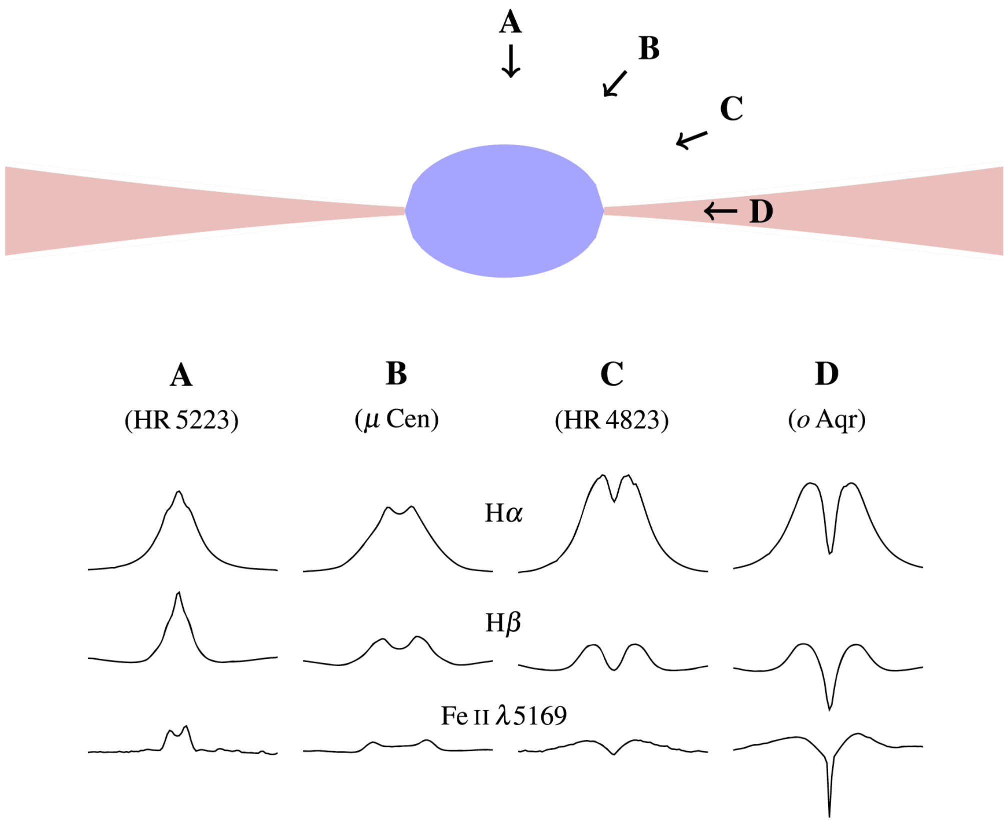
Be stars and disks: their interaction with compact objects

Atsuo Okazaki (Hokkai-Gakuen U.)

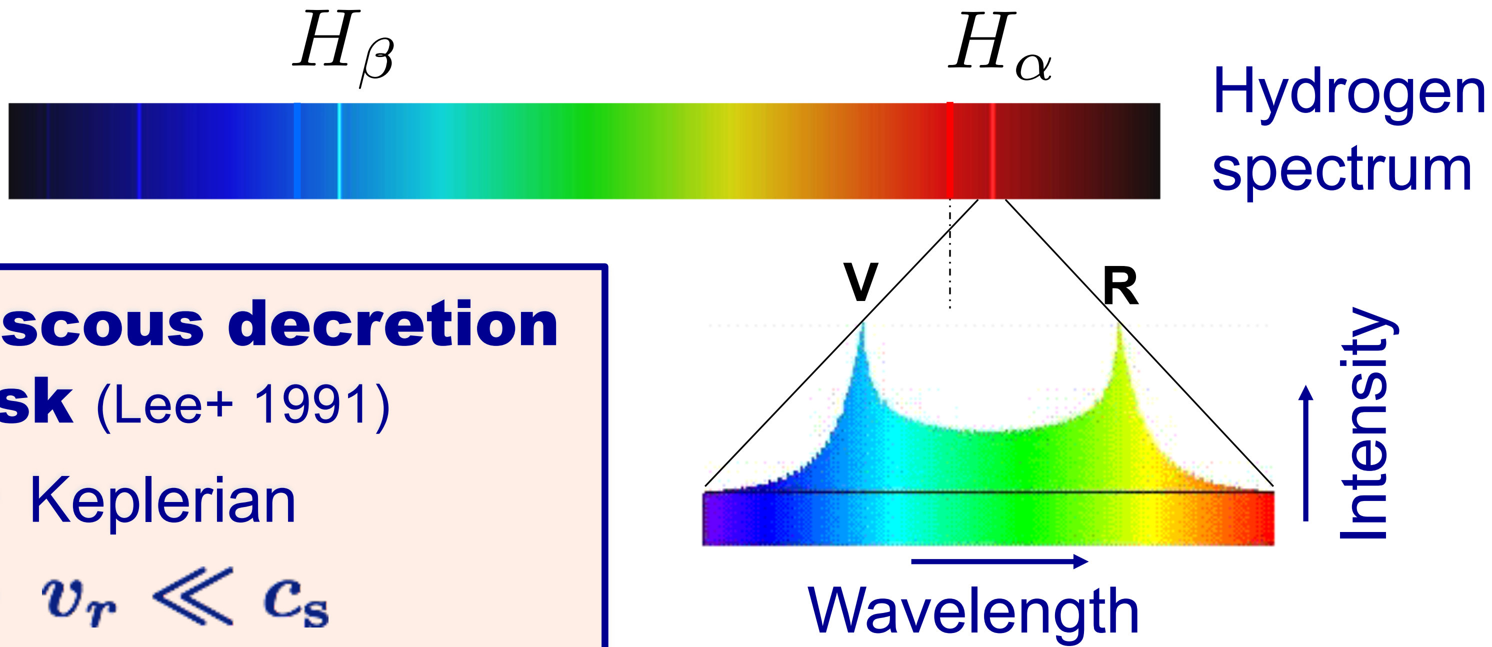
Be stars

- Definition: Non-supergiant B-type stars, which once has shown Balmer lines in emission (Collins 1977)
- Central star rotates at a rate close to critical
- Circumstellar envelopes
  - Line-driven wind emitting UV radiation
  - Equatorial disk with optical emission lines and IR excess



