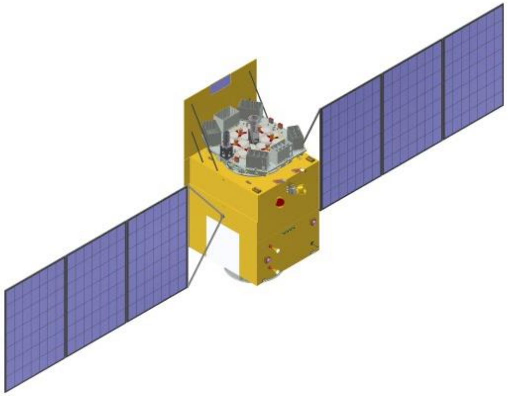


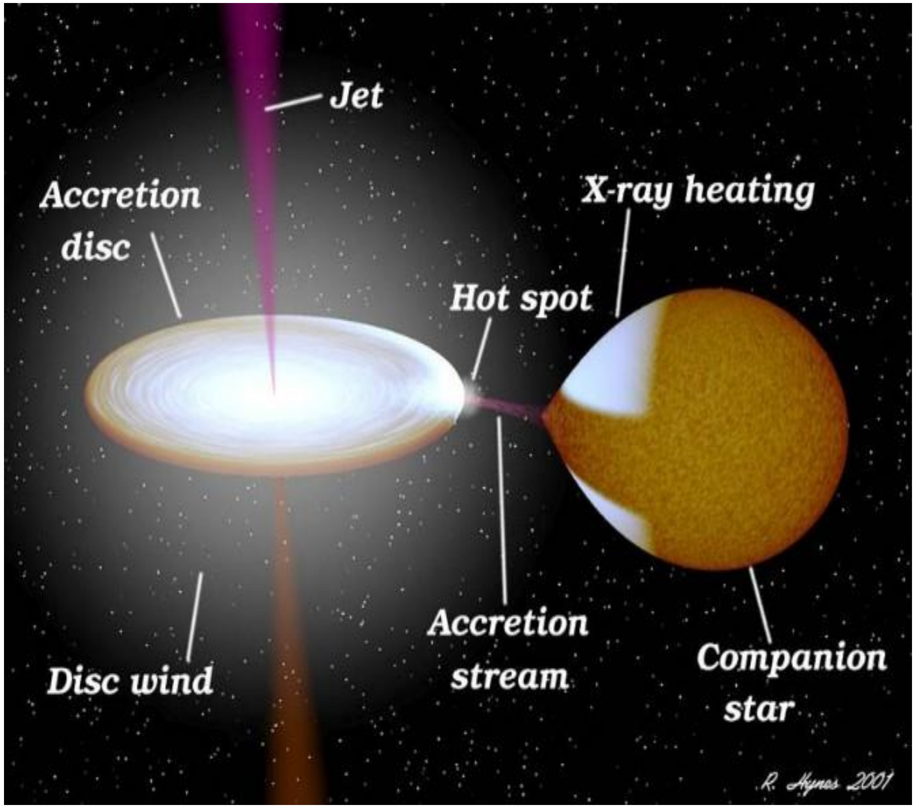
MAXIJ1820+070爆发的高能QPO和进动喷流

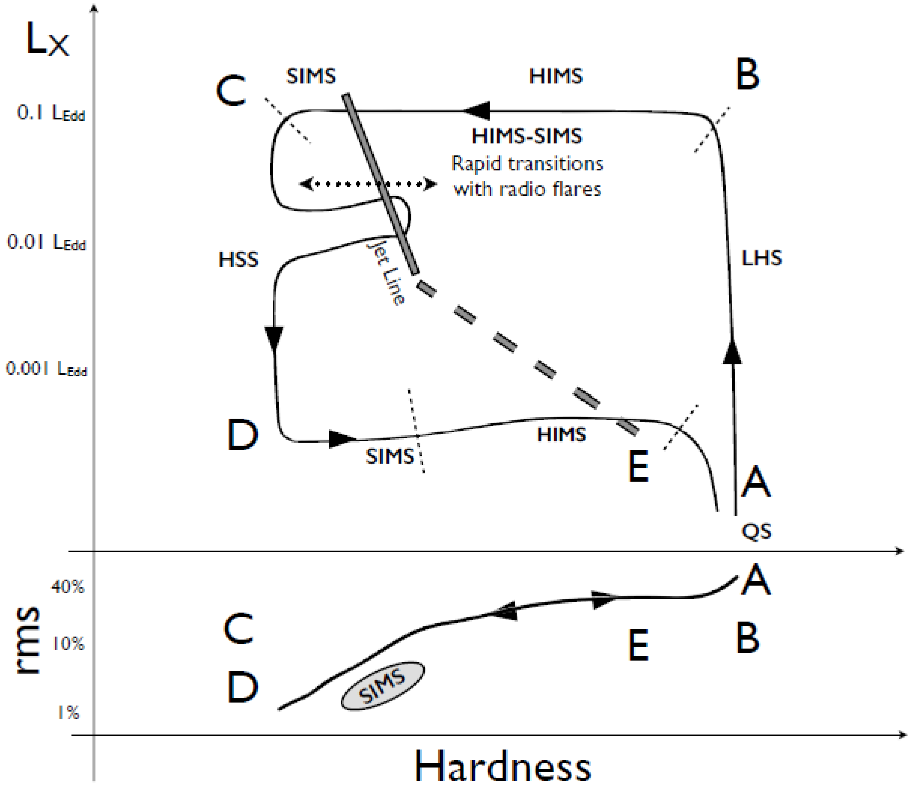
Xiang Ma , Lian Tao ✉ , Shuang-Nan Zhang ✉

On behalf of Insight-HXMT team

2022-6-16

Transient Black Hole Binaries & HID



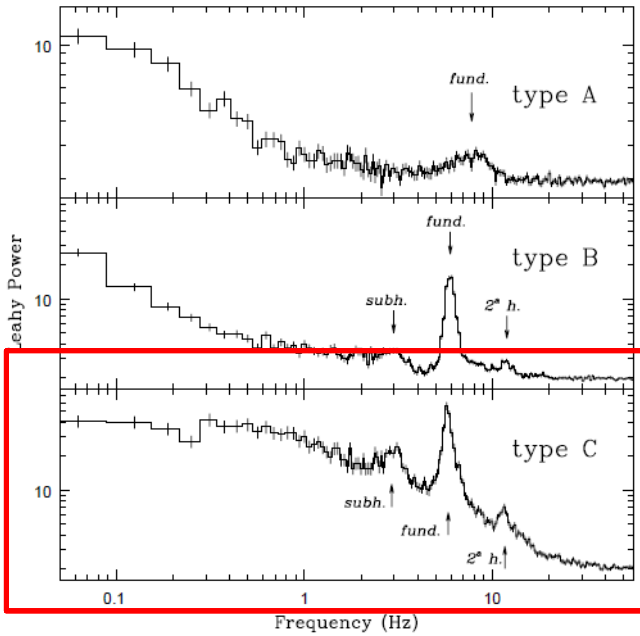


Belloni & Motta 2016

Fast time variability

- Low Frequency QPOs

Property	*TypeA*	*TypeB*	*TypeC*
Frequency (Hz)	~ 6	~ 6	$0.1 - 10$
Q $(\nu/FWHM)$	$\lesssim 3$	$\gtrsim 6$	$\gtrsim 10$
Amplitude (%rms)	$3 - 4$	~ 4	$3 - 16$
Noise	weak red	weak red	strong flat-top

