Hokkai-Gakuen University

Interaction between the pulsar wind and the circumstellar environment in the gamma-ray binary PSR J2032+4127/MT 91 213

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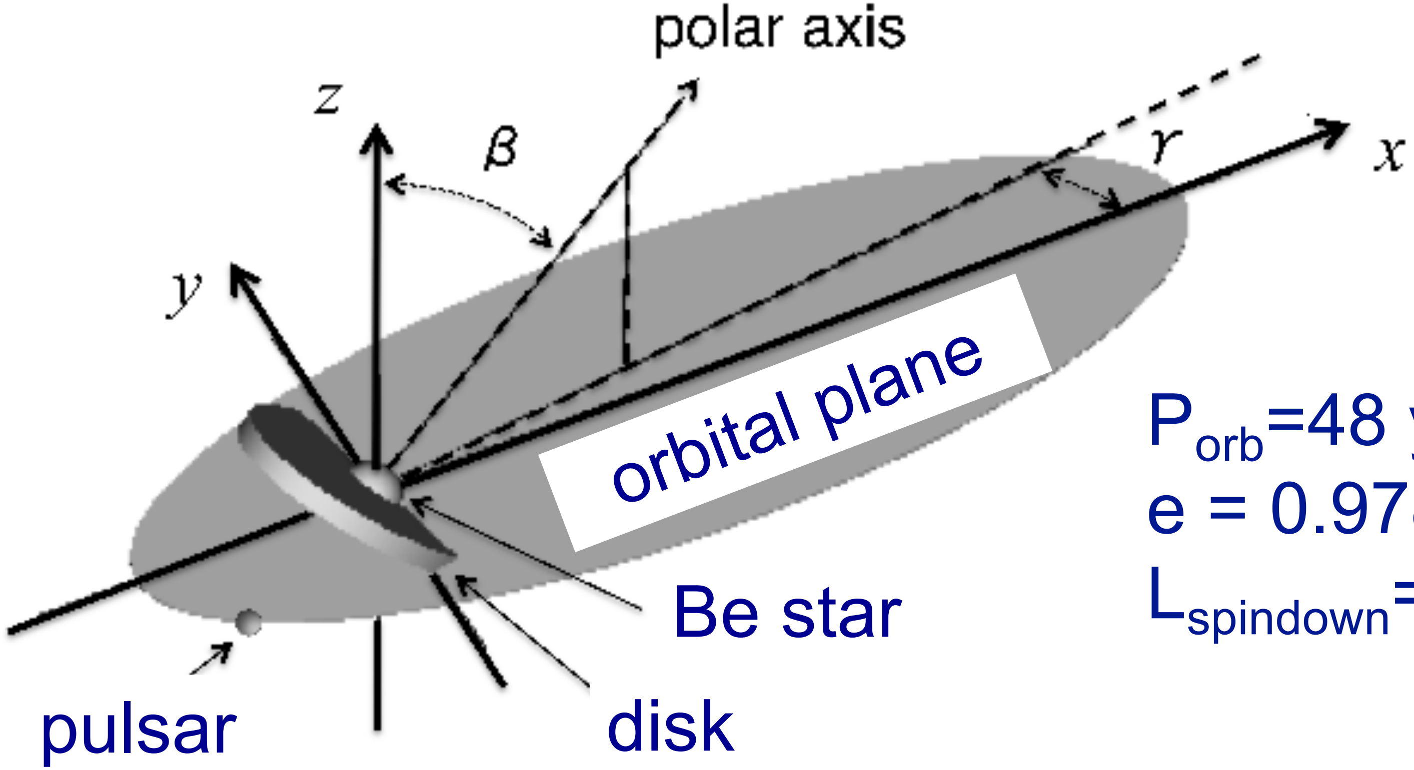
Talk outline

1. Gamma-ray binary PSR J2032+4127
   1.1. System parameters
   1.2. Observed features
2. Dynamic modeling of PSR J2032+4127
3. Concluding remarks

