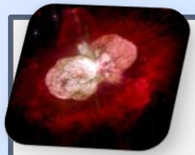

Accretion onto the Companion of Eta Carinae

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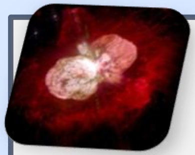
IAU XXVII General Assembly
Joint Discussion 13:
Eta Carinae in the Context of the Most Massive Stars
Rio de Janeiro, 13-14 August 2009



The Purpose of the *Accretion Model*

- The Accretion Model was introduced to explain observations along the entire orbit, mainly those close around the spectroscopic event.
- We use the standard parameters of the system and show that near periastron the secondary is very likely to accrete mass from the slow dense wind blown by the primary.
- The condition for accretion (that the accretion radius is large) lasts for several weeks. The exact duration of the accretion phase is sensitive to the winds' properties that can vary from cycle to cycle.

The Spectroscopic Event

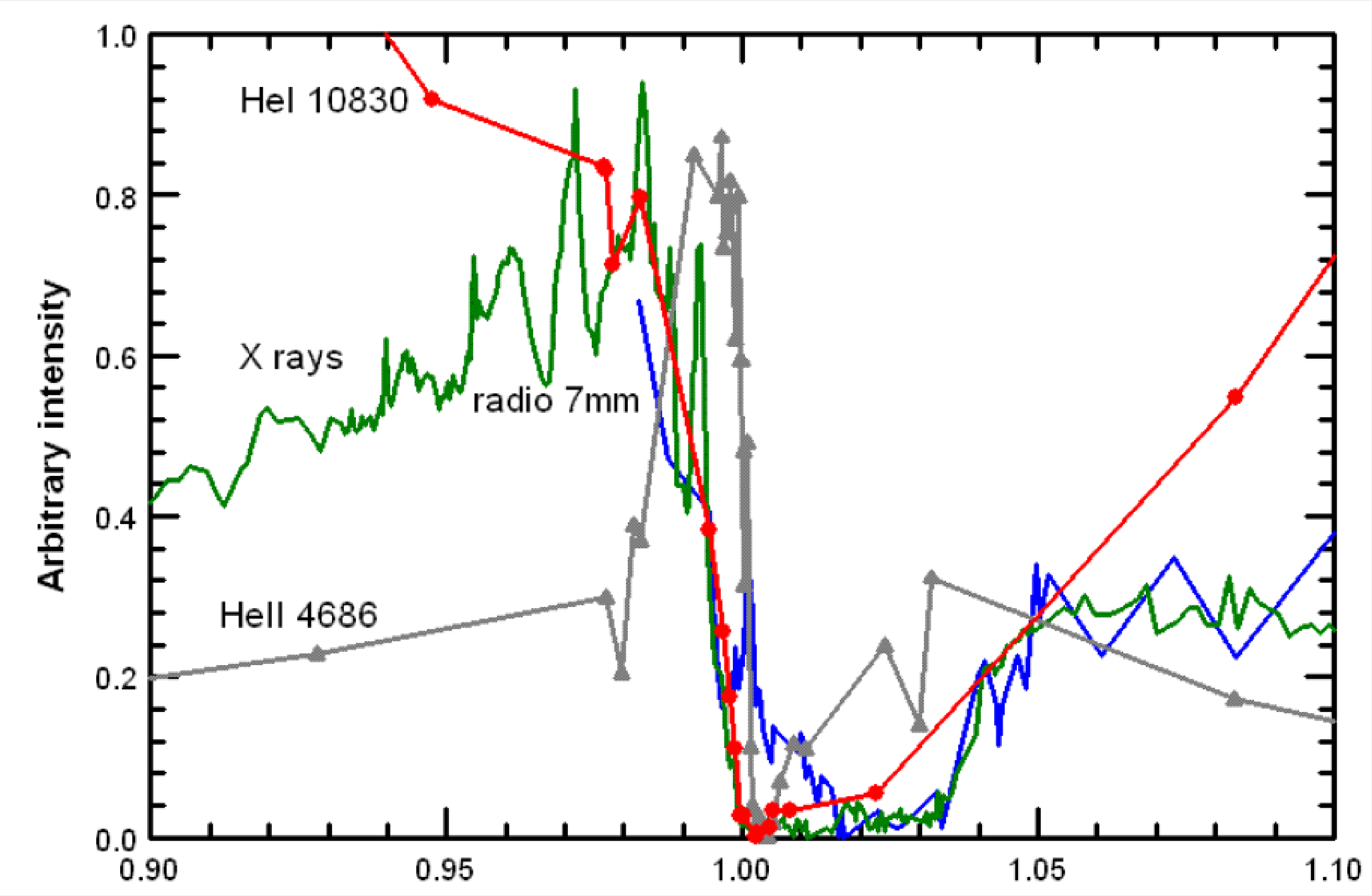
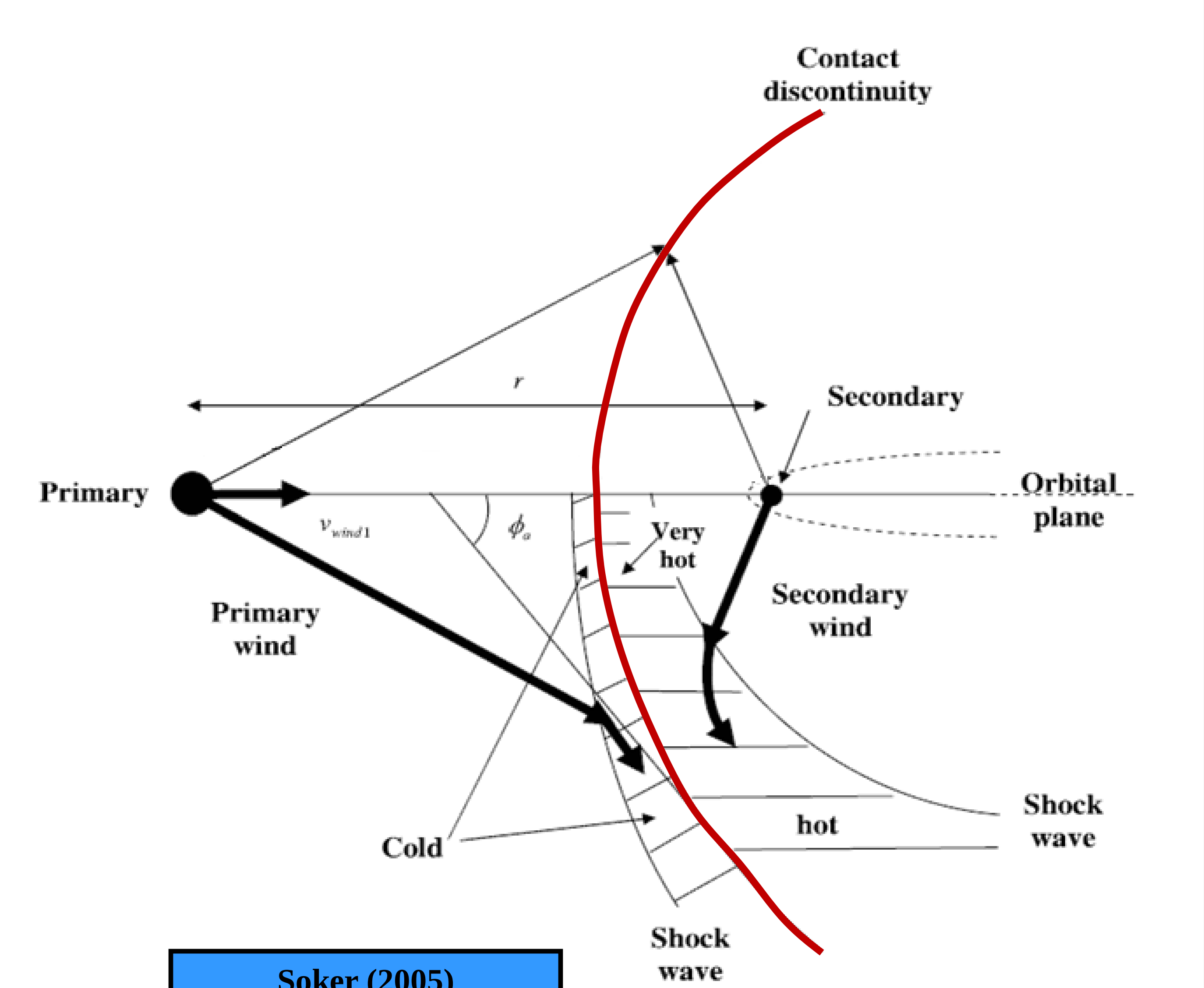


