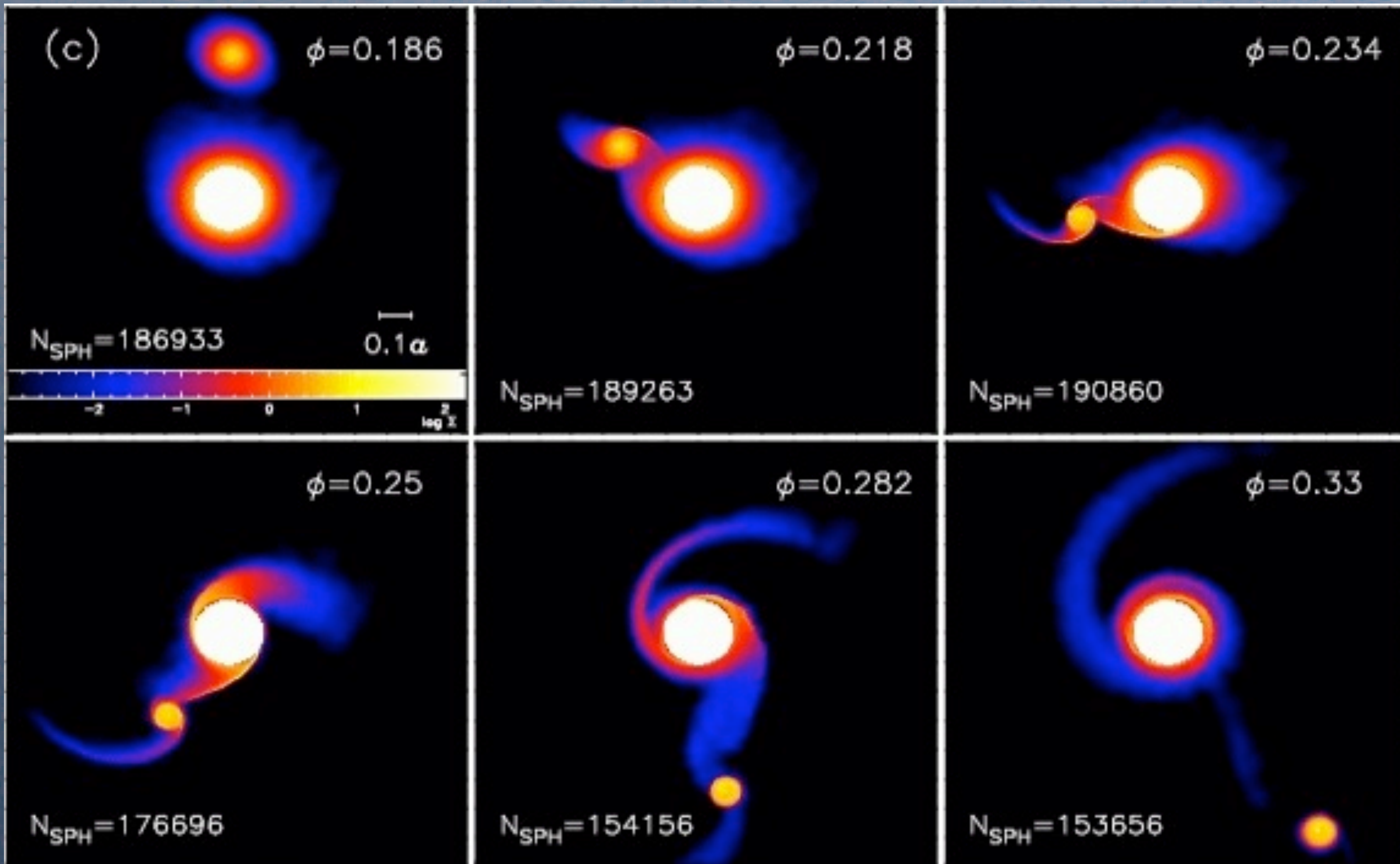
- In decretion/accretion sims, numerical viscosity adjusted to keep $\alpha_{\rm SS} = 0.1$
- In CW sims, $\alpha_{\rm SPH} = 1, \beta_{\rm SPH} = 2$
- Constant Mdot's from disk and star
- Be decretion disk: isothermal

