PROBING THE SECULAR EFFECTS IN QPE - EMRI

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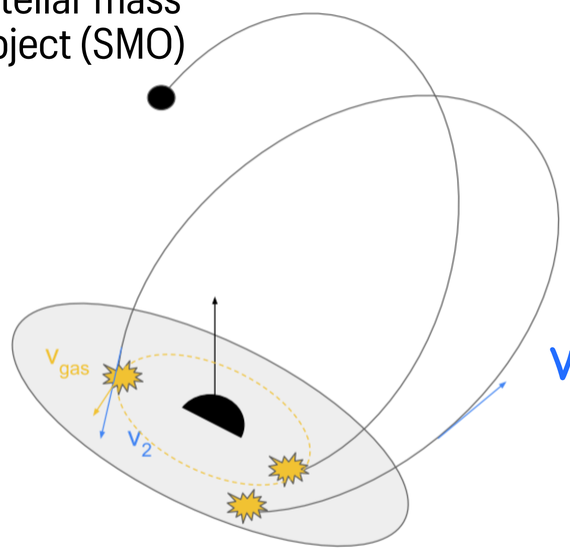
OVERVIEW

- QPE - EMRI
- Secular effects

QPE - EMRI

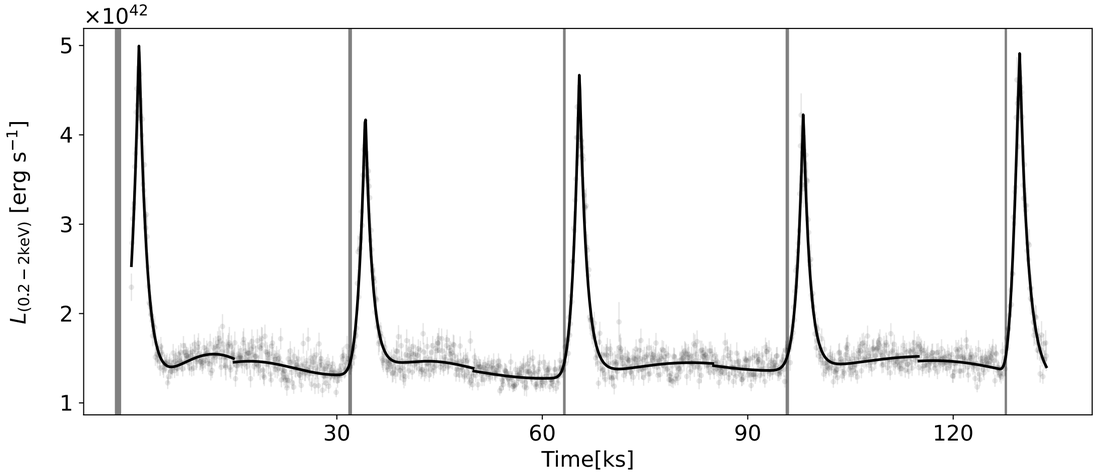
QPE - EMRI

Stellar mass object (SMO)

