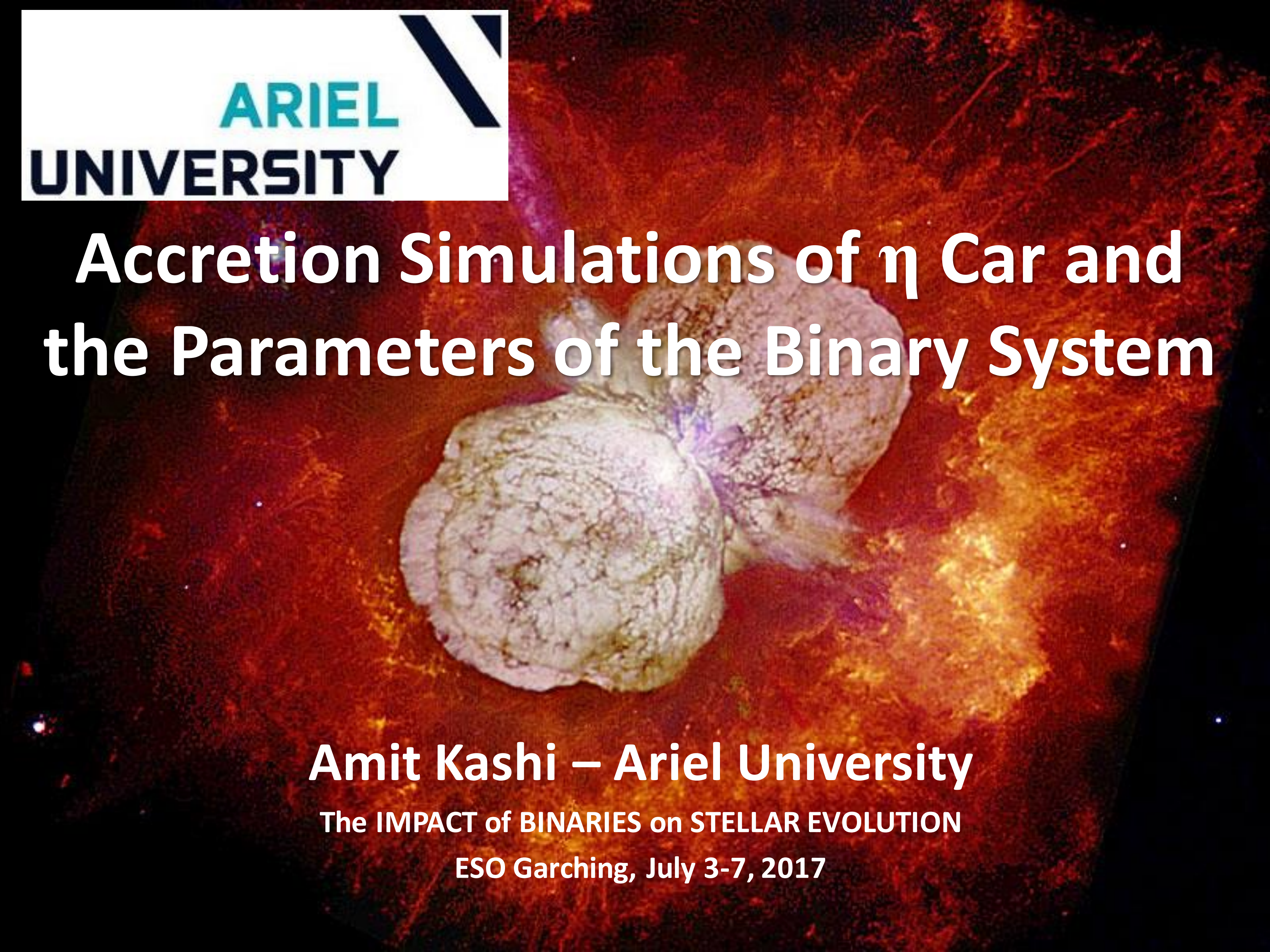


Accretion Simulations of η Car and the Parameters of the Binary System

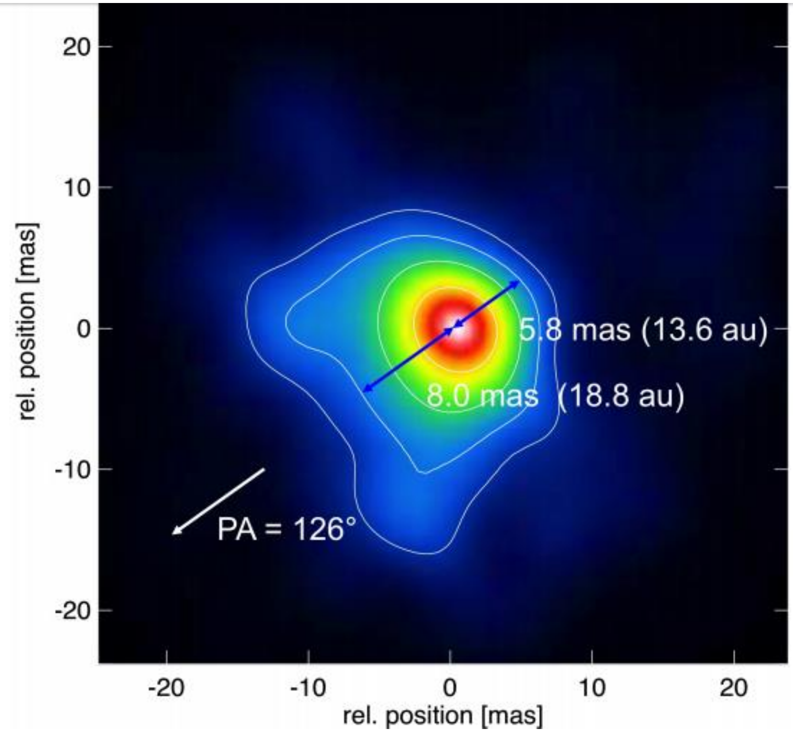
Amit Kashi – Ariel University

The IMPACT of BINARIES on STELLAR EVOLUTION

ESO Garching, July 3-7, 2017

η Car

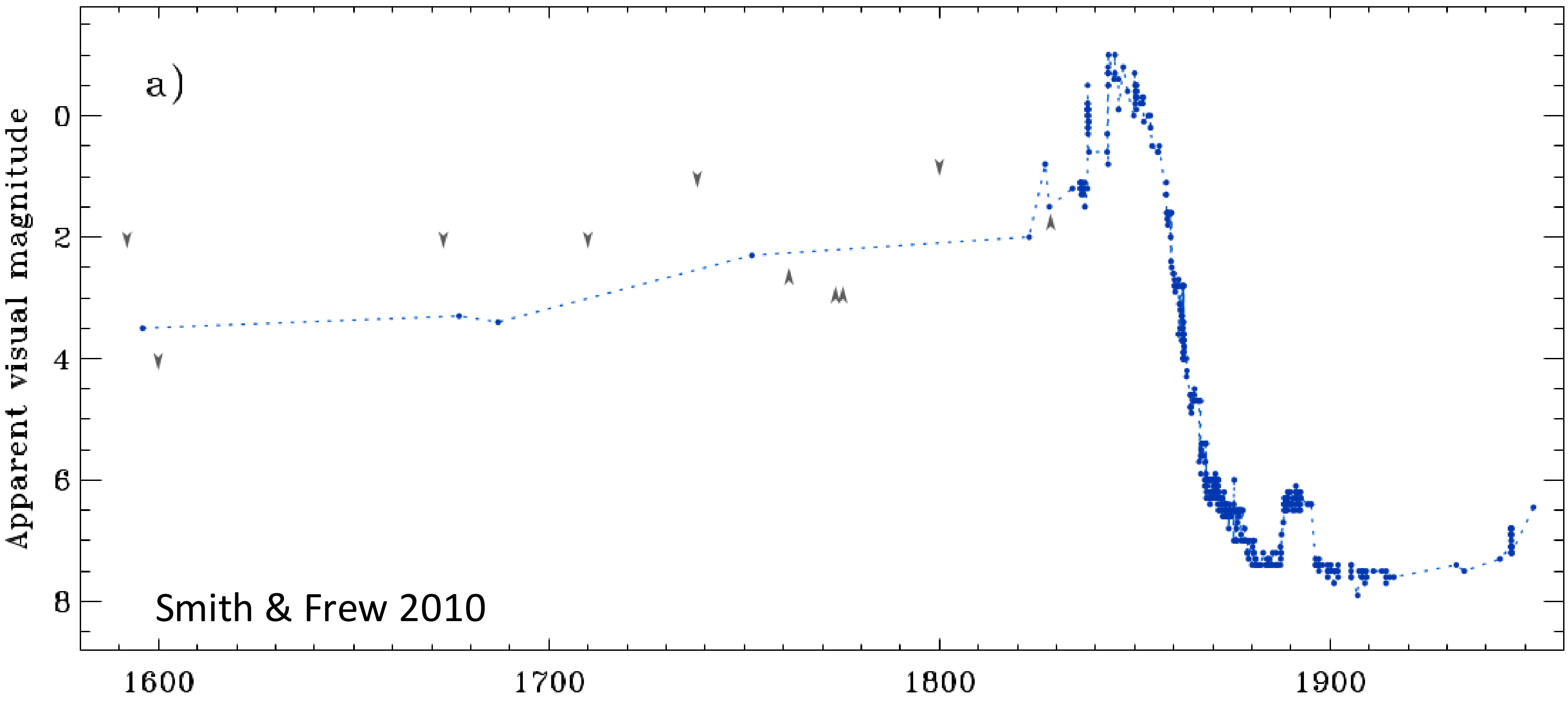
- A very massive binary system: $M_1 \simeq 90-170 M_{\odot}$
  $M_2 \simeq 30-80 M_{\odot}$
- Luminosity: $L \simeq 5\times10^{6} L_{\odot}$
- Period: $P \simeq 5.54 yr$
- Eccentricity $e \approx 0.85-0.9$
- Both stars blow winds that collide and form shocks.
- Spectroscopic event close to periastron passage.



η Car image of the Brγ line at velocity of −277 km/s (VLTI-AMBER; Weigelt+ 2016)

The giant eruptions of η Car

- The primary is recovering from giant eruptions in the 19 century.
- Secondary may have played a role in triggering the eruption.



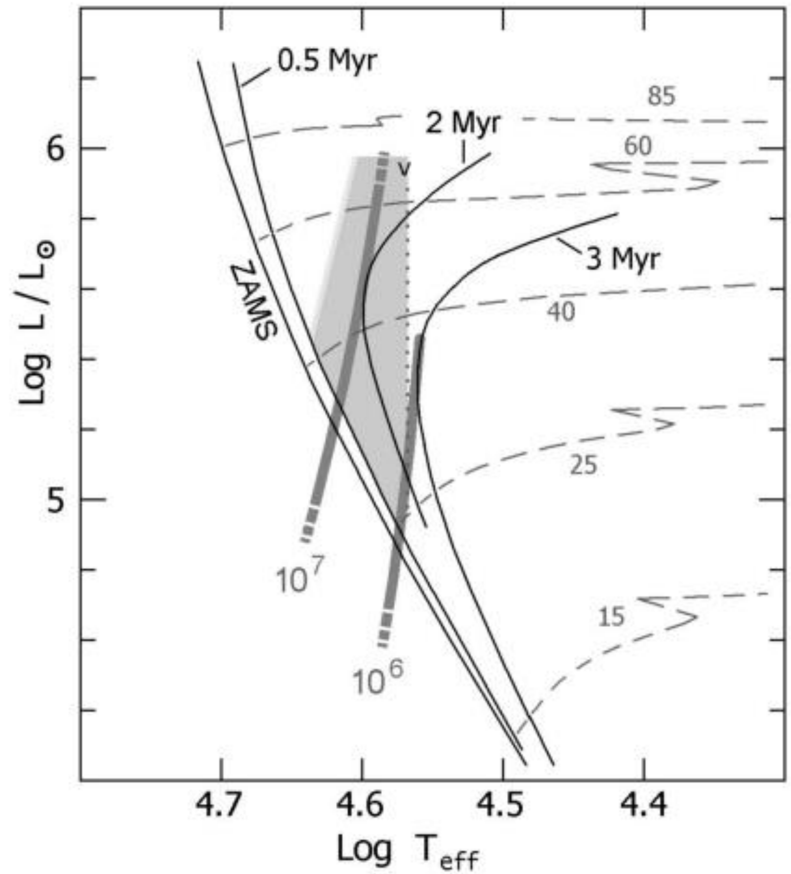
The binary system η Car (today)

- Mass-loss rate of the primary:

$$\dot{M}_1 = 2.5\times10^{-4} - 10^{-3} M_\odot \text{ yr}^{-1}$$

(e.g., Smith+ 2003, Davidson & Hymphrey 2012, Groh 2012, Madura+ 2012).