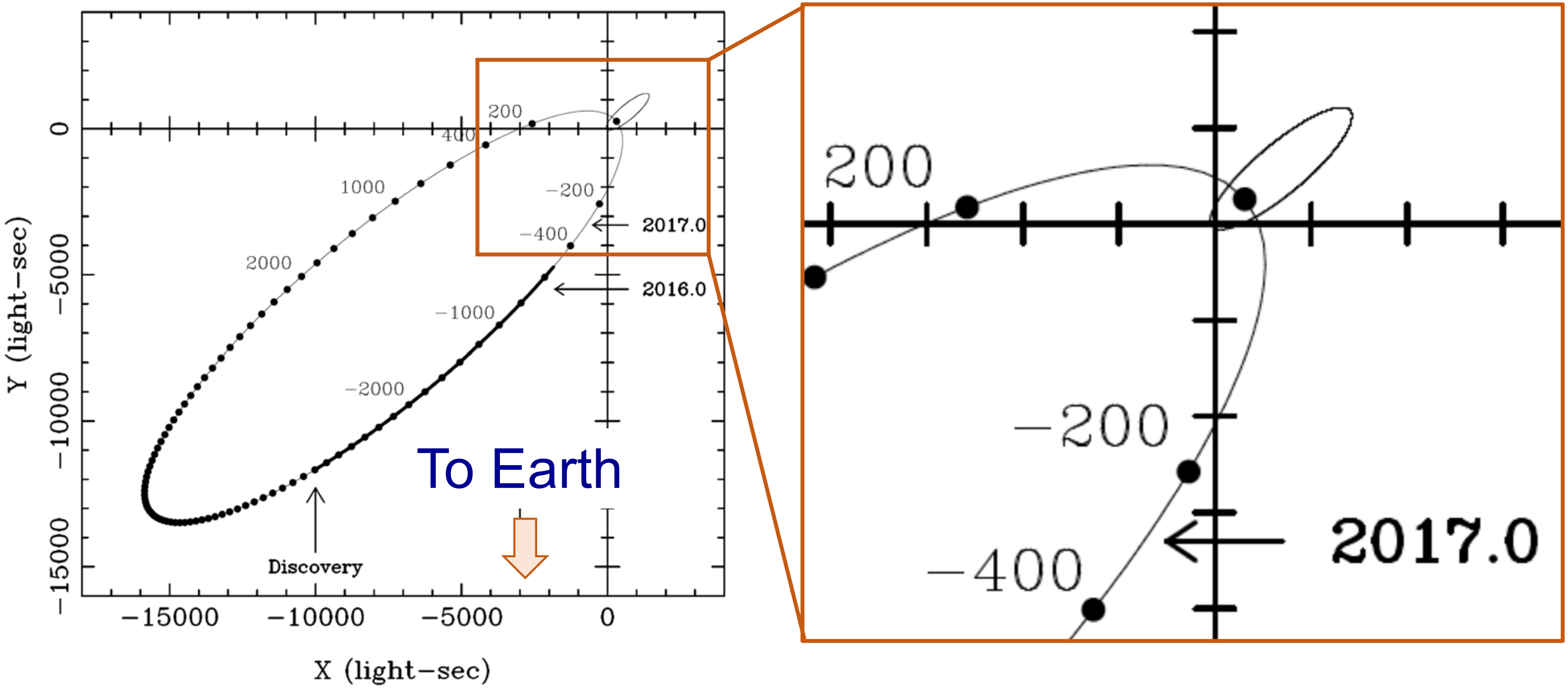
System parameters

PSR J2032+4127	MT 91 213
143 millisecond pulsar	B1e star



P_{orb}=48 yr
e = 0.978
$L_{spindown}$=1.5x10^{35} erg/s

Orbit



(Ho+ 2017)

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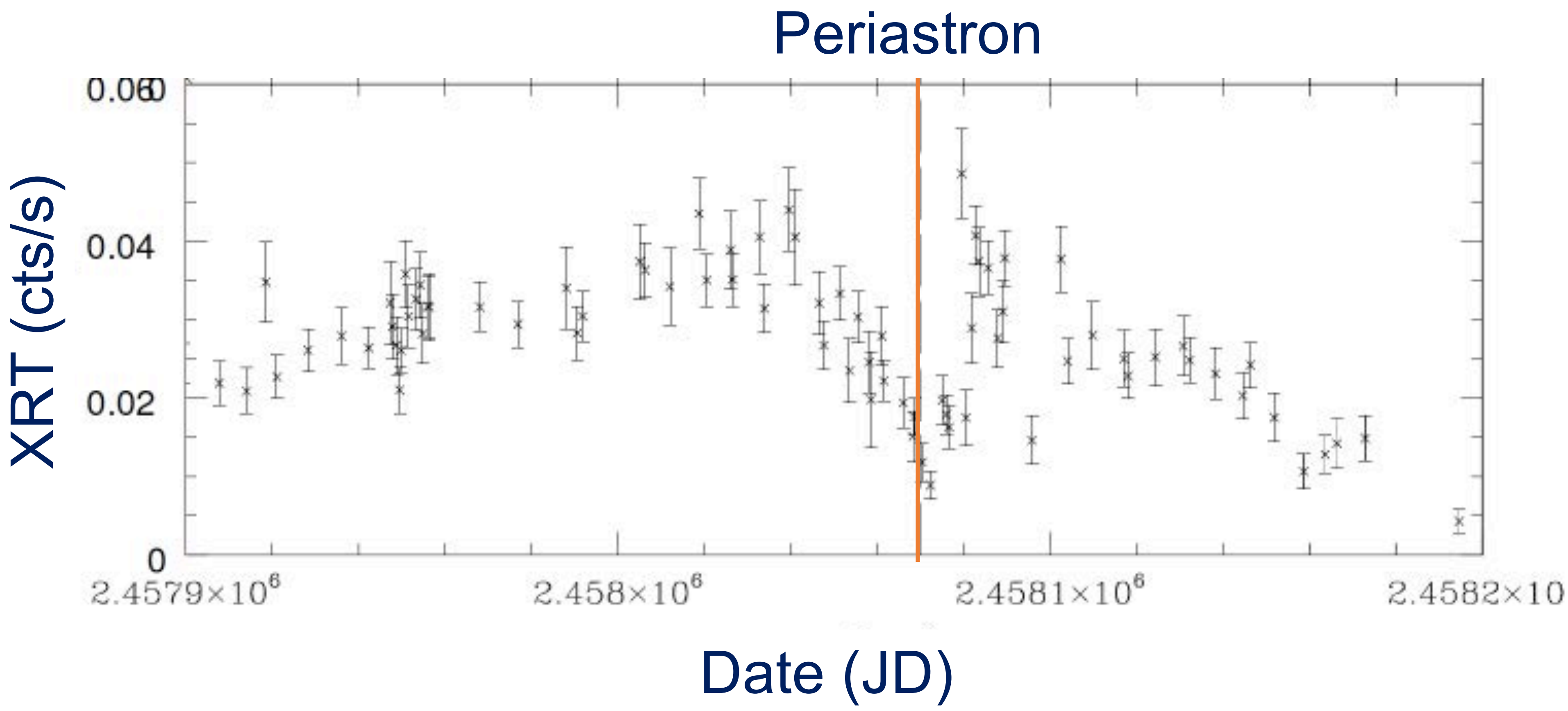
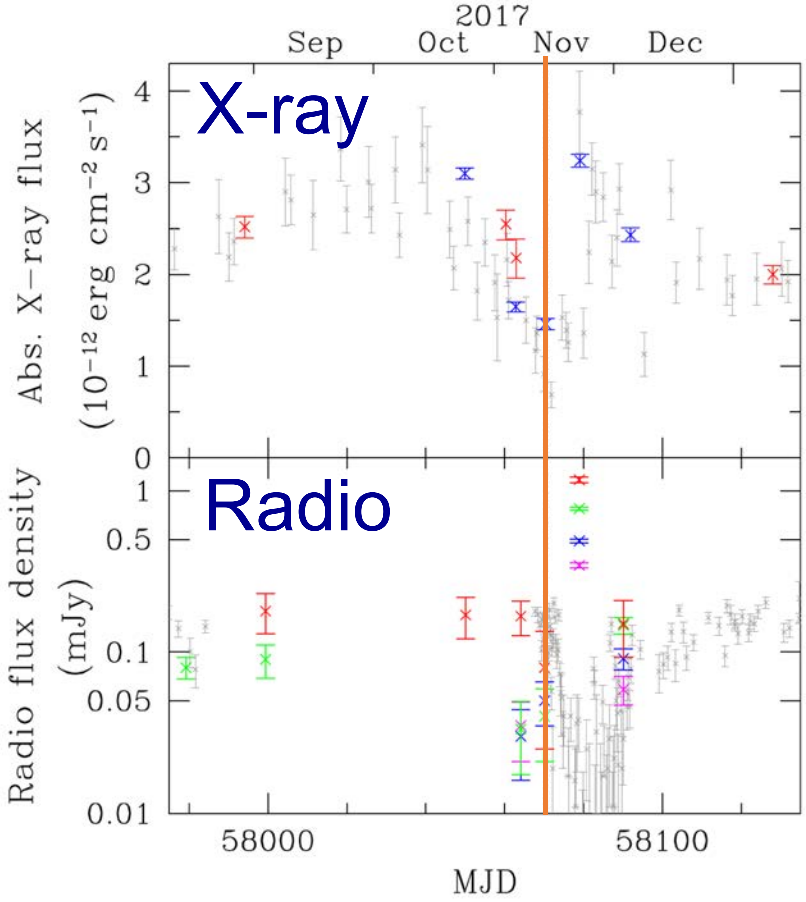
X-ray light curve