Figure by A. Damineli

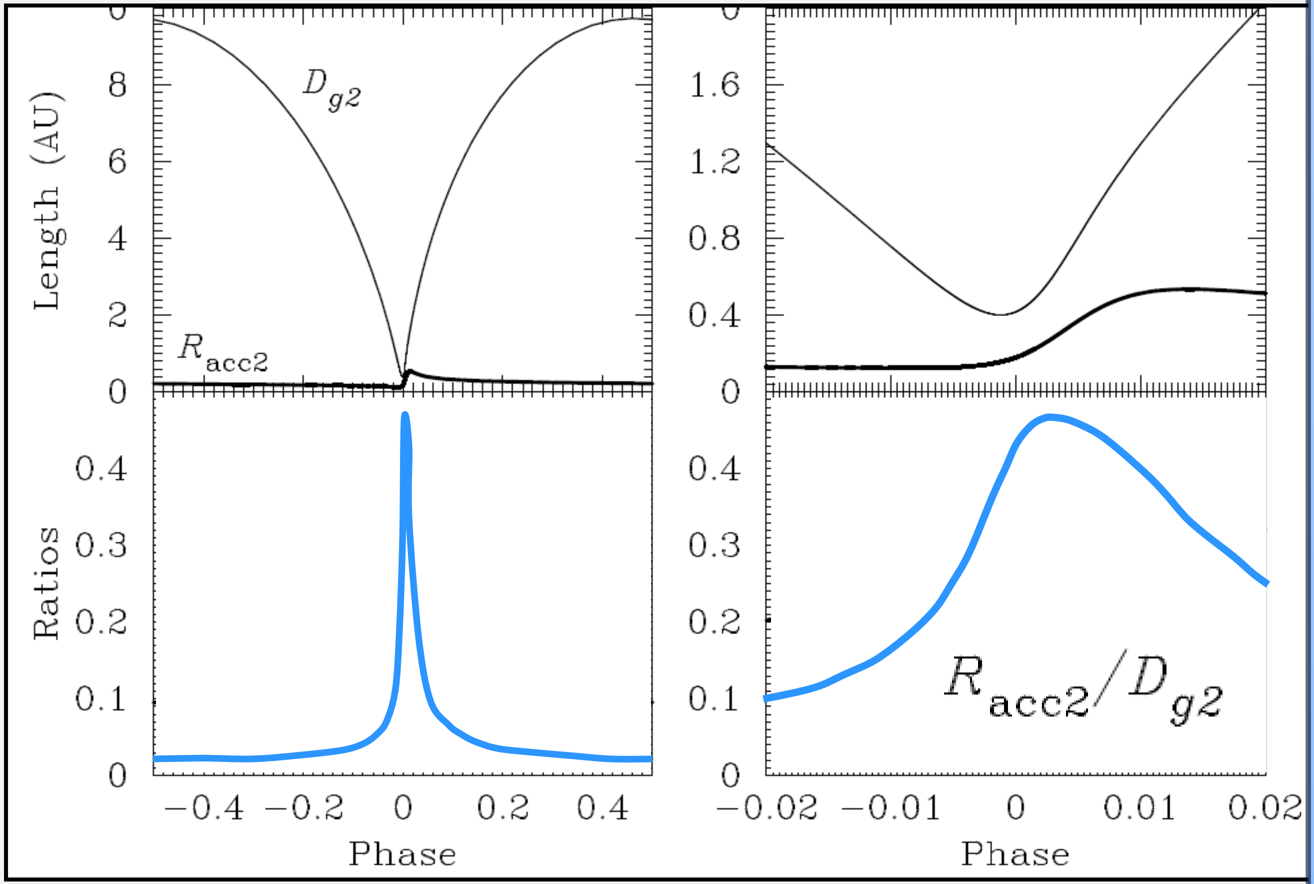
Colliding Winds Structure



Soker (2005)

Why is accretion favorable close to periastron passage?

- The ratio R_{acc2}/D_{g2} is a measure to the influence of the secondary gravity on the primary wind.
- Along most of the orbit the $R_{acc2} \ll D_{g2}$
- Close to periastron $R_{acc2}/D_{g2} \sim 0.5$.

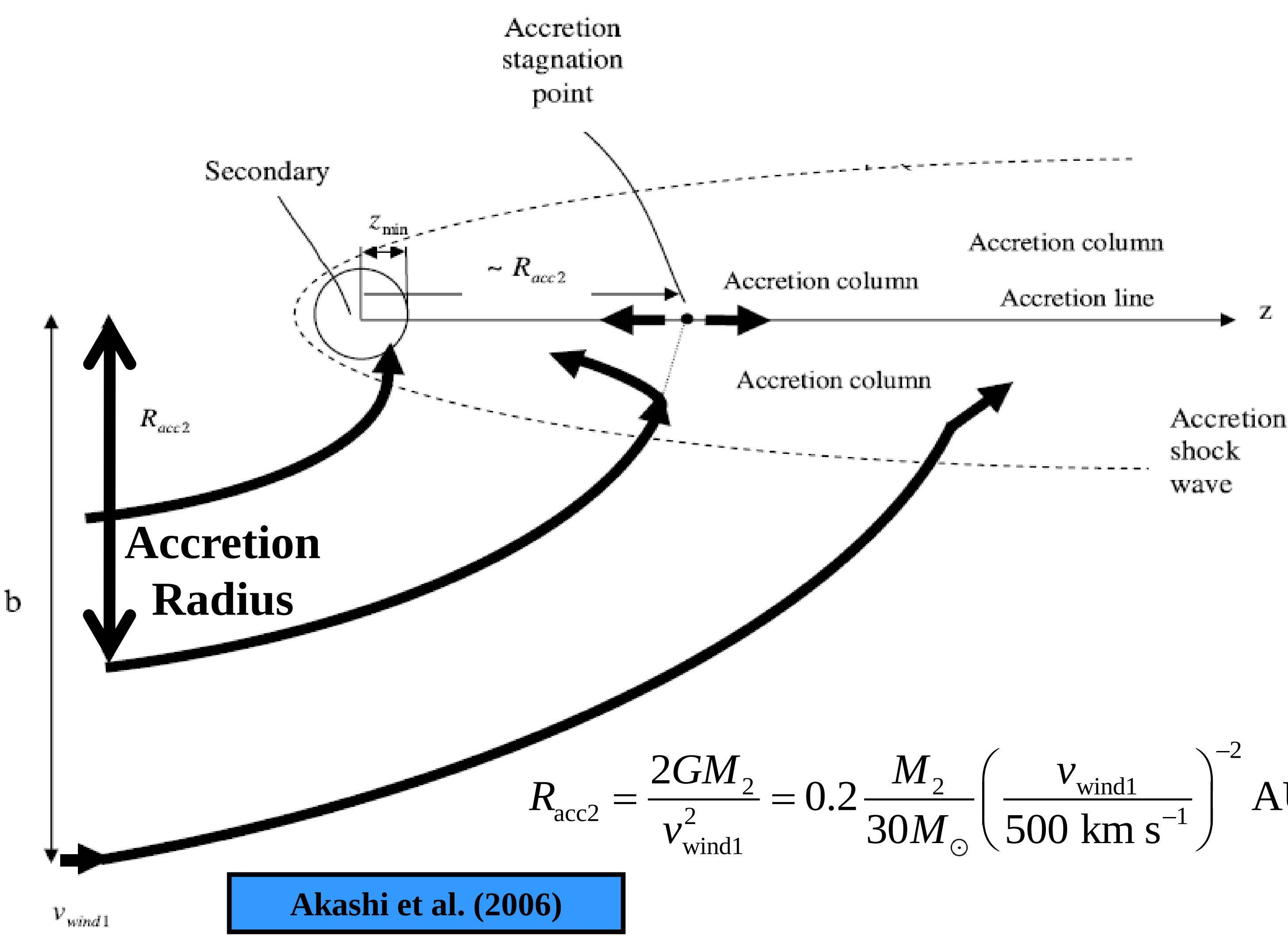


- R_{acc2} : the secondary accretion radius
- D_{g2} : distance from the stagnation point to the secondary

The *Accretion Model* (cont.)