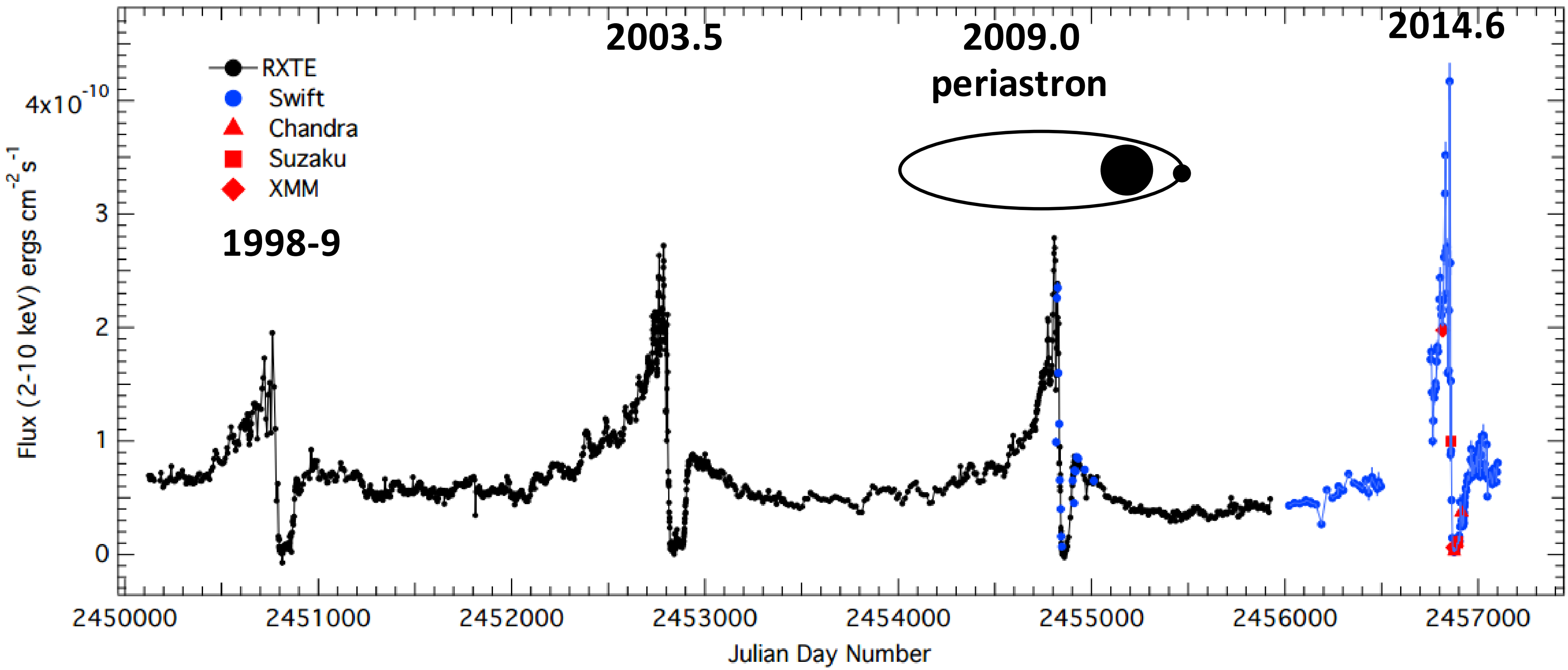
- The secondary:
  - Less massive
  - Smaller mass loss
  - It is the main source for ionizing photons
  - T=37000-41000K (Verner+ 2005; Teodoro+ 2008; Mehner+ 2010).



Likely positions for η Car's secondary star in the H-R diagram (Mehner et al. 2010)

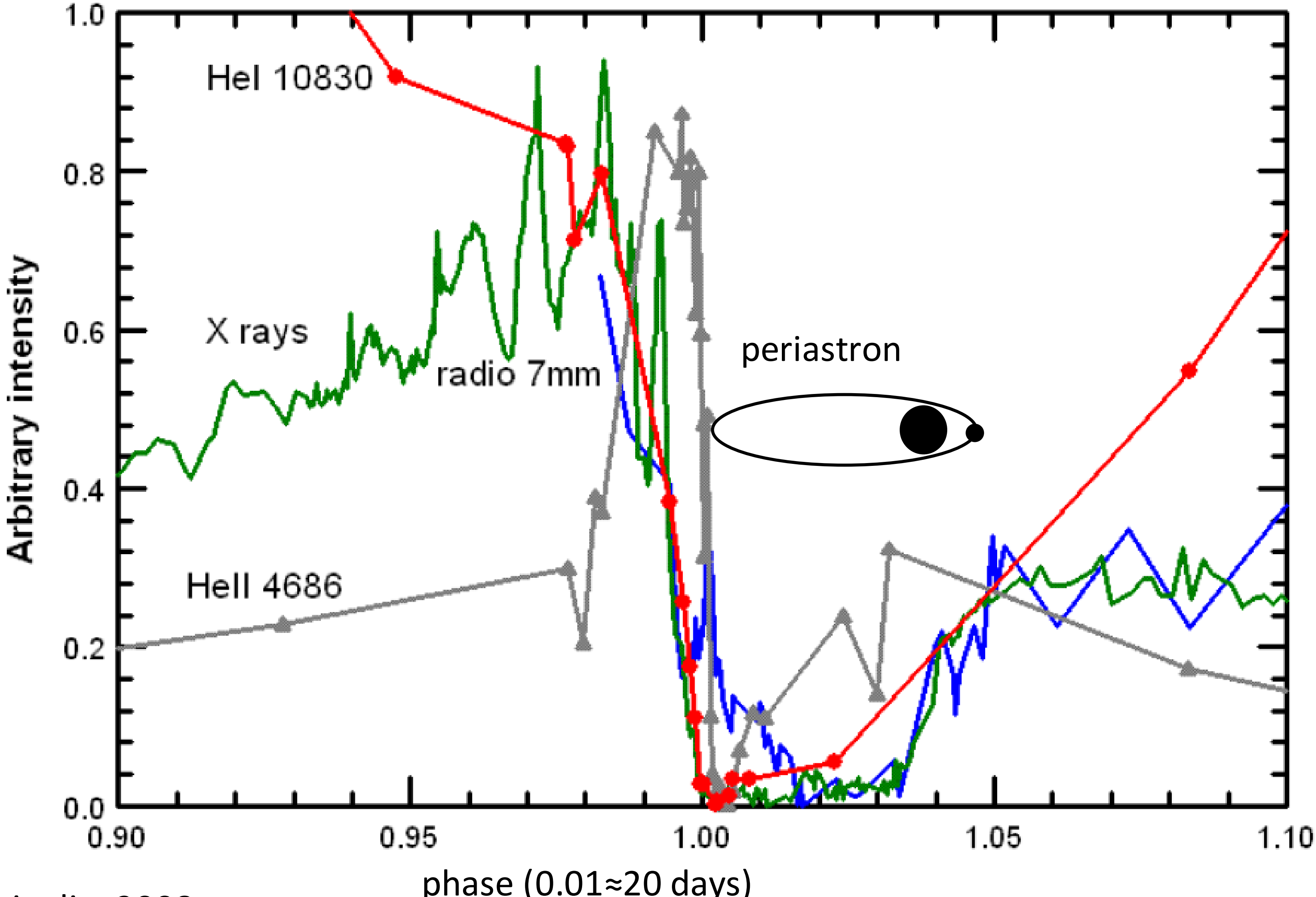
The X-ray Cycle

X-rays are produced in a bow shock due to the collision of the dense wind of the primary with the lower density, higher velocity wind of the secondary.



Corcoran et al. 2015

The Event



Damineli + 2008

Variation in line intensities indicates that there is far less UV radiation during the spectroscopic event.

The T ≃ 40000K secondary is the main ionization source.

during the event the secondary radiation must be obscured from the surrounding gas.

The effective temperature of the obscured secondary decreases from $T_{eff} \simeq 40000K$ to $T_{eff} < 25000K$ (Martin+ 2006).

η Car: Accretion model

(Soker 2003, 2005, 2007; Kashi & Soker 2009)

The hot secondary accretes dense primary wind close to periastron passage

It causes a reduction in the number of ionizing photons from the secondary

Spectroscopic event

Lower excitation lines

X-ray minimum

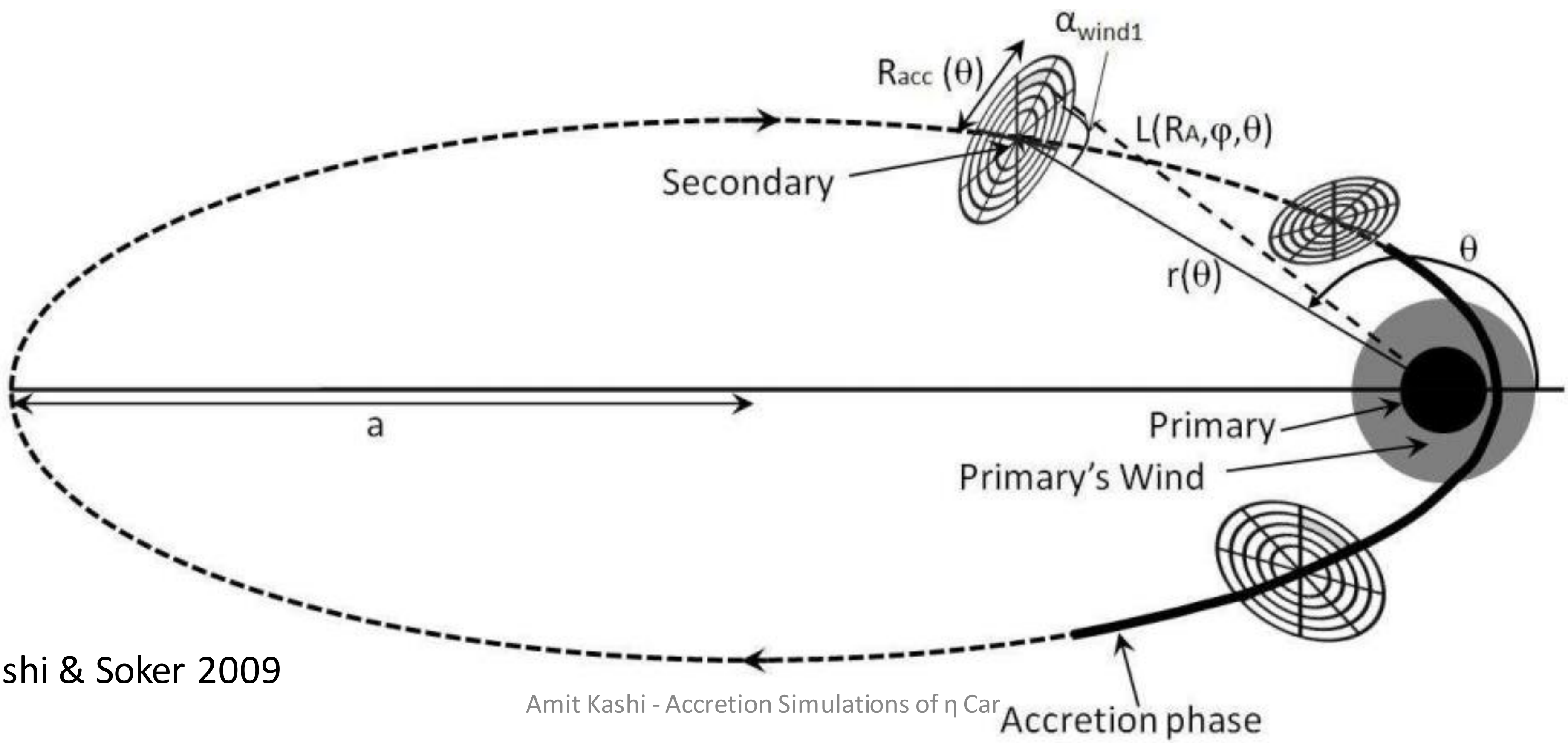
More massive stars (rest of parameters unchanged)

- Higher accretion rate
- Longer accretion

Better match observations of the event.

Our older analytic results

- Checked both Bondi-Hoyle and RLOF accretion rates
- Integration of accreted mass within the accretion radius over 70 days according to density distribution of primary wind.



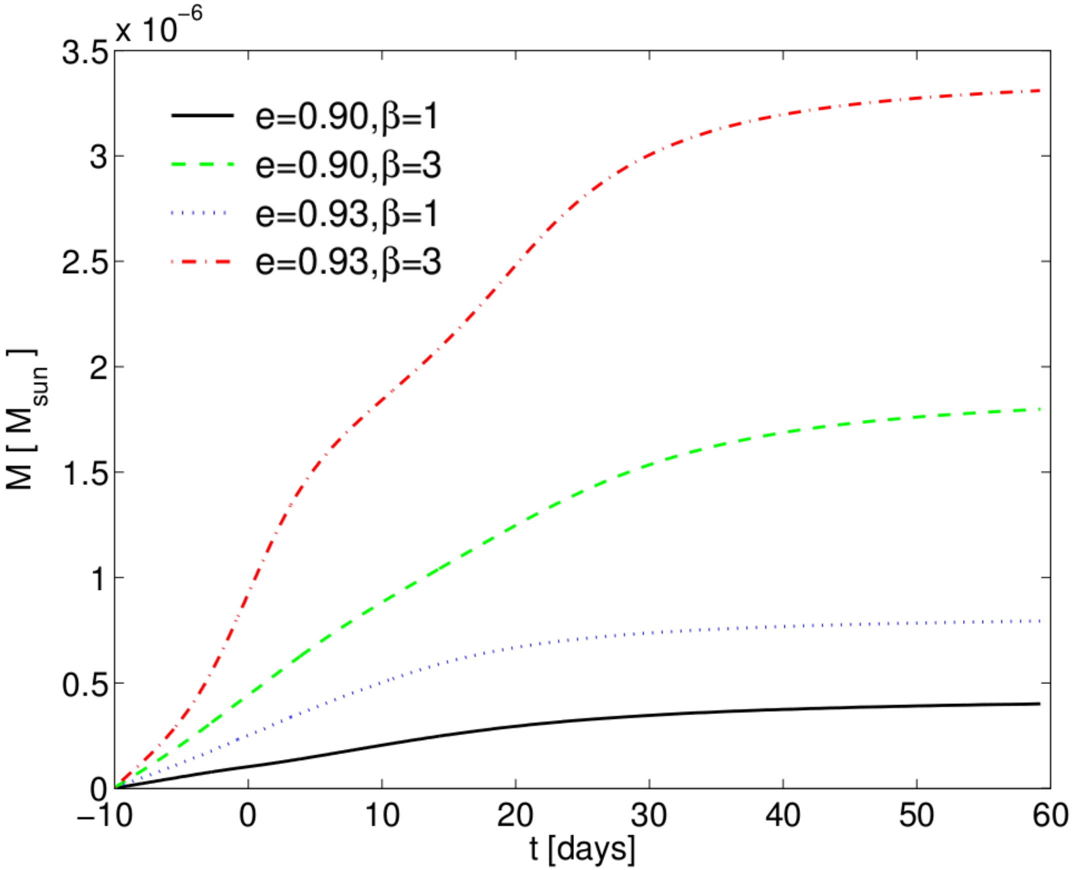
Kashi & Soker 2009

Our older analytic results, cont.

