בס"ד

Mass Accretion in the Binary Star η Carinae

Amit Kashi and Noam Soker,
Technion – Israel Institute of Technology, Haifa, Israel

VLTI, Keszthely
June 2008

η Car - **Binary** Parameters

Primary - LBV	Secondary - O5 / WR
$M_1 \simeq 120 M_\odot$	$M_2 \simeq 30 M_\odot$
$R_1 \simeq 180 R_\odot$	$R_2 \simeq 20 R_\odot$
$L_1 \simeq 5 \cdot 10^6 L_\odot$	$L_2 \simeq 9 \cdot 10^5 L_\odot$
$T_1 \simeq 20{,}000\mathrm{K}$	$T_2 \simeq 36{,}000 - 40{,}000\mathrm{K}$
$\dot{M}_1 \simeq 3 \cdot 10^{-4} M_\odot \mathrm{yr}^{-1}$	$\dot{M}_2 \simeq 10^{-5} M_\odot \mathrm{yr}^{-1}$
$v_{1,\infty} \simeq 500 \mathrm{~km~s}^{-1}$	$v_{2,\infty} \simeq 3000 \mathrm{~km~s}^{-1}$
$a \simeq 16.6\mathrm{AU}$	$P = 2022.7 \pm 1.3 \mathrm{~d}$
$e = 0.9 - 0.95$	$i = 41^\circ - 53^\circ$