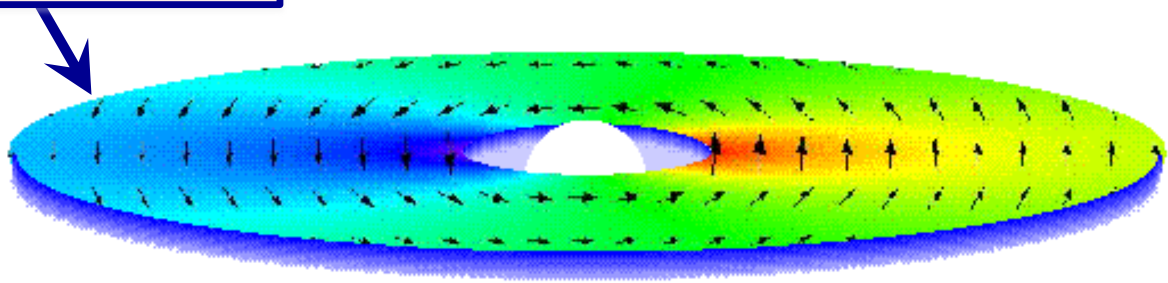
(Rivinius+ 2013)

Be disks



Viscous decretion disk (Lee+ 1991)

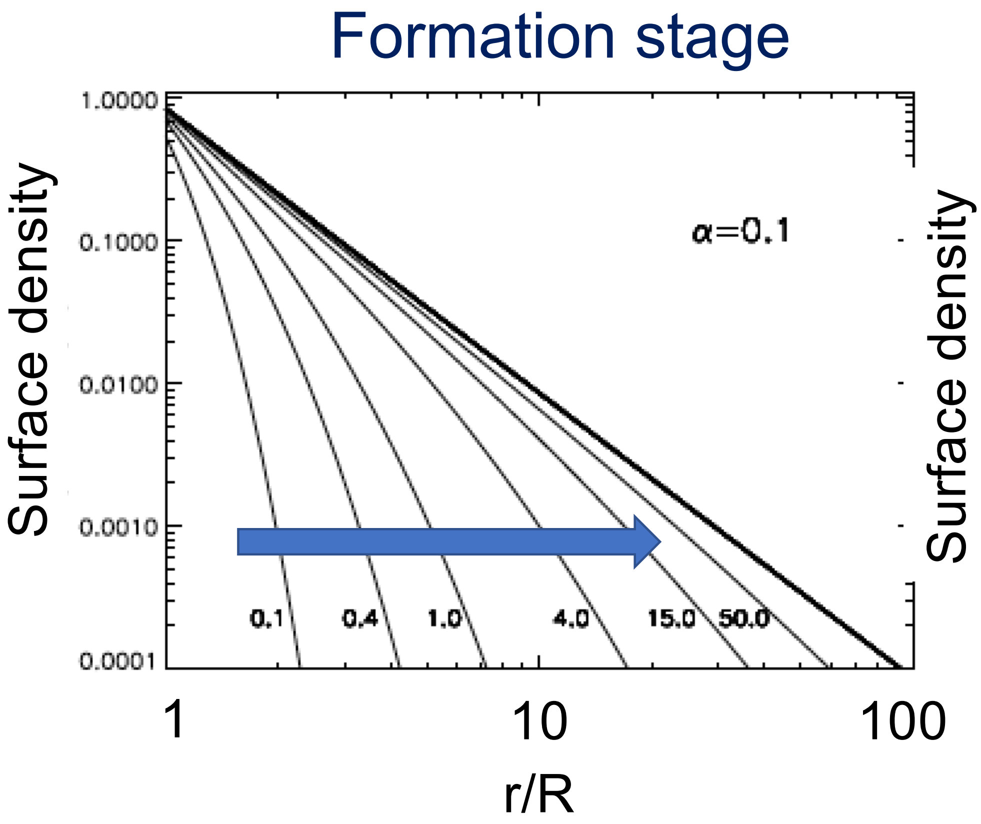
- Keplerian
- $v_r \ll c_s$

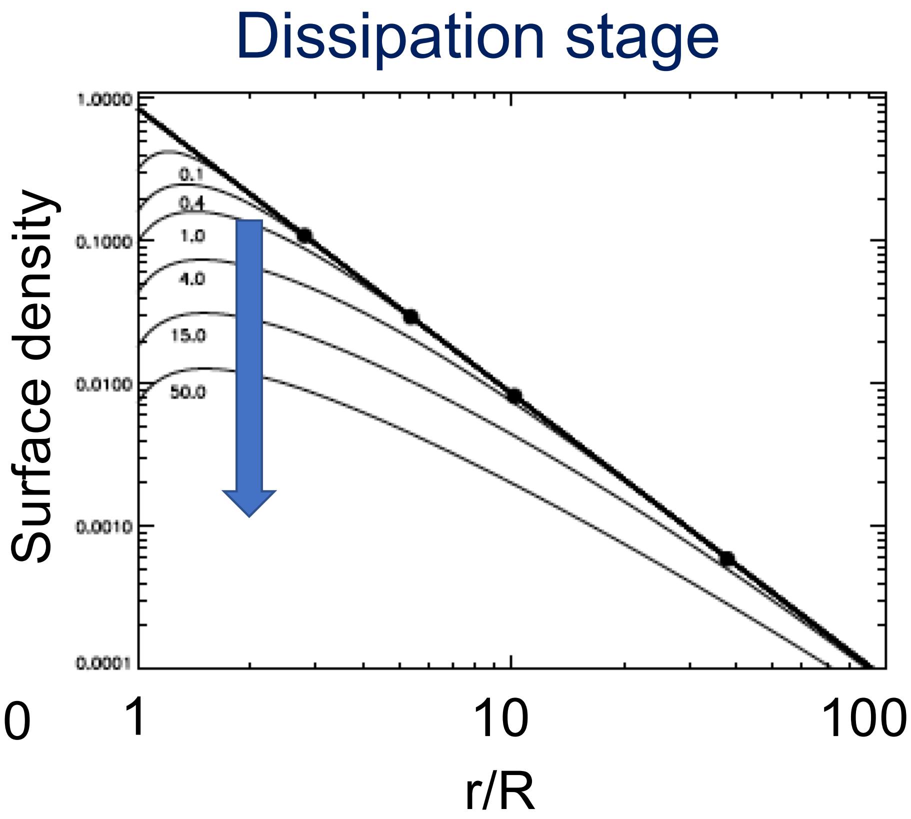


Courtesy of Stan Owocki

Disk formation and dissipation in single Be

(Haubois+ 2012)

