

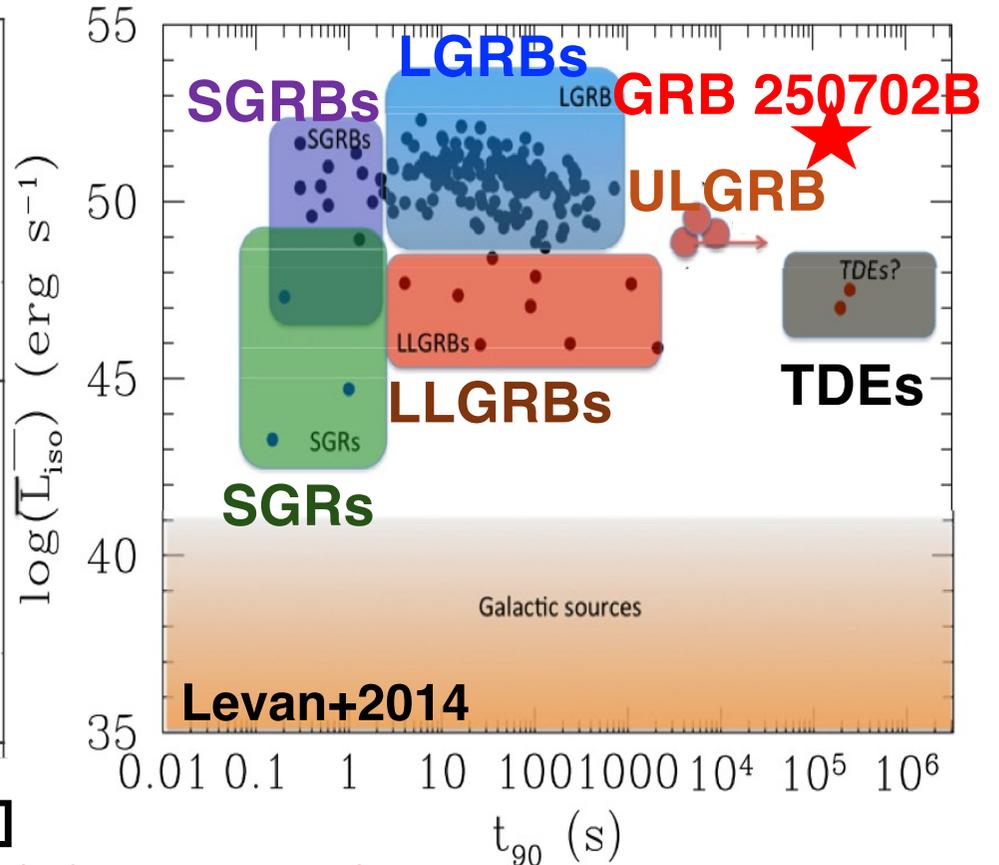
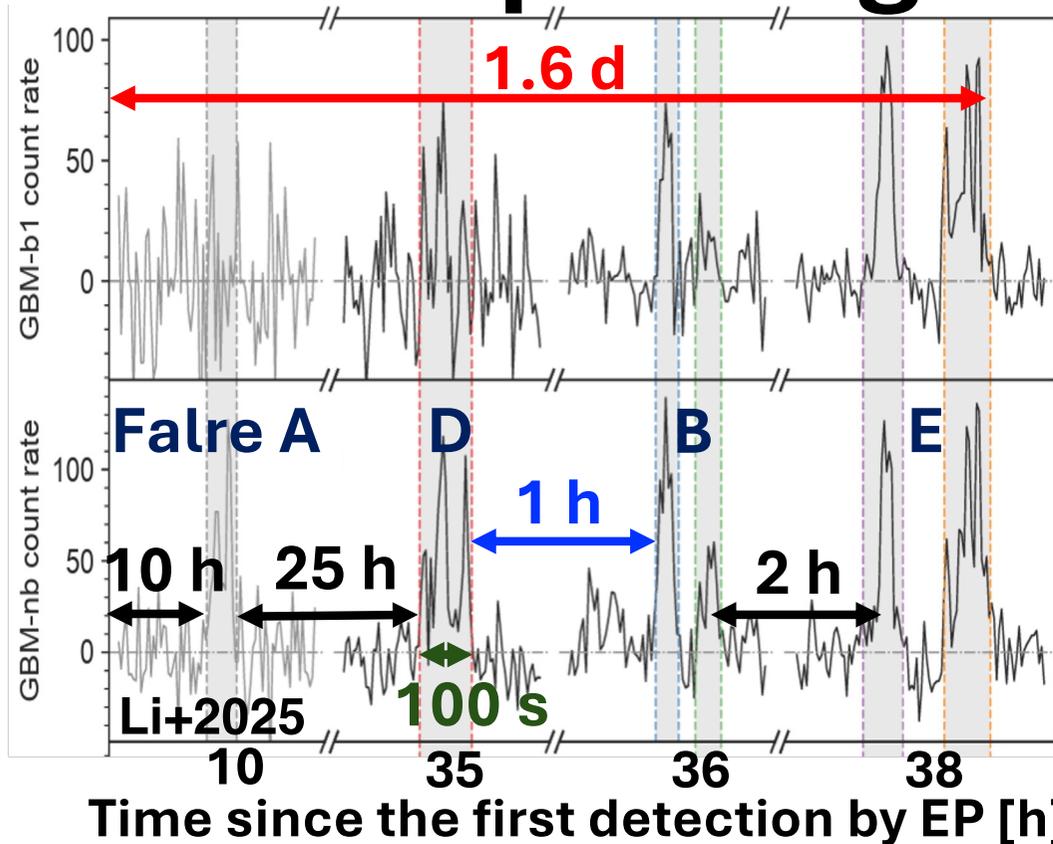
# **A Precessing Orbital Model in a White Dwarf–Black Hole System for Repeating GRB 250702B**