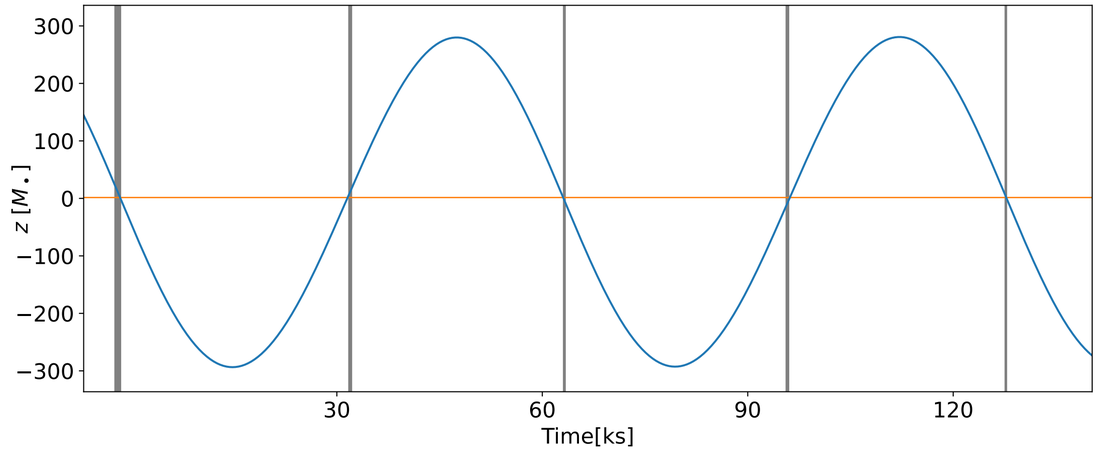


From A&A 675, A100 (2023)

One observation epoch of GSN 069



We only use timing information



SIGNS OF SECULAR EFFECTS

- SMO following geodesic motion
- Disk lying on the equatorial plane

	GSN 069	eRO-QPE1	eRO-QPE2	Swift J023017	RX J1301.9 +2747
p(M.)	279^{+188}_{-182}	$701^{+2276}_{-549}/727^{+2499}_{-562}$	$290^{+194}_{-189}/342^{+146}_{-205}$	963^{+942}_{-651}	52^{+80}_{-30}
e	$0.05^{+0.09}_{-0.05}$	$0.14^{+0.47}_{-0.13}/0.10^{+0.47}_{-0.10}$	$0.06^{+0.20}_{-0.05}/0.01^{+0.05}_{-0.01}$	$0.22^{+0.50}_{-0.21}$	$0.25^{+0.18}_{-0.20}$
T(ks)	$64.6^{+1.1}_{-1.9}$	$130.4^{+2.2}_{-2.8}/141.7^{+2.1}_{-2.8}$	$17.5^{+0.1}_{-0.1}/16.4^{+0.2}_{-0.1}$	$9.6^{+8.0}_{-9.7}$ day	$32.0^{+0.9}_{-1.0}$