- We obtained accreted mass

$$M_{acc} \approx 0.5-3\times10^{-6}\,M_{\odot}$$

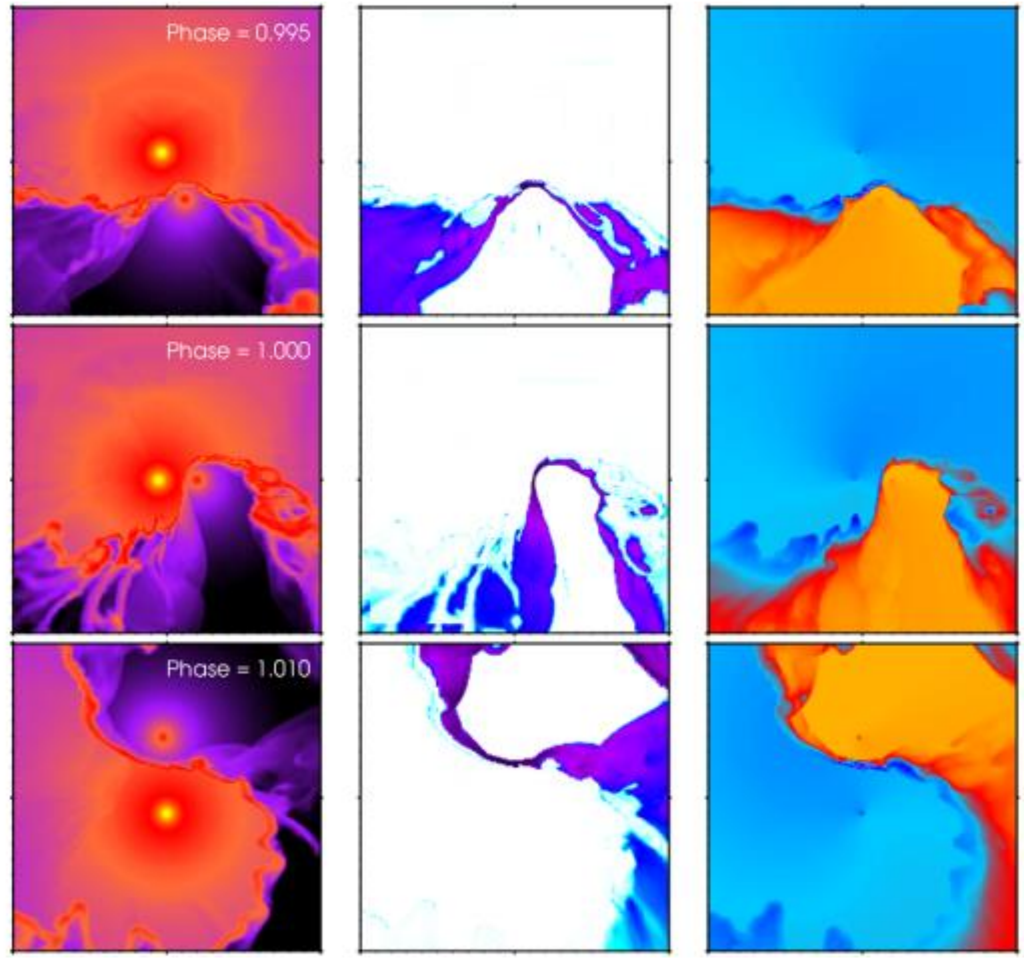
- Angular momentum calculations suggested a thick disk is formed, obscuring secondary light from equatorial directions.



Kashi & Soker 2009

Older simulations

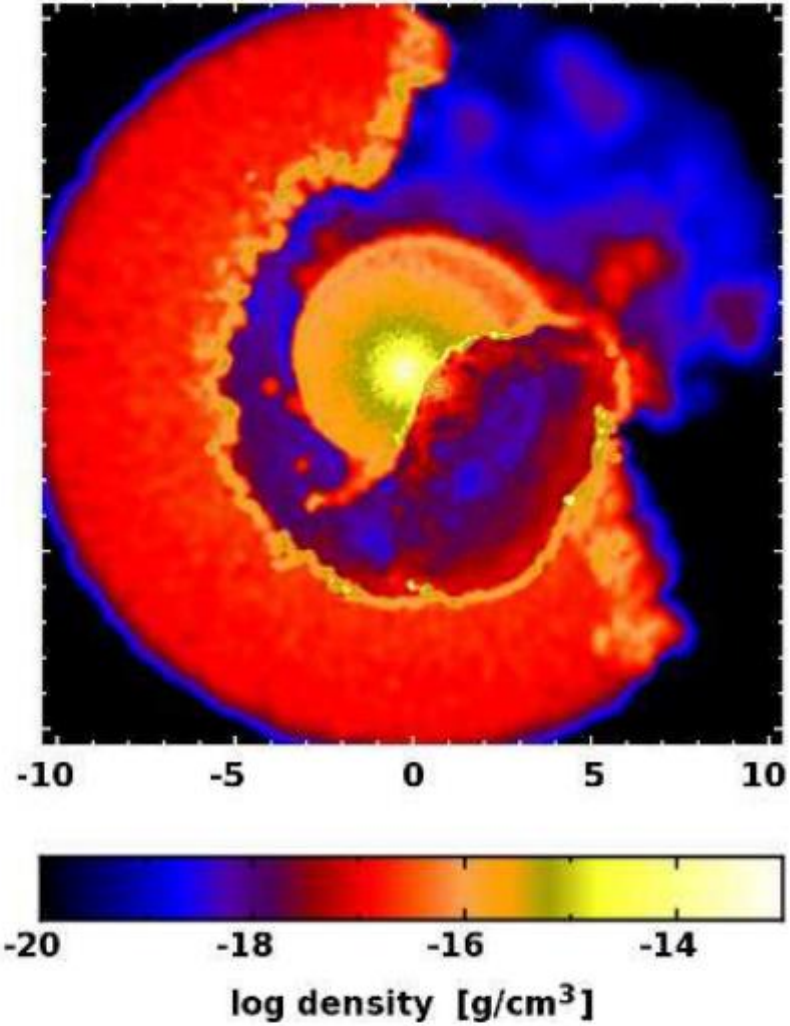
- Wind collision in a grid-based code.
- Secondary's gravity not included.
- X-ray minimum was not obtained by the simulation.
- Accretion was not obtained.
- Not surprising - models with no accretion fail to reproduce the X-ray minimum.

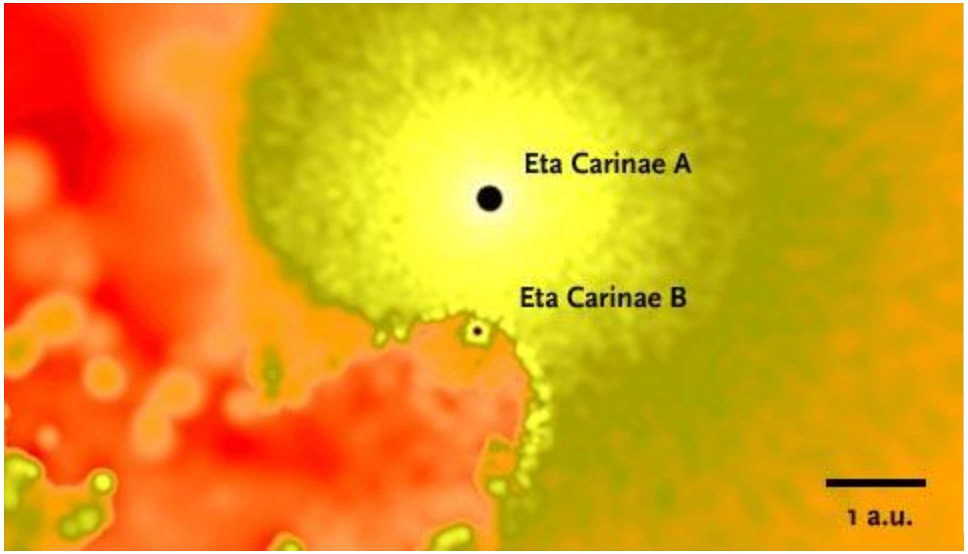


Parkin et al. 2006

Older simulations

- SPH simulations by Madura et al. (2013).
- The wind of the secondary curves around the wind of the primary.
- Colliding wind region remains
- No accretion.



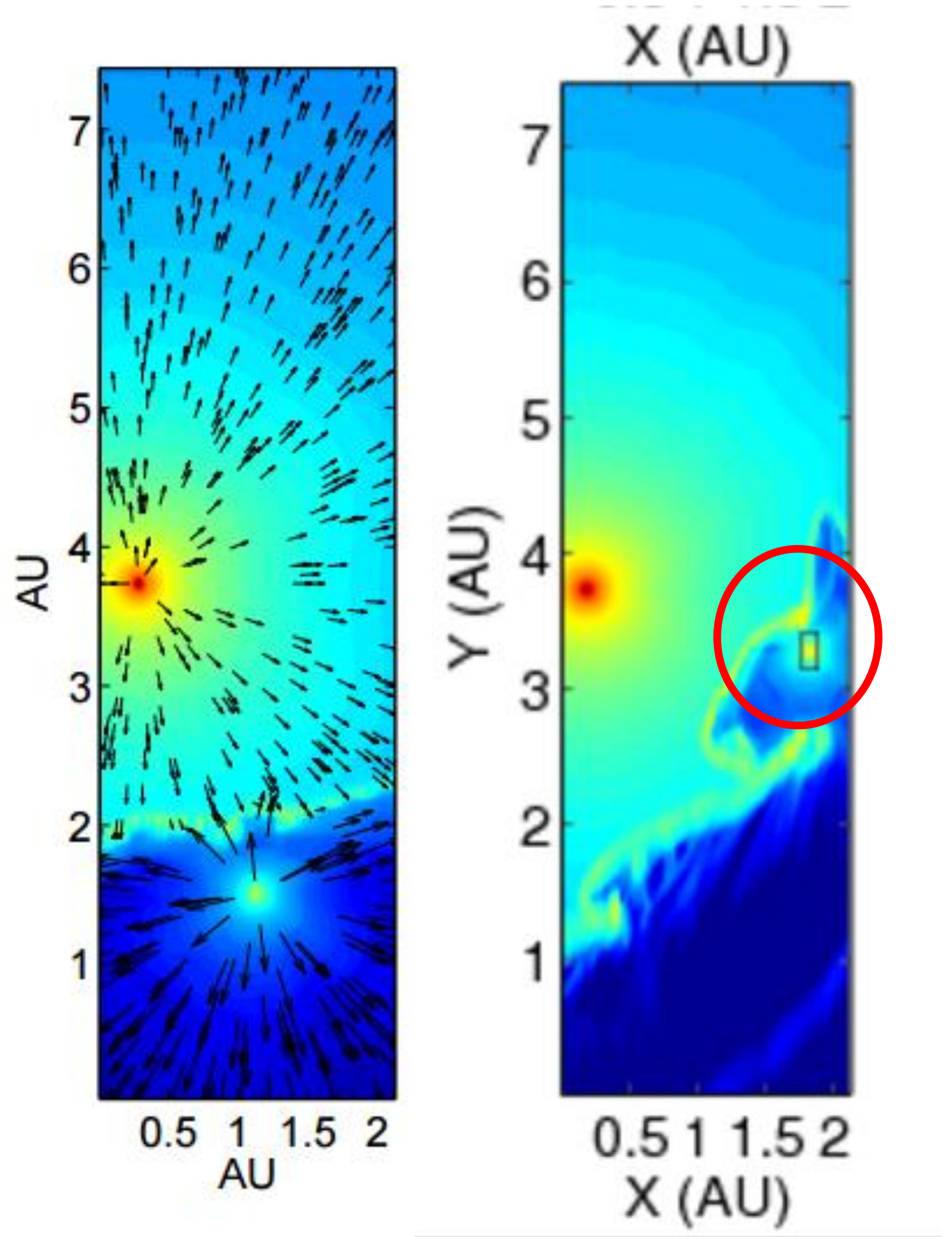


Madura et al 2013

A step forward

- Full 3D simulation by Akashi et al. (2013).
- Secondary gravity included, radiative cooling included.
- A filament of gas has reached the wind launching box around the secondary.

- ➔Secondary gravity is essential for accretion to occur.
- ➔Numerical viscosity is important.