**Tohoku University**

# **Yuri Sato**

**Rin Oikawa, Kazuma Kato (Tohoku U.),  
with Tatsuya Matsumoto (U. Tokyo), and  
Kazumi Kashiyama (Tohoku U.)**

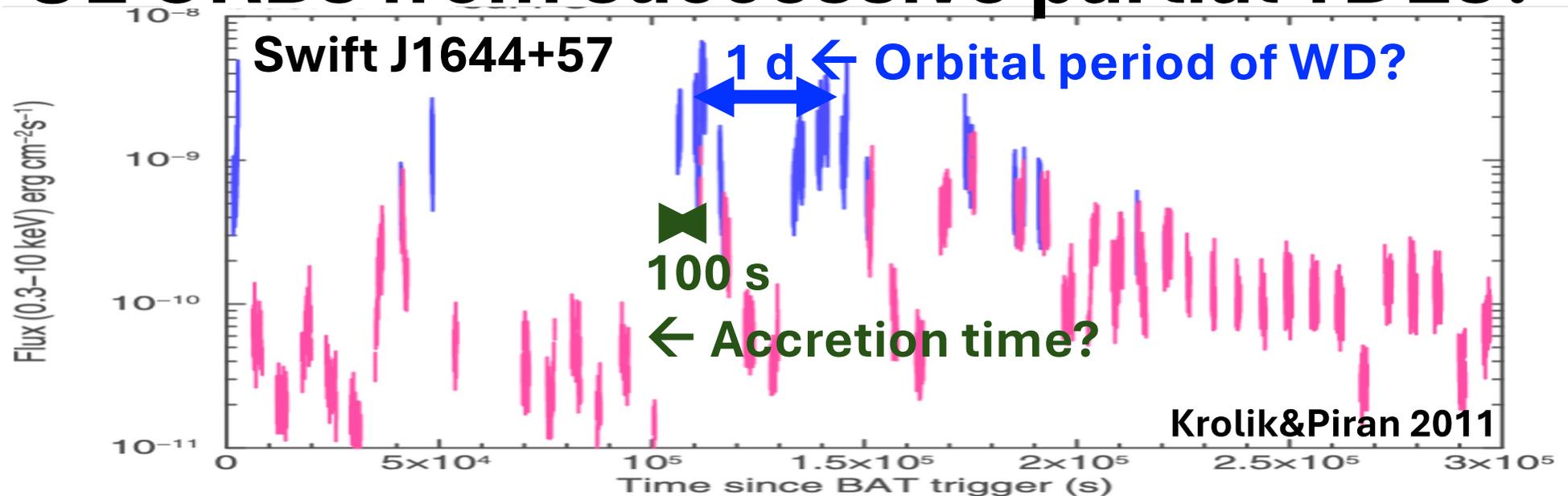
# Repeating GRB 250702B



**1-day prompt emission exhibiting four irregular flares.**

- Minimum flare interval:  $\sim 1$  h.
- Each flare duration:  $\sim 100$  s.
- Gamma-ray luminosity:  $\sim 5 \times 10^{51}$  erg/s.
- Total activity:  $\sim 1.6$  d (X-rays 10 hours before gamma rays).

# UL GRBs from successive partial TDEs?



Similar phenomenology was observed in the TDE Swift J1644+57.

→ Partial tidal disruptions have been proposed in white-dwarf-black hole (WD-BH) systems.

→ High-energy emission may originate from a relativistic jet.

(Krolik&Piran 2011)

Repeating GRB 250702B: flares last  $\sim 100$  s, shortest interval  $\sim 1$  h, total activity  $\sim 1.6$  d.

**Is GRB 250702B a Swift J1644+57-like phenomenon scaled to a compact WD-BH system?**

# Model: Mass stripping & BH accretion

Repeated partial tidal disruptions leading to accretion & relativistic jet emission in WD-BH system.

(WD-BH Systems: Targets for the next GW observatory LISA.)

## 1. Mass loss at periastron.

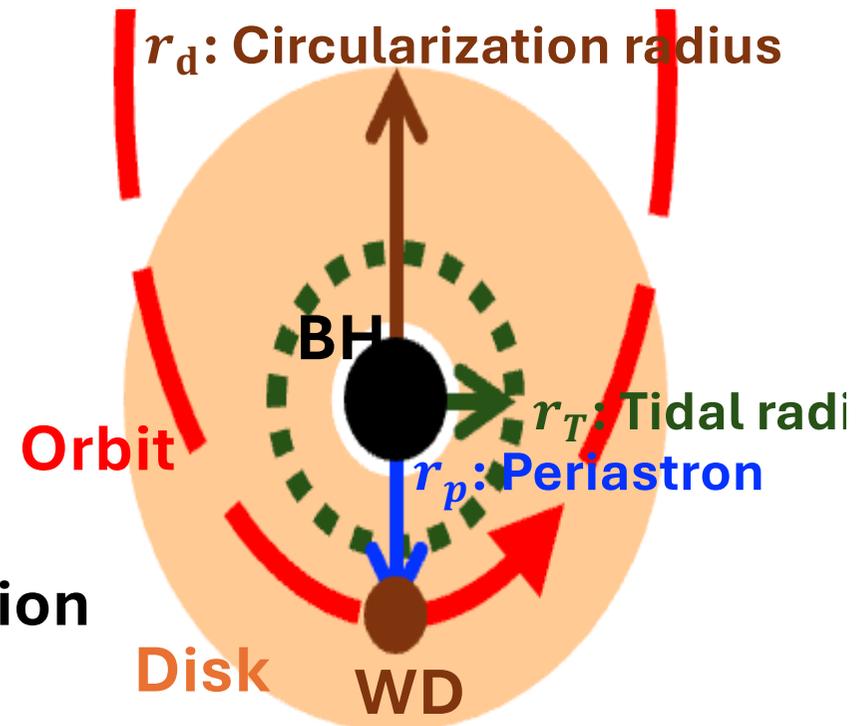
Mass lost during a single pericenter passage (Zalamea+2010)

$$\Delta M(\beta) \approx A \left(1 - \frac{1}{2\beta}\right)^{\frac{5}{2}} M_{\text{WD}}$$

$$A = 6.1 \left(1 - M_{\text{WD}}/1.43 M_{\odot}\right)^{0.67}$$

$\beta \equiv r_{\text{T}}/r_{\text{p}}$ : Penetration factor

$R_{\text{WD}}$ : WD radius,  $M_{\text{WD}}$ : WD mass



2. Accretion disk forms at circularization radius  $r_{\text{d}} \sim 2r_{\text{p}}$ .

Assume gamma-ray flare duration  $\delta t_{\text{flare}}$  corresponds to disk viscous time  $t_{\text{vis}}$ .