Low eccentricity

Non-zero eccentricity

Obvious apparent period evolution

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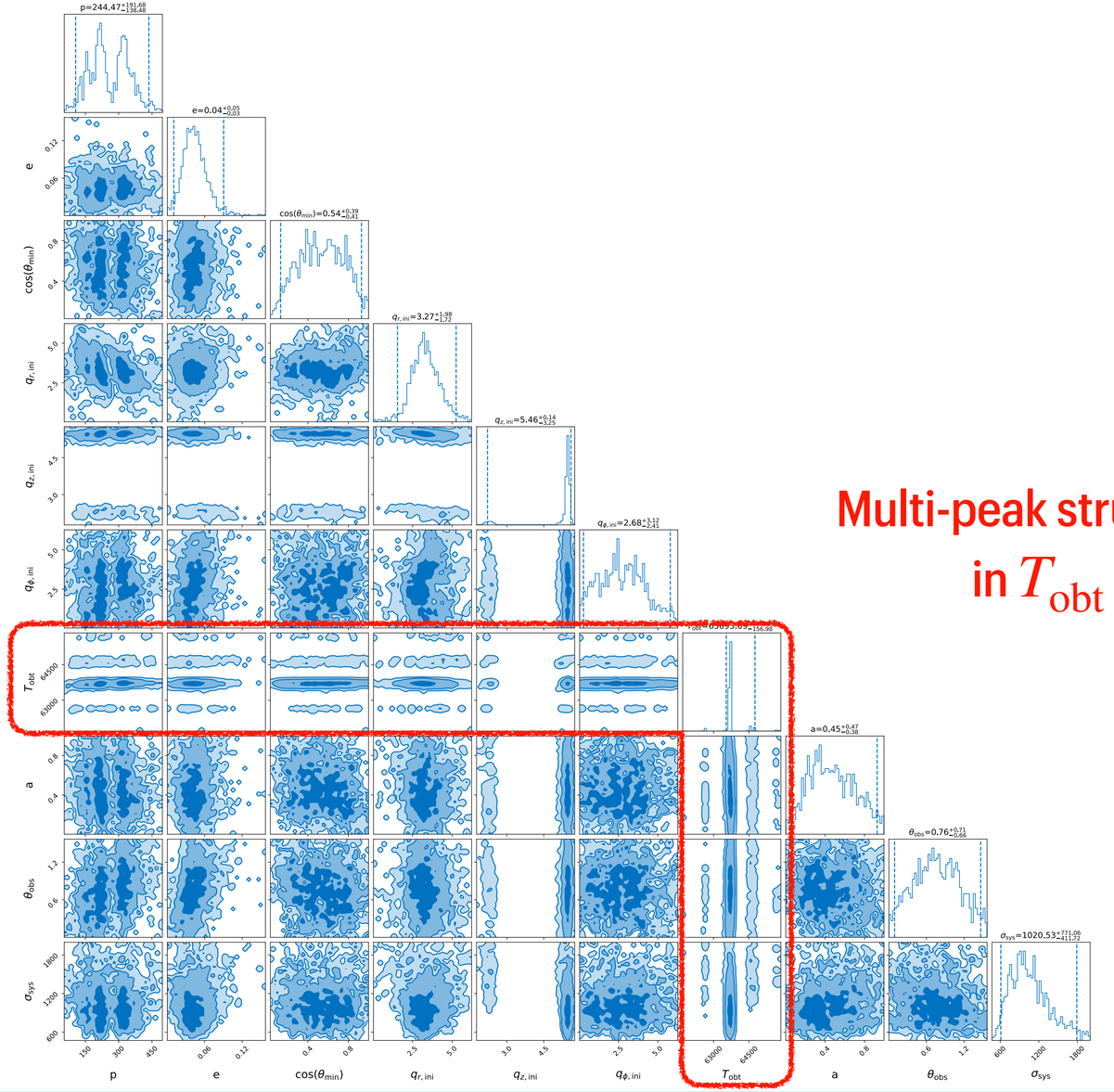


Multi-peak structure in T_{obt}

SECULAR EFFECTS

SMO-DISK COLLISION

- Integrals of motion {E, L, C} vary over time
- Relative changes in orbital parameters are similar in magnitudes, i.e.

Best constrained

$$\delta T_{\rm obt}/T_{\rm obt} \sim \delta e/e \sim \delta\theta_{\rm min}/\theta_{\rm min}$$