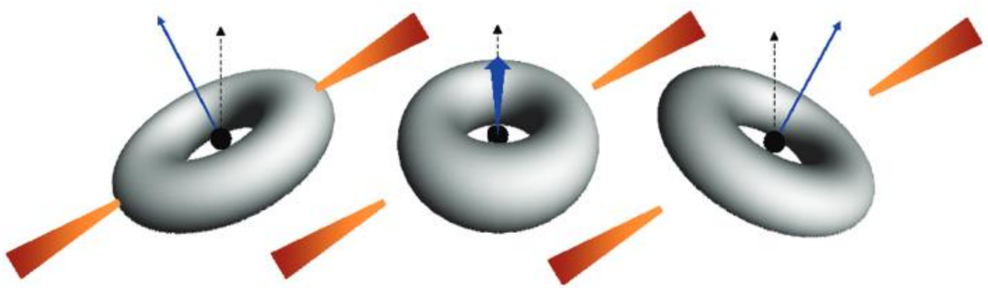


Casella et al. 2004

- ✓ Instabilities
- ✓ Geometrical effects

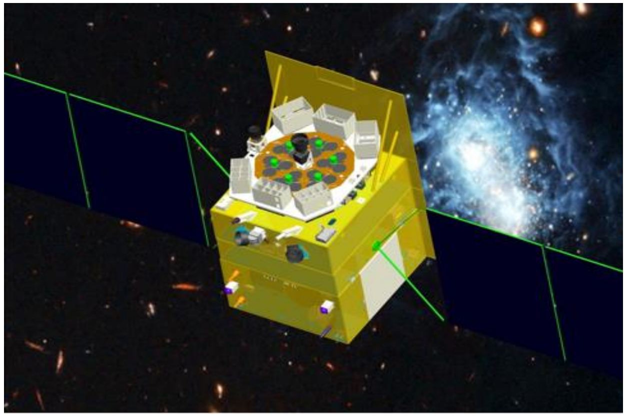
以前观测结果主要在< 30 keV

Lense-Thirring precession

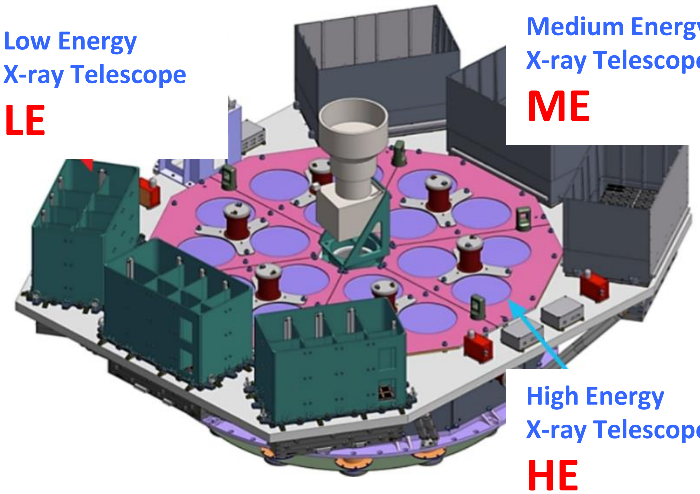


Ingram et al. 2009

Insight-HXMT satellite and payload

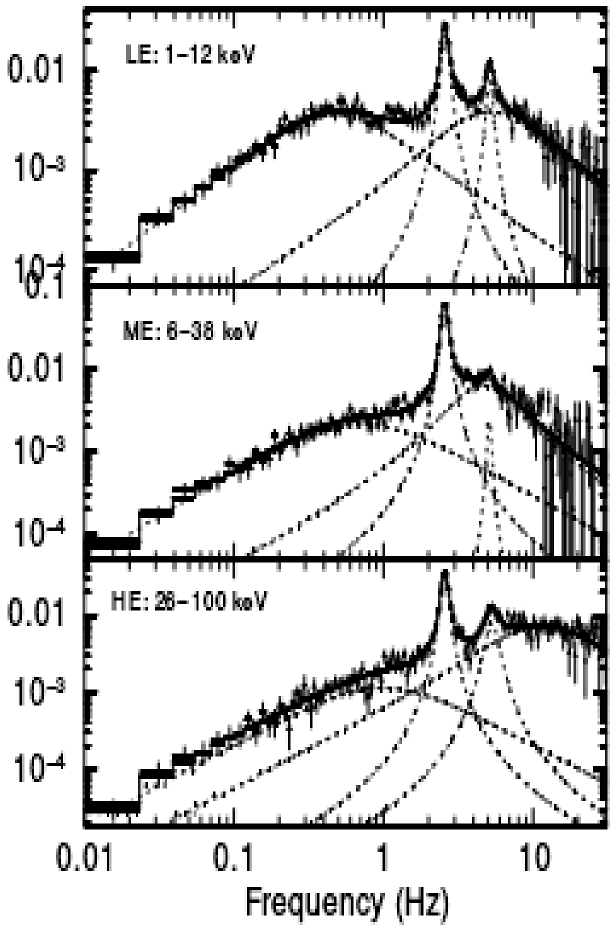


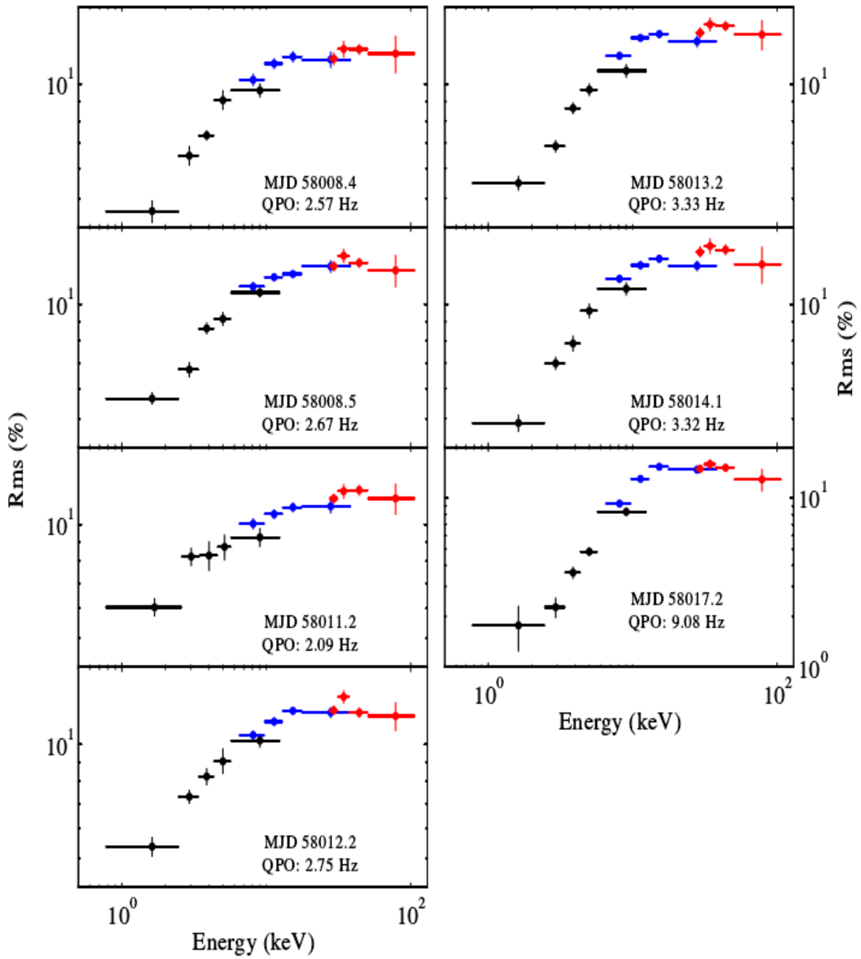
Launch: June 15, 2017
Orbit: 550 km, 43 deg



	HE	ME	LE
Detector	NaI/CsI	Si-PIN	SCD
Total area (cm2)	5100	952	384
Energy range(keV)	20-250 (collimator) 100-5000 (all-sky)	5-30	1-15
Time resolution	**2** µs	240 µs	1 ms

Insight-HXMT observation in MAXI J1535-571

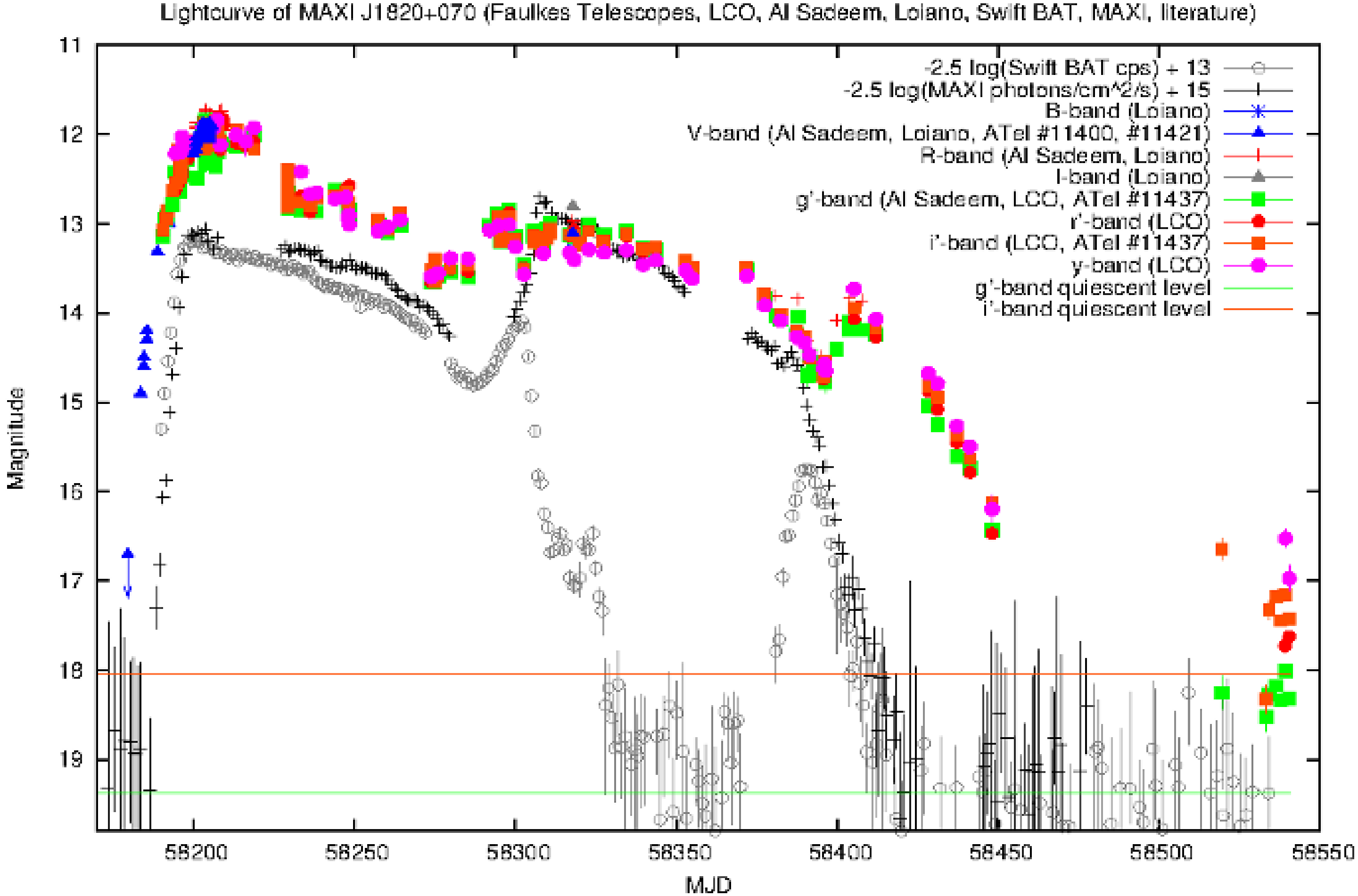




◆ **首次把C型QPO的研究拓展到100 keV**

MAXI J1820+070

2018-03-11 detected by MAXI, low-mass black hole X-ray binary, ASASSN-18ey， RA, Dec = 275.091 , 7.186



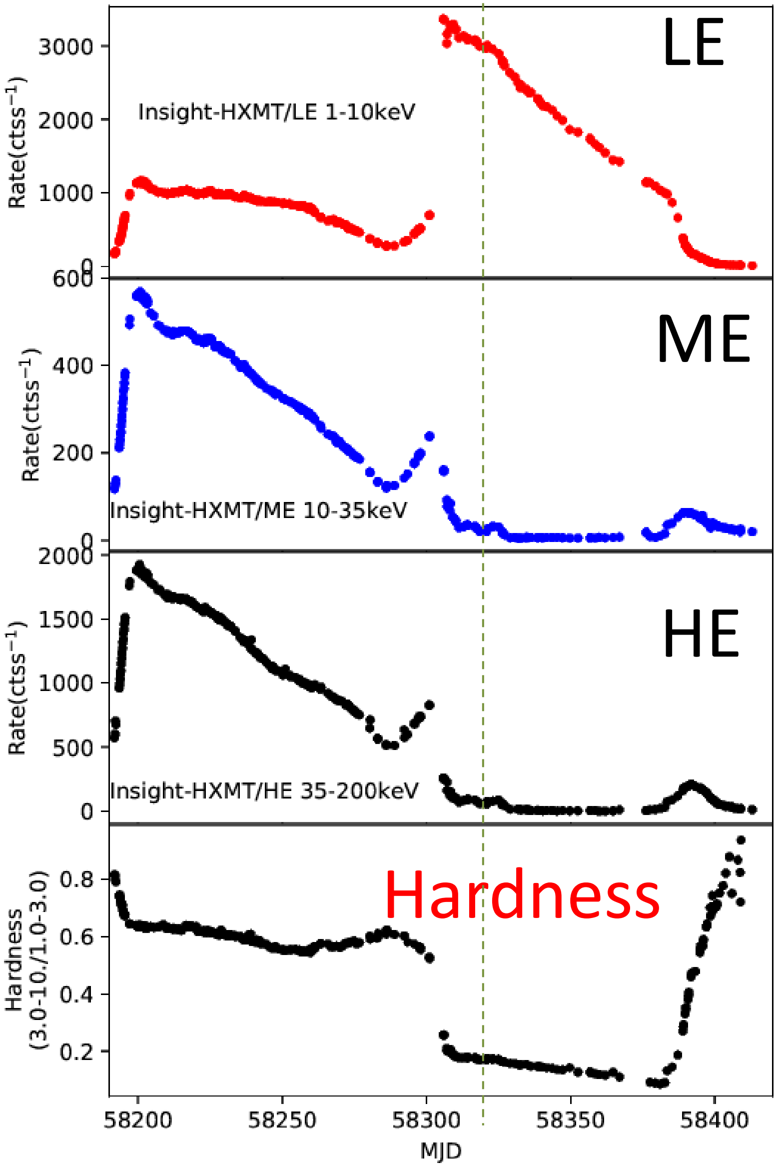
Atel (#12534)