(Coe, Okazaki+ 2019)

X-ray and radio fluxes

- X-ray: gradual increase
  - ⇨ dip for ~30d
  - ⇨ flare
  - ⇨ gradual decline
- Radio: pulsed flux disappeared for ~20d
- Simultaneous X-ray and radio flares



Red: Chandra
Blue: XMM Newton +NuSTAR
Grey: Swift

Color: VLA
Grey: pulsed flux

(Ng+ 2019)

Optical variability: EW

- EW(Halpha): Rapid decrease before periastron ⇨ rapid recovery after periastron

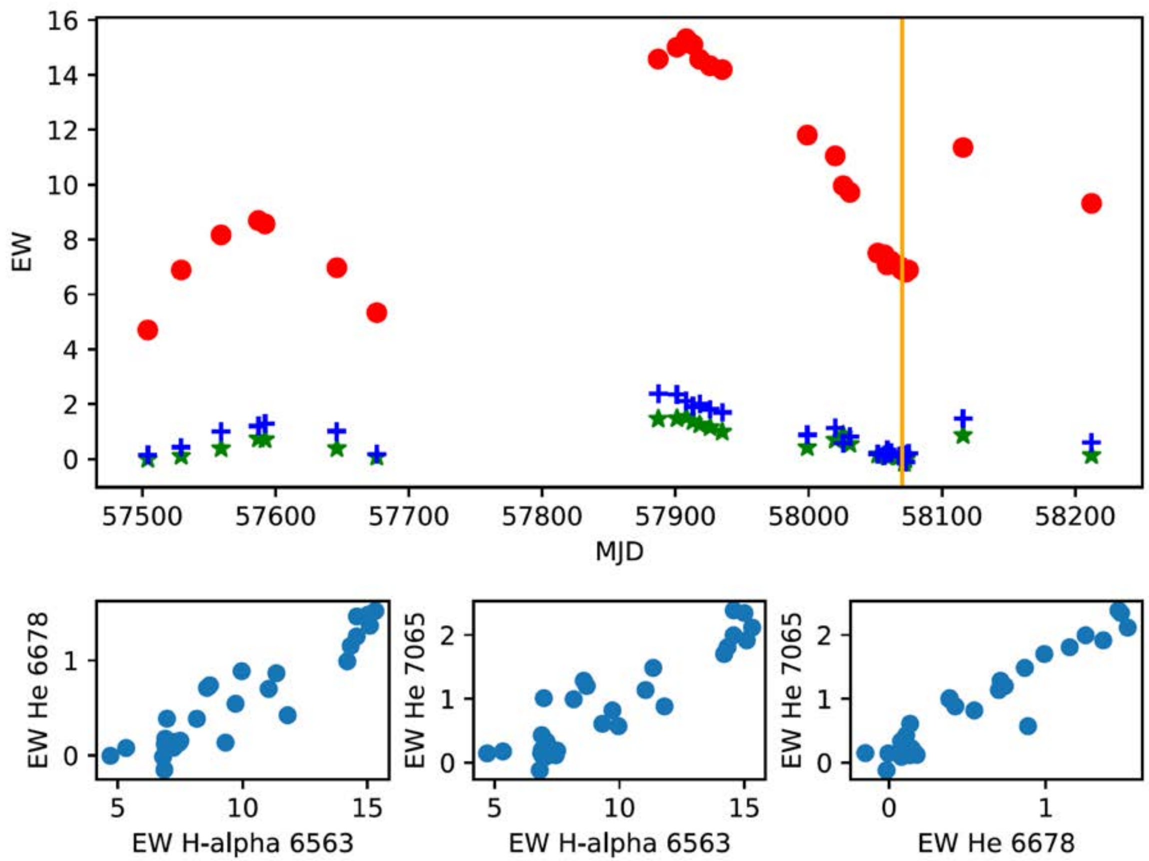


Figure 6. (Top panel) Equivalent widths of Hα (the red solid circles), He I 6678 Å (the green stars), and He I 7065 Å (the blue crosses) versus MJD. The vertical (orange) line indicates the date of periastron. The lower three panels show the correlation of all three equivalent widths.