Unmeasurable, set to 0

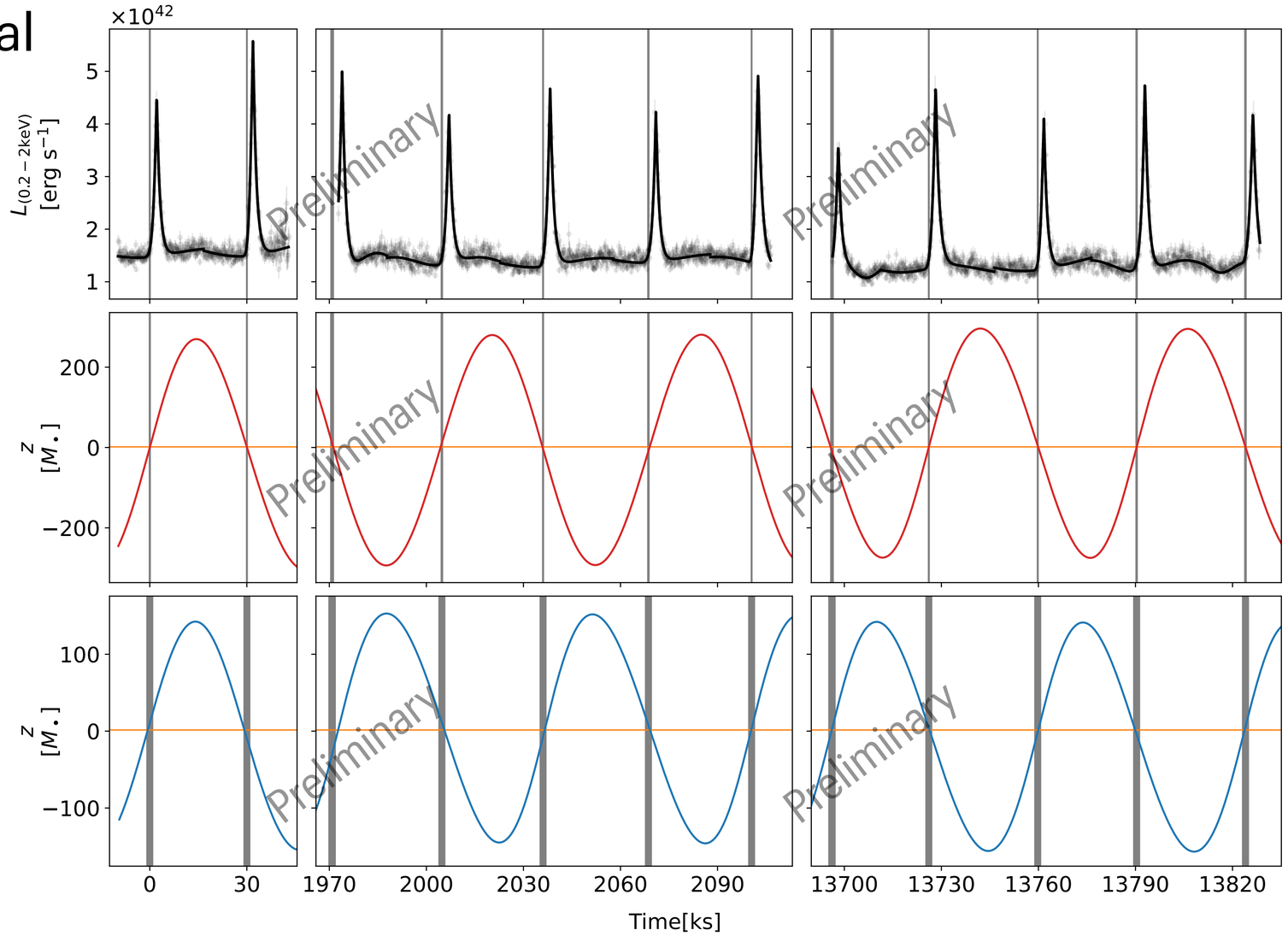
- Orbital period decay rate is modeled as proportional to the sine of the angle between the SMO's orbital plane and the disk plane, i.e.

$$\dot{T}_{\rm obt}(t) \propto \sin \iota_{\rm sd}(t)$$ (typically non-uniform)

SMO-DISK COLLISION: GSN 069

- Disk still lying on the equatorial plane

	Forced trajectory	Geodesic
p[M.]	292^{+167}_{-168}	262^{+191}_{-151}
e	$0.04^{+0.04}_{-0.03}$	$0.04^{+0.04}_{-0.04}$
T[ks]	$64.7^{+0.04}_{-0.07}$	$63.7^{+2.0}_{-1.0}$
Tdot	$-6.4^{+5.1}_{-0.4} \times 10^{-5}$	