$$\delta t_{\text{flare}} \approx t_{\text{vis}}(\beta) = \frac{1}{h^2 \alpha} \sqrt{\frac{8}{G \rho_{\text{WD}} \beta^3}}$$

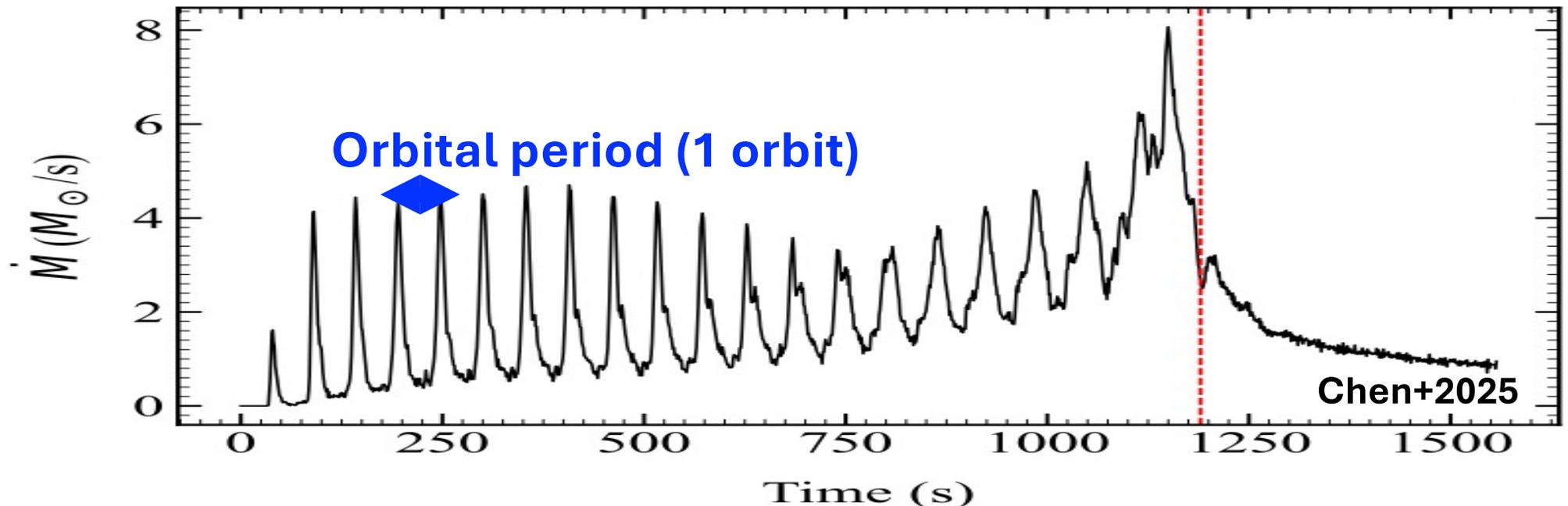
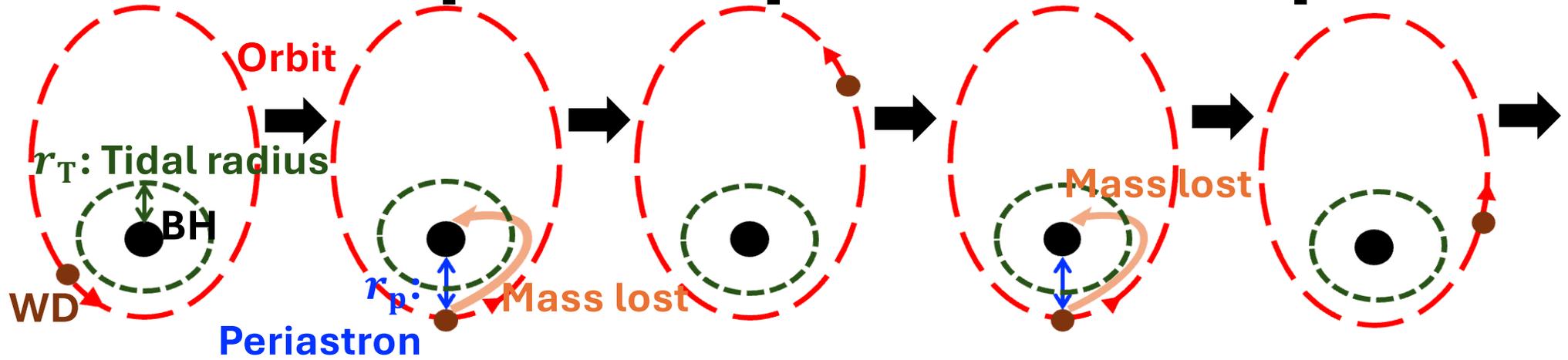
$h (= H/R \sim 0.5)$ : aspect ratio

