Origin of TDE and evolution of QPEs in GSN 069

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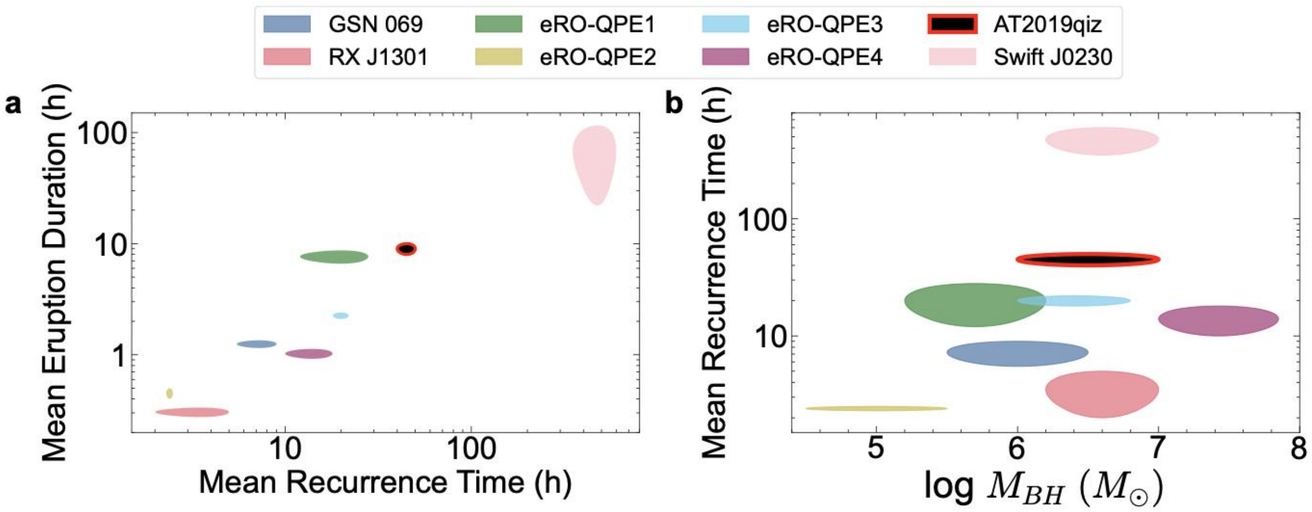
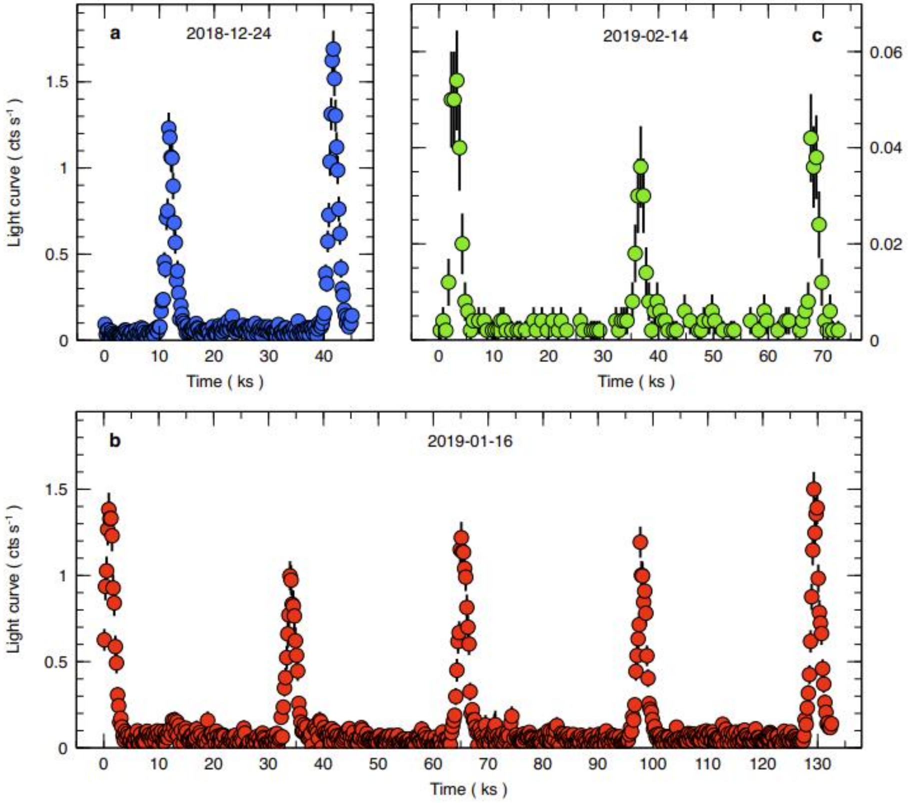
First discovered QPEs in GSN 069

- Soft X-ray band
- energy-dependence
- Thermal spectrum
- Relate to TDE (some)

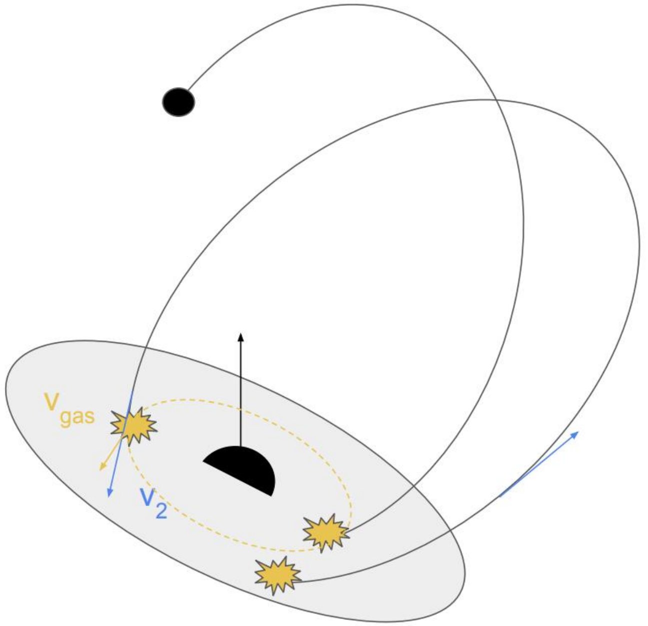




Miniutti+, 2019

QPEs Models

- Disk instability (Sniegowska et al. 2020; Raj & Nixon 2021; Pan et al. 2022; Kaur et al. 2022)
- Star–Disk Collisions (Xian et al. 2021, Franchini et al. 2023…)
- Periodic accretion (King 2020, 2022, Zhao et al. 2022, Wang et al. 2022, Krolik & Linial 2022, and Lu & Quataert 2022)