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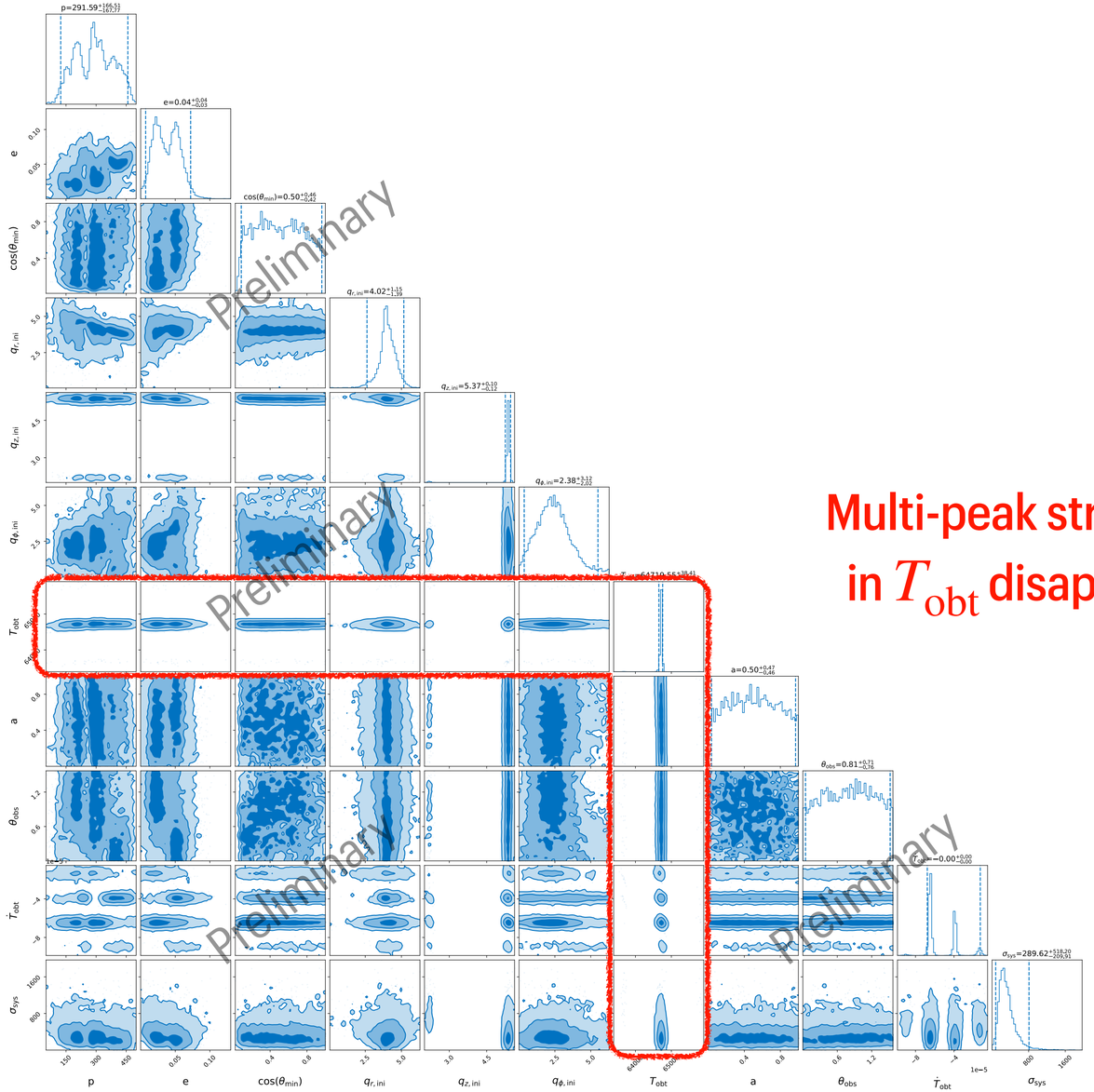

Multi-peak structure in $T_{\rm obt}$ disappears

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Decisive evidence: Bayes factor

$$\log \mathcal{B}^f_g = 5.1 \pm 0.3$$

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- SMBH mass:
$$\log_{10}(M_\bullet/M_\odot) = 5.6^{+0.6}_{-0.3}$$
- Orbital energy loss per collision:
$$E_{\rm col} = \frac{E}{3}\dot{T}_{\rm obt} = 6.1^{+8.7}_{-4.6} \times 10^{46} \left(\frac{m}{M_\odot}\right) \ {\rm ergs}$$
- Radiation efficiency:
$$\eta = \frac{E_{\rm QPE}}{E_{\rm col}} \approx 11^{+33}_{-6}\% \times \left(\frac{m}{M_\odot}\right)^{-1}$$