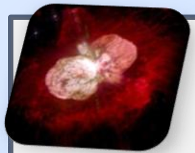
- The accreted mass **shuts down the secondary wind** for several weeks, depending on winds' properties.
- **Bondi Hoyle accretion** onto the secondary (Soker 2005a).
- **X-ray luminosity at minimum**, due to the collapse of the shocked secondary wind which is the source of X-ray emission (Akashi et al. 2006).
- **Disappearance of He I visible lines** due to absorption of ionizing flux by the accreted material, which also causes lowering of secondary's effective temperature (Soker 2007).
- **Near-IR decline** due to the pause in creating hot dust in the downstream of the conical shell (Kashi & Soker 2008a).
- An **accretion belt** around the secondary (Kashi & Soker 2009a).

Bondi – Hoyle Accretion



$$R_{\mathrm{acc2}} = \frac{2GM_2}{v_{\mathrm{wind1}}^2} = 0.2\frac{M_2}{30M_\odot}\left(\frac{v_{\mathrm{wind1}}}{500\ \mathrm{km\ s^{-1}}}\right)^{-2}\ \mathrm{AU}$$

Akashi et al. (2006)



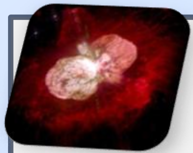
What is the Nature of the Accretion Disk?

- Periastron passage duration is ~6 days.
- Viscosity time of the disk is

$$t_{\mathrm{visc}} = \frac{R^2}{\nu} = \frac{R^2}{\alpha C_s H} \simeq t_{\mathrm{Kep}} \left(\frac{R}{H}\right)^2 \frac{1}{2\pi\alpha} = 30 \left(\frac{R}{10H}\right)^2 \left(\frac{R_2}{20R_\odot}\right)^{3/2} \left(\frac{M_2}{30M_\odot}\right)^{-1/2} \frac{1}{\alpha}\,\mathrm{days}$$

$$t_{\mathrm{pp}} \ll t_{\mathrm{visc}}$$

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



Modeling the Accretion

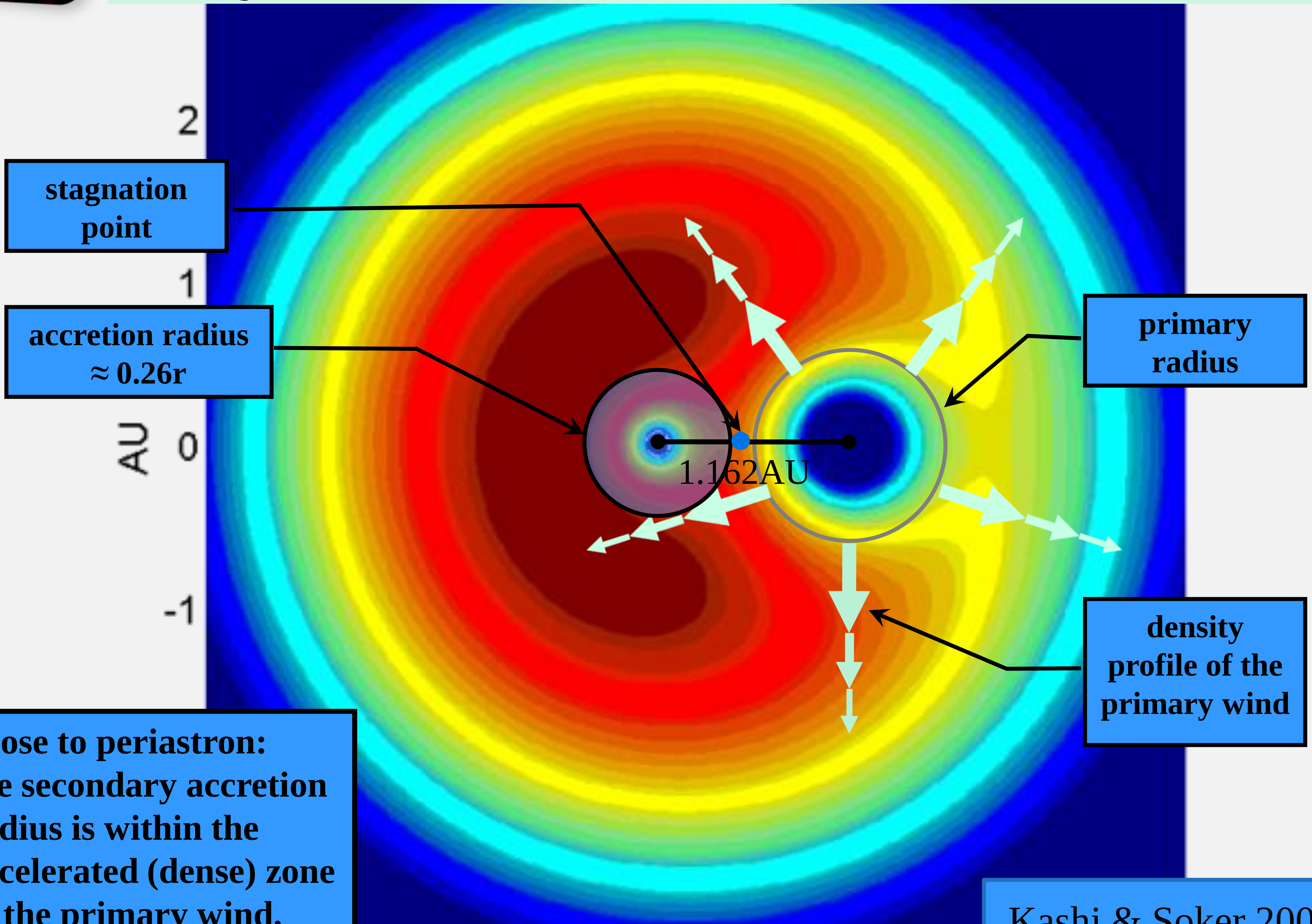
- The effective accretion radius of the secondary depends on several parameters, in particular on the orbital separation r(θ). Since the accretion radius is very close to the primary, the primary's wind acceleration zone is taken into account as a β-model with two extreme values:1 and 3.