Accretion disk: polytrope with $\Gamma = 1.2$

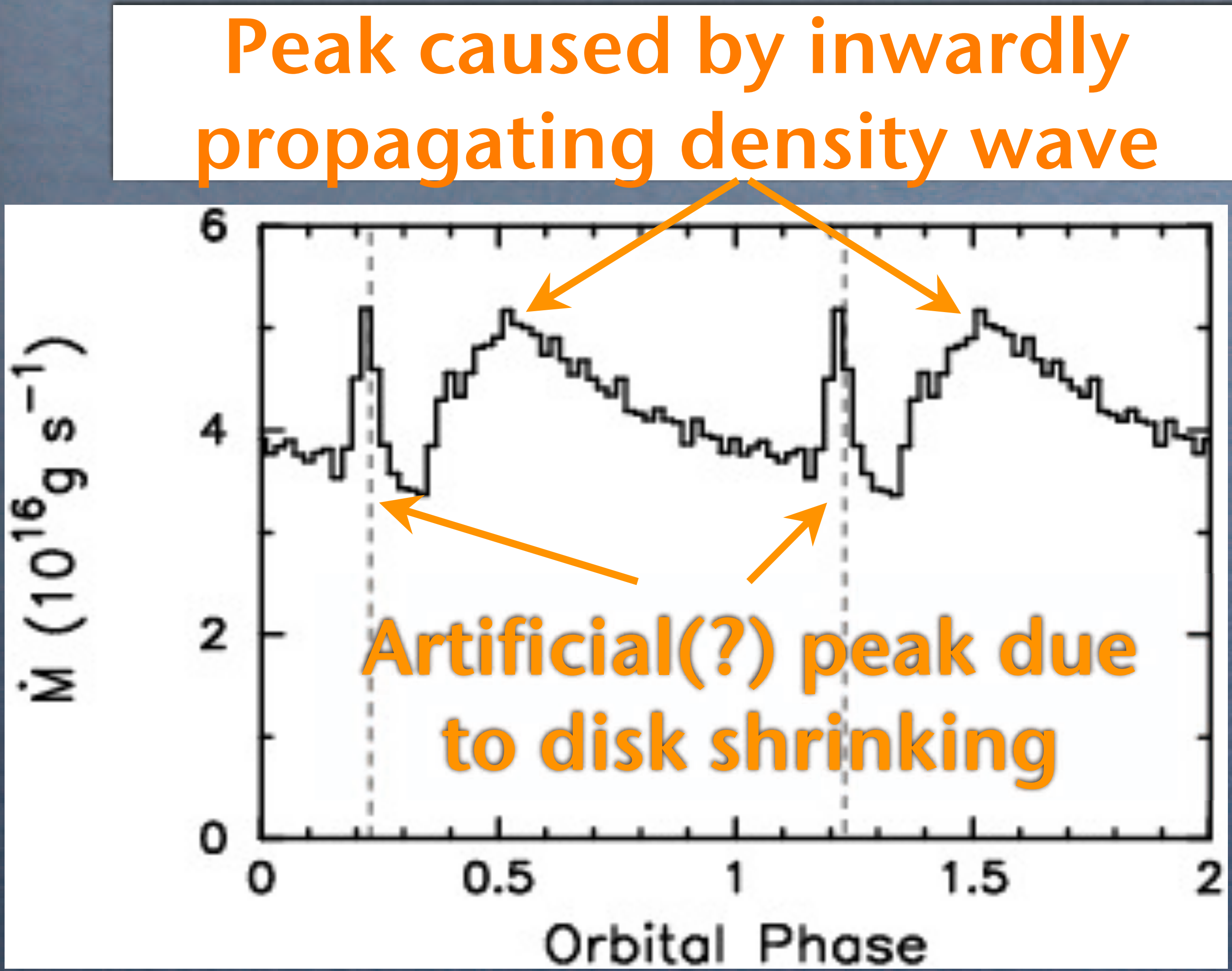
Stellar wind: with opt. thin rad. cooling

