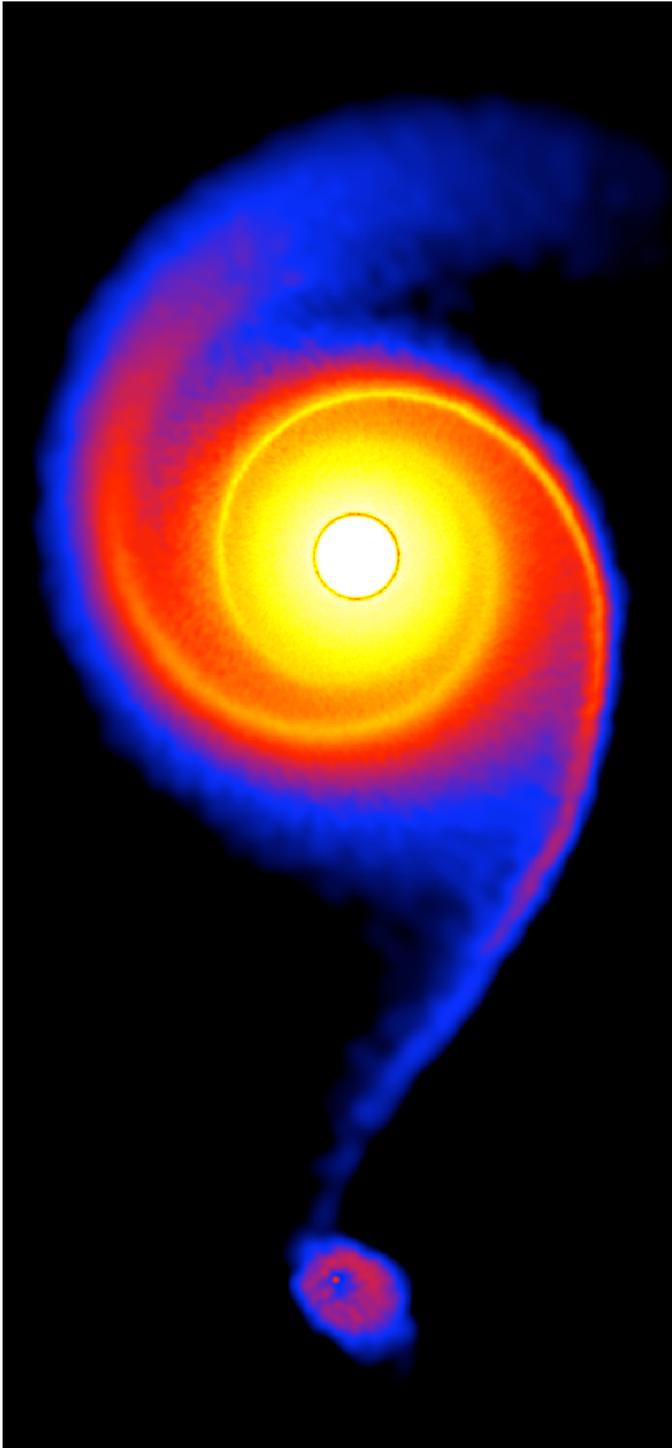


Decretion Disk Dynamics in Binary Be Stars

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Japan)



Talk Outline

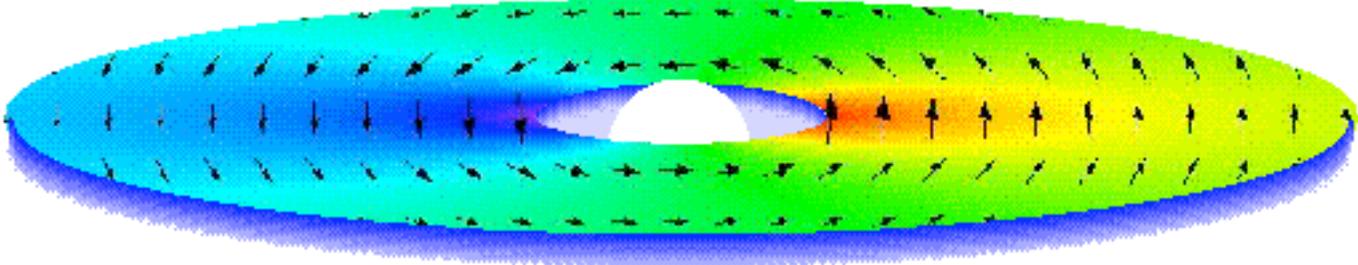
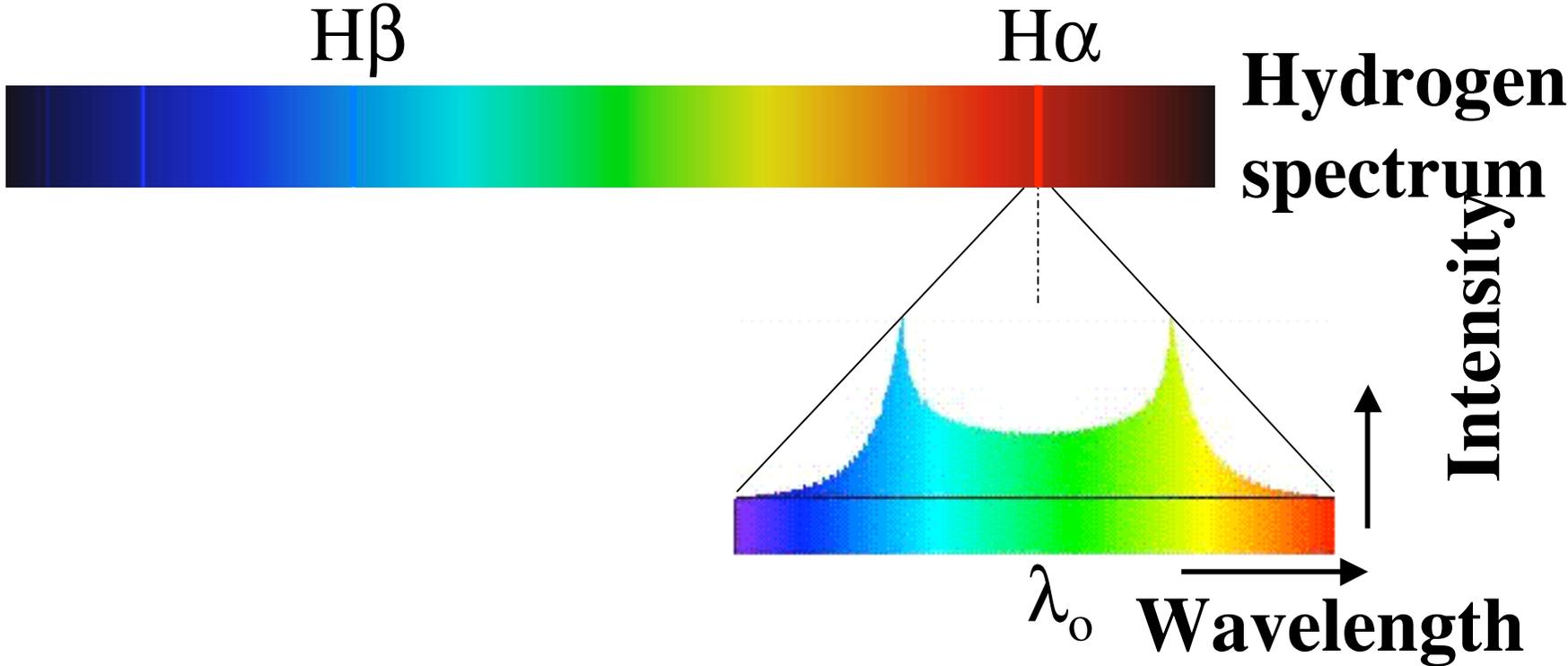
1. Brief introduction to Be stars
2. Dynamics of Be disks around single Be stars
3. Dynamics of Be disks around binary Be stars
 - Be/X-ray binaries
 - Other binaries
4. Conclusions

1. Be stars

- Non-supergiant B (late O - early A) stars which have once shown $H\alpha$ emission line
- Two-component envelope:
Fast polar wind + Equatorial Keplerian disk
- Fast rotators:
Close to the critical rotation rate?

By Stan Owocki

Be stars



2. Dynamics of Be disks around single Be stars: Viscous decretion disk model

Scenario (Lee et al. 1991)

Mass supply from the star,
at the Keplerian rotation velocity



Outward drift by viscosity

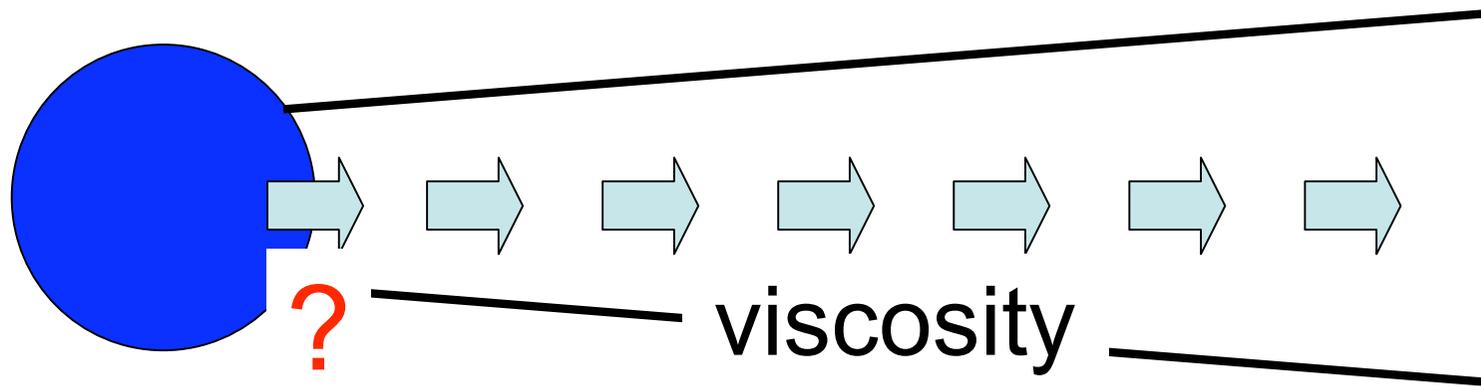


Formation of a disk

Decretion disks are never steady!

transport of angular momentum:

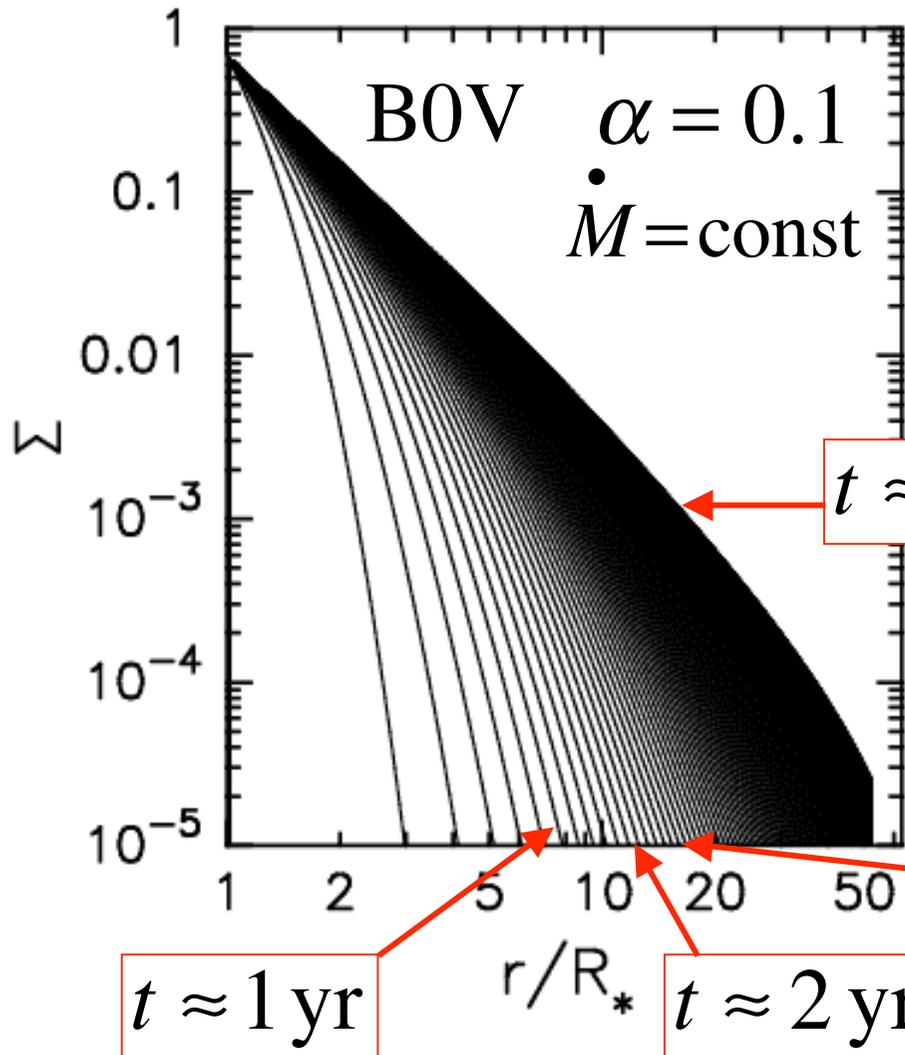
star → disk



Positive torque → growth of the disk

No/Negative torque → decay of the disk

1D simulation



$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left[\frac{\frac{\partial}{\partial r} (\alpha c_s^2 r^2 \Sigma)}{\frac{d}{dr} (r^2 \Omega)} \right]$$

Steady disk solution
 = structure at $t \rightarrow \infty$

3. Dynamics of Be disks around binary Be stars

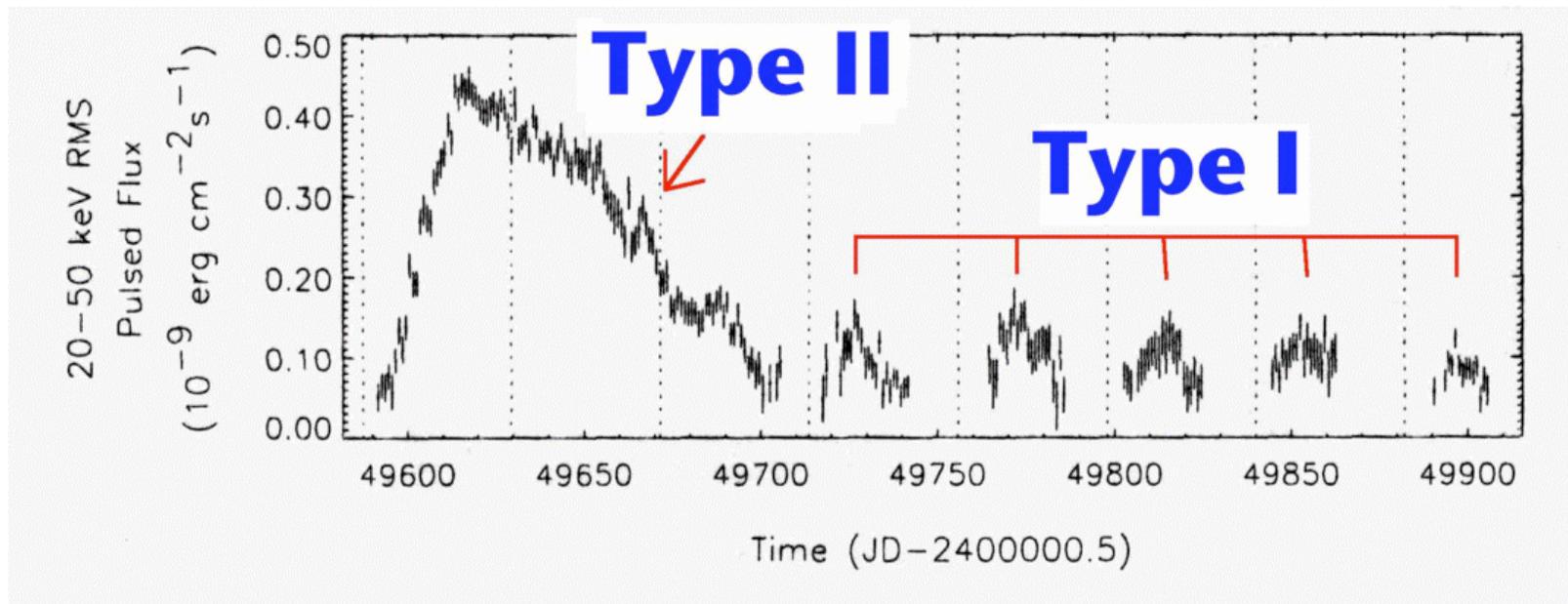
3.1. Be/X-ray Binaries

- Classification: largest sub-class of high mass X-ray binaries
($> 2/3$ of the identified systems)
- System: a Be star + a neutron star
- Orbit: wide ($12 \text{ d} < P_{\text{orb}} < 300 \text{ d}$) and eccentric ($e < 0.9$)

X-ray activity in Be/X-ray binaries

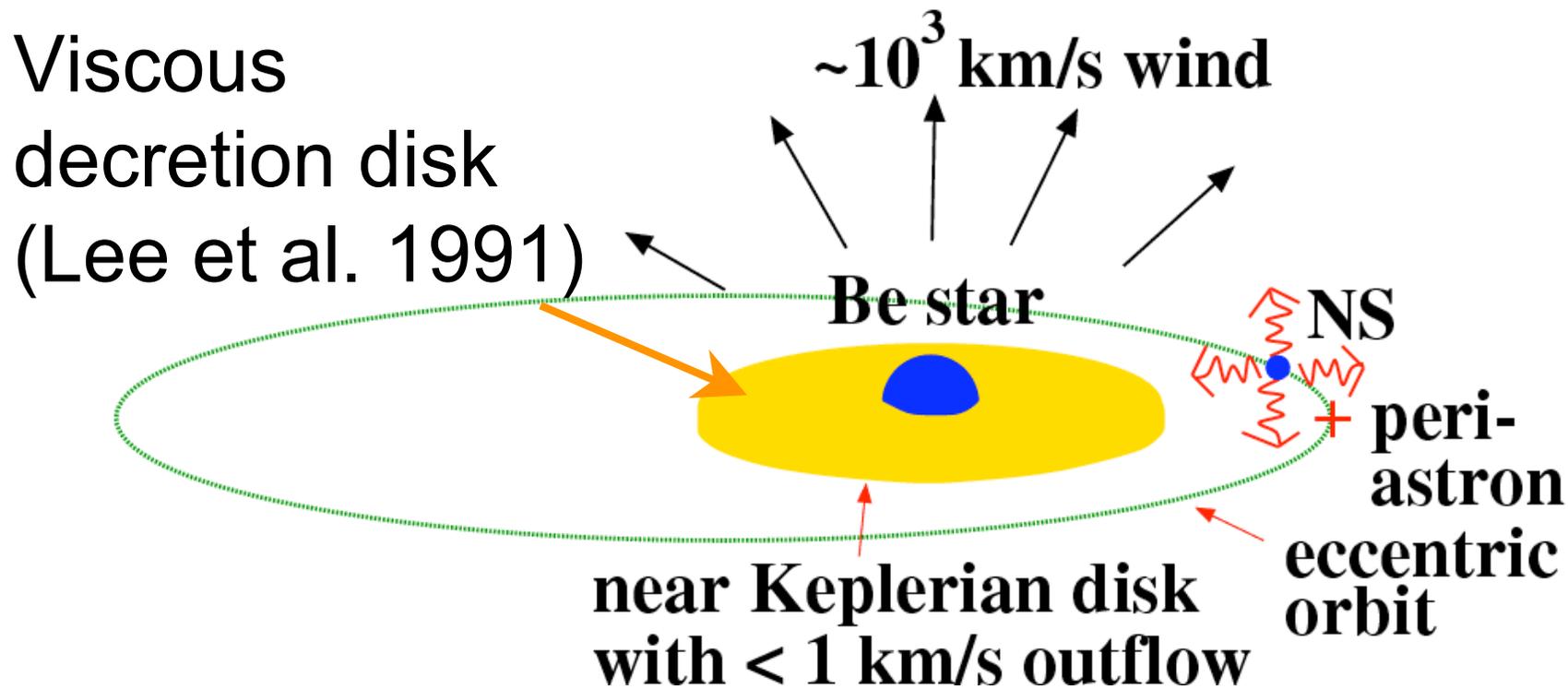
- Most systems show only transient activity
 - Three types of X-ray activity
 - low-luminosity, persistent X-ray emission ($L_X \leq 10^{34} \text{ erg s}^{-1}$)
 - periodical (**Type I**) outbursts
($L_X \approx 10^{36} - 10^{37} \text{ erg s}^{-1}$)
 - giant (**Type II**) outbursts
($L_X \geq 10^{37} \text{ erg s}^{-1}$)
- (Stella et al. 1986; Negueruela et al. 1998)

Type I/II X-ray outbursts (2S 1417-62)



(taken from Bildsten et al. 1997)

