An imaginary QPO in the soft-to-hard transition of MAXI J1820+070

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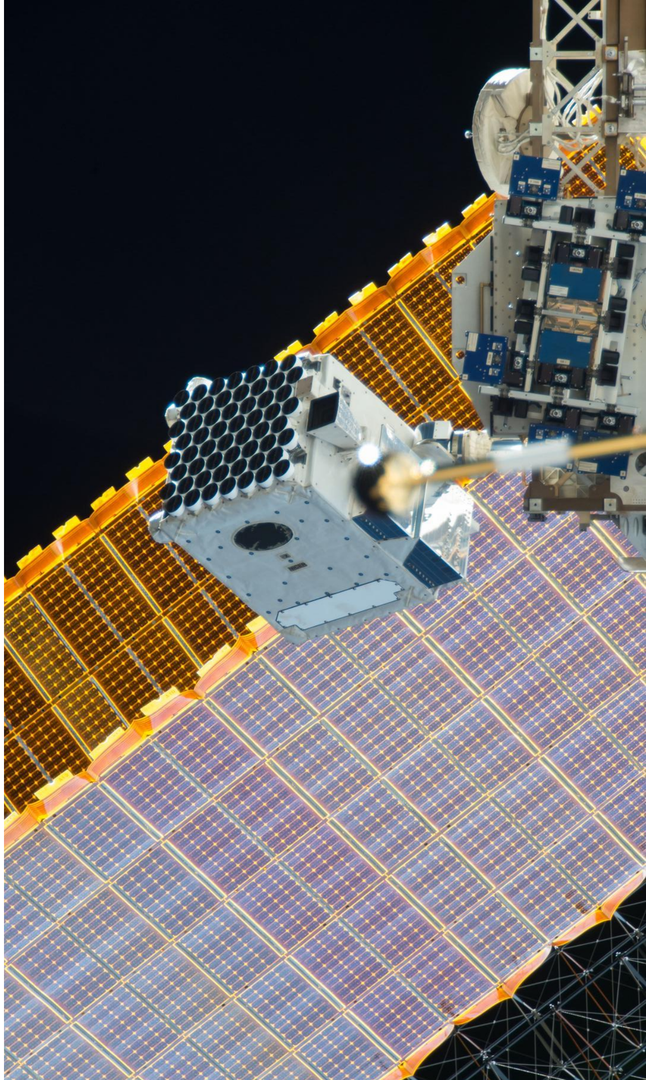
MAXI J1820+070

