

EM counterparts of extreme mass ratio inspirals: quasi-periodic eruptions

Zhen Pan (TDLI, Shanghai Jiao Tong Univ.)

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with C. Zhou, L. Huang, K. Guo, Y. Li, B. Zhong, Y. Zeng

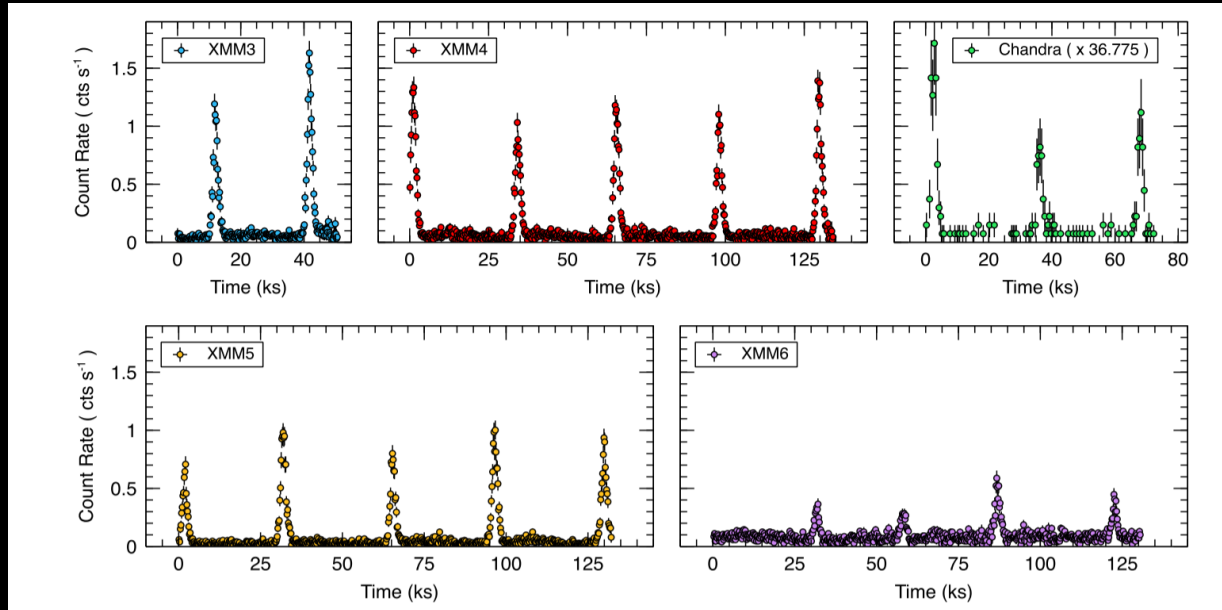
2024.10.15 @TDLI

Outline

1. Introduction to quasi-periodic eruptions (QPEs)
2. QPEs as EM counterparts of EMRIs
 - two pieces of direct evidence
3. QPE observations → EMRI orbits → EMRI formation
4. Summary

1. QPE intro

QPEs are fast bright soft X-ray bursts repeating every O(1-10) hours with peak luminosity $\sim O(10^{42} - 10^{43})$ ergs/s



Miniutti+2023

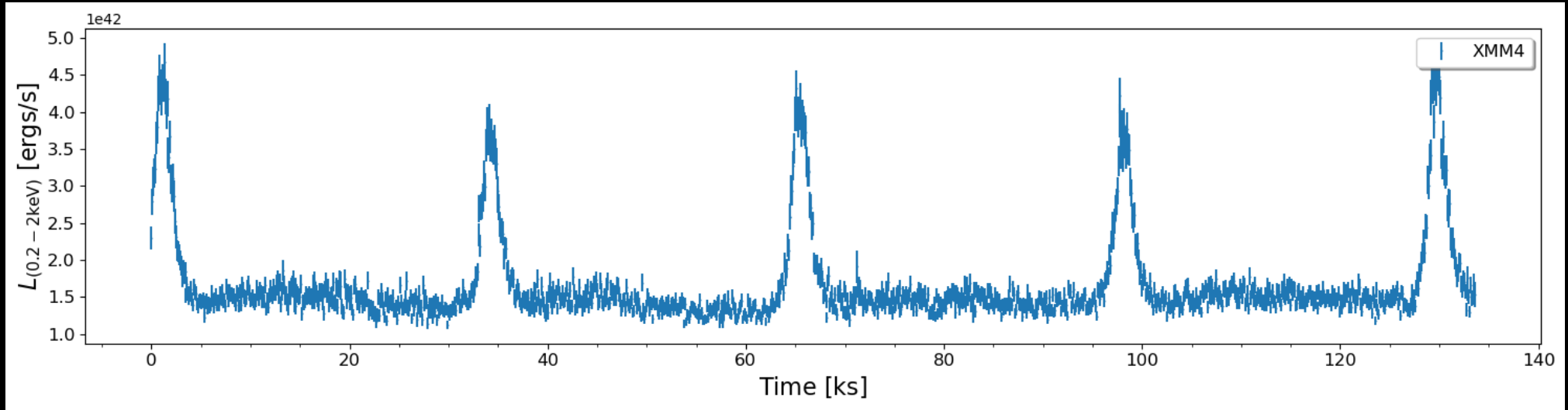
2. QPEs as EM counterparts of EMRIs

TDE association:

TDE first, $O(1)$ years later QPEs (see Matt's talk)

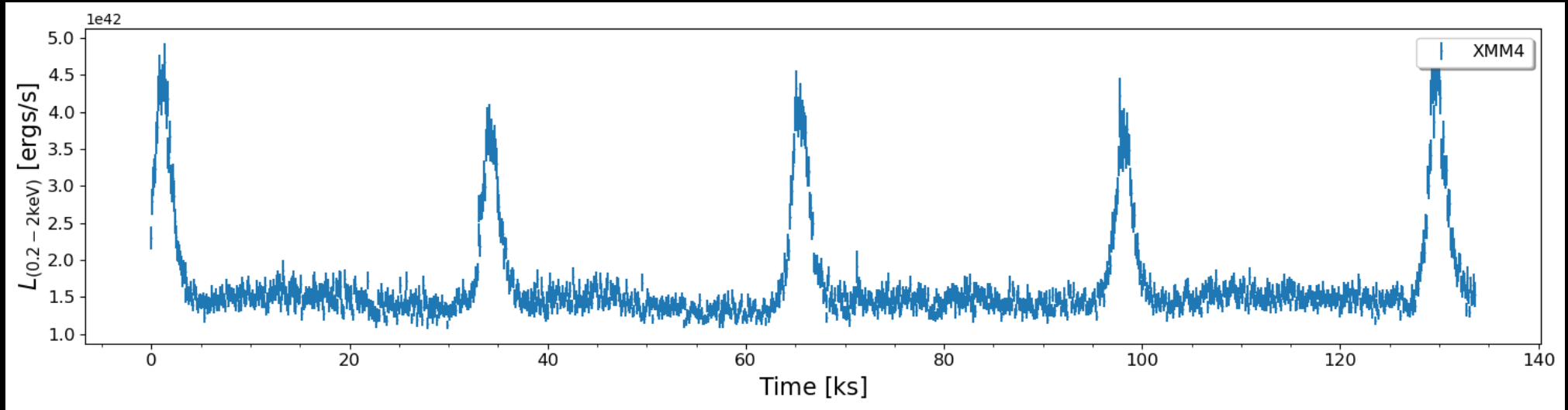
2. QPEs as EM counterparts of EMRIs

GSN 069: Miniutti+2023



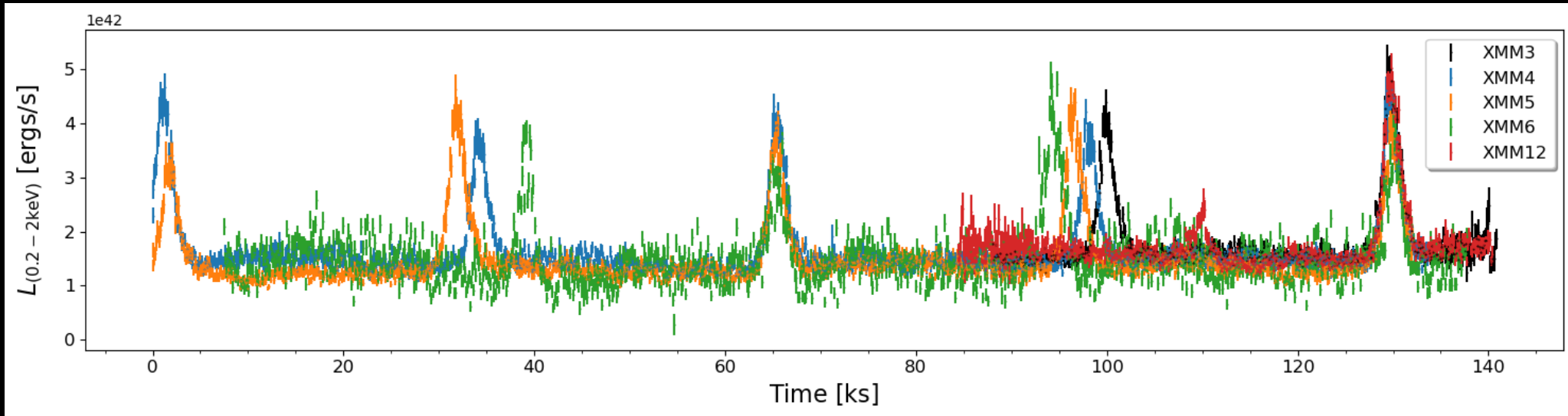
T_long & T_short

2. QPEs as EM counterparts of EMRIs



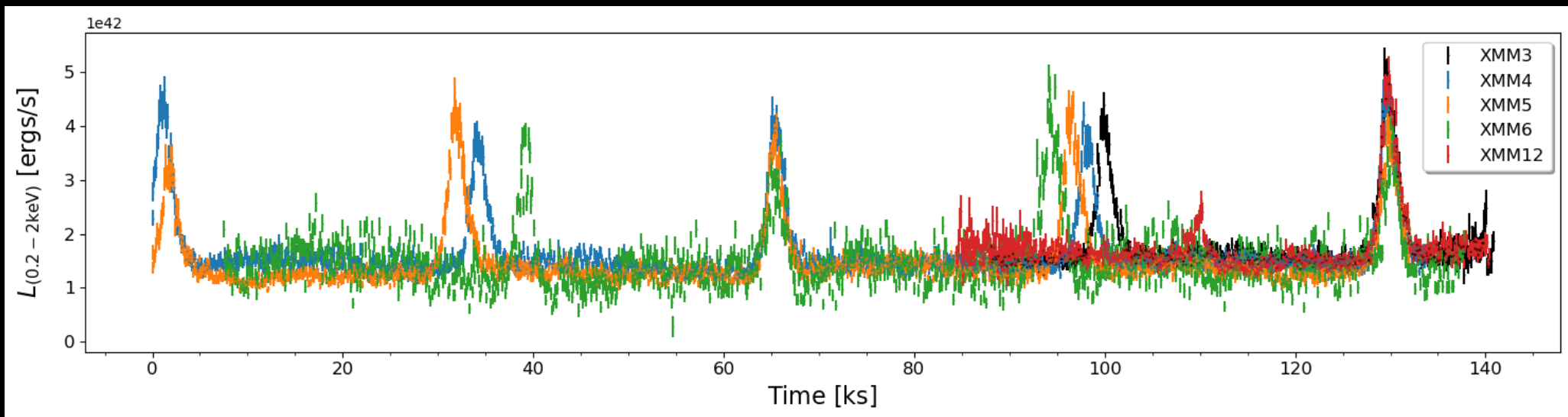
$T_{\text{long}}(t)$ & $T_{\text{short}}(t)$, $T_{\text{long}} + T_{\text{short}} = \text{const.}$

2. QPEs as EM counterparts of EMRIs



$T_{\text{long}}(t)$ & $T_{\text{short}}(t)$, $T_{\text{long}} + T_{\text{short}} = \text{const.}$

2. QPEs as EM counterparts of EMRIs



$T_{\text{long}}(t)$ & $T_{\text{short}}(t)$, $T_{\text{long}} + T_{\text{short}} = \text{const.}$

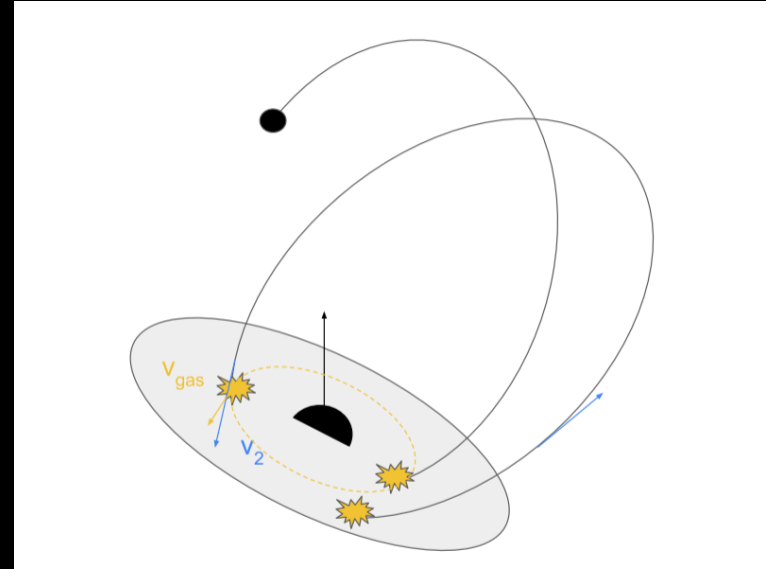
$T_{\text{long}} + T_{\text{short}}$ is the fundamental period.