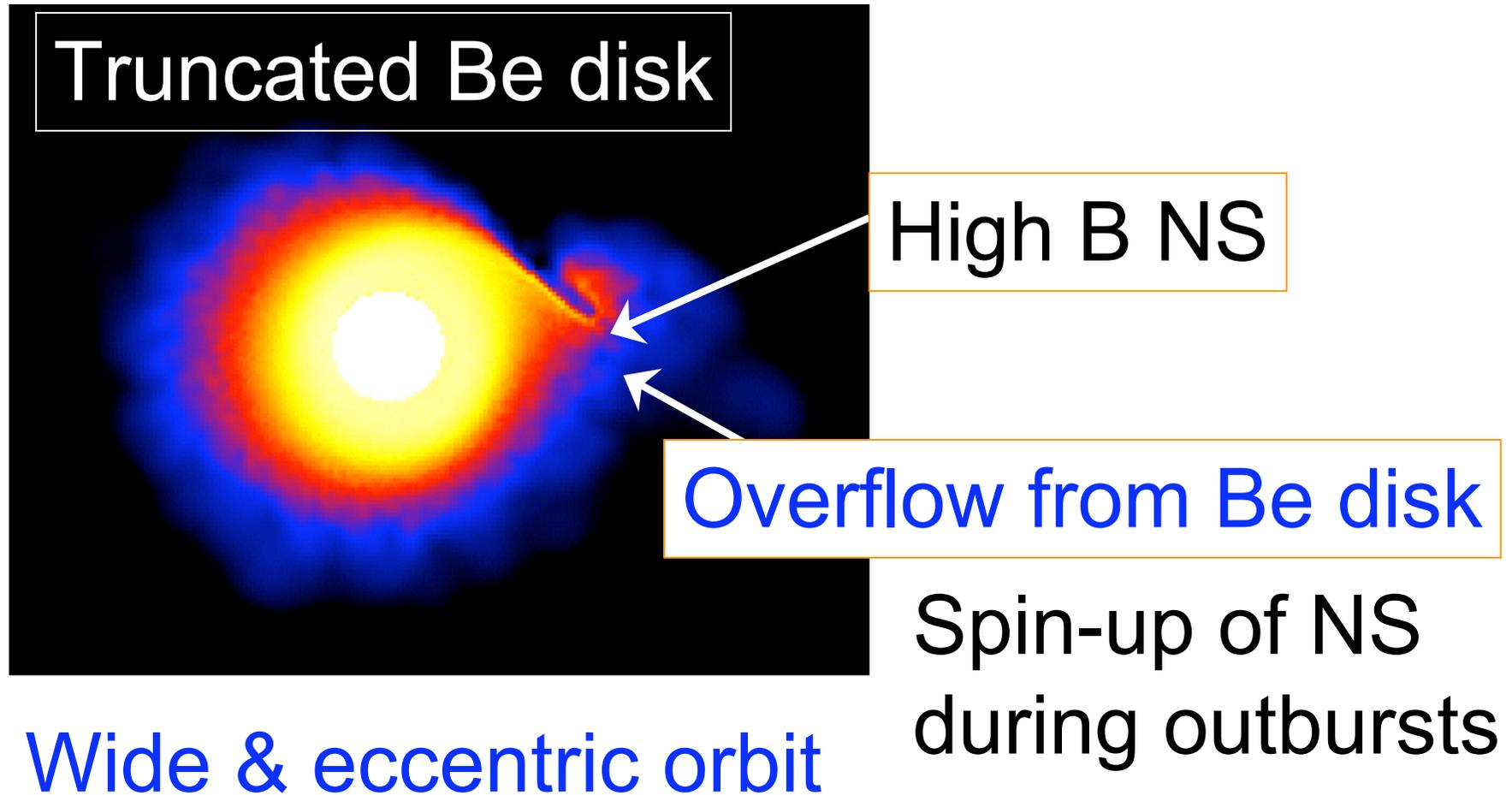
Truncated Be disks in Be/X binaries



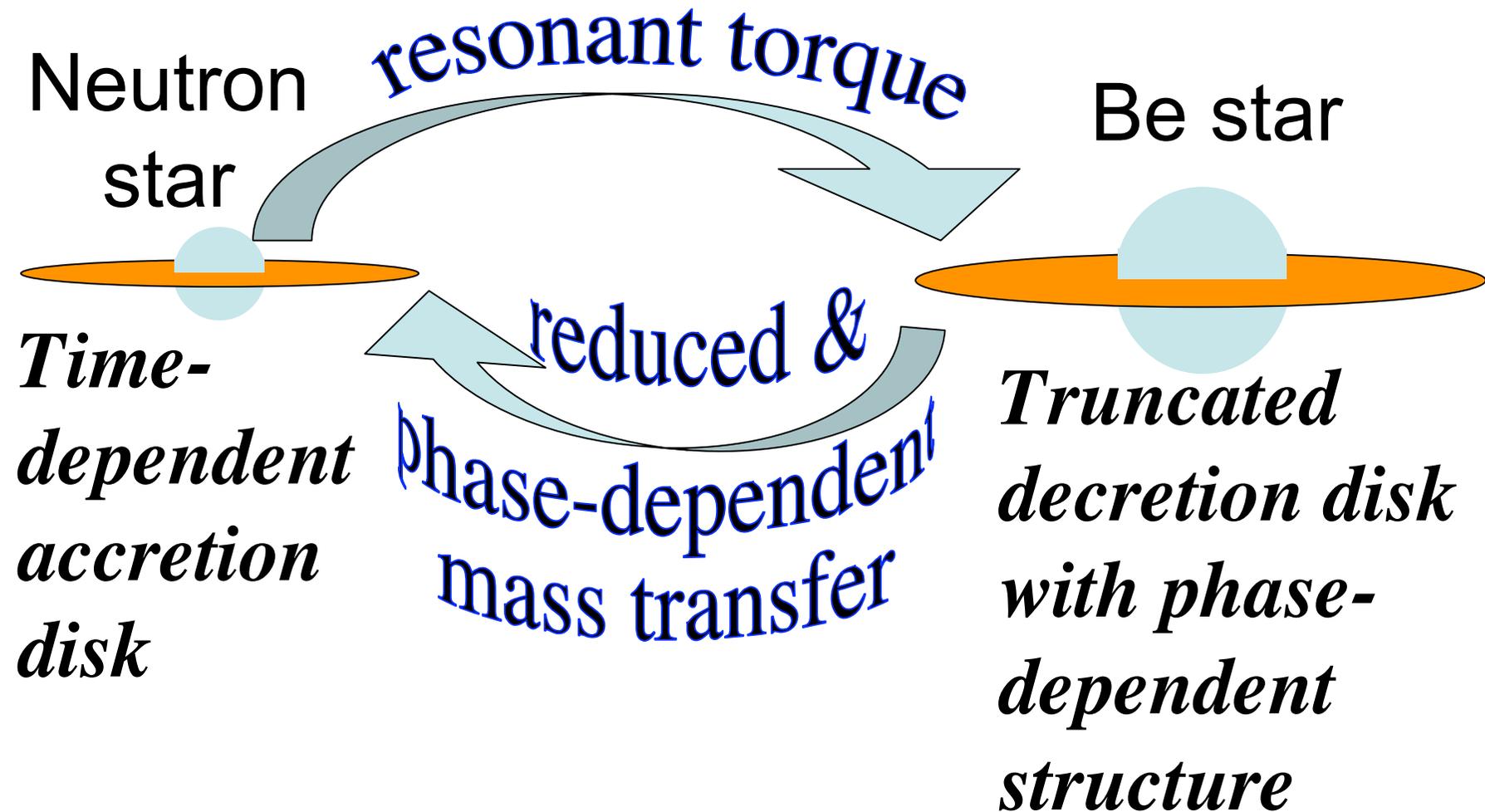
Obs: Reig et al. 1997; Zamanov et al. 2001

Theory: Artymowics & Lubow 1994; Negueruela
& Okazaki 2001; O&N 2001

Modern view of Be/X-ray binaries



Interaction between the neutron star and the Be disk in Be/X-ray binaries



Numerical model (→ Okazaki et al. 2002)

- 3D SPH code (Bate et al. 1995)
- Be star and NS as sink particles
- Numerical viscosity adjusted so as to keep $\alpha_{\text{SS}} = 0.1$
- Constant mass ejection from the equatorial region of the Be star
- Isothermal: $T_{\text{d}} = 0.5 T_{\text{eff}}$

(1) Be Disks in Coplanar Systems

1. Be disk is:

- formed by the viscous accretion
- truncated by the resonant torque by NS

2. Truncation radius decreases with increasing e (disk radius smaller than periastron distance)

3. Efficient truncation for low to moderate orbital eccentricities

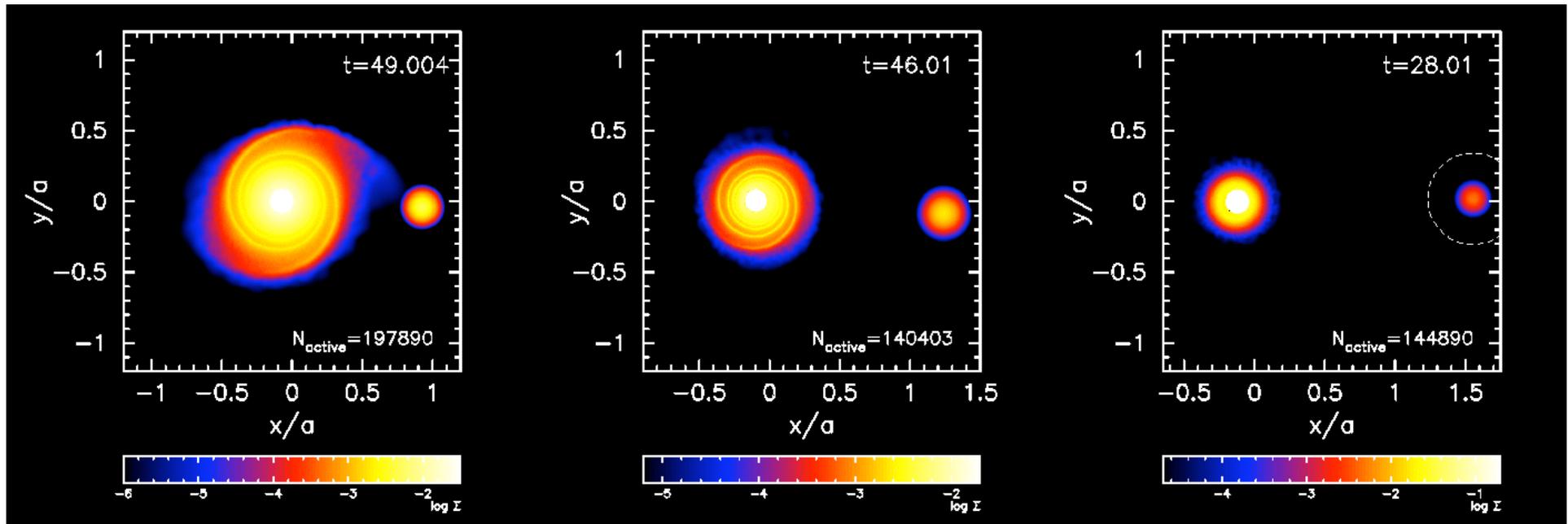
Effect of eccentricity on disk truncation

(coplanar disk for $P_{\text{orb}} = 24.3\text{d}$)