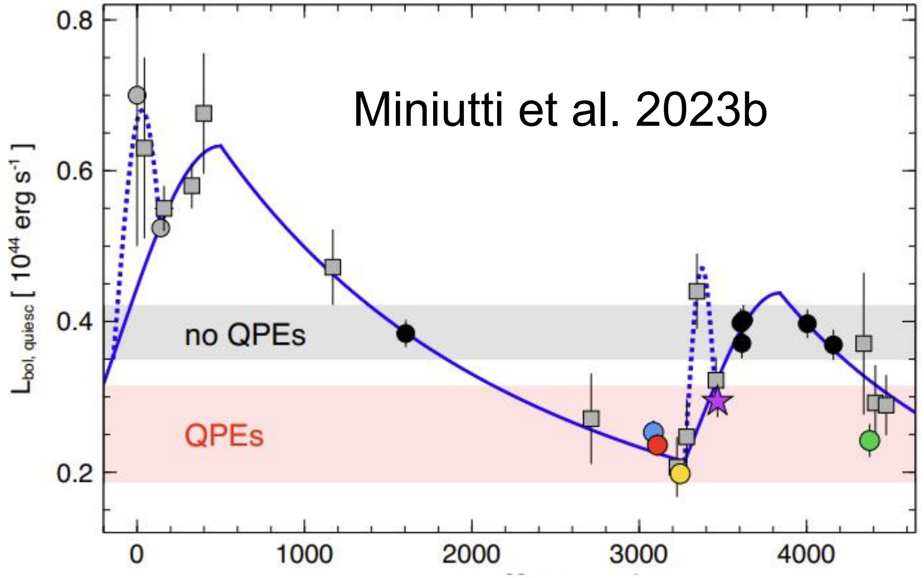


Franchini et al. 2023

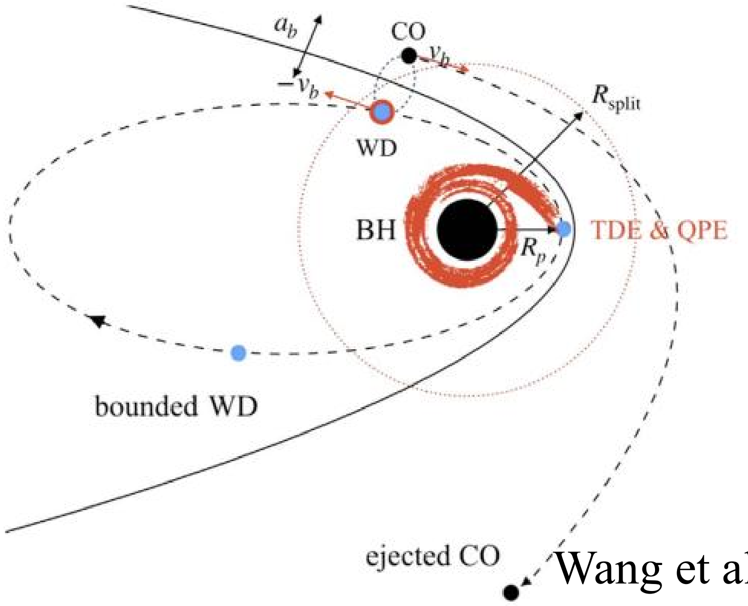
TDE of GSN 069

- Abnormal N/C abundance suggests a disruption of a red giant star (Sheng et al. 2021).
- Radius of disrupted star is about $5 \sim 12R_\odot$ from TDE (Miniutti et al. 2023a).