Mosaic from the Be Disk and AD Sims

(Romero+ 2007)



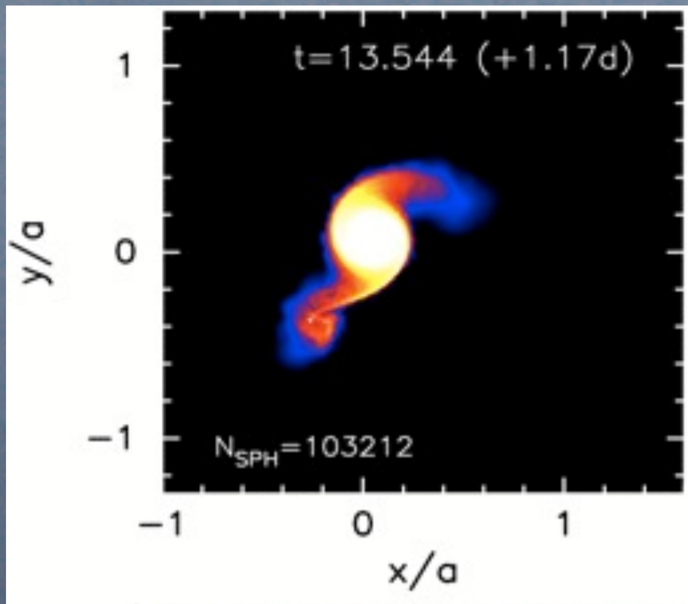
Orbital modulation in accretion rate

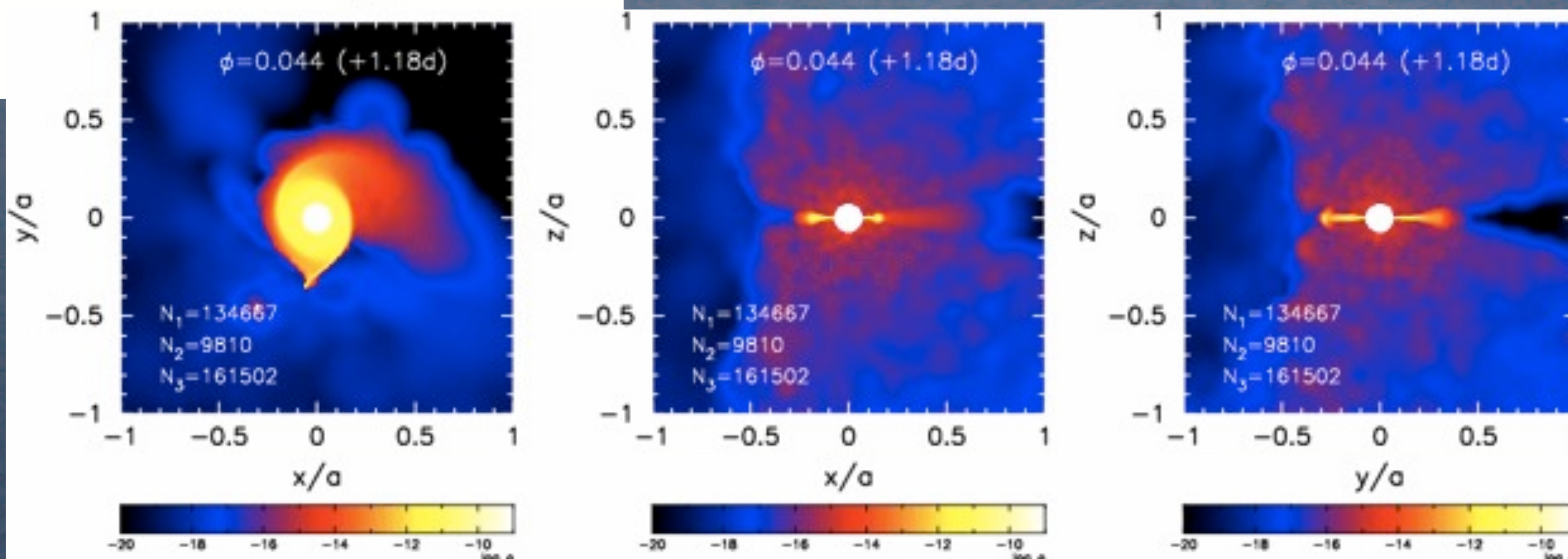


Accretion rate consistent with RIAF scenario

(Romero+ 2007)