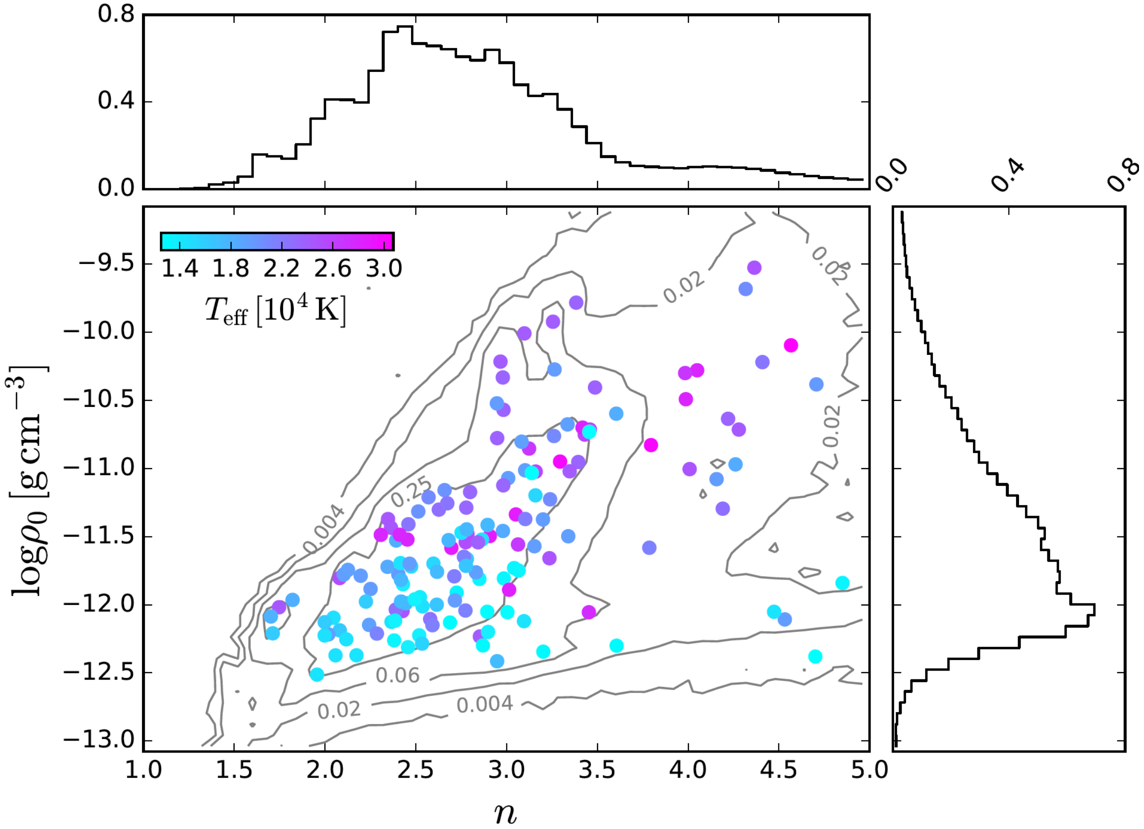




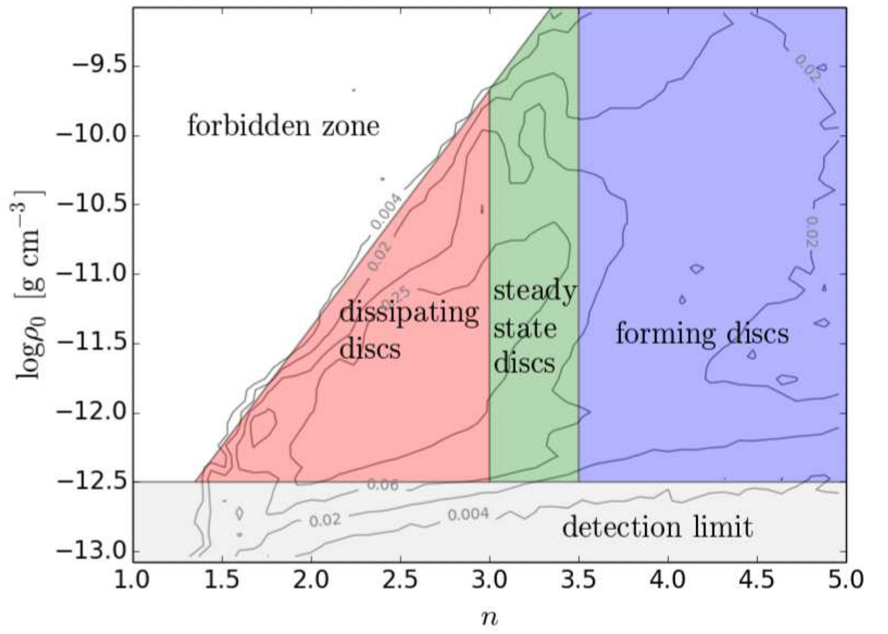
Be disk life cycle

(Vieira+ 2017)

IR+radio SED fitting of 169 Be stars

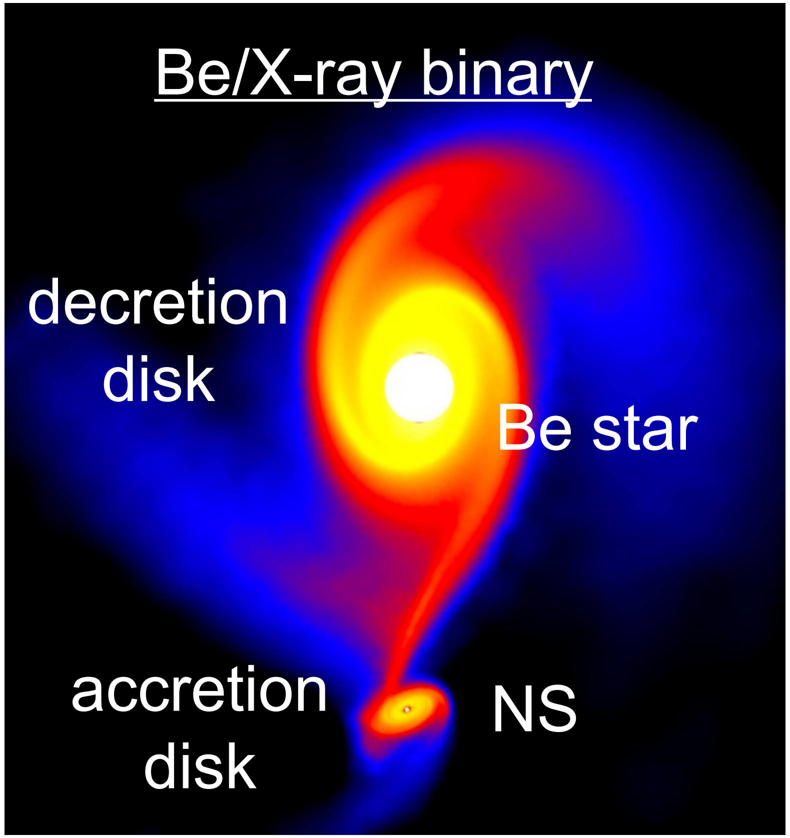


Interpretation



Be star population

- <10% of B0e in MW, while 35% of B0e in SMC (Martayan 2010)
- ~50% of high-mass X-ray binaries have Be star as mass donor (=Be/X-ray binaries). (Other ~50% are SG systems.)
- ~50% of gamma-ray binaries have Be stars as optical companion. (Other ~50% are O-star systems.)