Akashi, Kashi, Soker 2013

Onset of Simulation (Kashi 2017)

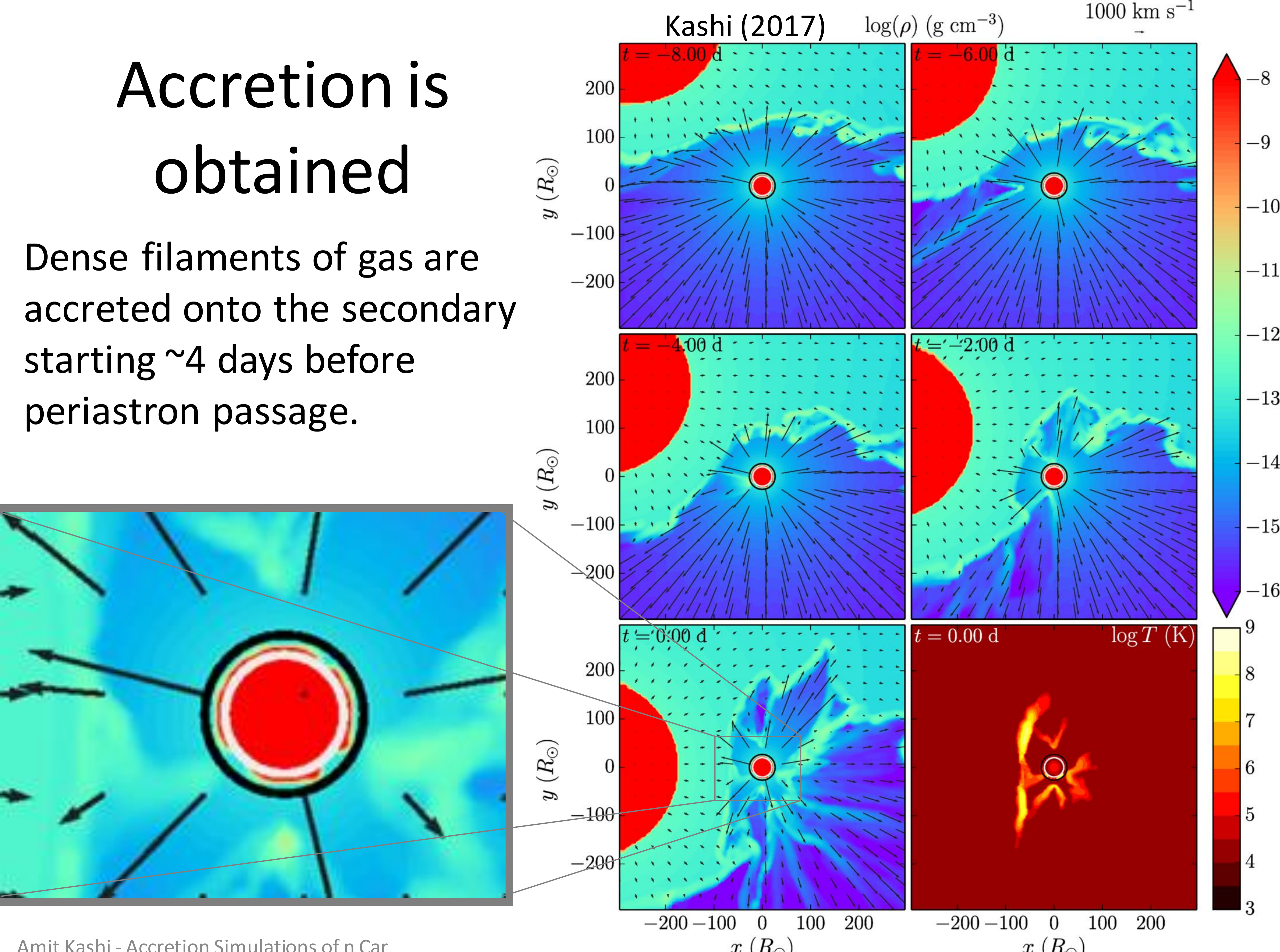
- We use version 4.3 of the hydrodynamic code FLASH.
- 3D Cartesian grid : (x, y, z) = ±8 AU
- Our initial conditions are set 50 days before periastron.
- We place the secondary in the center of the grid and send the primary on a Keplerian orbit with eccentricity e = 0.9.
- 5 levels of refinement with better resolution closer to the center ($\simeq$ 1.7 $R_\odot$).
- High resolution at the wind collision region – allows to follow hydrodynamic instabilities.

Physics included in the new simulations (Kashi 2017):

- Secondary gravity (important!).
- Self gravity (included but negligible).
- Radiative cooling (improved algorithm).
- Radiative transfer.
- Artificial viscosity (important for instabilities).
- Response of the secondary wind to accreted mass.

Accretion is obtained

Dense filaments of gas are accreted onto the secondary starting ~4 days before periastron passage.

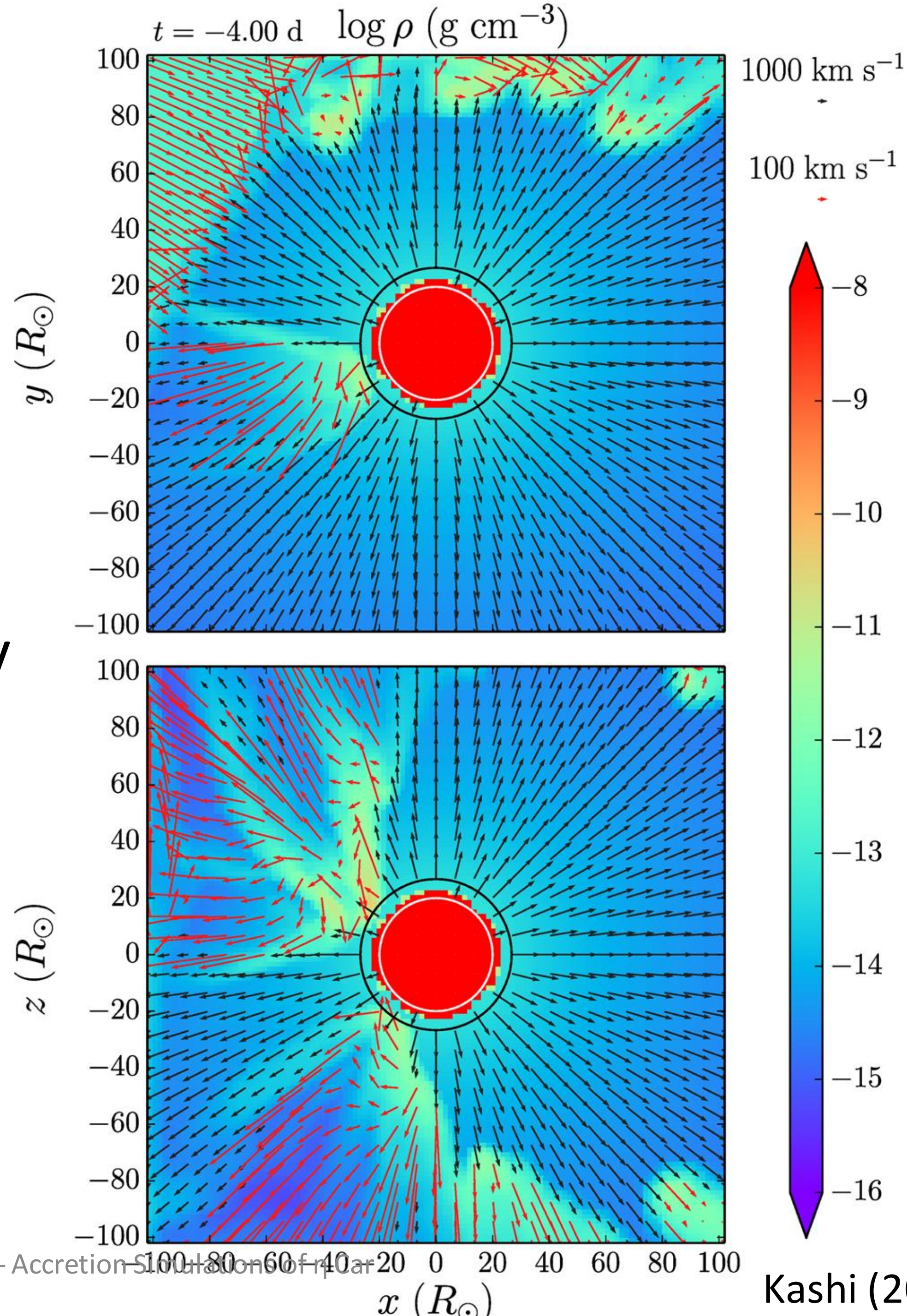


Accretion (cont.)

- The filaments come from different directions.
- They are not formed by self-gravity but rather by hydrodynamic instabilities and thermal instability.
- Density range:

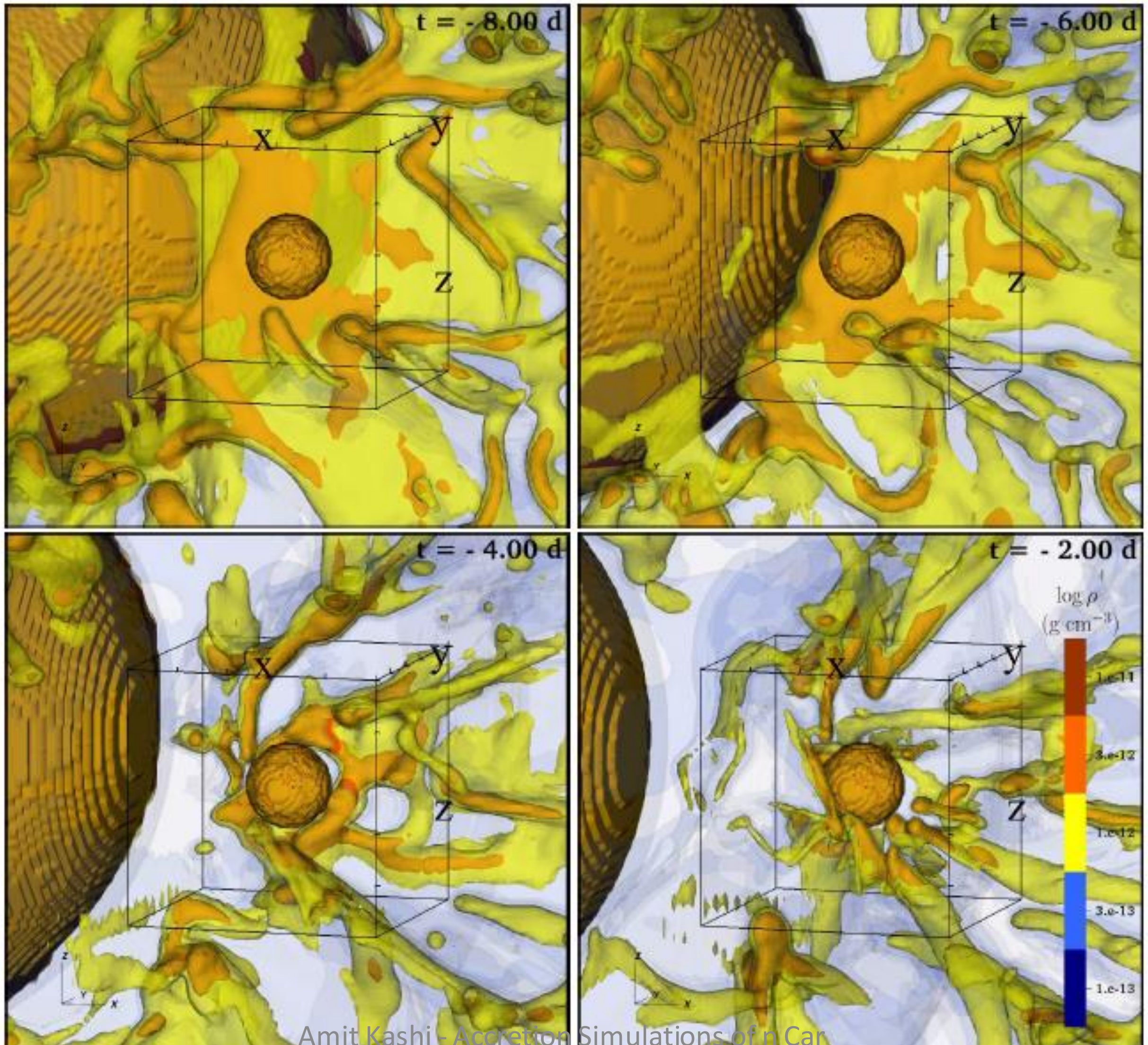
  $$\rho \simeq 10^{-12} - 10^{-11} \text{ g cm}^{-3}$$

- Filaments consequently break into clumps.