Accretion model vs. CWB model

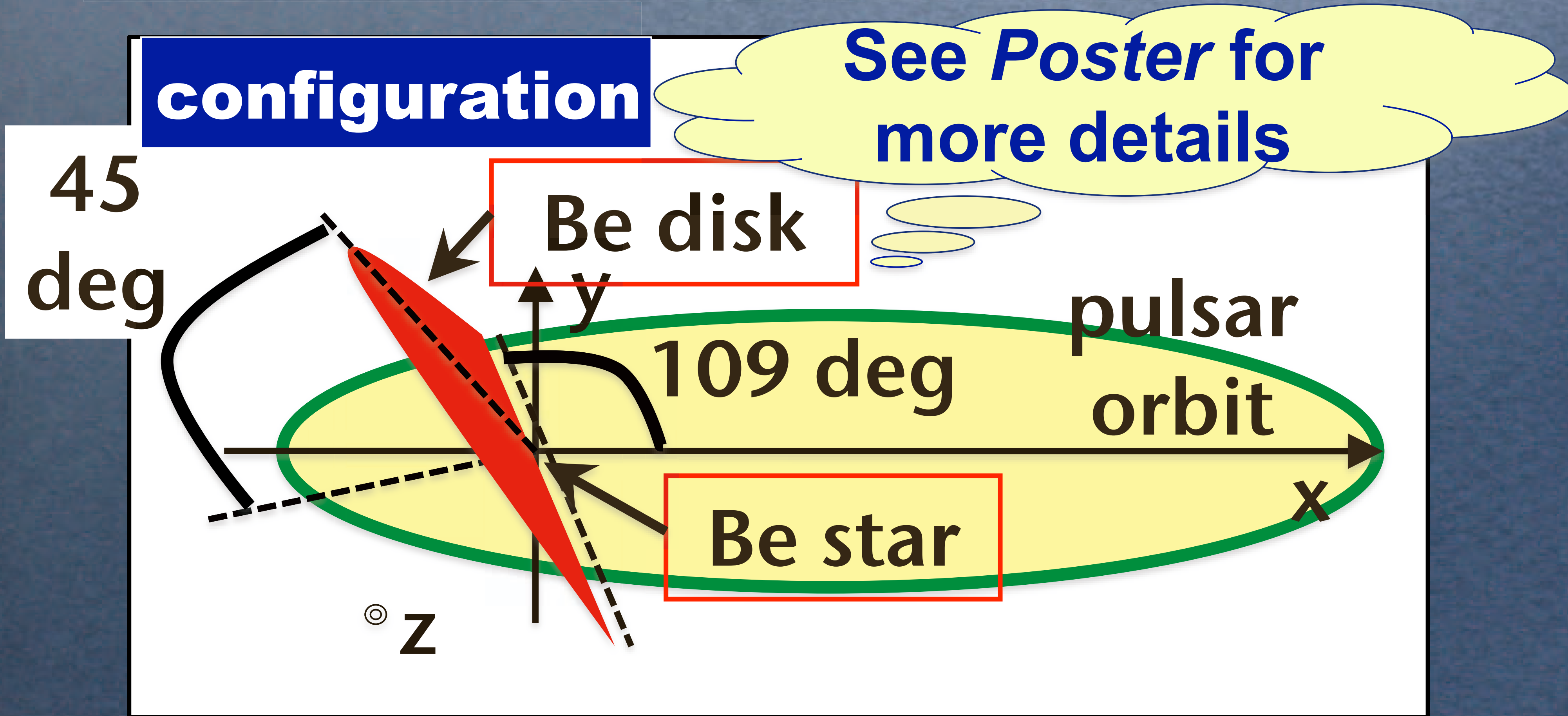




Summary of LS I +61 303 Sims

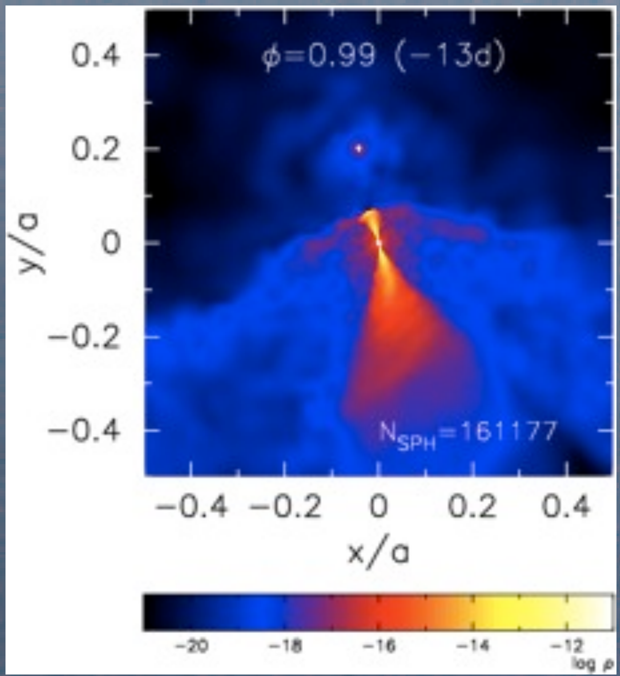
- Accretion/ejection scenario predicts modulation of accretion power < 2
- Opt. and IR observations of Be disk can be used to probe the nature of compact object
