

EMRIs in light of QPEs:

Recent observational and theoretical advances

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Quasi-Periodic Eruptions (QPEs)

- ~13+2 confirmed/candidate sources

- Soft X-ray (+delayed UV Guo+2026)

- Recurring on hours-days timescales

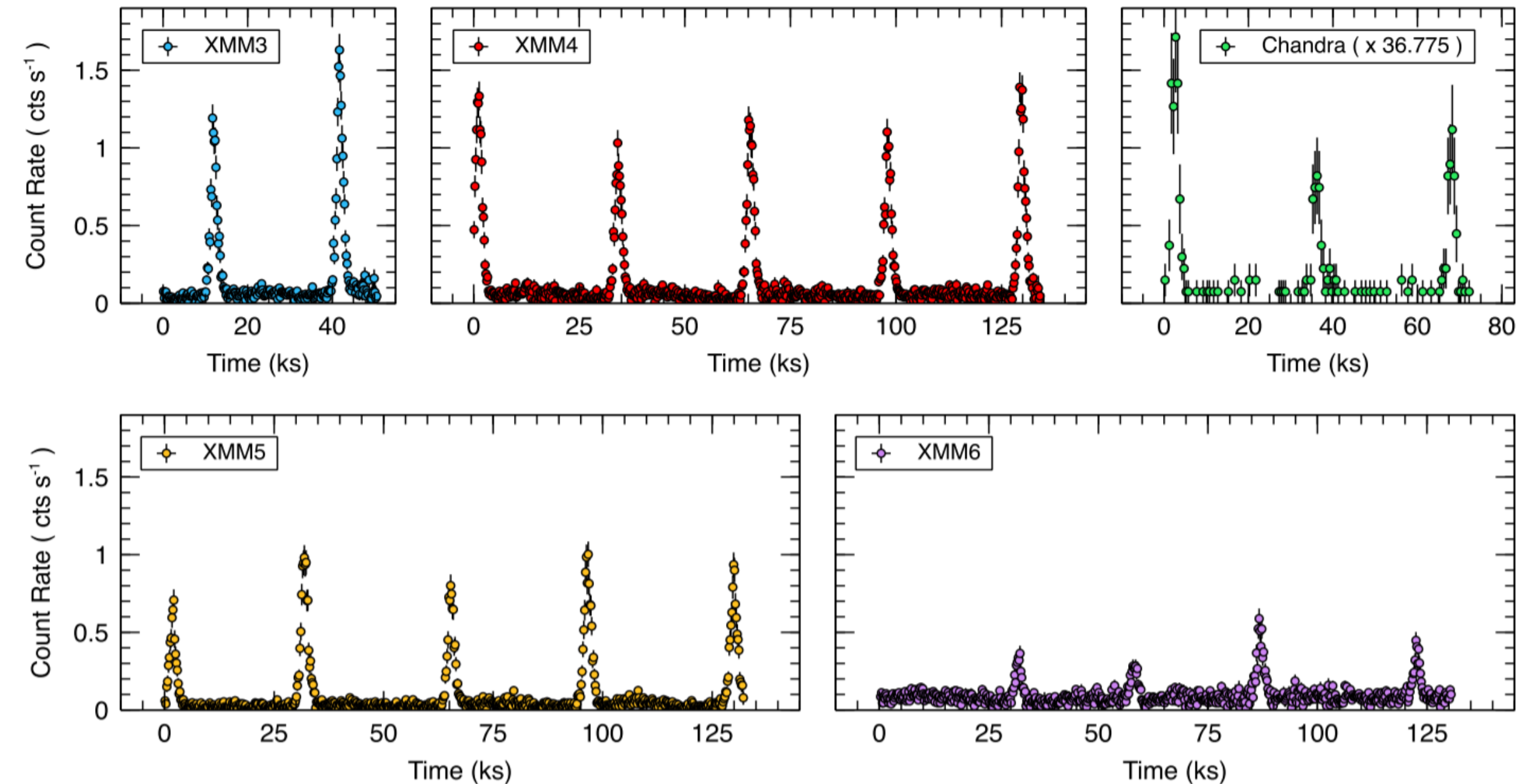
- Peak luminosity $\sim 10^{42-43}$ ergs/s

- Located in nuclei of dwarf galaxies

- SMBHs 10^5 - 10^7 M_{sun}

- ~10% of TDE hosts exhibit QPEs

- Overrepresentation of *EELRs* & *Infrared echoes* in QPE hosts

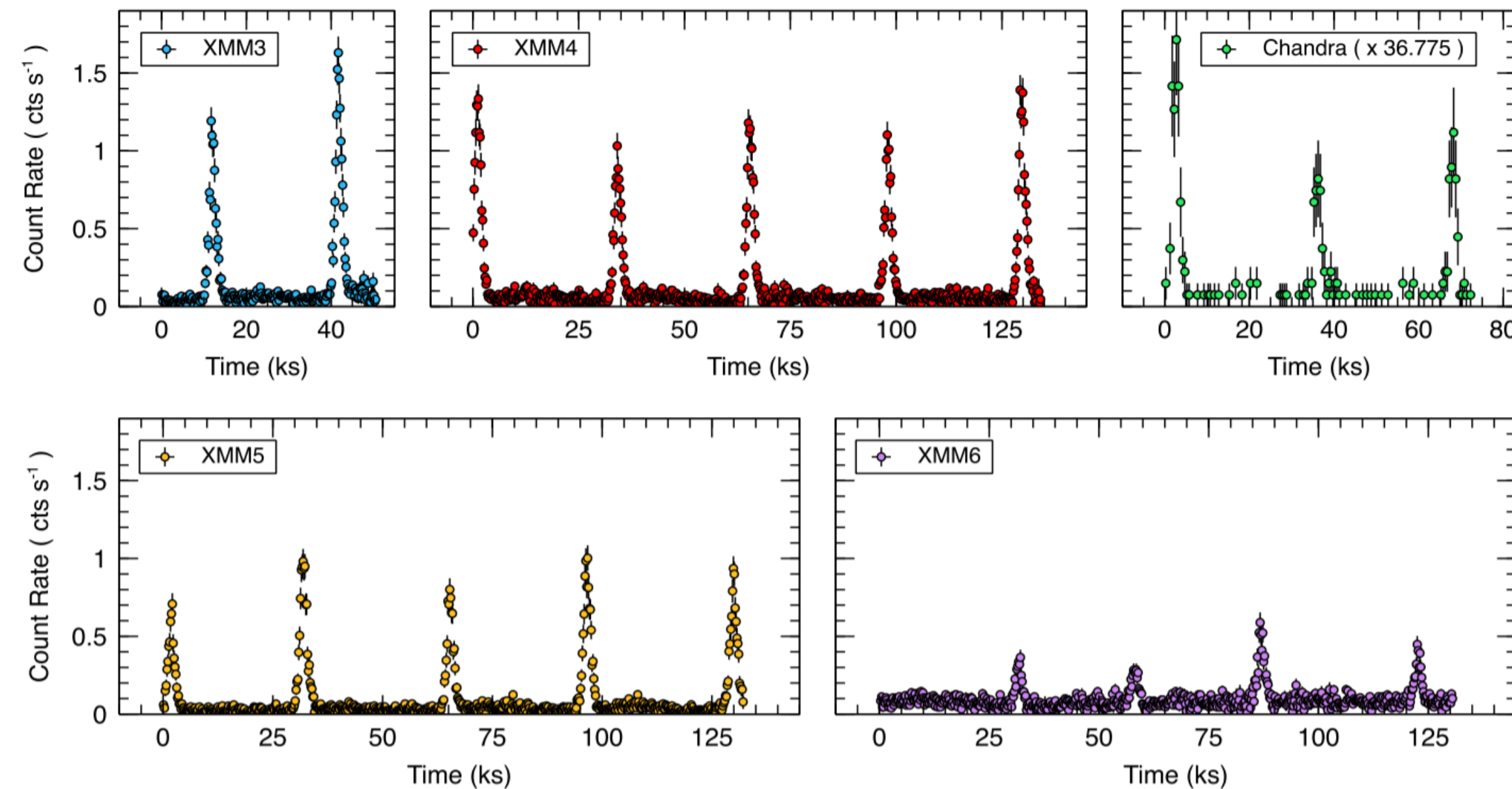


GSN 069 Miniutti+(2019)

Review of QPEs

- **Patterns in QPE timing → QPEs= EMRI+disk**
 - **Alternating long-short pattern (:Q-P)** (Miniutti+2019)
 - **$T_{\text{long}}(t) + T_{\text{short}}(t) = \text{const}$ (:P)** (Zhou+2024)
- **TDE-QPE association:**
 - **> 50% QPEs are found with TDEs (tidal disruption events)**
 - **QPEs prefer a subset of TDEs**
 - **EELR (extending emission line region)** (Wevers+2023/24, Xiong+2025)
 - **Infrared echo** (Wu+2025, Baldini+2026)

Why EMRI+disk ? 2 eruptions per period



Miniutti+(2019)

- Alternating T_{long} & T_{short}
- $T_{\text{long}}(t)$ & $T_{\text{short}}(t)$ varies
- $T_{\text{long}}(t) + T_{\text{short}}(t) \approx \text{const}$

Zhou+(2024)

Dai+(2010)

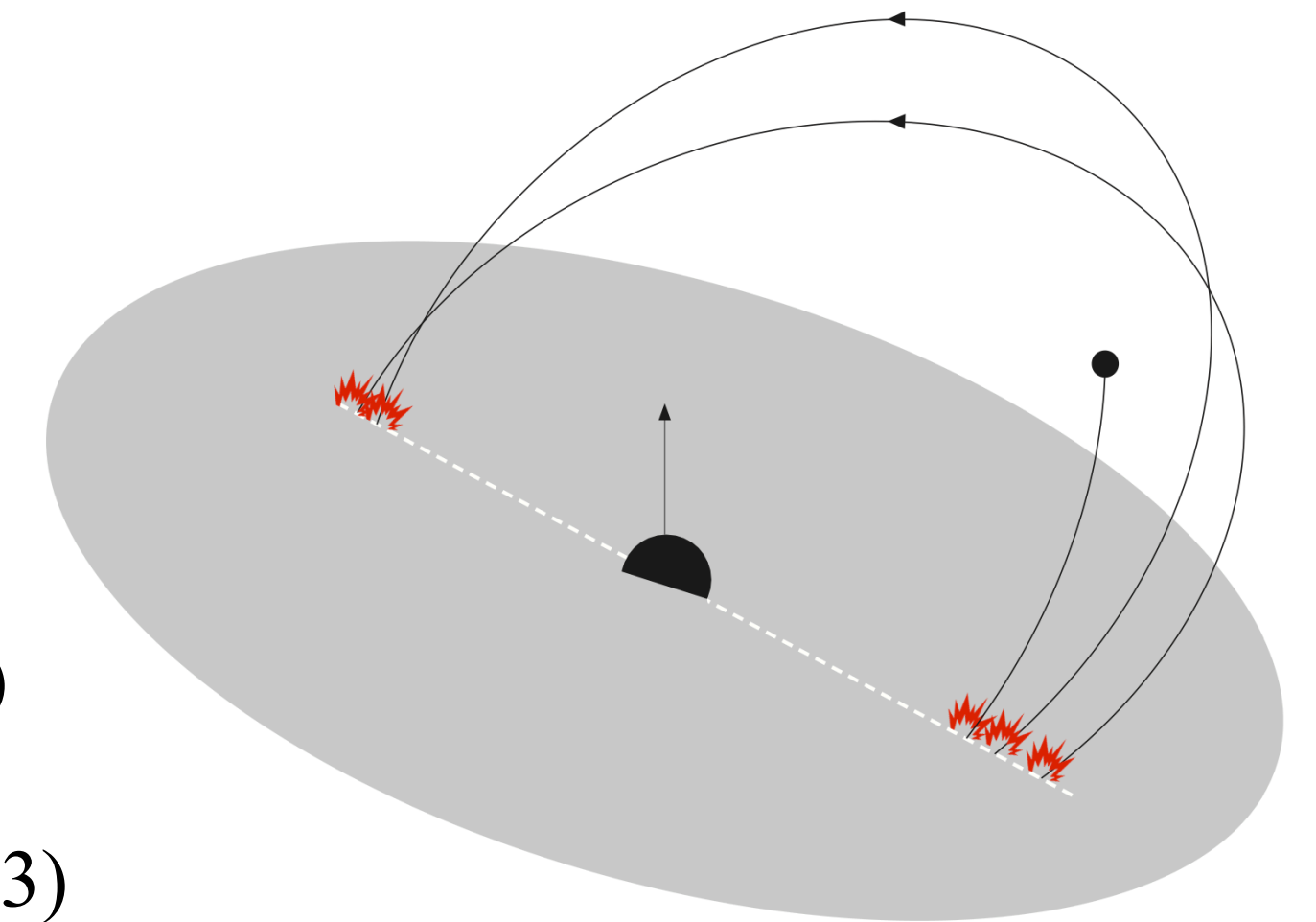
Xian+(2021)

