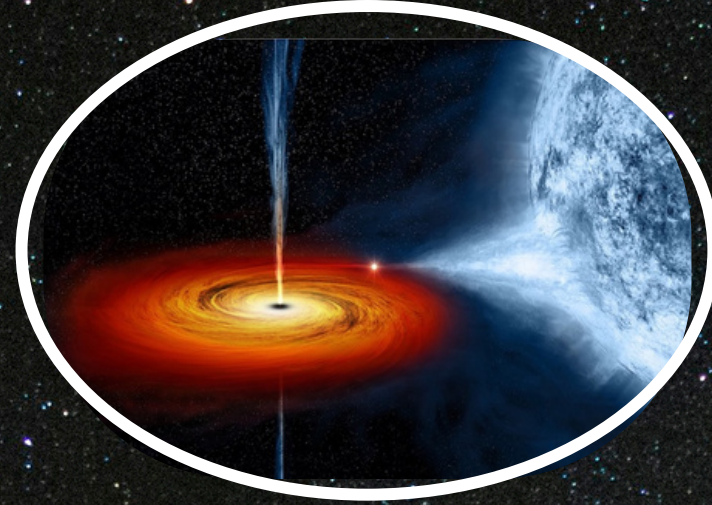




Flip-Flops and QPO Switching in GX 339–4 During the 2021 and 2024 NICER Outbursts

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Universitat Politècnica de Catalunya

In collaboration with
Barbara De Marco, Stefano Bianchi

The many tones of accretion 08/09/26



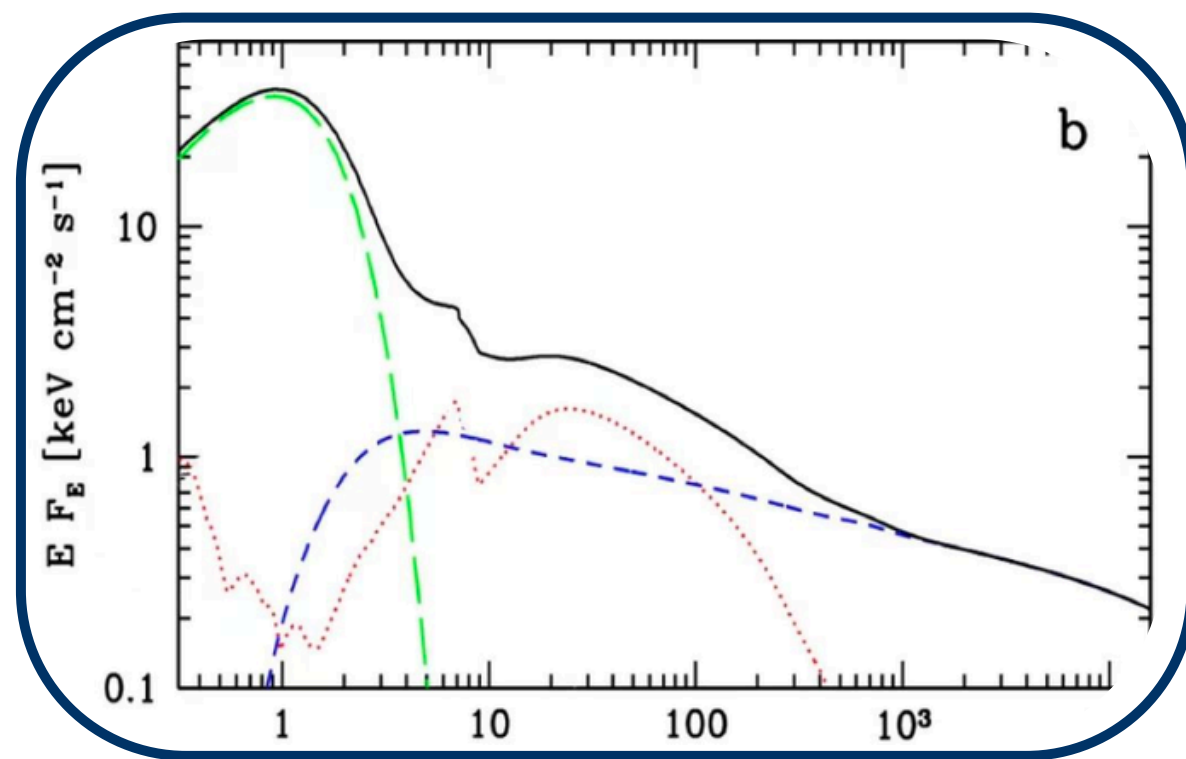
Roma Tre



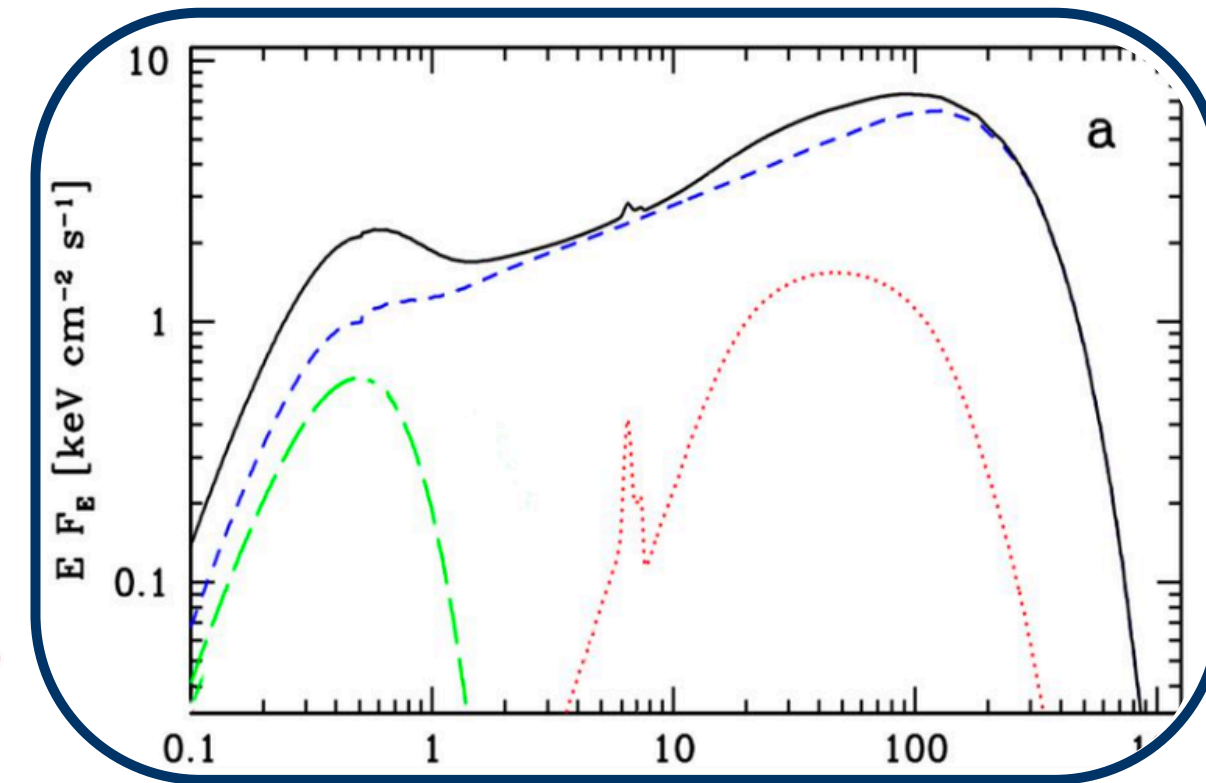
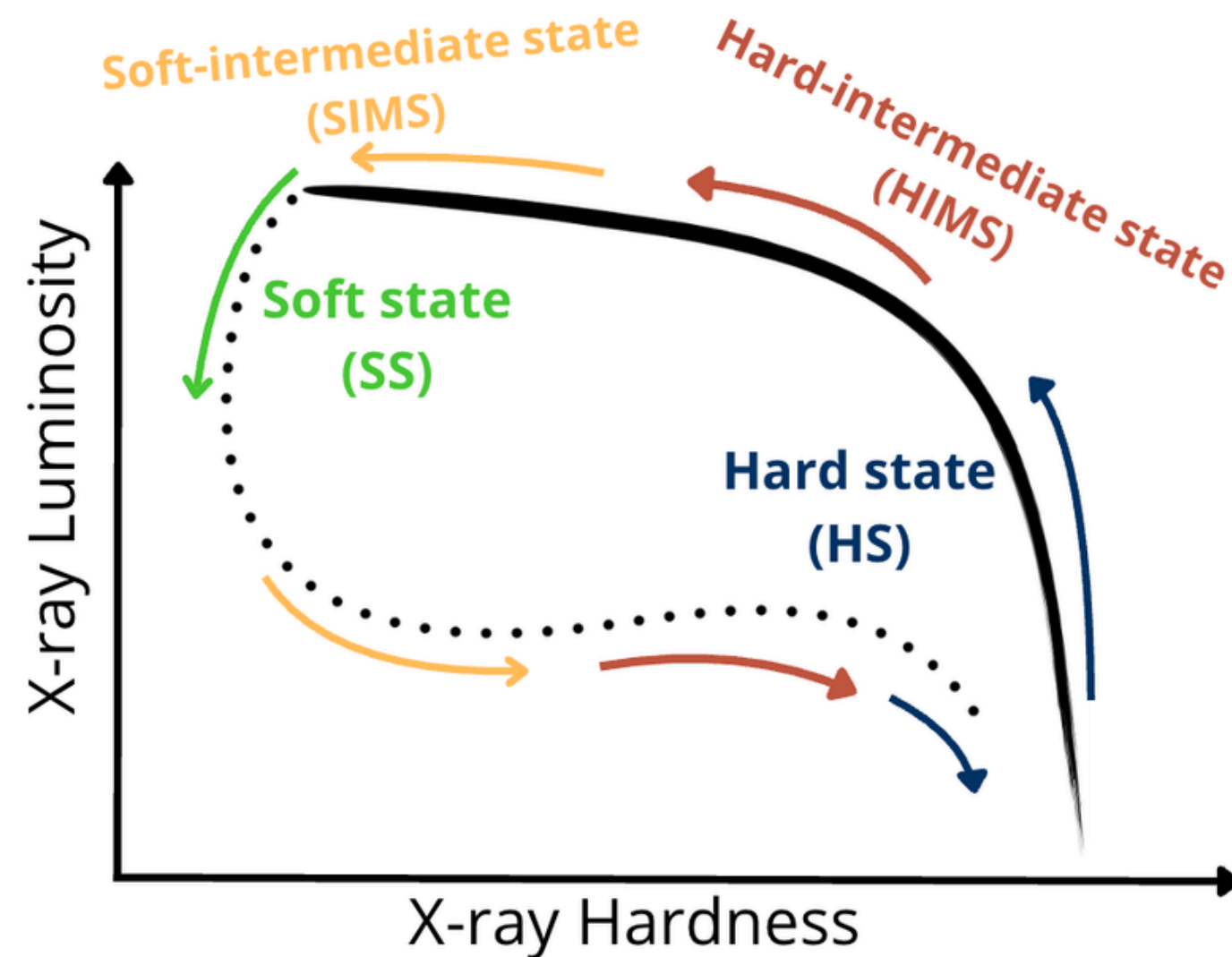
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

Outburst evolution on the HID

- GX 339-4 is a transient source: it alternates long quiescence phases to short 'outbursts'
- The spectral and timing properties of the source evolve, leading the system through different spectral-timing states