Zhou+2024a

2. EMRI+Disk model

T_{long} & T_{short}

$T_{long} + T_{short} = \text{const.}$



Franchini+2023: stellar-mass BH
Linial+, Tagawa+2023: normal star

2. EMRI+Disk model

$T_{\text{long}} \& T_{\text{short}}$

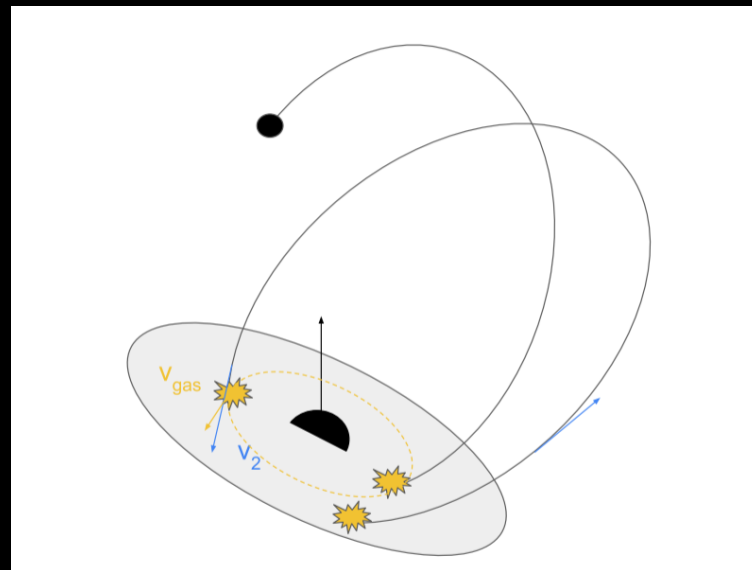
$T_{\text{long}} + T_{\text{short}} = \text{const.}$

$T_{\text{long}} + T_{\text{short}} \rightarrow \text{orbital period}$

$$T_{\text{obt}} = 2\pi(A/M_{\bullet})^{3/2}M_{\bullet}$$

$T_{\text{long}}(t) \& T_{\text{short}}(t) \rightarrow \text{precession period}$

$$T_{\text{prec}}/T_{\text{obt}} \approx A/3M_{\bullet}$$



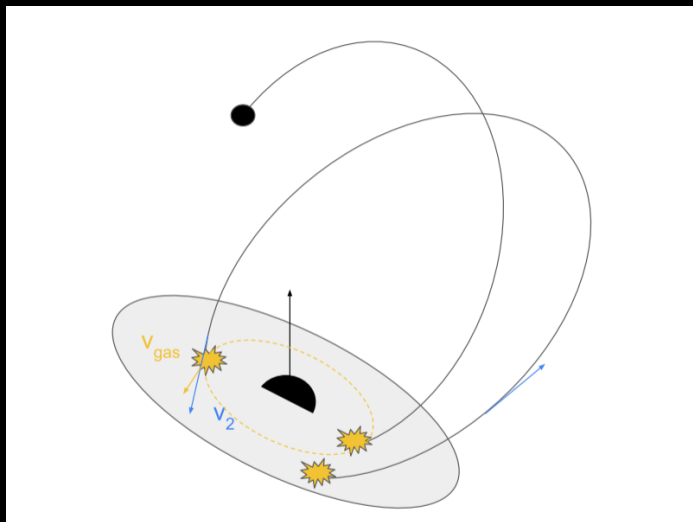
Franchini+2023:

stellar mass BH

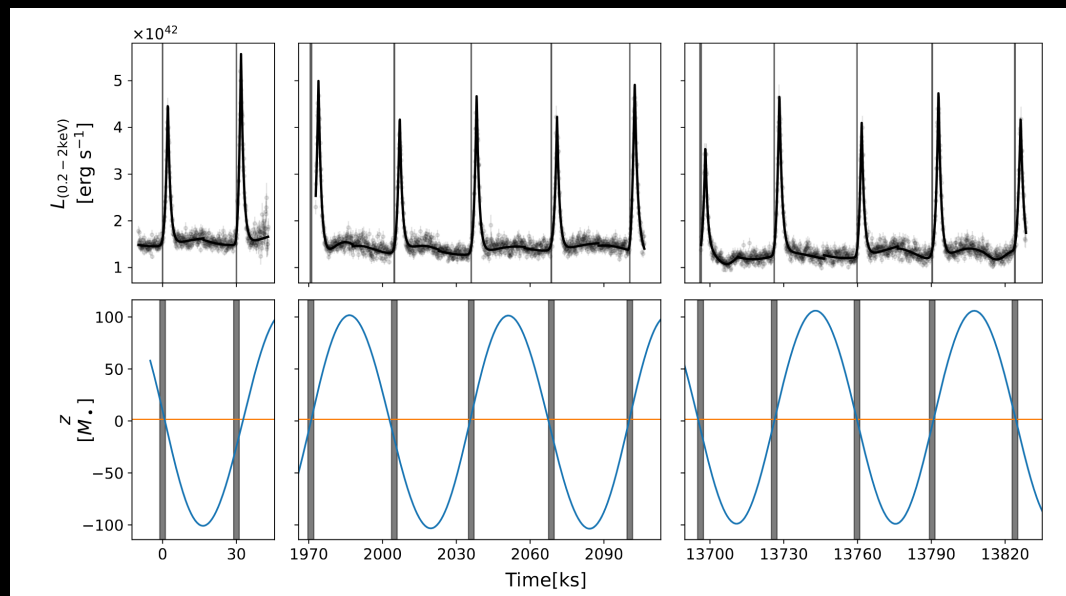
Linial+, Tagawa+ 2023:

normal star

2. EMRI + TDE disk model: GSN 069

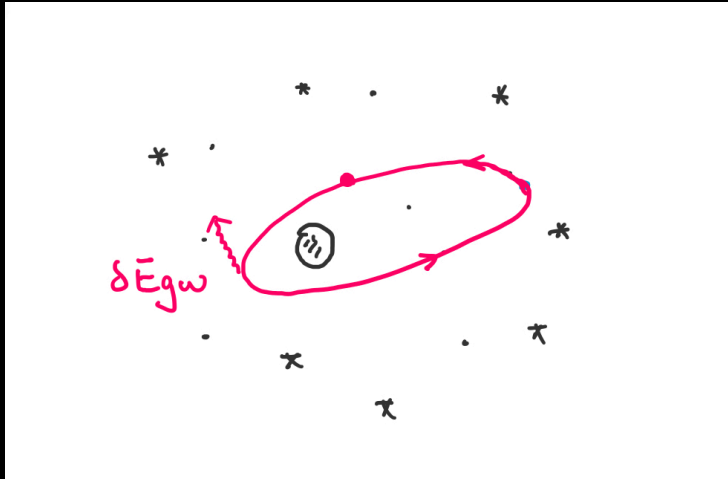


Franchini+2023: stellar mass BH
 Linial+, Tagawa+2023: normal star



$M=1e6 \text{ Msun}$, $a=170 \text{ M}$, $e=0.04$ ($e = 0.05^{+0.09}_{-0.05}$)