Linial+(2023)

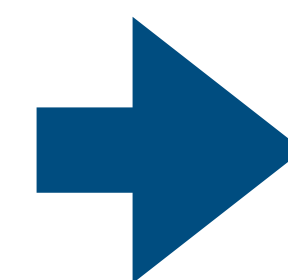
Tagawa+(2023)

Franchini+(2023)

Zhou+(2024/25)



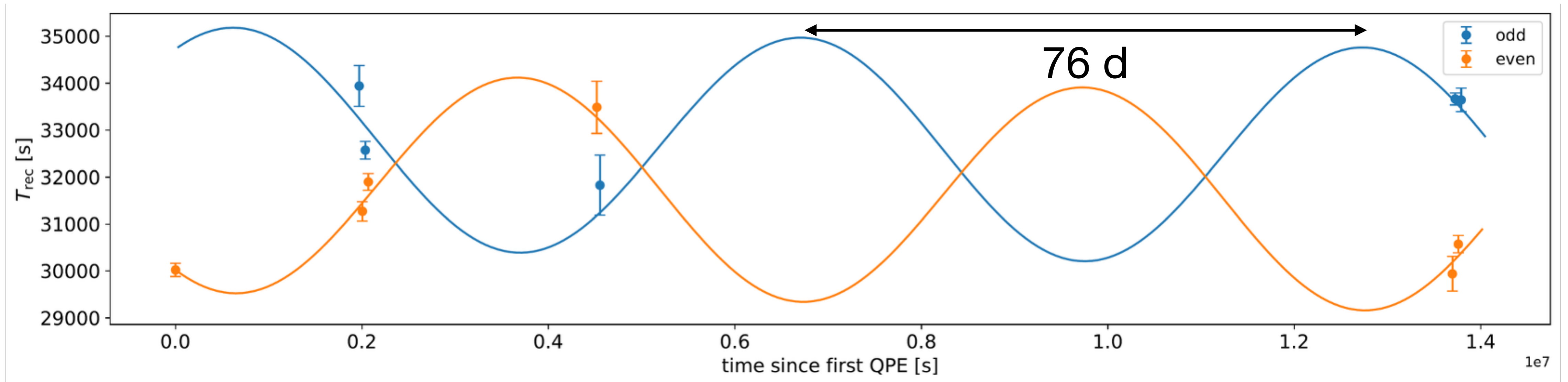
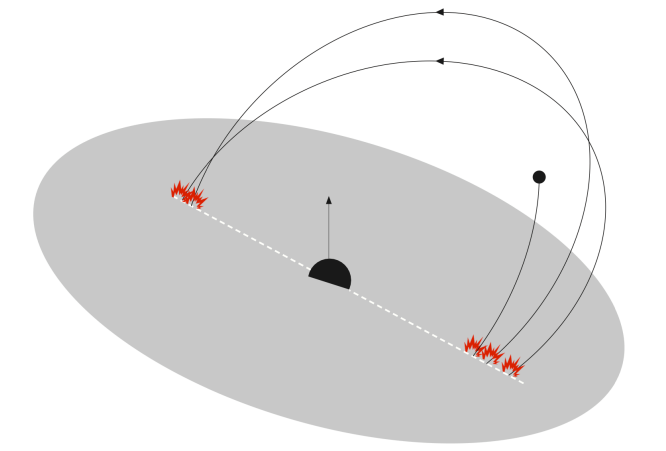
Zhou+(2025)



$T_{\text{long}} + T_{\text{short}}$ is the fundamental period
& 2 eruptions per period

QPE timing

GSN 069

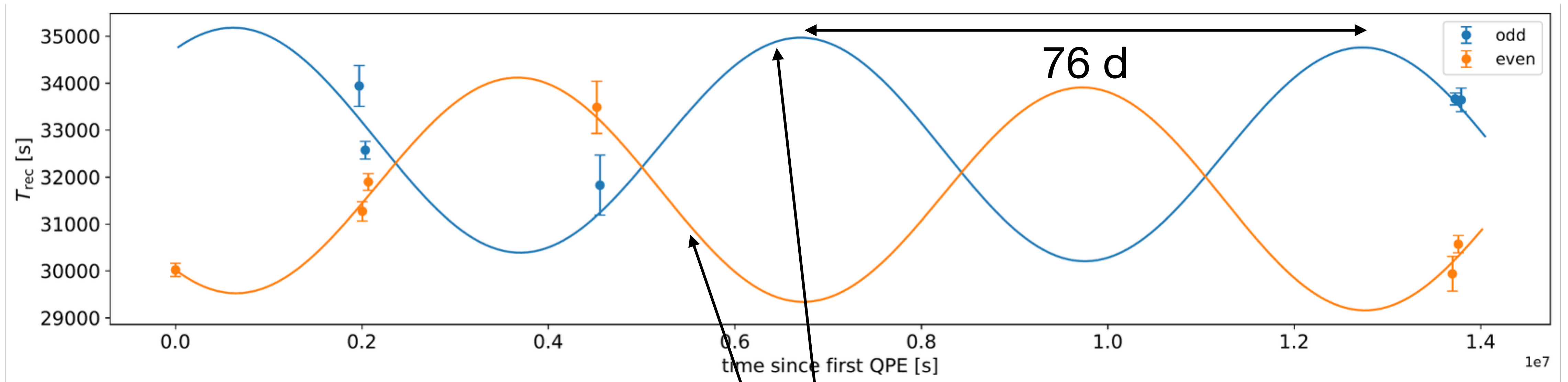
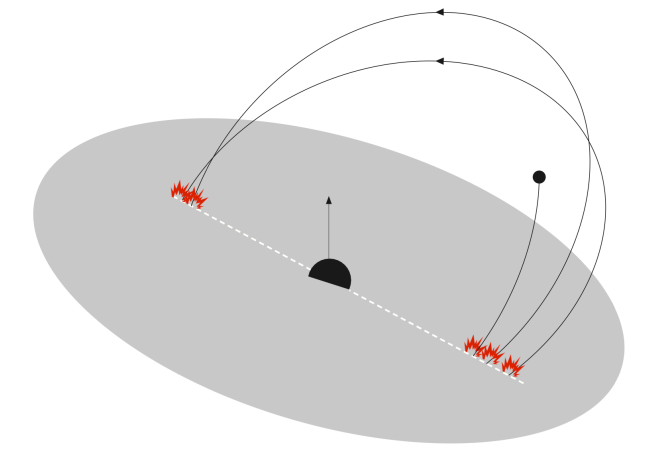


Zhou+(2026)

1. Alternating T_{long} & T_{short} : orbital eccentricity $e \approx 0.04$
2. $T_{\text{long,short}}(t)$ vary with time: apsidal precession period $T_{\text{aps}} \approx 76 \text{ d} \Rightarrow$
 $M_{\bullet} \approx 4 \times 10^5 M_{\odot}$
 $p \approx 300 M_{\bullet}$
3. $T_{\text{long}}(t) + T_{\text{short}}(t) \approx \text{const}$: orbital period $T_{\text{obt}} \approx 65 \text{ ks}$

QPE timing

GSN 069



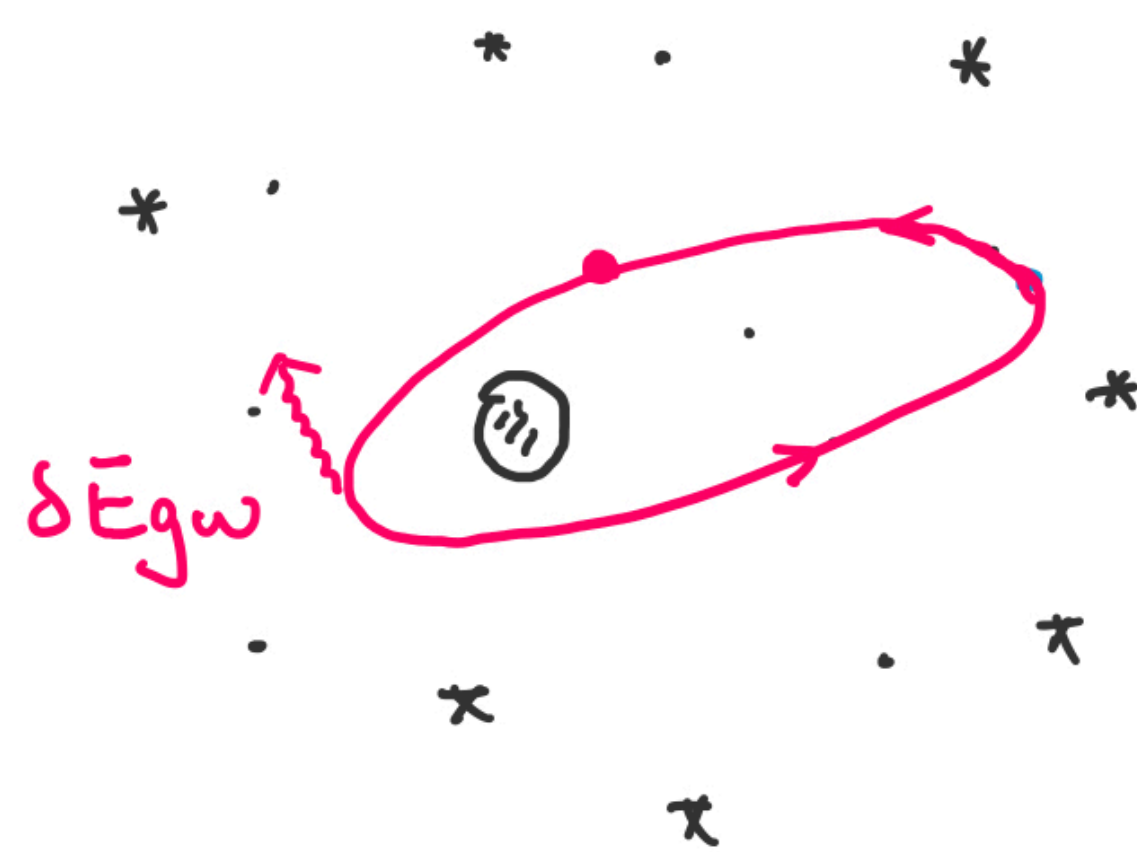
Zhou+(2026)