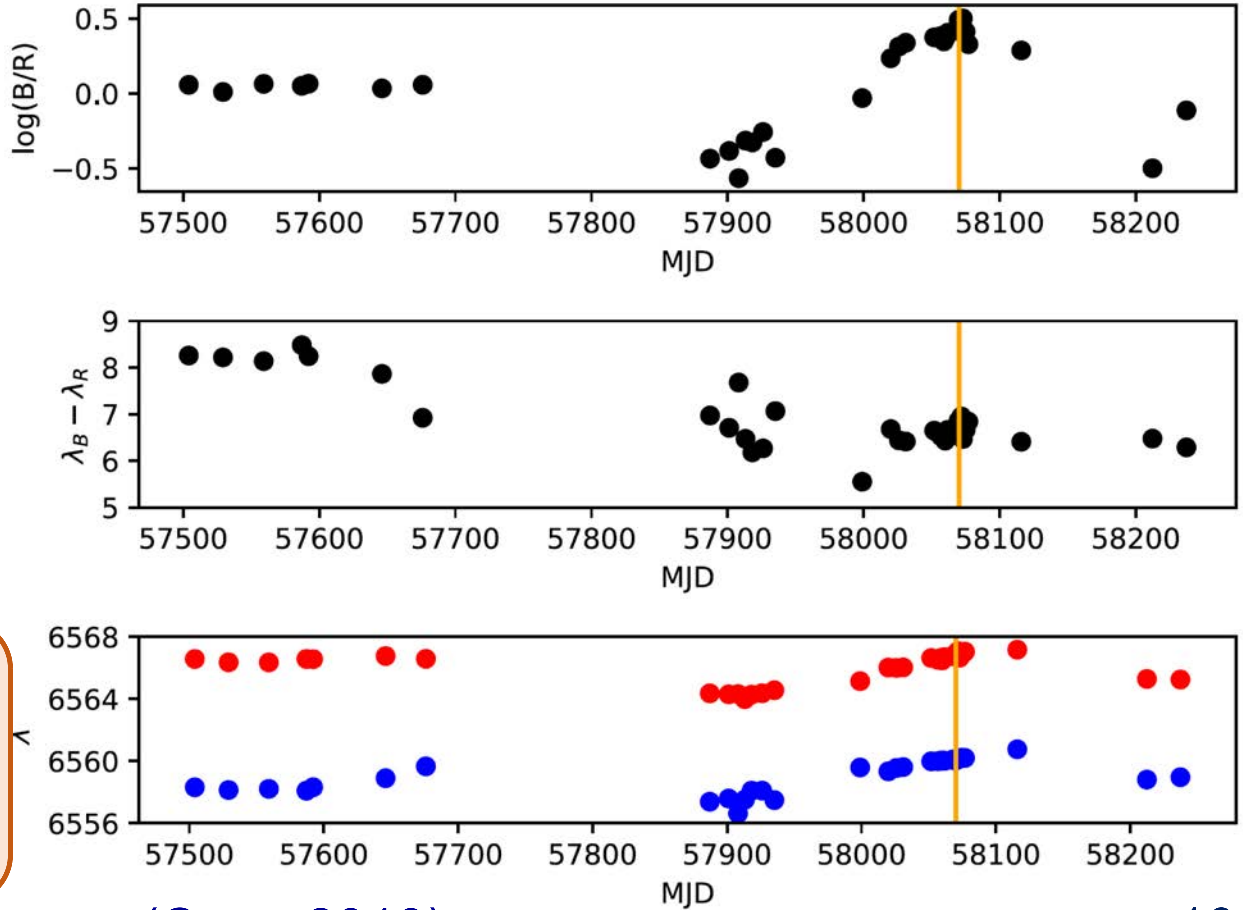
(Coe+ 2019)

Optical variability: Line asymmetry

- Halpha line profile changed from B<R to B>R before periastron
- Velocity of each peak increased during this period

Typical feature of precessing m=1 density wave in Be disk

B: blue-peak intensity, R: red-peak intensity



(Coe+ 2019)

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Numerical setup (1) Hydrodynamic model

- 3D SPH simulations with optically-thin radiative cooling
- Spherically symmetric stellar and pulsar winds
- Relativistic pulsar wind (PW) is modeled by a high-velocity (10^4 km/s), non-relativistic wind with the same momentum flux.
- Be star: M=14.5 M_{sun}, R=8.8 R_{sun}, T_{eff}=35,900 K
- Be wind: Mdot(wind)=10^{-8} M_{sun}/yr, v_{wind}=2,000 km/s
- Misaligned Be disk: initial base density=10^{-11} g/cm^3, initial T_{disk}=0.6 T_{eff}, initial radius r_{disk}=16R_{OB}, Mdot(disk)=10^{-8} M_{sun}/yr
- Pulsar: M=1.4M_{sun}, Lsd=1.5x10^{35} erg/s

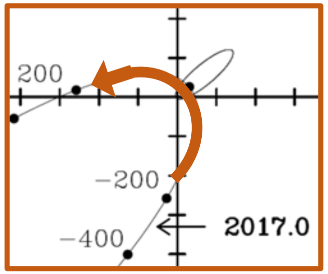
Numerical setup (2) Radiation model

Synchrotron emission is calculated by applying the following scheme to SPH data (Takata, Okazaki+ 2012).

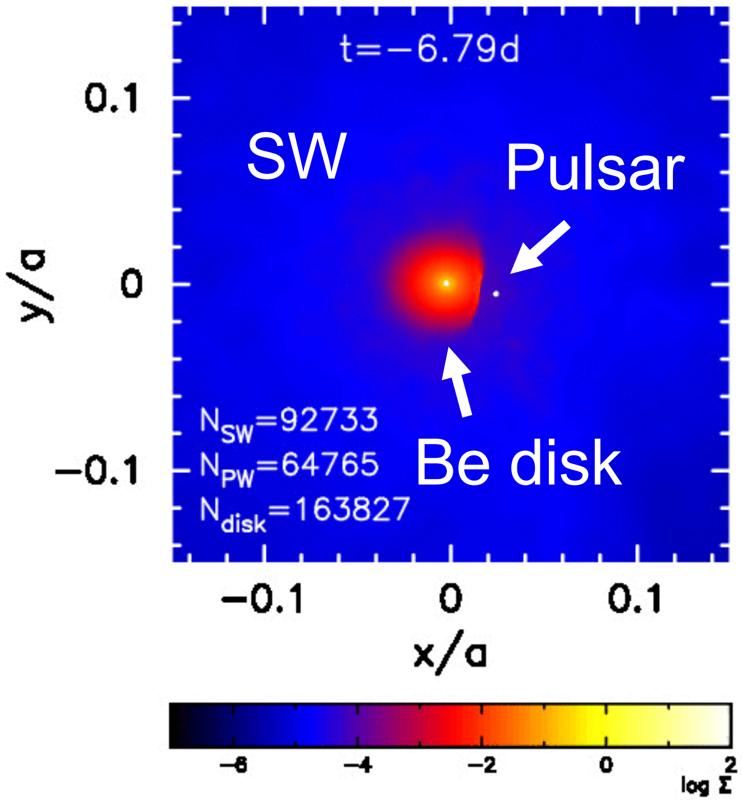
- Particle acceleration takes place in PW shocks
- Maximum Lorentz factor is determined by balancing the acceleration timescale with the synchrotron loss (or dynamical) timescale ($\gamma_{min}=5\text{x}10^5$, $\gamma_{max}\sim10^8$).
- Power index, p, of the shocked particles with p = 2.01
- $P_{mag}/P_{tot}=0.5$ in PW shocks