3. EMRI formation channels



Dry EMRIs
highly eccentric

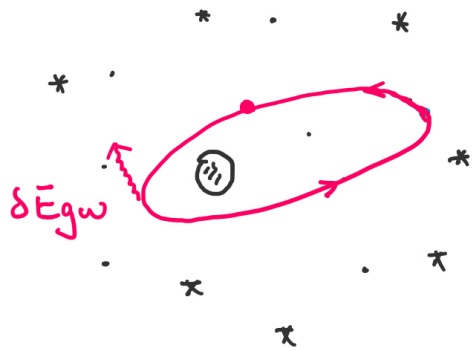
3. EMRI formation channels



Dry EMRIs
Highly eccentric

Hills EMRIs
Highly eccentric

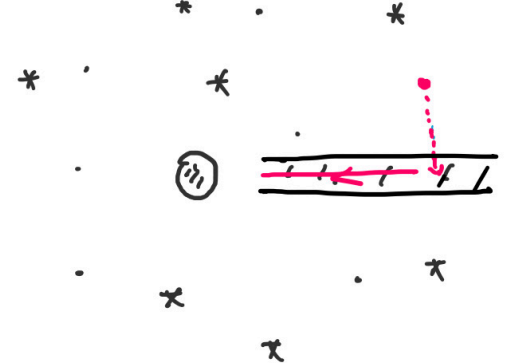
3. EMRI formation channels



Dry EMRIs
Highly eccentric

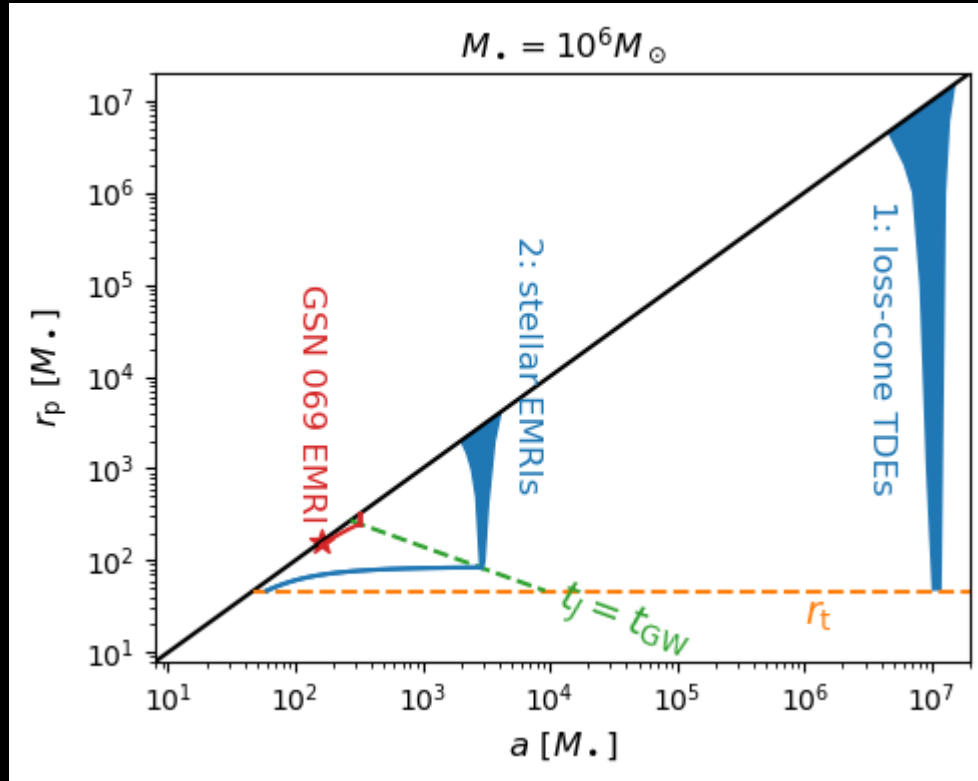


Hills EMRIs
Highly eccentric



Wet EMRIs
Nearly circular