BH X-ray binary

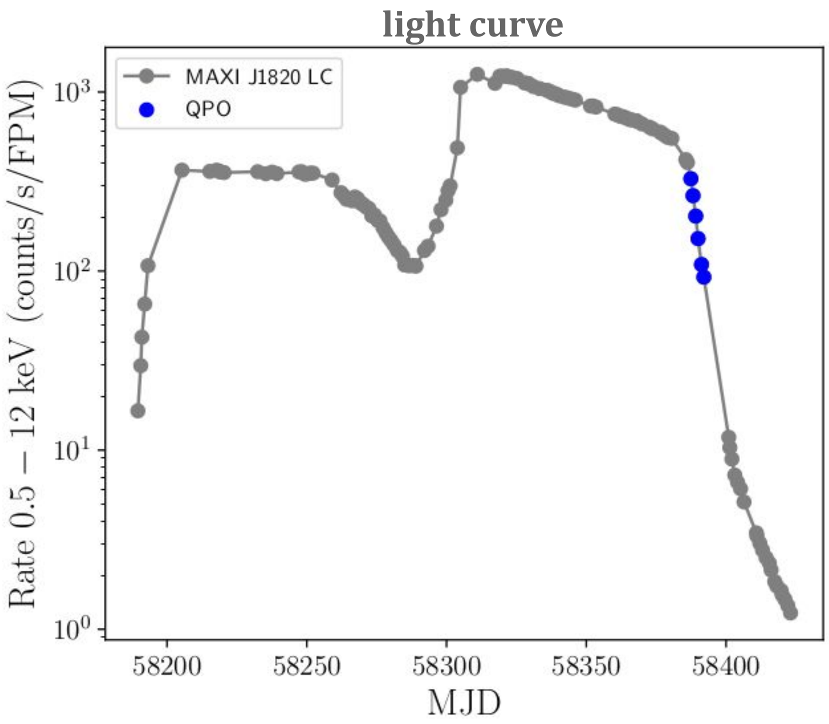
underwent an **outburst** in 2018

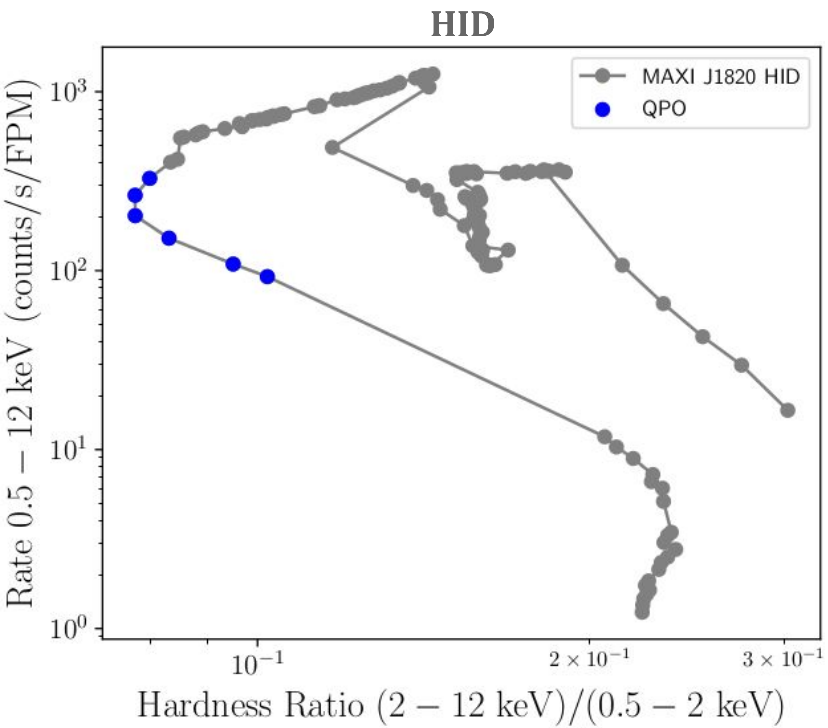
↓

closely monitored by ***NICER***



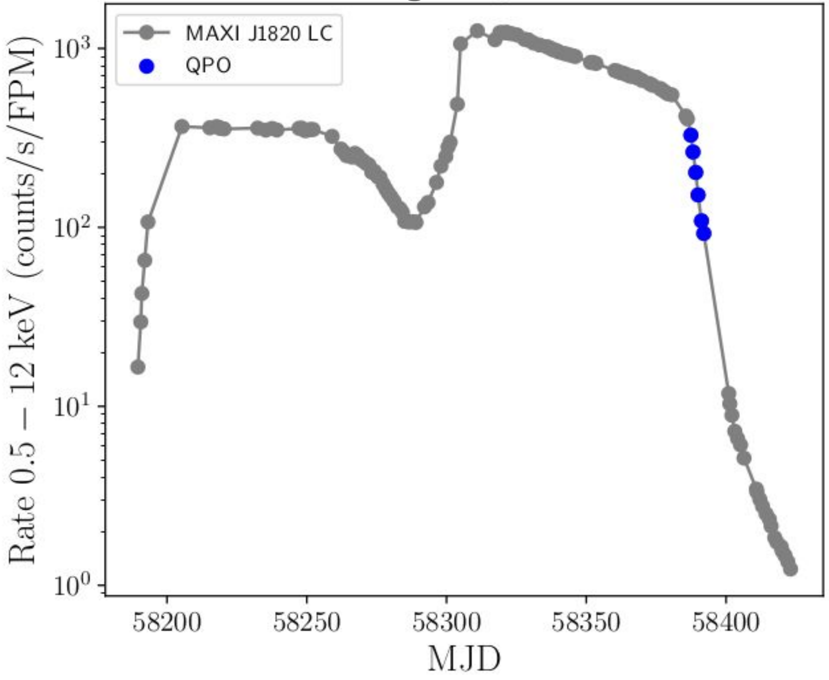
MAXI J1820+070: light curve & HID



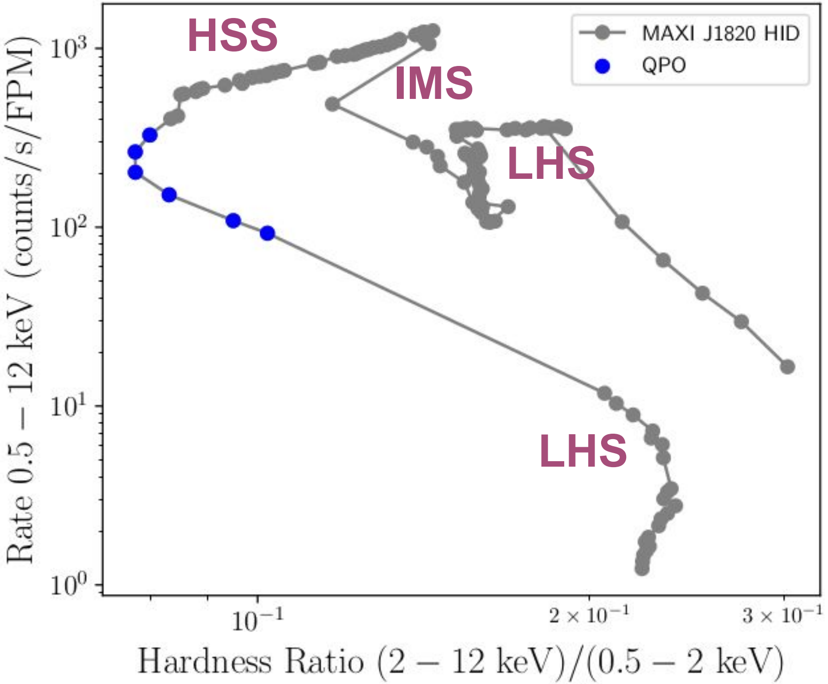


MAXI J1820+070: spectral states

light curve

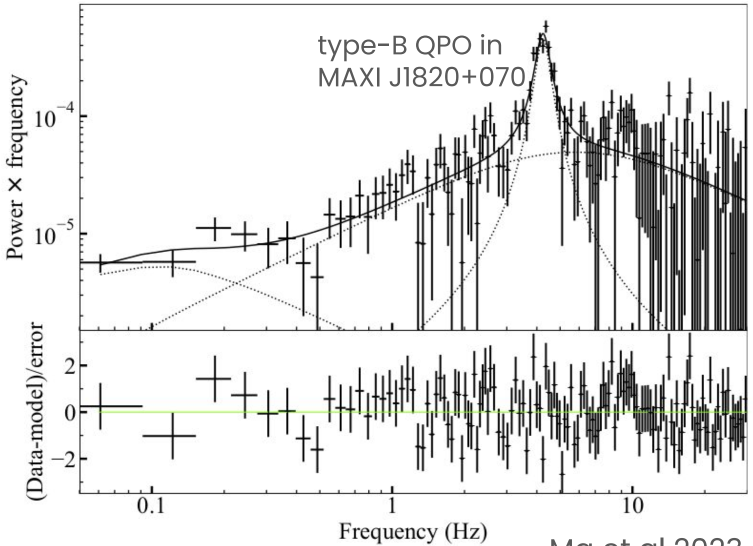


HID



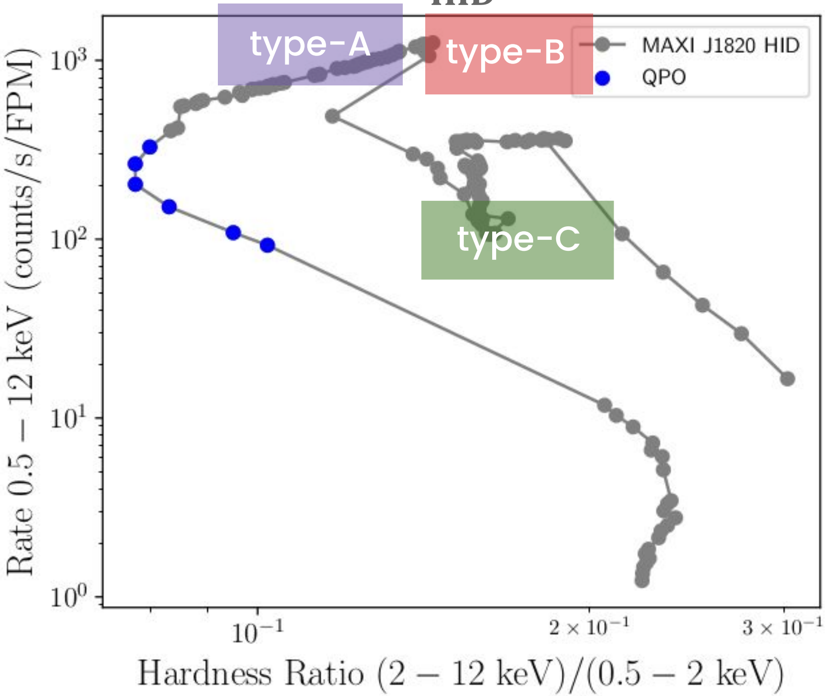