Interaction of PW with Be disk and wind

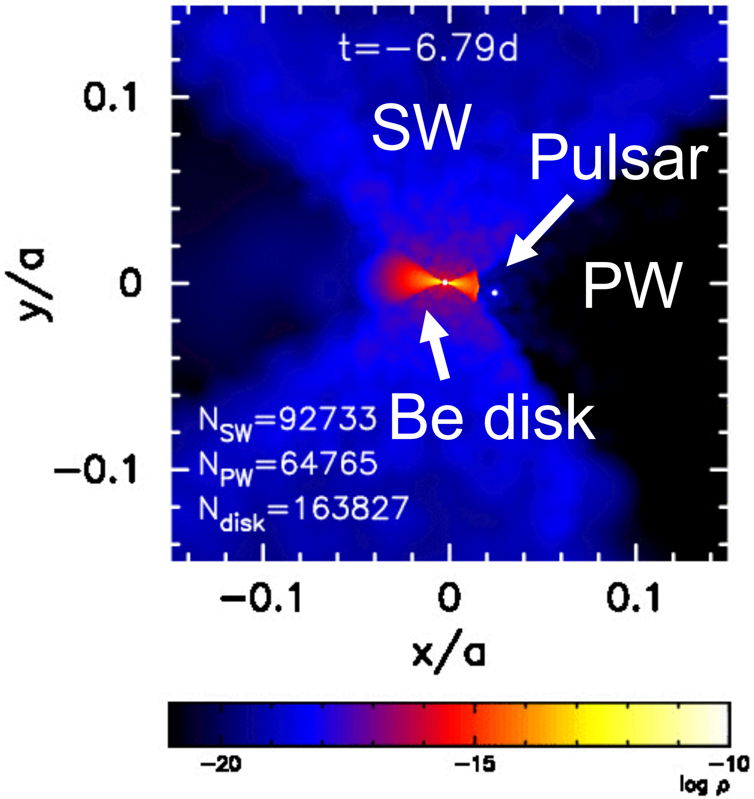
- Be disk with typical density is truncated by PW
- No disk crossing by pulsar