$e = 0$

$e = 0.34$

$e = 0.68$



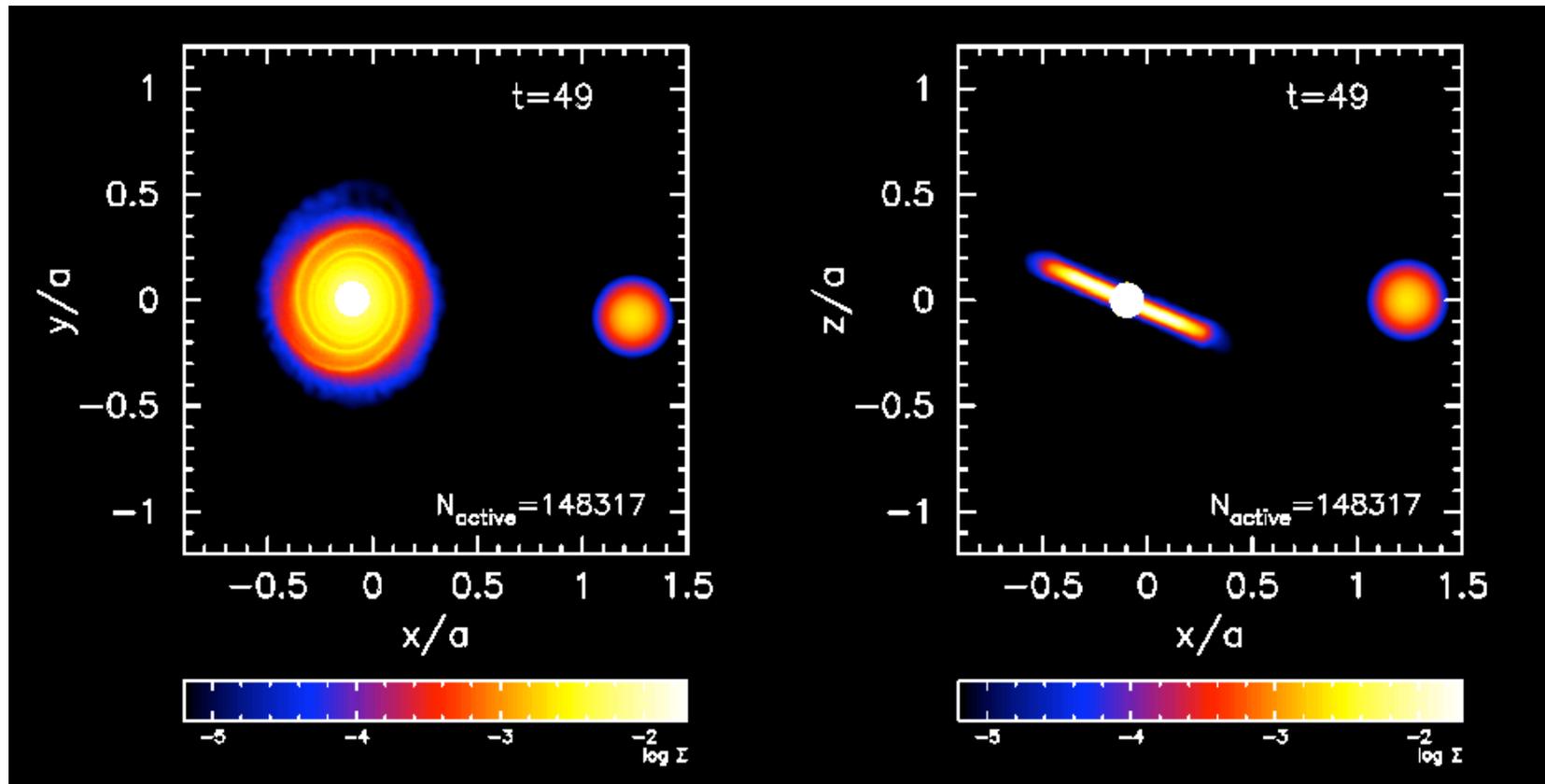
$\sim r(3:1)$

$\sim r(4:1)$

$\sim r(12:1)$

(2) Be Disks in Misaligned Systems

Resonant truncation works for Be disks in misaligned systems as well

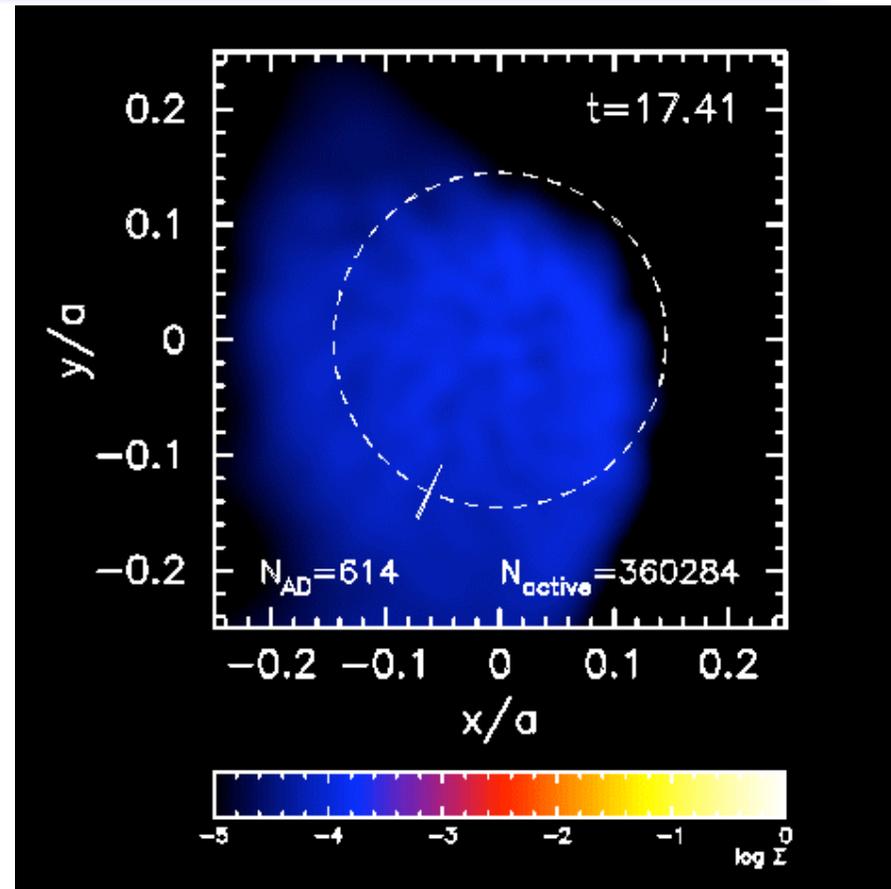
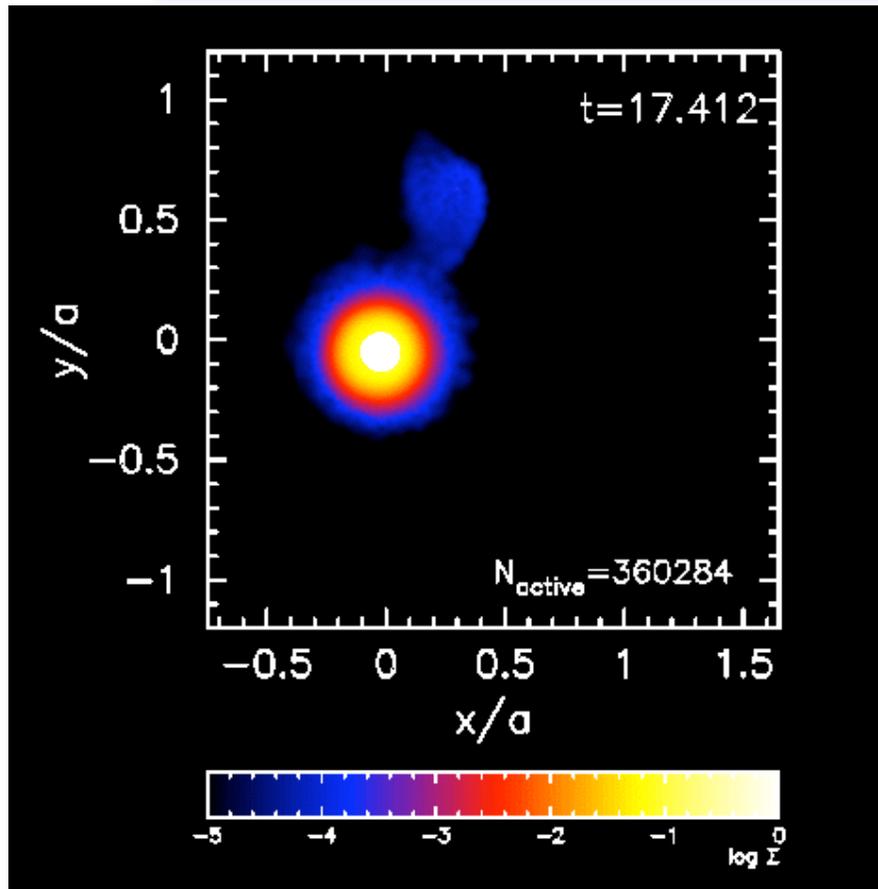


$P_{\text{orb}} = 24.3\text{d}$, $e = 0.34$, $i = 30^\circ$ about y -axis¹⁷

(3) Accretion disks in systems with high e

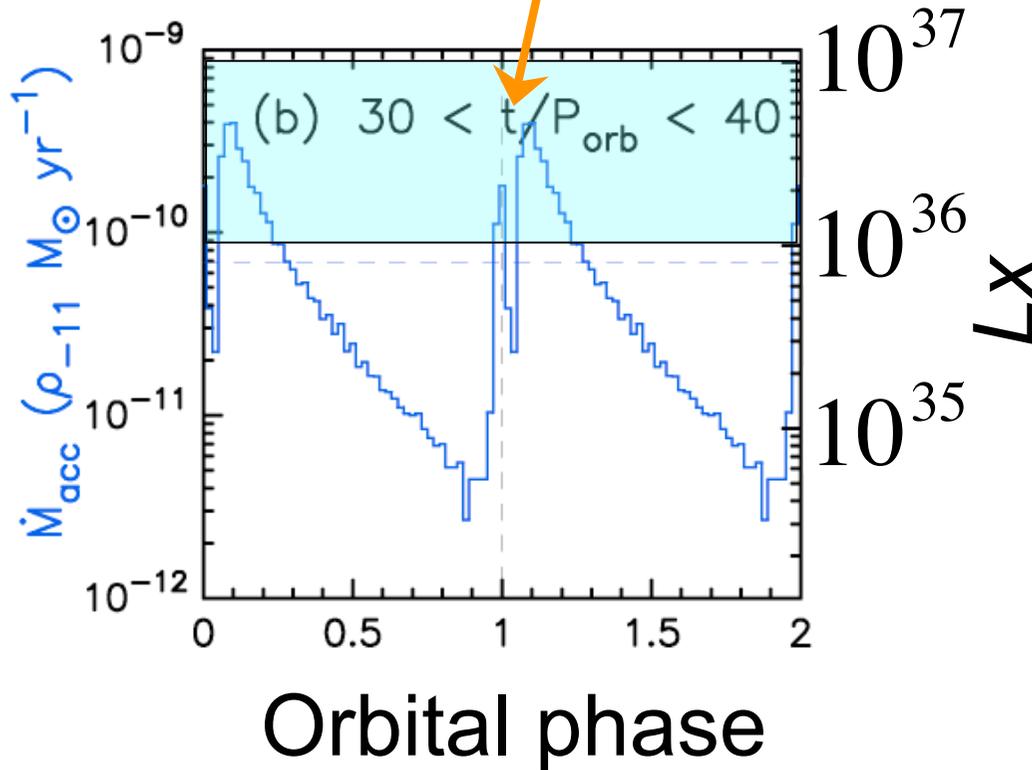
(a) Coplanar case: $P_{\text{orb}}=24.3\text{d}$, $e=0.68$, $i=0$