MAXI J1820+070: quasi-periodic oscillations

light curve

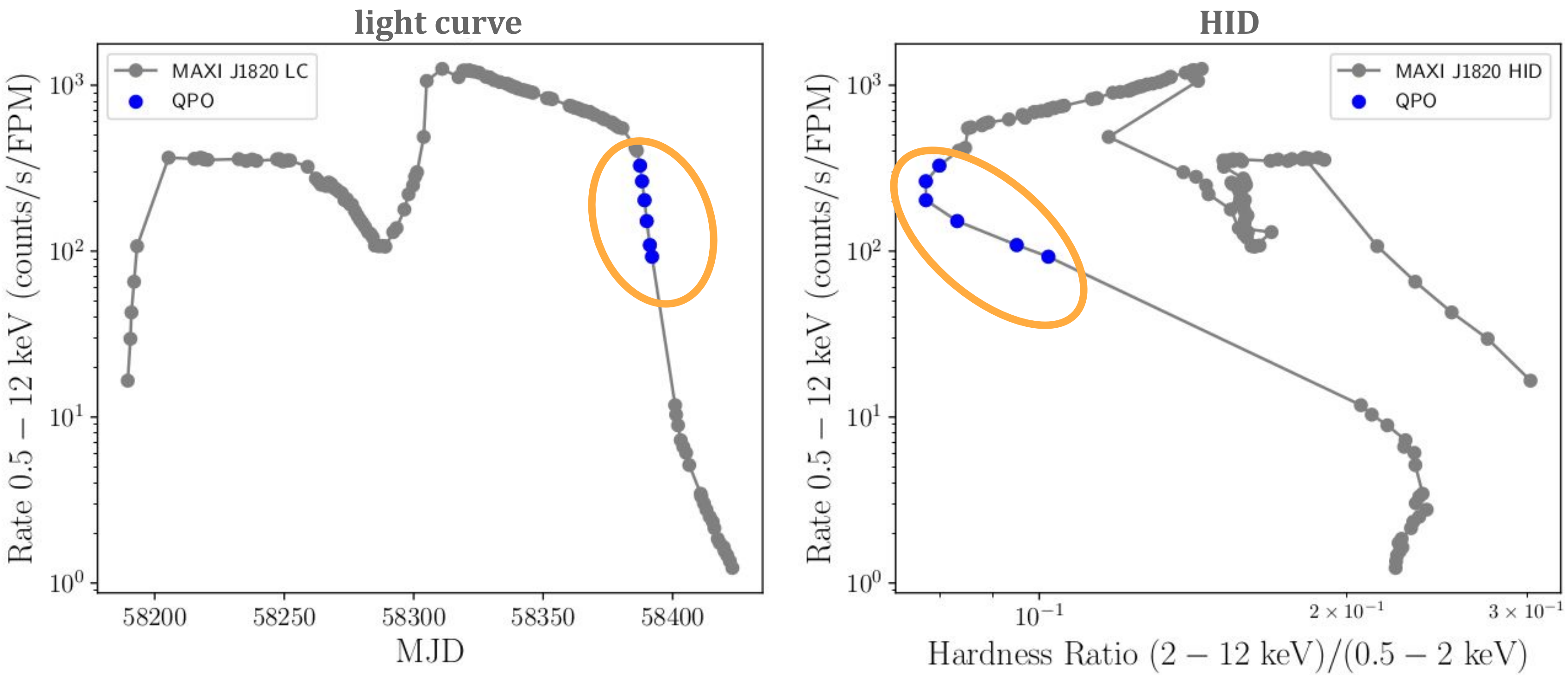


Ma et al 2023

HID



MAXI J1820+070: the soft-to-hard transition



Fourier timing analysis

$S(\nu); H(\nu)$ FFTs of soft and hard energy light curves

Phase lags

$\arg[< S^*(\nu)H(\nu) >]$ phase of the average cross spectrum

time lag = $\frac{\text{phase lags}}{2\pi\nu}$ measures the time delay between two signals