Interactions in binaries

- **Effects of NS/BH on Be-star's circumstellar disk**
  - Tidal truncation (Artymowicz & Lubow 1994)
  - Tidal warping/precession (Martin+ 2011; Suffak+ 2022)
  - Radiation-driven warping/precession (Pringle 1996)
  - Kozai-Lidov oscillations of disk eccentricity and inclination (Martin+ 2014; Suffak+2022)
- **Mass transfer from Be disk to accreting NS/BH**
- **Collision of Be disk and stellar wind with pulsar wind in systems with non-accreting pulsars**

On the origin of optical variability in PSR B1259-63

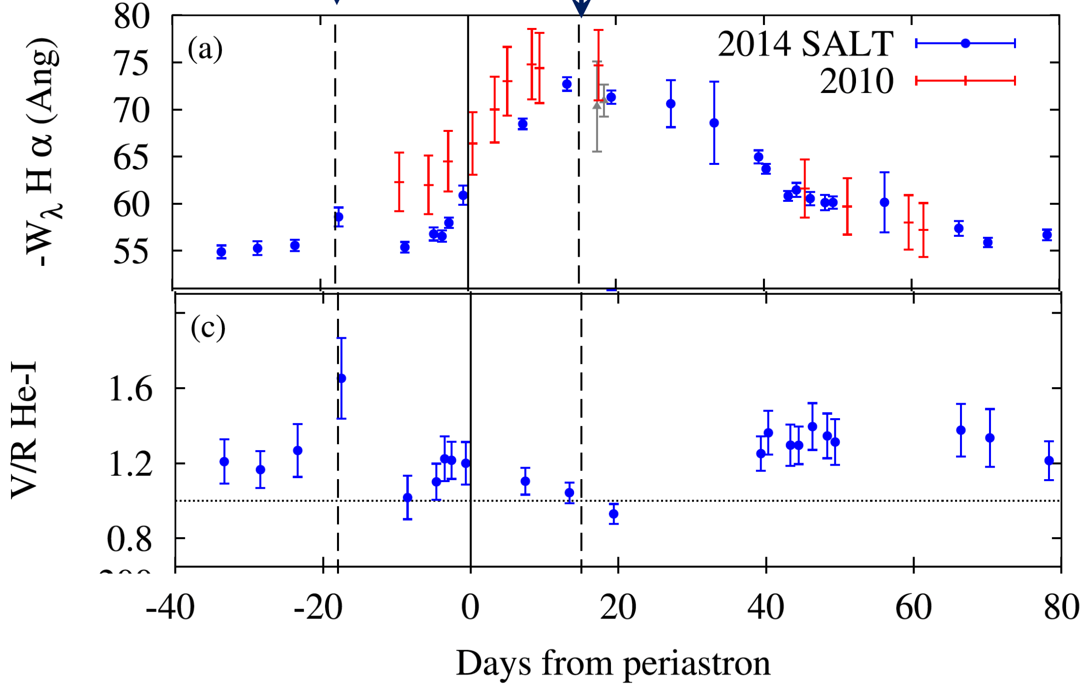
<u>Variability of optical emission lines</u>

(e.g., van Soelen+ 2016; Chernyakova+ 2021)

- H-alpha equivalent width (EW) started to increase sightly before periastron, and, reached a maximum around 2nd disk crossing, and then decreased gradually.
- H-alpha EW & V/R (He I) showed a change around 1st disk crossing.

1st disk crossing

2nd disk crossing



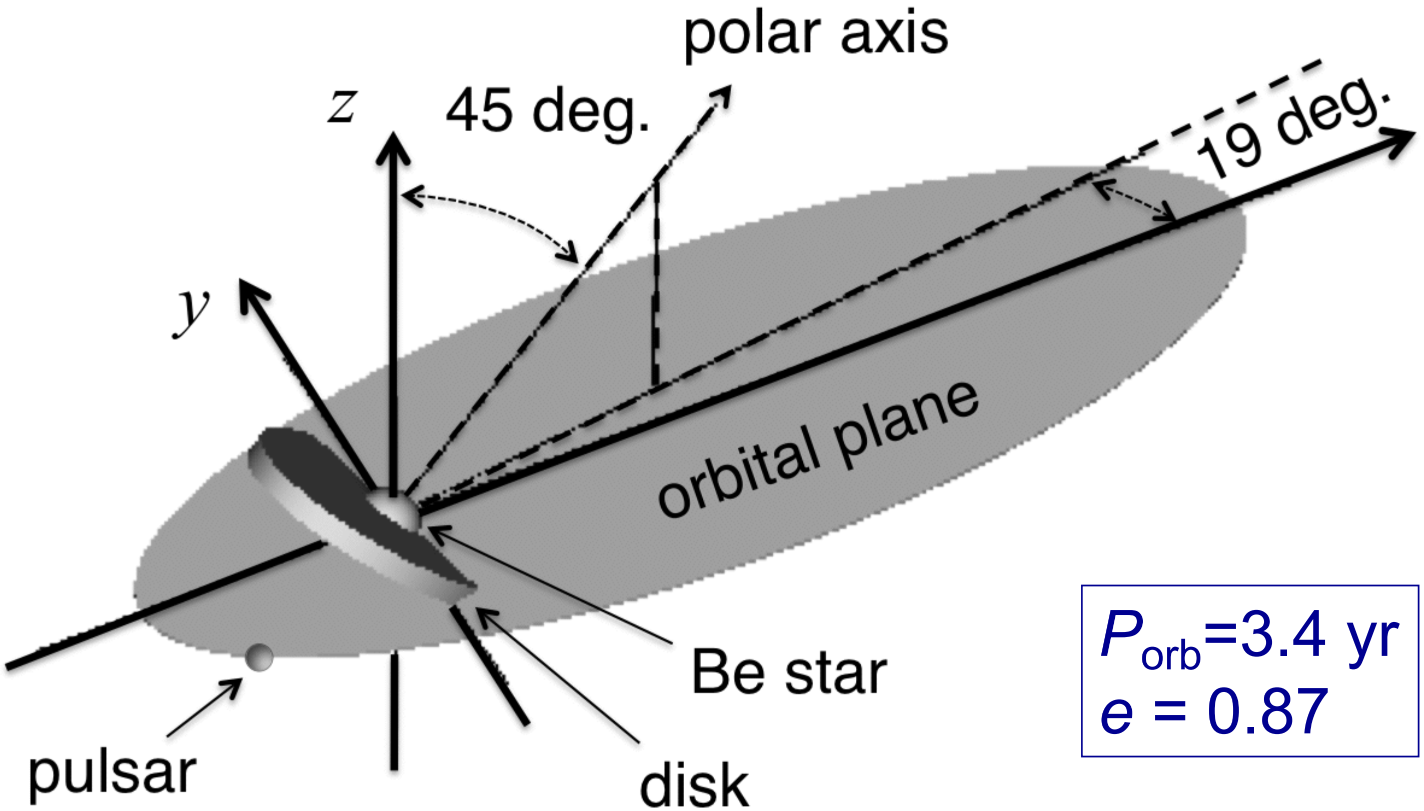
(van Soelen+ 2016)

Method

- 1st stage
  Run SPH simulations for three different cases:
  - without pulsar wind (PW) and stellar wind (SW). Typical disk density.
  - with PW and SW. Typical disk density.
  - with PW and SW. 10 times dense disk.
- 2nd stage
  Compute variability of H-alpha line profile for data from each of three simulations and compare them.