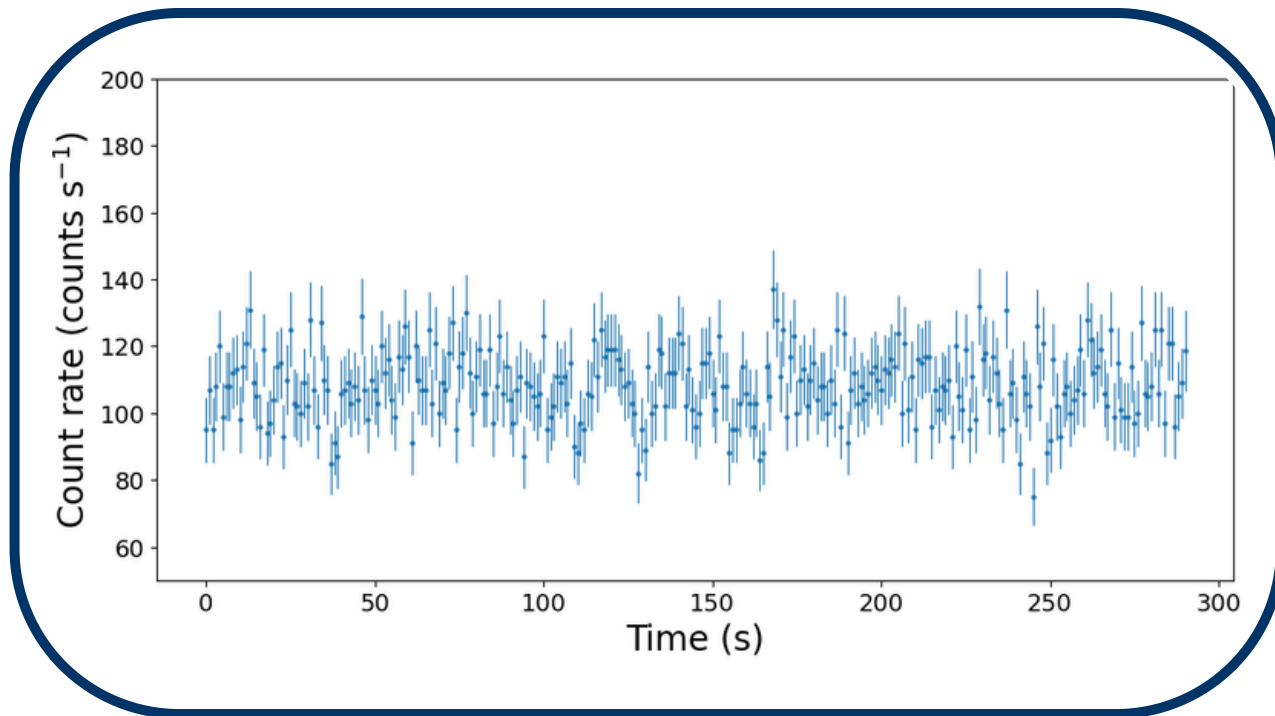
Soft state



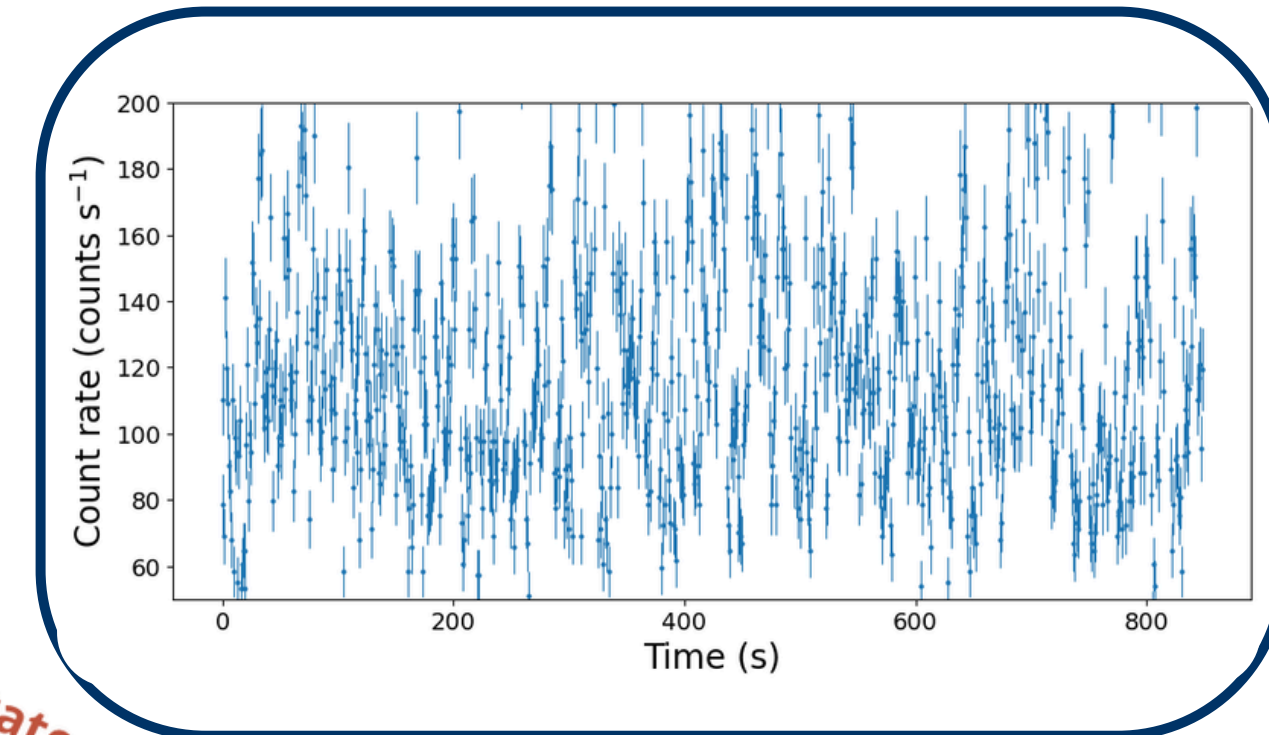
Hard state

Outburst evolution on the HID

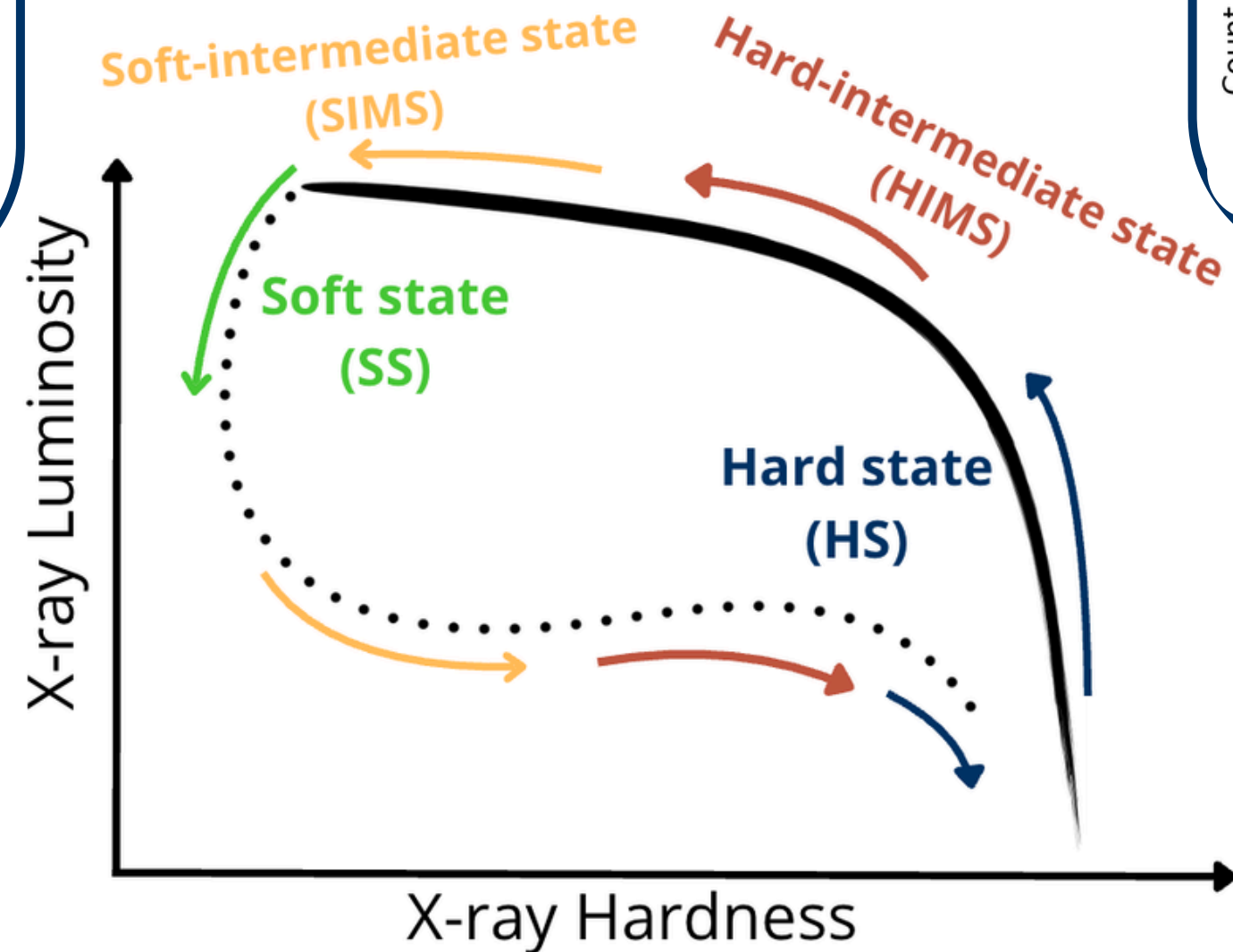
- GX 339-4 is a transient source: it alternates long quiescence phases to short 'outbursts'
- The spectral and timing properties of the source evolve, leading the system through different spectral-timing states