Coherence function

measures degree of linear correlation between two signals

$$\gamma^2(\nu) = \frac{|<S^*(\nu)H(\nu)>|^2}{|<S(\nu)>|^2 |<H(\nu)>|^2}$$

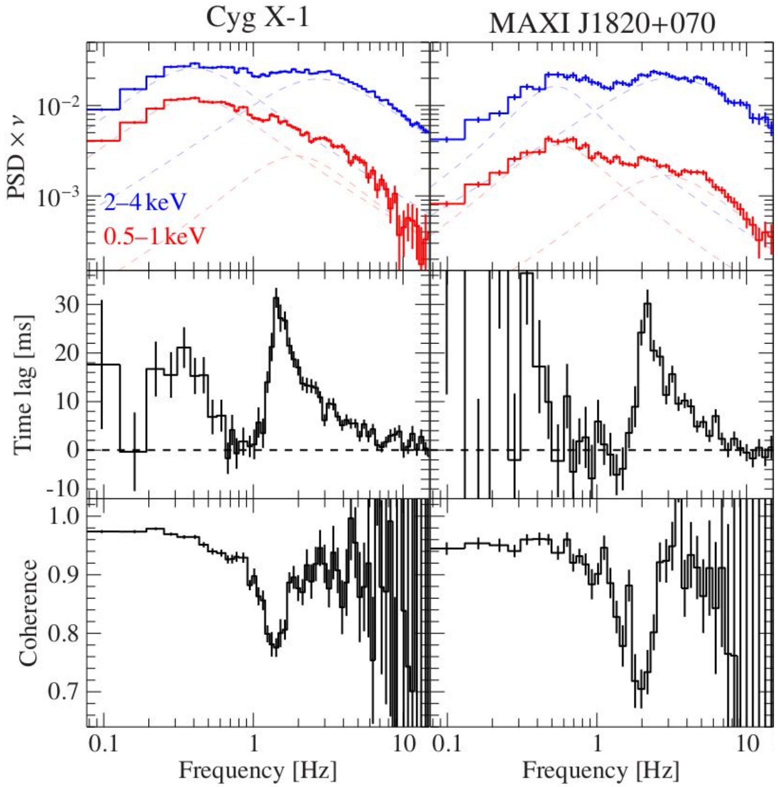
$S(\nu); H(\nu)$ related by linear transform → $\gamma^2(\nu) = 1$

$\gamma^2(\nu)$ drops if two components with different amplitudes and phases of their cross vectors contribute to the variability over the same frequency range

Vaughan & Nowak (1997)

Motivation of our work

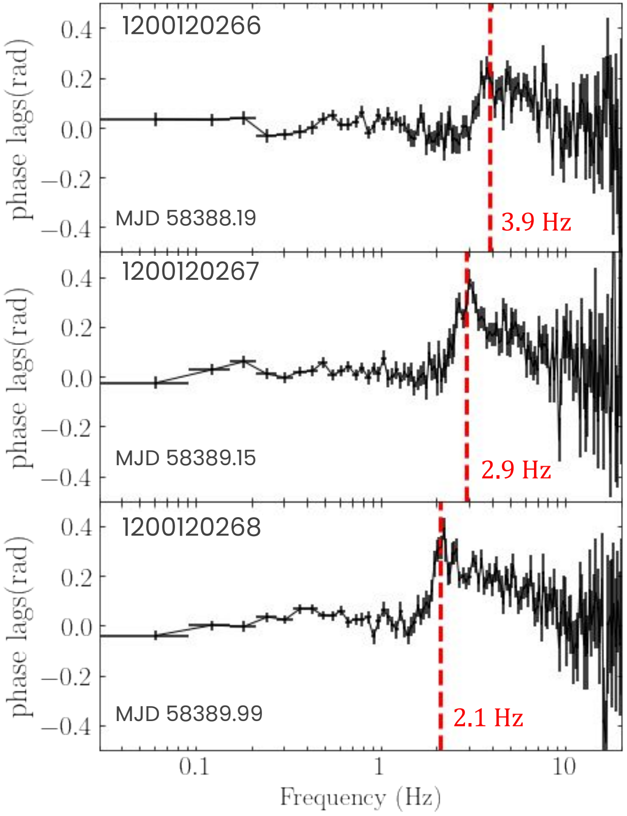
König et al 2024

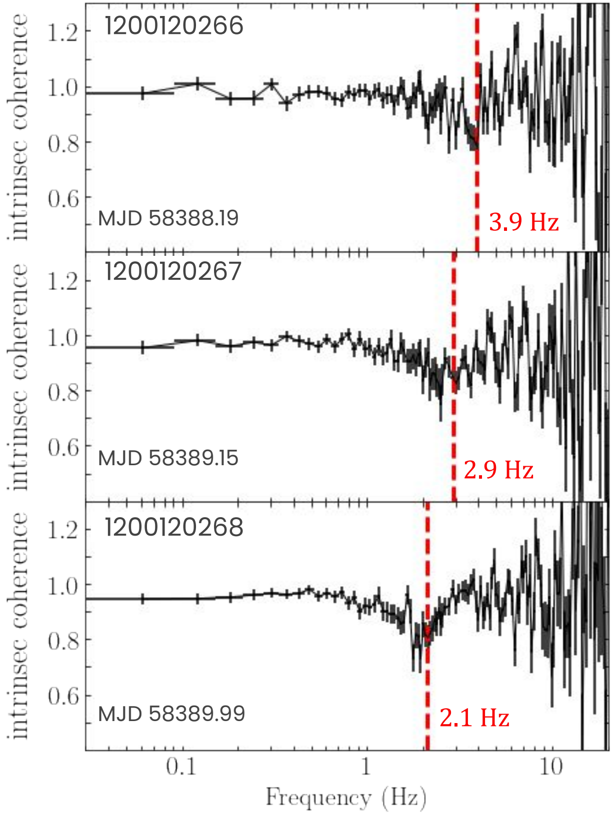


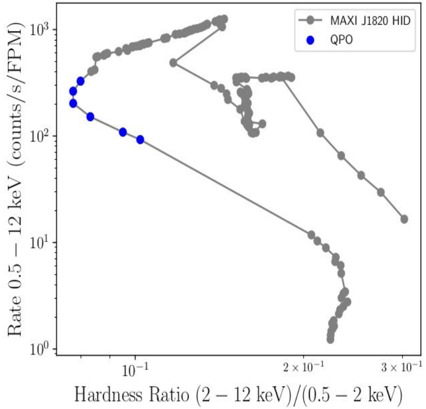
abrupt lag change
&
narrow drop in coherence