SMO-DISK COLLISION: GSN 069

- Orbital energy loss per collision
  - Star:

$$\delta E_\star \approx 3\times10^{46}\mathrm{ergs}\times\Sigma_5 R_{\star,\odot}^2 r_{100}^{-1}\sin\iota_{\rm sd}$$

$$\Sigma_5 = 2.0^{+2.9}_{-1.5} m_{\star,\odot} R_{\star,\odot}^{-2} r_{100} (\sin\iota_{\rm sd})^{-1}$$

  - Stellar mass BH:

$$\delta E_{\rm sBH} \approx 2\times10^{46}\mathrm{ergs}\left(\frac{\ln\Lambda}{10}\right)\Sigma_5 m_{30}^2 r_{100}\left(\frac{\sin\iota_{\rm sd}}{0.1}\right)^{-3}$$

$$\Sigma_5 = 92^{+130}_{-69}\left(\frac{\ln\Lambda}{10}\right)^{-1} m_{30}^{-1} r_{100}^{-1}\left(\frac{\sin\iota_{\rm sd}}{0.1}\right)^{3}$$

→ Too large to be plausible

- SMBH mass:

$$\log_{10}(M_\bullet/M_\odot) = 5.6^{+0.6}_{-0.3}$$

- Orbital energy loss per collision:

$$E_{\rm col} = \frac{E}{3}\dot{T}_{\rm obt} = 6.1^{+8.7}_{-4.6}\times10^{46}\left(\frac{m}{M_\odot}\right)\ \mathrm{ergs}$$

- Radiation efficiency:

$$\eta = \frac{E_{\rm QPE}}{E_{\rm col}} \approx 11^{+33}_{-6}\%\times\left(\frac{m}{M_\odot}\right)^{-1}$$

DISK MOTION

- Disk (rigid) precession + retrograde orbit → increase
- Disk (rigid) precession + { alignment / SMO-disk collision / alignment + SMO-disk collision }