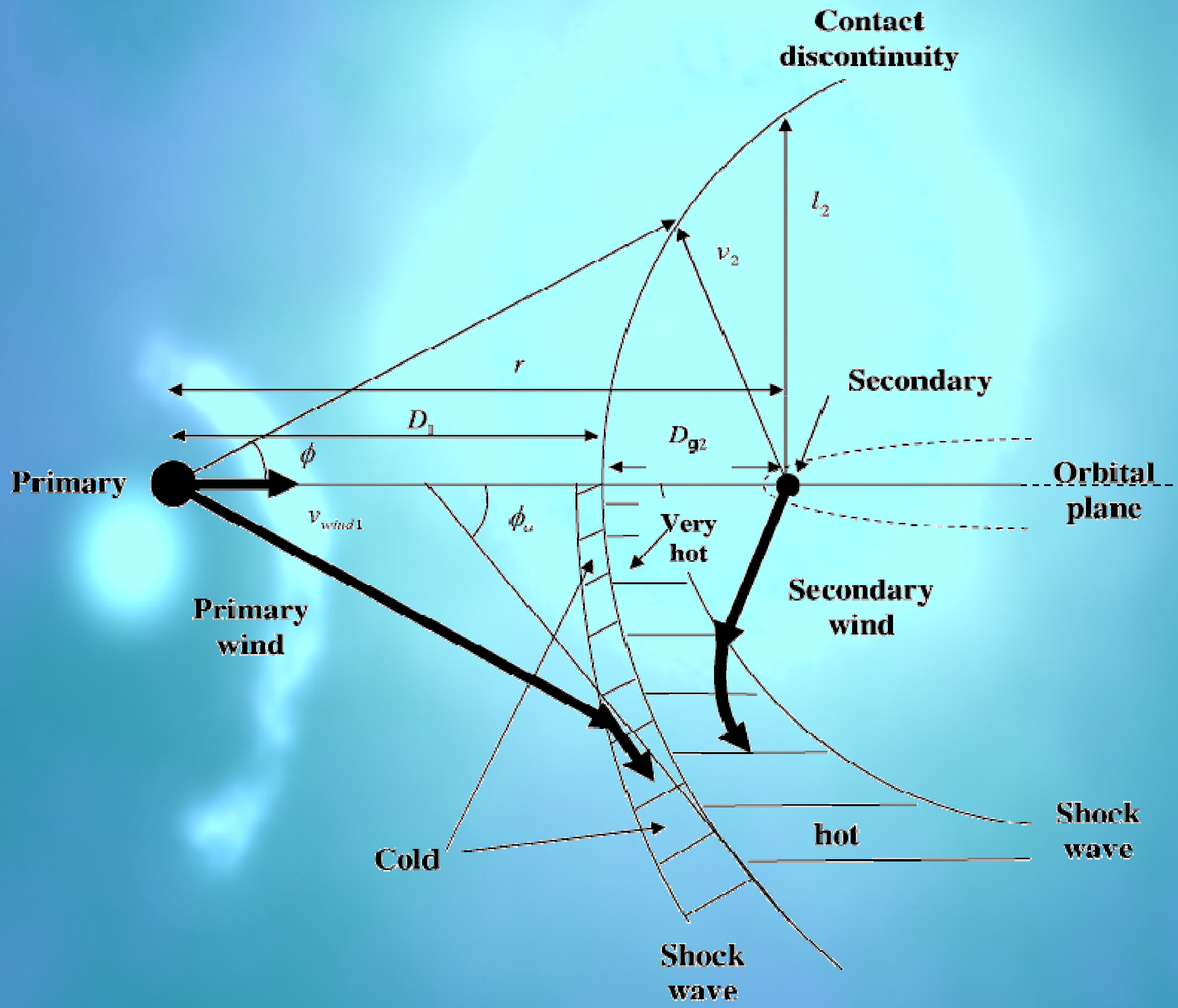
Supper massive

Slow and dense wind

Fast and less dense wind

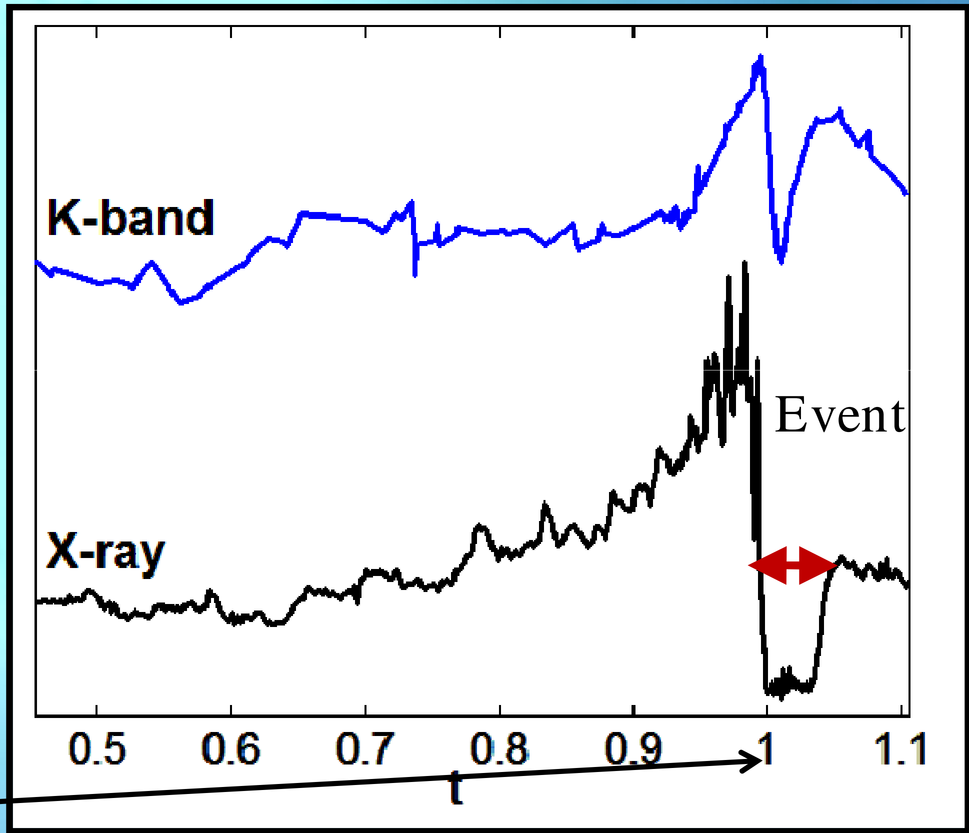
Very eccentric orbit

Colliding Winds "Cone" Structure



The Event

- A 5.54 year periodicity is observed in the radio, IR, visible and X-ray spectra.
- The spectroscopic event is defined by the fading, or even disappearance, of high-ionization emission lines.
- The X-ray cycle presents a deep minimum lasting ~70 days and occurring more or less simultaneously with the spectroscopic event.
- The X-ray minimum and the spectroscopic events are assumed to occur near periastron passages (t=1).
- Afterwards a slow and gradual recovery is observed.