Phase lags & coherence function

soft: 0.3 - 2 keV
hard: 2 - 12 keV

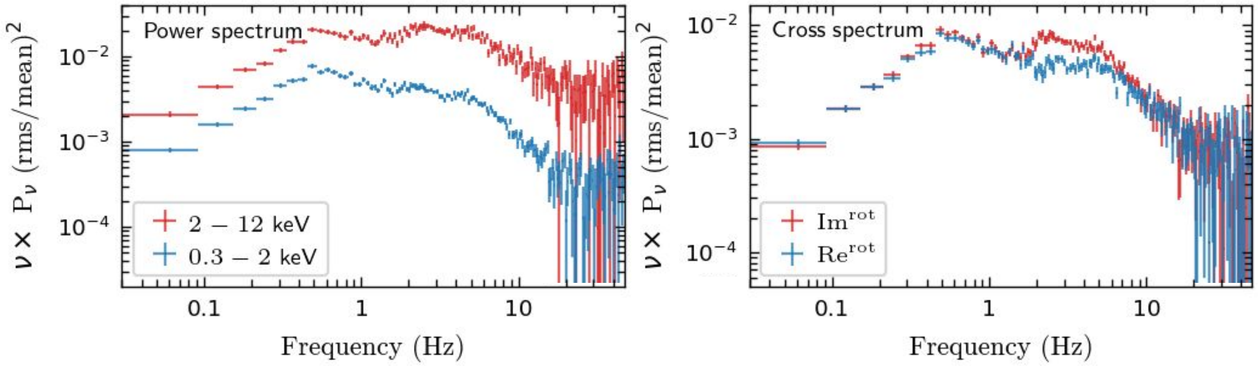






only seen when soft band is below 2 keV

FITTING THE PS & CS



We fit a **multi-Lorentzian model** (Mendez et al 2024)

same combination of Lorentzians
coherent in different energy bands but incoherent with each other

$$PS_{2-12} = \sum_{i=1}^{n} A_i L(\nu, \nu_{0,i}, \Delta_i)$$

$$Im[CS] = \sum_{i=1}^{n} \sqrt{A_i B_i} L(\nu, \nu_{0,i}, \Delta_i) sin(\Delta\phi_i)$$

$$PS_{0.3-2} = \sum_{i=1}^{n} B_i L(\nu, \nu_{0,i}, \Delta_i)$$

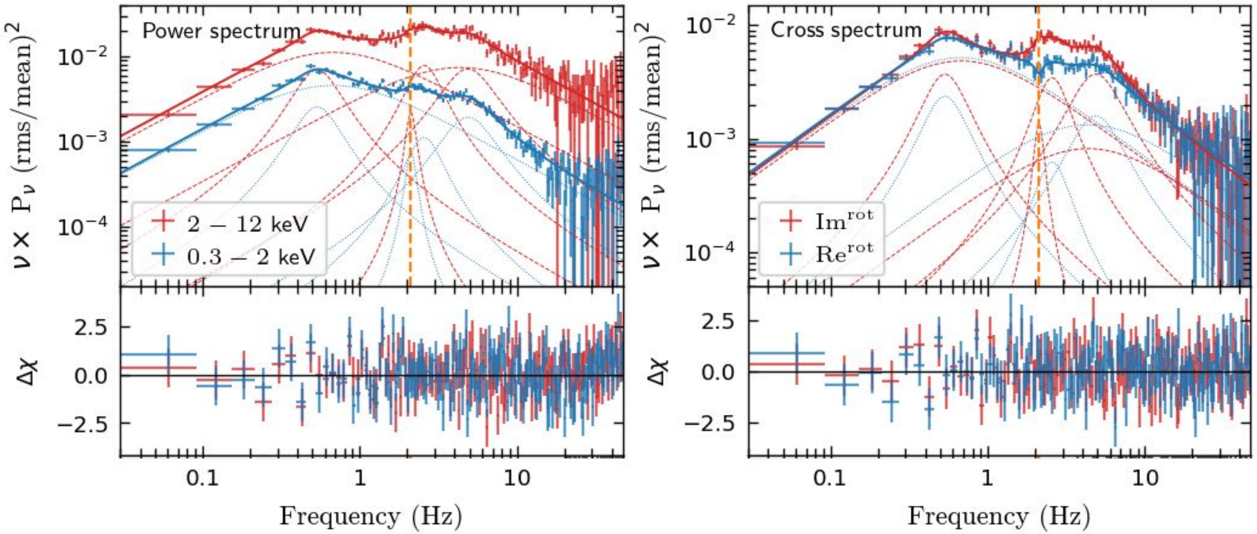
$$Re[CS] = \sum_{i=1}^{n} \sqrt{A_i B_i} L(\nu, \nu_{0,i}, \Delta_i) cos(\Delta\phi_i)$$

from the best-fitting model, we **derive** the model for the lags & coherence (Mendez et al 2024)