QPEs ~ 9 h VS TDE 500 ~ 800 d

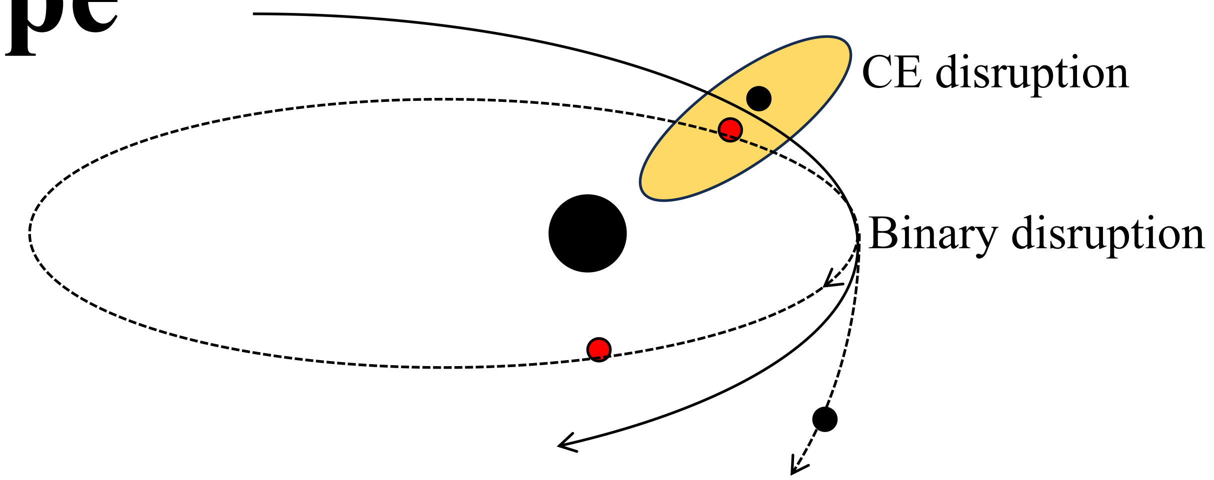


Miniutti et al. 2023b



Wang et al. 2022

TDE of Common Envelope

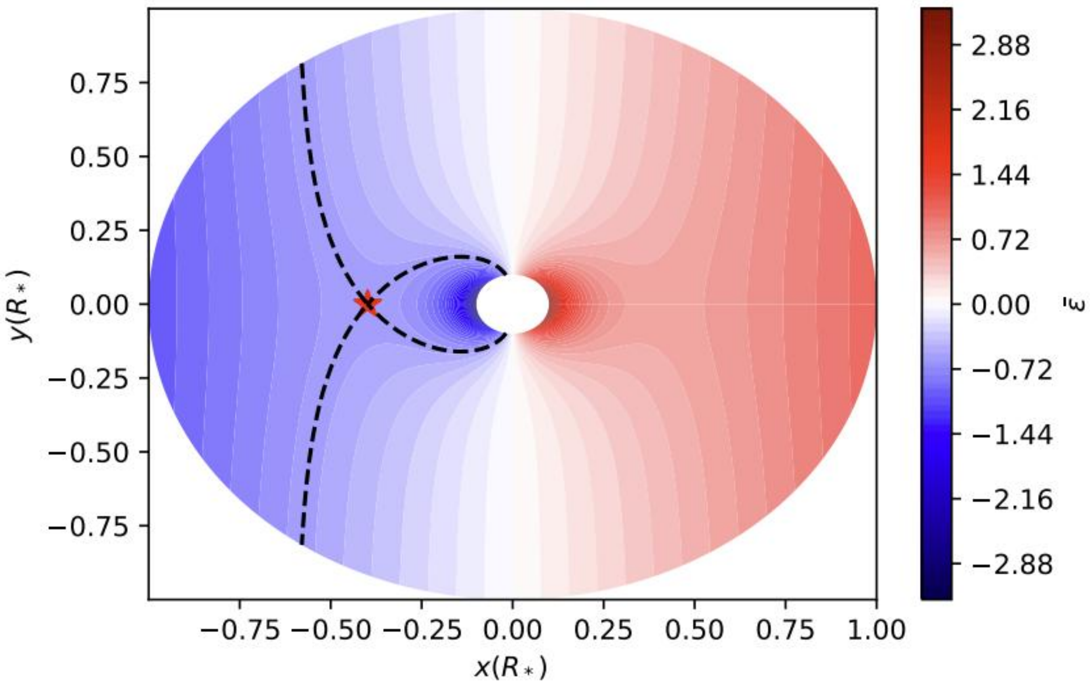


Differential rotation

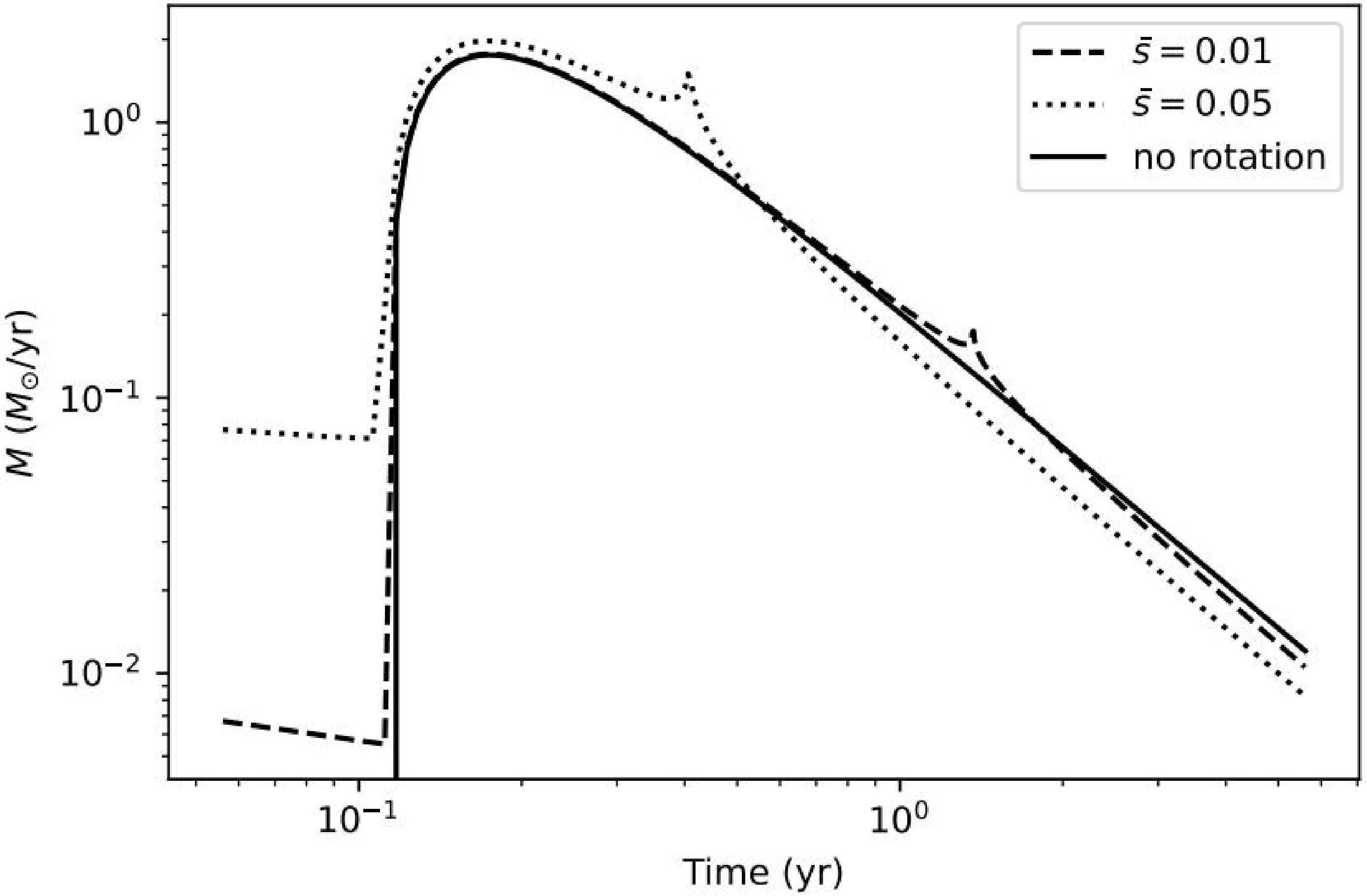
$$\Omega = \begin{cases} \Omega_0, & s \leq s_0 \\ \Omega_0 \left(\frac{s}{s_c}\right)^{-\alpha}, & s > s_0 \end{cases}$$