$\alpha (= \nu/c_s H \sim 0.1)$ :

viscosity parameter

$\rho_{\text{WD}}$ : WD density

# Model: Repeated partial disruptions



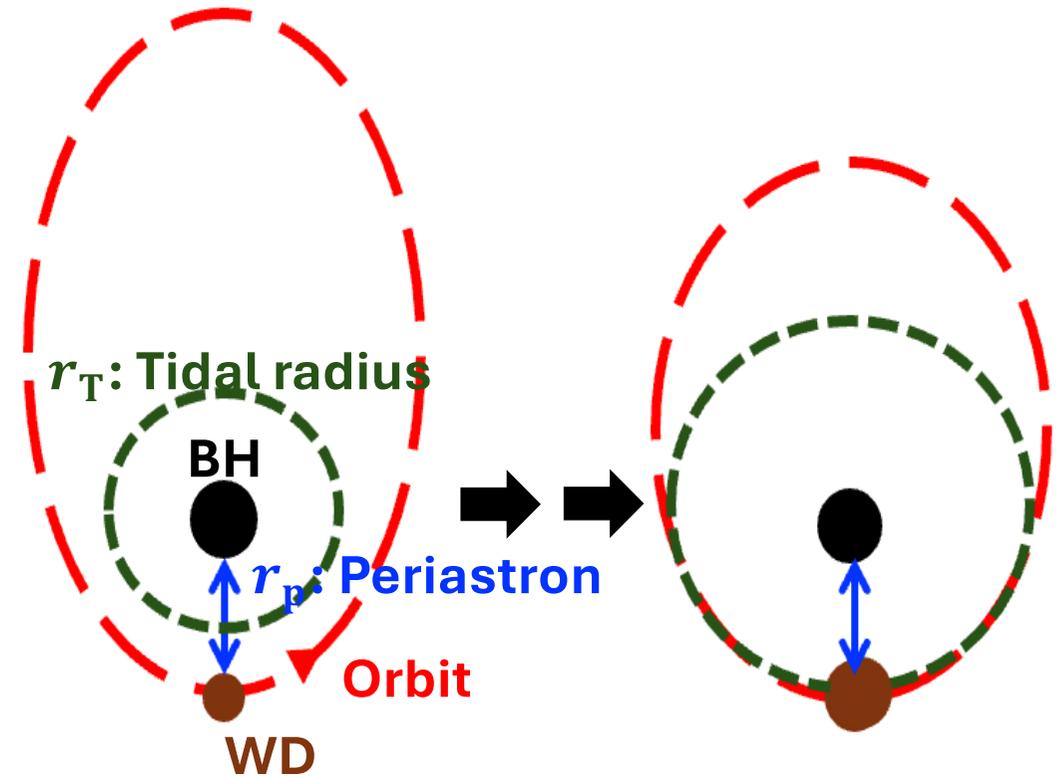
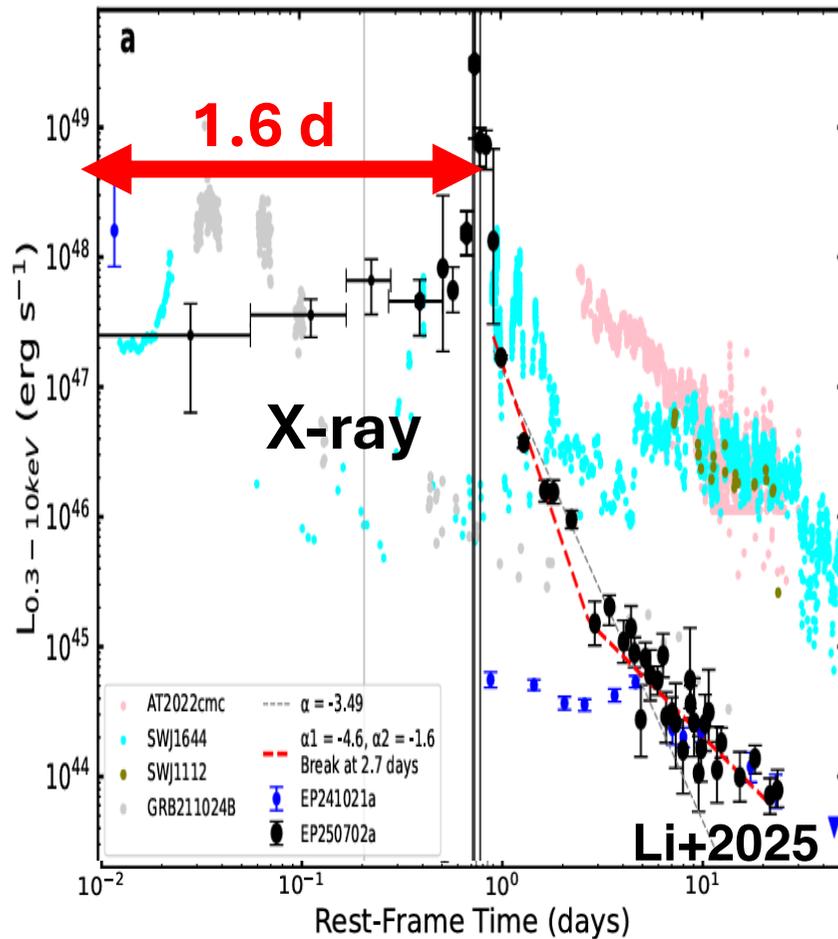
Assume shortest flare interval  $\Delta t_{\text{flare,min}}$  equals orbital period  $P_{\text{orb}}$ .

$$\Delta t_{\text{flare,min}} \approx P_{\text{orb}} = 2\pi \sqrt{a^3 / (GM_{\text{BH}})}$$

$a$ : Semi-major axis  
 $M_{\text{BH}}$ : BH mass

# Model: Orbital evolution due to mass loss

Mass loss  $\rightarrow$  angular momentum loss  
 $\rightarrow$  orbital secular evolution.



Assume total activity duration  $\delta t_{\text{tot}}$  equals secular evolution time  $t_{\text{sec}}$ .

$$\delta t_{\text{tot}} \approx t_{\text{sec}} \sim \frac{J}{\Delta J} P_{\text{orb}} \sim \frac{M_{\text{WD}}}{\Delta M} P_{\text{orb}}$$

$J$ : Angular momentum  
 $\Delta J$ : Angular momentum loss

# Parameter Constraints from Observed Timescales

WD properties:  $R_{\text{WD}} \sim 0.01 R_{\odot}$ ,  $M_{\text{WD}} \sim 1 M_{\odot}$ .