Explaining the Event with the *Accretion Model*

- Most of the 5.54 years orbital period the secondary's gravity has a negligible effect on the winds.
- Near periastron the secondary's gravity become very important- **the colliding winds cone collapses onto the secondary.**
- The accreted mass **shuts down the secondary wind** for ~70 days.
- **The X-ray luminosity comes to minimum**, due to the collapse of the shocked secondary wind, which is where it mostly comes from.
- **Bondi Hoyle Lyttleton accretion / RLOF** onto the secondary.
- An **accretion disk** around the secondary? Stable/unstable?
- More effects (**He II λ4686Å** , **Disappearance of He I visible lines** , **Near-IR decline**) – ***see other papers by Kashi & Soker.***
- ➔ **IMPORTANT CONCLUTION: Eta Car's secondary plays an important role in explaining many observations.**

What is the Nature of the Accretion Disk? (cont.)

- Viscosity time:

$$t_{\text{visc}} = \frac{R^2}{\nu} = \frac{R^2}{\alpha C_s H} \simeq t_{\text{Kep}} \left(\frac{R}{H}\right)^2 \frac{1}{2\pi\alpha}$$

$$= 30 \left(\frac{R}{10H}\right)^2 \left(\frac{R_2}{20R_\odot}\right)^{3/2} \left(\frac{M_2}{30M_\odot}\right)^{-1/2} \frac{1}{\alpha} \text{days}$$

- Dynamical time:

$$T_{Kep} = \frac{2\pi \cdot r^{3/2}}{\sqrt{G \cdot M_2}} = 1.9 \text{ days} \left(\frac{r}{20R_\odot}\right)^{3/2} = \begin{cases} 1.9 \text{ d} \;;\; r = R_2 \\ 6.4 \text{ d} \;;\; r = 2.25R_2 \end{cases}$$

- Disk existence time :

$$t_{\text{pp}} = \frac{2R_1}{v_{\text{orb}2,\text{per}}} \simeq 6 \left(\frac{R_1}{180R_\odot}\right) \left(\frac{v_{2,\text{per}}}{470\text{kms}^{-1}}\right)^{-1} \text{days}$$

$$t_{\text{Kep}} < t_{\text{pp}} \ll t_{\text{acc}} \sim t_{\text{visc}} \ll P$$

- ➔ **The accretion disk doesn’t reach equilibrium.**
- ➔ Shakura-Sunyaev α model for a thin stable disk cannot be used.
- ➔ Thick ***Accretion Belt***.