FITTING THE PS & CS

$\chi^2 \approx 582$ for 564 d.o.f

obsID 1200120268

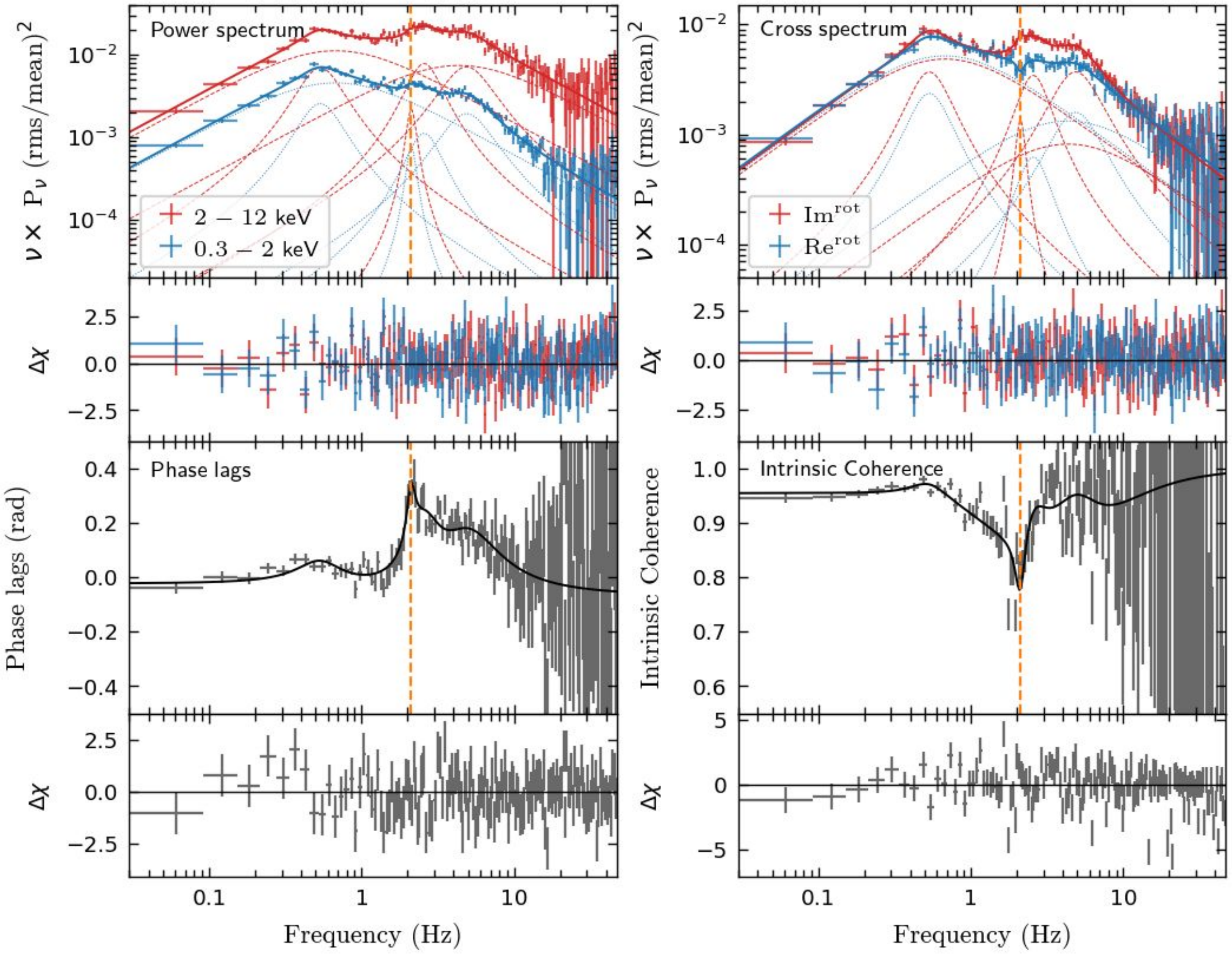


component significant only in the CS, not in the PS

small real part but large imaginary part → imaginary QPO

FITTING THE PS & CS

the imaginary QPO explains the narrow features



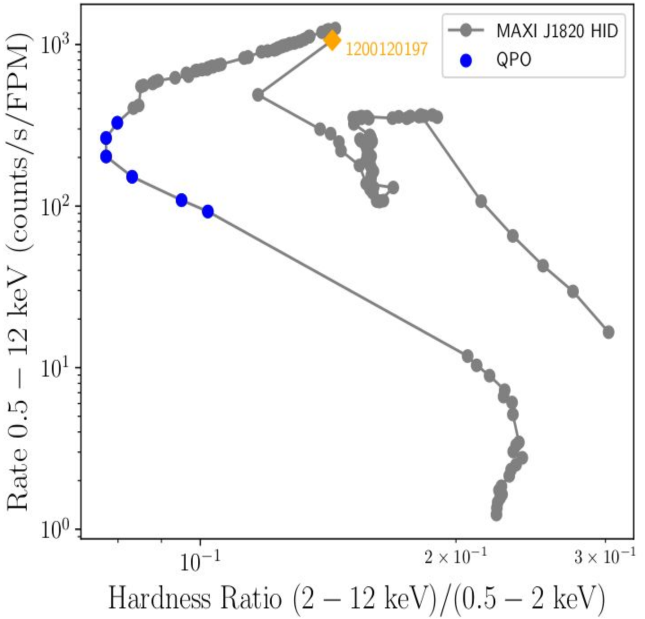
PROPERTIES OF THE IMAGINARY QPO

ΔT (days)*	$\nu_{\mathrm{QPO}}\,(\mathrm{Hz})$
0	6.1
0.8	6.7
1.1	3.7
1.7	2.9
2.6	2.1
3.8	1.5
4.6	1.2

* time since the first obsID considered

QPO	$\nu_{\mathrm{QPO}}\,(\mathrm{Hz})$	$Q = (\nu_{\mathrm{QPO}}/\mathrm{FWHM})$
imaginary	$\sim 1-7$	$\sim 2-14$
type B	$\sim 5-6$	$\gtrsim 6$
type C	$\sim 0.1-15$	$\sim 7-12$