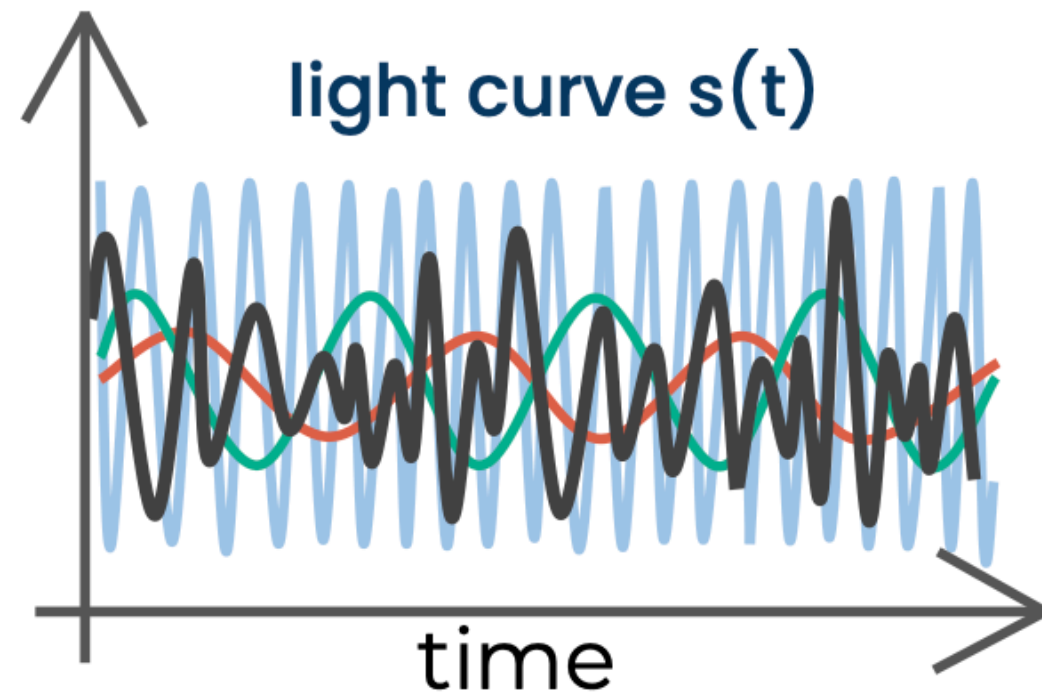
Soft state
few percent or zero RMS



Hard state
~ 40% RMS

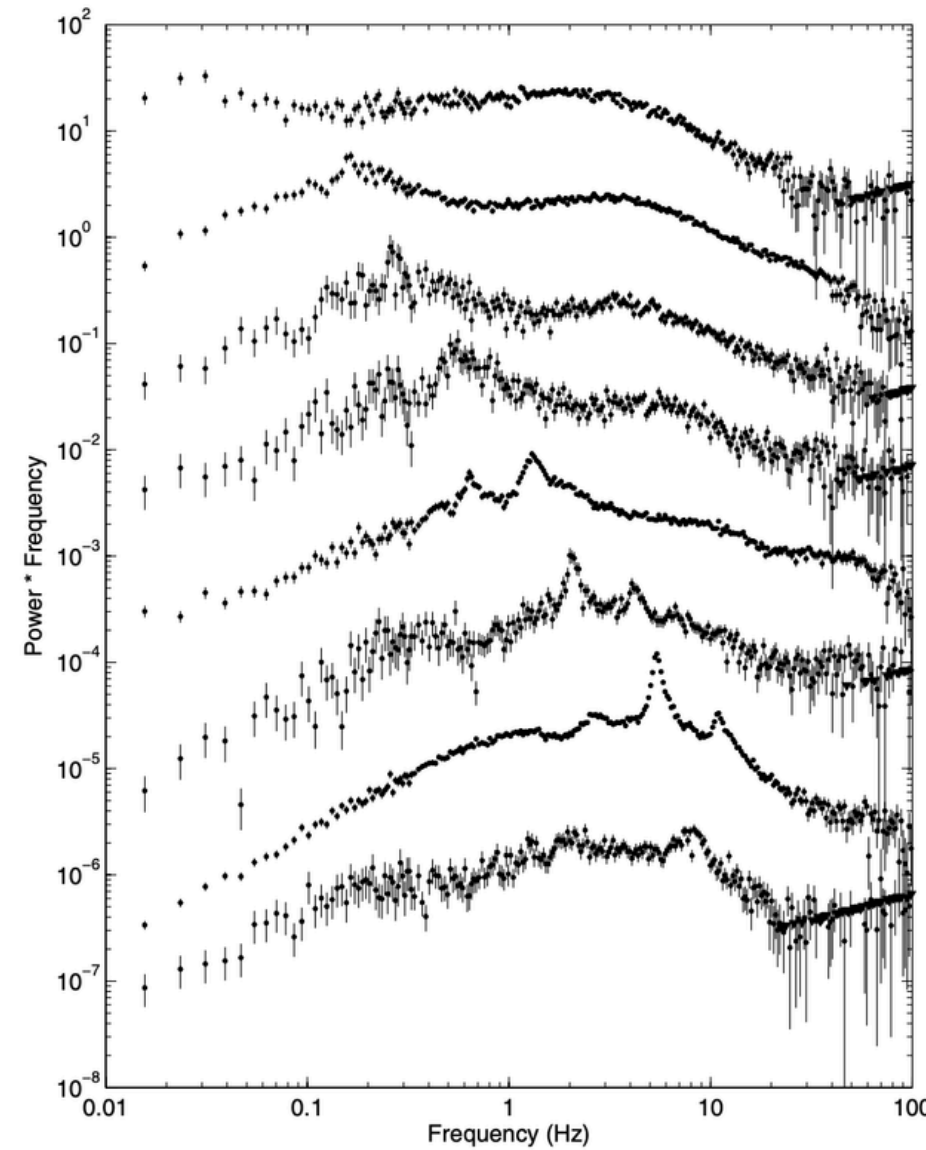


Evolution of timing characteristics



Credits: Valentina Peirano

Fourier



Belloni et al. 2005

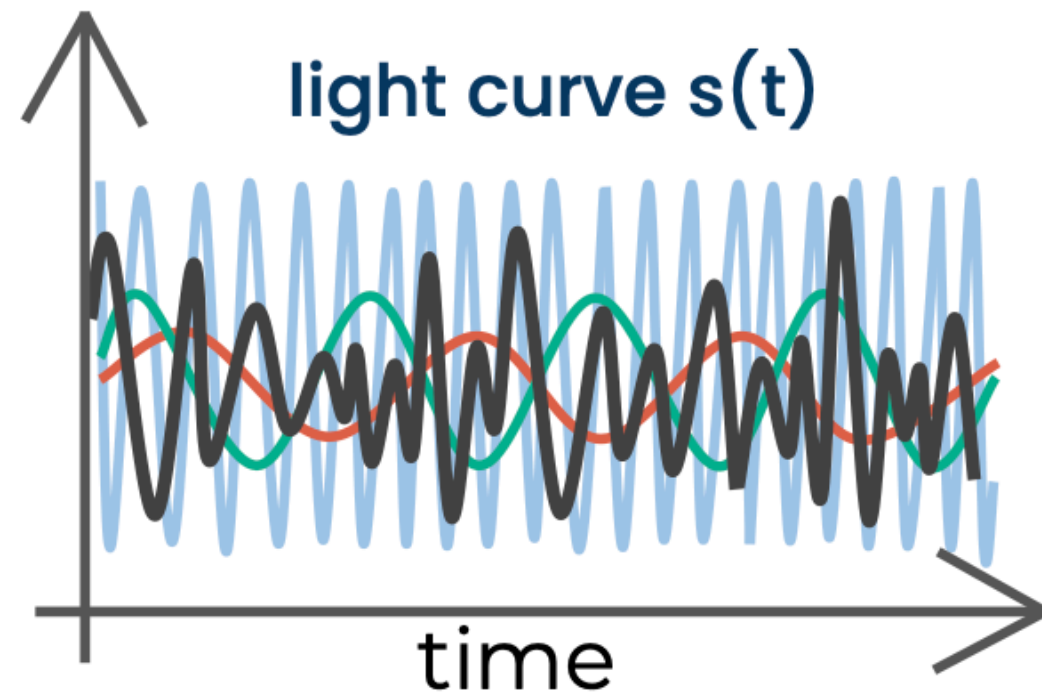
Hard State



Soft State

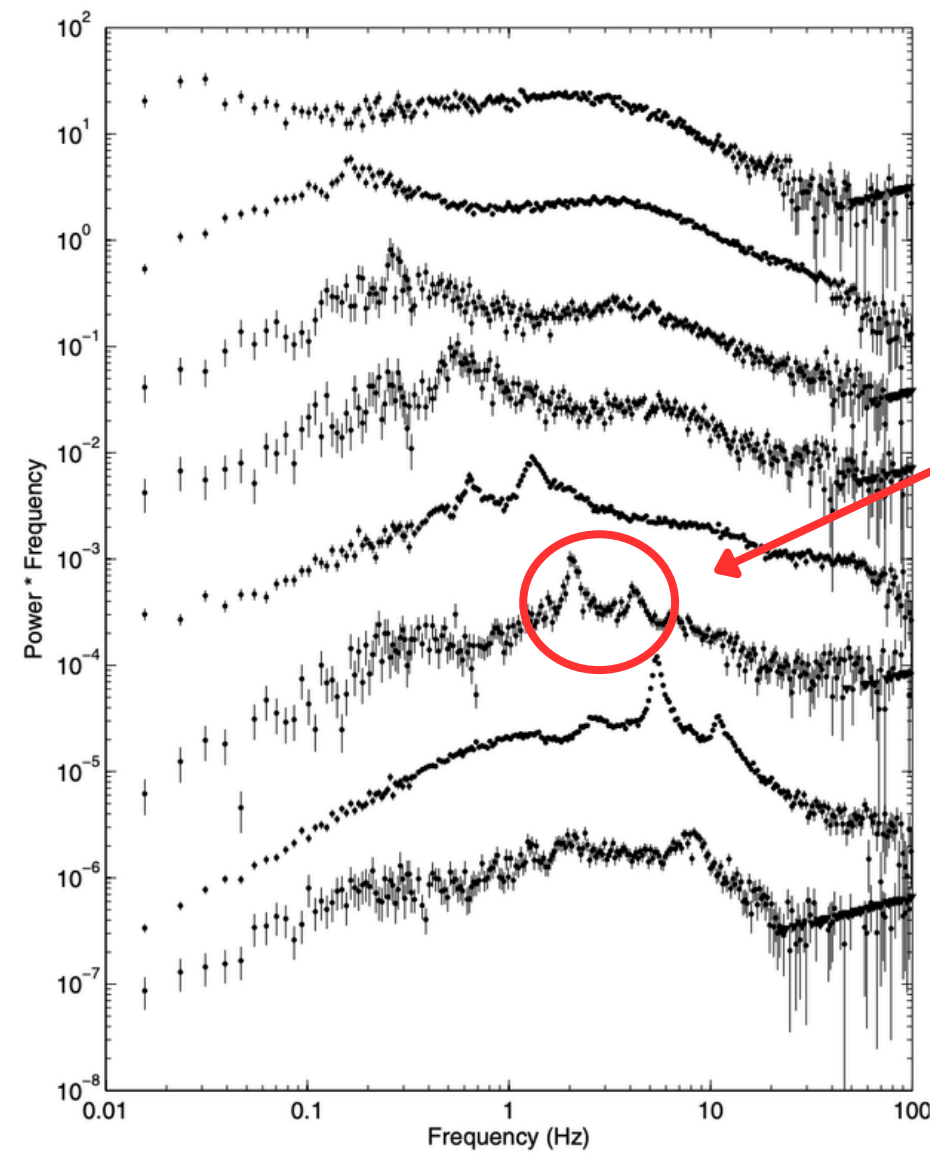
- **Power spectrum** $P(\nu) = A|X(\nu)|^2$