Orbital binding energy (Golightly+ 2019)

$$\epsilon \approx \left(\vec{v} \times \vec{\Omega} + \frac{GM_{\rm BH}}{R_t^3}\vec{R}_t\right) \cdot \vec{r}$$
$$= \epsilon_0 \bar{s}\left(1 + k\bar{s}^{-\alpha}\right)\cos\phi$$



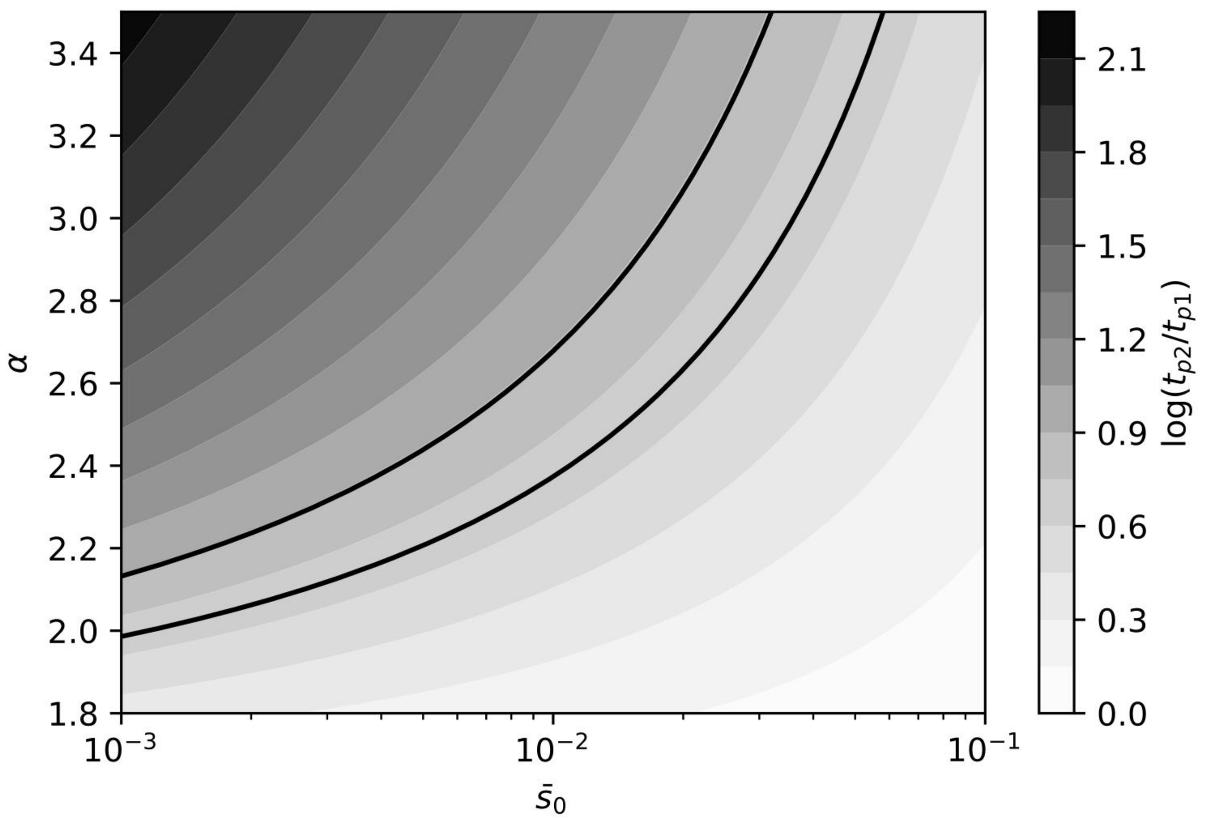
Fallback Rate



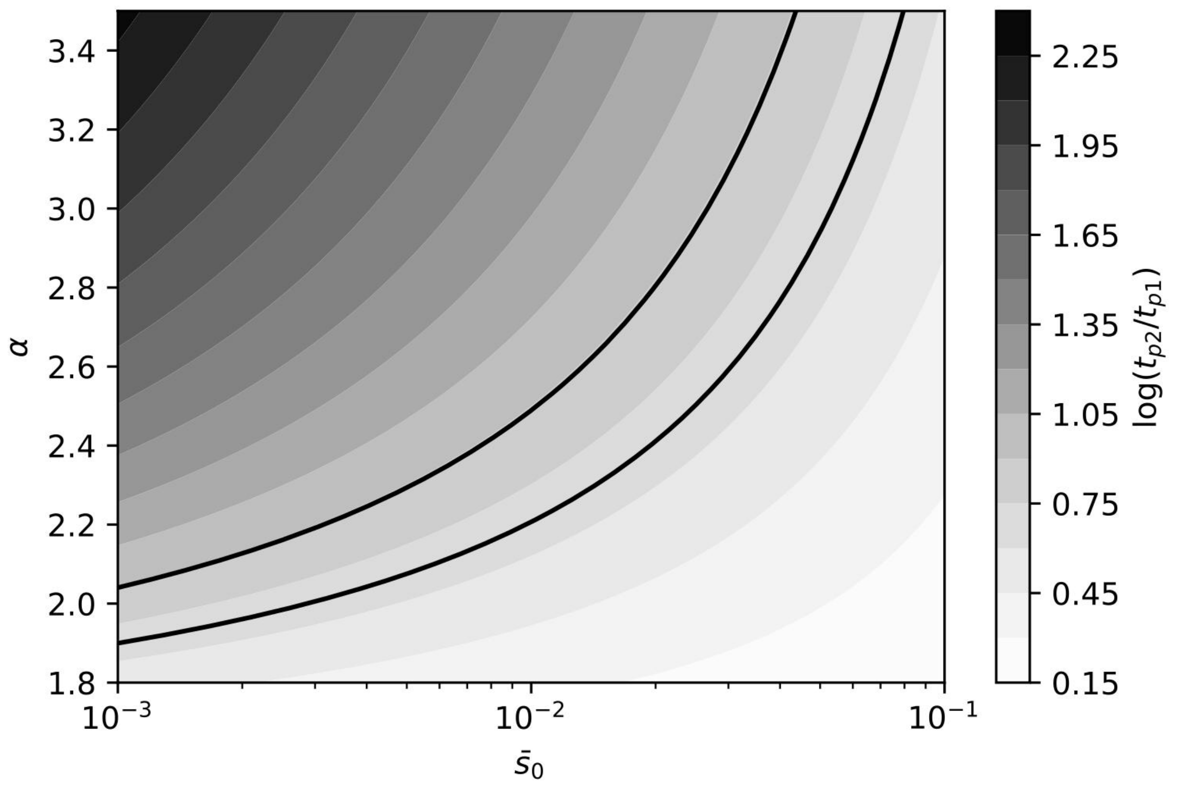
$$\dot{M} = \frac{dM}{d\epsilon}\frac{d\epsilon}{dt} = \frac{2\pi}{3}\left(GM_{\rm BH}\right)^{2/3}\frac{dM}{d\epsilon}t^{-5/3}.$$

Constraint on the Common Envelope