$t_{\text{vis}}(r_{\text{d}}) \sim 100 \text{ s}$ ,  $P_{\text{orb}} \sim 1 \text{ h}$ ,  $t_{\text{sec}} \sim 1.6 \text{ d}$ .



Eccentricity :  $e \sim 0.97$ .

Combination of semi-major axis and BH mass :

$$\left(\frac{a}{R_{\odot}}\right)^3 \left(\frac{M_{\text{BH}}}{M_{\odot}}\right)^{-1} \sim 0.1.$$

Mass loss per partial disruption:  $\Delta M \sim 2 \times 10^{-2} M_{\odot}$ .

Penetration factor:  $\beta \equiv r_{\text{T}}/r_{\text{p}} \sim 0.6$ .

Mass loss:  $\Delta M(\beta) \sim 2 \times 10^{-2} M_{\odot}$ .

**→ Consistent with mass lost estimated from timescale.**

# Gamma-ray Luminosity

**Can observed gamma-ray luminosity be explained by mass loss inferred from timescale?**

**Gamma-ray radiation:** Assume jet emission powered by BH spin energy via magnetic fields.

$$L_{\gamma, \text{iso}} \approx \frac{\eta_{\text{rad}} \eta_{\text{BZ}} \Delta M c^2}{\theta_j^2 \delta t_{\text{flare}}}$$
$$\sim 5 \times 10^{51} \eta_{\text{BZ}} \left( \frac{\eta_{\text{rad}}}{0.1} \right) \left( \frac{\delta t_{\text{flare}}}{100 \text{ s}} \right)^{-1} \left( \frac{\Delta M}{2 \times 10^{-2} M_{\odot}} \right) \left( \frac{\theta_j}{0.1 \text{ rad}} \right)^{-2} \text{ erg s}^{-1},$$

$\theta_j$ : Jet half-opening angle

$\eta_{\text{BZ}}$ : Jet power efficiency

$\eta_{\text{rad}}$ : Radiative efficiency

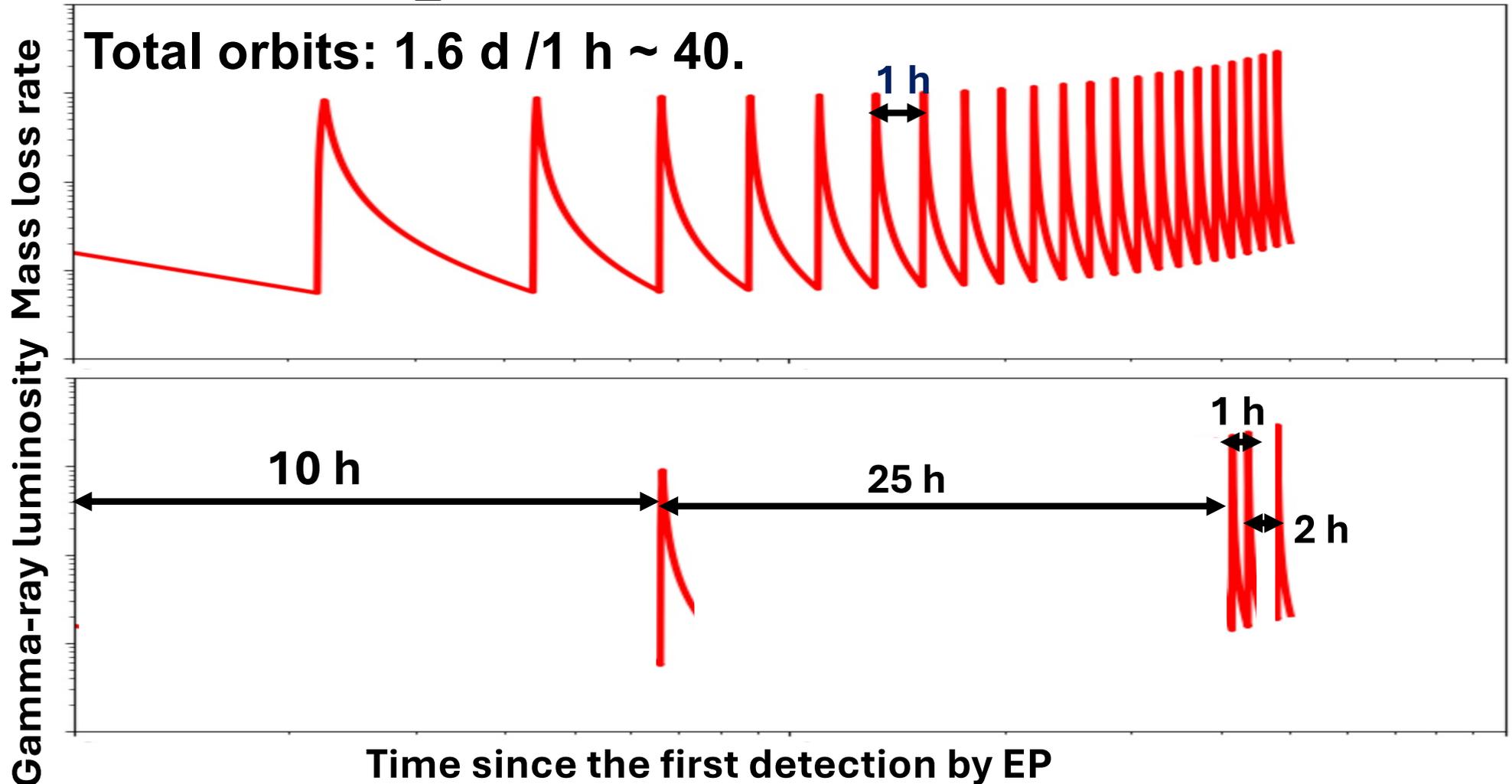
To reproduce the observed gamma-ray luminosity,

$\eta_{\text{BZ}} \eta_{\text{rad}} \sim 0.1$  is required.

→ High-efficiency jet needed.