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

- 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:

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

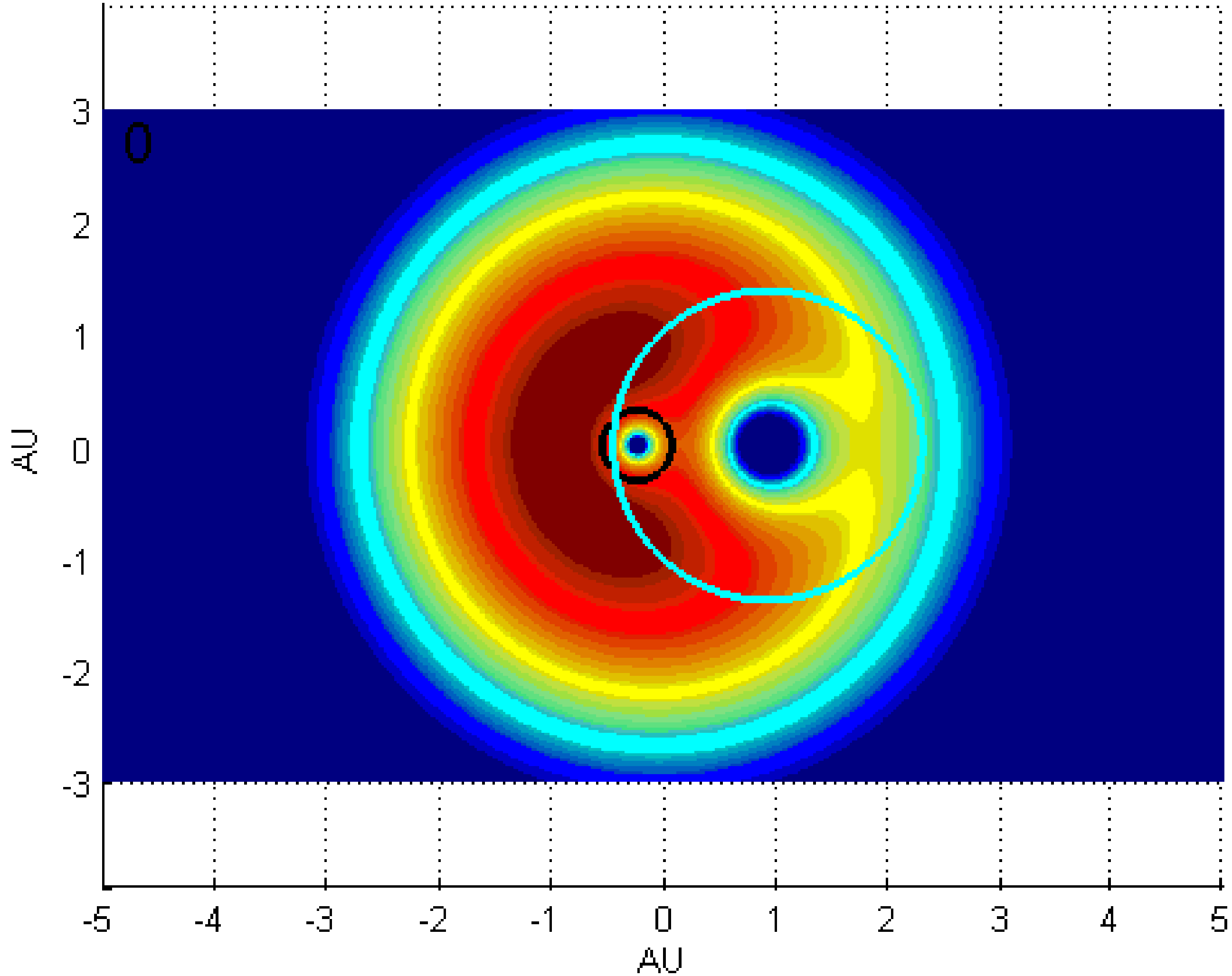
Why is Accretion Favorable close to PP?