$\beta = 1$



$\beta = 10$



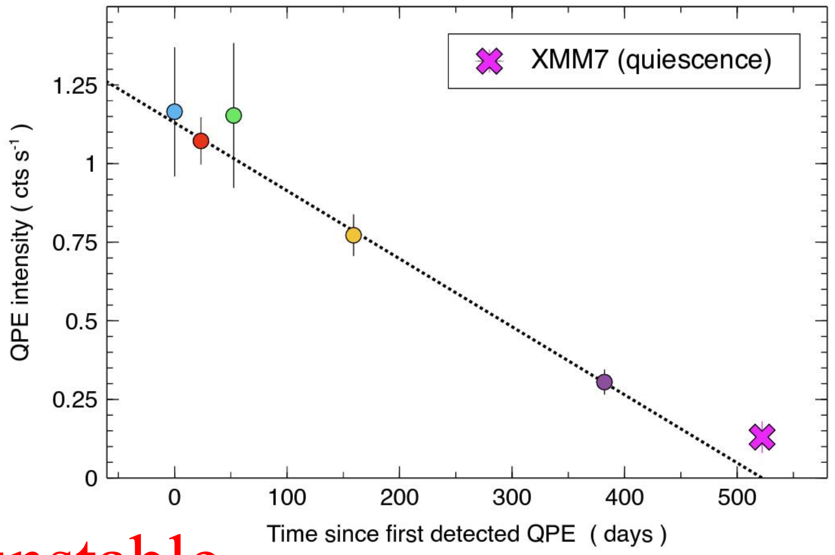
Binary scale is about $11 - 26 R_\oplus (\alpha = 3)$

Stability of mass transfer

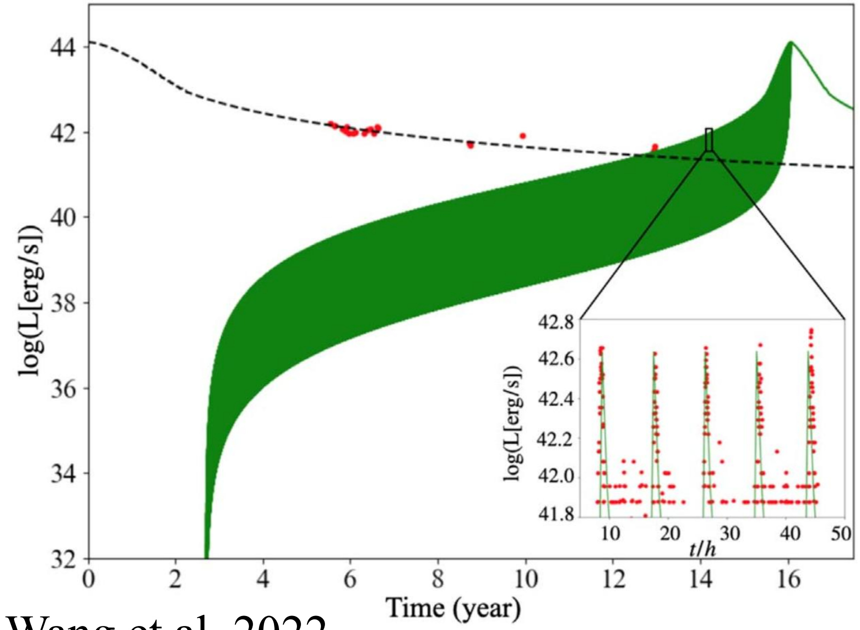
$$\frac{d(\Delta M)}{\Delta M dt} \approx \frac{5\beta_0}{2(\beta - \beta_0)}\frac{\dot\beta}{\beta} \qquad \beta \equiv r_t/r_p \qquad \beta_0 \approx 0.5$$

$$\left\langle \frac{\dot\beta}{\beta} \right\rangle_{\dot M} = \frac{\dot M}{M}\left(\zeta - \frac{1}{3}\right) \qquad R \propto M^{\zeta}$$