Evolution of timing characteristics



Credits: Valentina Peirano

Fourier



Belloni et al. 2005

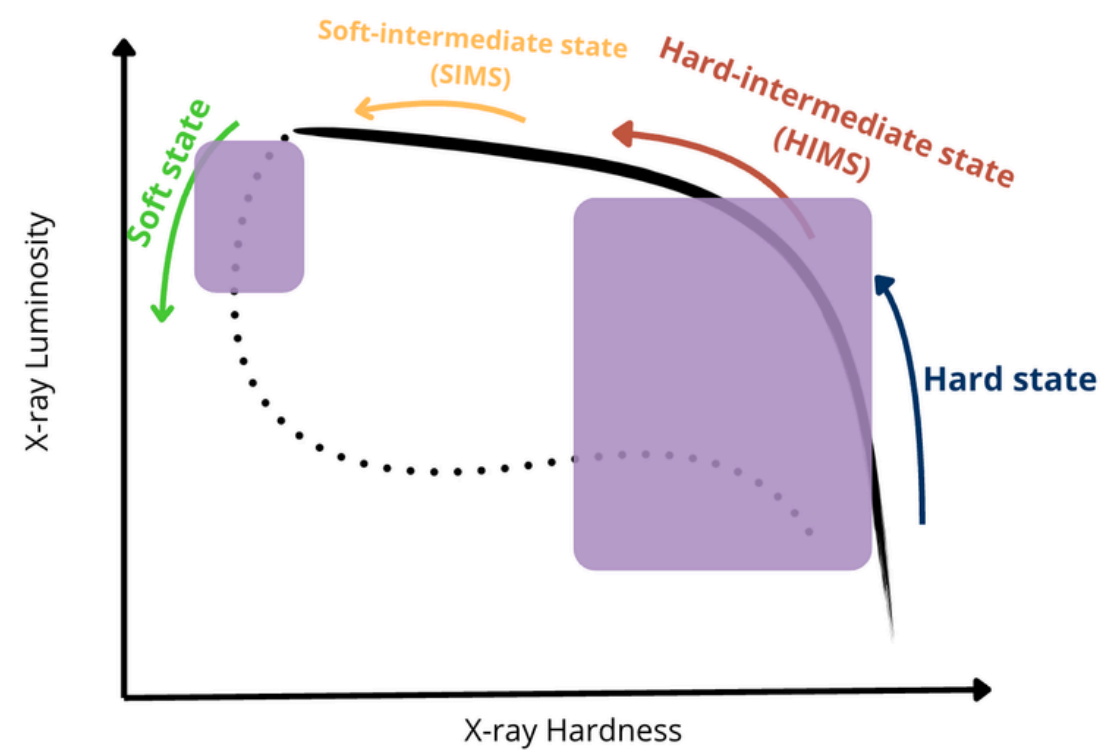
Hard State

QPO

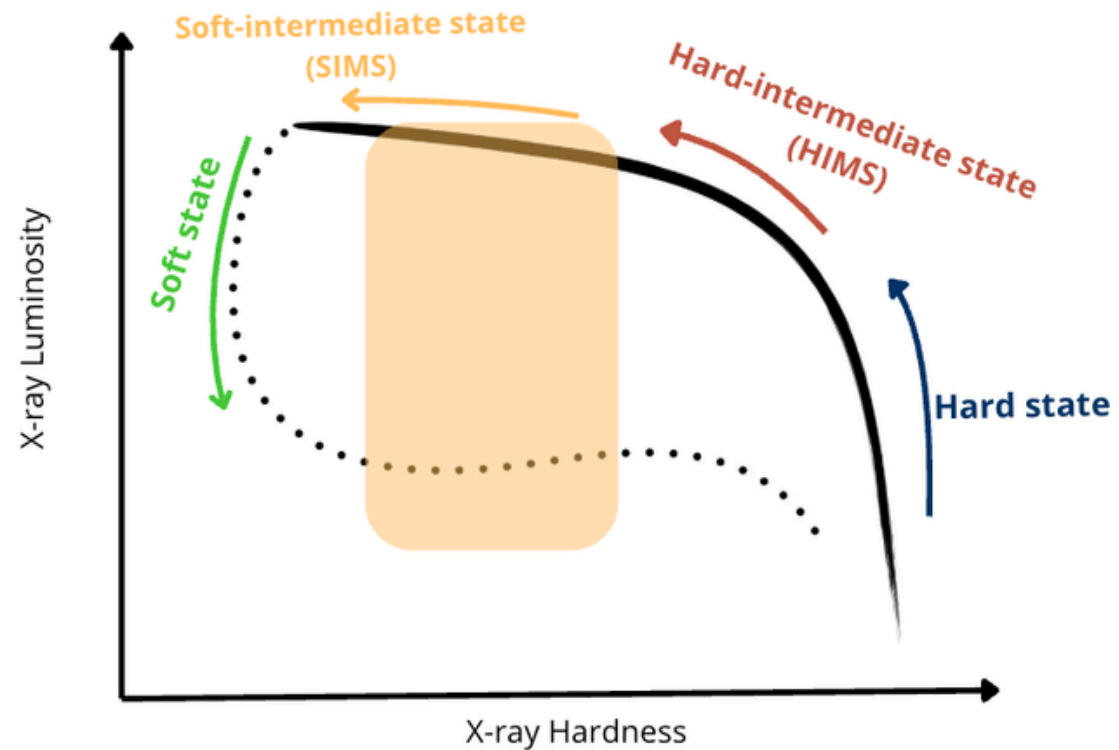
Soft State

- Power spectrum $P(\nu) = A|X(\nu)|^2$

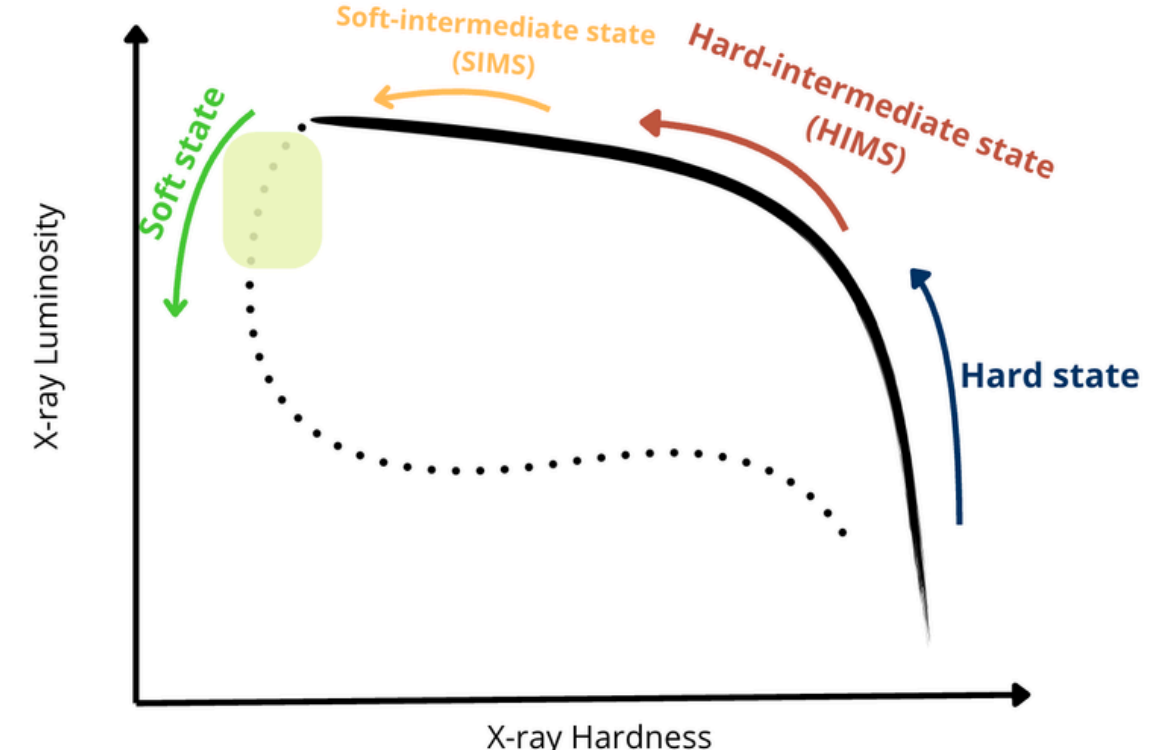
Low-frequency QPOs



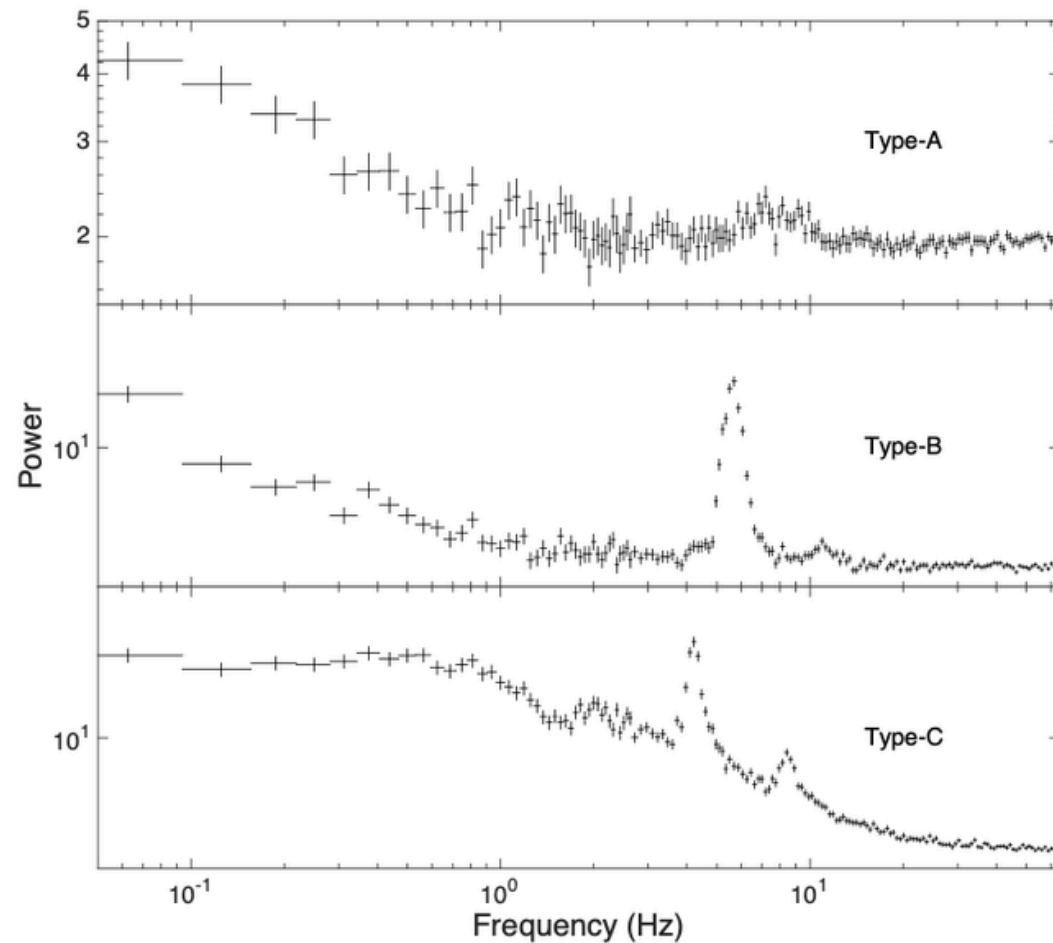
Type-C QPOs



Type-B QPOs



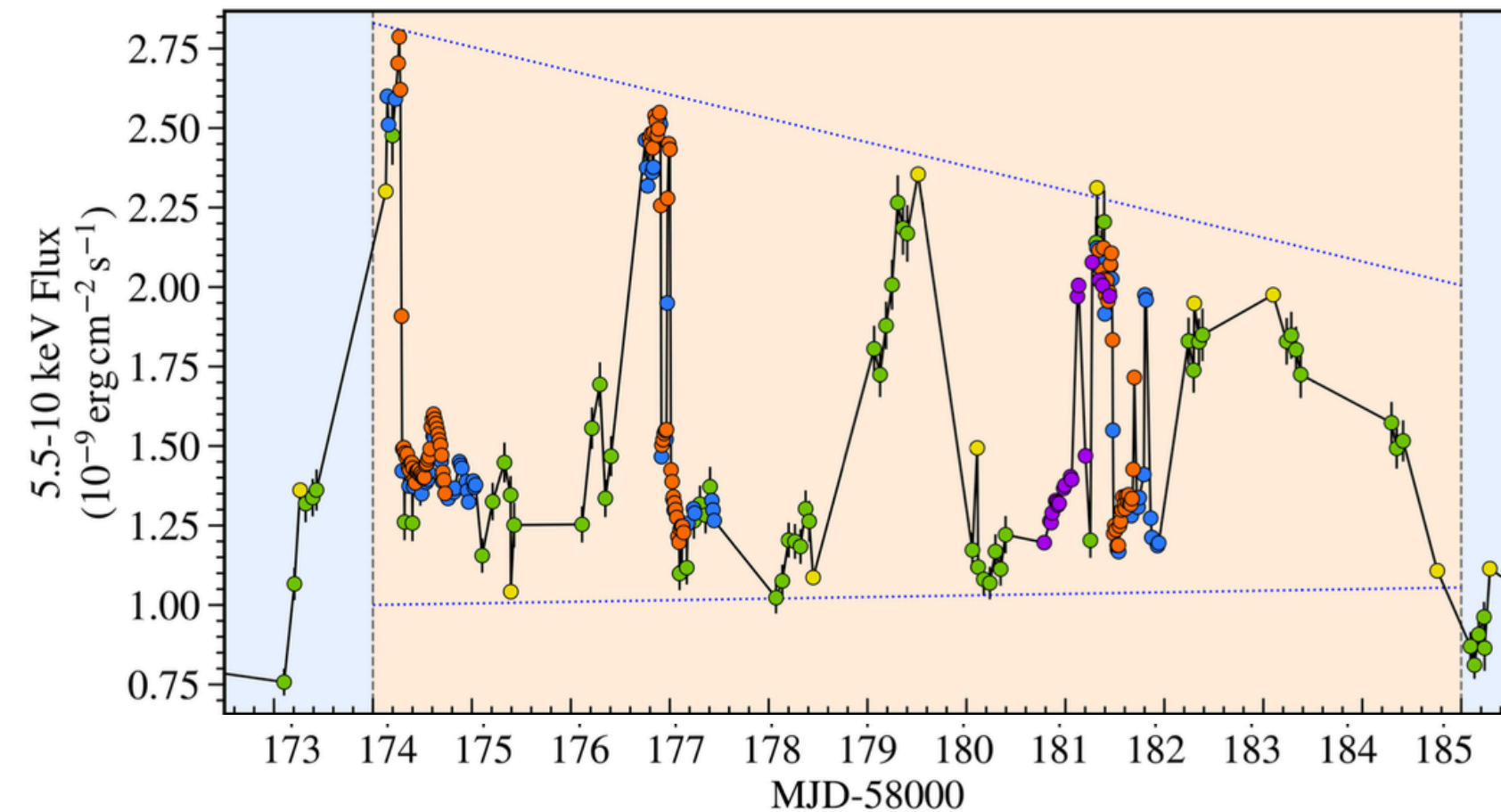
Type-A QPOs



- Type A: rare
- Type B: observed during transitions
- Type C: most common and best studied