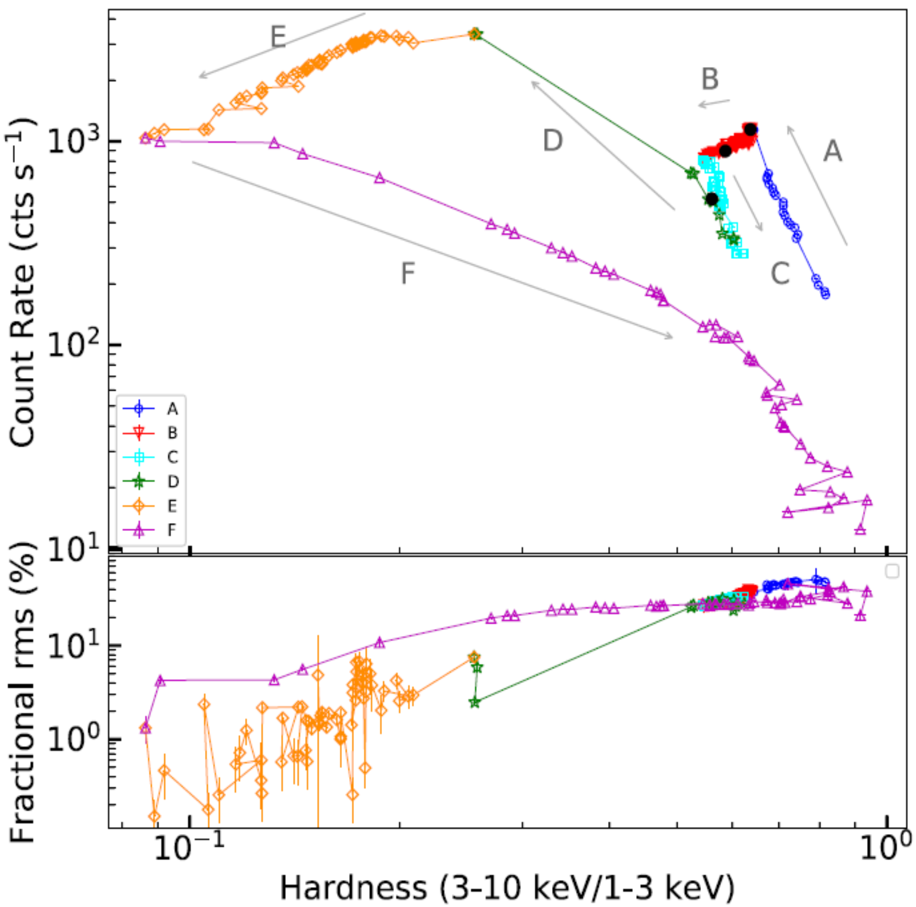
Insight-HXMT Observation

- **Observation Time: （ToO）**
  - **2018-03-14~2018-10-21：Monitor > 140 times**
  - **Total exposure: ~2000ks.**
- **Insight-HXMT Features:**
  - **Large effective area**
  - **High timing res.**
  - **Wide energy band (1 keV- 250 keV)**
  - **No pileup**