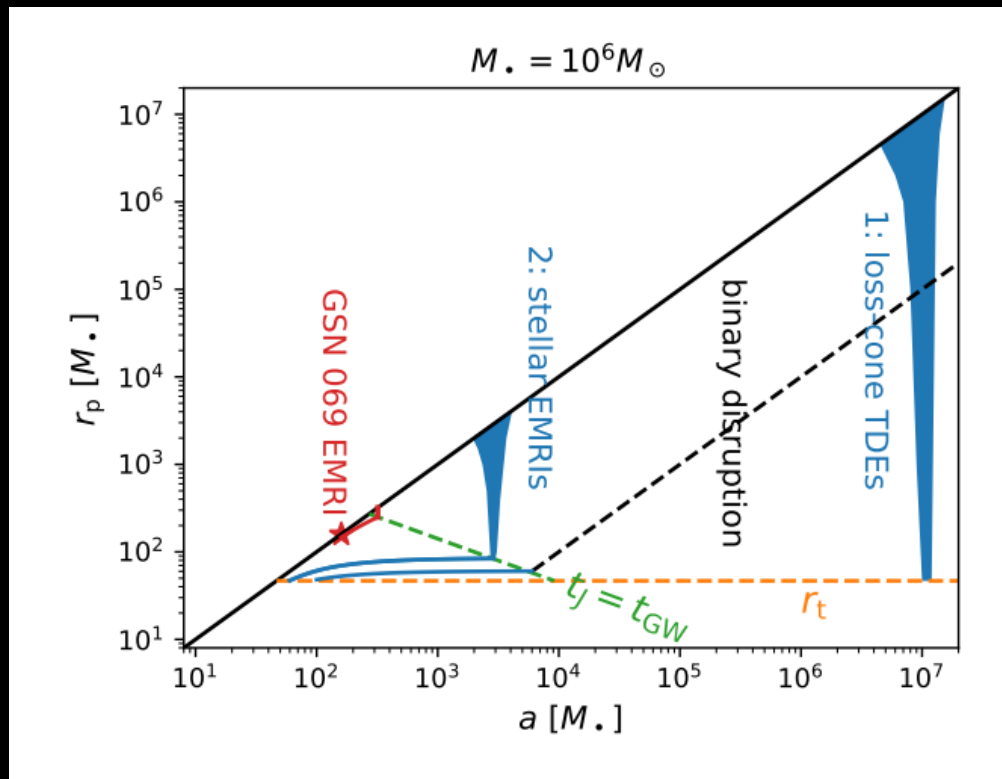
3. GSN 069 EMRI: dry



$$\frac{R_{\star}(< 300 M_{\bullet})}{R_{\star}(< r_h)} \approx 10^{-5},$$

Very Unlikely

3. GSN 069 EMRI: Hills



No Way

3. GSN 069 EMRI: wet

a) Semi-major axis $a \sim O(10^2 \text{ M})$

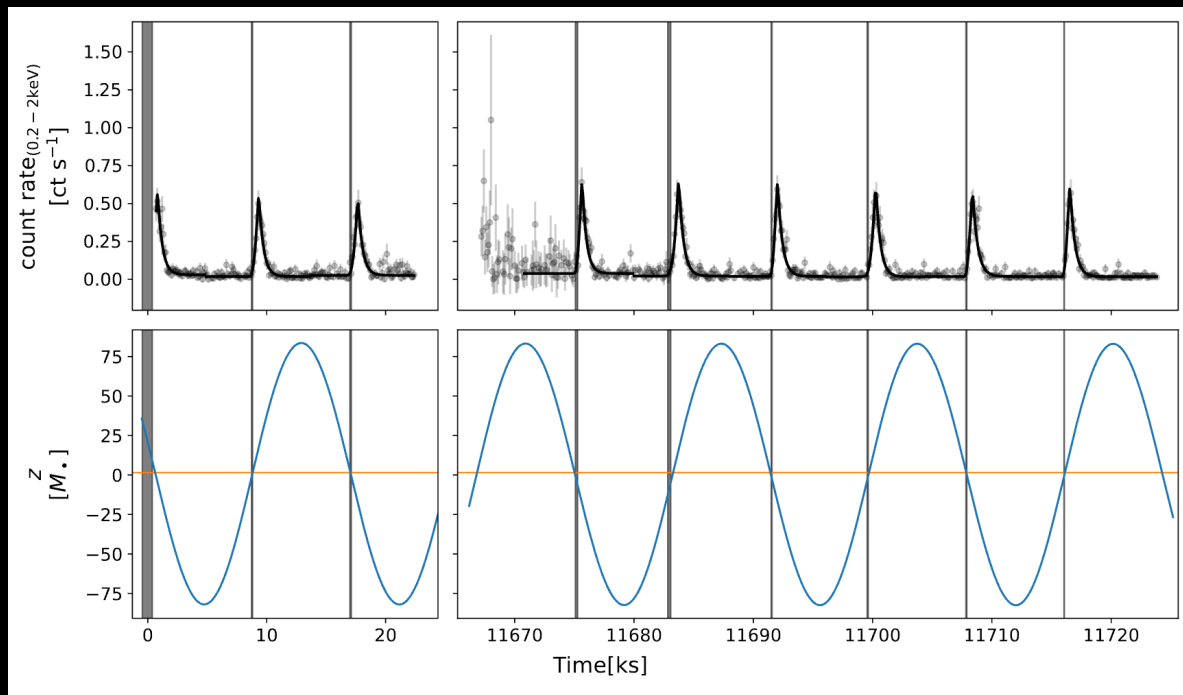
$r < O(10^2 \text{ M})$ GW emission

$r > O(10^2 \text{ M})$ Type-I migration

b) Eccentricity $e \sim h \sim O(10^{-2})$?