What we know about Flip-Flops

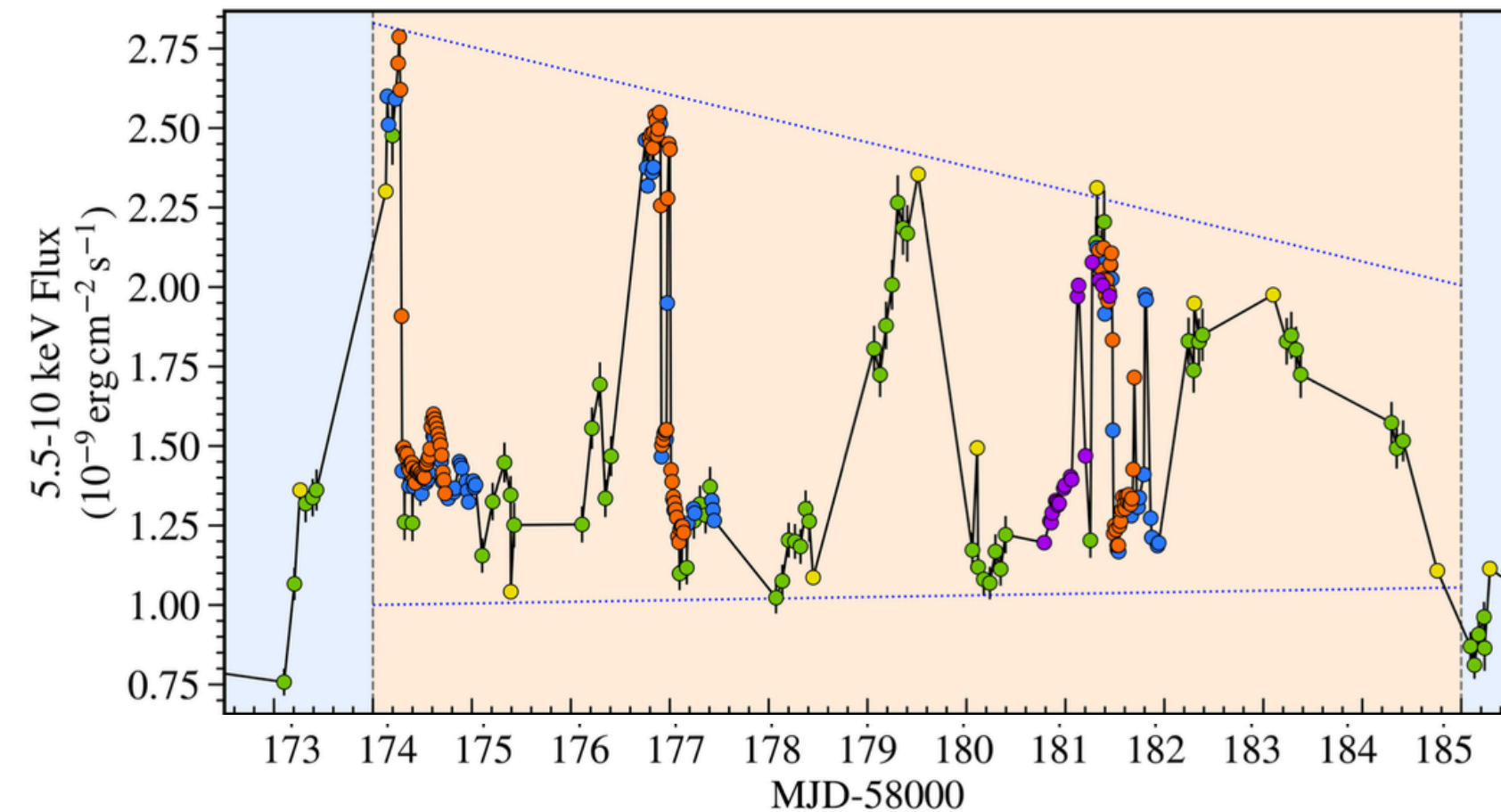
- Have rarely been observed so far and they are considered to be associated with some state transition
- The flux can change up to 77% (Bogensberger et al. 2020)
- The variability pattern of the source can also change:
 - different type of QPO (e.g. Casella et al. 2004; Bogensberger et al. 2020)
 - appearance/disappearance of a QPO (e.g. Yang et al. 2023, Buisson et al. 2025).



Bogensberger et al. (2020)

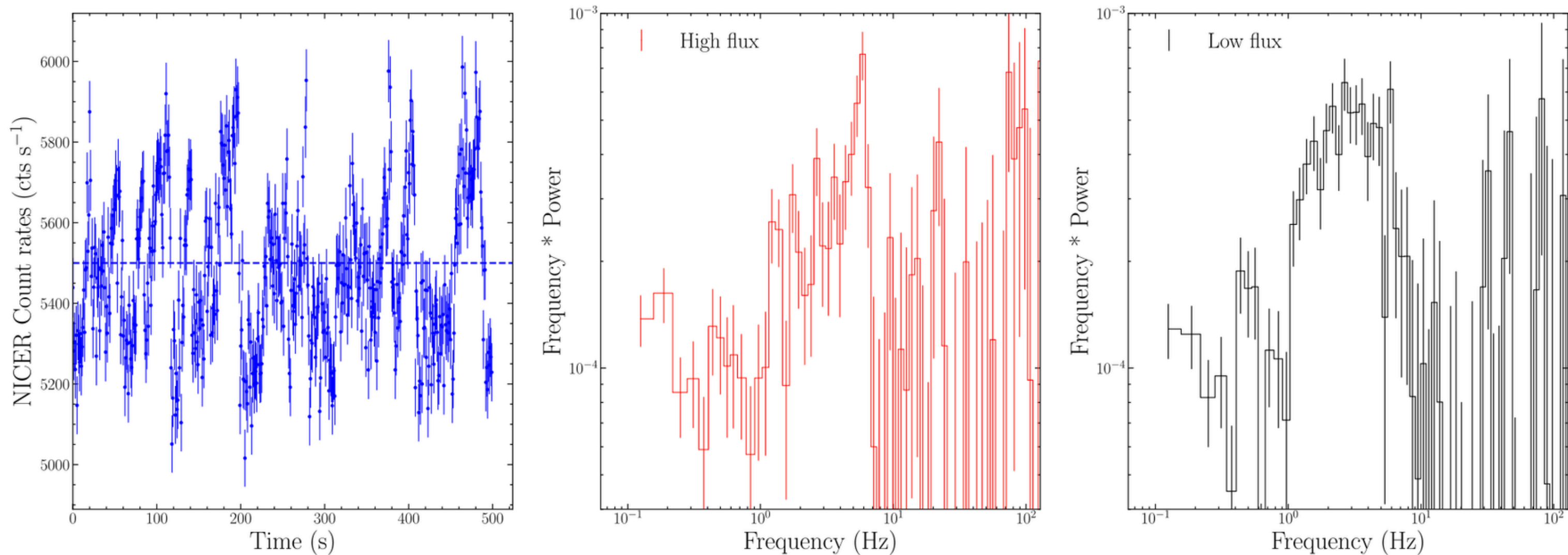
What we know about Flip-Flops

- Redistribution of accretion power between disc and corona (Zhang et al. 2021)
- Rapid changes in the intrinsic coronal power, without significant changes in disc-corona geometry (Liu et al. 2022)
- Possible sonic transition in the hot flow controlling the Type-B QPO (Buisson et al. 2025)



Bogensberger et al. (2020)

Goal of the analysis

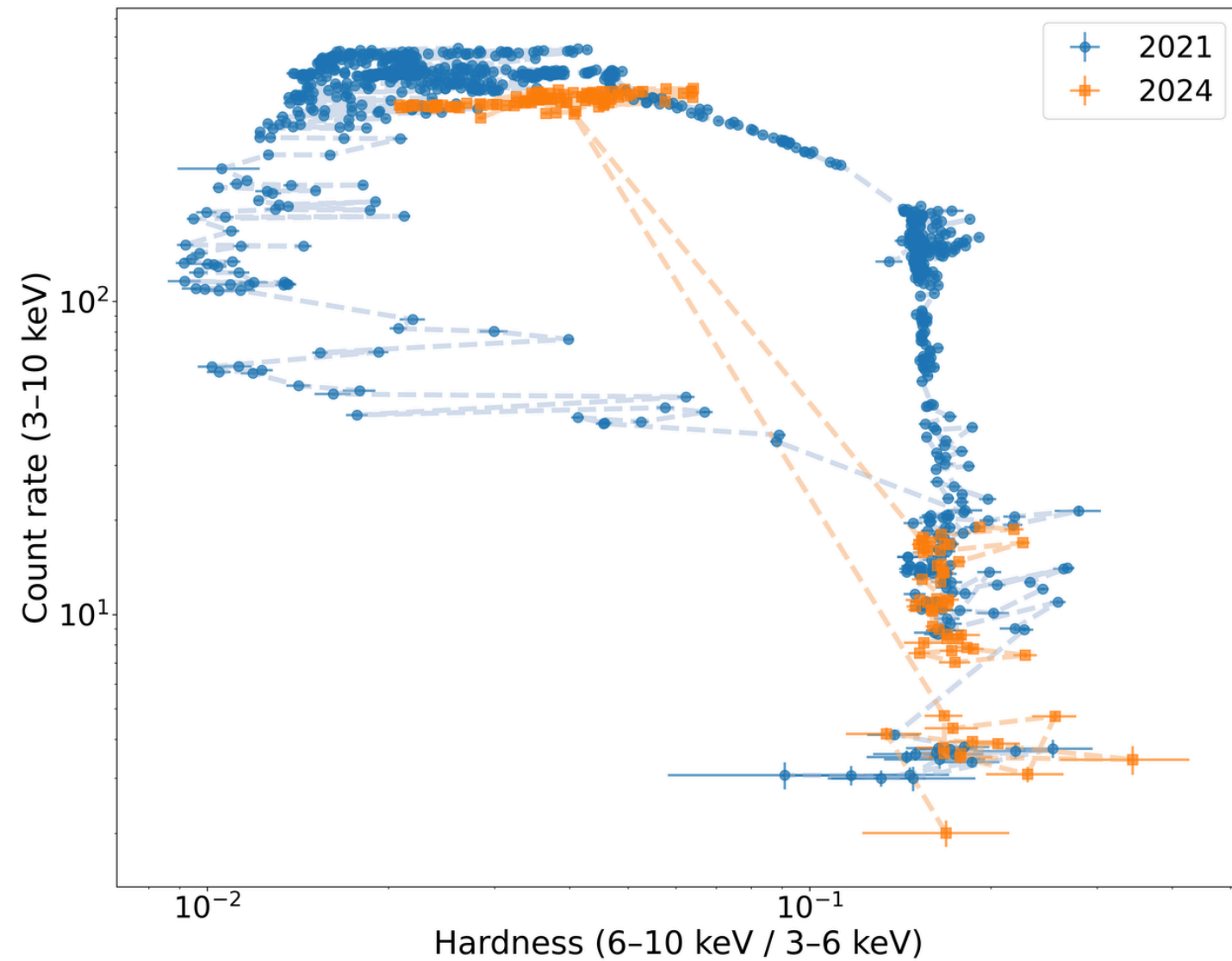


Yang et al. 2023

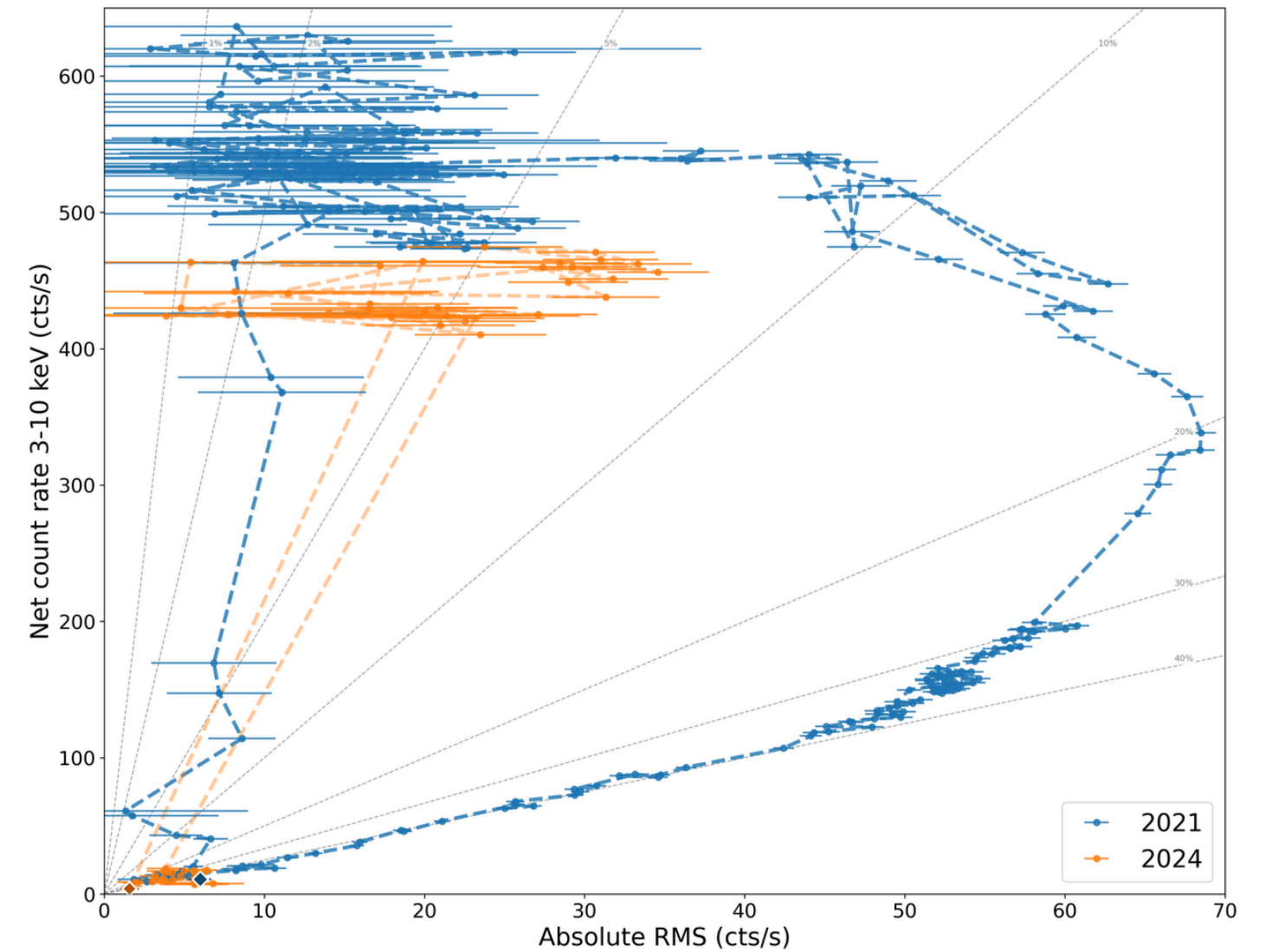
- Usual approach: the light curve is split into high-flux and low-flux intervals, an average PSD is extracted for the bright and the dim states
- Goal: perform a statistically robust, time-resolved study of changes in the PSD during flip-flops, constrain characteristic timescales for these changes