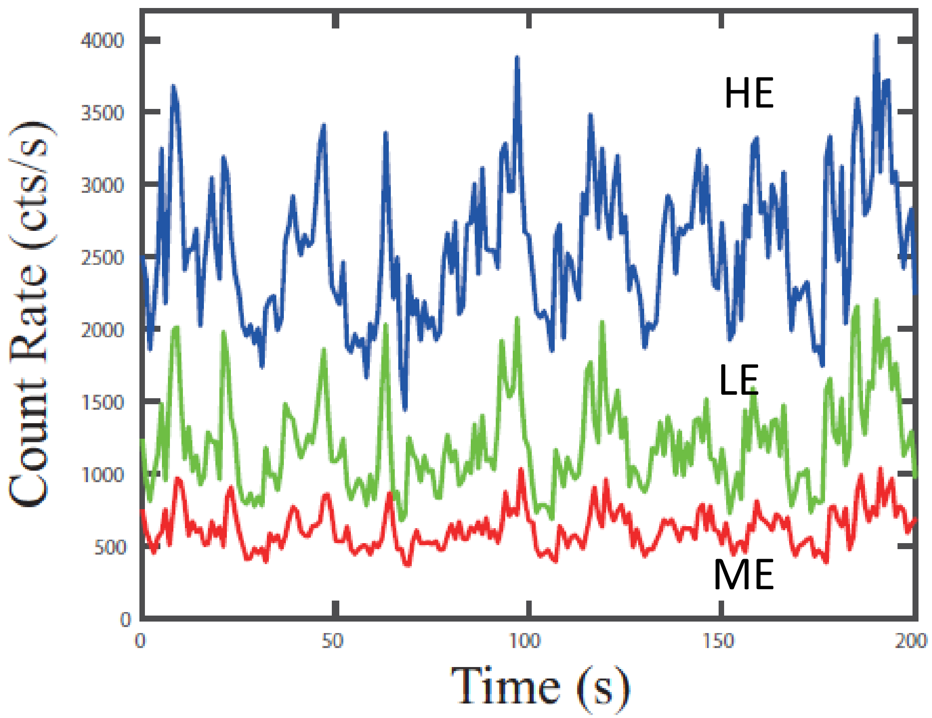
Insight-HXMT Timing Result

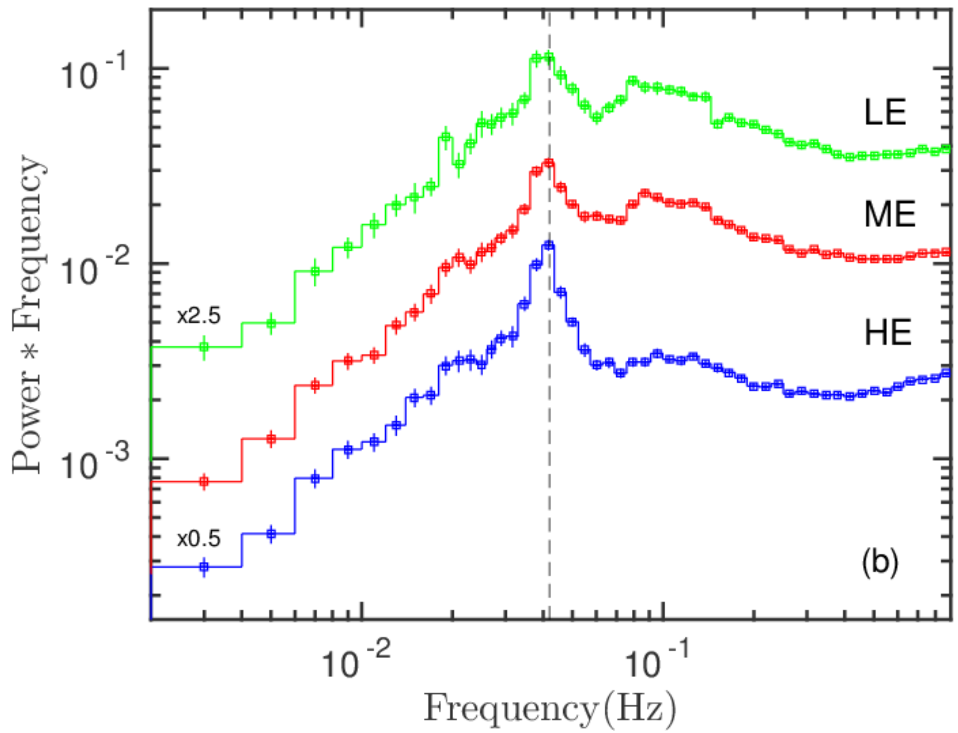
The Outburst Evolution：LC & HID





Power Density Spectra

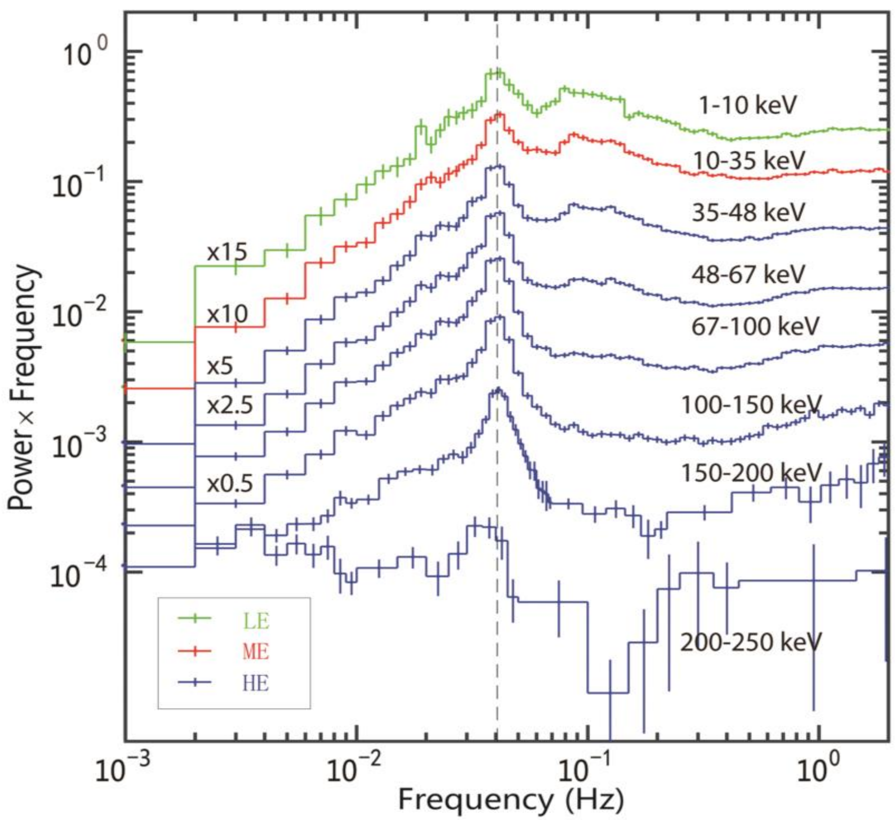


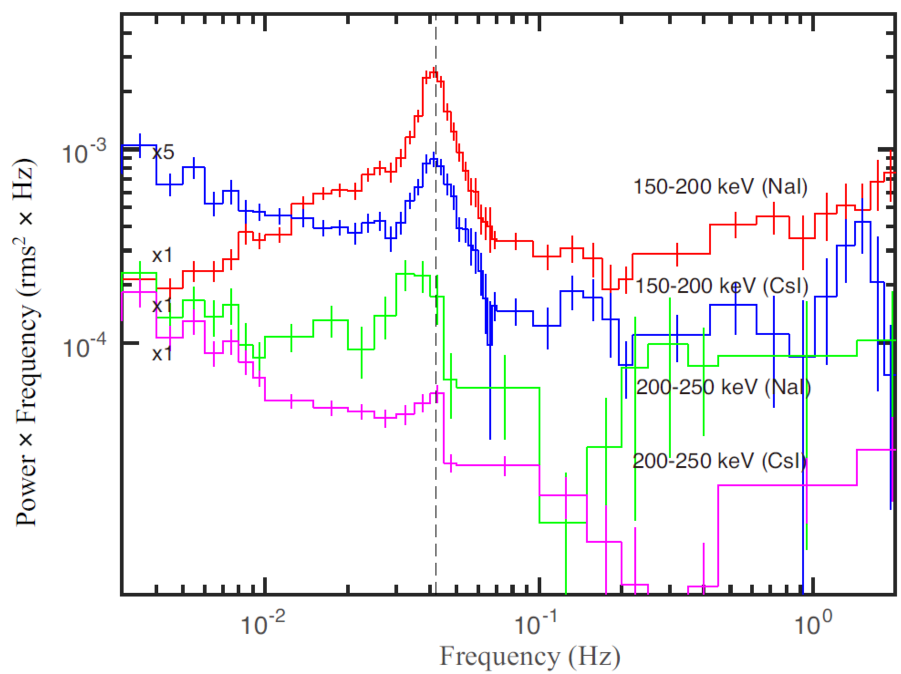


ObsID: P0114661004

“慧眼”发现黑洞周围最高能量的QPO

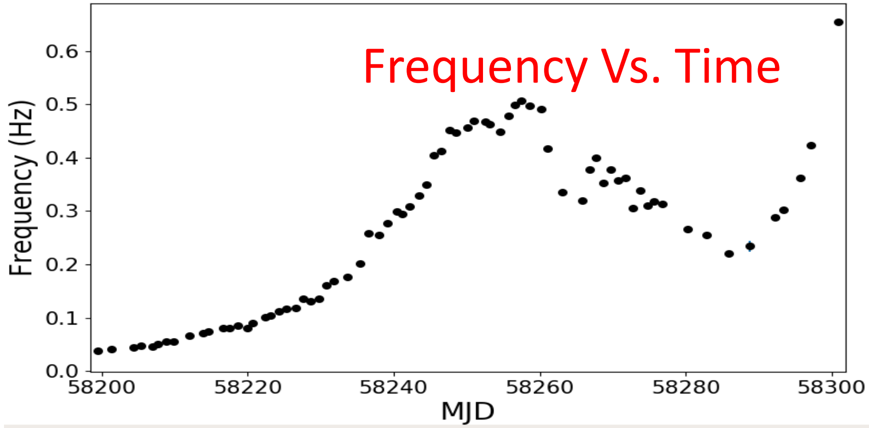
- 首次在>200 keV发现了低频QPO信号

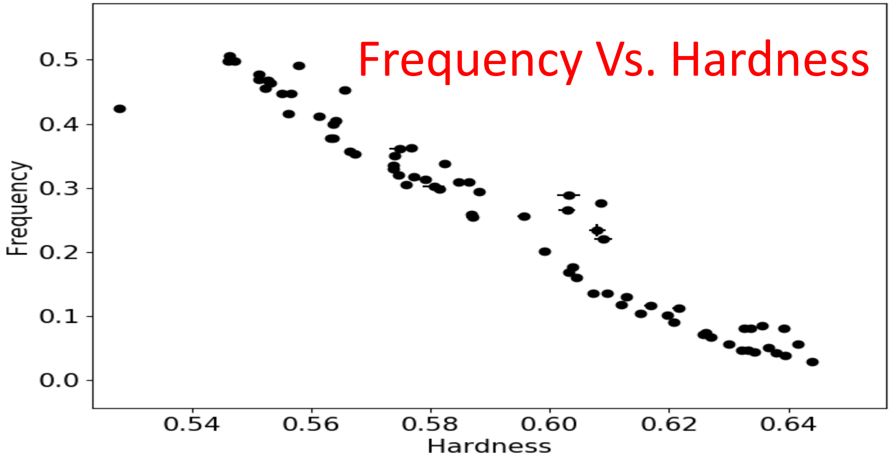


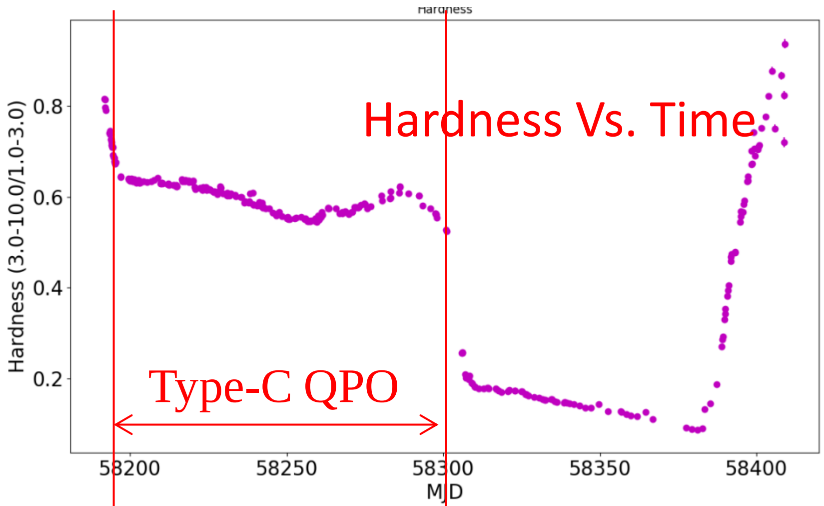


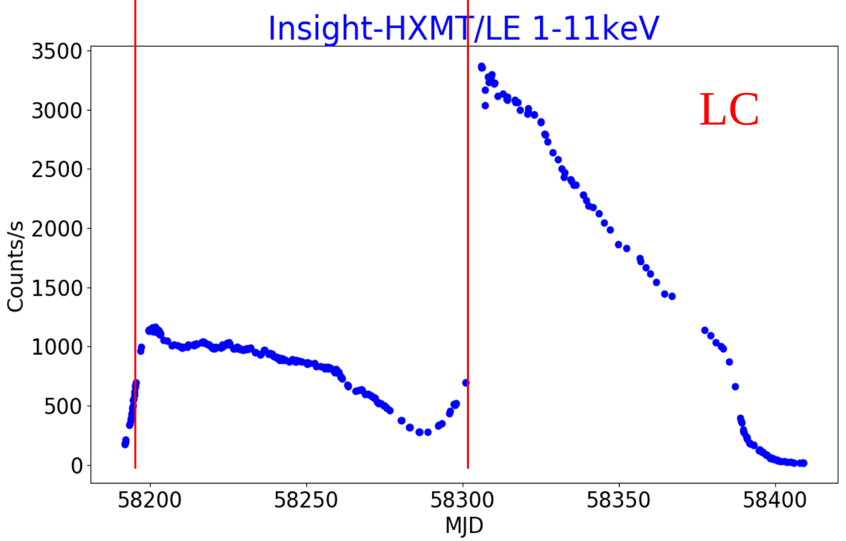