Column density along orbital axis



Density in orbital plane

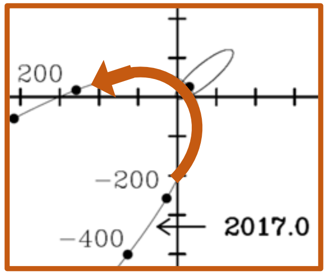


$\beta \sim 30°,$

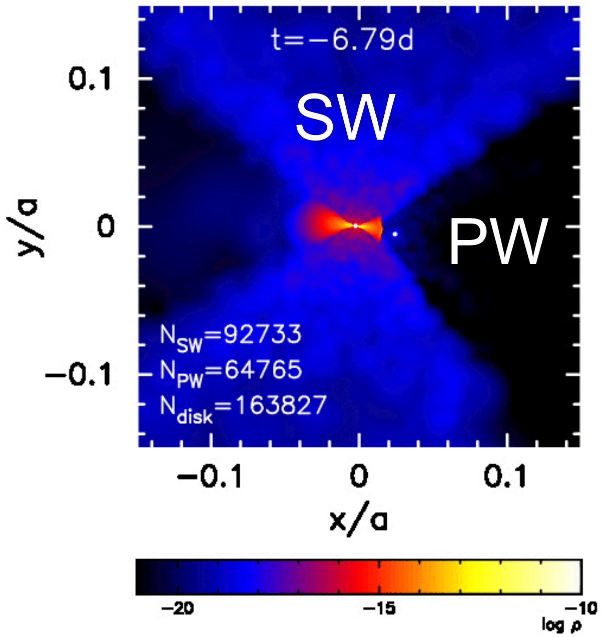
$\gamma \sim 45°$

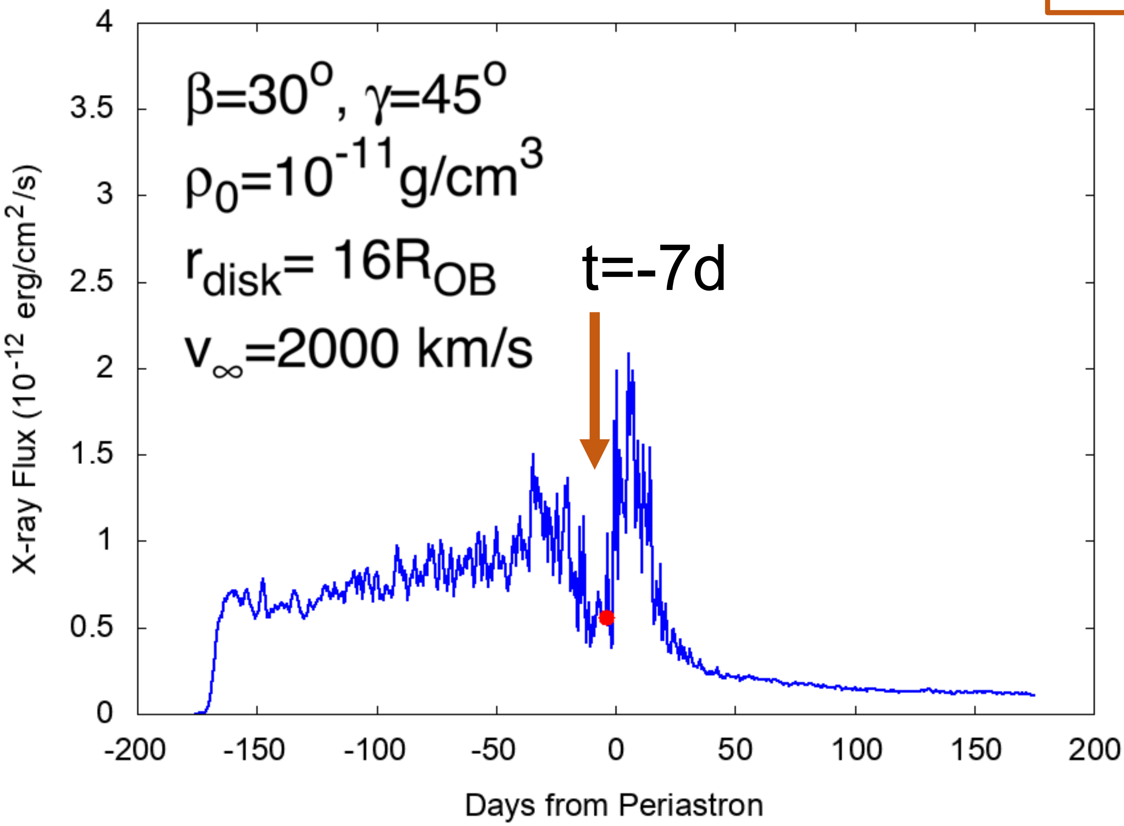
Model X-ray light curve

- X-ray flux goes down when pulsar is in Be-disk shadow



Density in orbital plane

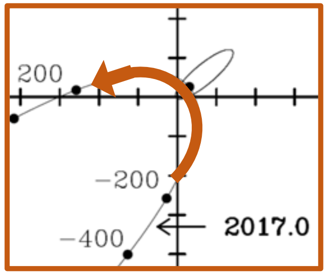




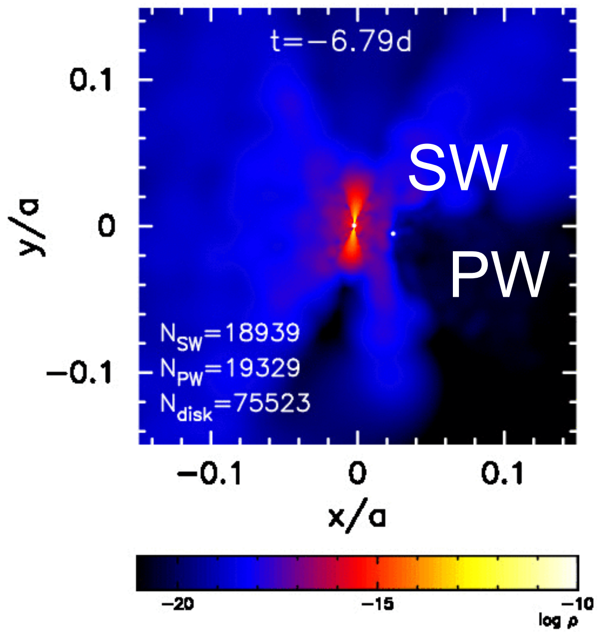
Model X-ray light curve

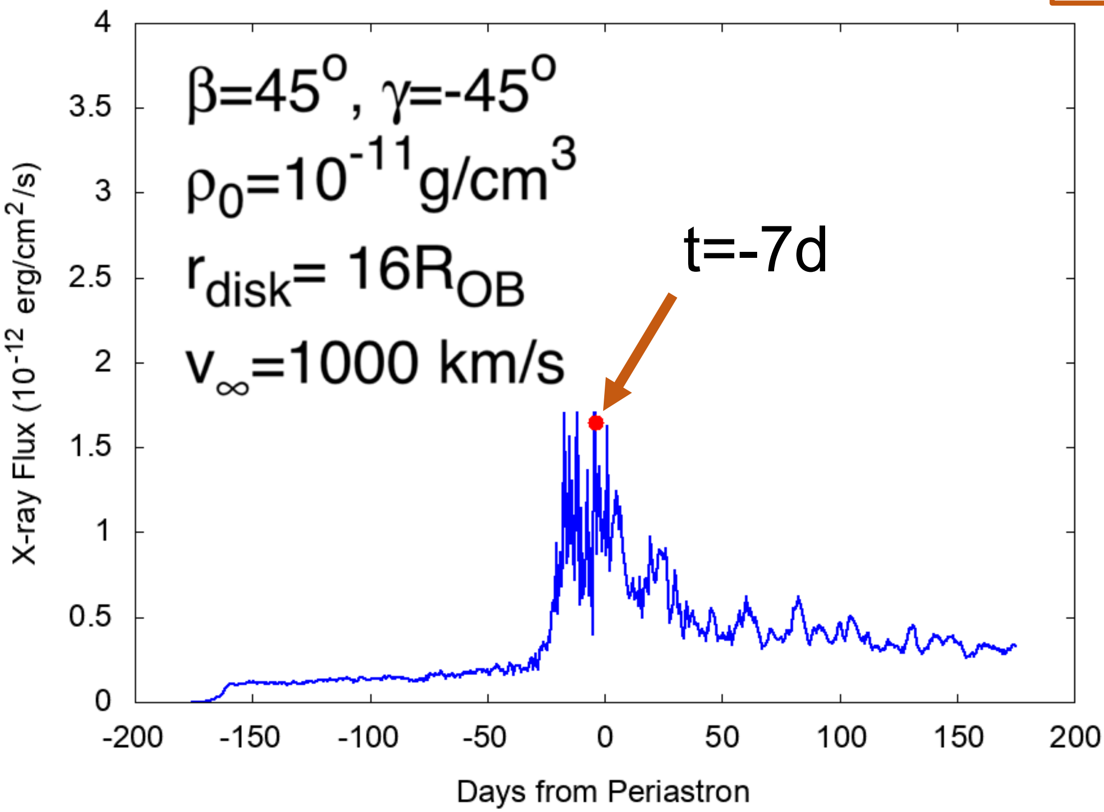
- X-ray light curve is sensitive to disk orientation