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

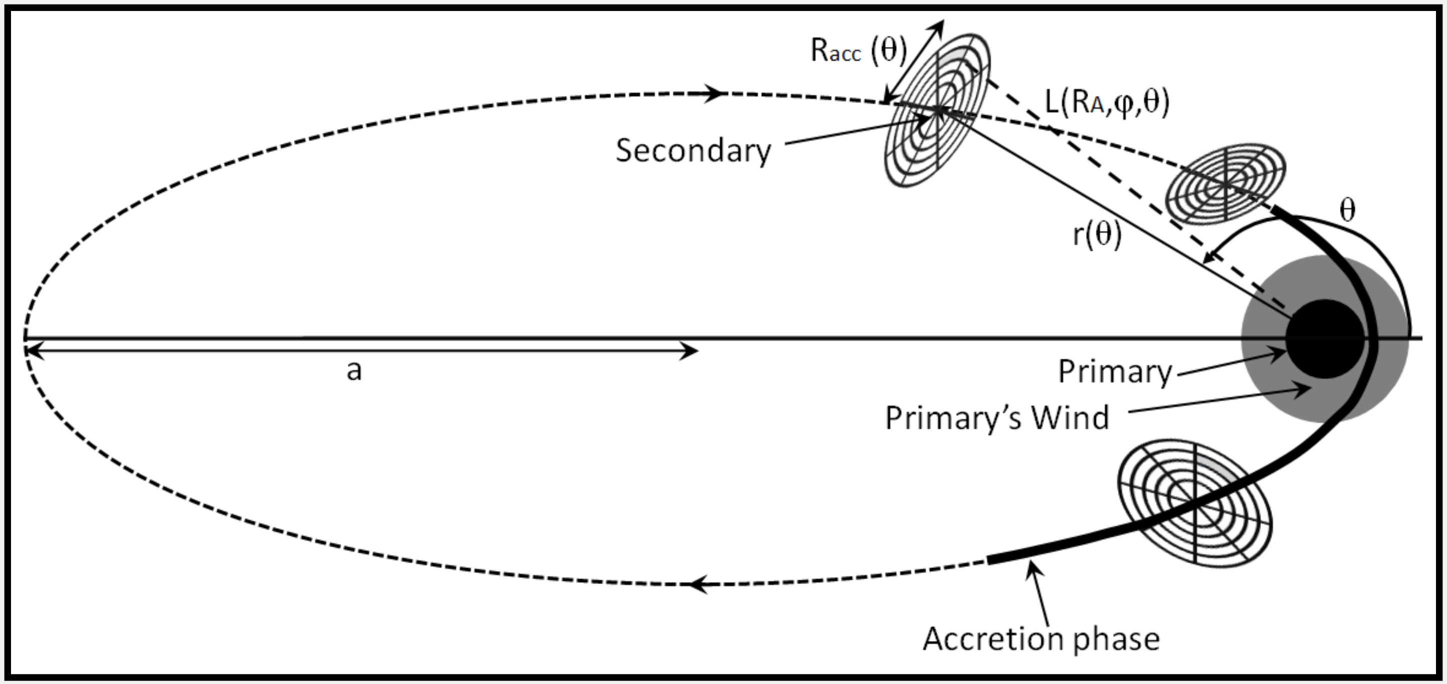
Kashi & Soker 2009a

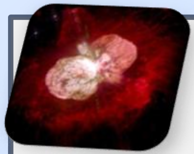
Calculation: Accretion Onto the Secondary



Modeling the Accretion (cont.)

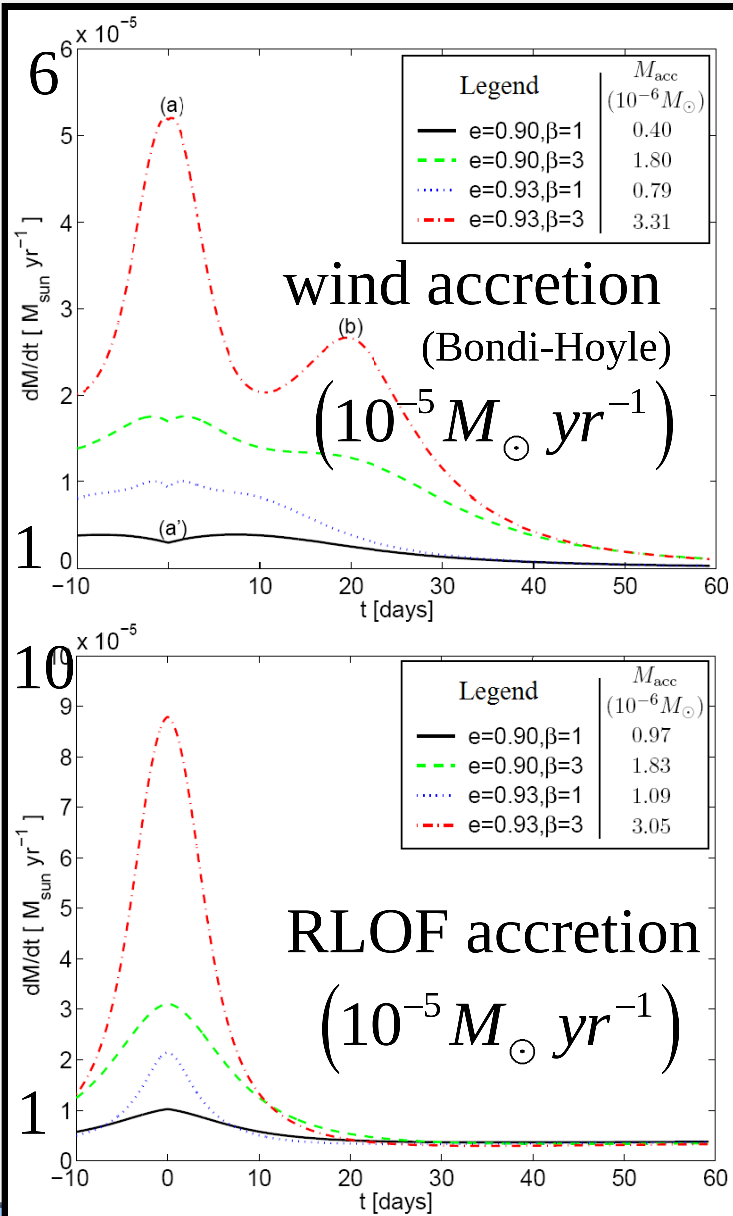
- To calculate the dependence of the primary wind density on the azimuth angle and on the distance from the secondary, we slice the cross section into differential arcs.
- The accreted mass from each arc is calculated separately according to the density at that point, and it is added to the accreted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