LFQPOs Evolution with Time

- **Type-C LFQPO： 0.02Hz~0.65Hz**



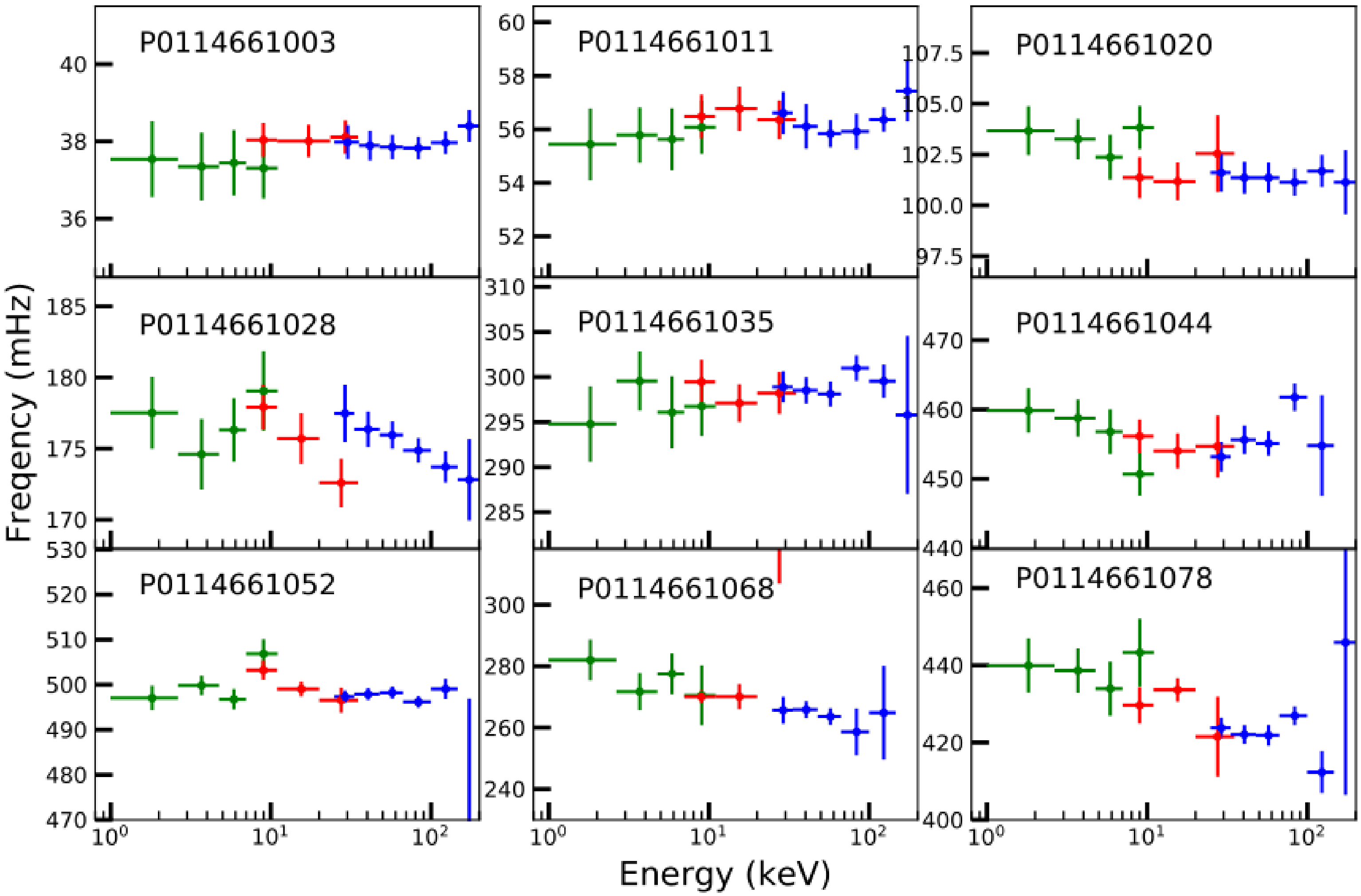




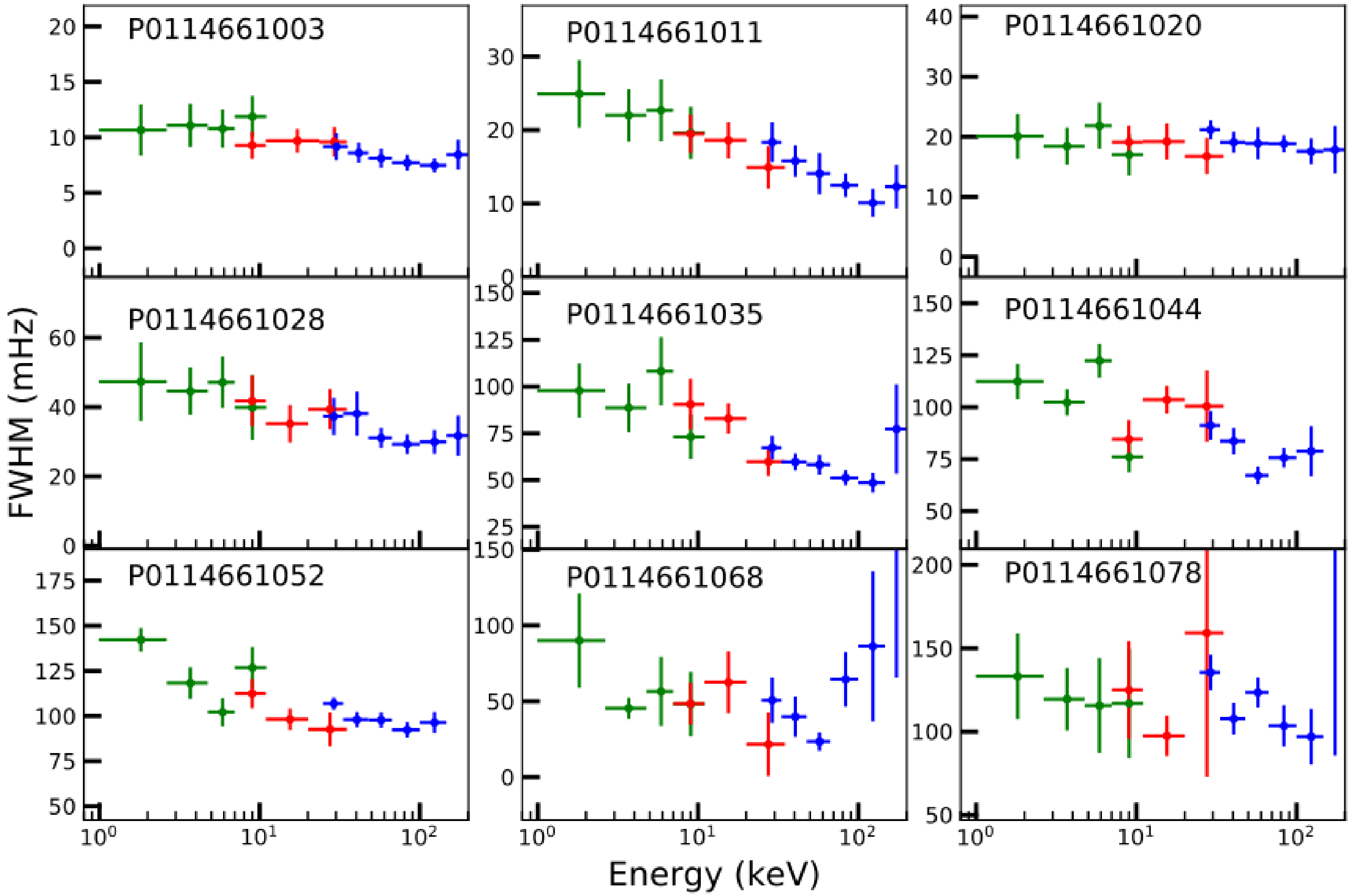


No significant high-frequency peaks were found in the PDS

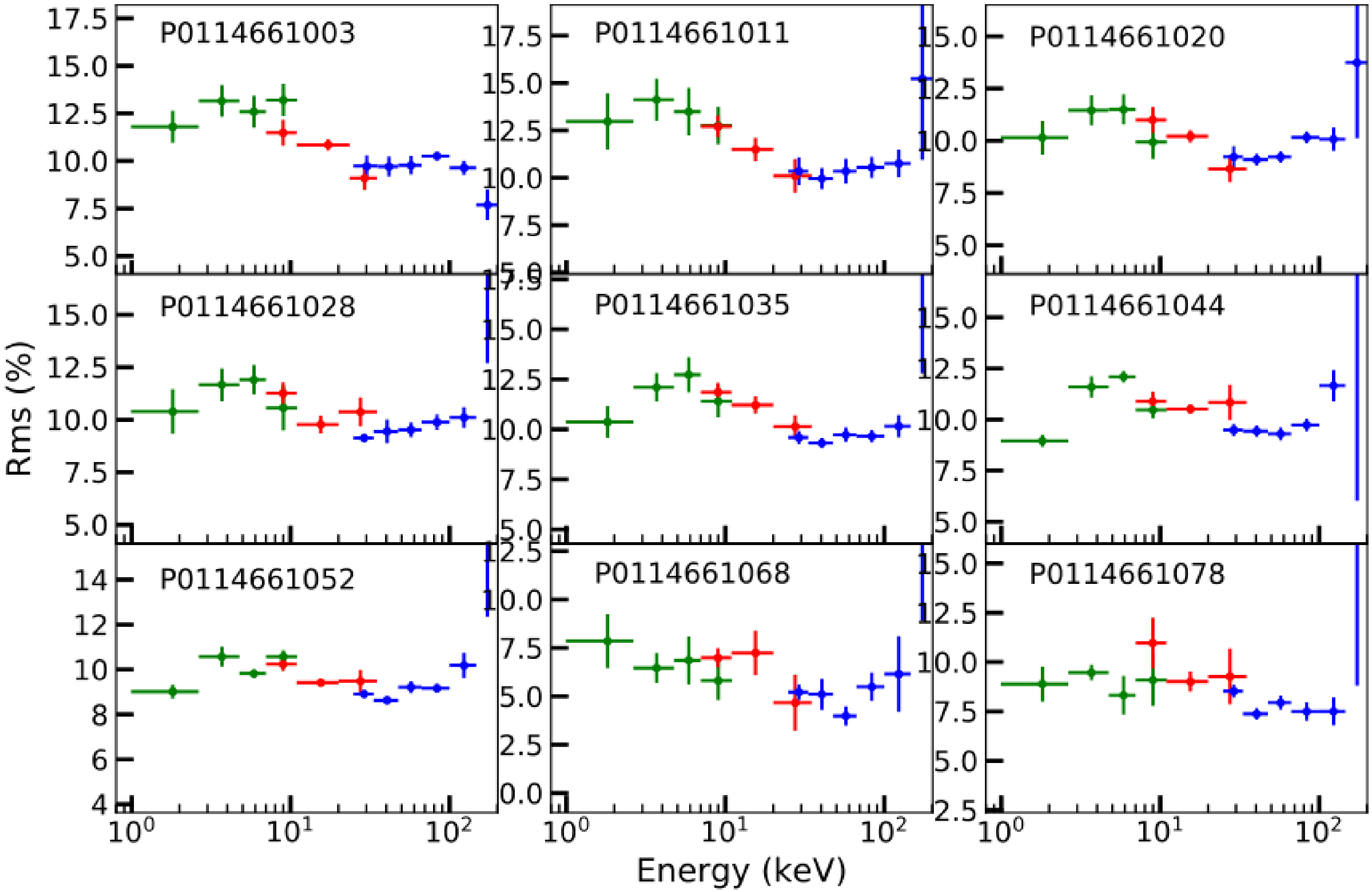
LFQPO Frequency vs. Energy



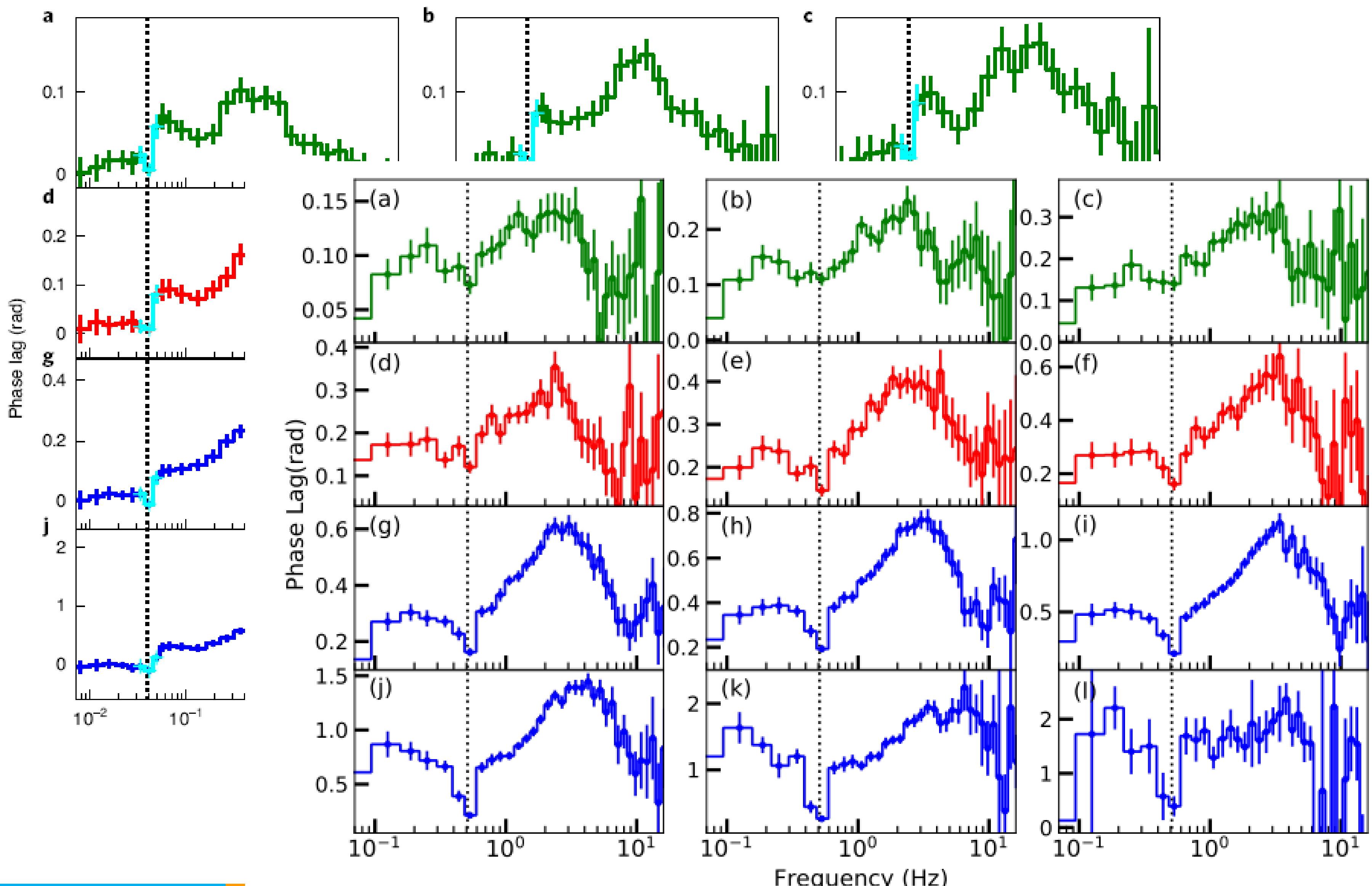
LFQPO FWHM vs. Energy



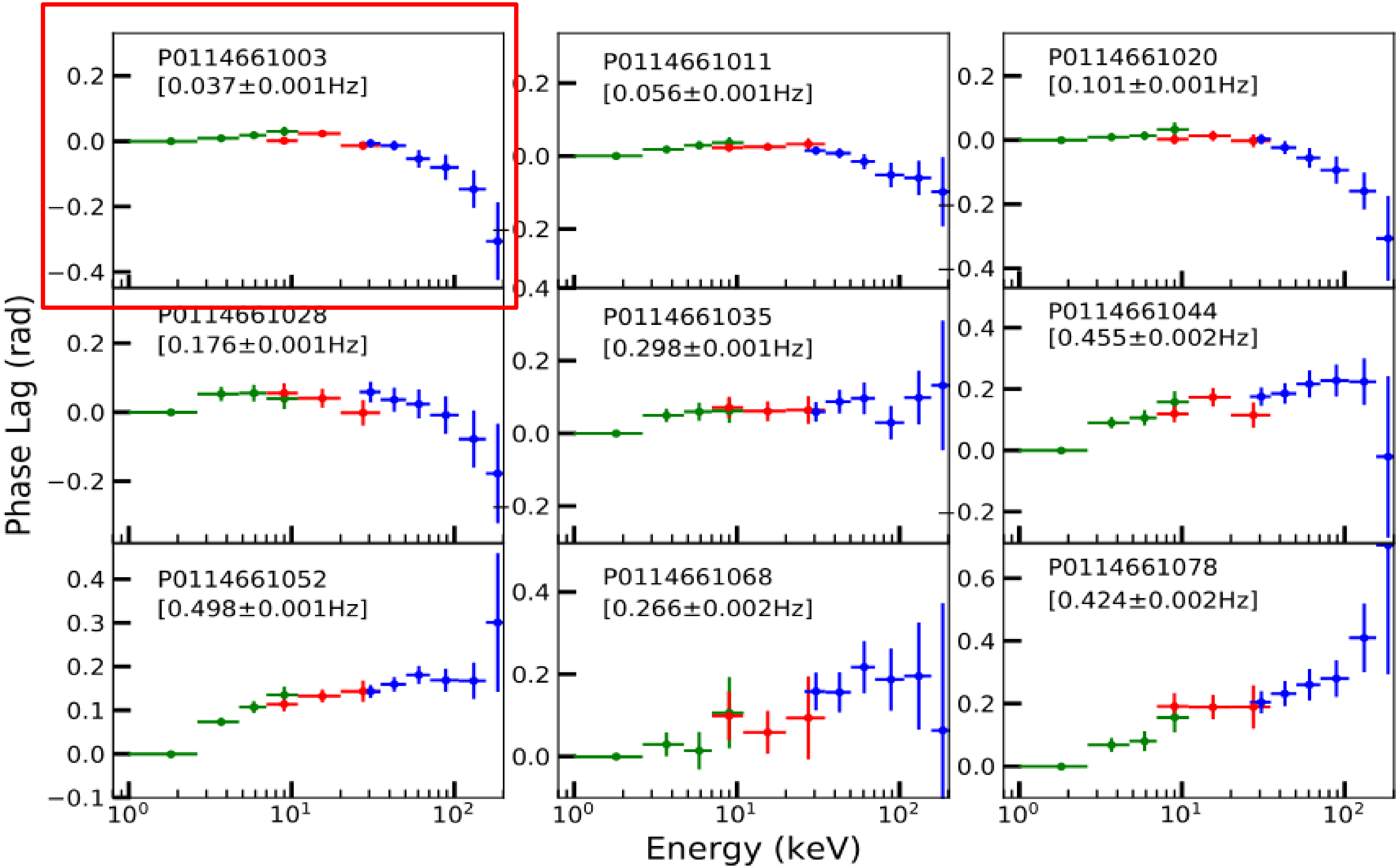
LFQPO RMS Vs. Energy



Phase Lag vs. Frequency