GX 339-4: HID and RMS-Intensity Diagram

HID: 2021 vs 2024 NICER Outbursts



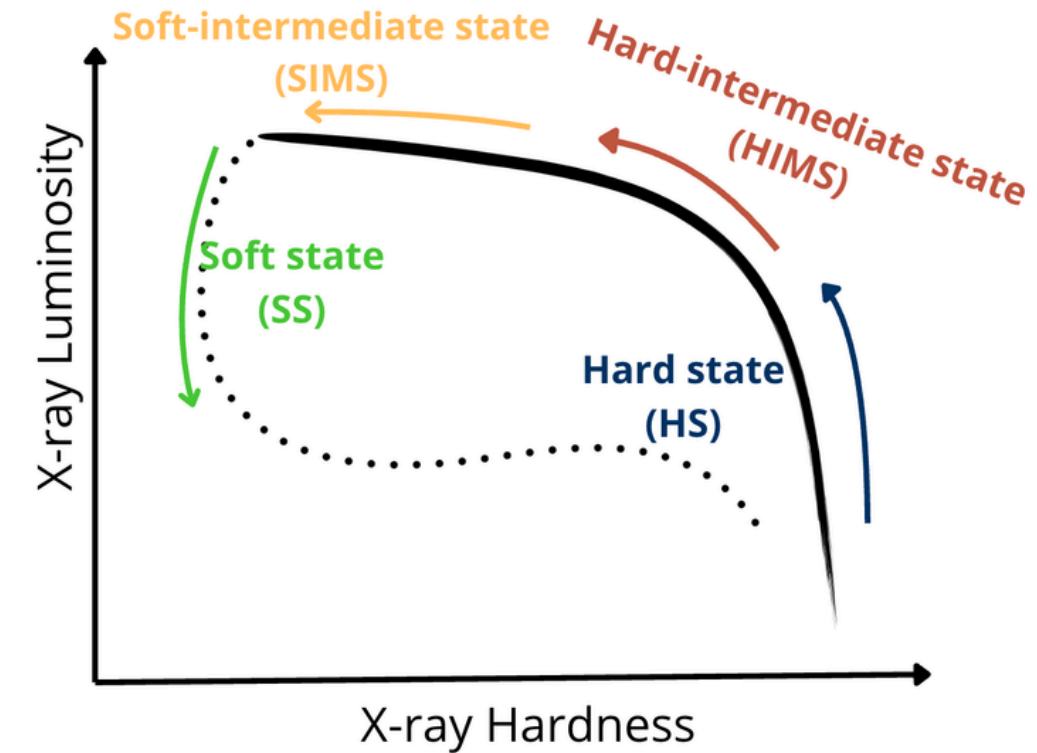
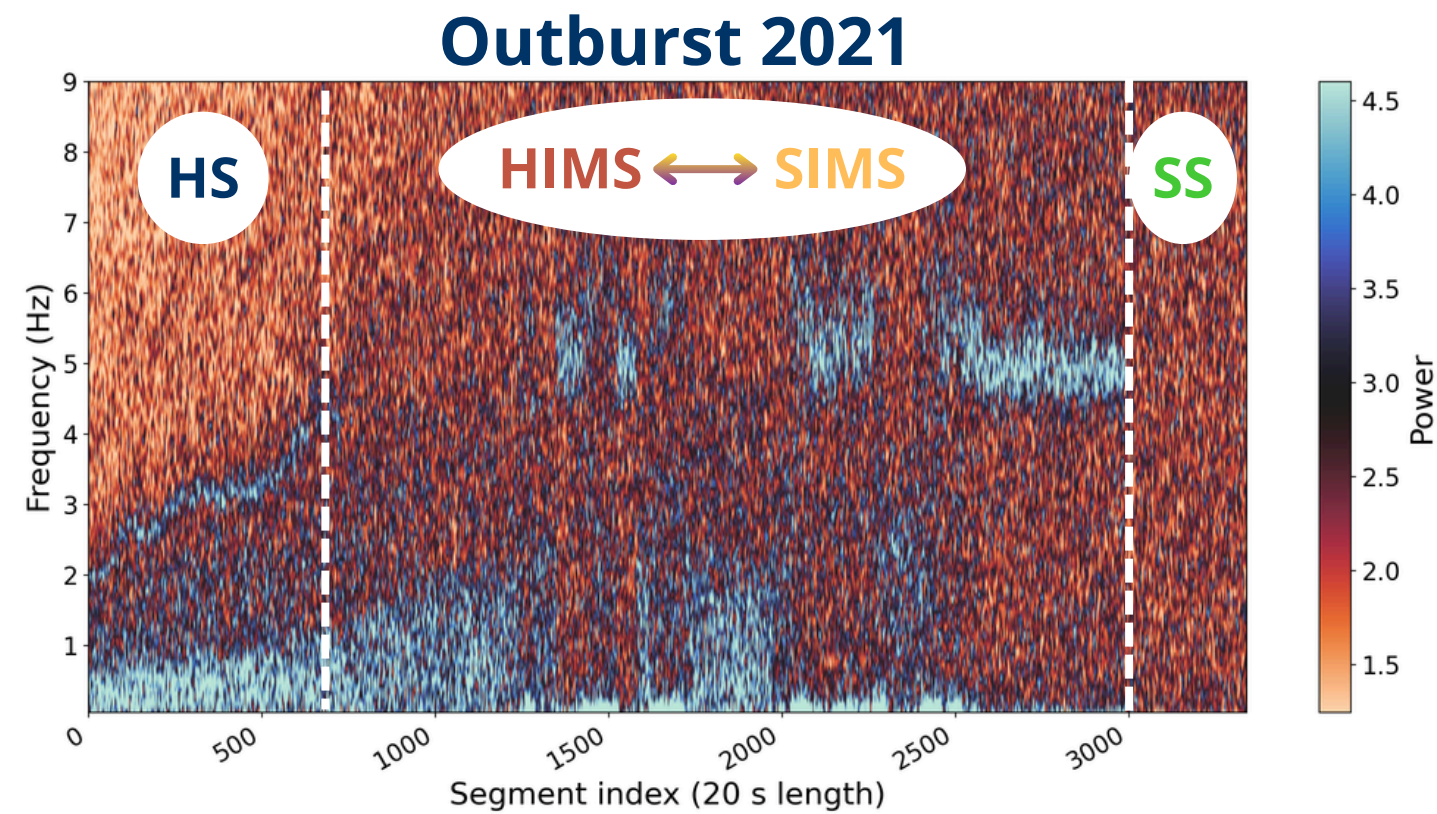
RMS-Intensity Diagram of GX 339-4 (2021 vs 2024)



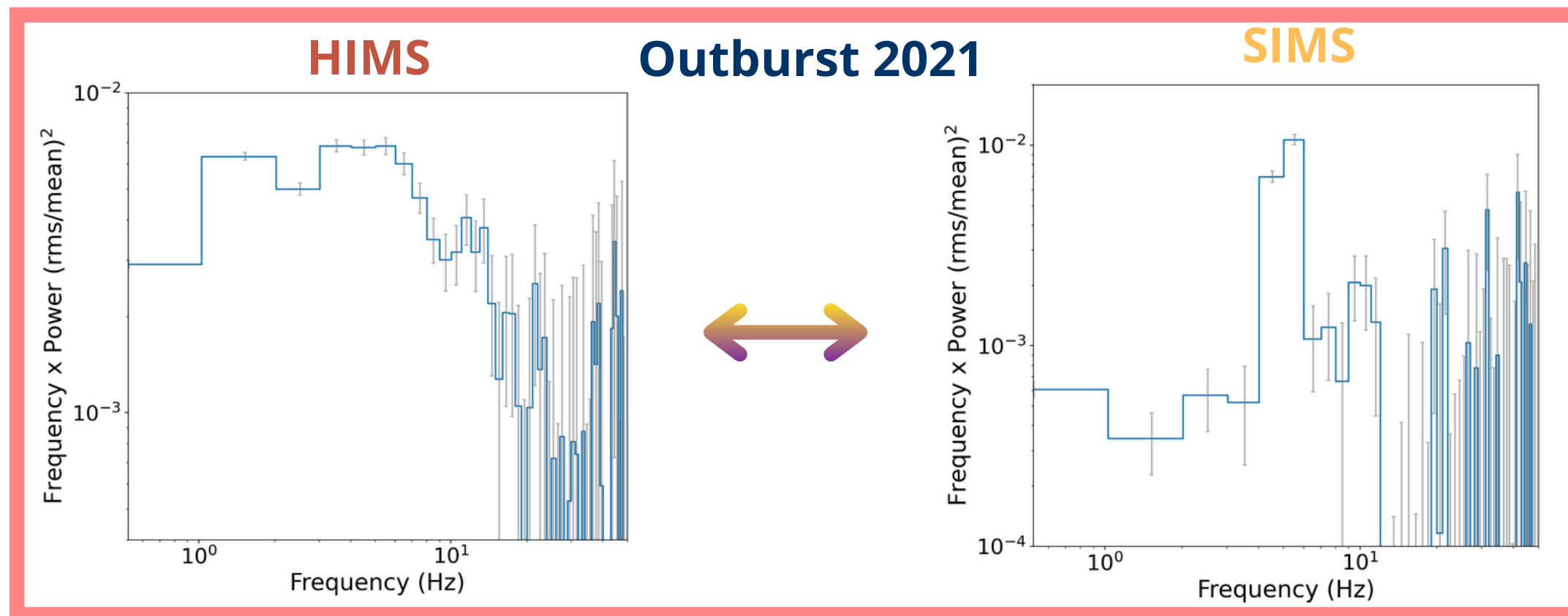
- The 2024 outburst covers the low-luminosity hard state and the end of the hard-to-soft transition.

- The rms is computed in the 3-10 keV energy band and over the range of frequencies 0.1-50 Hz.