Modeling the Accretion (cont.)

- Full RLOF-like accretion cannot occur because the primary spin and orbital motion are not synchronized near periastron passage.
- Therefore, for ~10 days very close to periastron passage, 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, for the standard wind parameters the total accreted mass is $0.4–3.3\times10^{-6}M_\odot$, with average value of $\mathbf{M_{acc} \sim 2\times10^{-6}M_\odot}$.



Removing the Belt

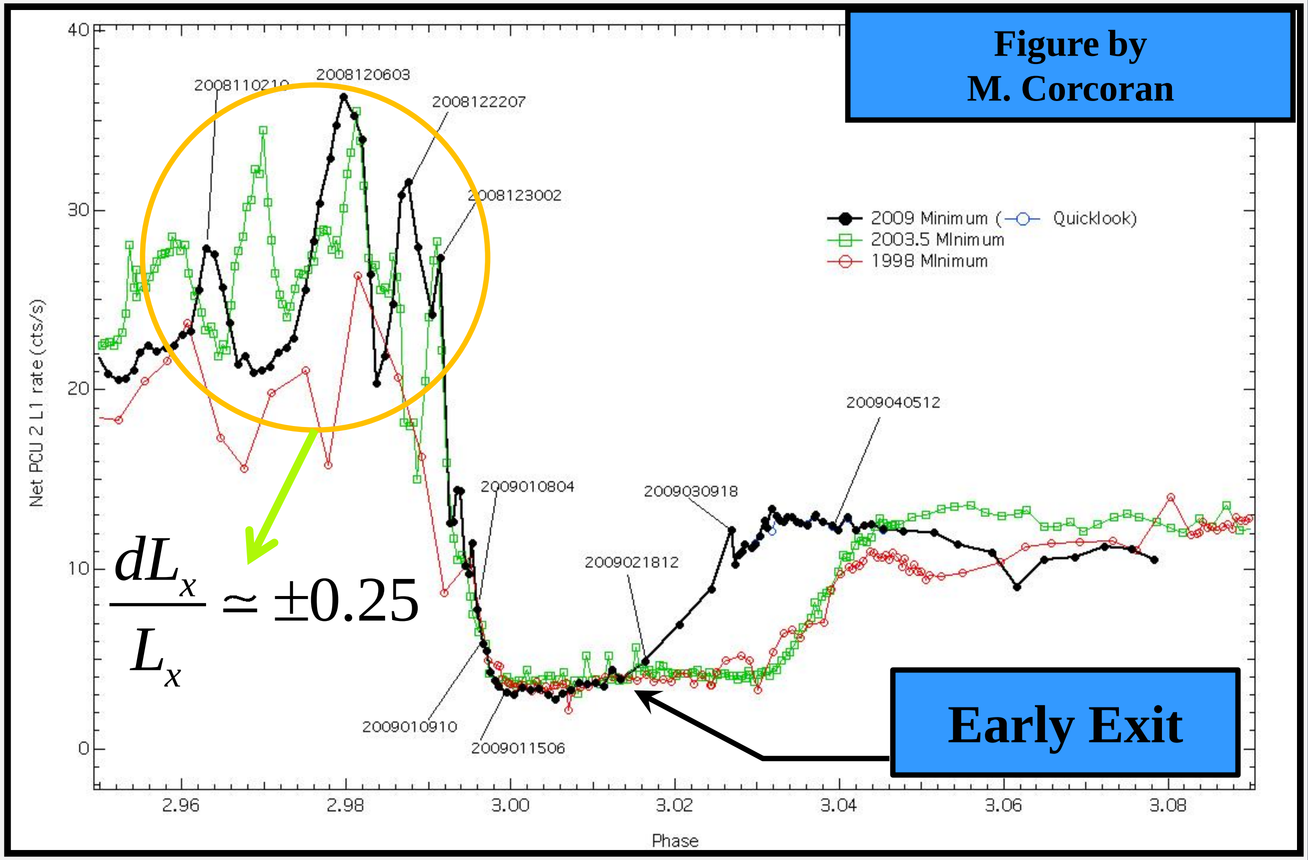
- Because of the long viscosity time and the high mass loss rate, this belt is destroyed mainly by mass loss rather than accretion on the secondary.
- We assume that the mass loss rate per unit solid angle from the belt is as that from the secondary.
- The belt covers a fraction δ of the secondary's stellar surface (for example, if this belt extends from the equator to latitudes ±30°,then δ = 0.5). The belt will be blown away during a time:

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

- If the mass loss process starts ~60 days after the event starts, then the recovery ends ~7 months after the event starts. We identify this duration with the recovery phase of η Car from the spectroscopic event.