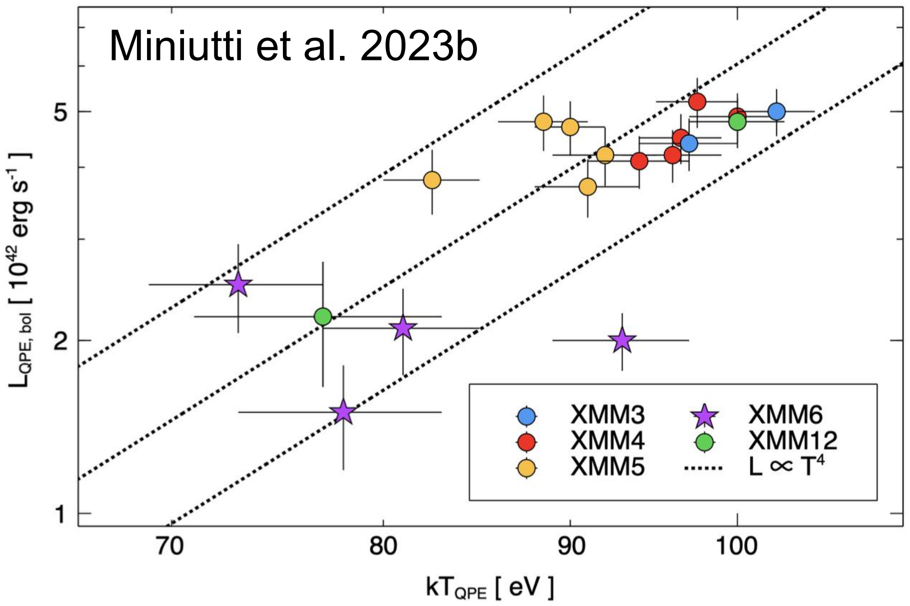
Miniutti et al. 2023a



Mass transfer of WD is unstable



Wang et al. 2022



Drag force for a star inside the gaseous disk

- Drag force by the accretion disk

$$\mathbf{a} = -\frac{\mathbf{v}_{rel}}{\tau_F}$$

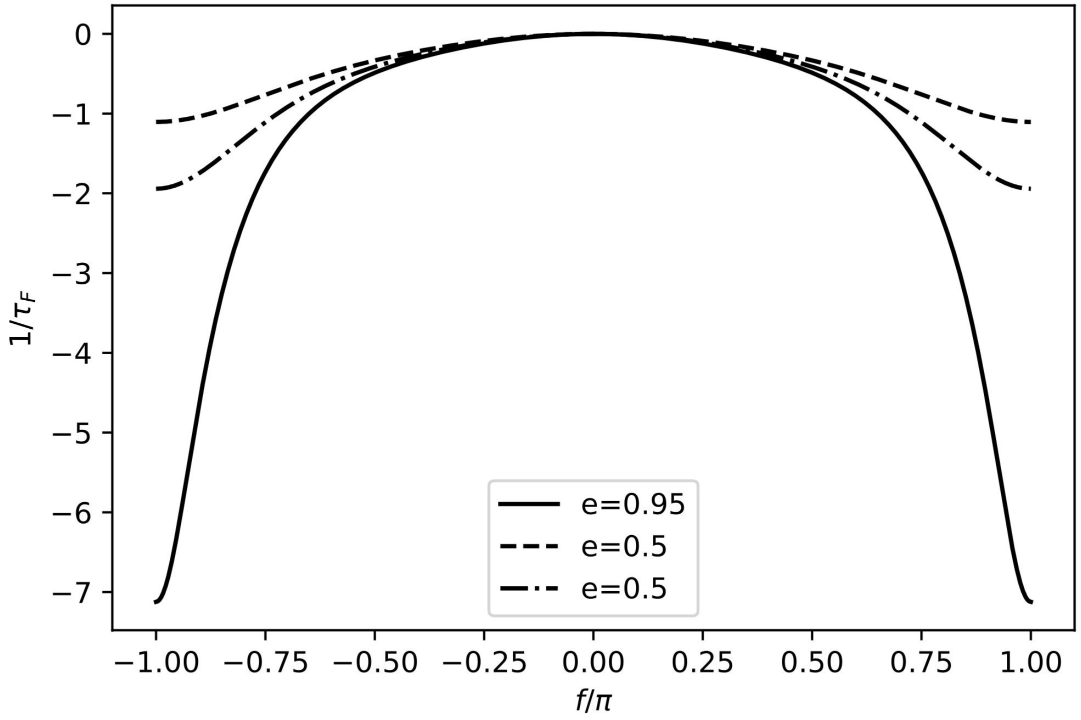
- Two forces
  - Hydrodynamic force

$$\tau_H = \frac{2M}{C_D \pi R^2 \rho_g v_{rel}}$$

  - Dynamical friction