(BH is likely rapidly spinning ( $a_{\text{spin}} \sim 1$ ) and that the accretion disk is in a magnetically arrested disk state?)

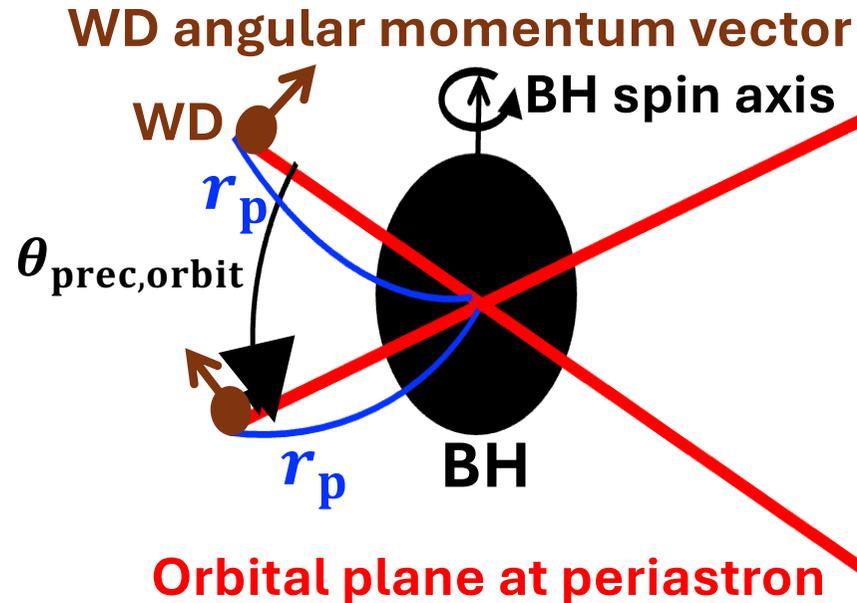
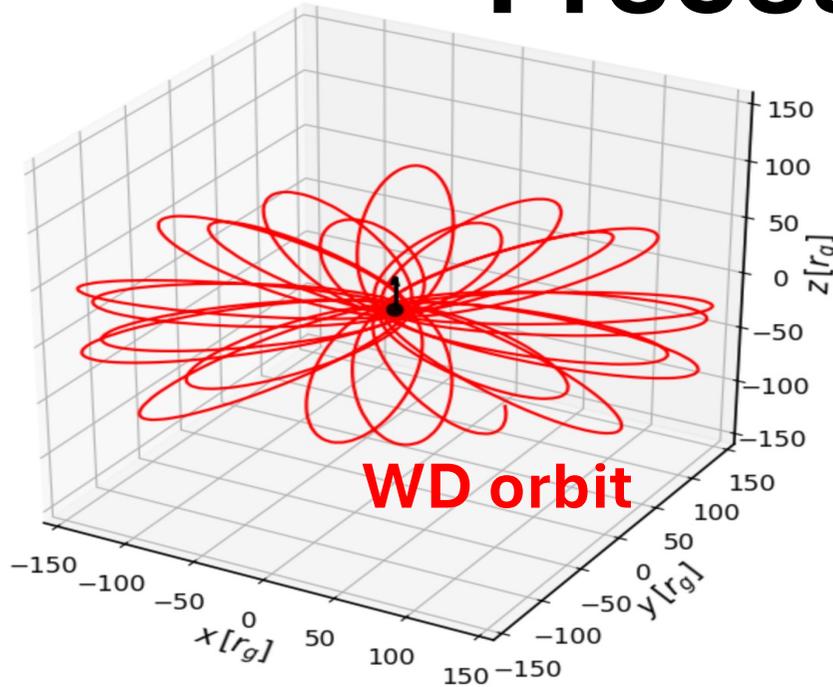
# Irregular Flare Intervals



The irregular gamma-ray flare Intervals cannot be explained by repeating partial disruptions.