Strongly phase dependent accretion



Type I outbursts

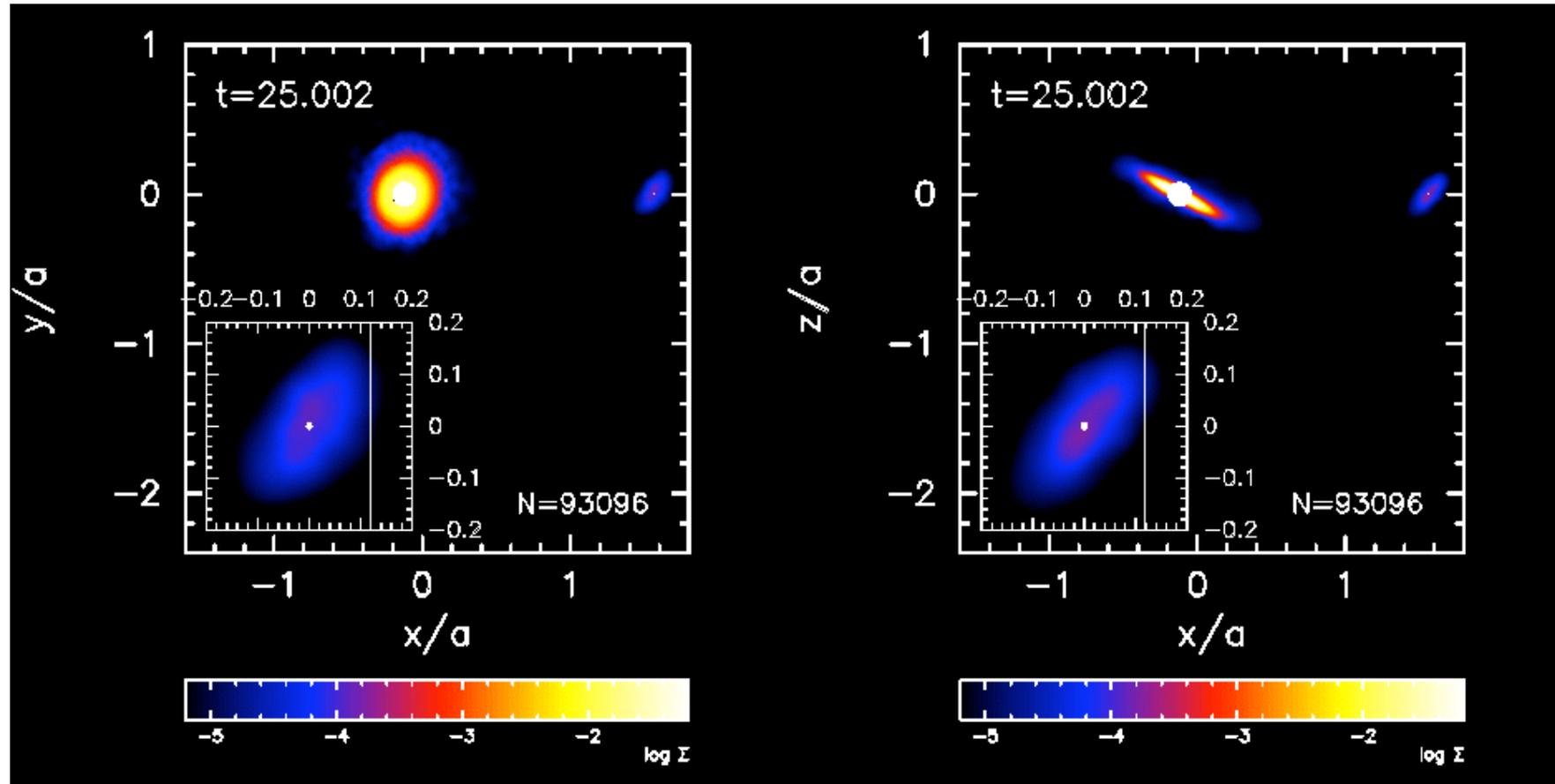
Accretion rate profile



The system likely to show the **Type I X-ray outburst at periastron**

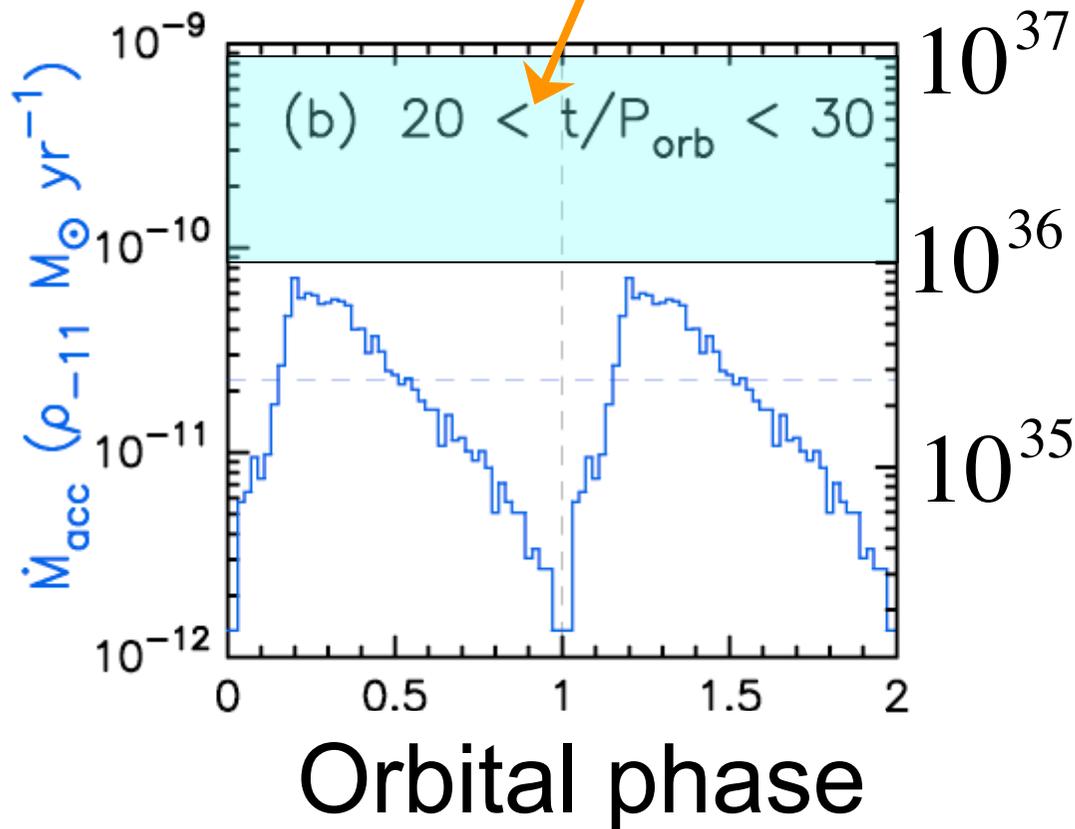
(b) Misaligned case: $P_{\text{orb}} = 24.3\text{d}$, $e = 0.68$,
 $i = 30$ deg about y -axis