Numerical setup

Model configuration



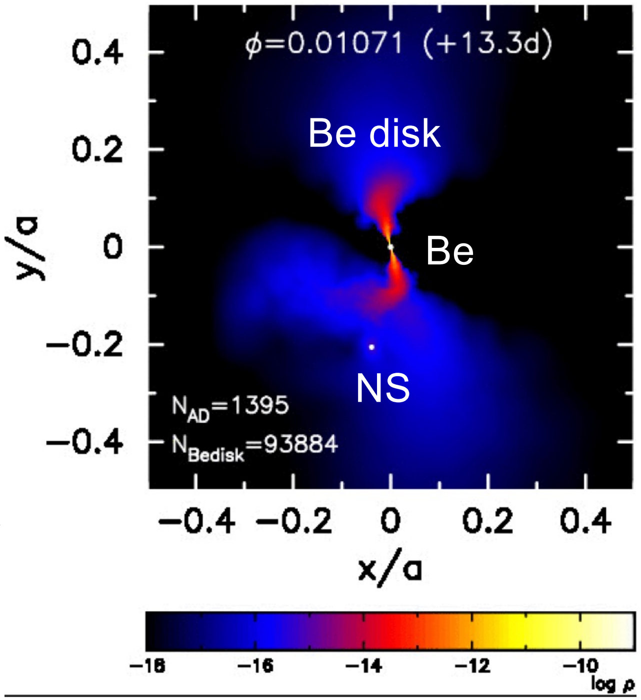
P_{orb}=3.4 yr
e = 0.87

(Okazaki+ 2011)

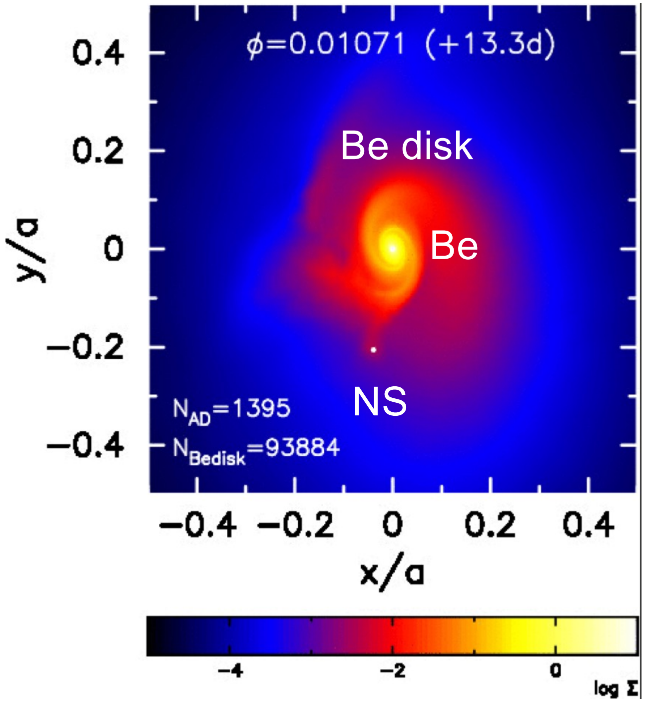
Simulation without PW and SW

- Simulation was run until the disk is fully developed.
- Be disk is assumed to be isothermal at Tdisk = 0.6Teff.
- Shakura-Sunyaev viscosity parameter alpha=0.1 is emulated, using artificial viscosity parameters alpha(SPH)=1 and beta(SPH)=0.