Kashi (2017)

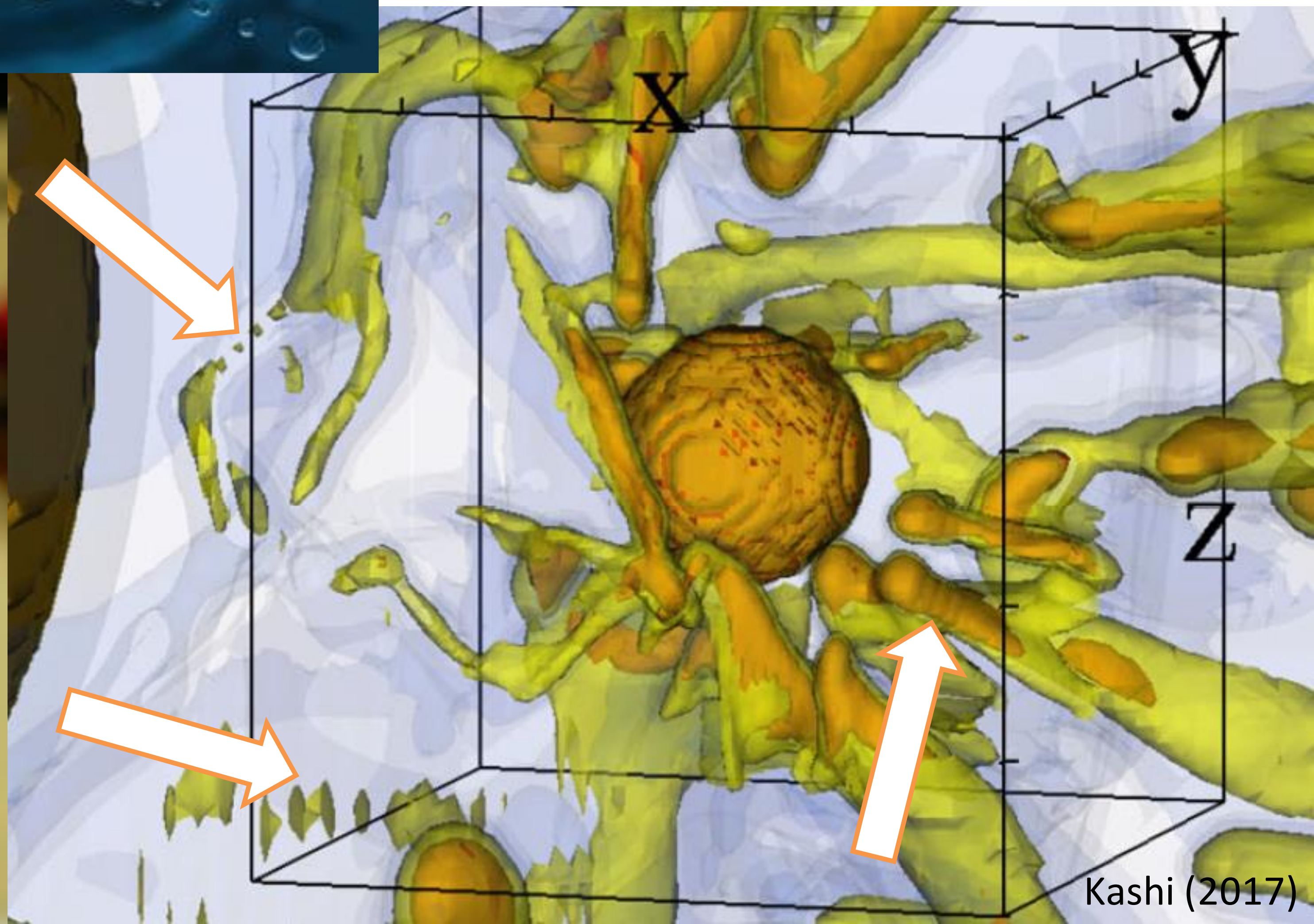
Destruction of wind collision region, followed by accretion onto the secondary



Kashi (2017)

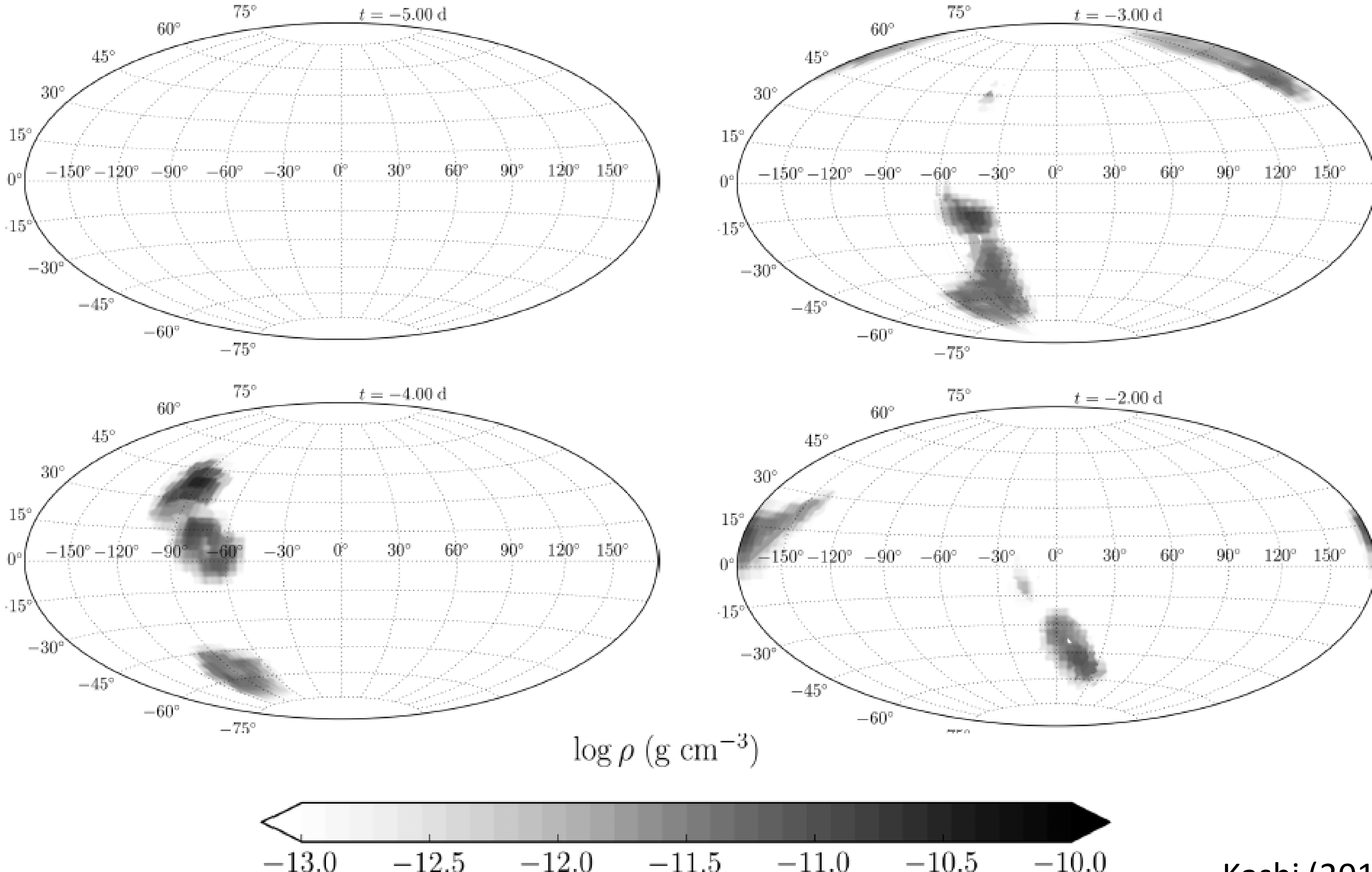
Clumps Formation by the Plateau-Rayleigh Instability

smooth surface→ filaments → clumps



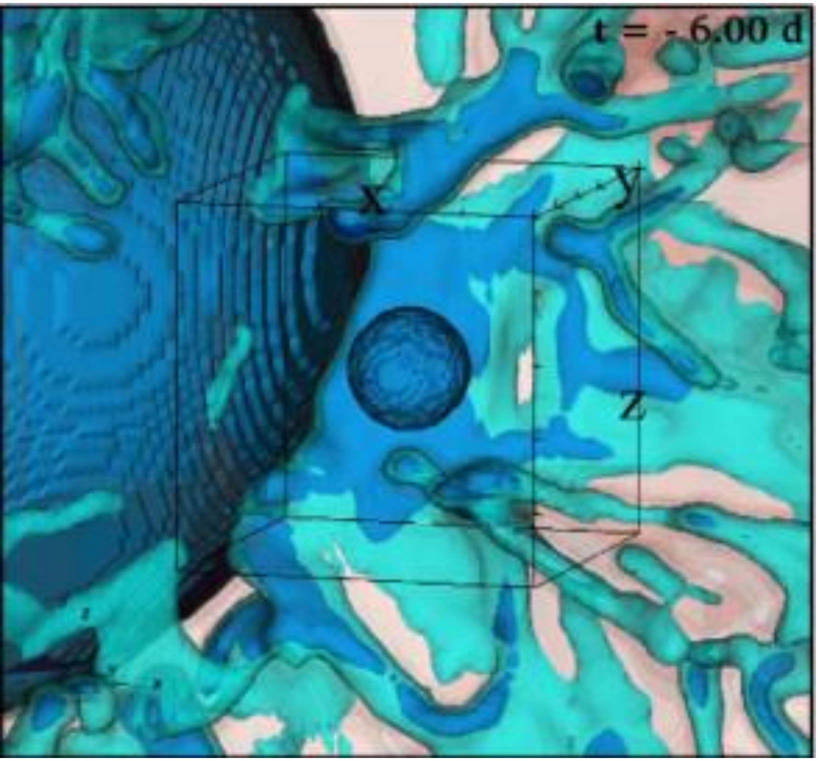
Kashi (2017)

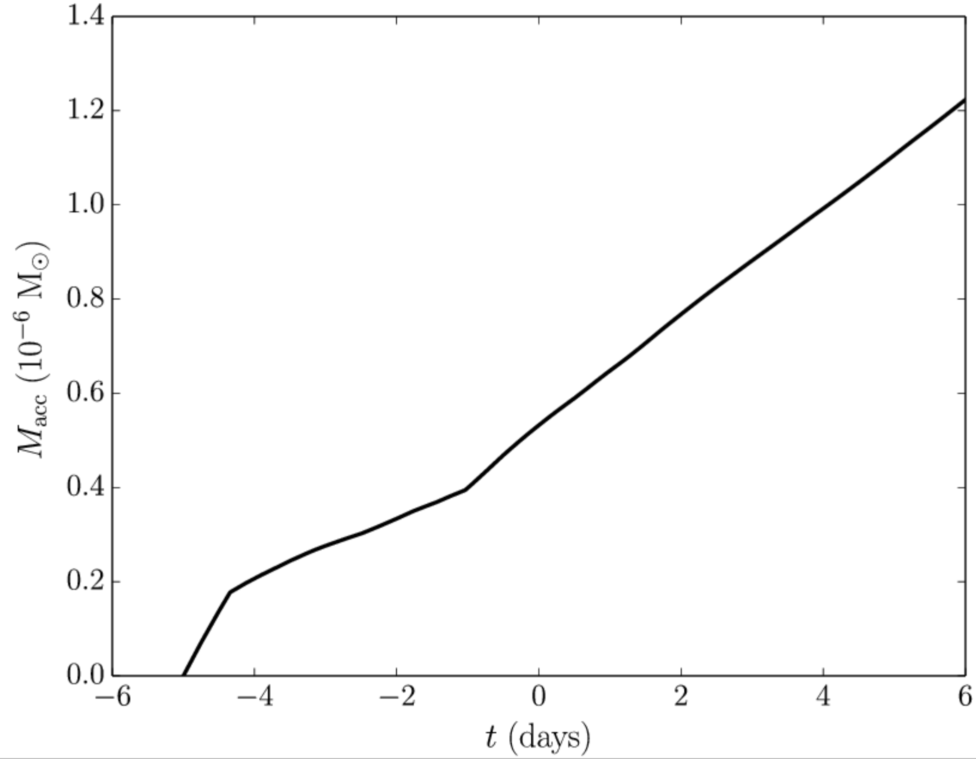
Accretion Panoramic View



Kashi (2017)