Modeling the Accretion

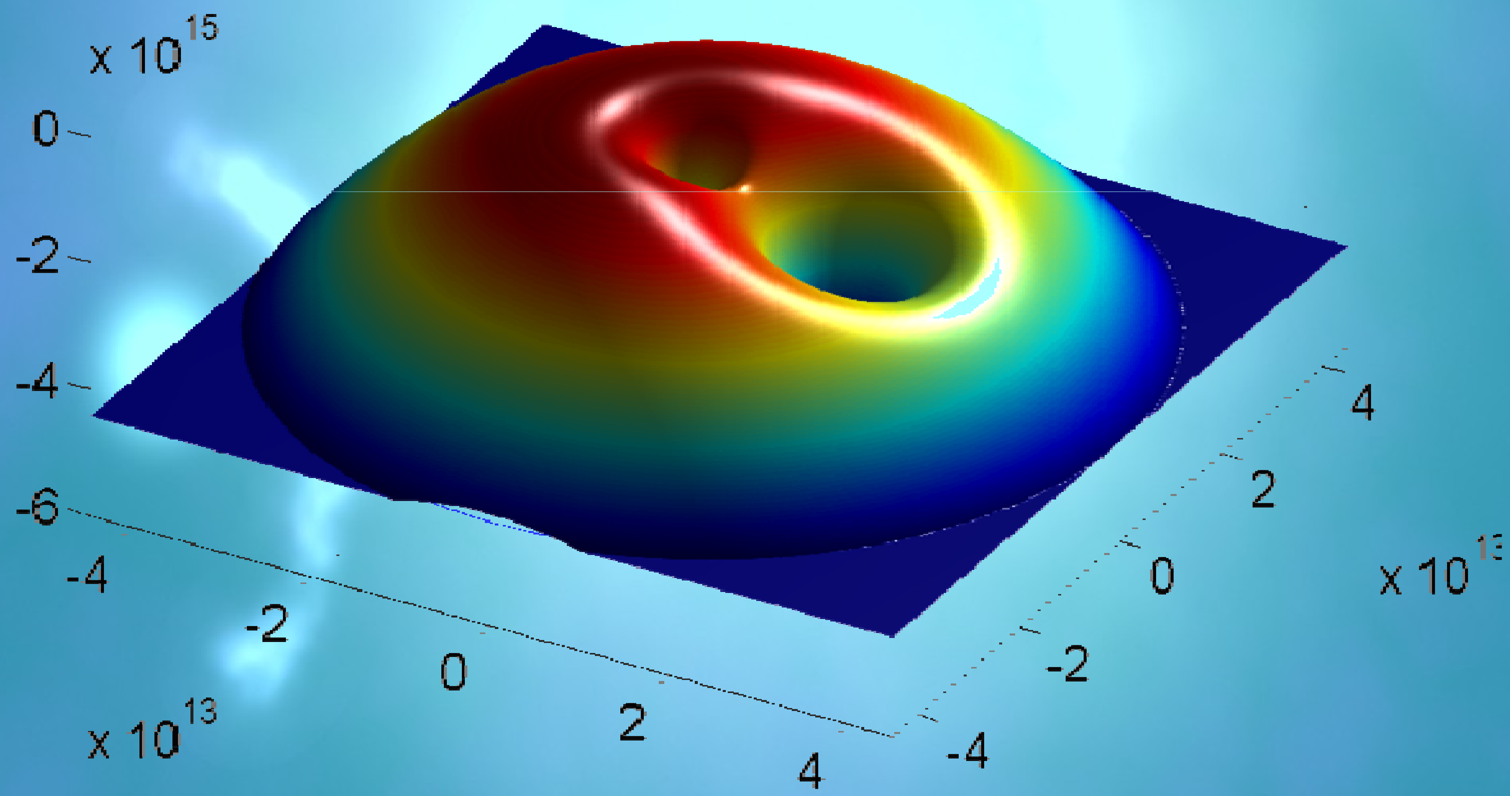
- The effective accretion radius of the secondary depends on several parameters, in particular on the orbital separation r(θ).
- Since the accretion radius is very close to the primary, the primary's wind acceleration zone is taken into account as a β-model with two extreme values:1 and 3.