Density on orbital plane

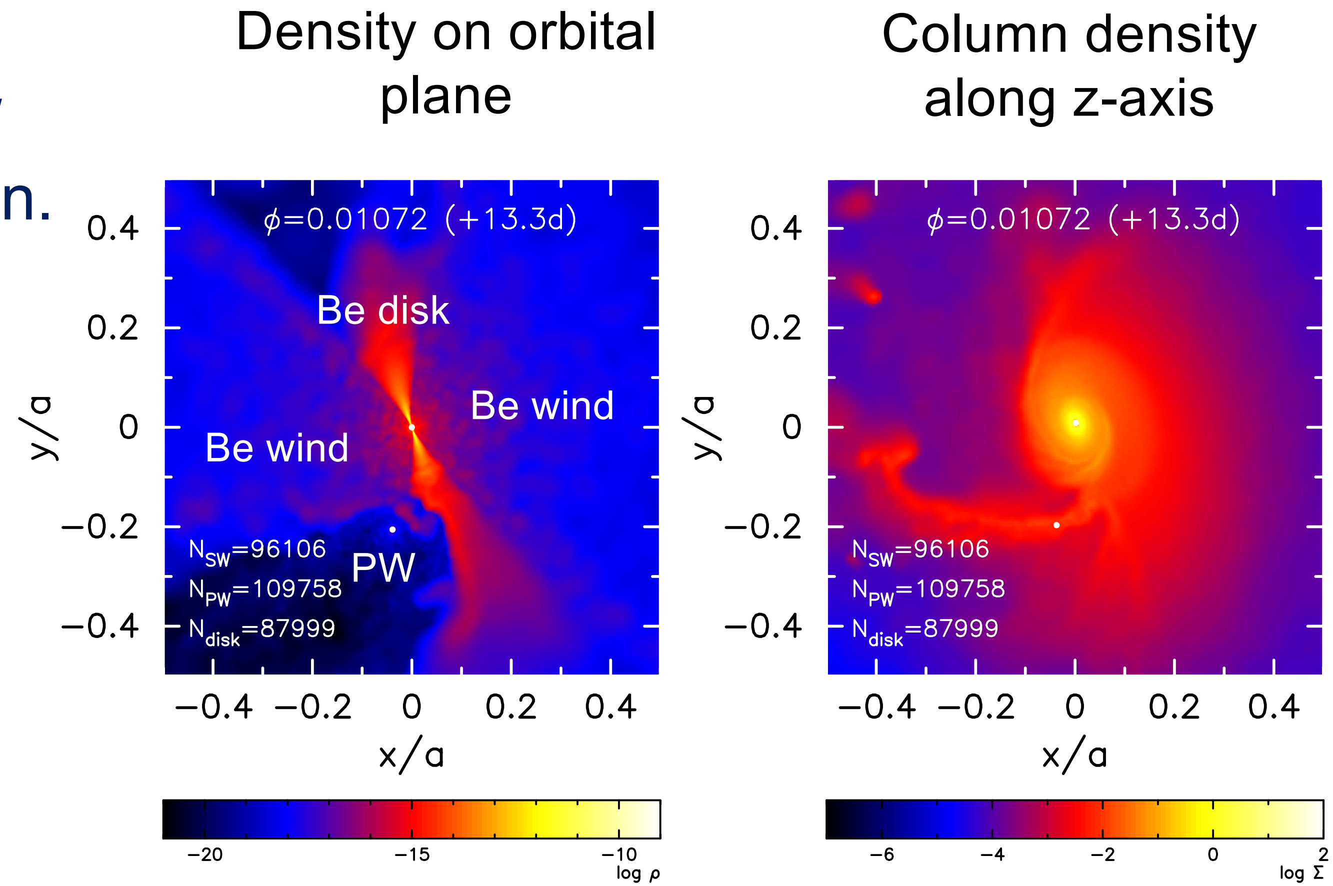


Column density along z-axis



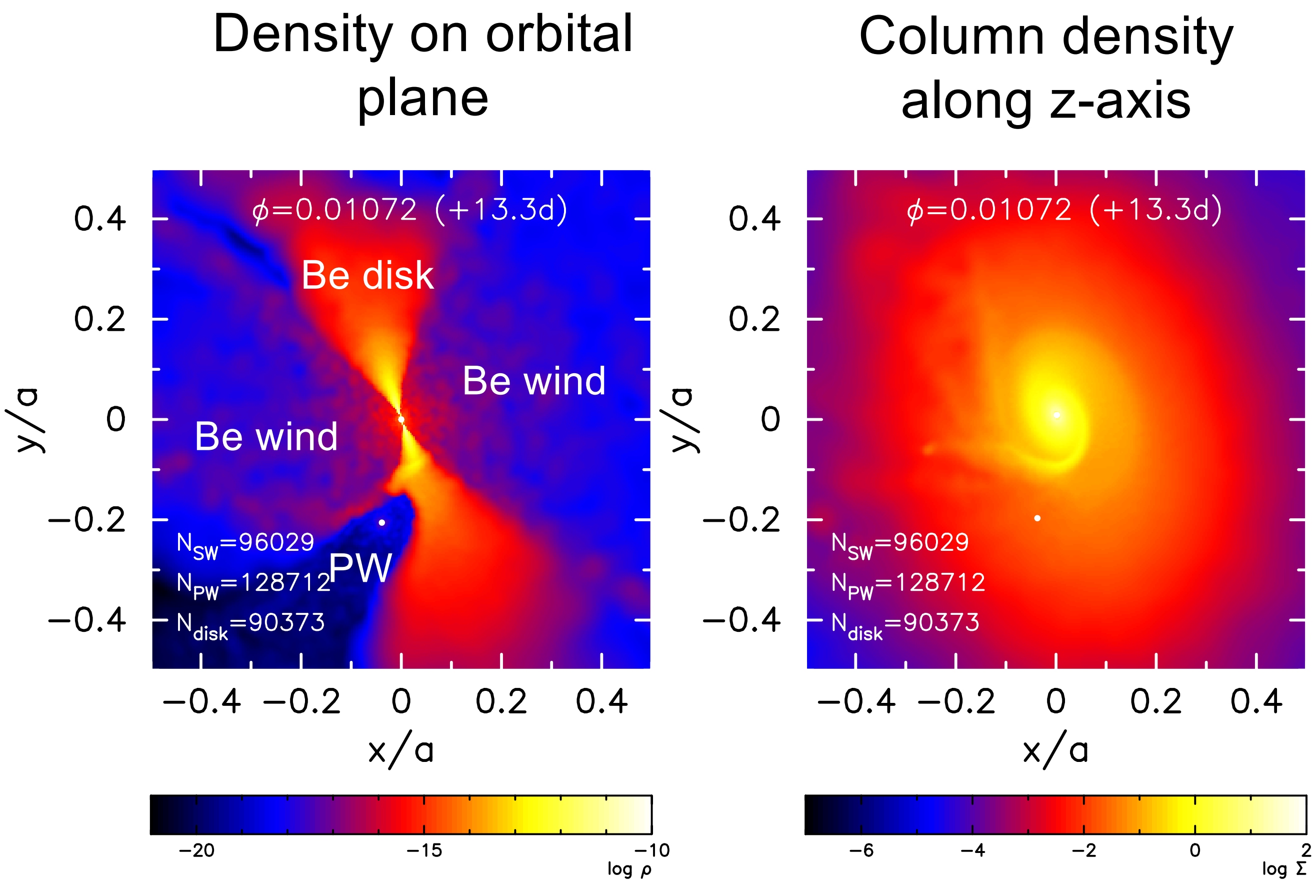
Simulation with PW and SW & typical disk density

- A Be disk is set up initially, and then PW and SW are turned on.
- w/ optically thin, radiative cooling
- Artificial viscosity: alpha(SPH)=1, beta(SPH)=2.



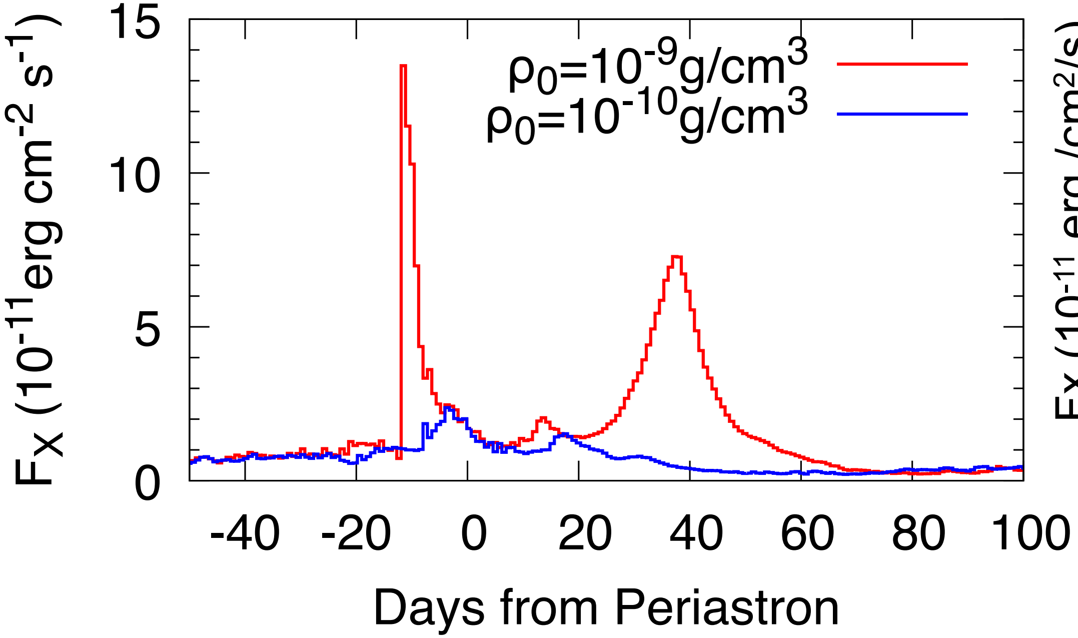
Simulation with PW and SW & 10x dense disk