Casella et al 2005;
Motta 2016

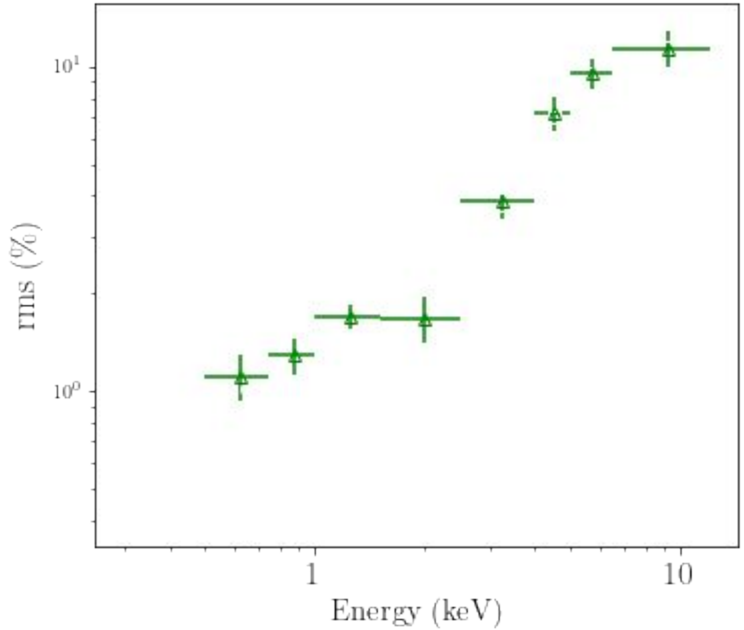


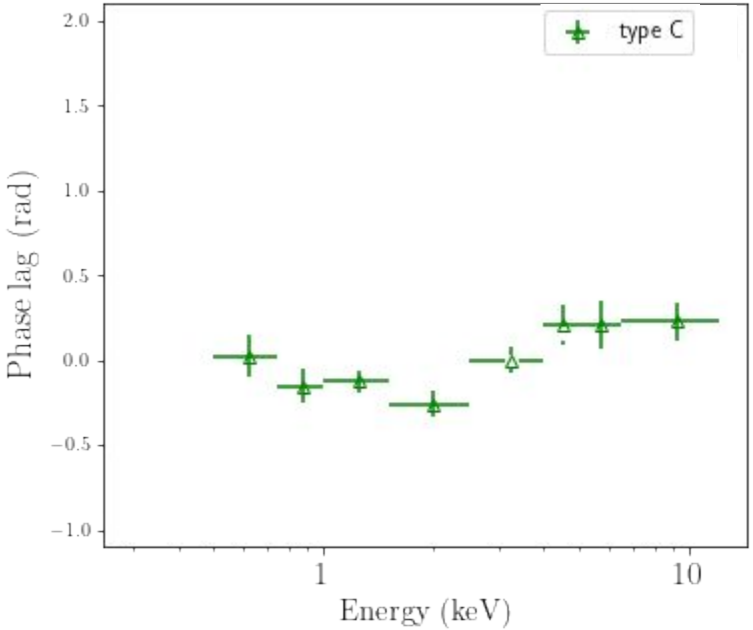
previous type C with *Q* between 0.2 & 7
(Alabarta et al 2022 ; Ma et al 2023)