Apsidal precession: Two **anti-phase** branches in $T_{\text{rec}}(t)$

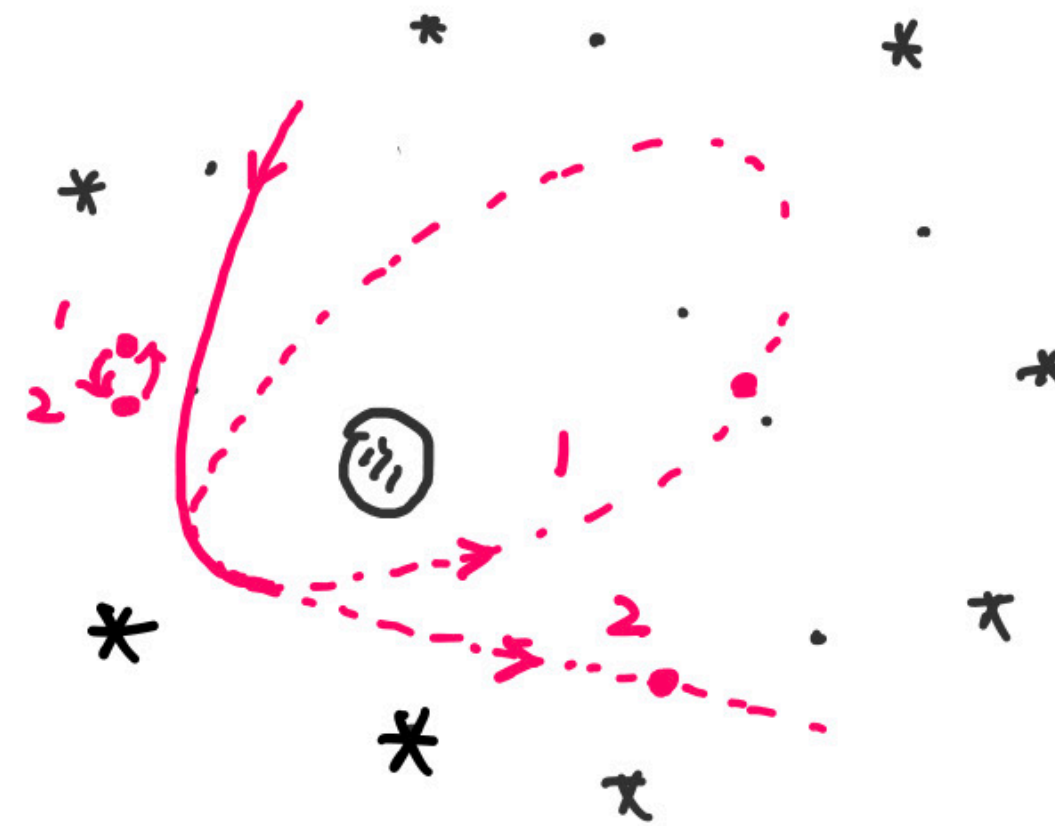
External modulation (disk precession, EMRI around a companion SMBH):

Two **in-phase** branches in $T_{\text{rec}}(t)$

EMRI formation channels



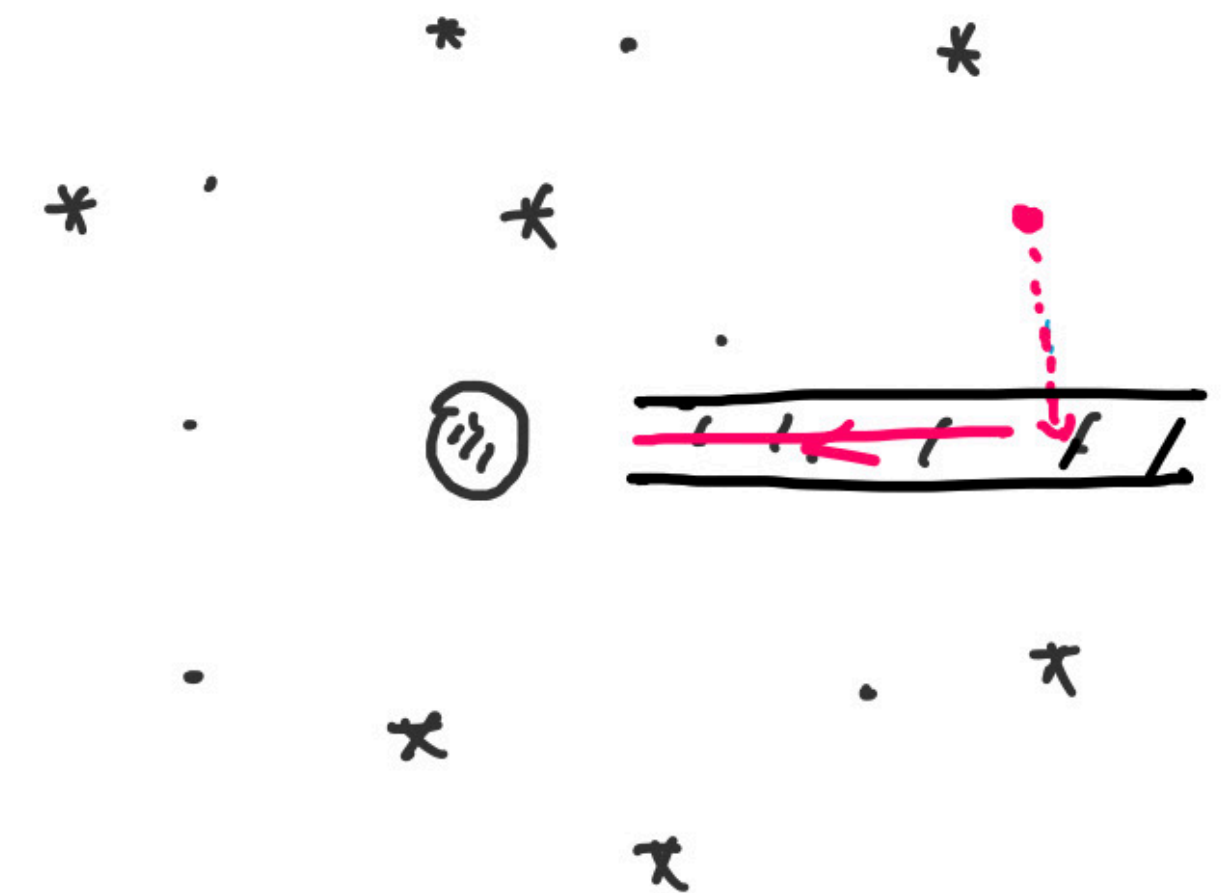
Dry EMRIs
Highly eccentric



Hills EMRIs
Zero-eccentricity (X)
Highly eccentric (✓)

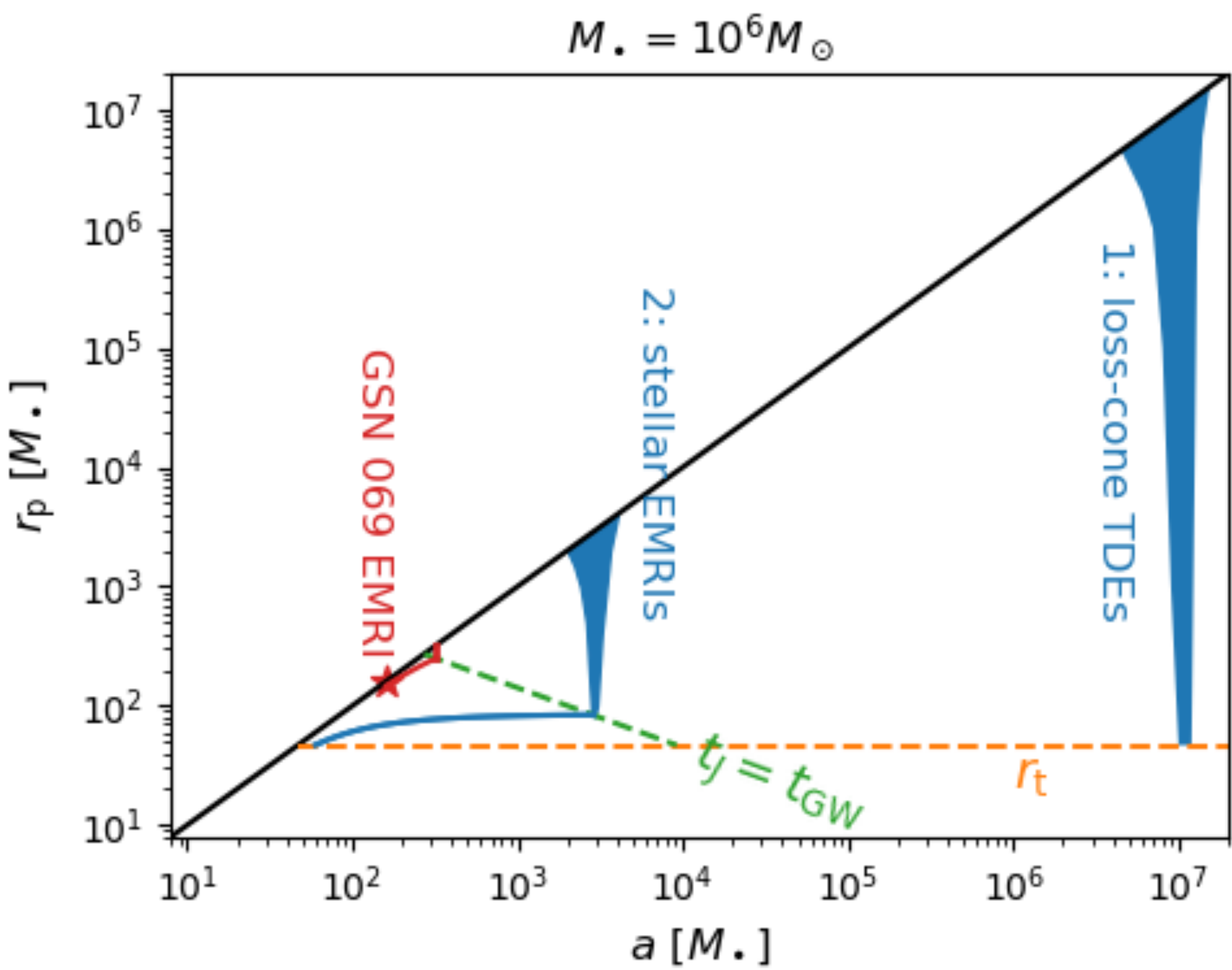
Miller+(2005)

Raveh & Perets (2021)