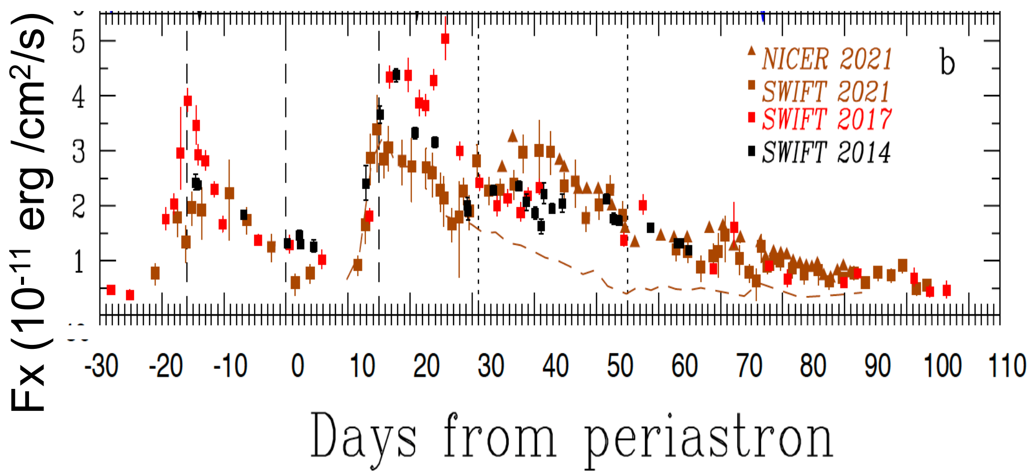
- Same parameters as those for typical density case, except that initial disk density is increased by a factor of 10.



High energy emission from shocked PW regions

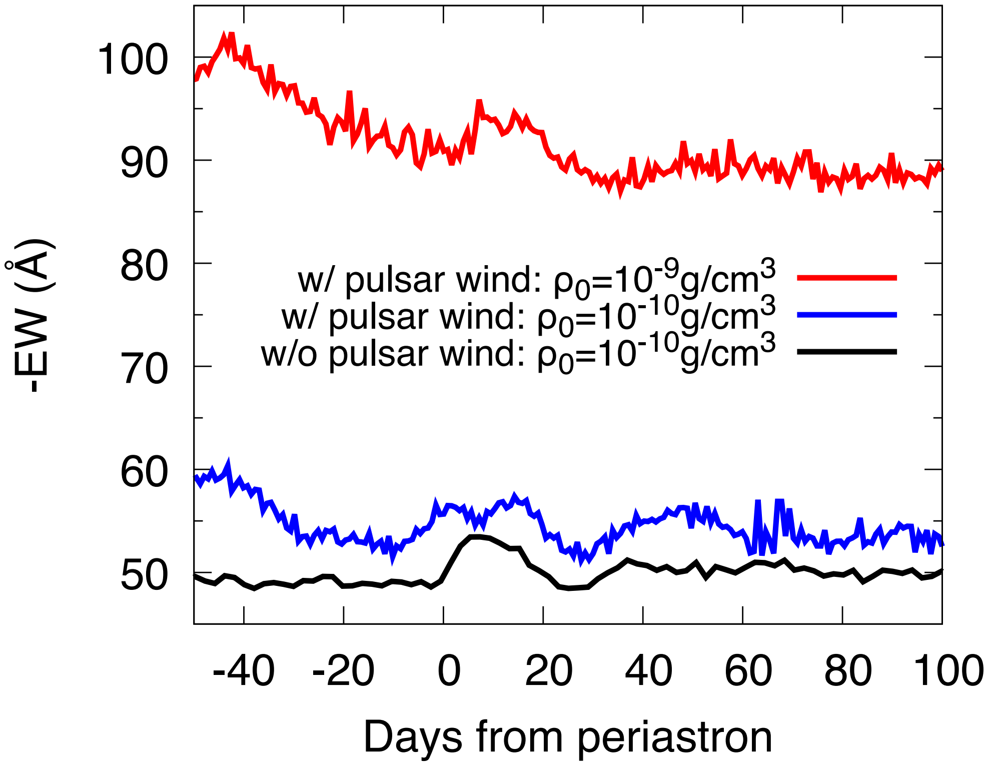
X-ray (0.3-10keV) light curves



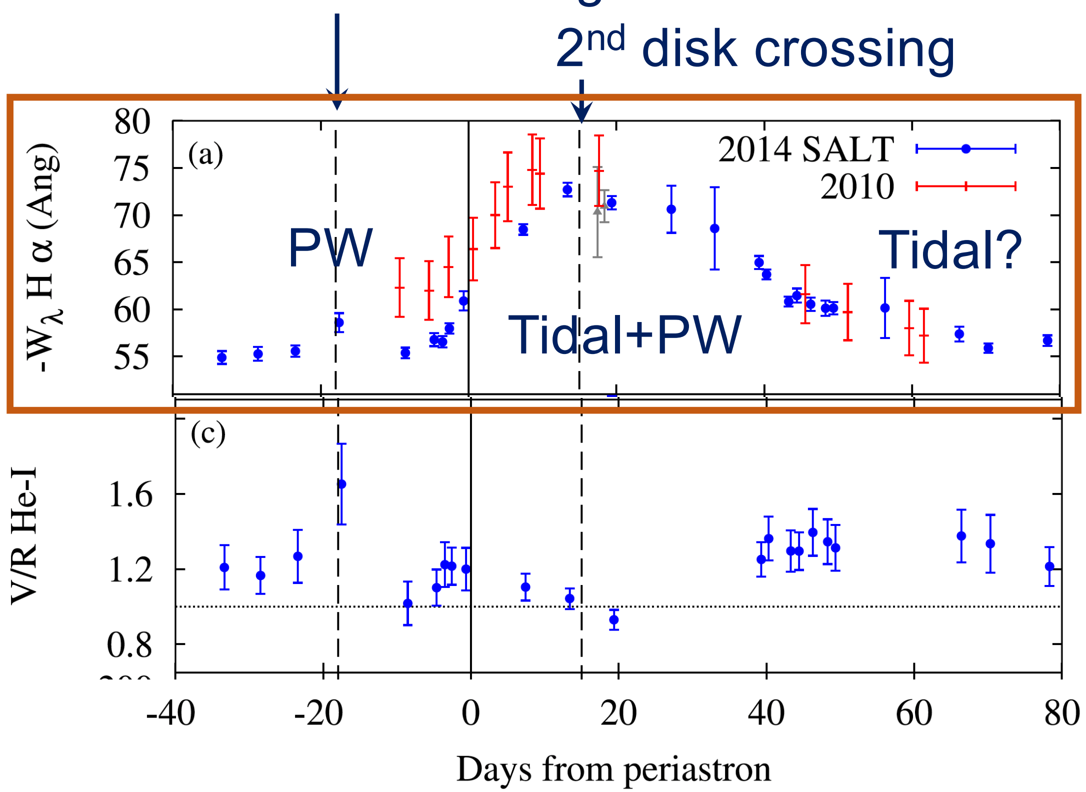


Variability of H-alpha emission: EW(H-alpha)