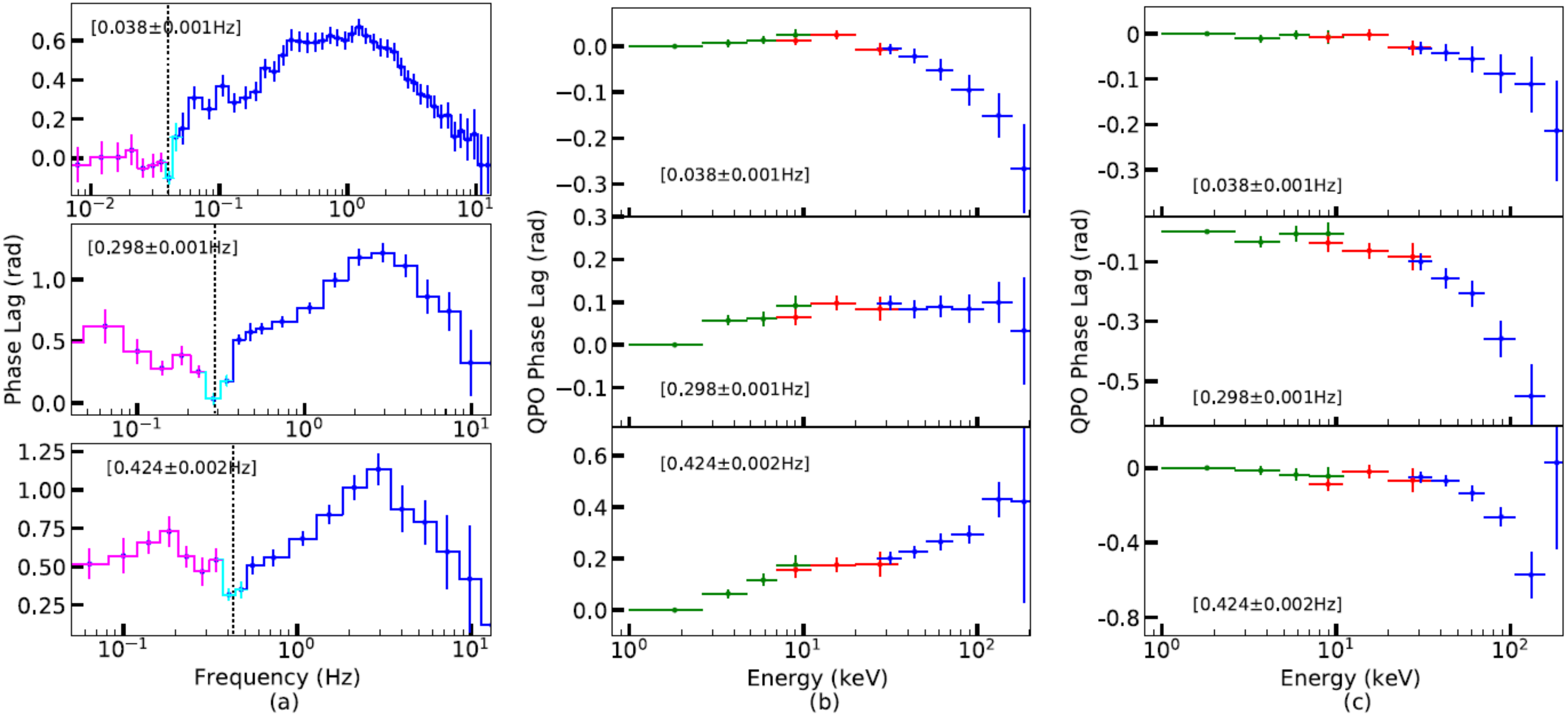


QPO PhaseLag Vs. Energy



QPO PhaseLag

- "Correct" QPO PhaseLag

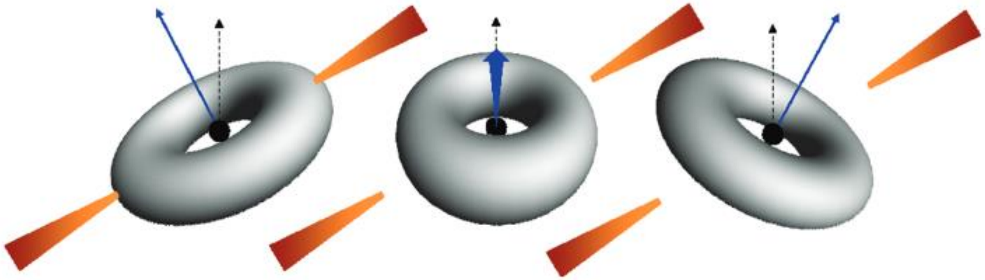


Current model of LFQPO

- **Instabilities**
  - Disk:
    - High energy (~ 200 keV)
  - Corona:
    - lag of 1 s corresponds to a size of 3.9x10^5 km, 10^4 r_g for a 7–10$M_\odot$ BH
    - Inverse Comptonization -> Hard lags
    - Rms-energy spectra increase
- **Geometry effects**
  - Precession of the hot inner flow (L-T precession)