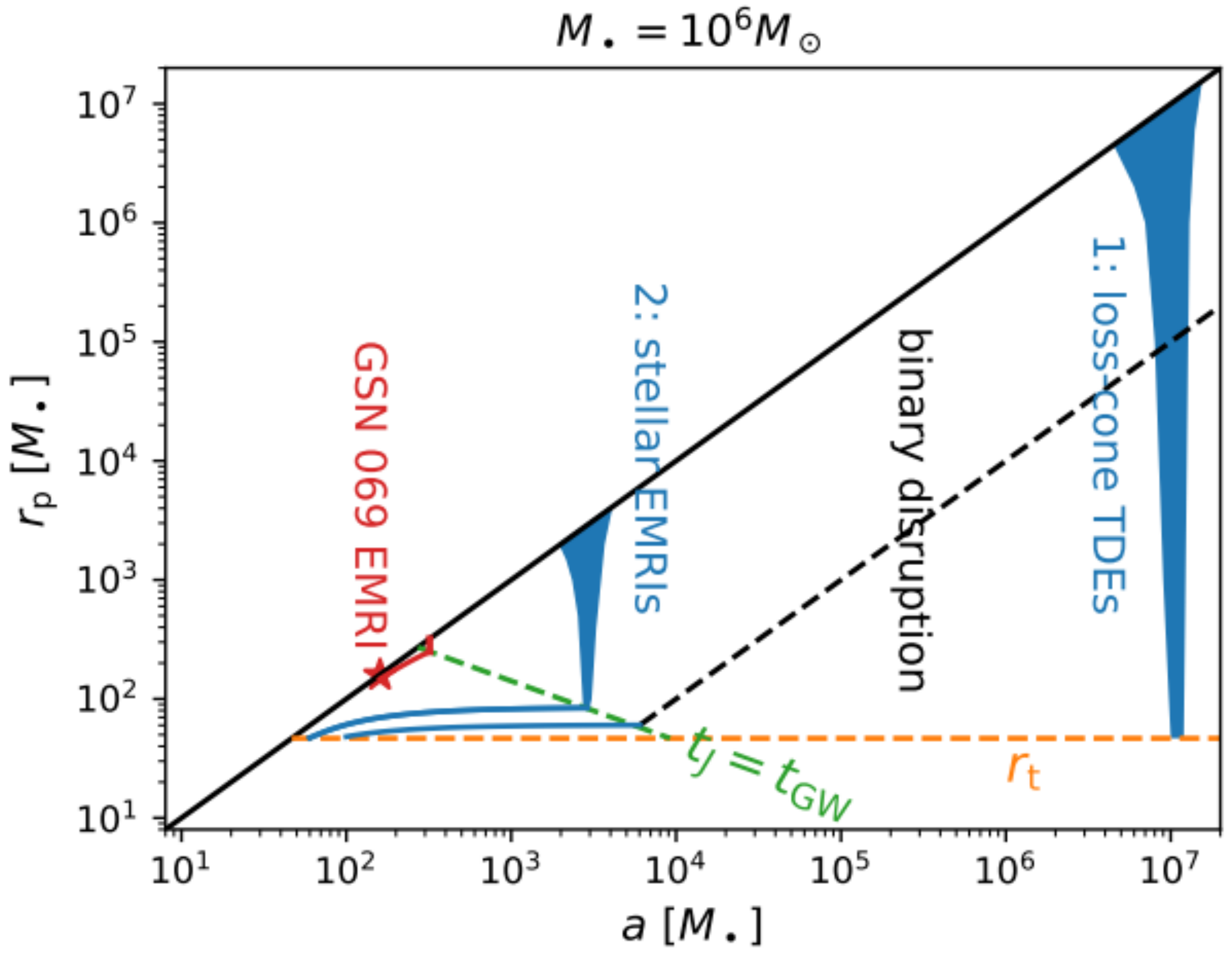
Wet EMRIs
Nearly circular

GSN 069 EMRI formation



Very unlikely Dry

Consistent with Wet



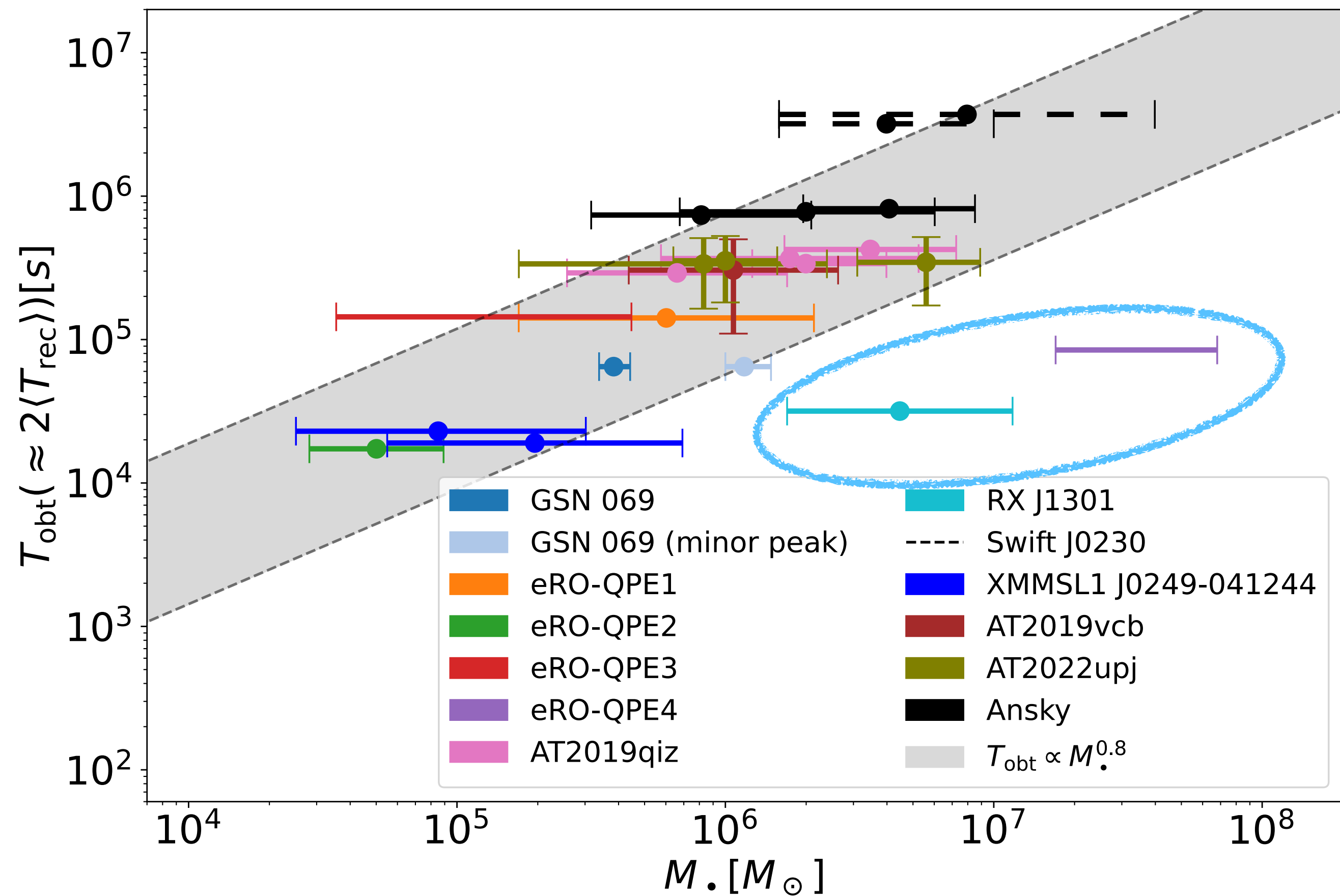
No way Hills

Zhou+(2024/25), Allievi+(2026), Sun+(2026), Rom+(2026)

QPE population statistics

- A low-e population
 - Wet (✓)
- A high-e population
 - Dry/Hills (✓)

Multiple formation channels (?)



Zhou+(2025)

Review of QPEs

- Patterns in QPE timing:
 - Alternating long-short pattern (:Q-P)
 - $T_{\text{long}}(t) + T_{\text{short}}(t) = \text{const}$ (:P)
- **TDE-QPE association:**
 - $> 50\%$ QPEs are found association with TDEs: TDE first, $O(1)$ yr later QPE
 - QPEs prefer a subset of TDEs
 - EELR (extending emission line region): AGN + Galactic clouds
 - TDE infrared echo: AGN dust torus

TDE-QPE association

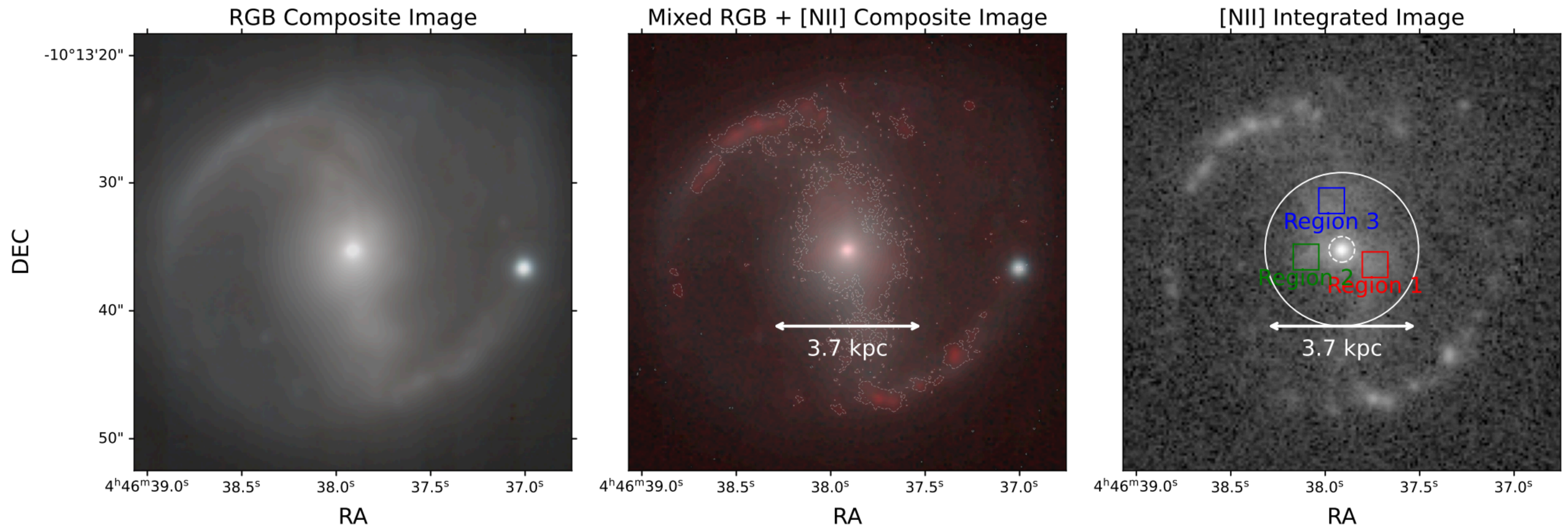
- AT 2019qiz: TDE first, ~4 yr later QPEs (Nicholl+2024)
- ~7/13 QPEs with TDE association (Jiang & Pan 2025) (Chakraborty+2025)
- ~5/13 QPEs in recently faded AGNs (Jiang & Pan 2025) (~9/13 Wevers in prep.)

$$\frac{R_{\text{QPE}}}{R_{\text{TDE}}} \approx 10\% \frac{10\text{yr}}{\tau_{\text{QPE}}}$$

Source (1)	Redshift (2)	Black Hole Mass $\log_{10}(M./M_{\odot})$ (3)	TDE (4)	Recently Faded AGN (5)	References (6)
RXJ1301	0.0237	6.65 ± 0.42	No ?	Yes	(1, 4)
GSN 069	0.0182	5.99 ± 0.5	Yes	Yes	(1, 4, 5, 6)
AT 2019qiz	0.0151	6.48 ± 0.33	Yes	Yes	(2, 7, 8)
eRO-QPE1	0.0505	5.78 ± 0.55	?	No?	(1, 4, 9)
eRO-QPE2	0.0175	4.96 ± 0.54	?	Yes	(1, 4, 9)
eRO-QPE3	0.024	5.1 ± 0.55	?	No?	(3, 4)
eRO-QPE4	0.0437	$7.24^{+0.32}_{-0.12}$	?	?	(3)
J0249	0.0186	5.29 ± 0.55	Yes	?	(1, 10)
AT 2019vcb	0.089	6.03 ± 0.39	Yes	?	(2, 11, 12)
eRO-QPE5			?	?	
AT 2022upj			Yes	?	
Ansky			Yes	?	
J2344			Yes	Yes	