The Early Exit from the 2009 Minimum

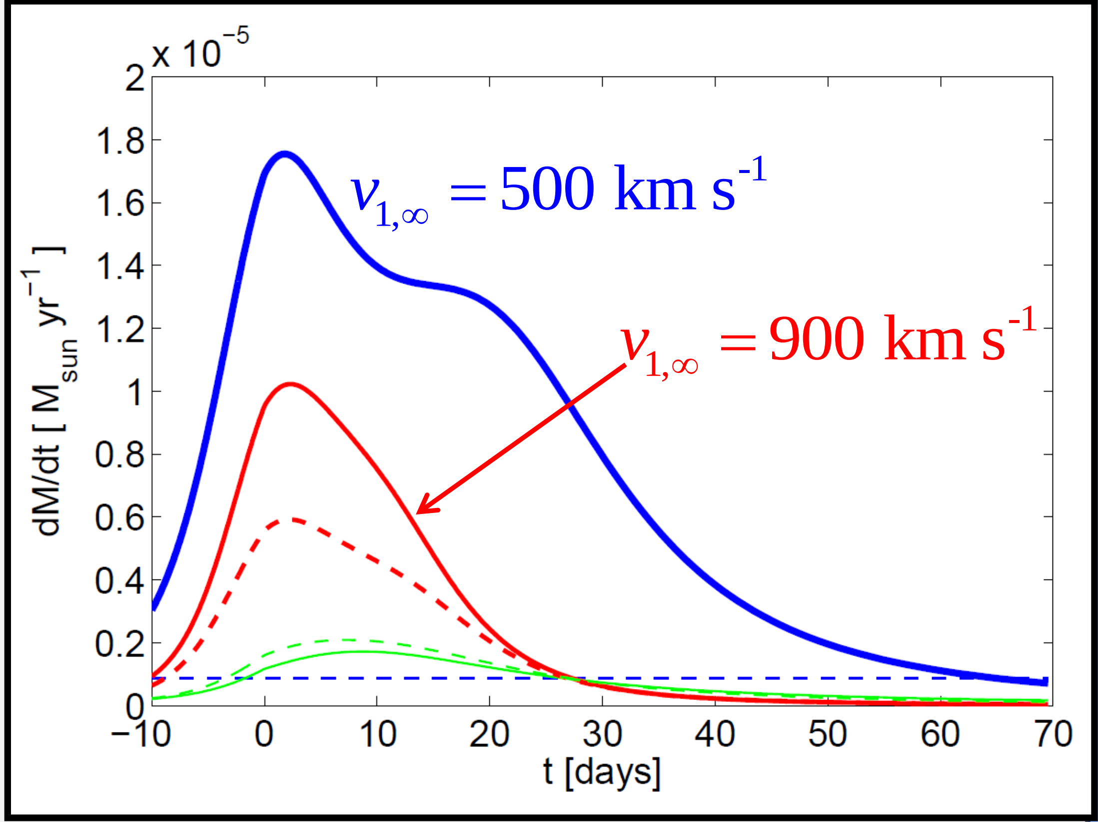
- Early exit from the 2009 X-ray minimum after four weeks, instead of ten weeks as in the two previous minima.



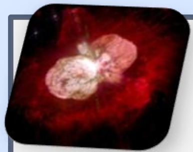
$$\frac{dL_x}{L_x} = \frac{1}{2(1+\zeta)} \frac{d\dot{p}_1}{\dot{p}_1} \xrightarrow{\zeta \equiv \left(\frac{\dot{M}_2 v_2}{\dot{M}_1 v_1}\right)^{1/2} \simeq 0.45} \frac{d\dot{p}_1}{\dot{p}_1} \simeq \pm 0.7 \longrightarrow v_{1,\infty} = 300 - 850 \text{ km s}^{-1}$$

The Early Exit from the 2009 Minimum (cont.)

- We attribute the early exit in the last cycle to the primary wind that we assume was somewhat faster and of lower mass loss rate than during the two previous X-ray minima.



- ➔ This results in a much lower mass accretion rate during the X-ray minimum.



The Early Exit from the 2009 Minimum (cont.)

- The changes which occurred near periastron passage, are most likely due to the strong tidal interaction.
- Most likely, the tidal interaction amplified a small internal change in the wind properties, e.g., as might results from magnetic activity.
- Using fluctuations in mass loss and wind velocity that are within the range deduced from fluctuations in the X-ray flux outside the minimum, we can account for the short duration of the last X-ray minimum.

Summary

- The main findings are:
  - The secondary accretes ~ $2\times10^{-6}M_{\odot}$ close to periastron.
  - This mass possesses enough angular momentum to form a geometrically thick disk, or a belt, around the secondary.
  - The viscous time is too long for the establishment of equilibrium, and the belt must be dissipated as its mass is being blown in the reestablished secondary wind.
  - This processes requires about half a year, which we identify with the recovery phase of η Car from the spectroscopic event.
- Mass transfer is an important process in the evolution of close massive binaries.

  The high luminosity and ejected mass of many eruptive events can be explained by mass transfer, e.g., the Great Eruption of Eta Carinae.