$$v_1(r) = v_{1,\infty}\left(1 - \frac{R_1}{r}\right)^{\beta}$$

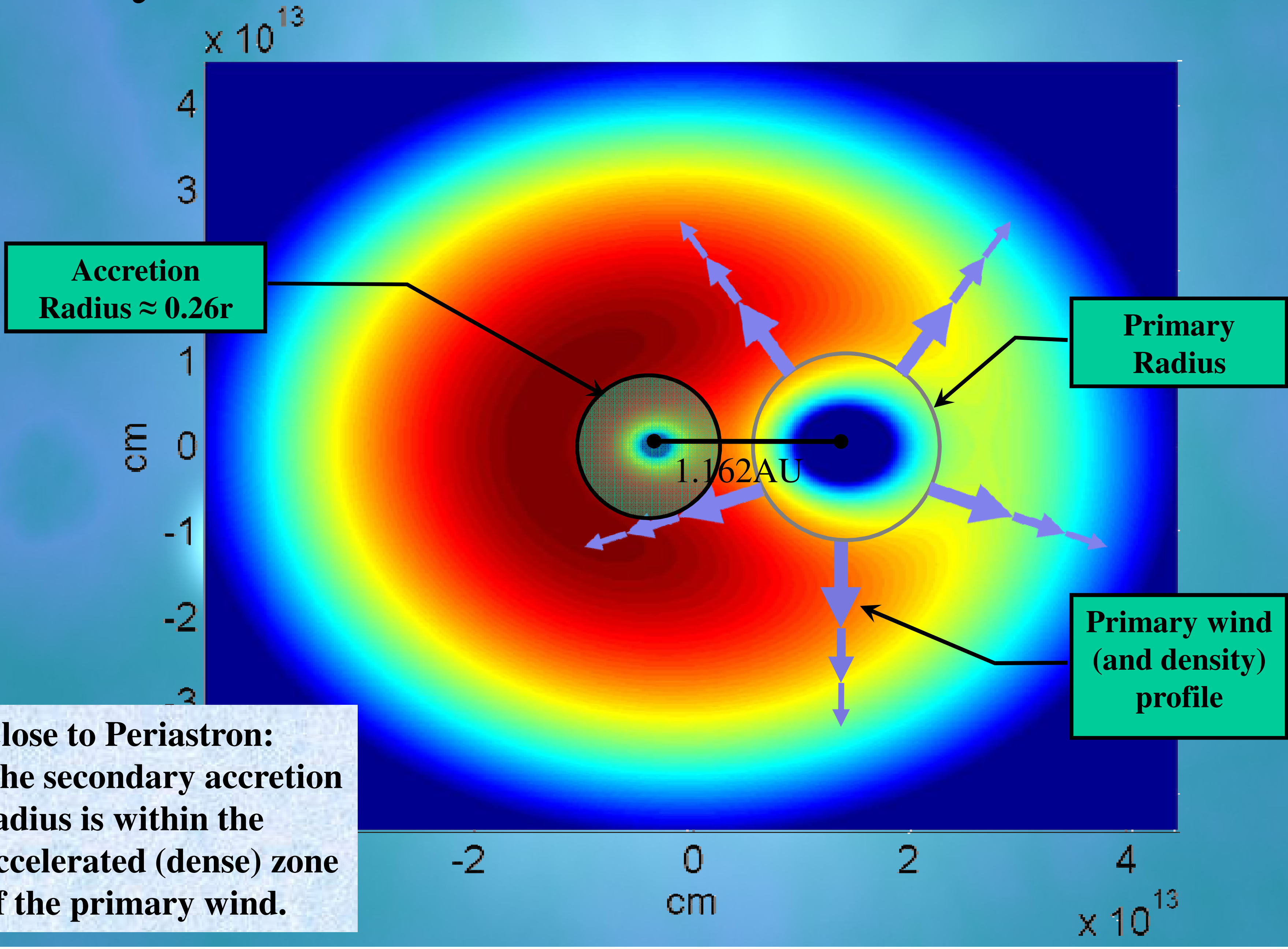
- We consider the two limits: RLOF, taking the accretion radius as the Roche lobe equivalent radius, $R_{RL}(\theta)$, and Bondi-Hoyle-Lyttleton (BHL) accretion, where:

$$R_{BHL}(\theta) = \frac{2GM_2}{v^2_{\mathrm{wind1}}} \ ; v^2_{\mathrm{wind1}} = v^2_{2,\theta} + (v_1 - v_{2,r})^2$$