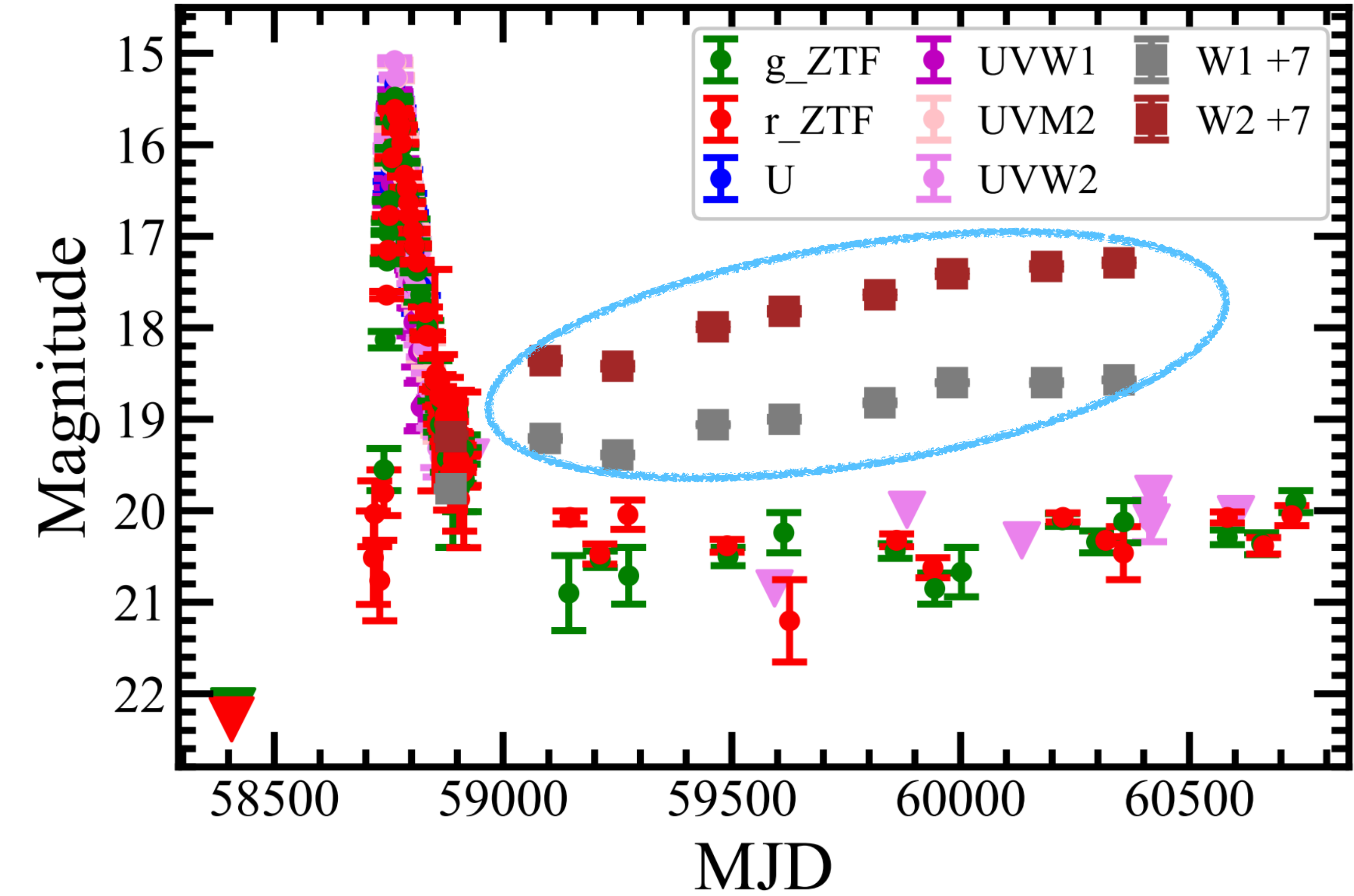
QPEs prefer EELR

AT 2019qiz: TDE, QPE & EELR (~kpc scale narrow line region)



Xiong+(2025)

QPEs prefer IR echo



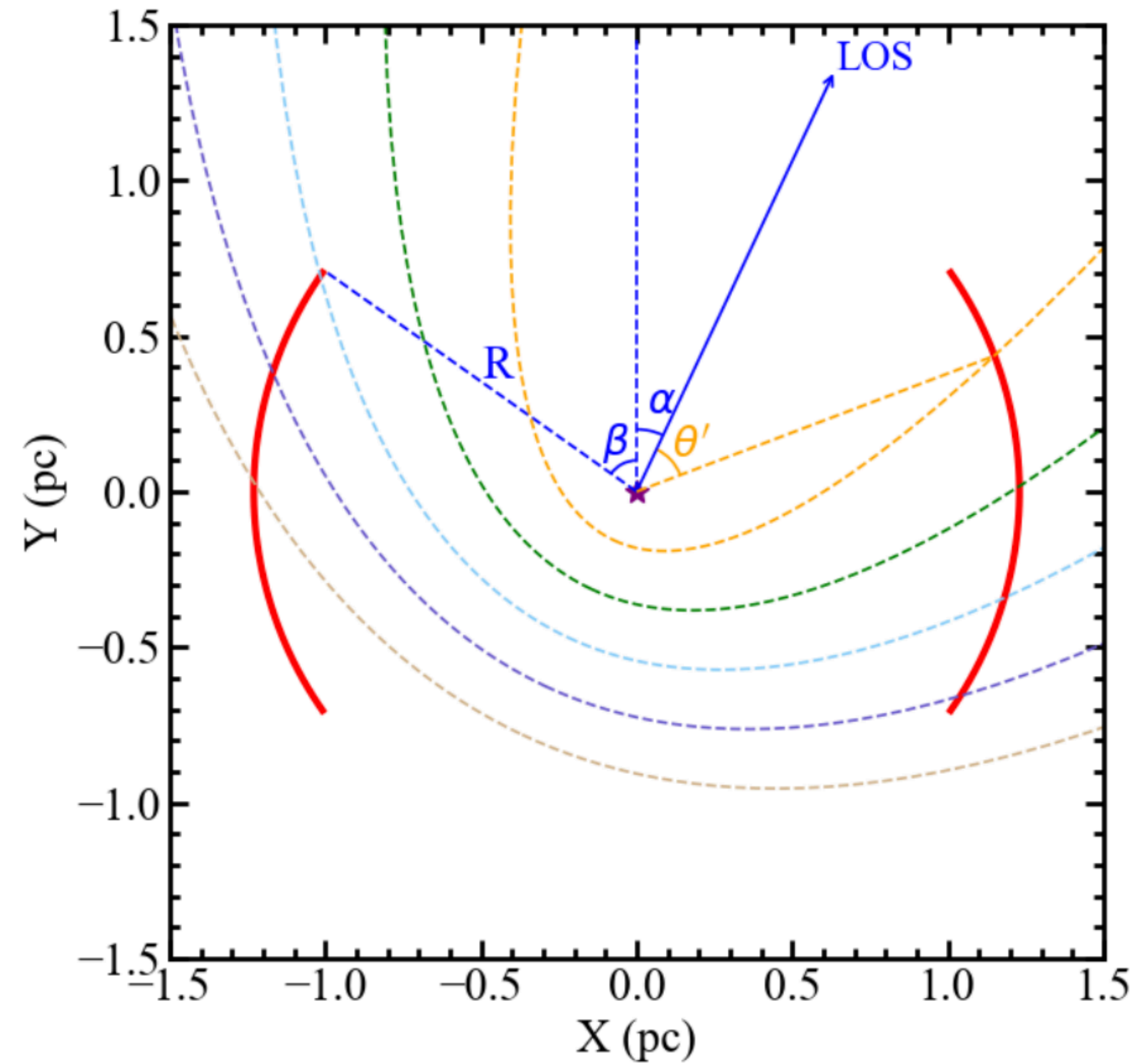
AT 2019qiz light curves

UV/optical prompt emission

+ **Infrared echo**

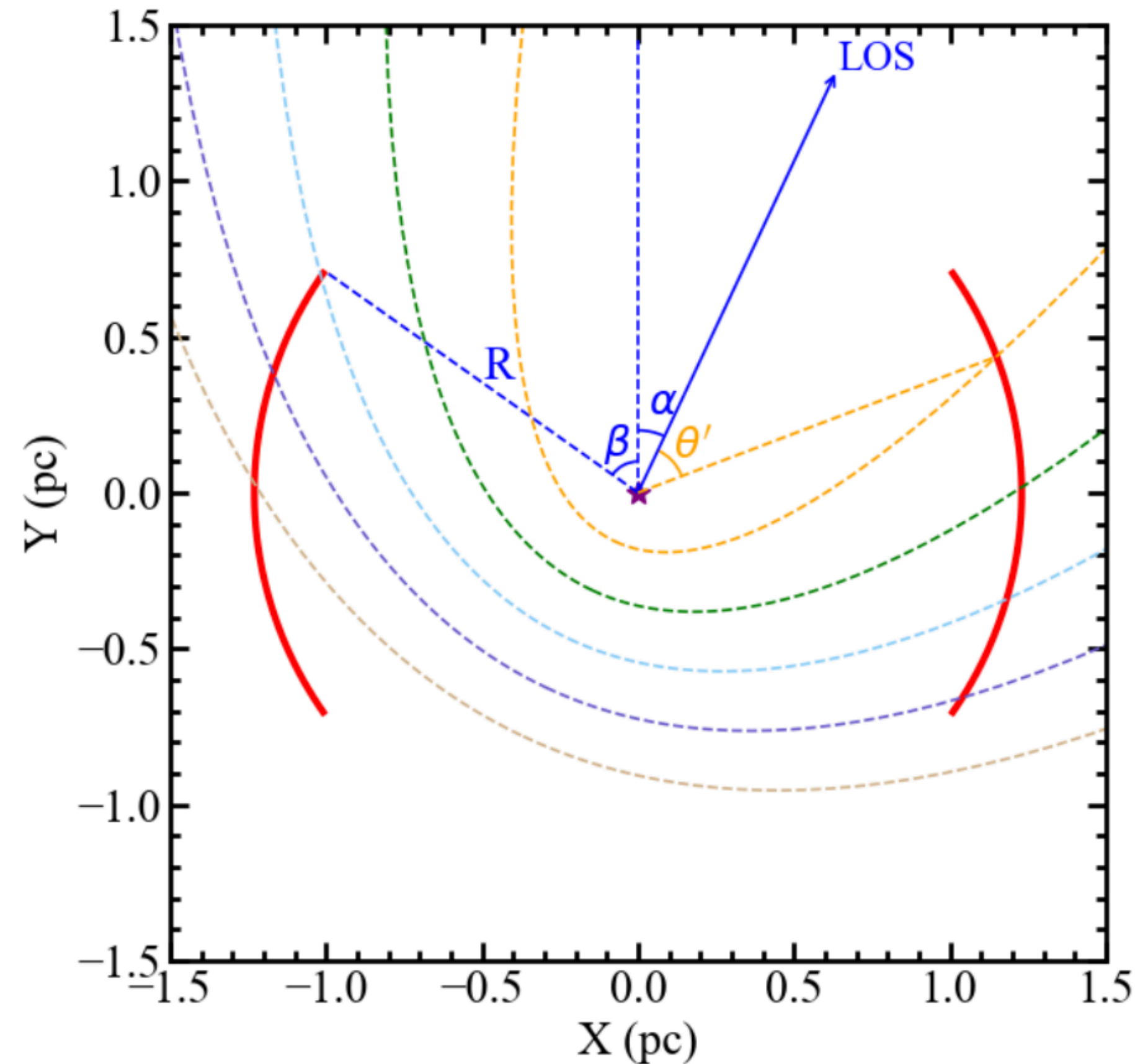
Wu+ (2025)

QPEs prefer IR echo $\rightarrow$ Dust Torus



Wu+ (2025)