**Why are only four irregular gamma-ray flares observed even though mass loss is nearly periodic?**

# Precessing Orbits



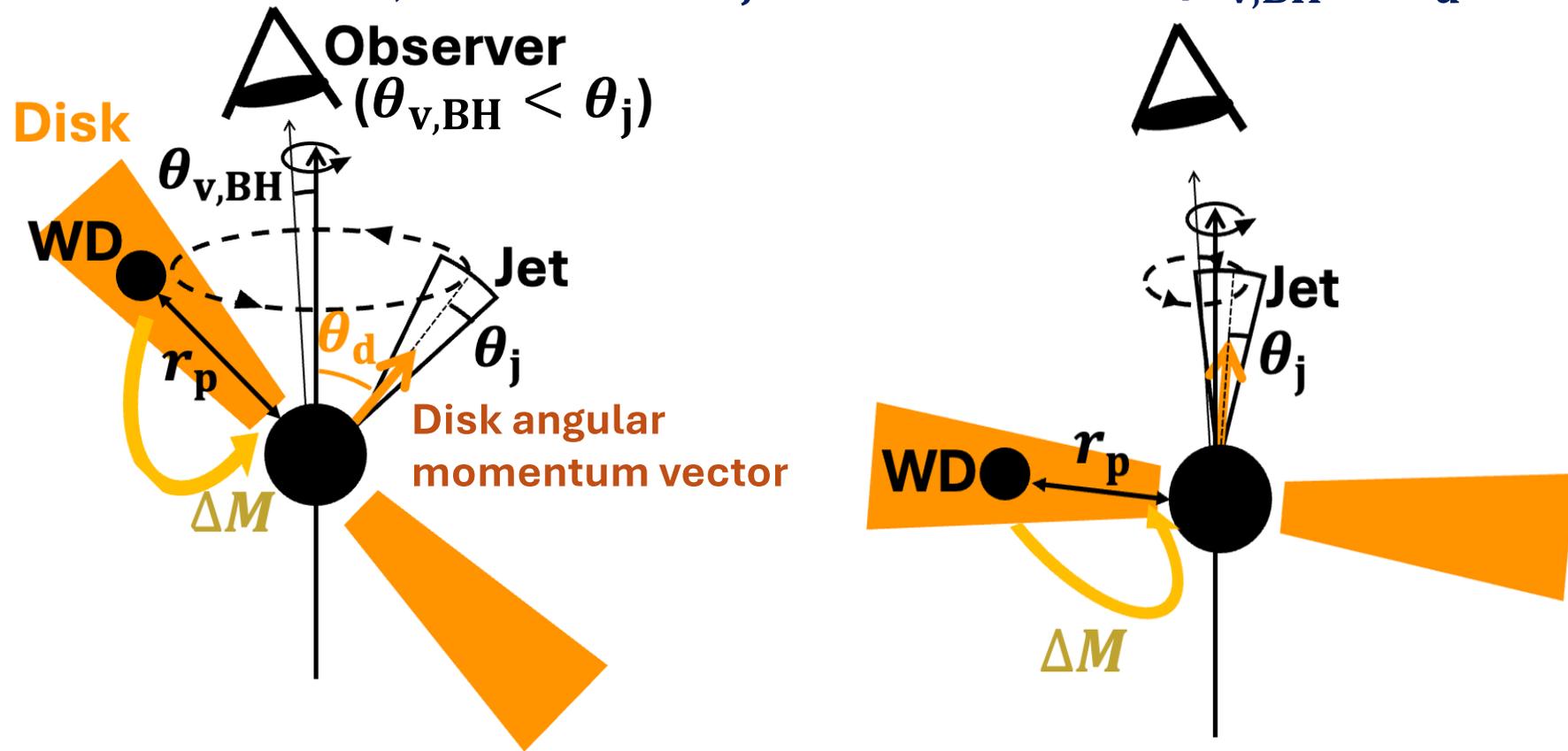
For  $e \sim 0.97$ ,  $\left(\frac{a}{R_\odot}\right)^3 \left(\frac{M_{\text{BH}}}{M_\odot}\right)^{-1} \sim 0.1$ ,  $\beta \sim 0.6$ ,  $r_g$ : Gravitational radius  
 if  $M_{\text{BH}} \gtrsim 10^5 M_\odot$  (i.e.,  $r_p \lesssim 3 r_g$ ) and the minimum polar angle measured from the BH equatorial plane is  $\gtrsim 7^\circ$ ,  
 the per-orbit precession angle satisfies  $\theta_{\text{prec,orbit}} \gtrsim \theta_j$ .

→ The orbital plane precesses beyond the jet opening angle.

→ **WD angular momentum vector is randomized at each periastron passage.**

# Lense-Thirring precession

Unobservable ( $|\theta_{v,BH} - \theta_d| > \theta_j$ ). Observable ( $\theta_{v,BH} + \theta_d < \theta_j$ ).



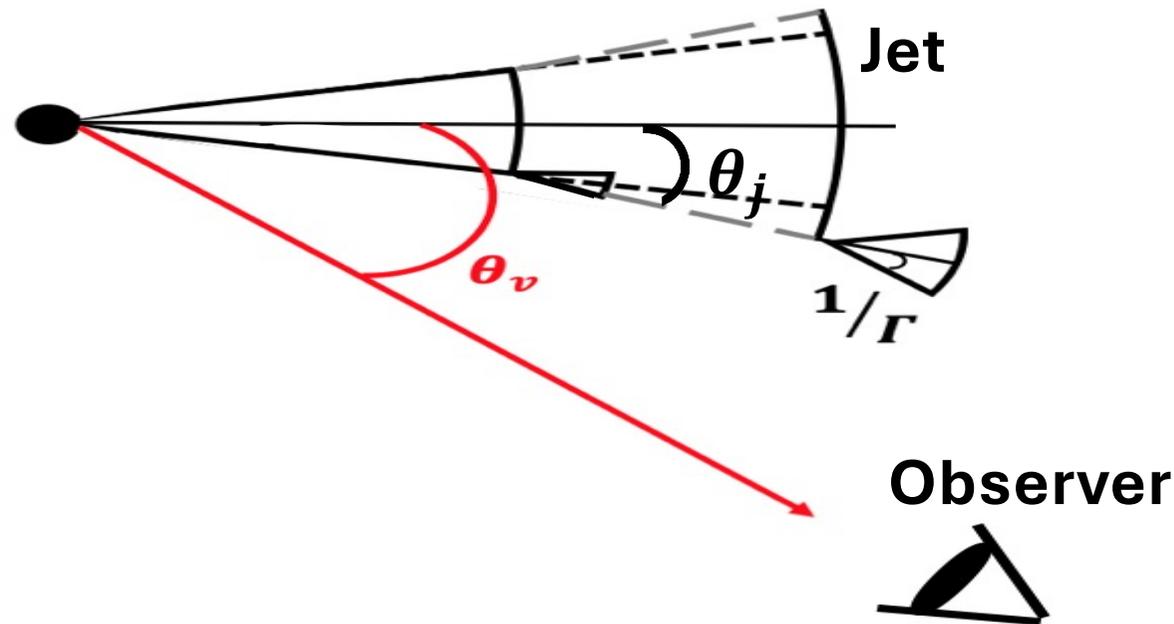
Disk angular momentum aligns with the WD orbit at pericenter.

A misaligned disk with  $\theta_d$  undergoes Lense-Thirring torque.

→ Disk and the associated jet precess on a cone with  $\theta_d$ . (Lu+2024)

**Observable phases modulated by orbital precession.**

# Identifying orbital precession via radio afterglow



As the jets decelerate, relativistic beaming weakens, allowing these off-axis jets to become visible to the observer.

**Maximum case:** 40 (1.6d/1 h) jet emission.

**Minimum case:** Only 4 jet emission corresponding to 4 flares.

We compare these two scenarios using their predicted afterglow emission.

# Radio Afterglow Calculation

## Maximum case:

- Emission is the sum of 40 jets.
- Viewing angles are randomly distributed ( $0 \sim \pi/2$ ).