Roche Potential at Periastron

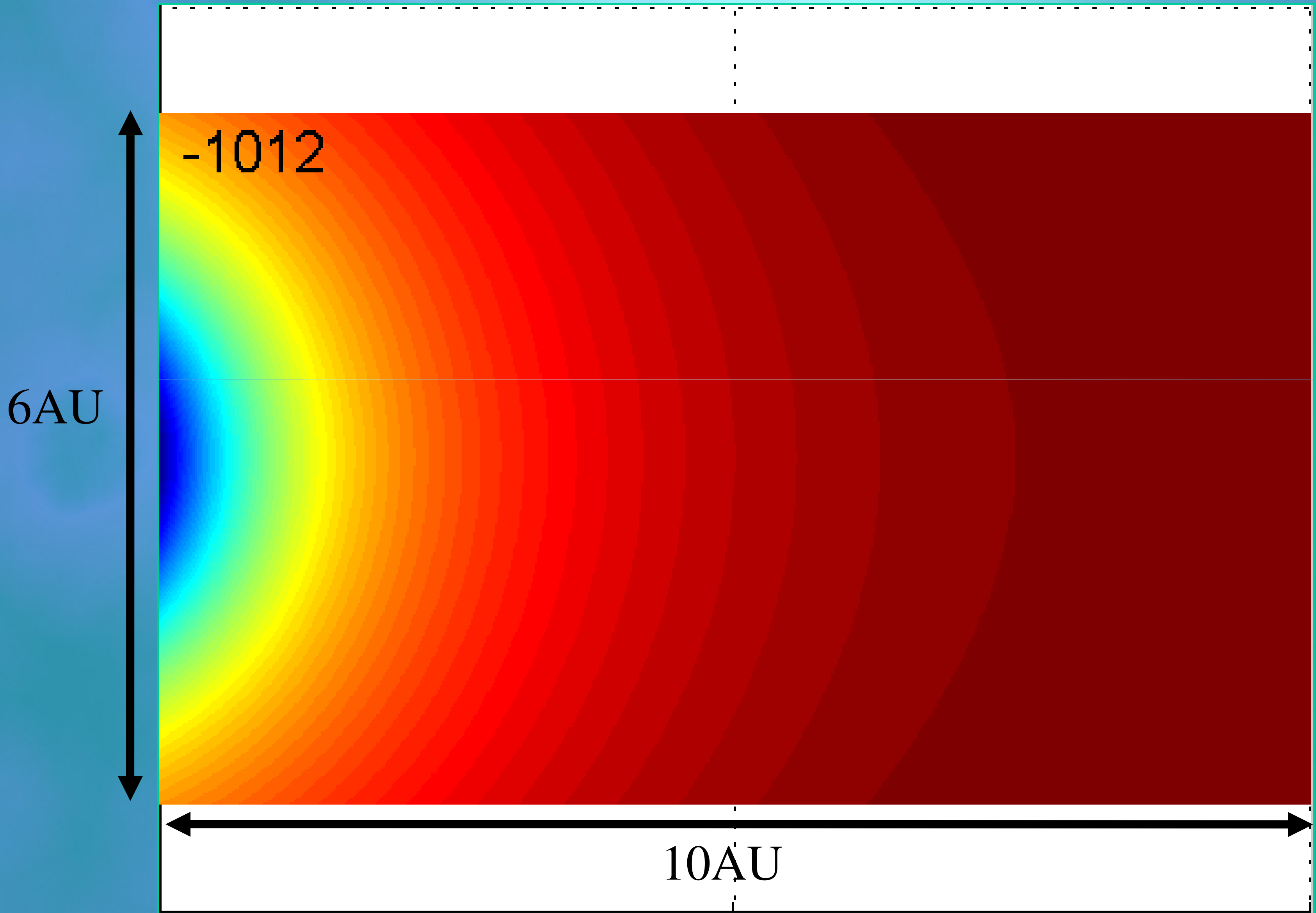


Why Accretion is Favorable close to PP?