QPEs prefer IR echo —> Dust Torus



Parsec scale dust shell

$$R = 1.55^{+0.44}_{-0.25} \text{ pc}$$

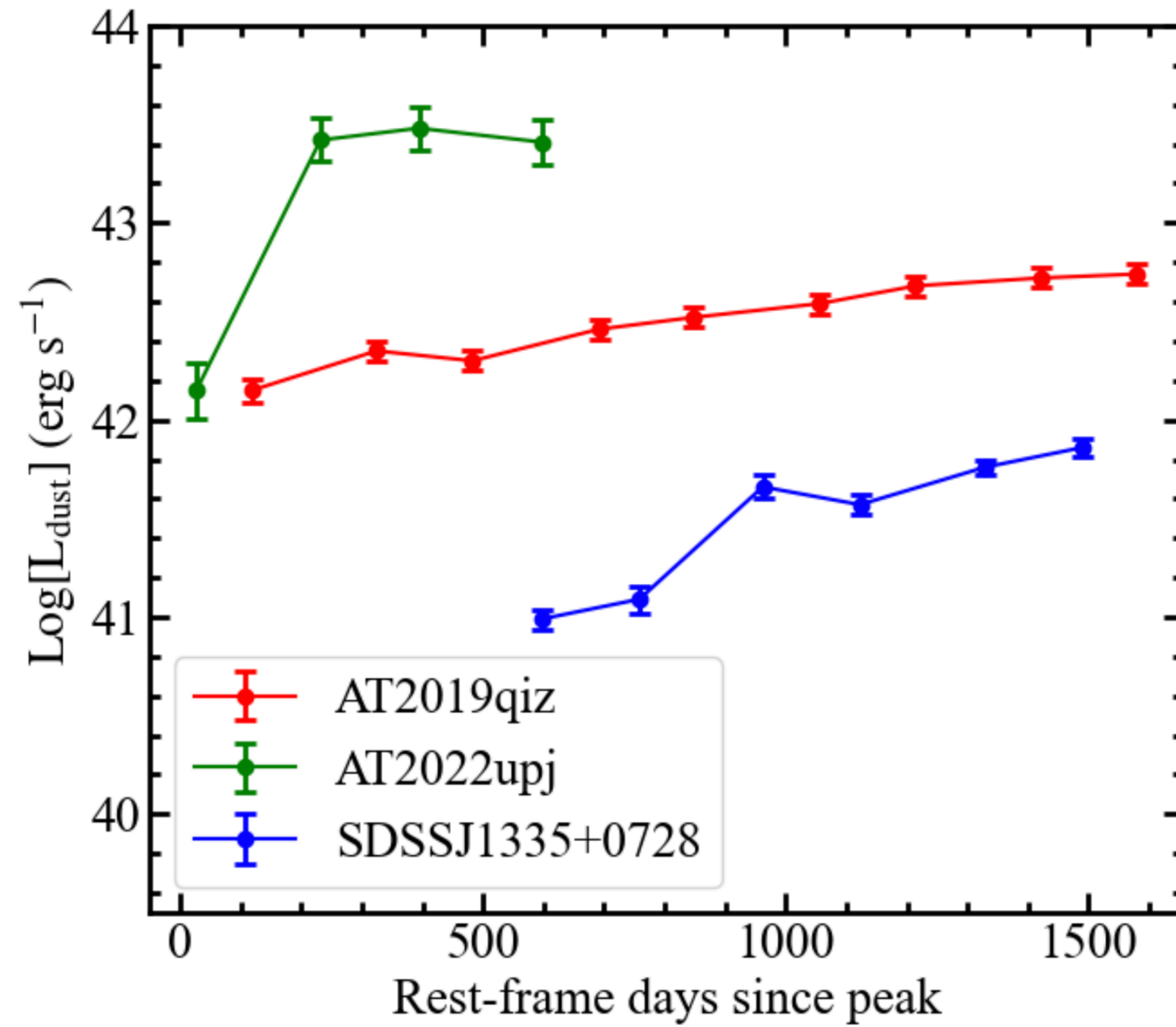
$$f_c = 0.65 \pm 0.07 \text{ @68\% C.L.}$$

Wu+ (2025) *Typical AGNs $f_c \in (0.5, 1)$*

(—> Recently faded AGN)

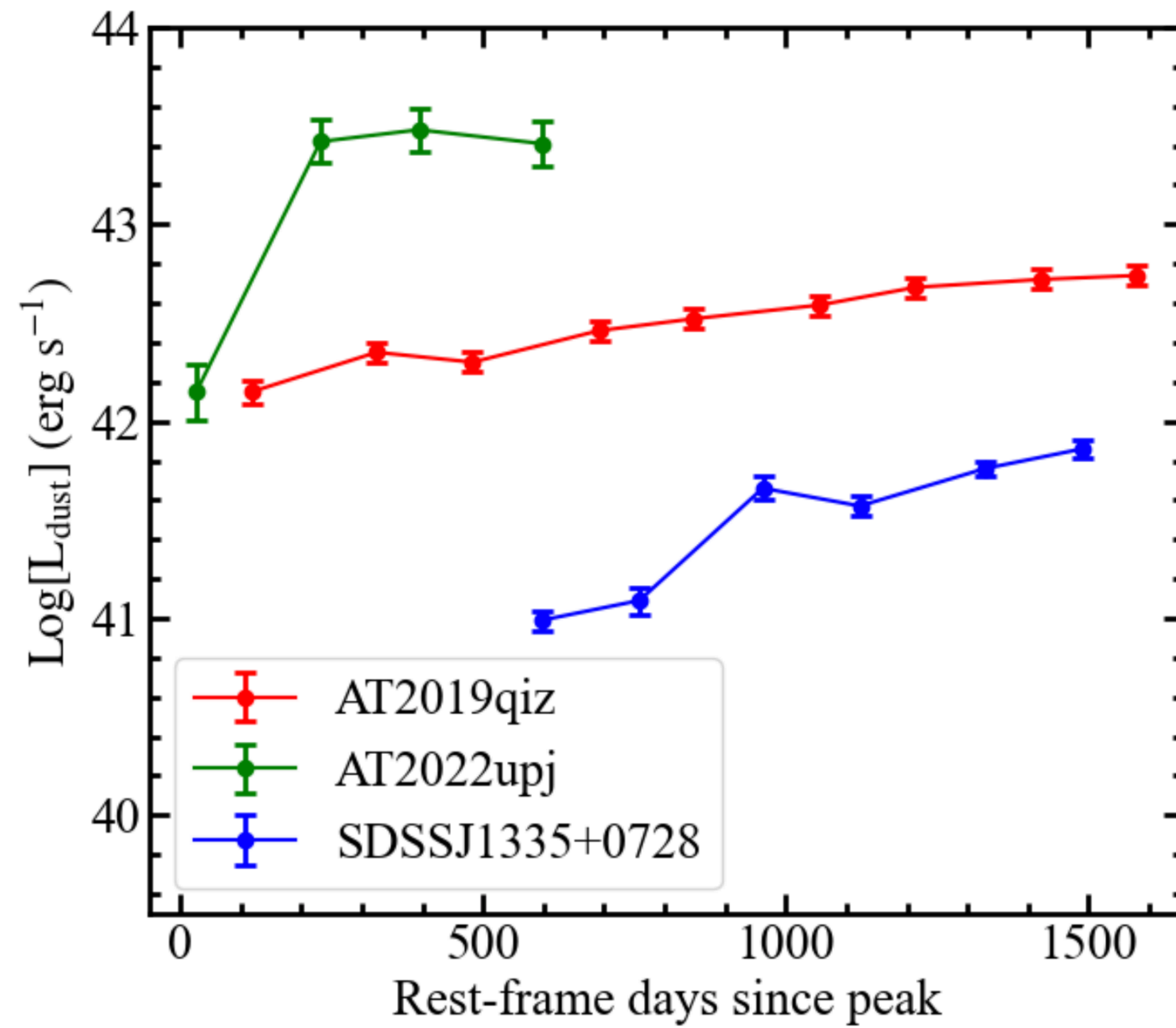
AT 2019qiz: **TDE** (2019) & **QPE** (2024) & **EELR** (2025) & **IR echo** (2025)