  ⇨ Info on disk orientation from X-ray LC



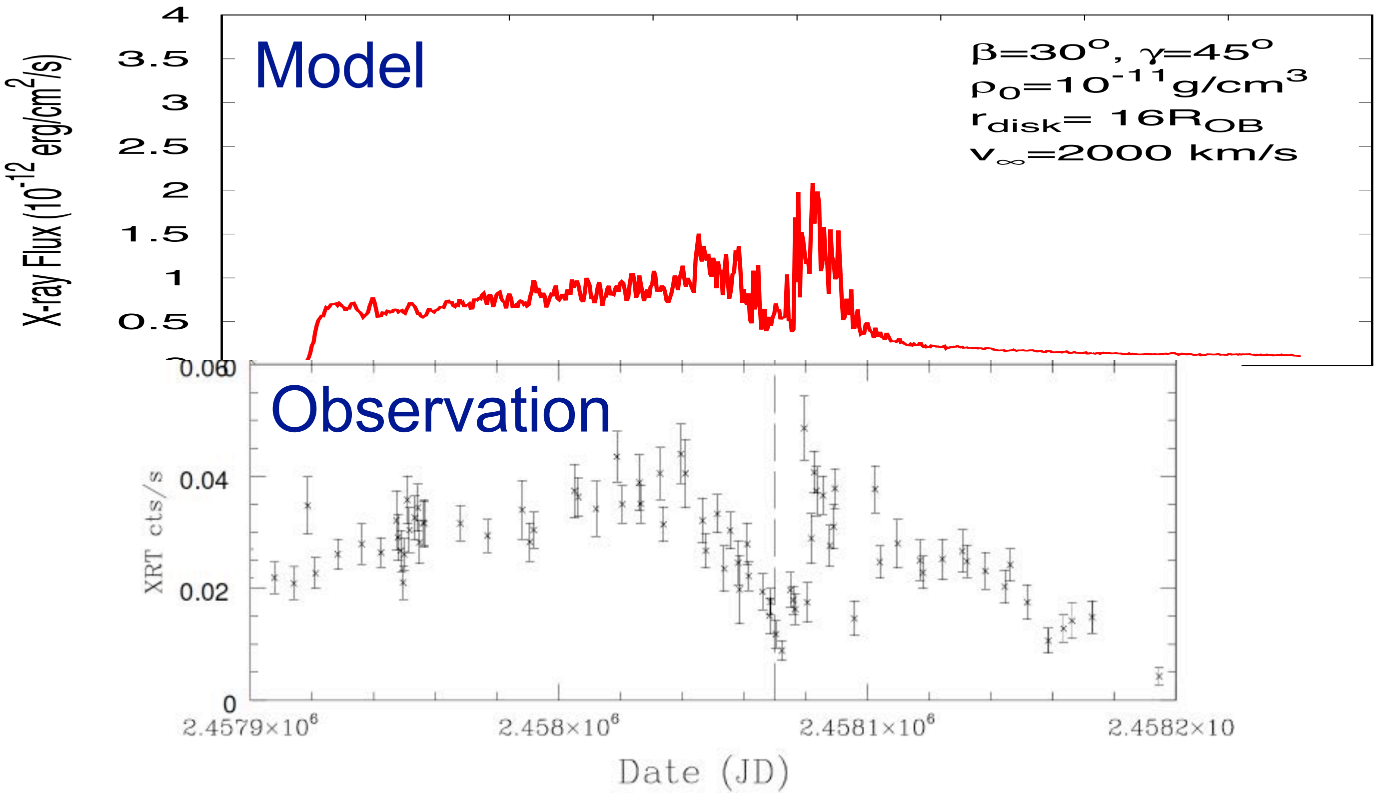
Density in orbital plane





Model vs. observed X-ray light curves

- Model explains global feature of observed X-ray light curve
- But, poor similarity for post-periastron X-ray brightening