  → non-uniform decrease

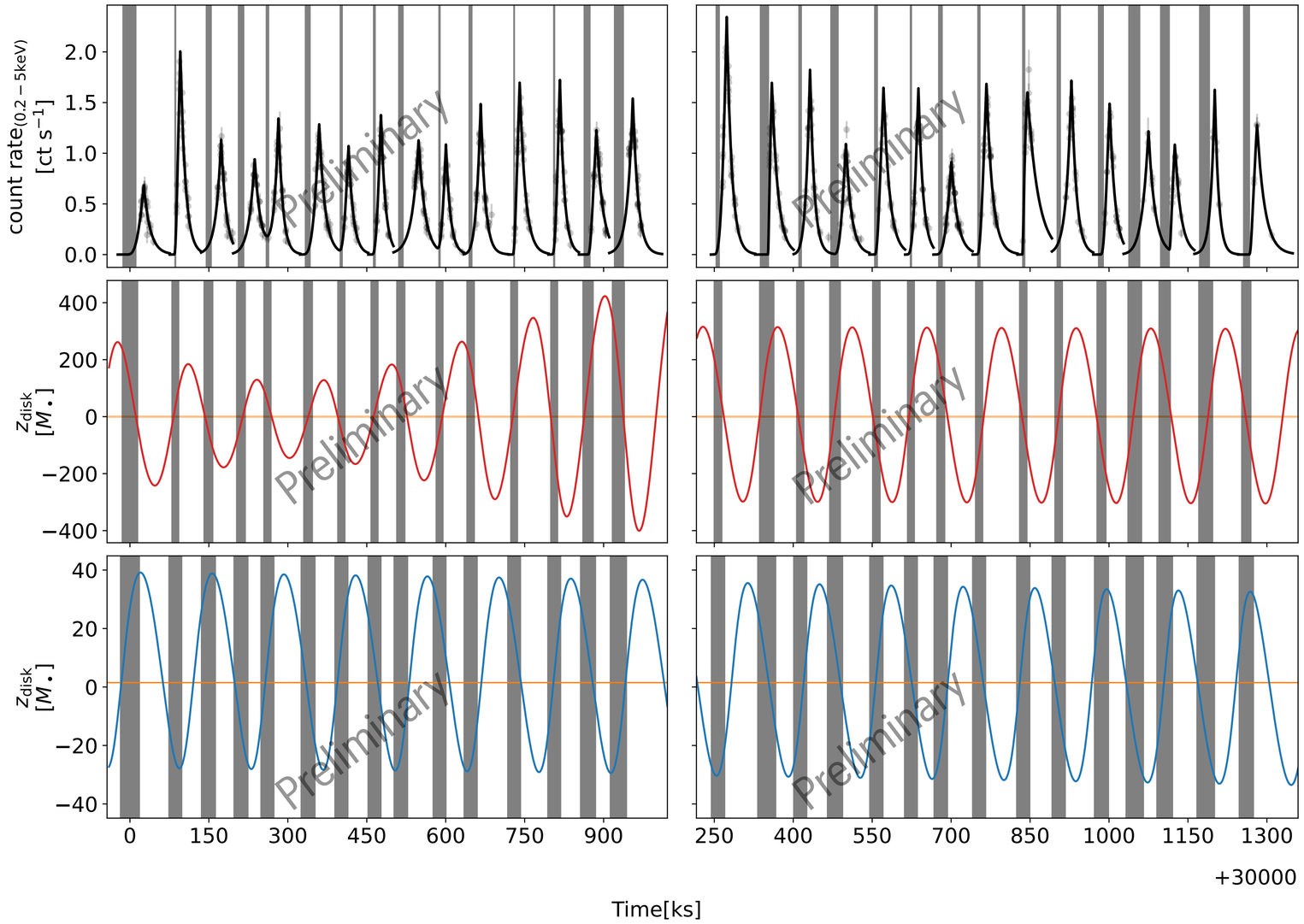
	eRO-QPE1	eRO-QPE2
p(M.)	$701^{+2276}_{-549}/727^{+2499}_{-562}$	$290^{+194}_{-189}/342^{+146}_{-205}$
e	$0.14^{+0.47}_{-0.13}/0.10^{+0.47}_{-0.10}$	$0.06^{+0.20}_{-0.05}/0.01^{+0.05}_{-0.01}$
T(ks)	$130.4^{+2.2}_{-2.8}/141.7^{+2.1}_{-2.8}$	$17.5^{+0.1}_{-0.1}/16.4^{+0.2}_{-0.1}$

increase

decrease (non-uniform)