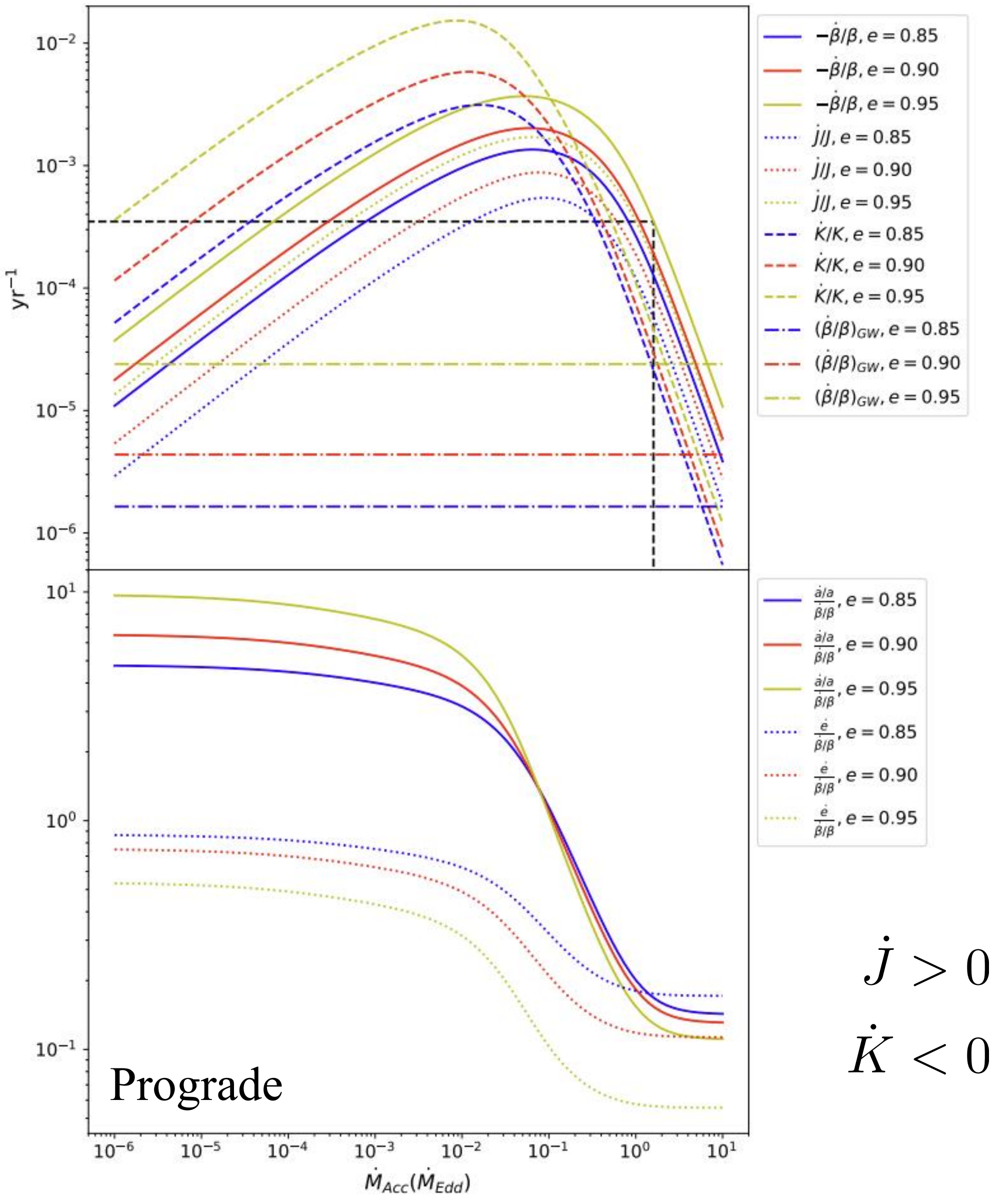
$$\tau_D = \frac{v_{\rm rel}^3}{4\pi G^2 M \rho_g F(\mathcal{M})}$$

$$\left\langle \dot{\beta}/\beta \right\rangle_{Disk}$$



For a prograde orbit, gas drag can stabilize mass transfer

Effect of gas drag



Accreted mass of QPEs $\sim 3.7 \times 10^{-8}\ \mathrm{M}_\odot$ (Miniutti+, 2023a)

$$\left\langle \frac{\dot{\beta}}{\beta} \right\rangle_{\dot{M}} \approx 1.1 \times 10^{-4} \mathrm{yr}^{-1}$$