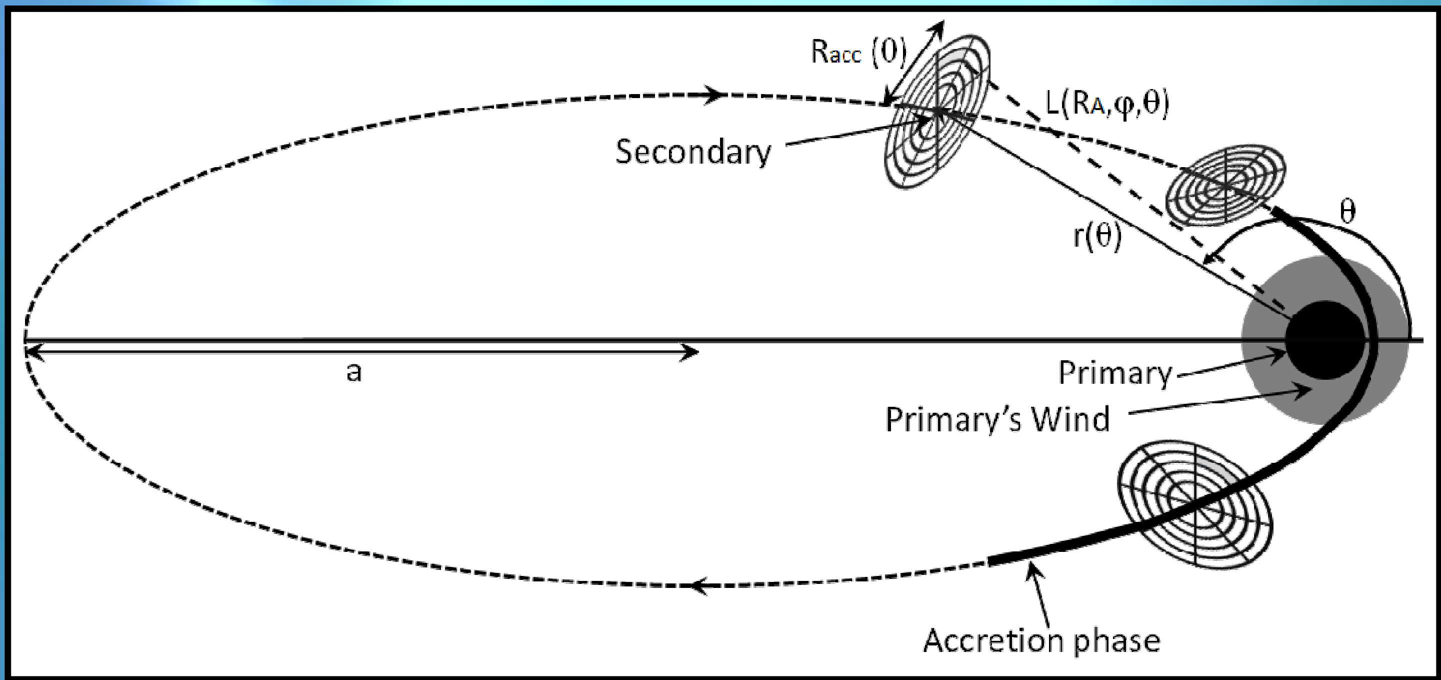
Close to Periastron: The secondary accretion radius is within the accelerated (dense) zone of the primary wind.