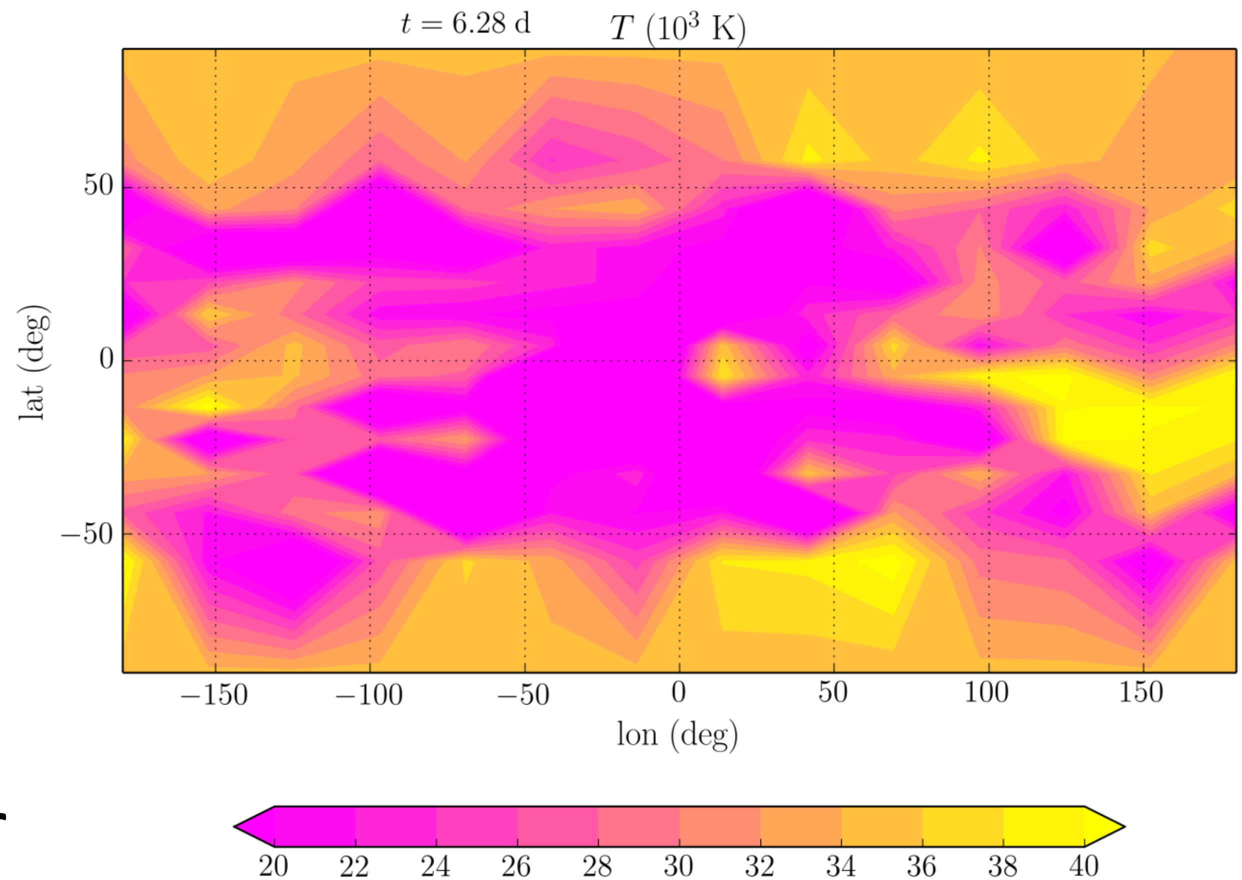
Simulation results: accreted mass





The effective temperature

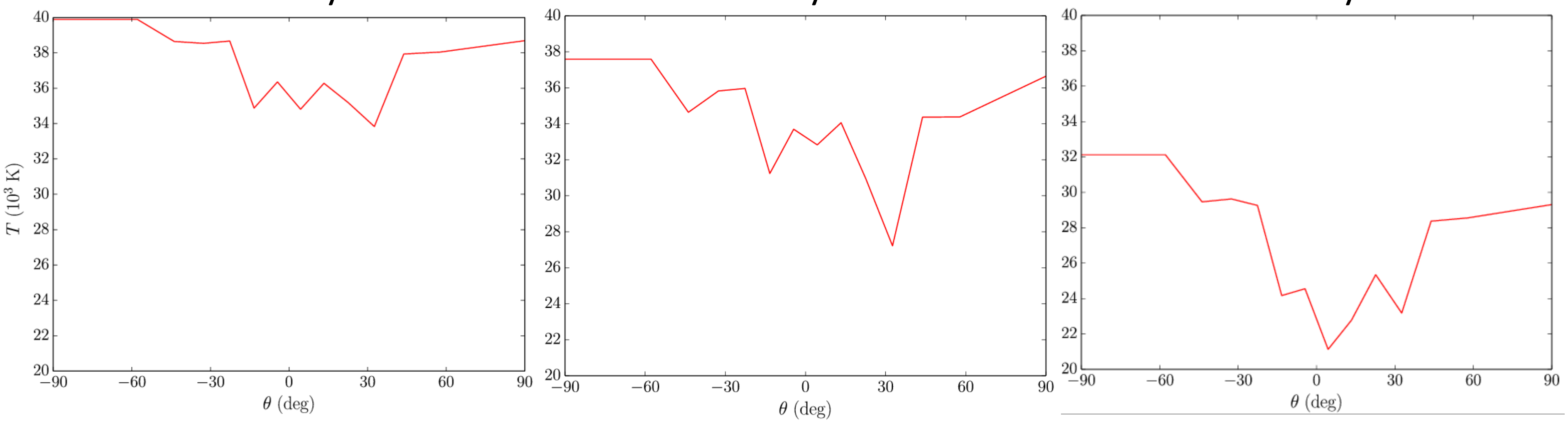
- Accreion is mostly close to equator.
- But in the meantime the secondary is spinning.
- Stellar rotation might average the values over latitude.



The effective temperature

- Accreion is mostly close to equator.
- Therefore the temperature around the equator drops more considerably.
- The poles of the secondary can continue to ionize the wind for longer time.

t= -4 days   t=0 days   t= +6 days



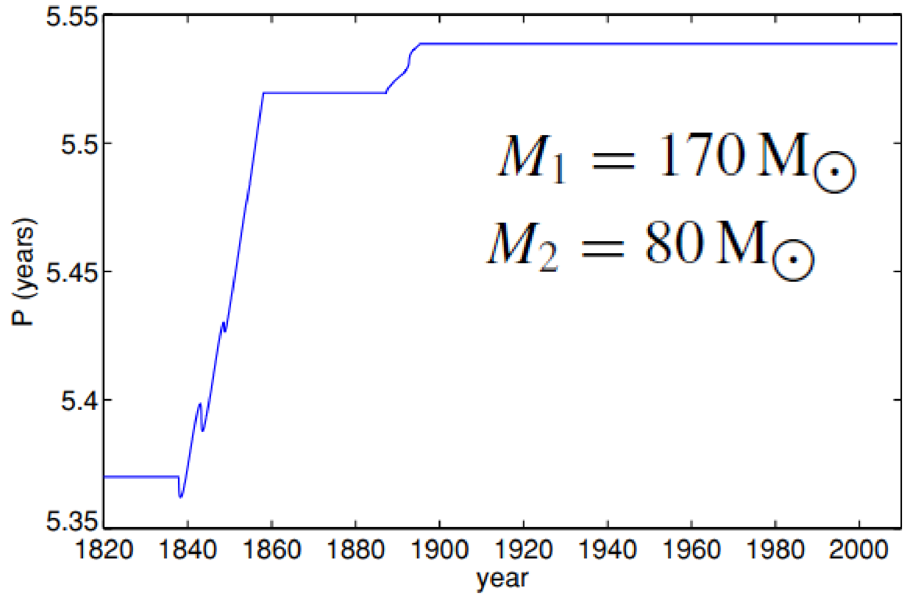
Parameters of the Binary System

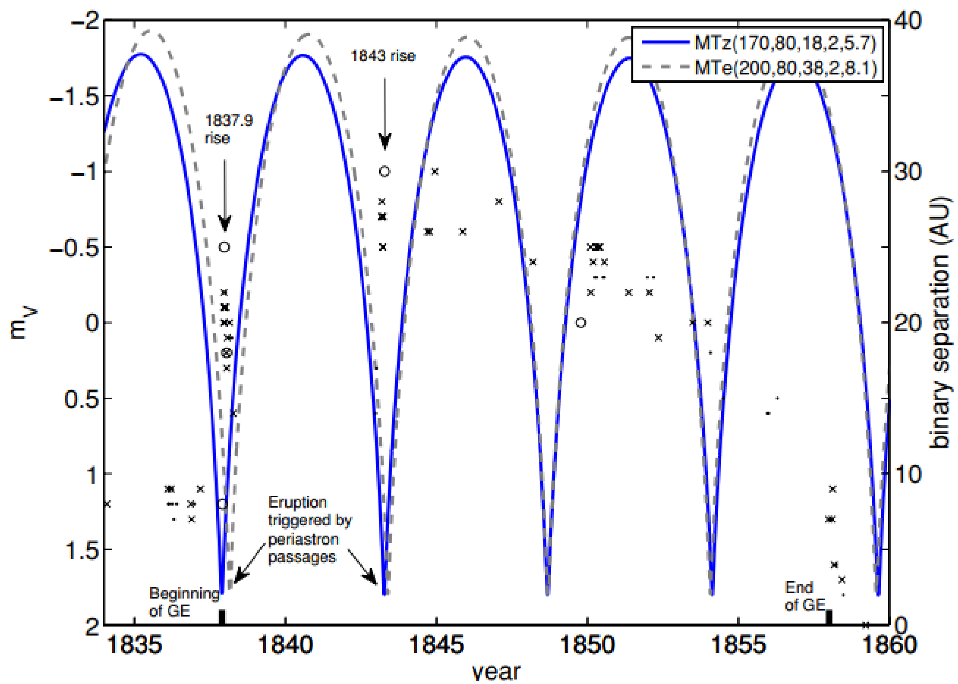
Parameter	Meaning	Conventional mass model	High mass model
P	Orbital period	2023 days	2023 days
e	Eccentricity	0.9	0.9
a	Semi-major axis	16.64 AU	19.73 AU
M_1	Primary mass	120 $M_\odot$	170 $M_\odot$
M_2	Secondary mass	30 $M_\odot$	80 $M_\odot$
R_1	Primary radius	180 $R_\odot$	180 $R_\odot$
R_2	Secondary radius	20 $R_\odot$	20 $R_\odot$
v_1	Primary wind velocity	500 km s^{-1}	500 km s^{-1}
v_2	Secondary wind velocity	3 000 km s^{-1}	3 000 km s^{-1}
$\dot{M}_1$	Primary mass loss rate	6×10^{-4} $M_\odot$ yr^{-1}	6×10^{-4} $M_\odot$ yr^{-1}
$\dot{M}_2$	Secondary mass loss rate	10^{-5} $M_\odot$ yr^{-1}	10^{-5} $M_\odot$ yr^{-1}

The High Mass Model

- Assumptions:
  - the two 19th century eruptions were triggered by periastron passages.
  - mass was lost
  - mass was transferred from primary to the secondary
  - the energy of the eruptions comes from gravitational energy of the accreted mass

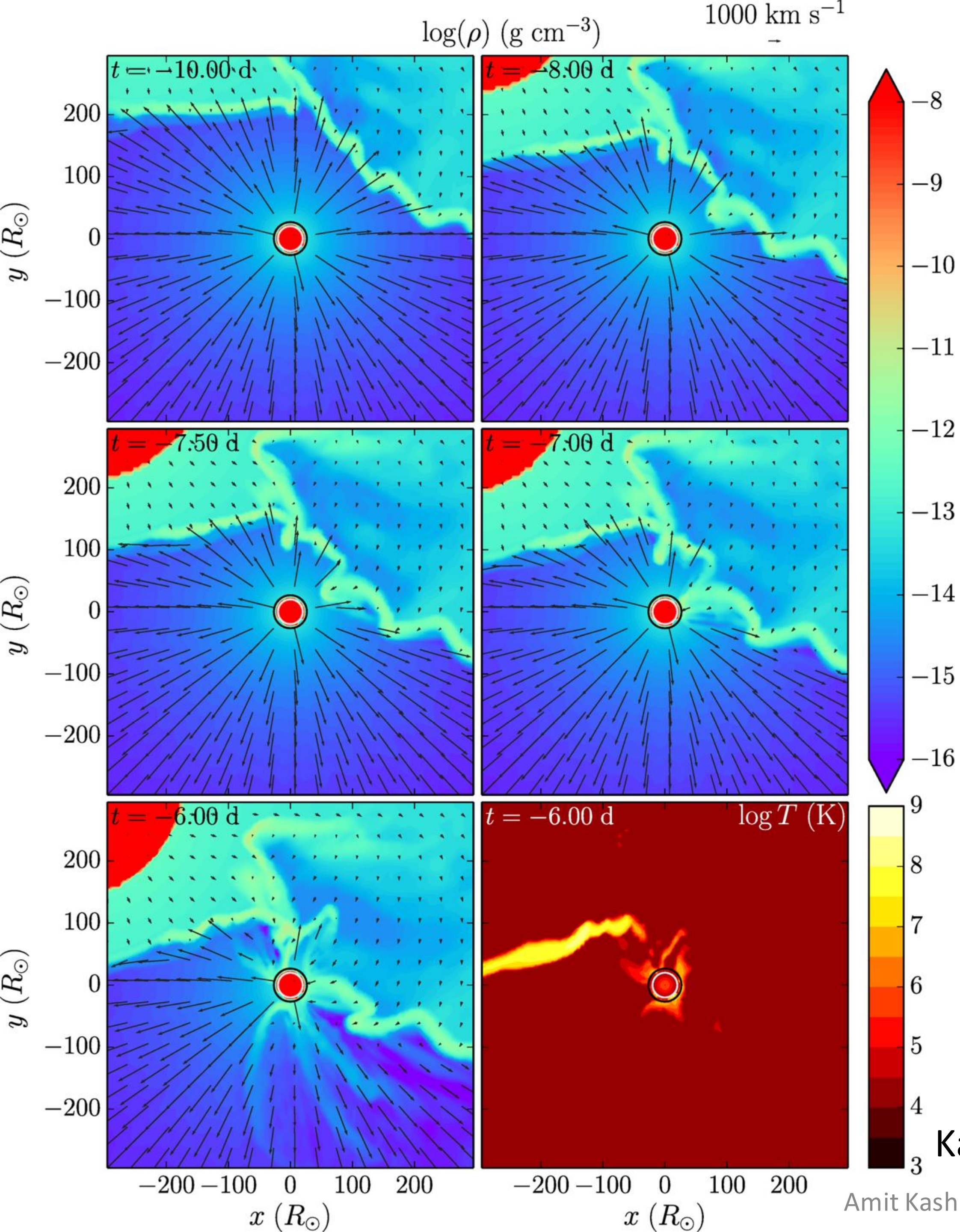
- Result: High mass binary better matches the peaks of the eruption to occur during periastron passages.