GX 339-4: Dynamical power spectrum

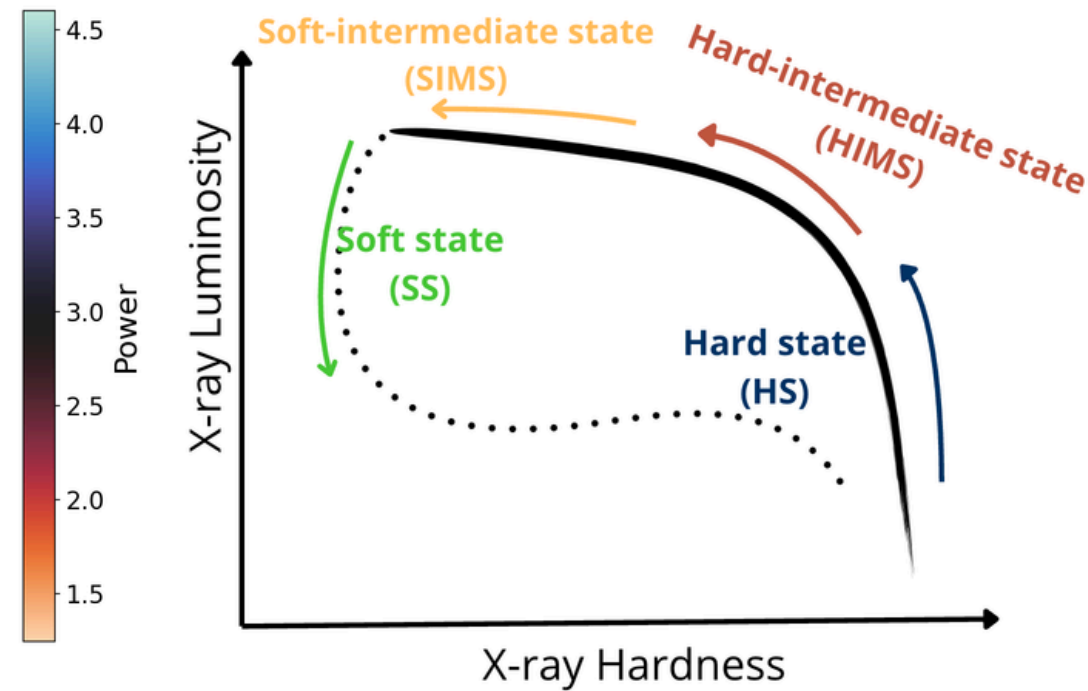
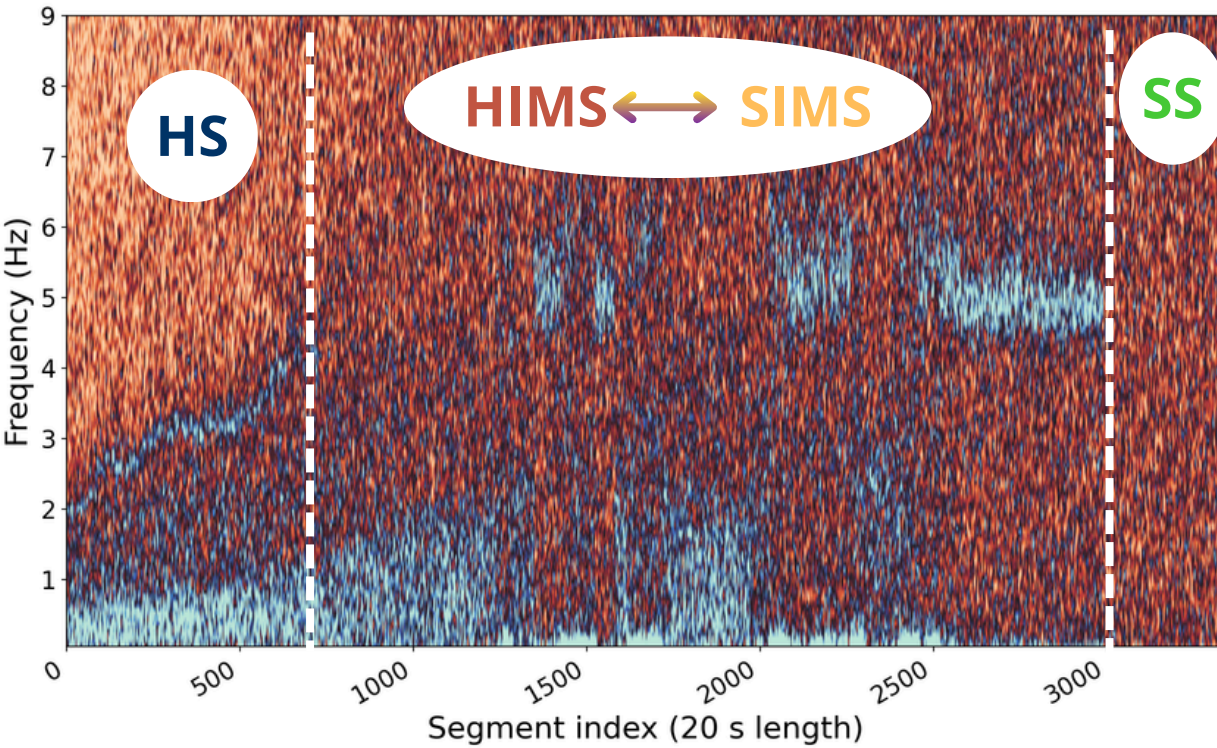


Computed from 3–10 keV lightcurves (0.01 s binning, 20 s segments) considering only the hard-to-soft transition (Buisson et al. 2025)

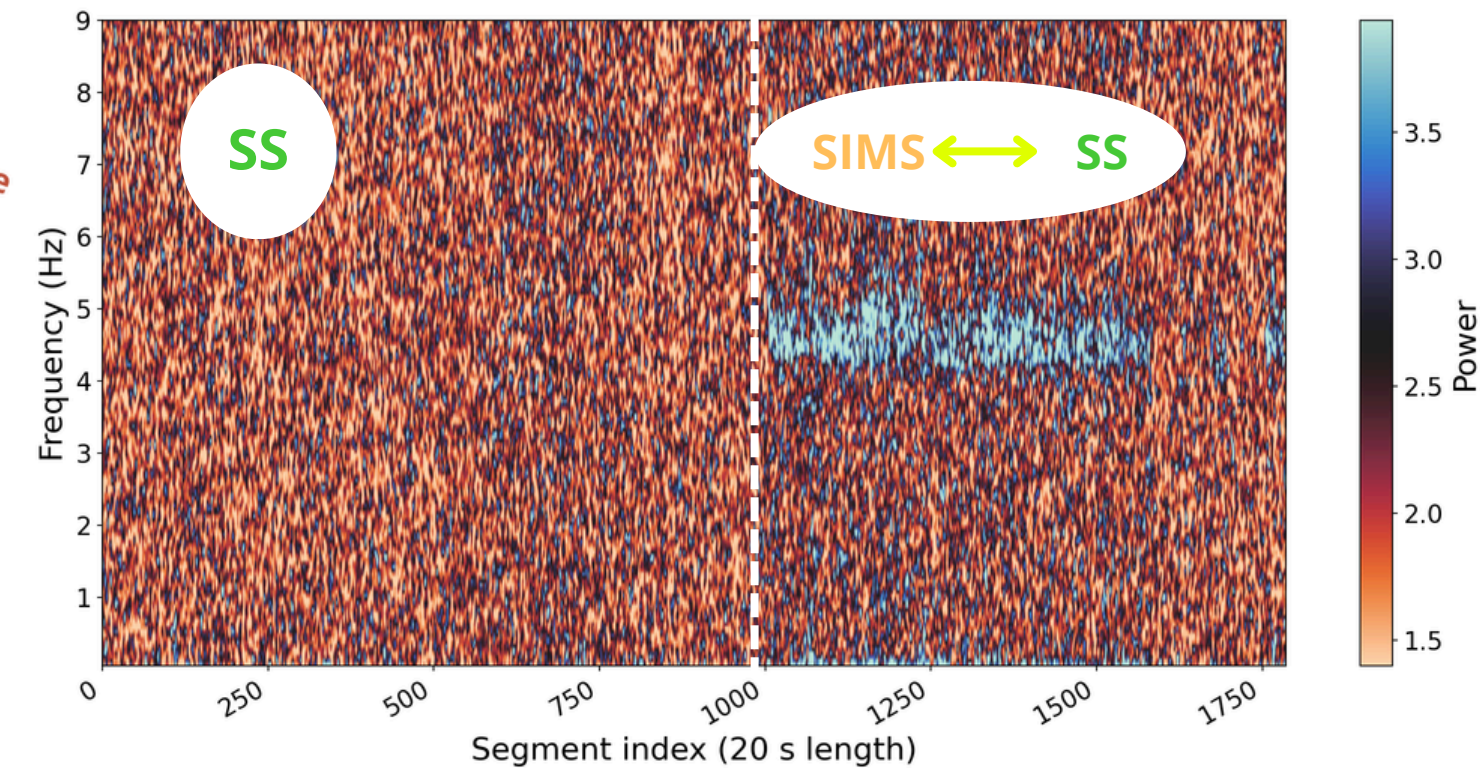


GX 339-4: Dynamical power spectrum

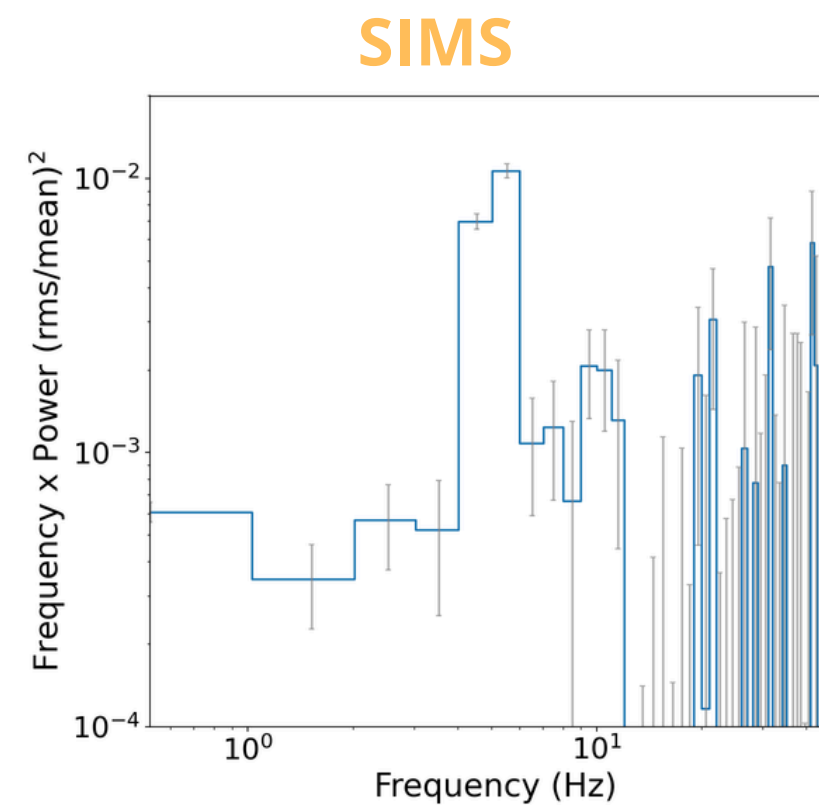
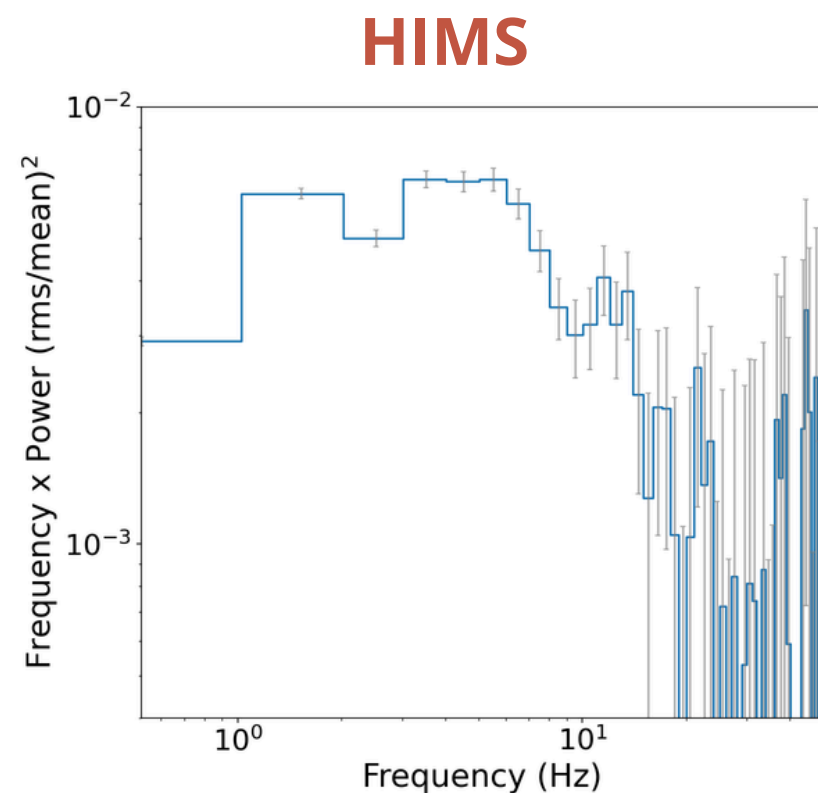
Outburst 2021



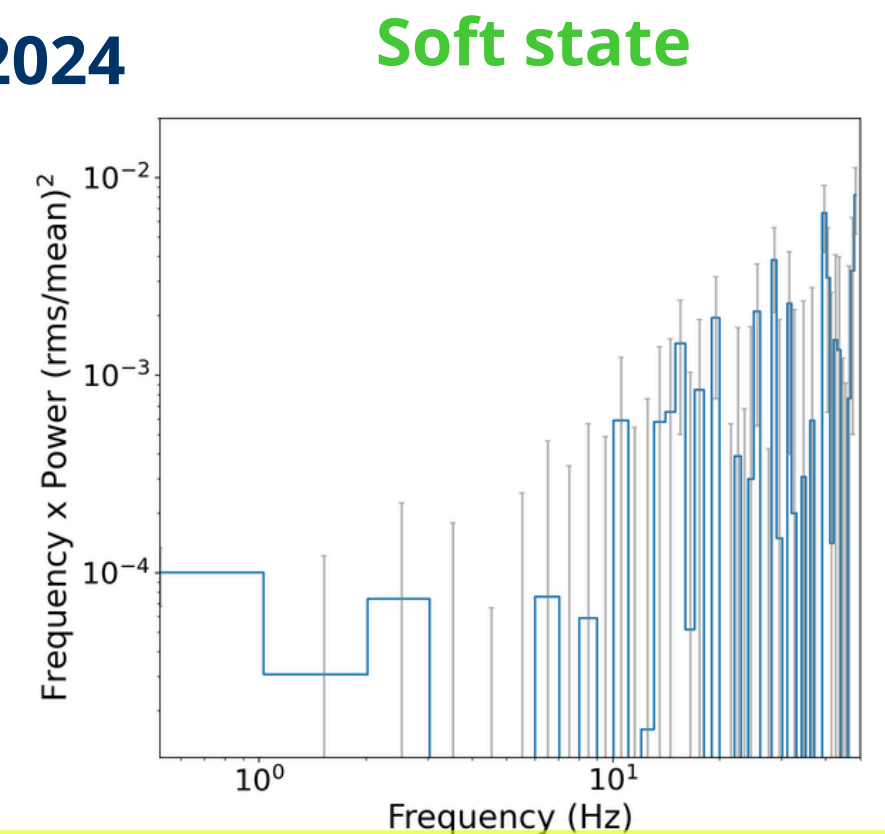
Outburst 2024



Computed from 3–10 keV lightcurves (0.01 s binning, 20 s segments) considering only the hard-to-soft transition (Buisson et al. 2025)