rms & phase-lag spectra

type-C QPO in MAXI J1820+070
obsID 1200120197

$\nu_C = 4.4$ Hz

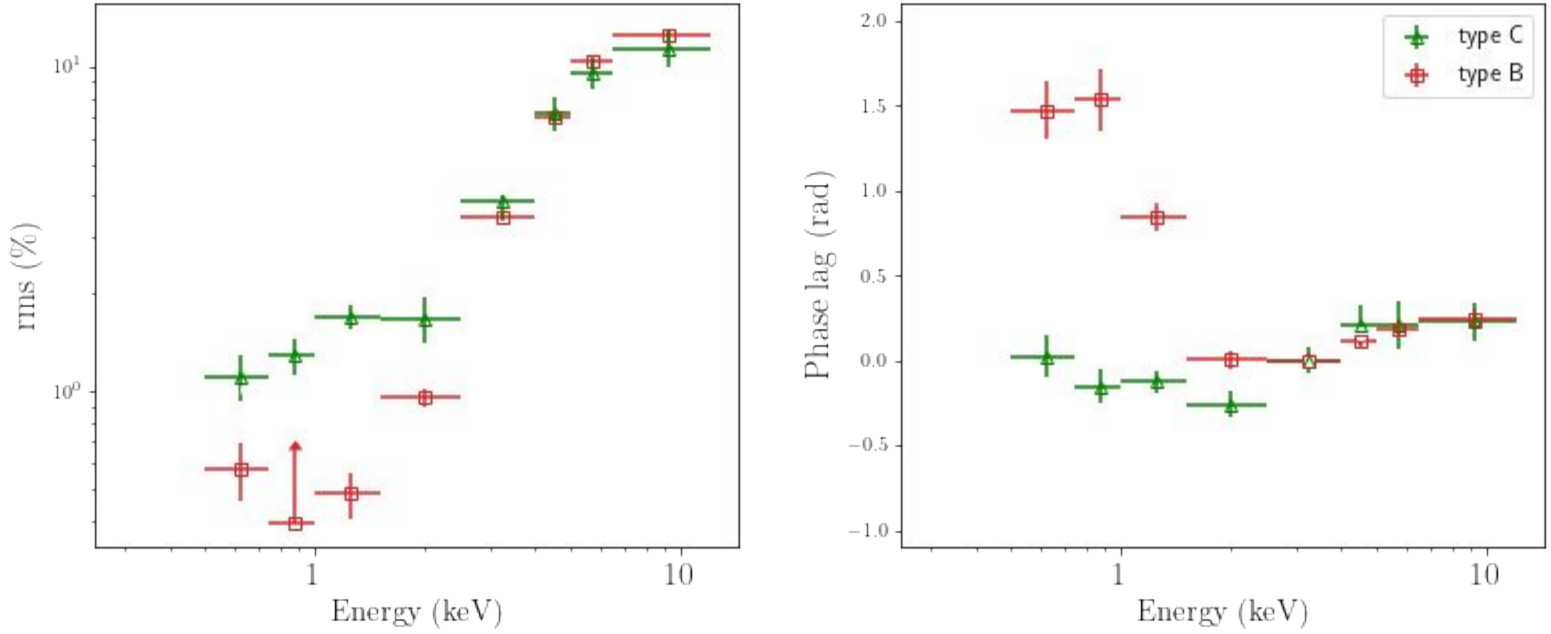




rms & phase-lag spectra

type-B QPO in MAXI J1820+070
obsID 1200120197

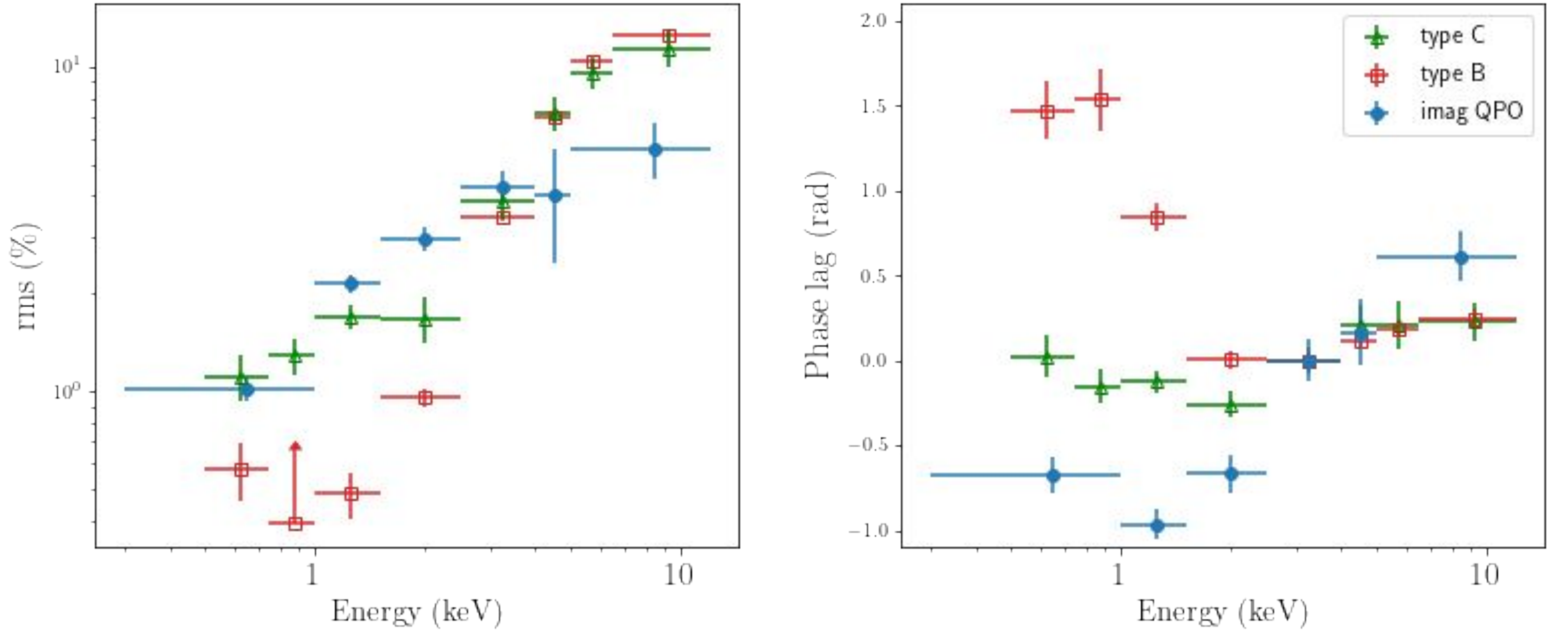
$\nu_C = 4.4$ Hz $\quad \nu_B = 4.0$ Hz



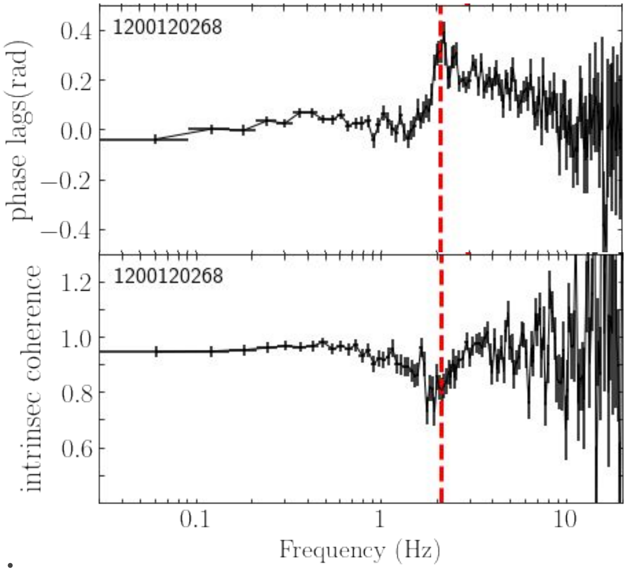
rms & phase-lag spectra

imag QPO in MAXI J1820+070
obsID 1200120266

$\nu_C = 4.4$ Hz $\nu_B = 4.0$ Hz $\nu_{\mathrm{imag}} = 3.8$ Hz



Conclusions



Discovery of **imaginary QPOs** along the soft-to-hard transition of **MAXI J1820+070**

Multi-Lorentzian model (Mendez et al 2024) fit explains the narrow drop of the coherence

Soft band needed ->component variable at low energies

Seen in the transition -> increase of inner disc radius or
reappearance of corona over disc (feedback)

Study of properties of imaginary QPO, new type of QPO?

Future work

Analysis of sources during the decay considering soft X-ray data -> NICER data

Appendix

BEST-FITTING VALUES OF THE IMAGINARY QPO

obsID	ν_{QPO} (Hz)	FWHM (Hz)	$Q = (\nu_0/\mathrm{FWHM})$	$\mathrm{rms}^{a}_{QPO}(\%)$	$\mathrm{rms}^{b}_{0.1-50\ \mathrm{Hz}}(\%)$
1200120265	6.10 ± 0.08	2.9 ± 0.3	2.1 ± 0.2	7.9 ± 0.4	18.6 ± 0.2
1200120266_p1	6.67 ± 0.09	1.2 ± 0.3	5.5 ± 1.2	4.2 ± 0.7	20.0 ± 0.2
1200120266_p2	3.75 ± 0.03	0.6 ± 0.1	6.6 ± 1.4	3.9 ± 0.8	24.4 ± 0.2
1200120267	2.96 ± 0.05	0.7 ± 0.2	4.1 ± 1.2	3.4 ± 1.1	26.5 ± 0.2
1200120268	2.11 ± 0.03	0.3 ± 0.1	6.1 ± 2.5	2.4 ± 0.8	27.4 ± 0.2
1200120269	1.55 ± 0.04	0.5 ± 0.1	3.2 ± 0.8	2.3 ± 2.0	27.0 ± 0.8
1200120270	1.26 ± 0.02	0.09 ± 0.03	14.6 ± 5.0	4.4 ± 1.1	26.7 ± 0.3
Type B	$\sim 5 - 6$		$\gtrsim 6$		
Type C	$\sim 0.1 - 15$		$\sim 7 - 12$		

[a] The rms amplitude of the QPO in the 2.0 – 12.0 keV band.
[b] The rms amplitude of the broadband in the 0.3 – 12.0 keV band.

previous type C with *Q* between 0.2 & 7 (Alabarta et al 2022 ; Ma et al 2023)

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Need of narrow component