Kashi & Soker 2010

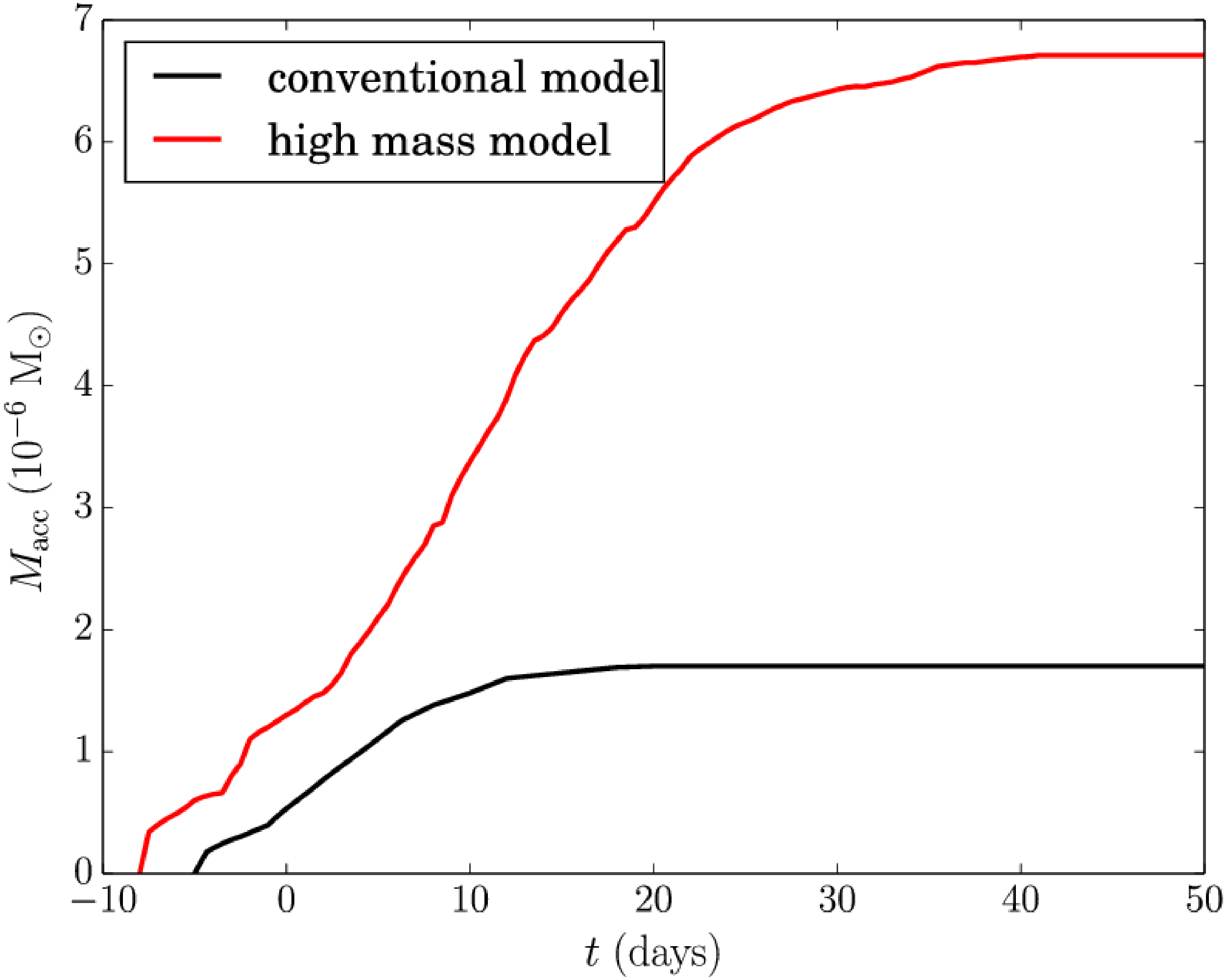
High Mass model

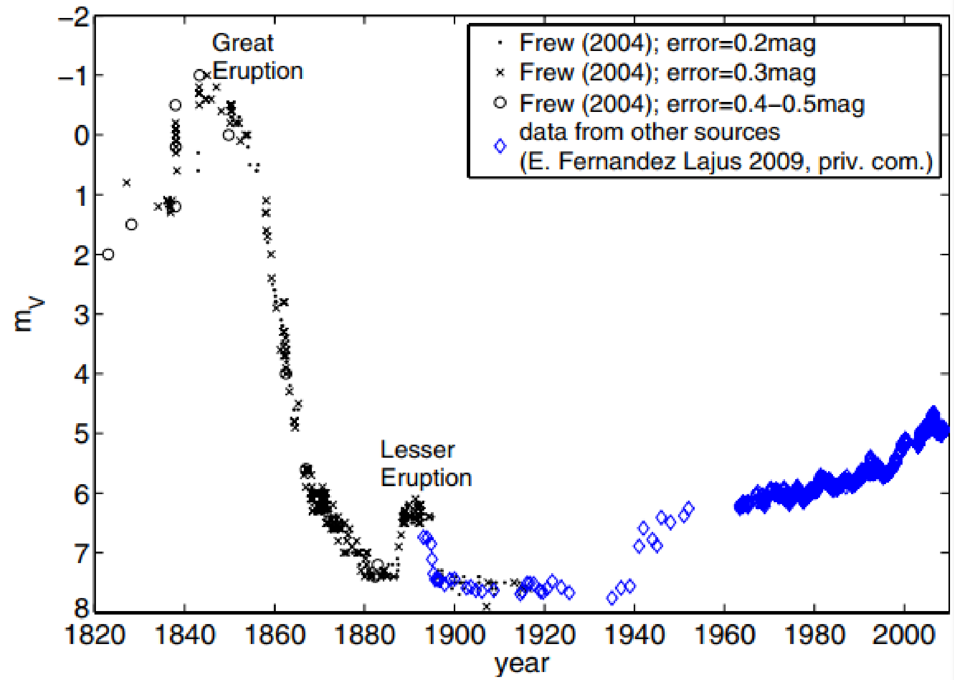


- We take: $M_1 = 170\,\mathrm{M}_\odot$ $M_2 = 80\,\mathrm{M}_\odot$
- Same orbital eccentricity, same mass loss rates.
- Results:
  - Accretion starts earlier.
  - Accretion rate is higher.
  - Accretion lasts longer.
  - Secondary's ionizing radiation is lower for longer duration.

Kashi (2017)

Mass accreted onto the secondary





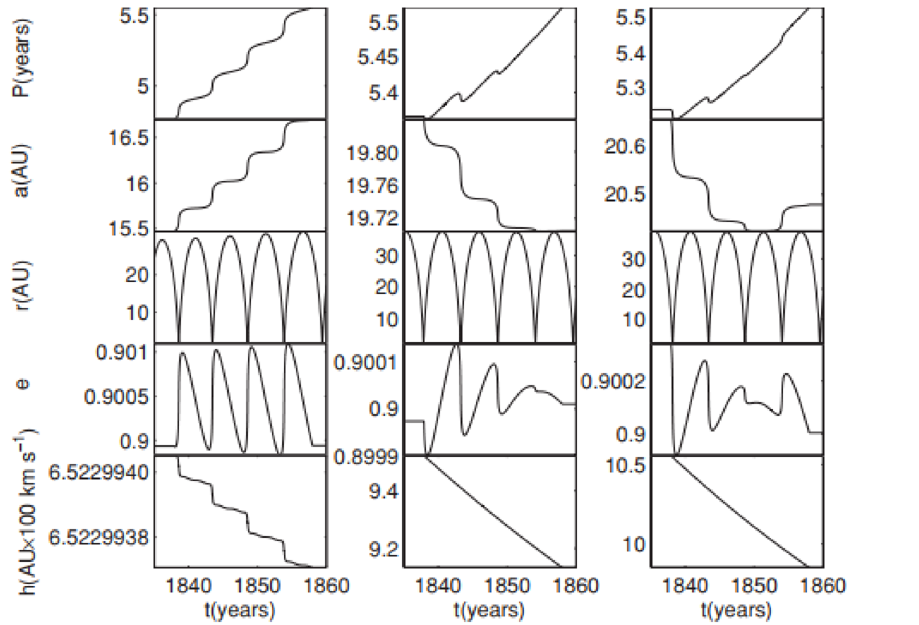
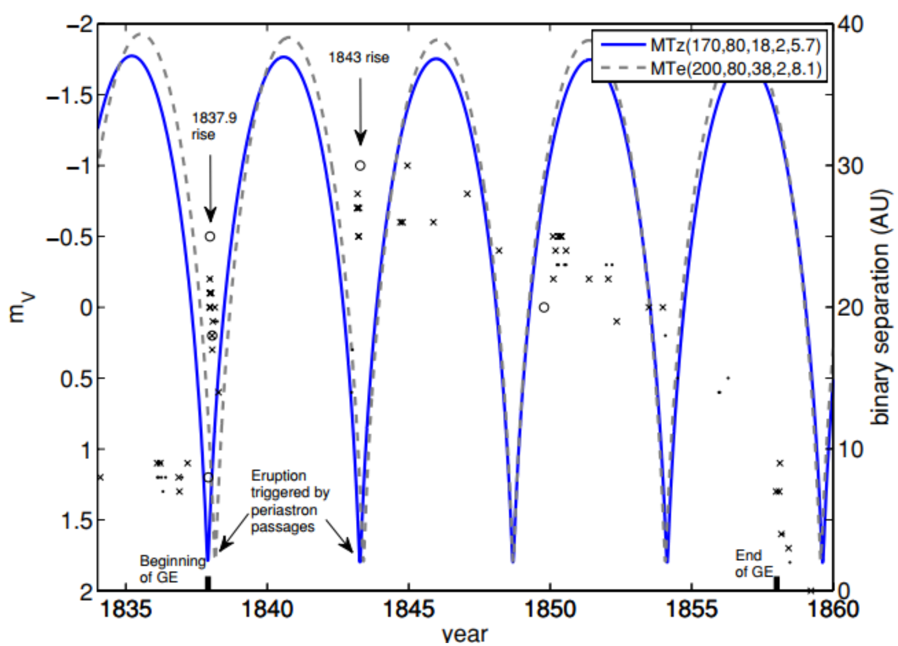
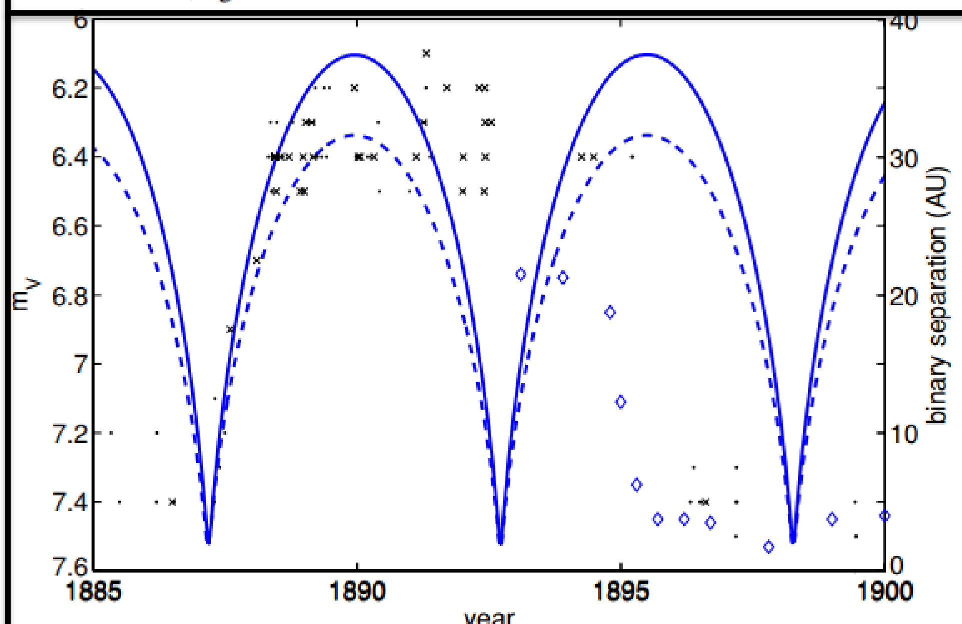
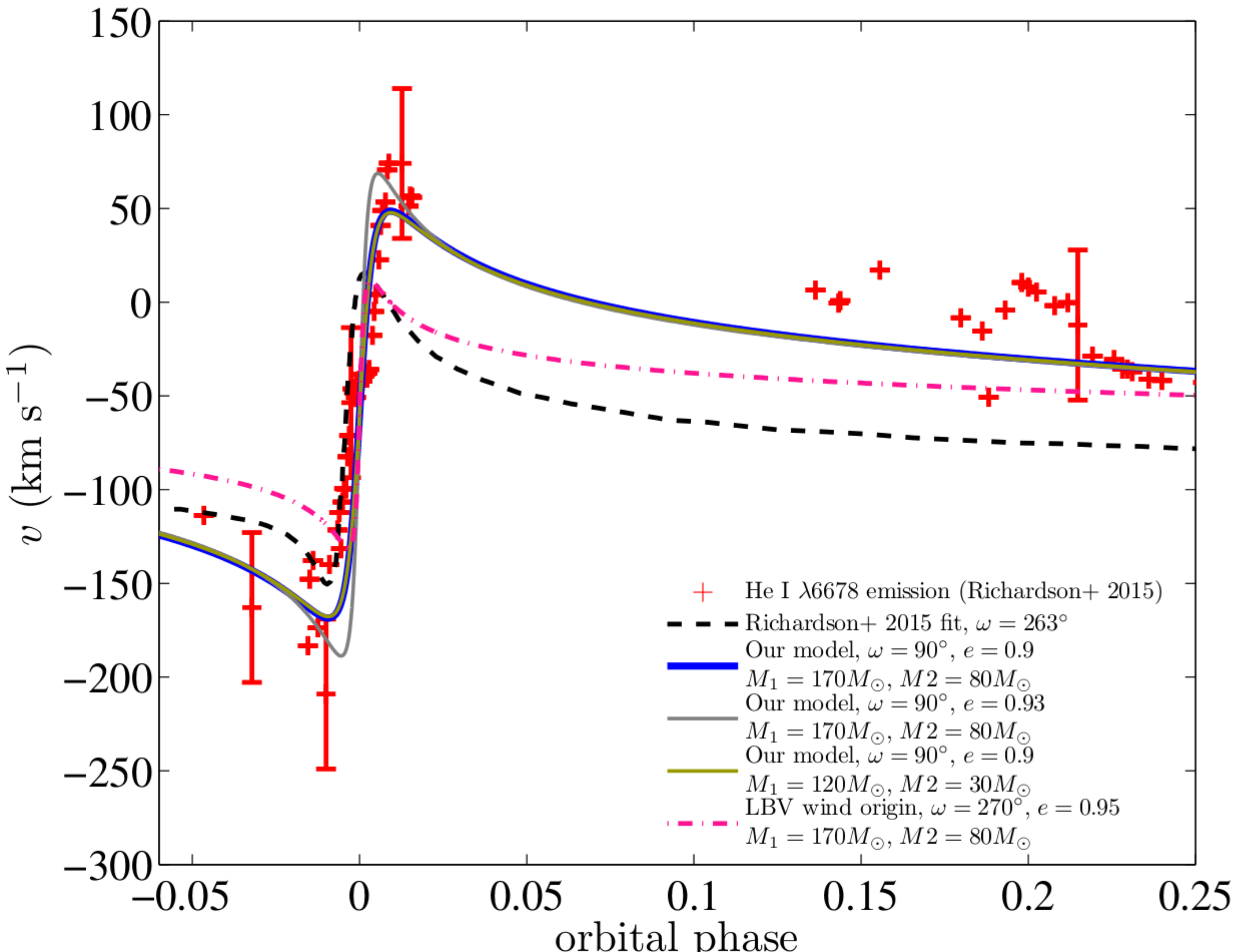


Figure 5. Variation of the binary parameters (orbital period P, semimajor axis a, orbital separation r, eccentricity e, and specific angular momentum h) during the 20 year long GE of η Car. The variations are given for different sets of parameters we use in the paper (see Table 1). Left: "Common model"; middle: "MTz" model; right: "MTe" model.