Inclined accretion disk is formed

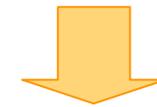


Type I outbursts

Accretion rate profile

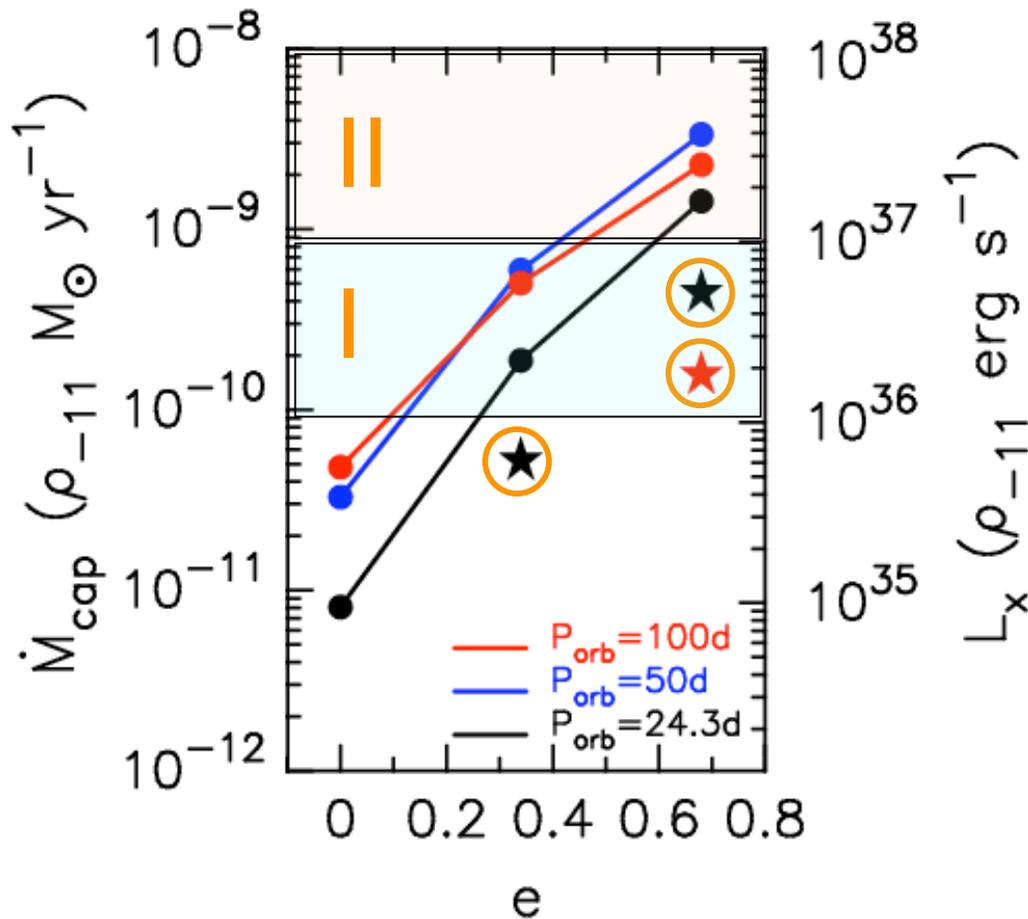


Accretion rate
much smaller
than in
coplanar case



Periodic X-ray
outbursts less
likely to occur

Peak mass-transfer rate vs. Peak mass-accretion rate

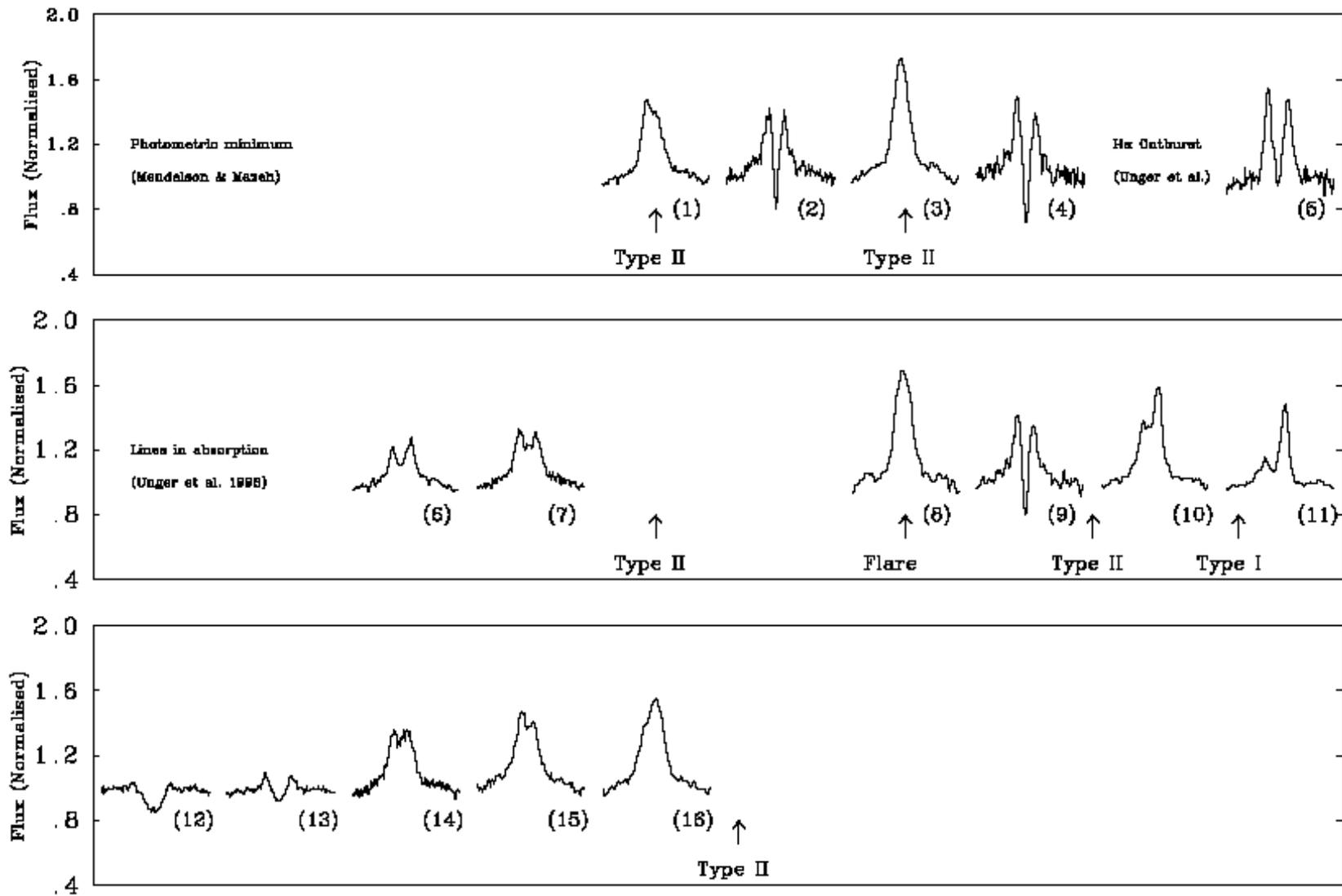


- Peak accretion rate \ll Peak mass-transfer rate
- Type I outbursts likely to favor high e , coplanar systems.

(4) On Type II X-Ray Outbursts

- Giant outbursts which last much longer than Type I's
- A few systems show disk warp and precession before Type II outbursts
- Gradual decrease in disk brightness before Type II outbursts
- Be disk is often lost after a Type II outburst

Profile variations in 4U0115+63

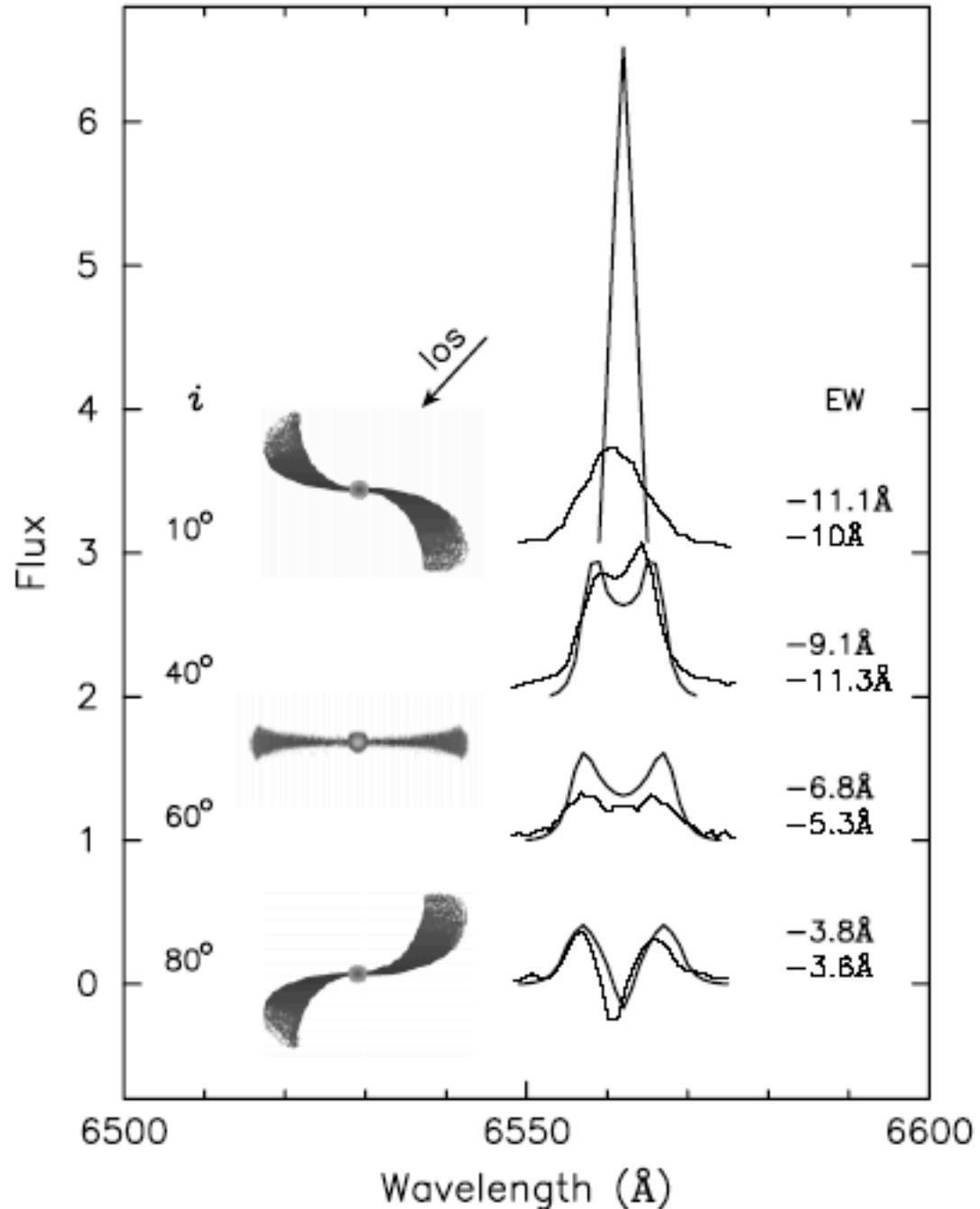


(Negueruela et al. 2001)²⁴

Interpretation

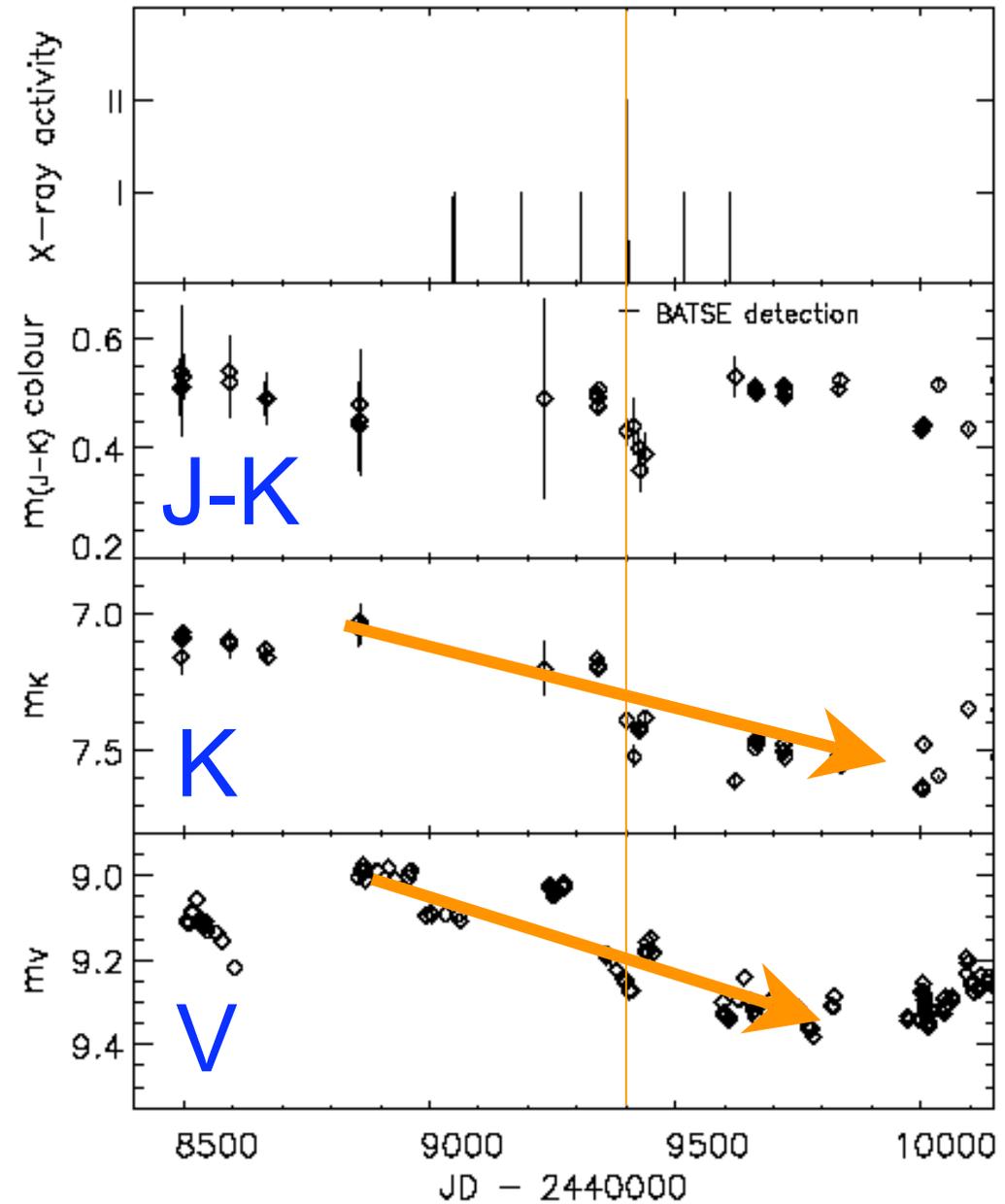
Precessing
warped disk

(driven by
radiation from
the Be star?)
(Pringle 1996,
Porter 1998)