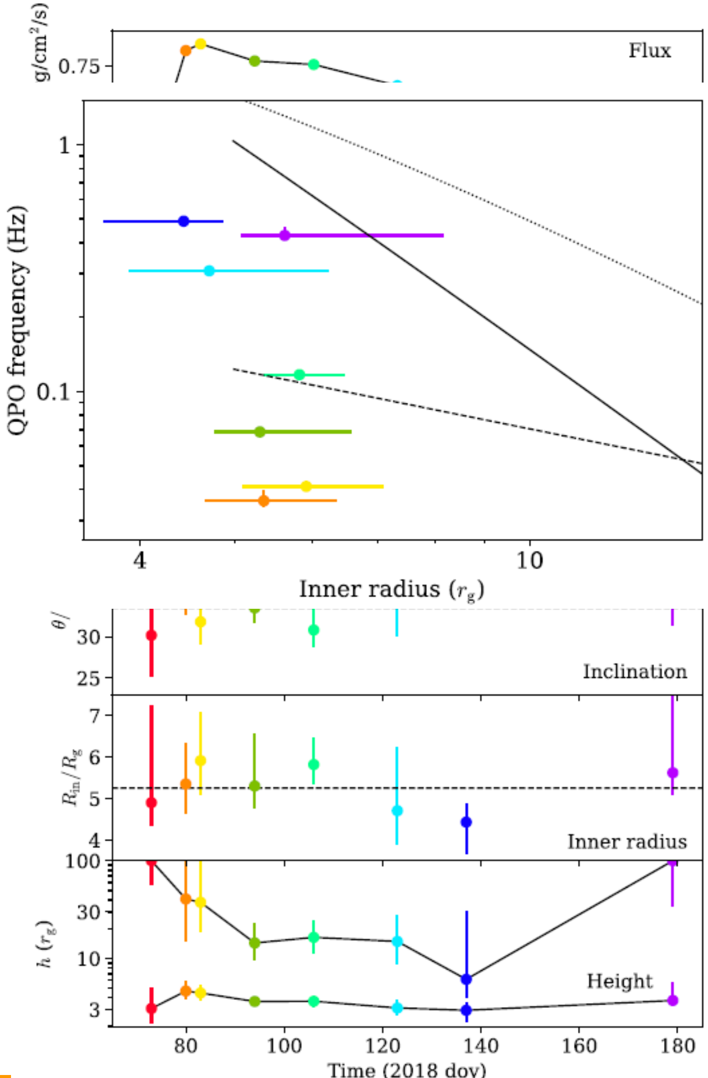
Current model of LFQPO--LT

Lense-Thirring precession

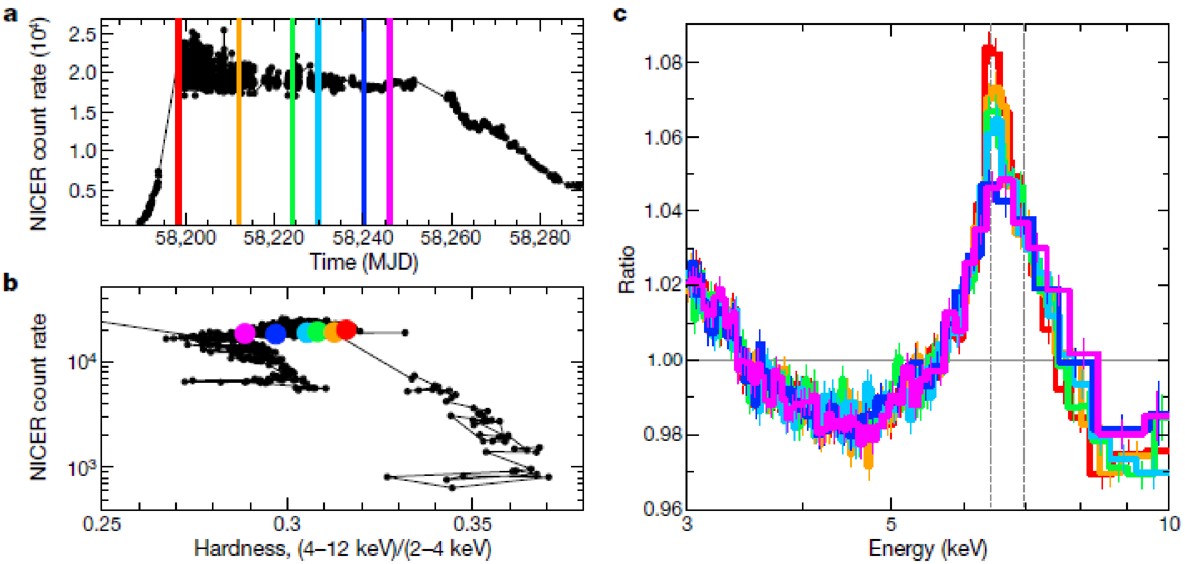


Ingram et al. 2009

NuSTAR

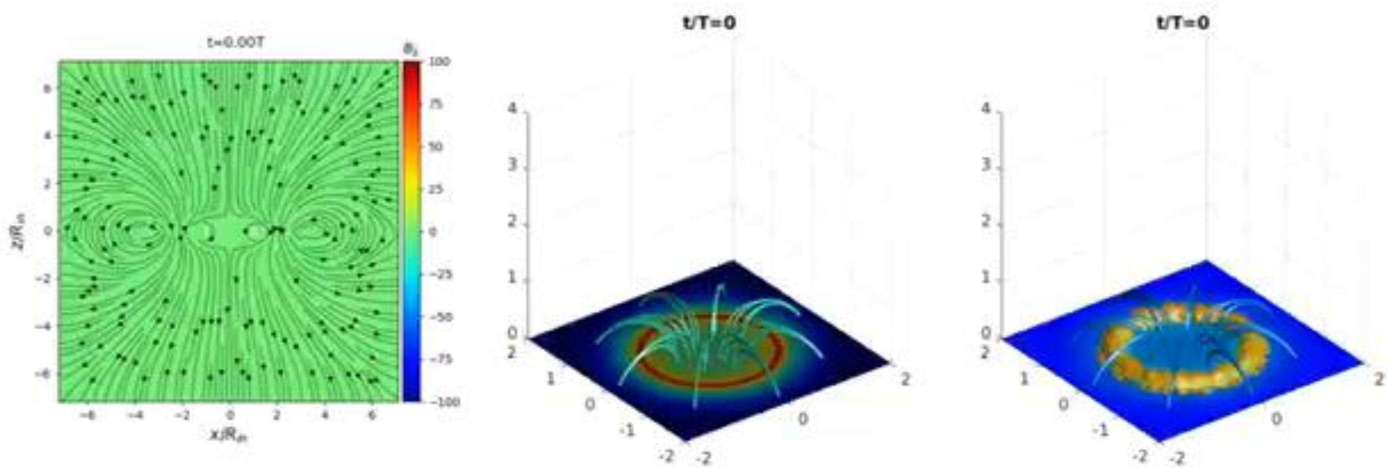


NICER



Model of LFQPO-- jet precession

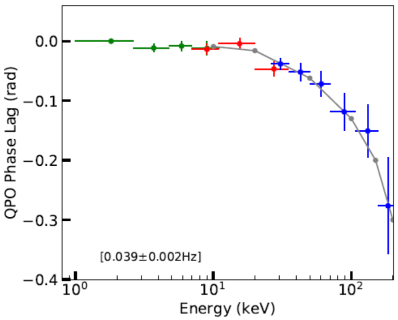
- Formation and radiation mechanisms for the small-scale jet around the black hole.
  - Magnetic flux tubes (magnetororational instability or magnetic buoyancy).
  - Flux tubes can form a close zone with a size of a few gravitational radii-> the balance between the pressure of the twisted field induced by BH spin and the confinement pressure from external field.
  - With the release of magnetic energy, charged particles attached to the closed zone can be accelerated.
  - Soft photons from the accretion disk can be inverse Compton scattered by the energetic electrons into X-rays.

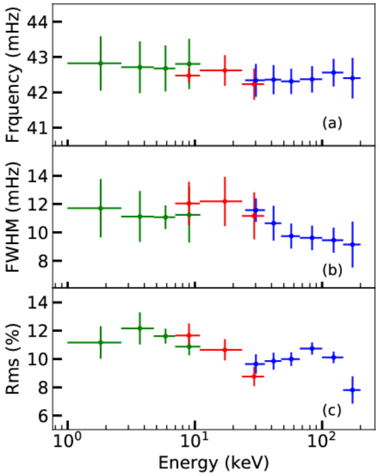


Yuan Y., 2019

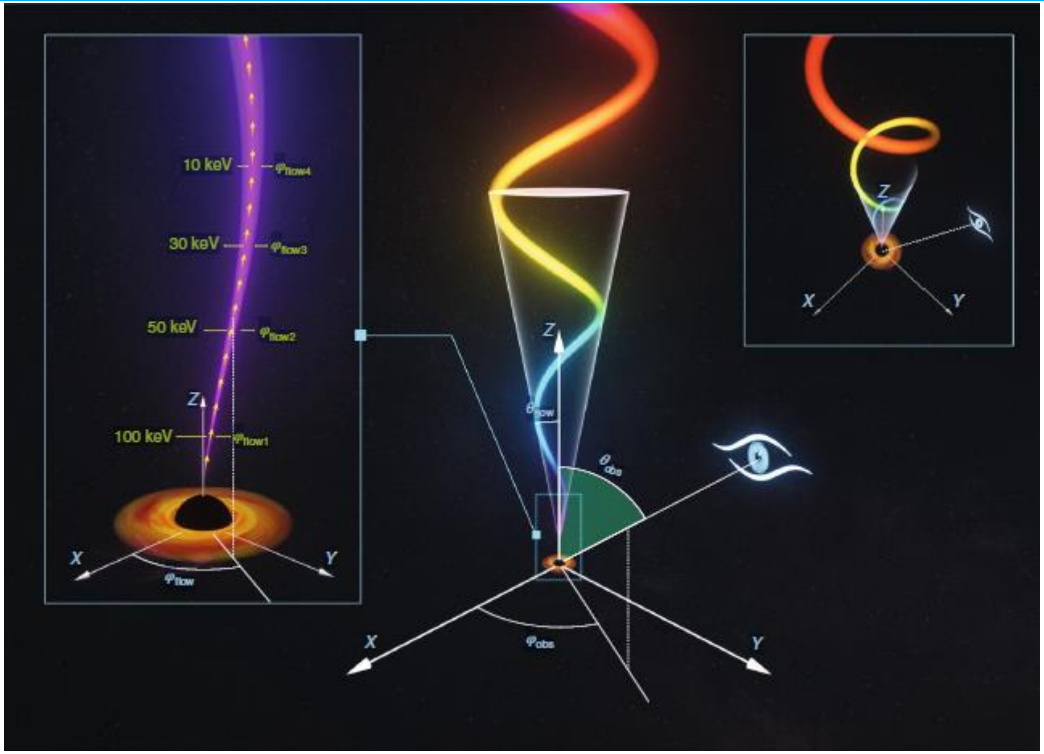
Model of LFQPO-- jet precession

- Relativistic frame-dragging -> jet precession -> LFQPO





Model of LFQPO-- jet precession



Doppler boosting

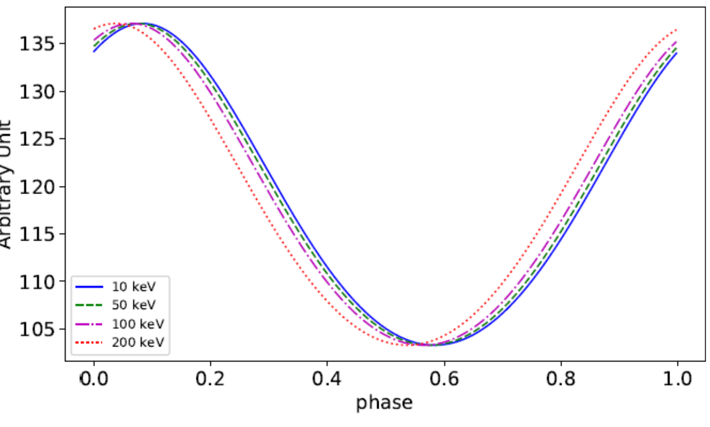
$$S_o = S_e D^p \qquad D = \frac{1}{\gamma(1-\beta\cos\theta)}$$

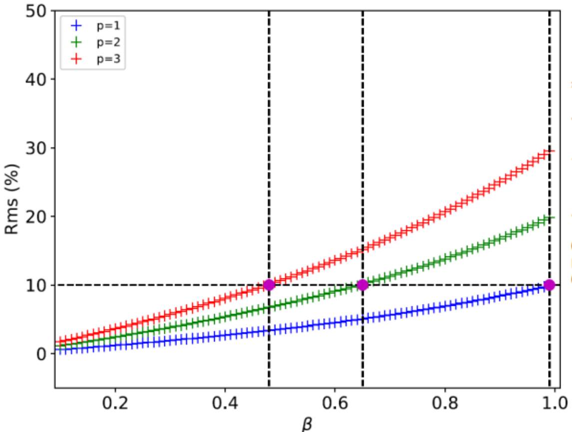
$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta = \frac{v_j}{c}$$

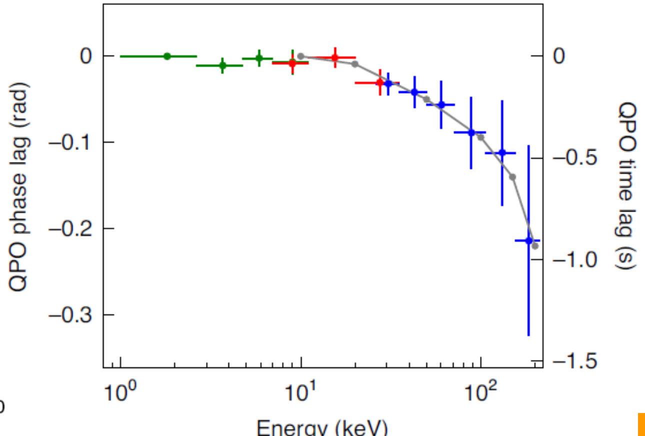
Assuming $\theta_{obs} = 63°$, $\varphi_{obs} = 30°$