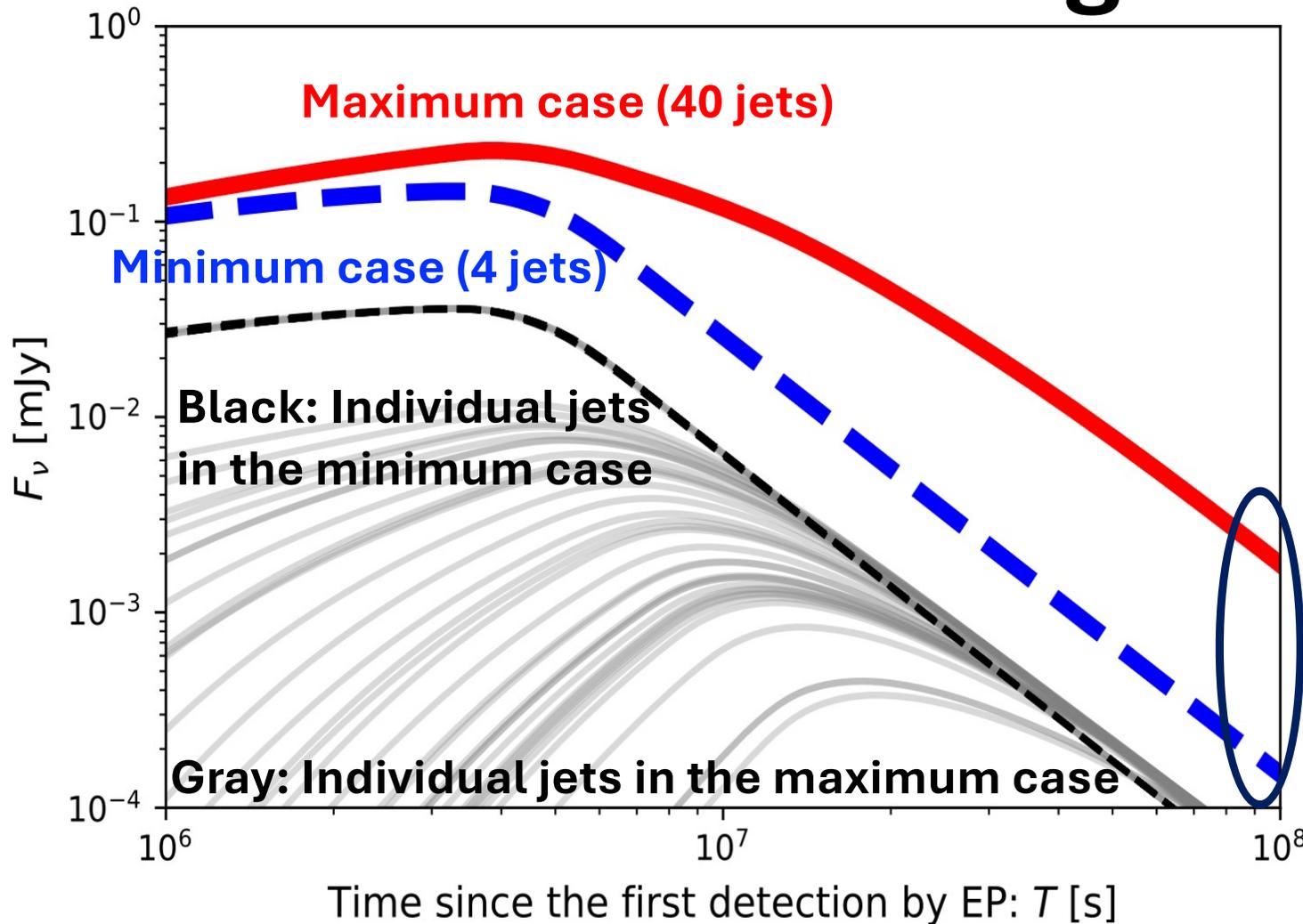
## Minimum case:

- Jets are launched only at the times when observed gamma-ray flares.
- All jets are assumed to be viewed on-axis.

## Afterglow model (single top-hat jet):

- A relativistic jet interacts with the circumburst medium (CBM).
- External shock produces synchrotron emission.
- Microphysical parameters are assumed constant.
- Electron energy distribution: power-law with index  $p$ .

# Radio Afterglow



## Parameter

Jet half-opening angle: **0.1 rad**

Bulk Lorentz factor: **100**

Isotropic kinetic energy:  **$4 \times 10^{54}$  erg**

CBM density:

**$0.1 \left( \frac{r}{10^{17} \text{ cm}} \right)^{-1} \text{ cm}^{-3}$**

Electron power-law index: **2.6**

Energy fraction of internal energy going into magnetic field:  **$1 \times 10^{-5}$**

**$1 \times 10^{-5}$**

Energy fraction of internal energy going into electrons: **0.01**

Number fraction of accelerated electrons: **0.1**

**Maximum case significantly brighter than minimum case.**

**Future radio observations are important.**

# Conclusion

Ref.: Sato et al. 2026, arXiv:2602.01073

## Precessing orbital model for repeating GRB 250702B

- Hierarchical timescales (100 s / 1 h / 1.6 d)  
→  $e \sim 0.97$ ,  $\left(\frac{a}{R_{\odot}}\right)^3 \left(\frac{M_{\text{BH}}}{M_{\odot}}\right)^{-1} \sim 0.1$ ,  $\beta \sim 0.6$ .
- Bright gamma-ray luminosity ( $L_{\gamma,\text{iso}} \sim 5 \times 10^{51}$  erg/s).  
→ Jet from a MAD disk around a rapidly spinning BH ( $a_{\text{spin}} \sim 1$ )?
- Irregular flare intervals  
→ Orbital precession ( $M_{\text{BH}} \gtrsim 10^5$ ,  $a \sim 20 R_{\odot}$ )?

Afterglow emission is a powerful probe of orbital precession.

**Future radio observations are particularly important.**