Be disk
begins to fade
before Type II

A0535+26
(Haigh et al. 2004)



3.2. Be Disks in Other Binaries

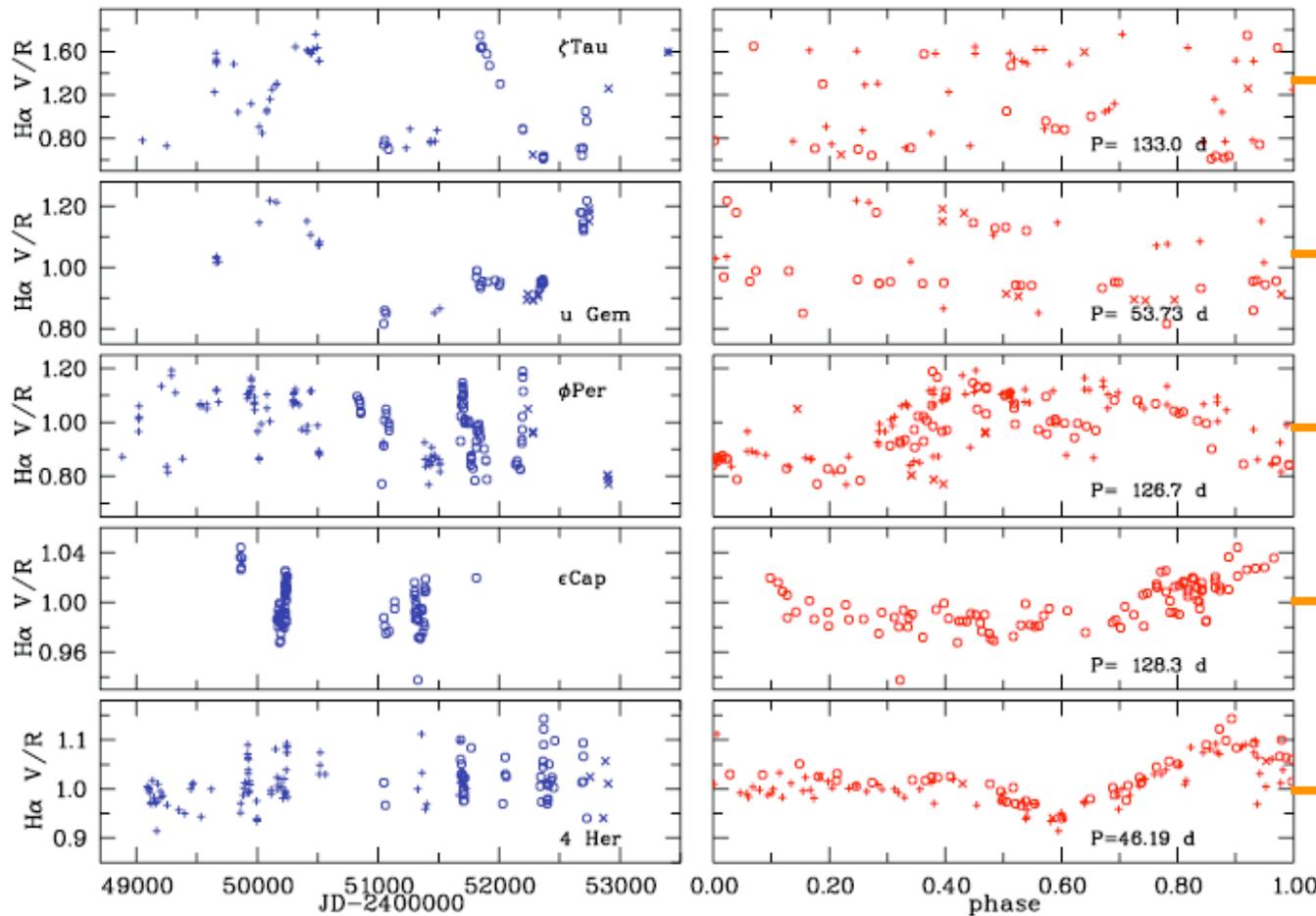
Other features not observed in isolated Be stars

- Two types of **global disk variations**
 - **Synchronized with orbital phase**
 - Similar to normal V/R variations, but the line profile has **a triple peak** over a range of V/R phase
(Stefl et al. 2006)
- **Precession** of the Be disk (Hirata et al. 2006)

V/R variations in binary Be stars

Figure 1. Temporal V/R variations of ζ Tau, ϵ Cap, 4 Her, ϕ Per, ψ Per, ν Gem (left panels) and sorted with the orbital periods (right panels). Observations from HEROS and FEROS spectrographs are represented by the \circ symbols, those from the Ondřejov slit spectrograph by the \times symbols.

(Stefl et al. 2006)



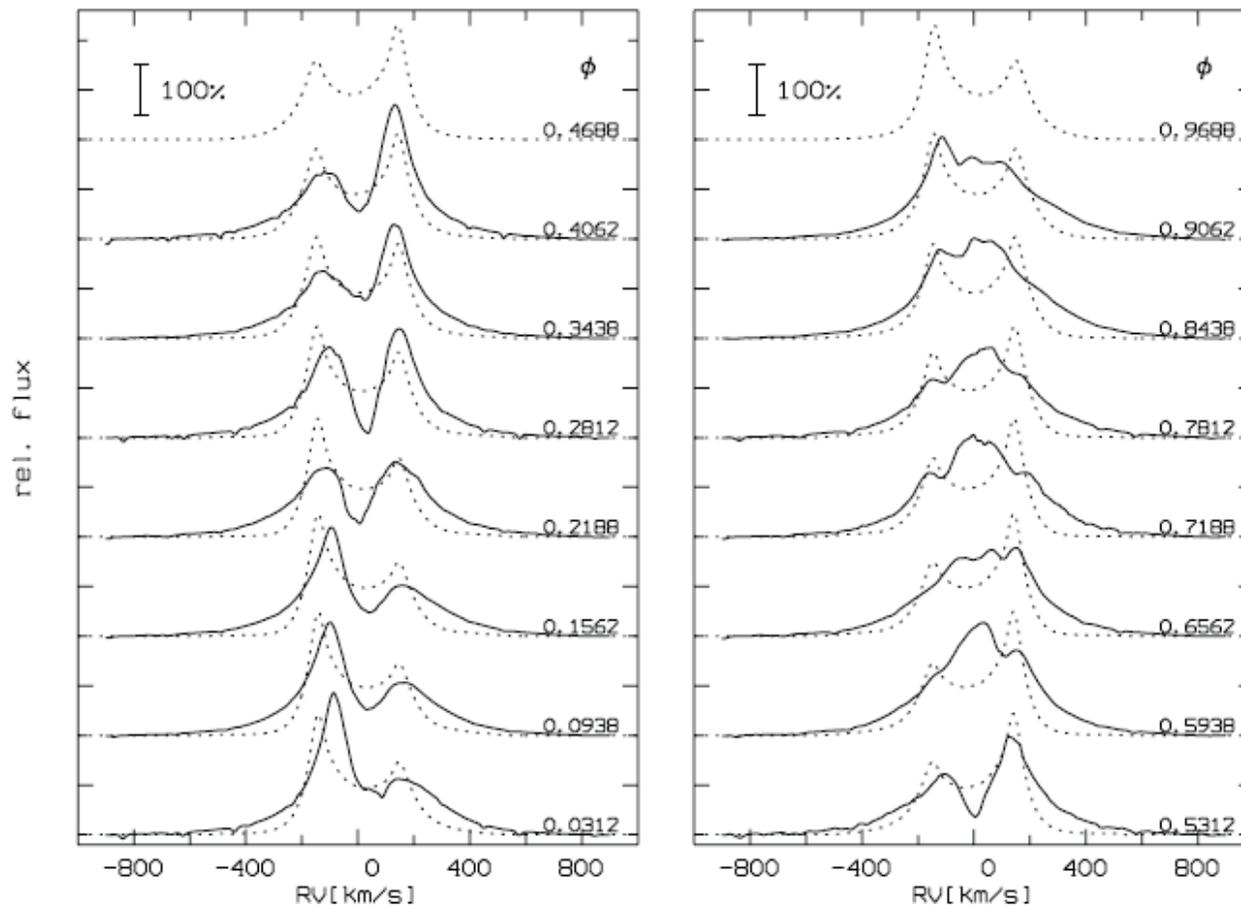
No sync.
(zeta Tau,
nu Gem)

Sync.
(phi Per,
eps Cap,
4 Her)

V/R variation of zeta Tau

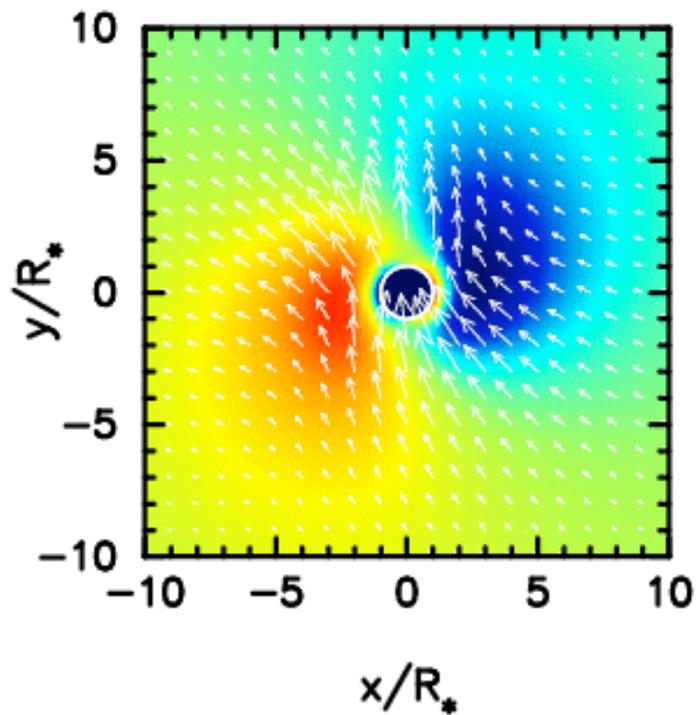
Figure 3. ζ Tau: H α line profiles. Observations averaged in 16 phase bins corresponding to the cycle of 1503 d. $m=1$ model profiles (dotted lines) were computed for $\tau_0 = 10^3$ and parameters summarized in Tab. 2. No profiles in phase bins around 0.4688 and 0.9688 were obtained.