QPEs prefer some TDEs: Bright IR echo



7 QPE-TDE association pairs
4 are found with **bright IR echo**

QPEs prefer some TDEs: Bright IR echo



7 QPE-TDE association pairs

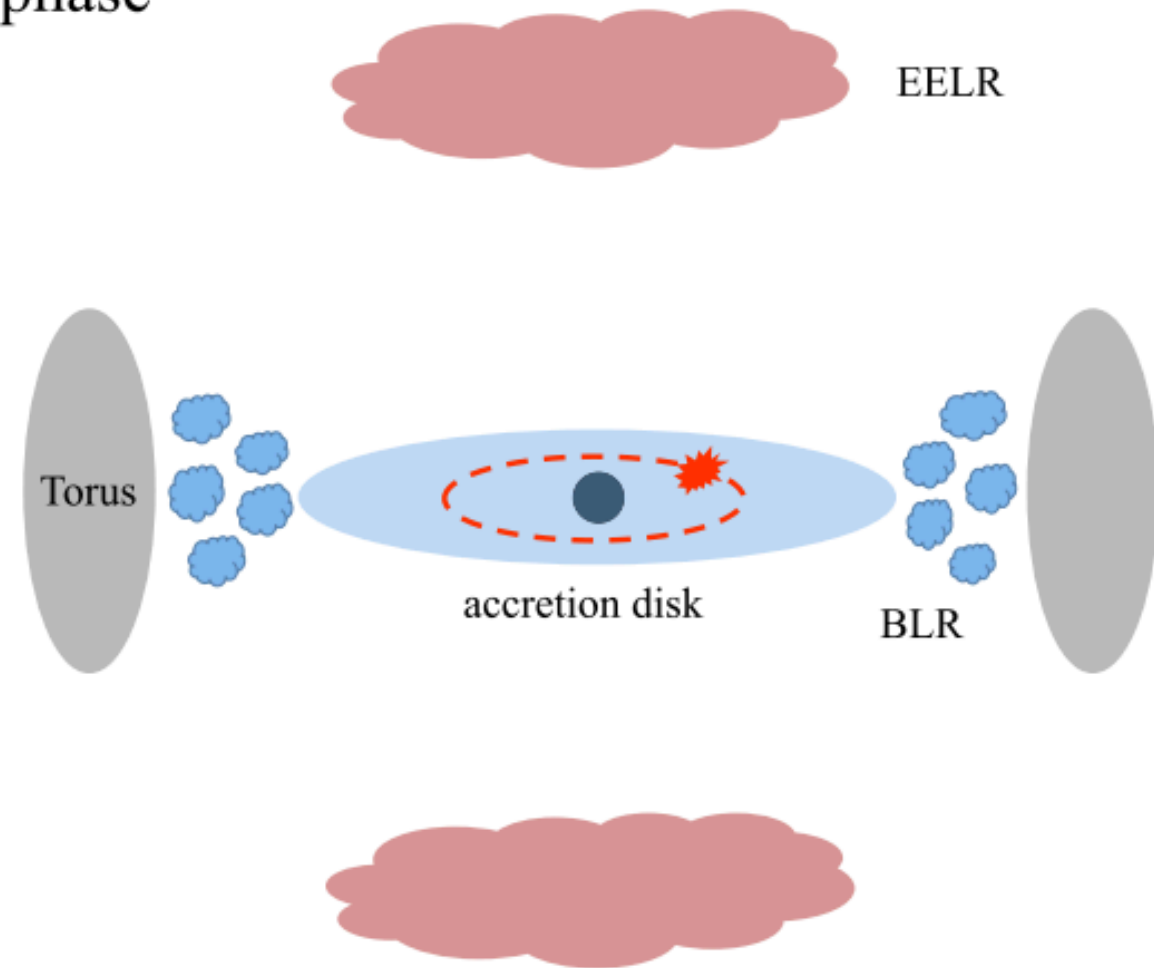
4 are found with **bright IR echo**

(low-e) **EMRI+TDE**

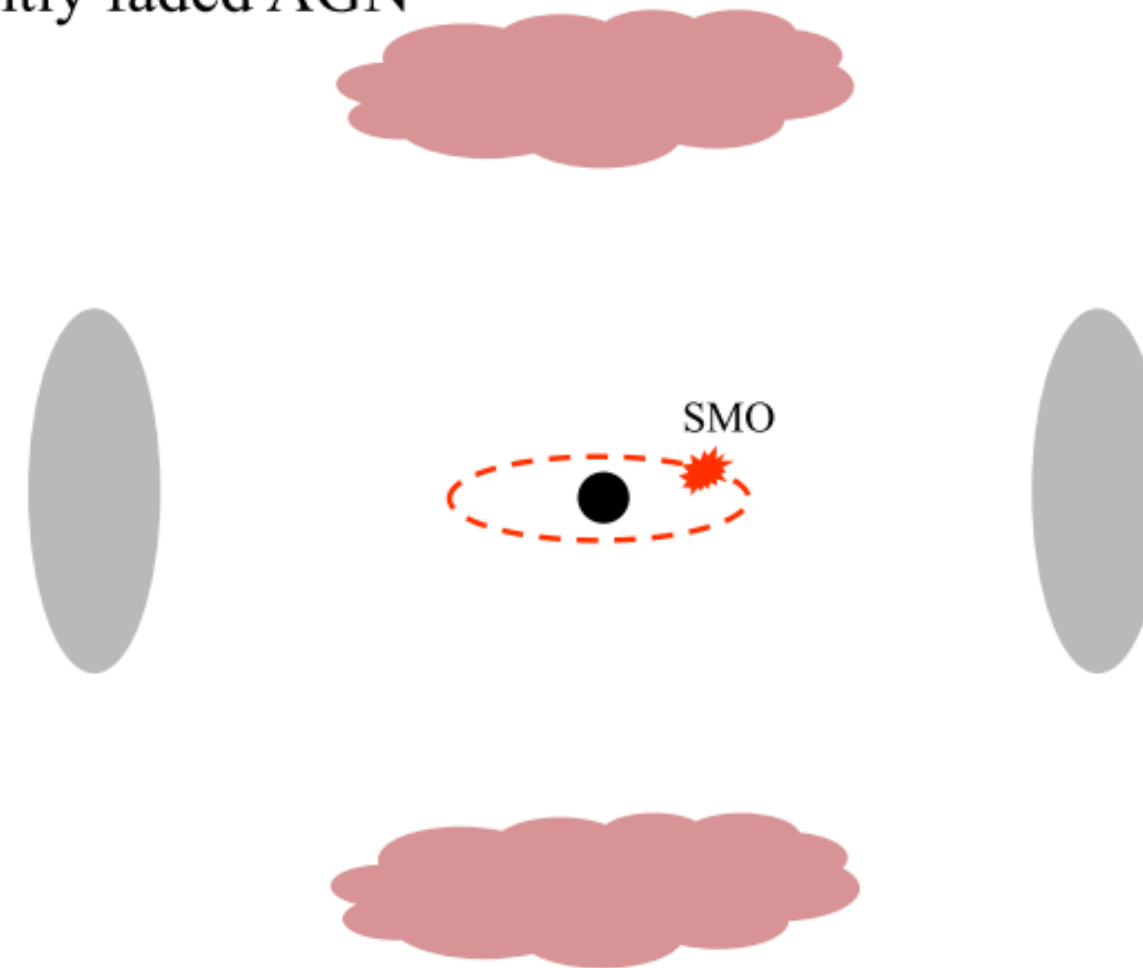
QPE — **EELR** & **Dust torus**

$\mathcal{O}(10^2)M_{\odot}$ kpc $\sim \mathcal{O}(10^{10})M_{\odot}$ pc $\sim \mathcal{O}(10^7)M_{\odot}$

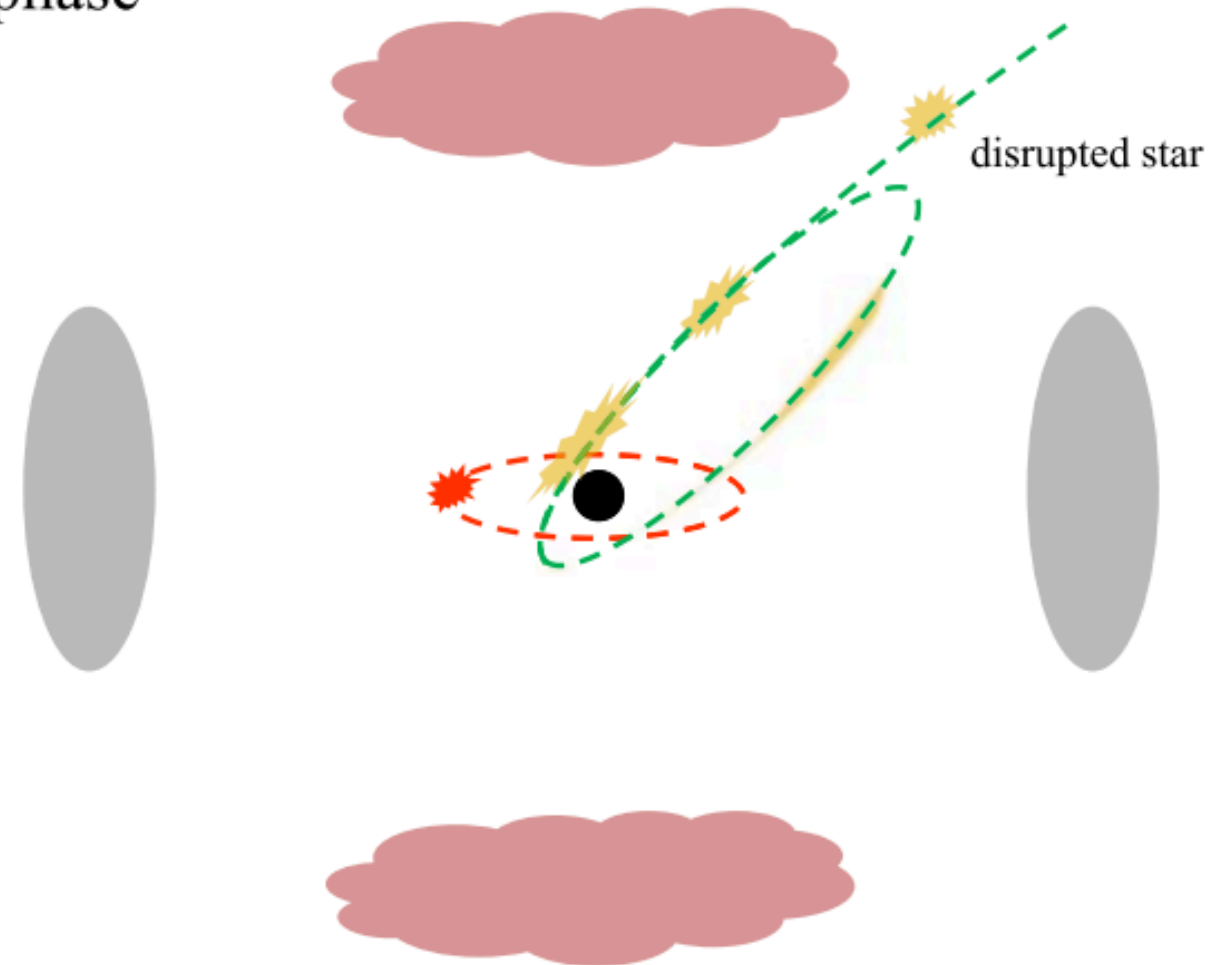
(a) AGN phase



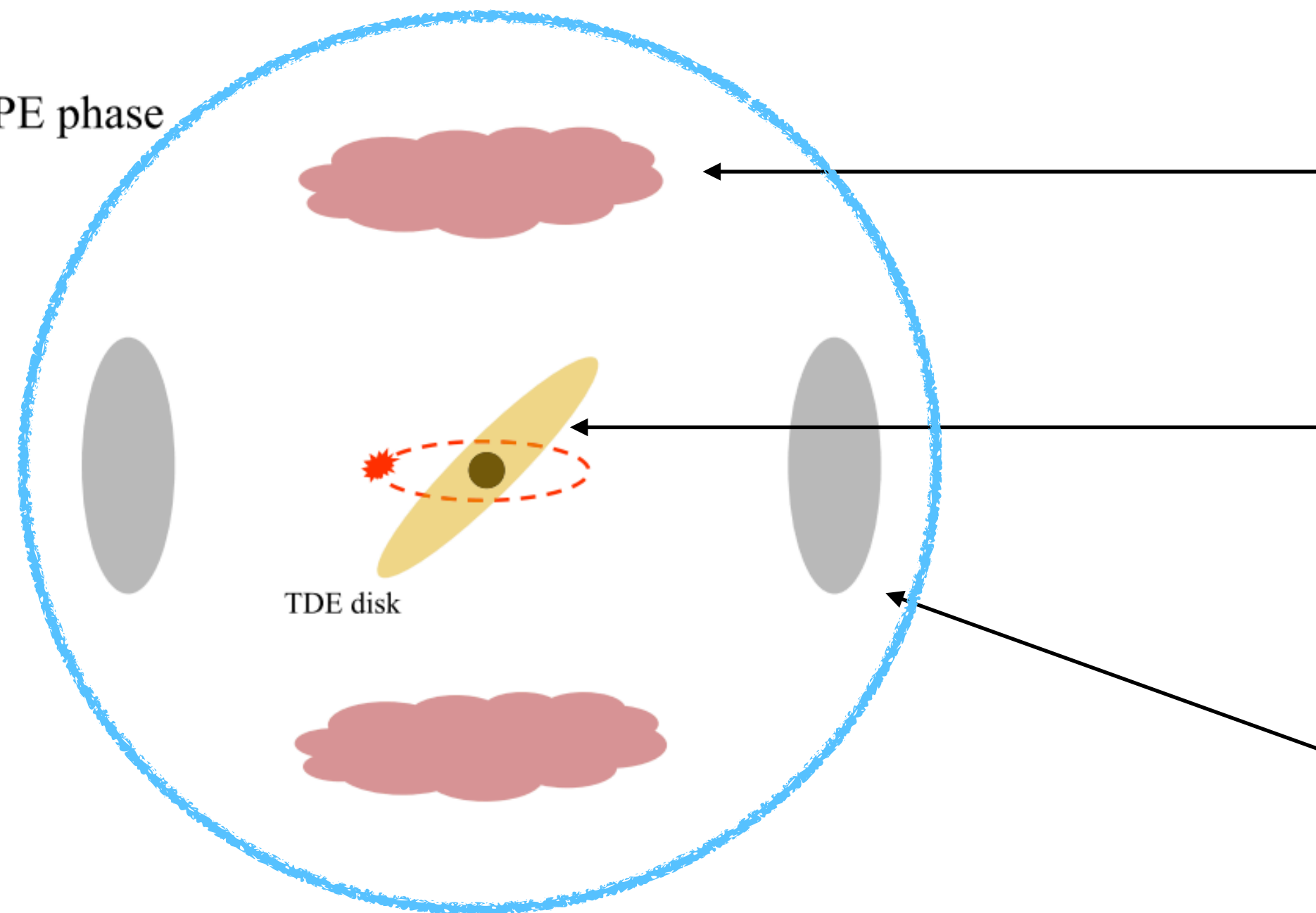
(b) Recently faded AGN



(c) TDE phase



(d) QPE phase



Embers of AGNs:

TDEs & QPEs

Jiang & Pan (2025)

EELR

(low-e) EMRI

+ TDE = QPEs

Dust torus

Embers of AGNs: TDEs and QPEs

- (1) AGNs enhance formation of EMRIs (and possibly TDEs)
- (2) EMRI + TDE disk = QPE
- **Prediction:** QPEs prefer TDEs in recently faded AGNs (Jiang & Pan 2025)

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 - TDE in a recently faded AGN J2344 (Homan+2023: *EELR & IR echo*)

Embers of AGNs: TDEs and QPEs

- (1) AGNs enhance formation of EMRIs (and possibly TDEs)
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- **Prediction:** QPEs prefer TDEs in recently faded AGNs (Jiang & Pan 2025)
 - TDE in a recently faded AGN J2344 (Homan+2023: *EELR & IR echo*)
 - QPE found in J2344 (Baldini+2026) (✓)

Embers of AGNs: TDEs and QPEs

- (1) AGNs enhance formation of EMRIs (and possibly TDEs)
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- **Prediction:** QPEs prefer TDEs in recently faded AGNs (Jiang & Pan 2025)

QPE found in ZTF19acnsky (Sanchez-Saez+2024)

EELR found in the host (Sanchez-Saez+2026)

- (Not fully) faded AGN: an on-going low-luminosity AGN is allowed by observation
- Frequent TDEs: stellar EMRI survival/QPE rate/BH EMRI rate/low-e EMRIs/high- f_c dust torus ?