Simulated variability



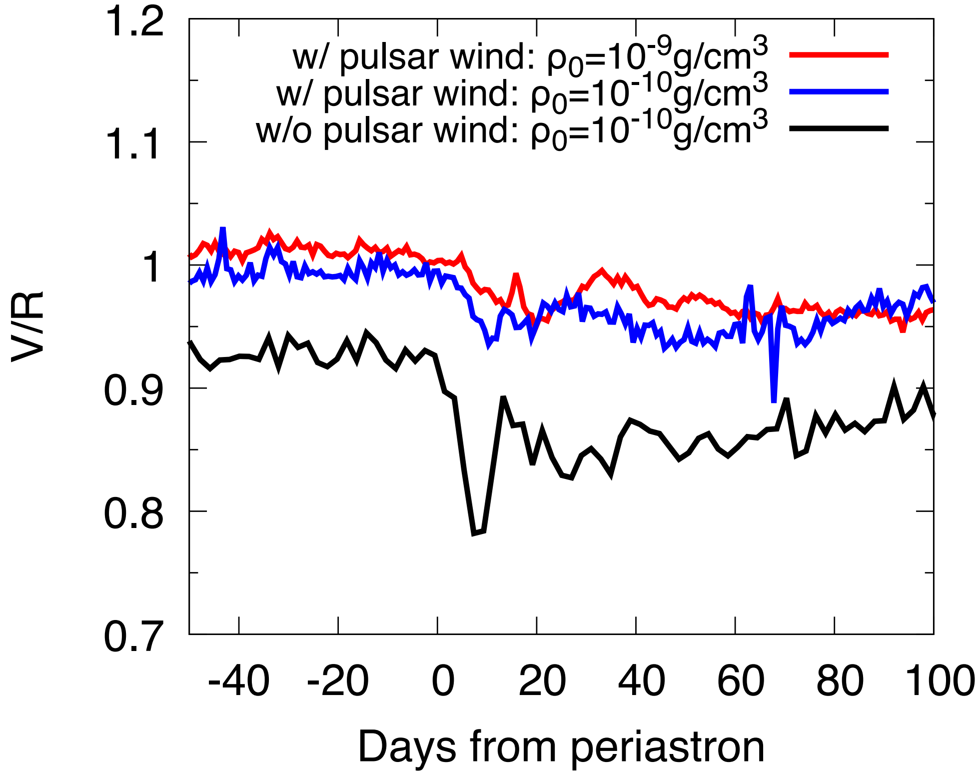
Observed variability



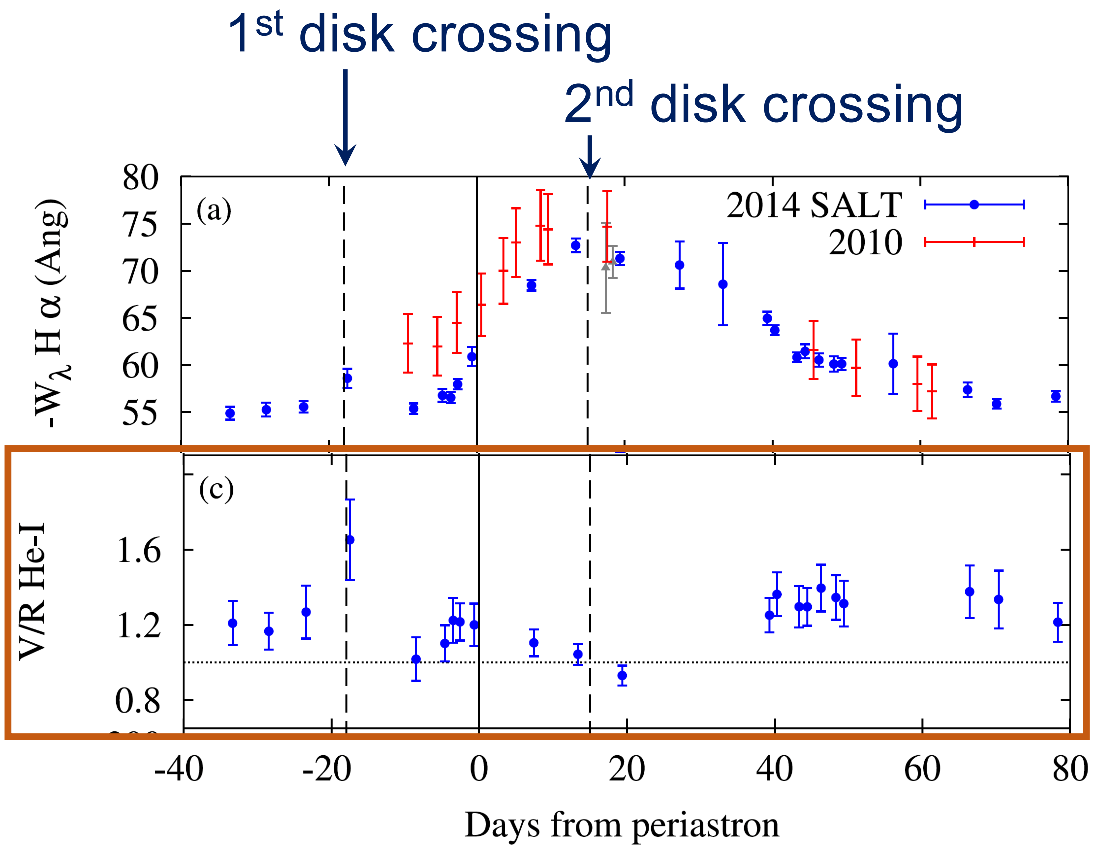
(van Soelen+ 2016)

Variability of H-alpha emission: V/R

Simulated variability



Observed variability



(van Soelen+ 2016)

Summary

- We studied the origin(s) of optical (H-alpha emission line) variability, using SPH simulations w/o PW or SW, w/ PW and SW with typical and 10x dense disk density for PSR b1259-63.
- We found that in the EW variability, features caused by the tidal interaction and those by PW can distinguished.
- In PSR B1259-63, increase of EW(H-alpha) around periastron is basically due to the tidal interaction, but the interaction with the PW also contribute to it significantly. On the other hand, change around the 1st disk crossing is solely due to the effect of PW.
- Regarding the V/R variability, the model failed to explain the observed features. More improvements of the model is needed.