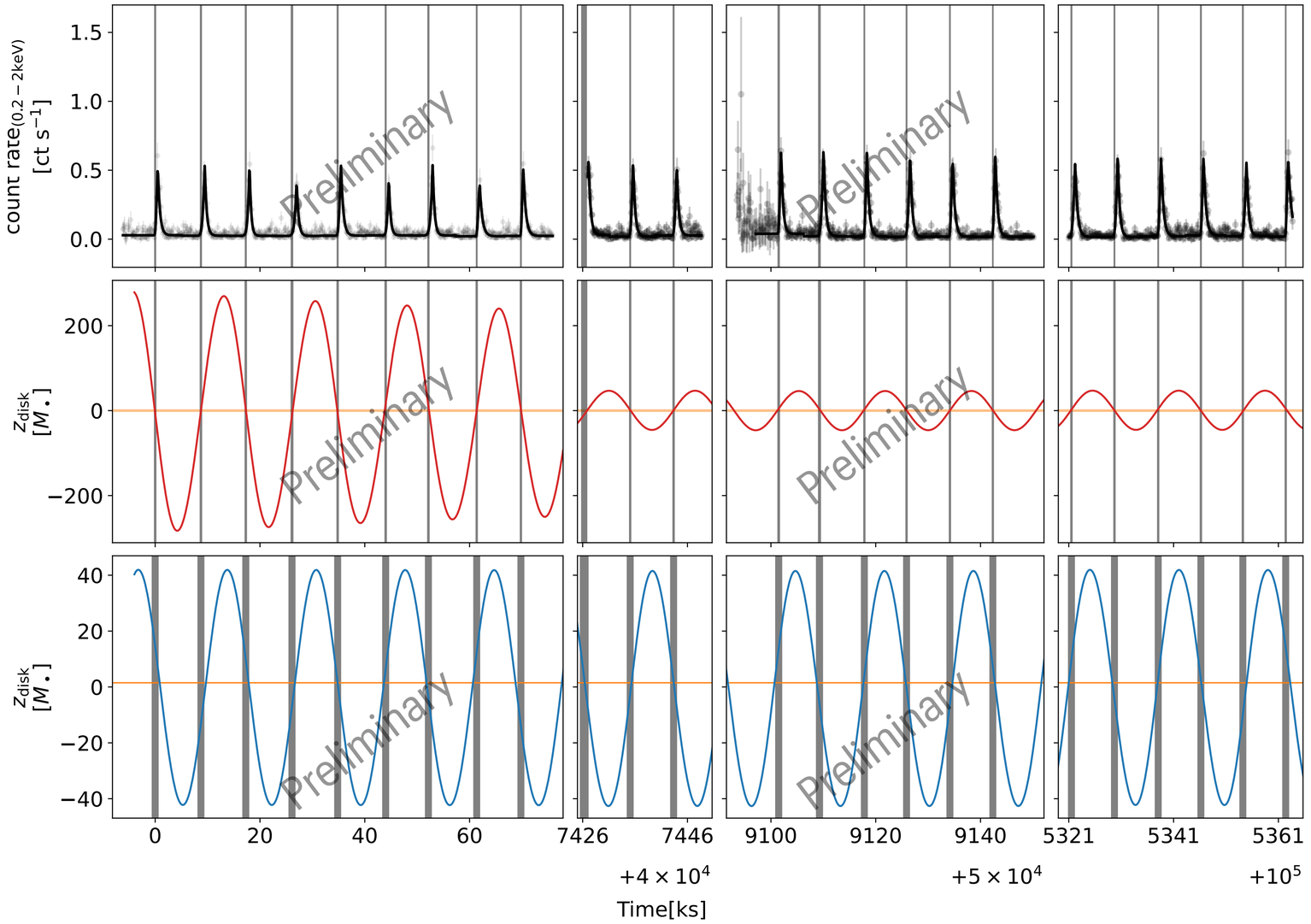
DISK MOTION: ERO-QPE1

- Disk (rigid) precession + retrograde orbit
- Reach alignment by the second epoch
- Bayes factor:
  $\log \mathcal{B}_g^d = 10.2 \pm 0.2$
- Precession period ~ 34 days
  Alignment speed lower limit ~ 0.89 rad/yr
- SMBH mass
  $\log_{10}(M_\bullet/M_\odot) = 5.2^{+1.0}_{-0.8}$



DISK MOTION: ERO-QPE2

- Disk (rigid) precession only
- Reach alignment by the second epoch
- Bayes factor:
  $\log \mathcal{B}_g^d = 20.0 \pm 0.2$
- Precession period ~ 3 days
  Alignment speed lower limit ~ 0.63 rad/yr
- SMBH mass
  $\log_{10}(M_\bullet/M_\odot) = 4.5^{+0.3}_{-0.2}$



SUMMARY

- Decisive evidence for
  - non-zero orbital decay in GSN 069
  - Disk precession in eRO-QPE1 and eRO-QPE2
- The SMO in GSN 069 EMRI is more likely a star