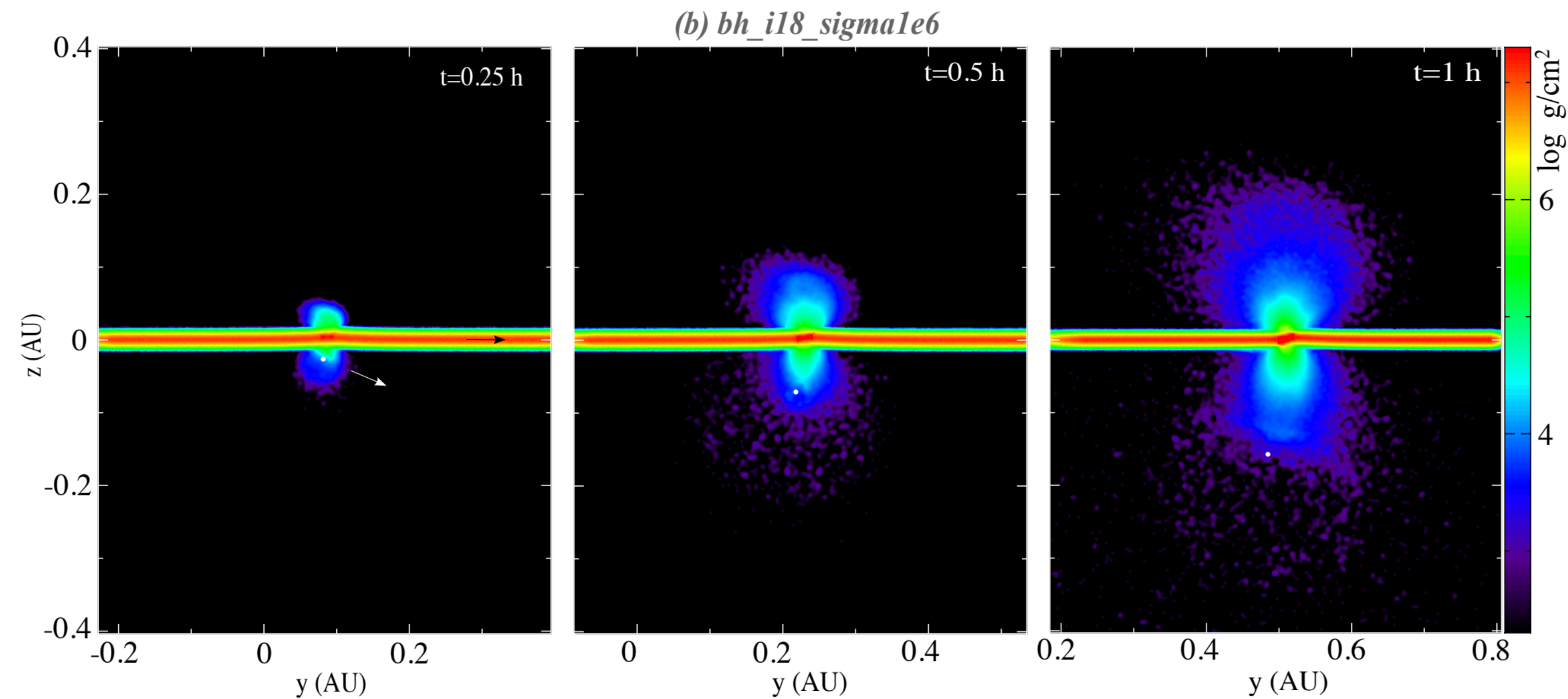
Summary

- QPEs = EMRI + disk $\leftarrow$ **Two** eruptions per fundamental period $\leftarrow T_{\text{long}}(t) + T_{\text{short}}(t) \approx \text{const}$
- QPE timing $\rightarrow (T_{\text{obt}}, T_{\text{aps}}, e) \rightarrow$ **SMBH mass** & **EMRI orbital parameters**
 - **Two populations of QPE EMRIs**
 - Majority **Low-e** (consistent with Wet) $\leftarrow$ *Recently faded AGN*
 - Minority **high-e** (consistent with Dry/Hills)
- QPEs prefer a subset of TDEs
 - **EELR** $\leftarrow$ *Recently faded AGN*
 - **IR echo** $\leftarrow$ *Recently faded AGN*
- QPEs $\rightarrow$ $\sim 10\%$ SMBHs host a star at $r \sim \mathcal{O}(10^2)M_{\bullet}$ if stellar EMRIs ; higher fraction if BH EMRIs.
 - *Tidal resonance seems inevitable !*

BH EMRI or Stellar EMRI ?

BH+disk $\rightarrow$ Symmetric forward and backward ejecta Ivanov+(1998)

$\rightarrow$ 2 eruptions per period



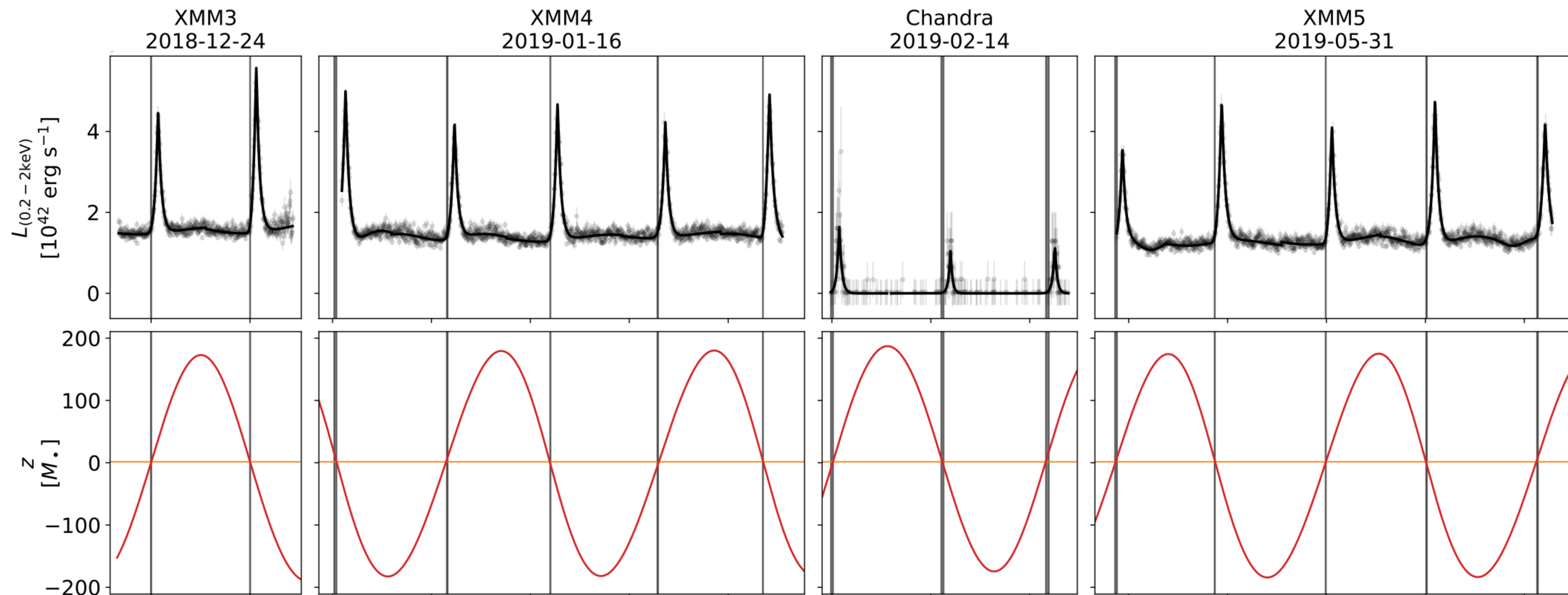
Liu+ (2026)

BH EMRI or Stellar EMRI ?

Star+disk: 1 or 2 eruptions per period?

- Huang, Linial and Jiang (2025): **2**, alternating strong-weak
- Jankovic, Bonnerot, et al. (2026): **2**, alternating strong-weak
- Huang, Huang, et al. (2026):
Either 1 or 2, depending on numerical resolution and inclination
- Yao, Quataert, Jiang and Linial (2026):
Either 1 or 2, depending orbital period (*star debris stream-disk*)

GSN 069: SMBH mass

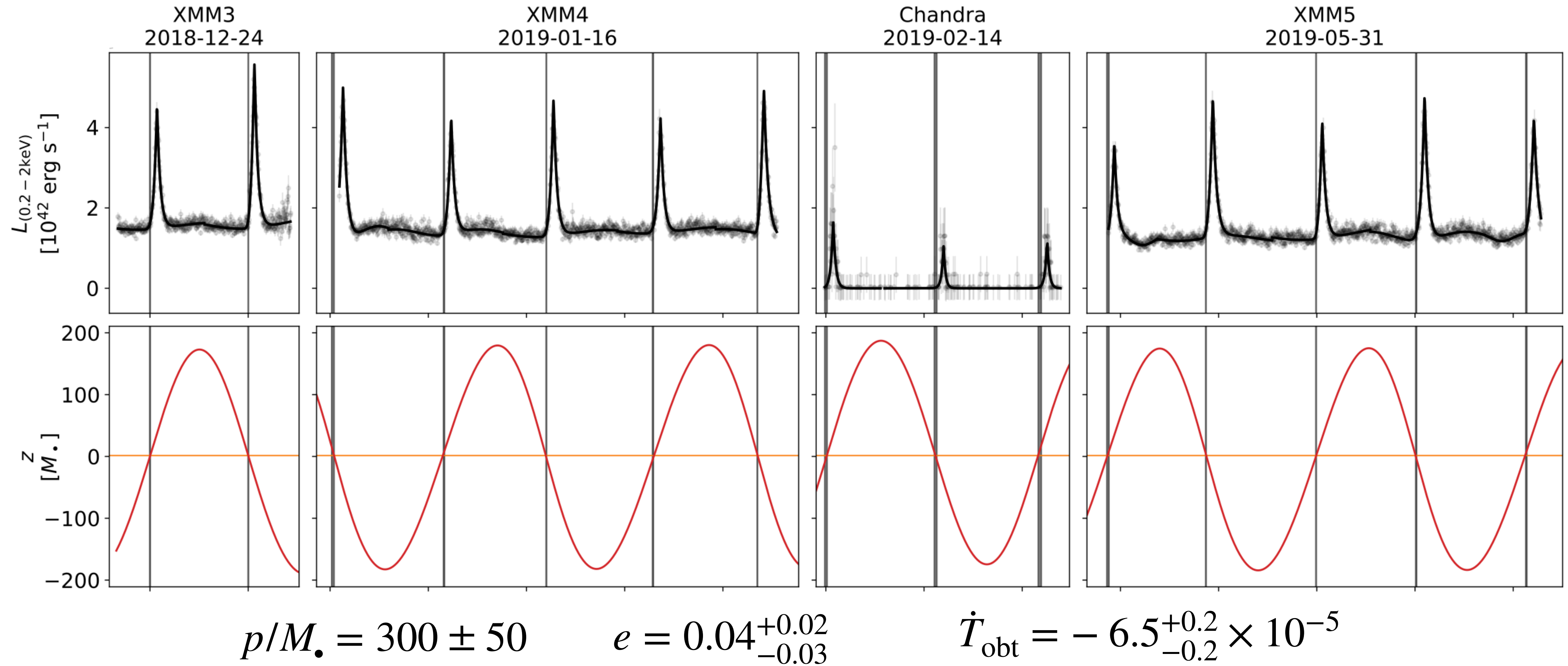


$$\log_{10}(M_{\bullet}/M_{\odot}) = 5.6^{+0.1}_{-0.1} \text{ (QPE timing)}$$

$$\log_{10}(M_{\bullet}/M_{\odot}) = 6.0^{+1.0}_{-1.0} (M - \sigma_{\star})$$

95% C.L.

GSN 069: EMRI Orbital parameters



95% C.L.