Yes

More QPE sources: eRO-QPE2



$$M = 1e5 \text{ Msun}$$

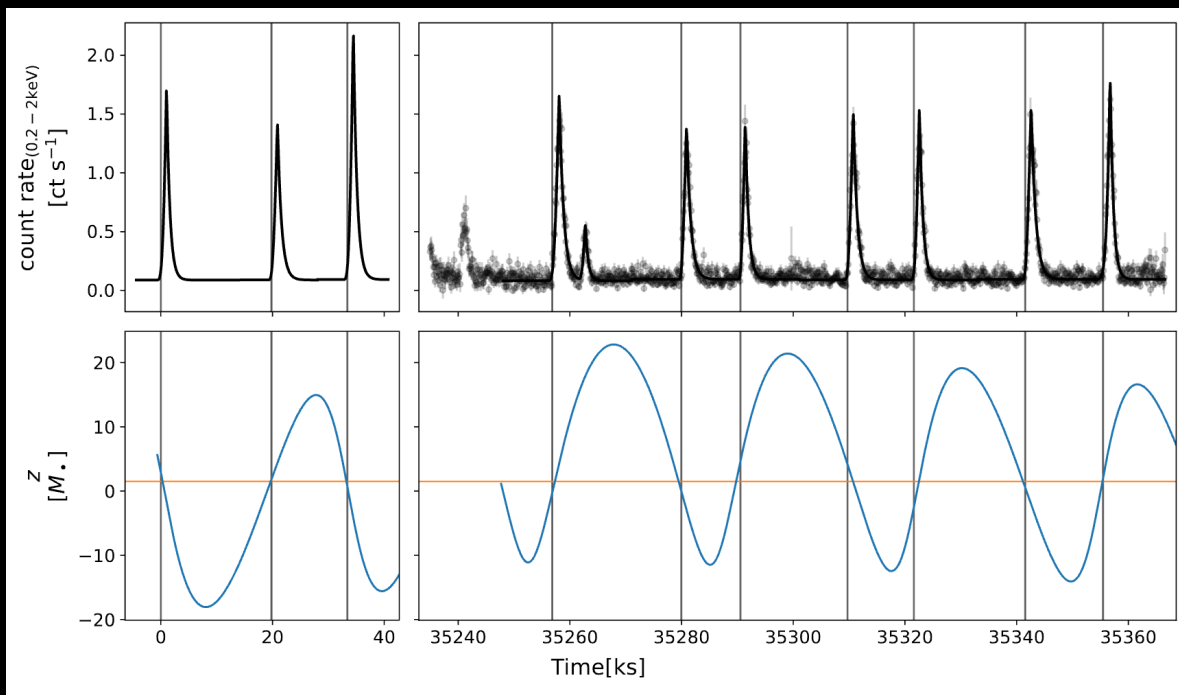
$$p = 328 \text{ M}$$

$$e = 0.01$$

$$e = 0.01^{+0.05}_{-0.01}$$

Wet

More QPE sources: RX J1301



$$M = 1e7 \text{ Msun}$$

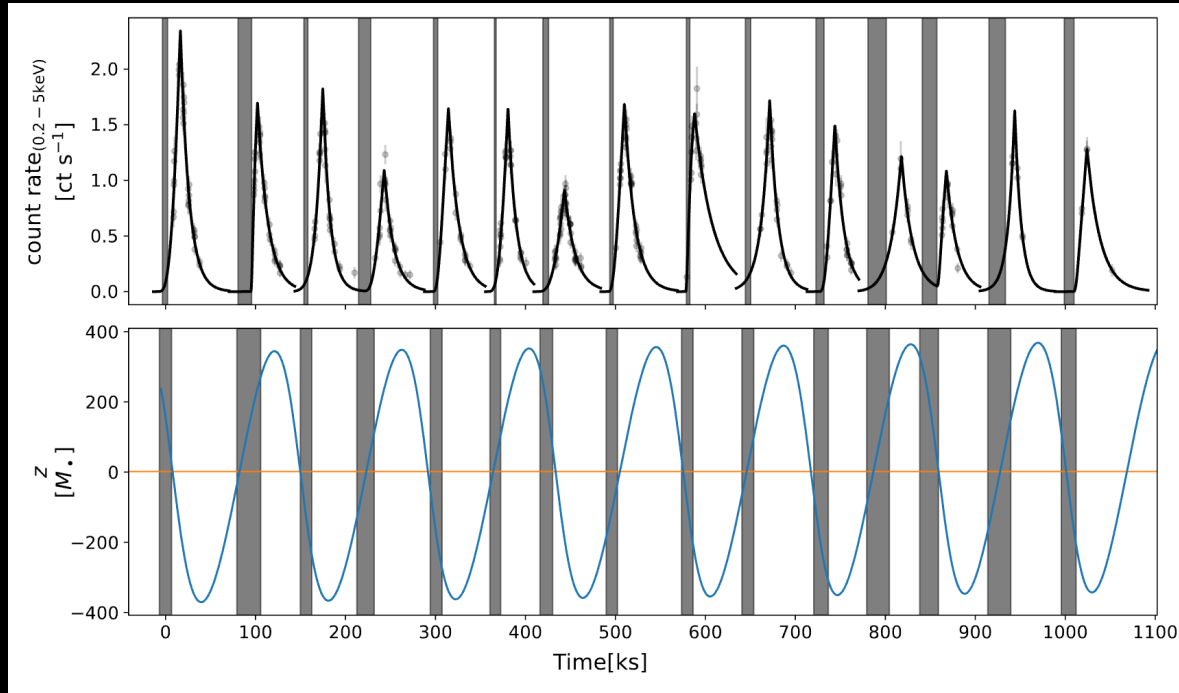
$$p = 36 \text{ M}$$

$$e = 0.35$$

$$e = 0.25^{+0.18}_{-0.20}$$

Dry or Hills

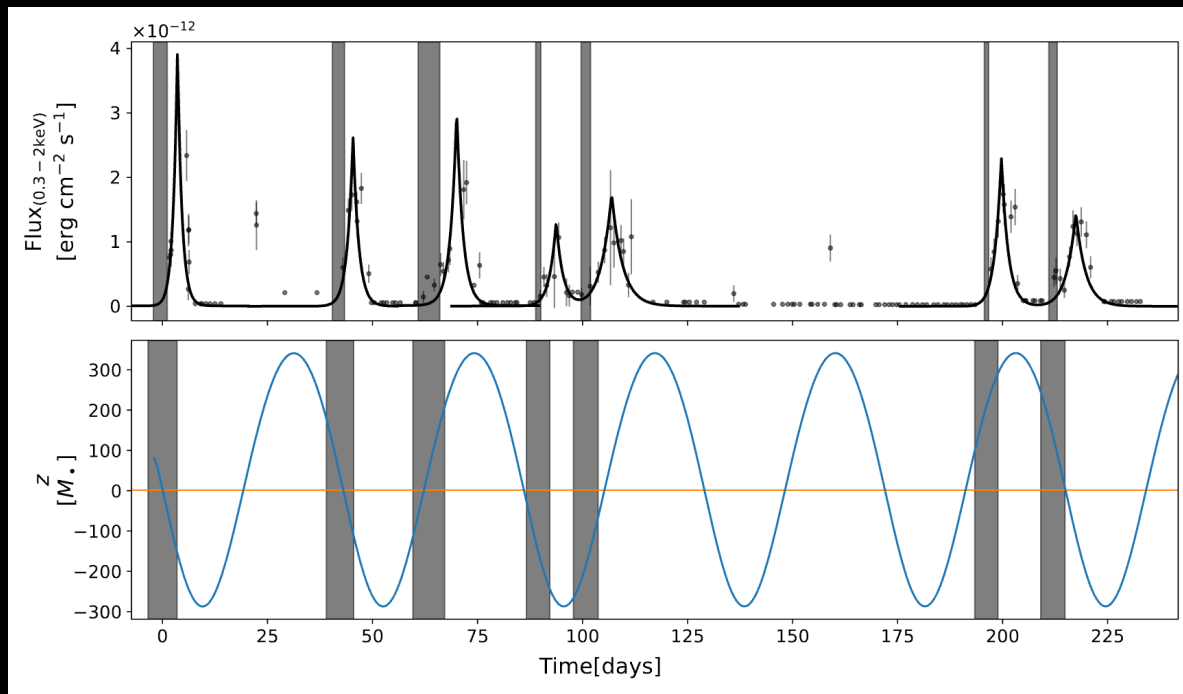
More QPE sources: eRO-QPE 1



$$e = 0.10^{+0.17}_{-0.10}$$

Wet

More QPE sources: Swift J023017



$$e = 0.22^{+0.50}_{-0.21}$$

Wet

Summary

1. QPEs as EM counterparts of EMRIs
2. QPE flare timing (5 sources)
 - EMRI orbital parameters
 - 2 populations: 4 wet and 1 dry/Hills
3. Precise measurement of SMBH masses
4. Secular effects (see Cong's talk)