$\theta_{flow} = 5°$ and $p = 1-3$,

Jet speed: 0.48-0.99c
$\Delta\varphi_{flow}$ =12°

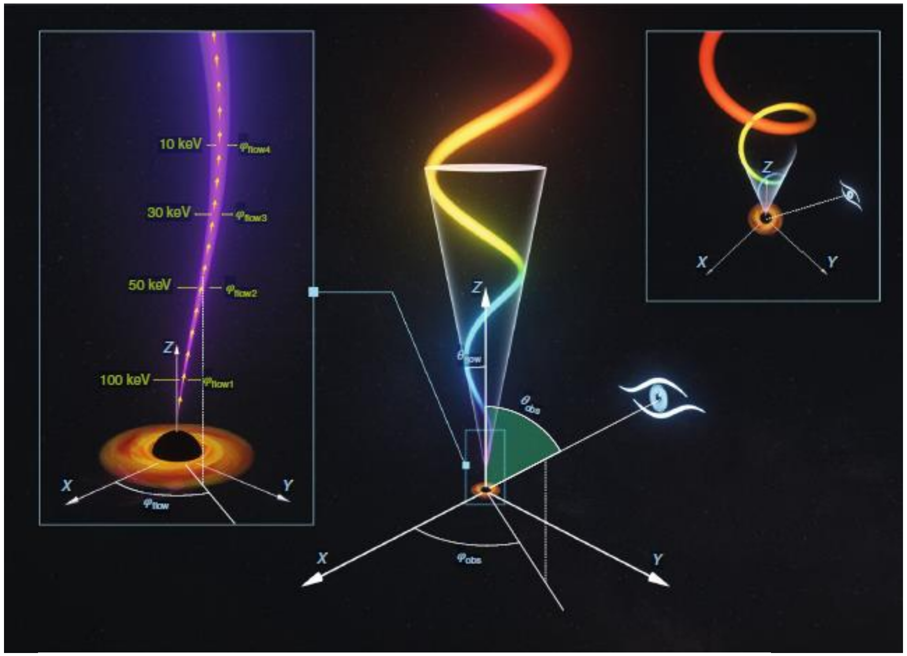


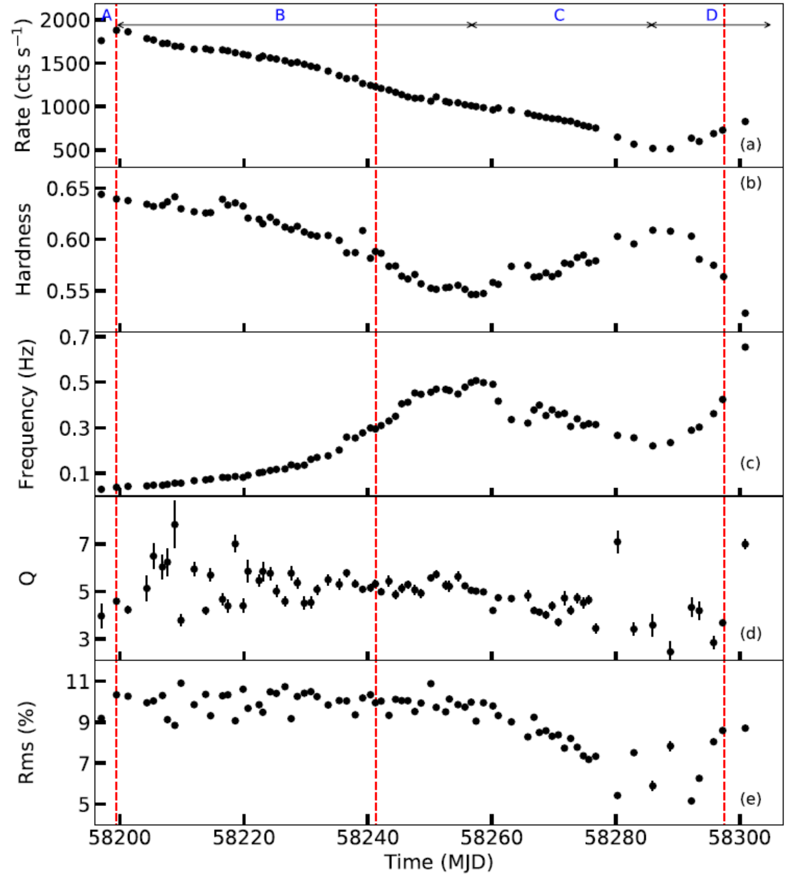


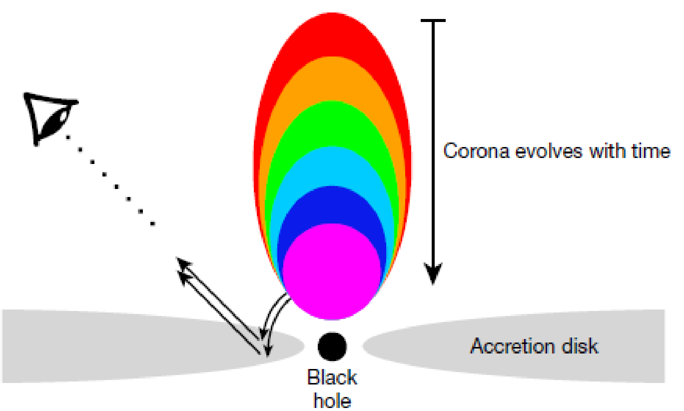


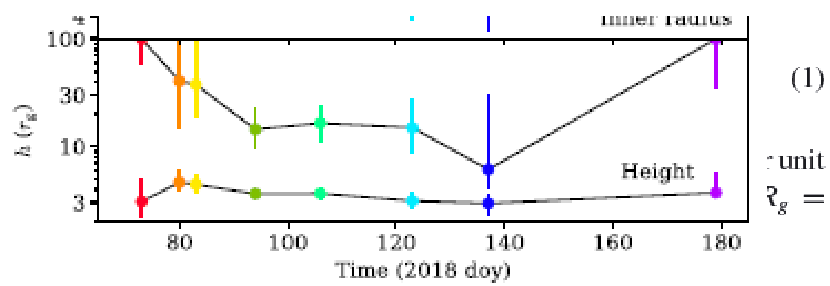
Model of LFQPO-- jet precession

距离黑洞最近的相对论喷流



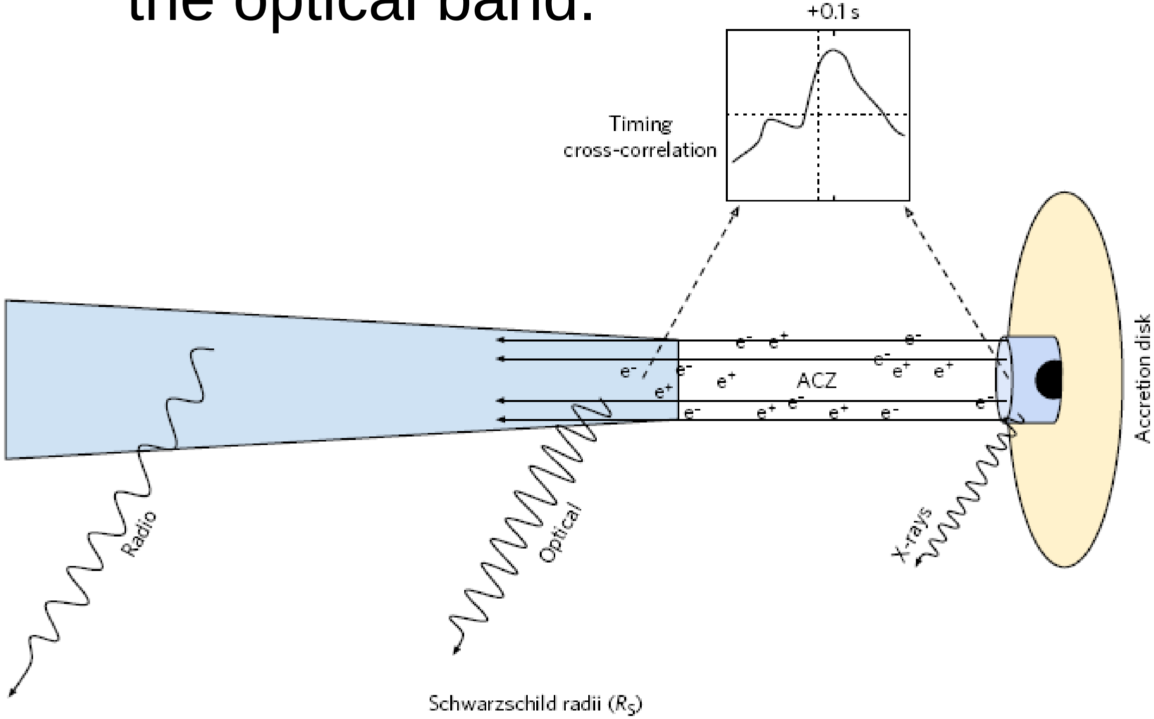


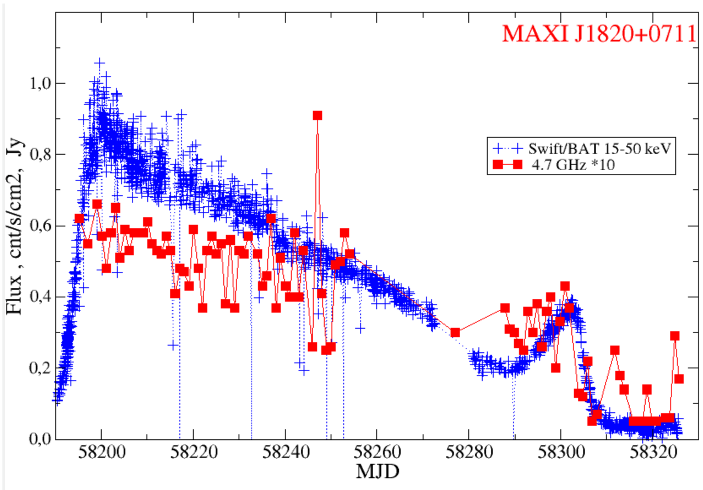




Model of LFQPO-- jet precession

- The Small-scale jet can be accelerated and collimated into a relativistic, large-scale jet by the magnetic field.
- The large-scale jet will power broadband synchrotron radiation from optical to radio.
- The jet precession can also produce the LFQPO observed in the optical band.





Optical QPO in MAXI J1820

- **Optical QPO explained by the precessing jet model**
  - optical frms value: 3% (6%)
  - opening angle：

    1) 1.5±1 deg (Zdziarski, Andrzej A.， 2021)

    2) $\phi=0.45^{+0.13}_{-0.11}$ deg (Tetarenko, A. J., 2021)

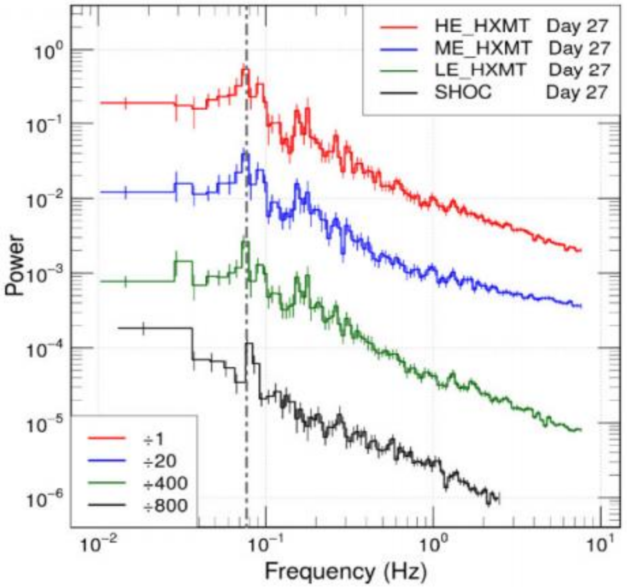


Figure 2. X-ray QPOs from *Insight*-HXMT LS power spectra in the *HE*, *ME*, and *LE* bands (see the box for colour coding), on day 27 (April 7) simultaneous with the SHOC optical QPO. The vertical dot–dashed line is passing through the QPO values.

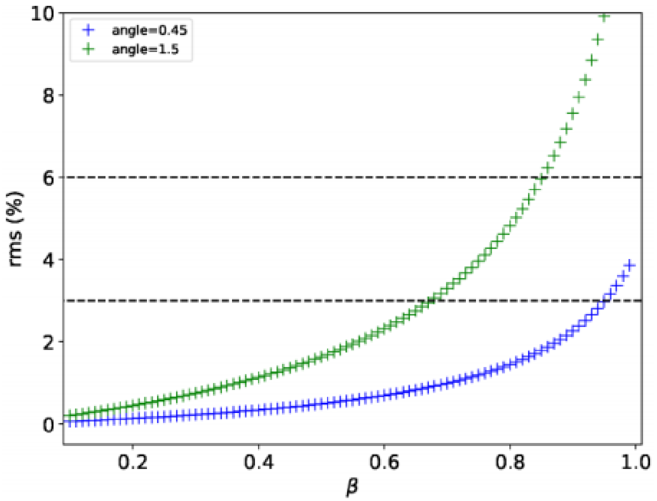


Figure 5. Relation between QPO rms and β ($=v_{\rm jet}/c$) for opening angles of ϕ = 1.°5 (green; Zdziarski et al. 2021b) and 0.°45 (blue; Tetarenko et al. 2021). The lower horizontal dashed line indicates the original QPO rms of 3 per cent, while the upper line indicates the QPO rms of 6 per cent from the jet when considering the contribution of the disc emission to the optical flux (Shidatsu et al. 2018).

Jessymol, MNRAS,513 (2022)

Summary

- Insight-HXMT has monitored the outburst of new black hole candidate MAXI J1820+070
- In the LHS, type-C LFQPOs are significantly detected above 200 keV by Insight-HXMT.
- From the energy dependence of the QPO properties, type-C LFQPOs of high energy band may arise from precession of the small-scale jet.

We expect Insight-HXMT will improve our understanding of the X-ray variability in bright BHBs!

THANK YOU!