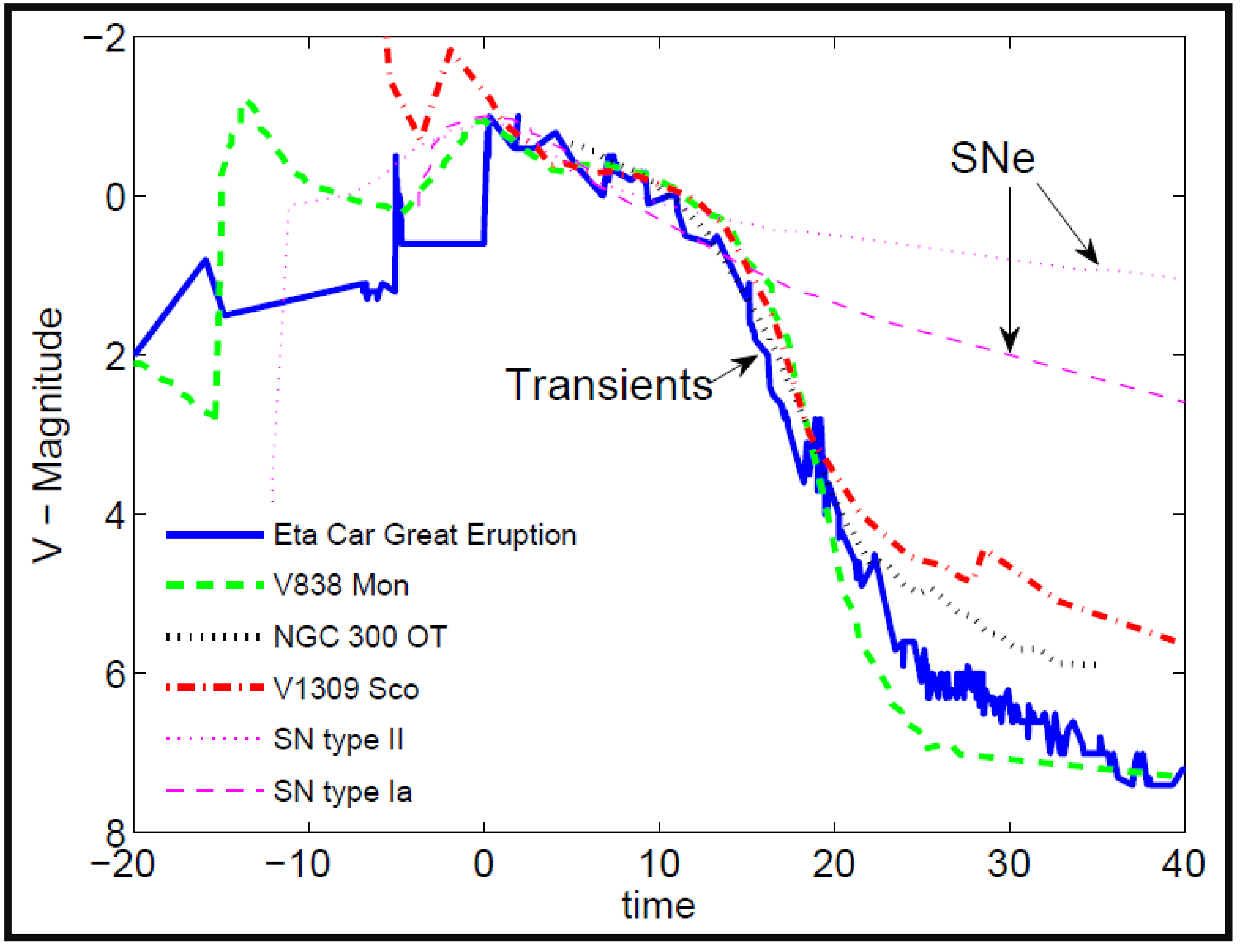




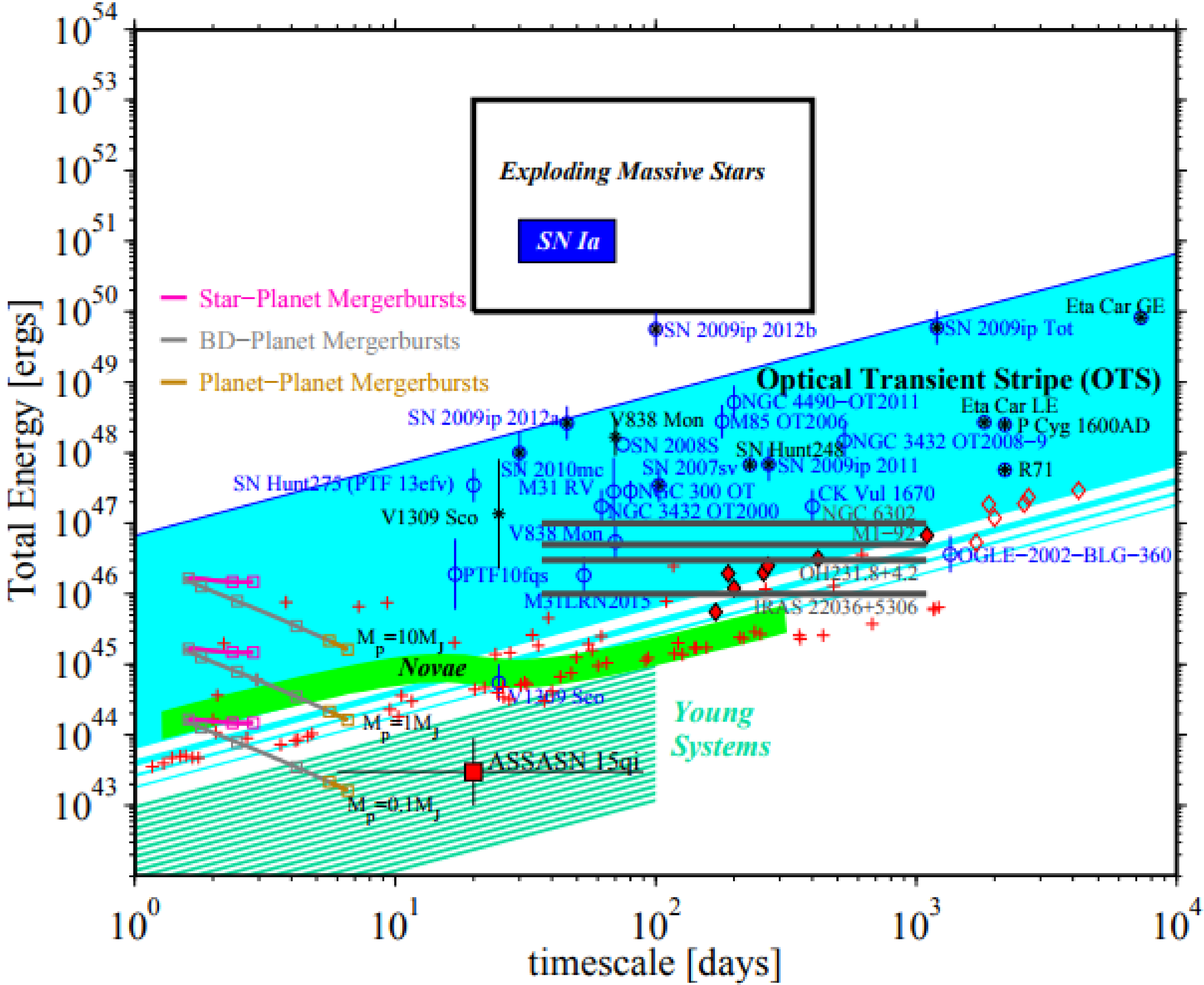
Line variations during the event are better explained with the high mass model



Kashi & Soker (2016)

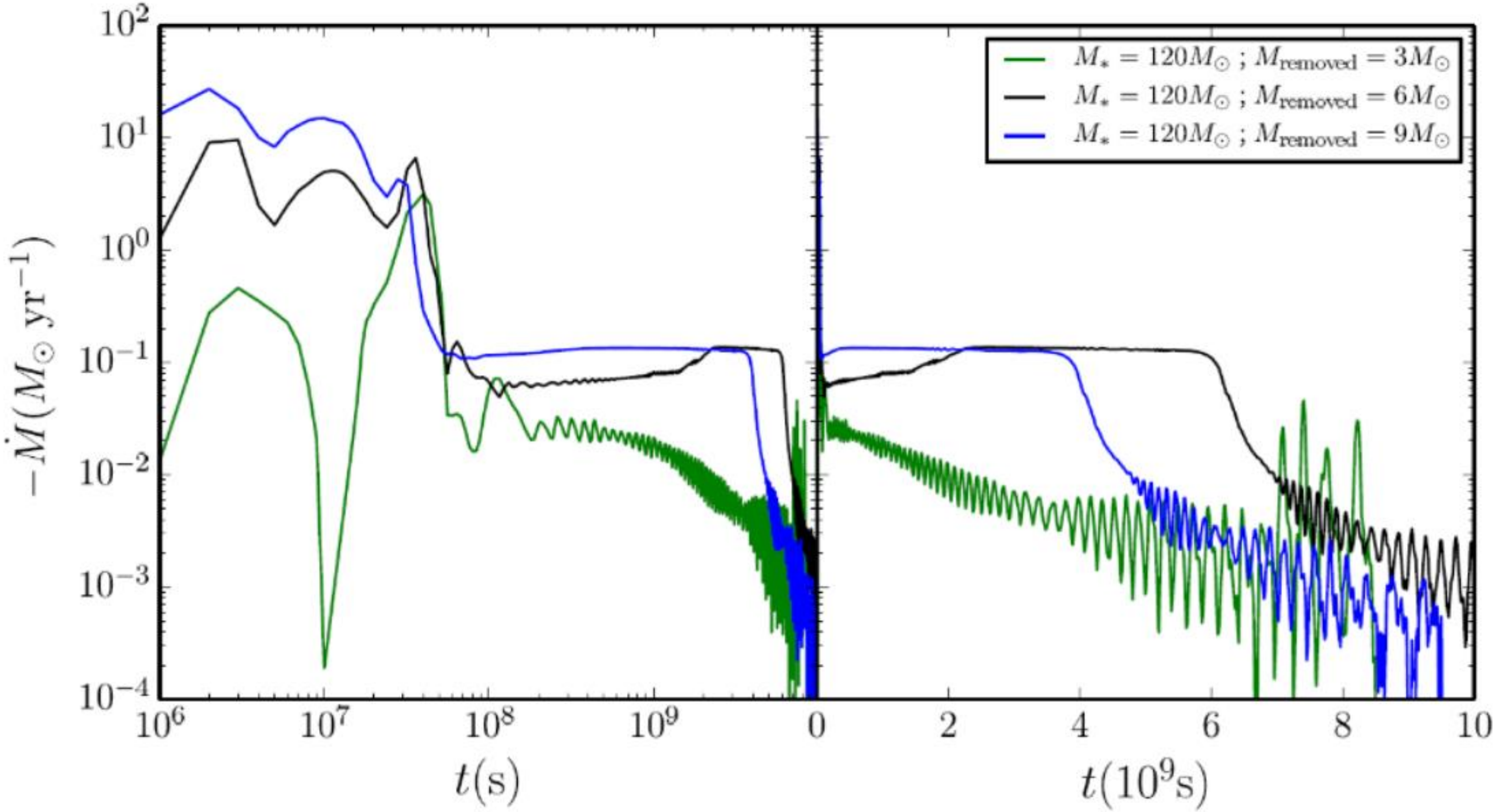


−2
0
2
4
6
8
−20
−10
0
10
20
30
40
time
V - Magnitude
SNe
Transients
Eta Car Great Eruption
V838 Mon
NGC 300 OT
V1309 Sco
SN type II
SN type Ia



Kashi & Soker 2017

Simulations of a VMS recovering from a giant eruption



Kashi, Davidson & Humphreys 2015

Summary

- **Accretion in η Car confirmed.**
- **Our simulations confirm that a $\simeq$ few x10^{-6} $M_\odot$ are accreted onto the secondary during periastron passage.**
- **Our older analytic calculations of the accreted mass gave nice results.**
- **The accreted gas lowers the effective temperature from 37000-41000K to >25000K, mostly at low latitudes.**
- **It reduces the number of UV photons and explains the spectroscopic event.**
- **High mass model M_1 =170$M_\odot$, M_2 =80$M_\odot$ better agrees with observations.**
- **As accretion occurs now, it surely occurred during the giant eruptions!**