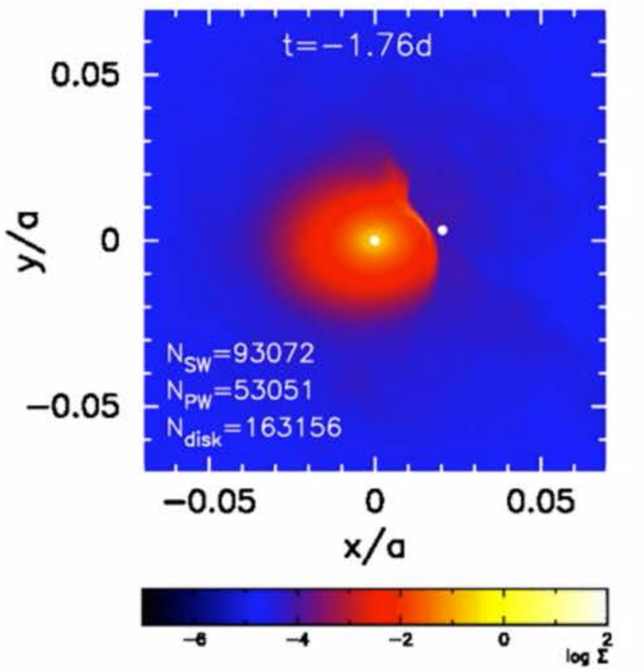
$\beta \sim 30^\circ,$

$\gamma \sim 45^\circ$

Obscuration of radio pulses by Be disk

- Pulsar is behind disk for ~20d after periastron

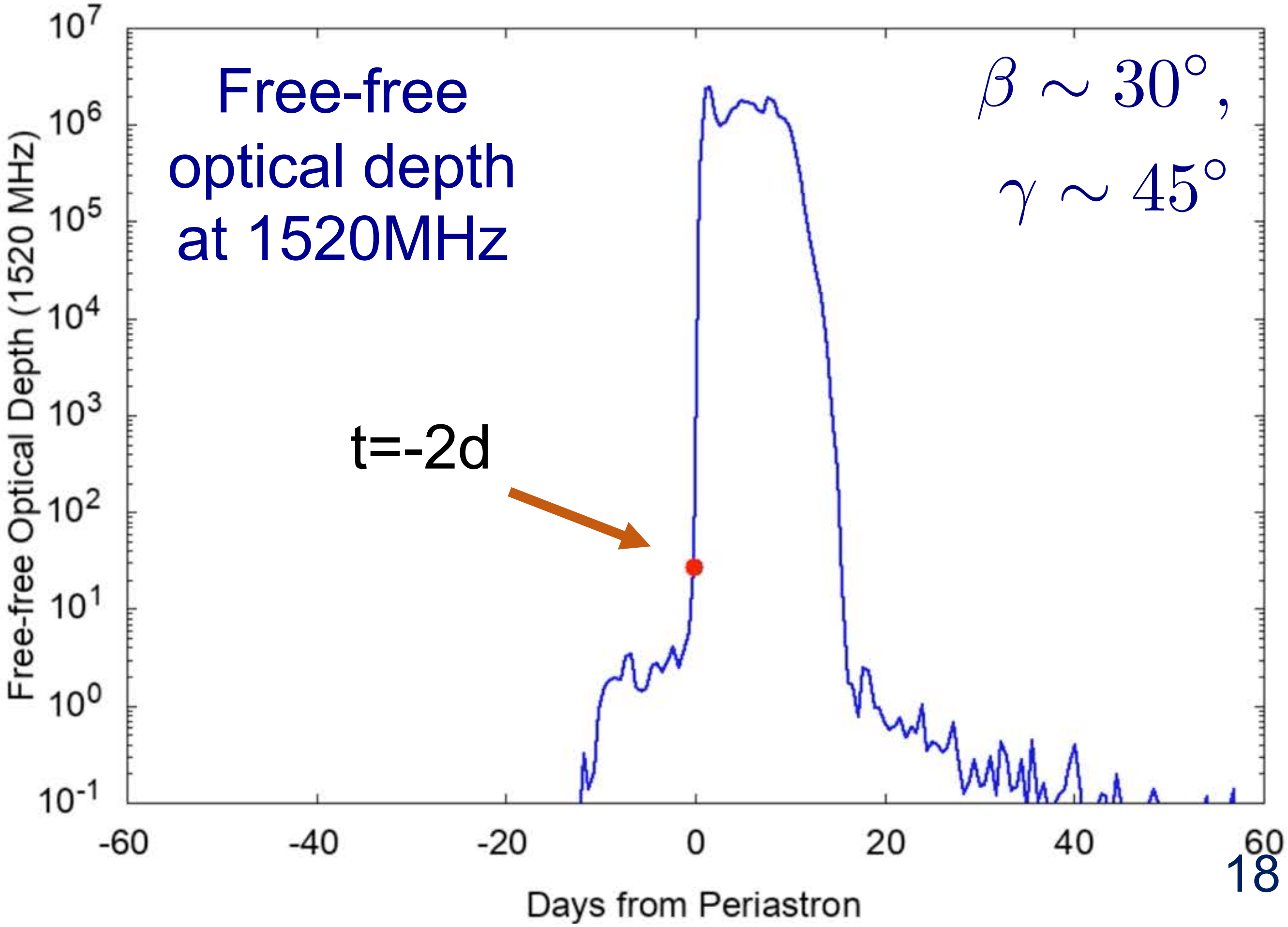
Column density along orbital axis



Free-free optical depth at 1520MHz

$\beta \sim 30^\circ,$

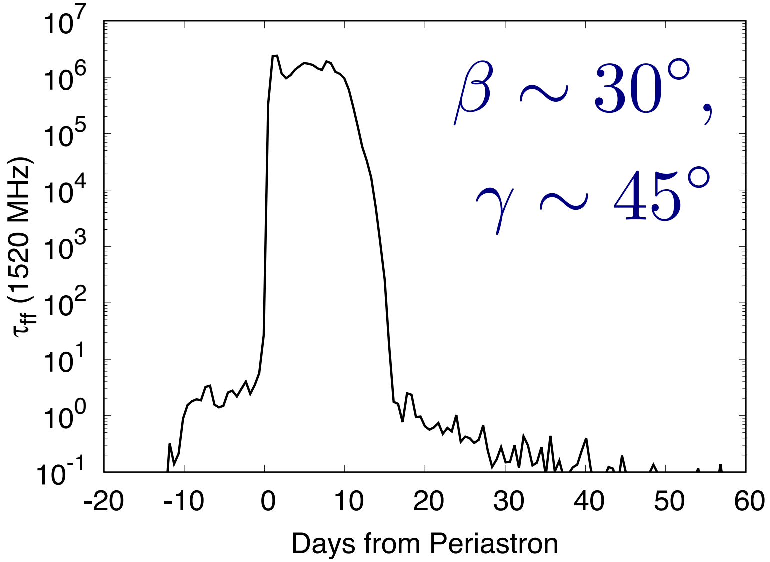
$\gamma \sim 45^\circ$

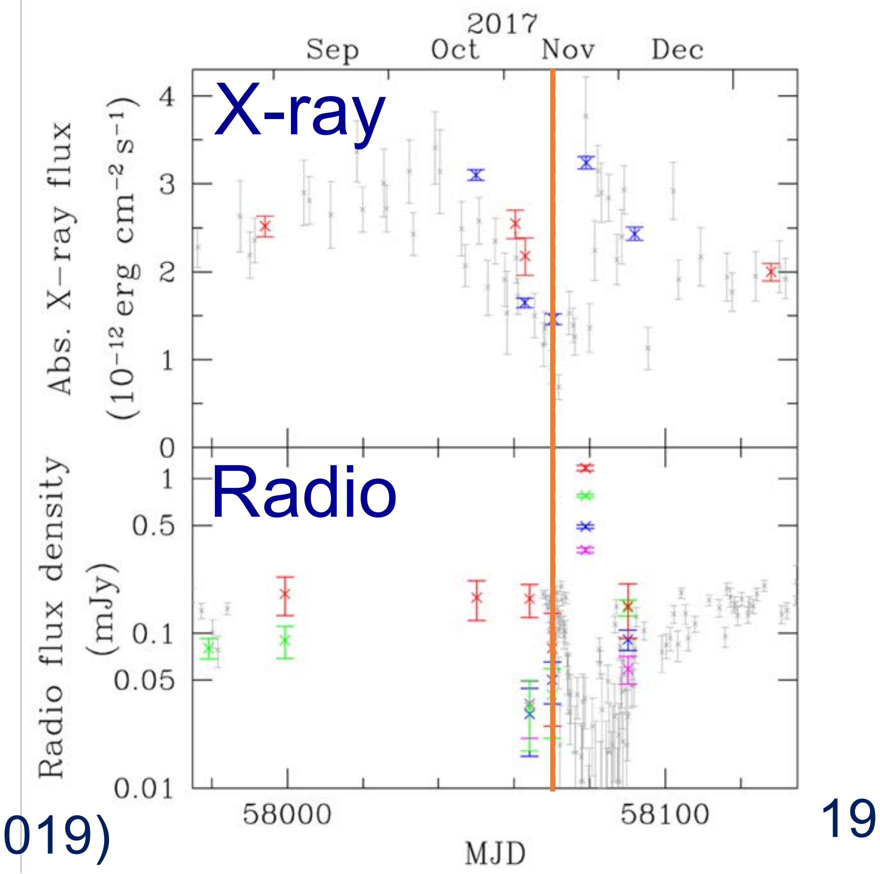


Obscuration of radio pulses by Be disk

- Model explains observed disappearance of radio pulses after periastron

Free-free optical depth at 1520MHz





(Ng+ 2019)

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Concluding remarks

- Dynamic modeling is important to probe properties/physics of complicated systems such as gamma-ray binaries with Be stars.
- Two types of X-ray LCs in Be/gamma-ray binaries:
  - Peak at disk transit for high density disk
  - Dip at disk transit for low density disk
- PSR J2032+4127 is bright in X-ray when PW collides with stellar wind, while it is dim when pulsar is in disk shadow.
- Be disk of PSR J2032+4127 has typical density and misaligned with orbital plane by $\beta \sim 30^\circ, \ \gamma \sim 45^\circ$
- It is possible that optical variability is due to dynamical effect of PW on Be disk