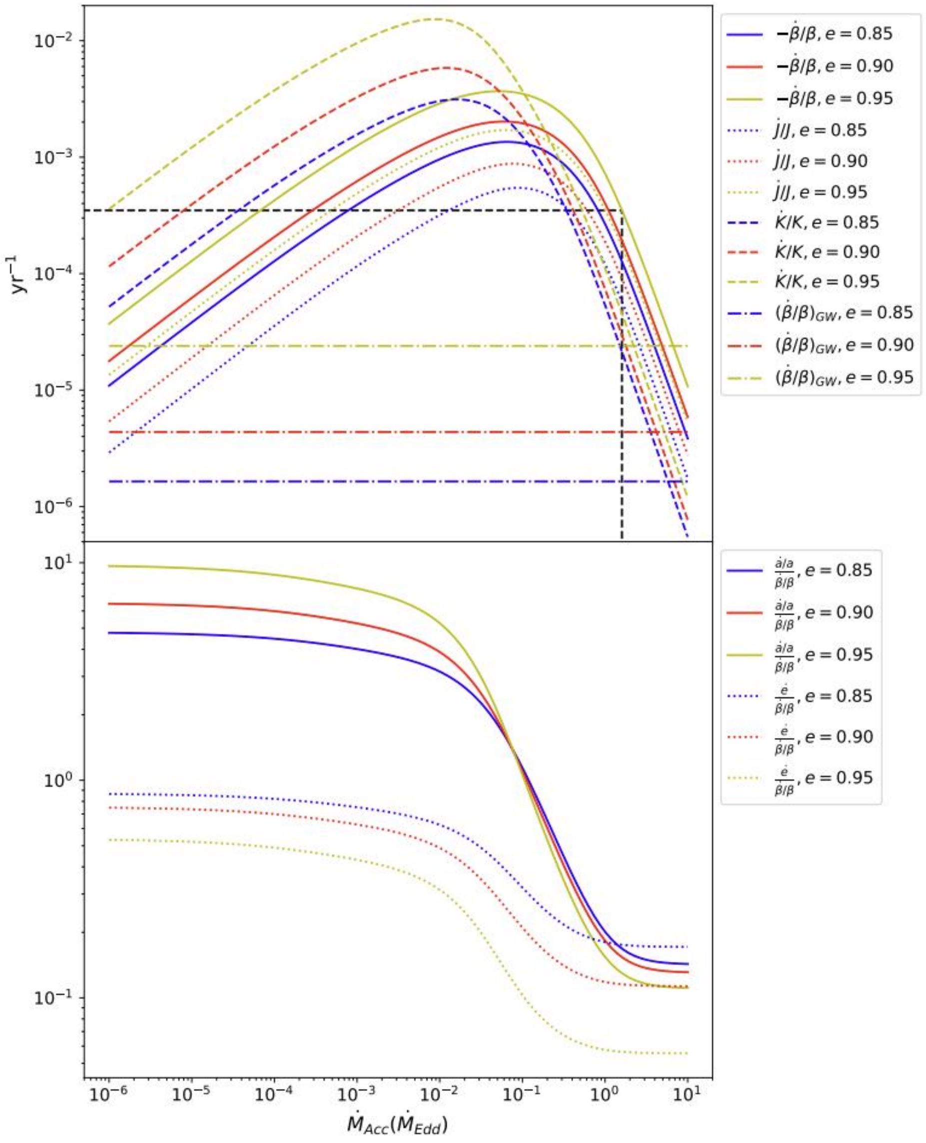
Accretion rate $\sim 10^{44}\ \mathrm{erg/s} \sim 1.6 \dot{M}_{Edd}$ (Miniutti+, 2023a)

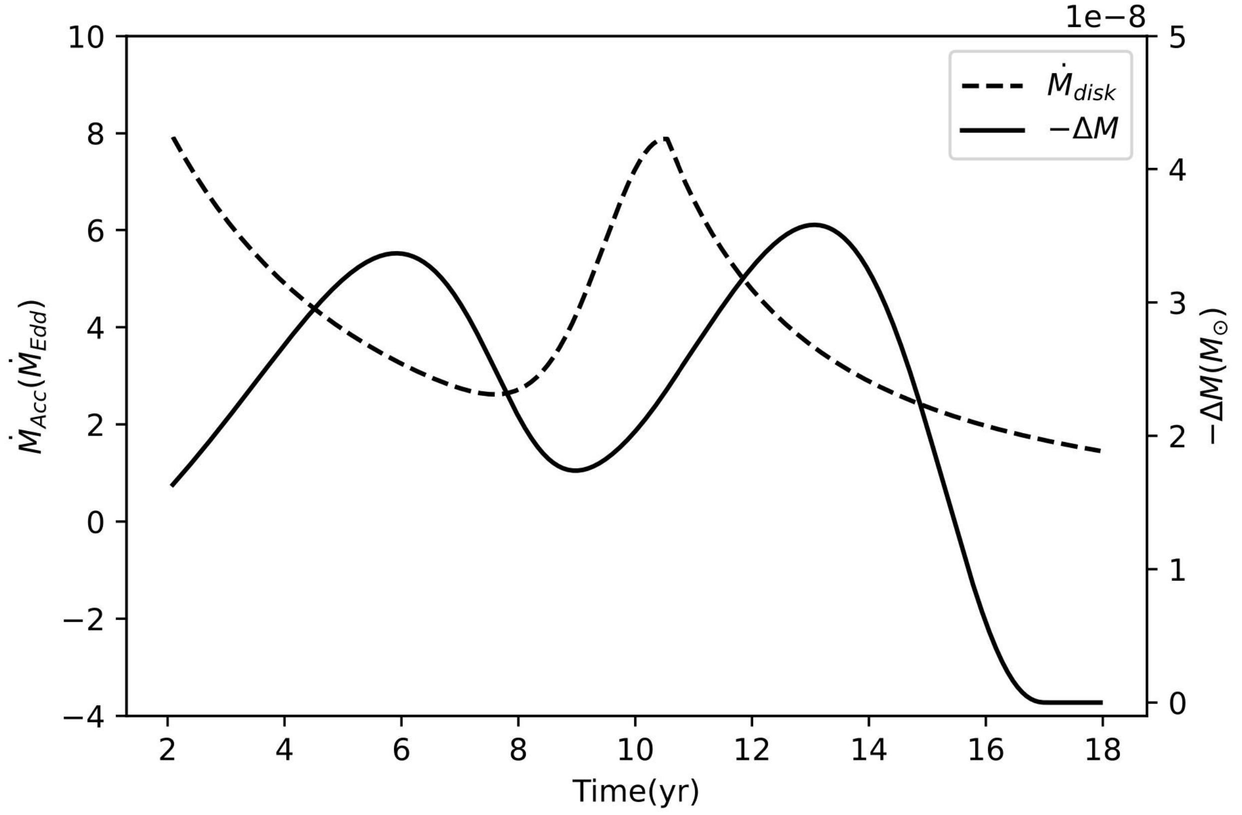
$$\left\langle \frac{\dot{\beta}}{\beta} \right\rangle_{Disk} \approx -3.5 \times 10^{-4} \mathrm{yr}^{-1}$$

$\dot{J} > 0 \quad \dot{a} < 0$

$\dot{K} < 0 \quad \dot{e} < 0$

Secular evolution





Summary

- The tidal disruption of the common envelope can explain both timescale and second flare of the TDE in GSN 069.

- Drag force by the disk have ability to stabilize the mass transfer of the eccentric EMRI in GSN 069.