Simulation- Accretion Onto the Secondary



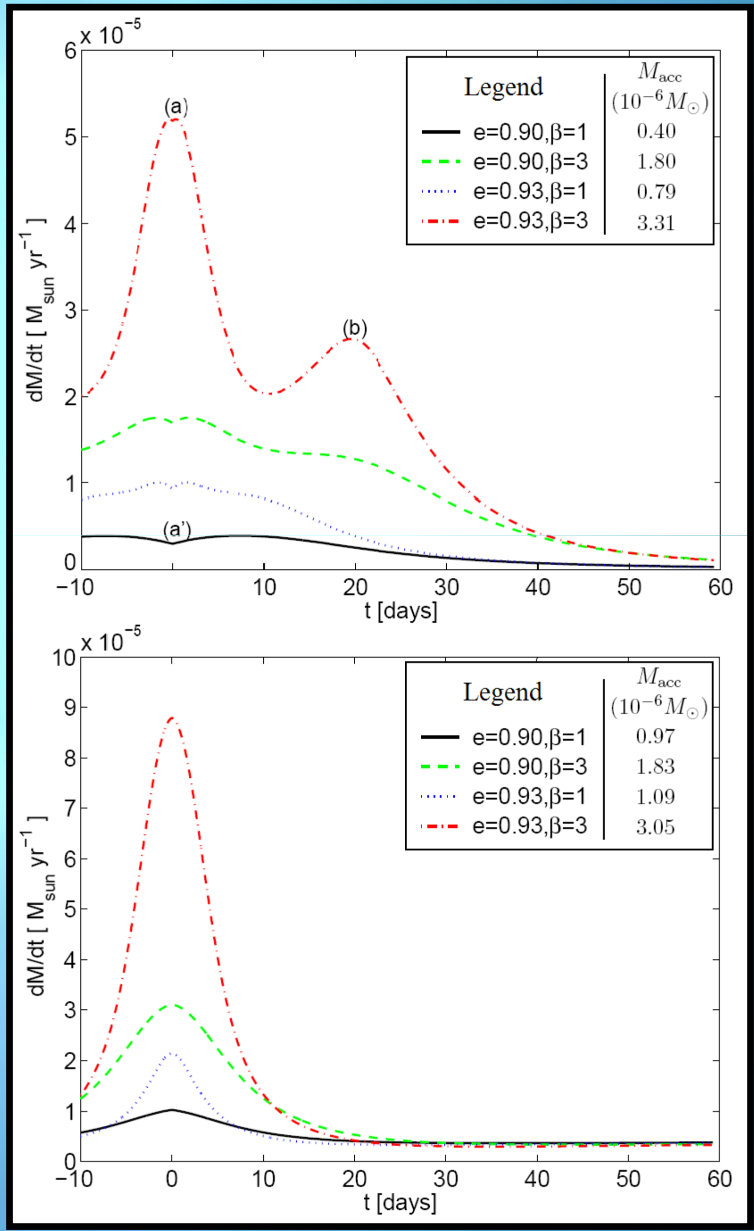
Modeling the Accretion

- To calculate the dependence of the primary's wind density on the azimuth angle and on the distance from the secondary, we slice the cross section into differential arcs. The accreted mass from each arc is calculated separately according to the density at that point, and it is added to the accreted mass.



Modeling the Accretion (cont.)

- The accretion process will be an hybrid of the BHL and the RLOF mass transfer processes. At the end of the accretion phase the accretion will be more of the BHL type.
- Over all, the total accreted mass of the belt is $0.4–3.3\times10^{-6}M_{\odot}$, with average value of M_{acc} ~ $2\times10^{-6}M_{\odot}$.



Removing the Accretion Belt

- The belt covers a fraction δ~0.5 of the secondary's stellar surface.
- The belt will be blown away in a time of:

$$t_{\rm belt} = \frac{M_{\rm acc}}{\delta \dot{M}_2} \simeq 5 \left(\frac{M_{\rm acc}}{2 \times 10^{-6} M_\odot} \right) \left(\frac{\dot{M}_2}{10^{-5} M_\odot {\rm yr}^{-1}} \right)^{-1} \left(\frac{\delta}{0.5} \right)^{-1} \text{ month}$$

- If the mass loss process starts ~60 days after the beginning of the event, the recovery then ends ~7 months after the event starts. We identify this duration with the recovery phase of η Car from the spectroscopic event.
- The accretion disk, or belt, will survive for weeks to months after the accretion ends. During that time the secondary will illuminate and ionize the polar directions much more than in the equatorial plane.

Summary

- We present the *Accretion Model* for the behavior of the supermassive binary system η Car close to periastron passages.
- The model assumes that for 10 weeks near periastron the secondary star accretes mass from the slow dense wind blown by the primary star.
- This Assumption is examined theoretically.
- The main findings are:
  1. Accretion is indeed likely to take place, with an accretion rate in the range $0.4\text{–}3.3\times10^{-6}M_{\odot}$
  2. This mass possesses enough angular momentum to form a thick disk, or a belt, around the secondary.
  3. The viscous time is too long for the establishment of equilibrium, and the belt must be dissipated as its mass is being blown along with the reestablishment of the secondary wind.
  4. This processes requires about half a year, which we identify with the recovery phase of η Car from the spectroscopic event.