- Explaining the radio maps is an open question.

Effects of the Pulsar Wind on the Circumstellar Environment of the Be Star in B1259-63

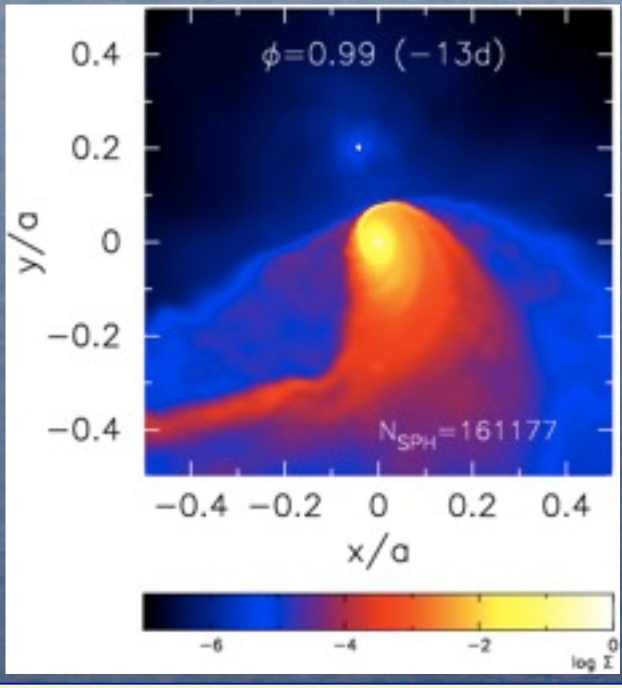


B1259-63

Density on orbital plane



Column density along z-axis



Pulsar wind dominates Be wind and truncates Be disk, causing a strongly asymmetric circumstellar structure