(Stefl et al. 2006)

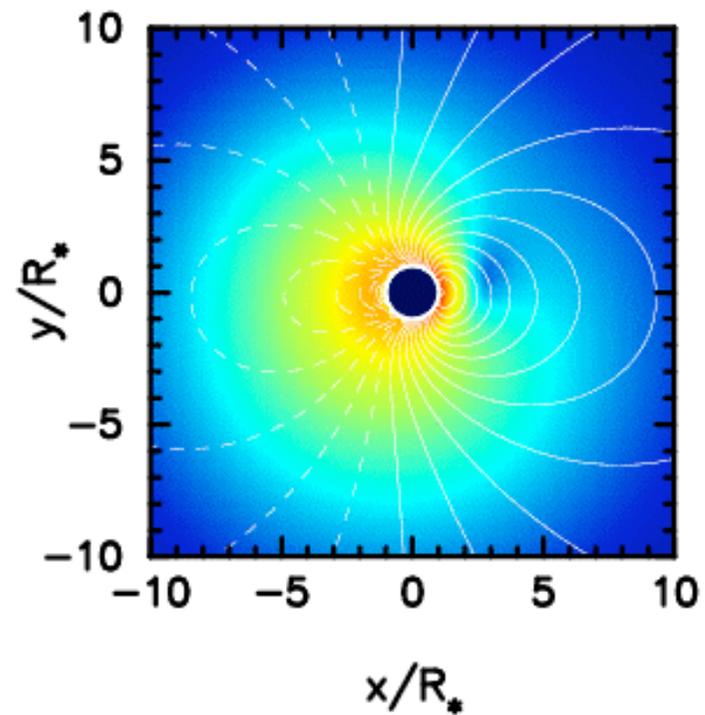


Third peak shows up in the 2nd half of V/R cycle

$m=1$ mode on a viscous decretion
disk of zeta Tau ($\alpha=0.1$)

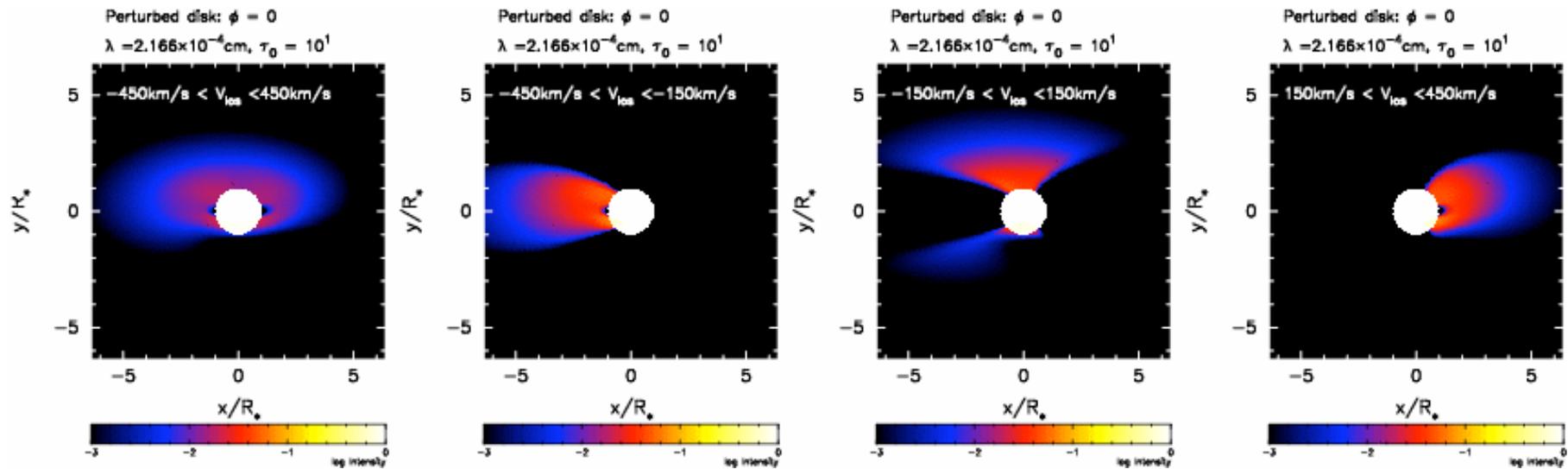


Perturbation



Total density

Asymmetric intensity map for an eccentric disk of zeta Tau



No spectral
resolution

-450km/s
< V(los) <
-150km/s

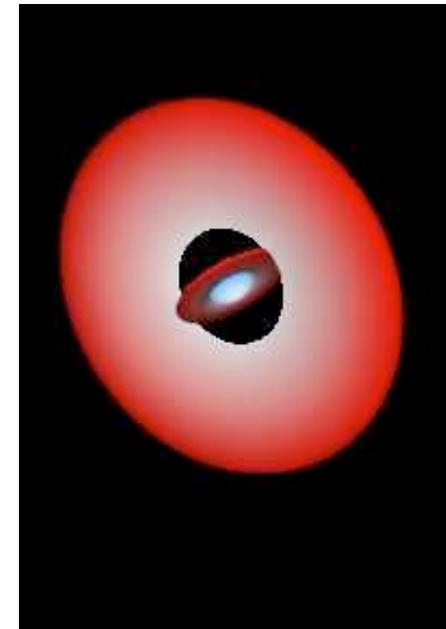
-150km/s
< V(los) <
+150km/s

+150km/s
< V(los) <
+450km/s

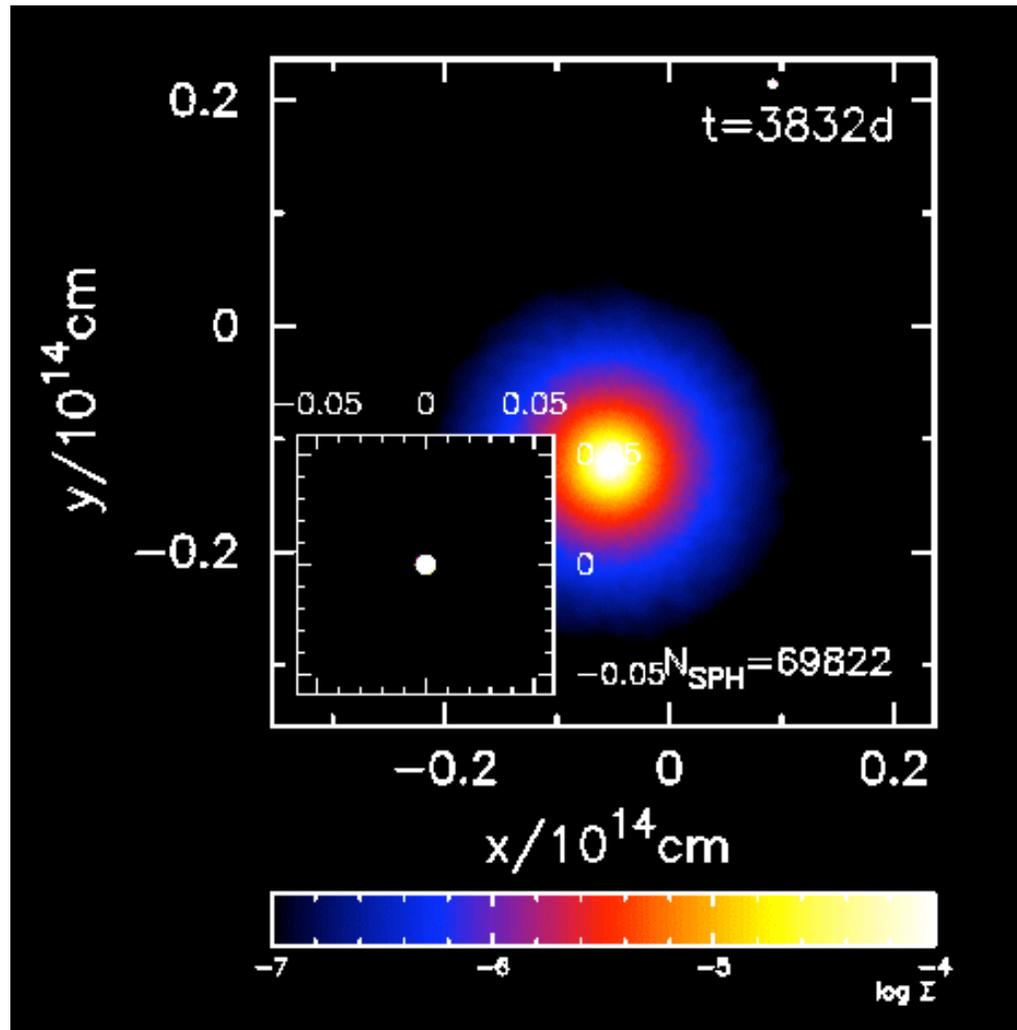
Disk precession & emergence of a new disk in Pleione ($P_{\text{orb}}=218$ d, $e=0.6$)

(Hirata 2006)

- Disk precession (period ~ 81 yr)
 - { Polarization angle: 60 deg \Rightarrow 130 deg
 - { H_{α} : Edge-on type \Rightarrow Pole-on type
- Recently emerged inner disk is about to begin contact with the outer old disk



Companion-disk encounter in delta Sco at the next periastron passage



4. Conclusions

Presence of companion adds interesting complexities on dynamics of Be decretion disk.

- Tidal truncation of Be disk at a radius depending on orbital parameters.
- Strongly phase-dependent interaction with companion in eccentric binaries. Transient density wave excited at companion's periastron passage.

4. Conclusions (continued)

- In Be/X's, accretion rate increases with e . Highly eccentric, coplanar systems favored for Type I X-ray outbursts.

?

Mechanism(s) for Type II outbursts is a biggest mystery of Be/X study.

- Some Be binaries show:

?

Phase-locked V/R variations.

?

Triple-peaked profiles.

?

Disk precession