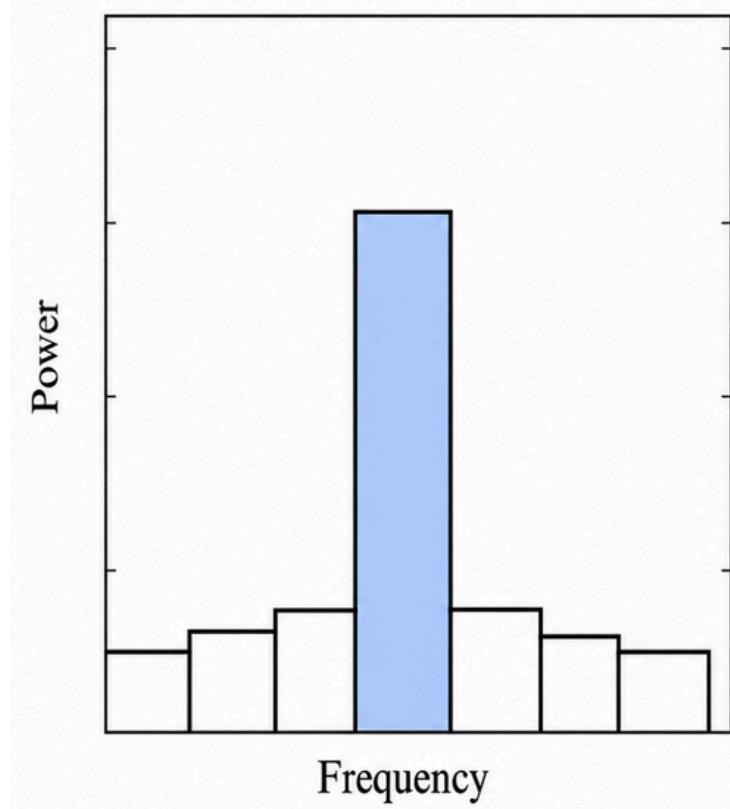


Outburst 2024

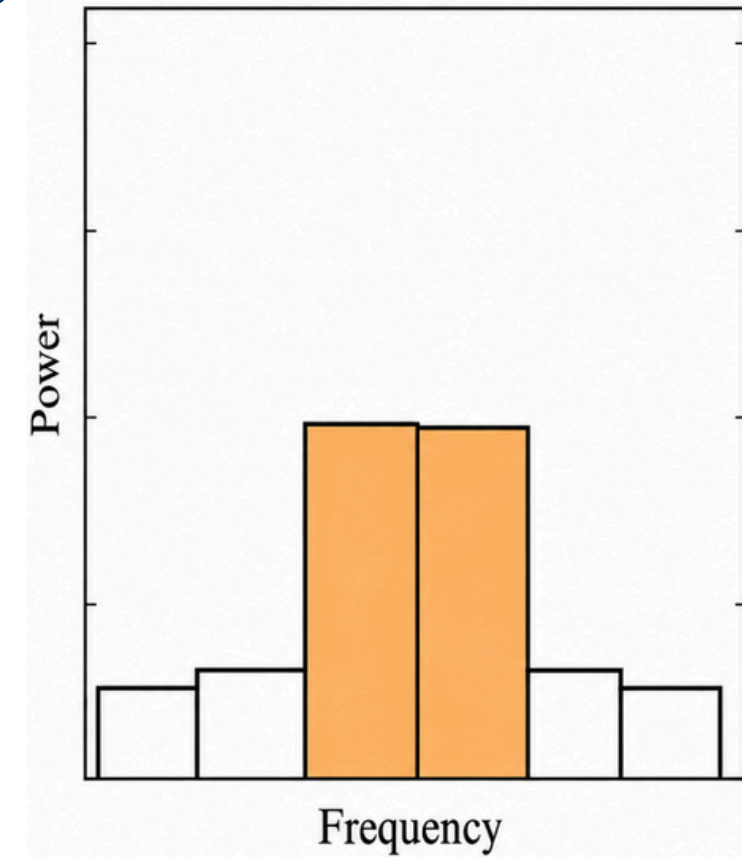


Monte Carlo analysis

- For each 20 s segment:
 - compute the PSD
 - search in 4–7 Hz for excess power
- Detection statistic designed to be robust to bin-splitting:



$$S_{\nu_j}^{(1)} = \frac{P_{\nu_j} - 2}{2 / \sqrt{(MW)_{\nu_j}}}$$



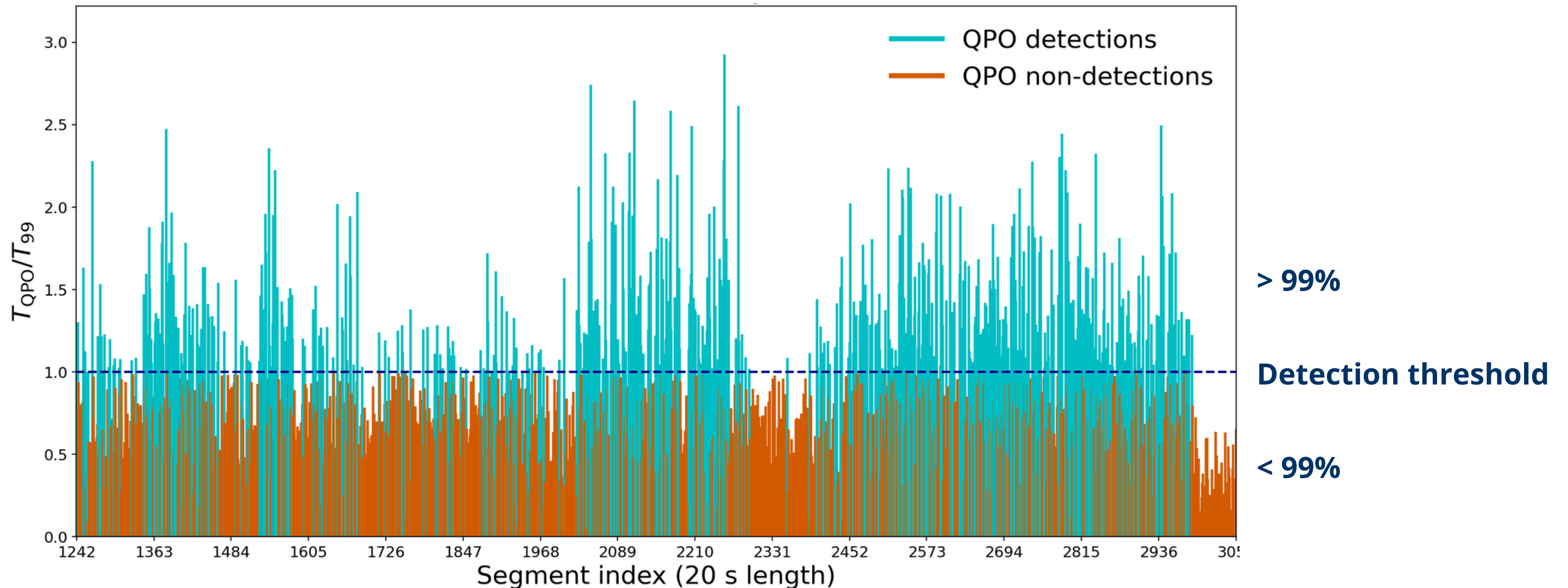
$$S_{\nu_j}^{(2)} = \frac{P_{\nu_j} + P_{\nu_{j+1}} - 4}{2 \sqrt{\frac{1}{(MW)_{\nu_j}} + \frac{1}{(MW)_{\nu_{j+1}}}}}$$

- $T_{\nu_j} = \max(S_{\nu_j}^{(1)}, S_{\nu_j}^{(2)}), \quad T_{QPO} = \max(T_{\nu_j})$
- Then we run Monte Carlo simulations, compute T for each simulated PDS, and obtain a p-value for the observed T

$$P_{\nu_j}^{(sim)} = \frac{\chi_{2MW_{\nu_j}}^2}{MW_{\nu_j}}, \quad p = \Pr(T_{sim} \geq T_{QPO})$$

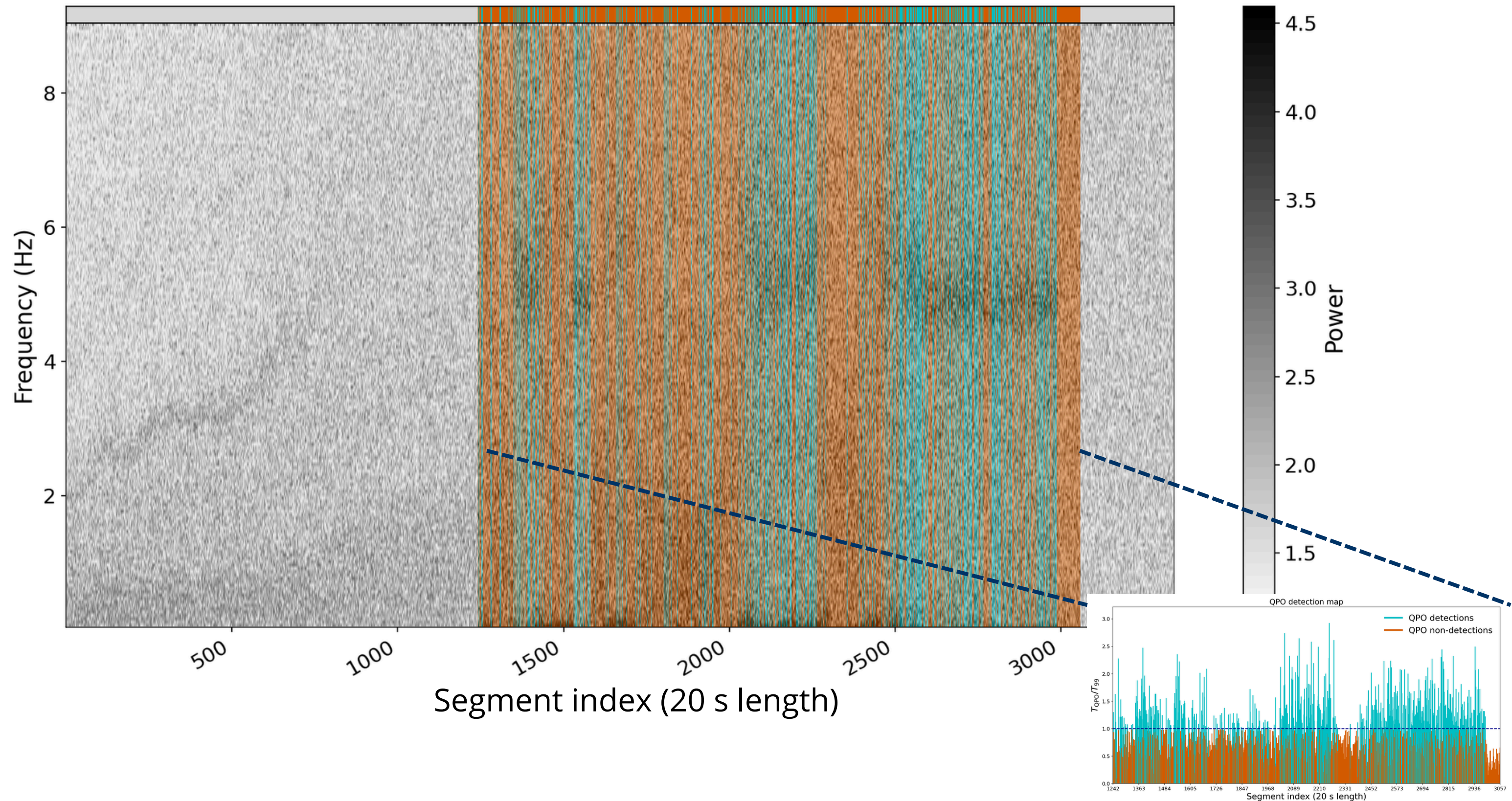
QPO time-resolved detection map

2021 outburst QPO detection map



- Cyan segments exceed the 99% threshold; orange segments do not
- 2024 outburst working in progress

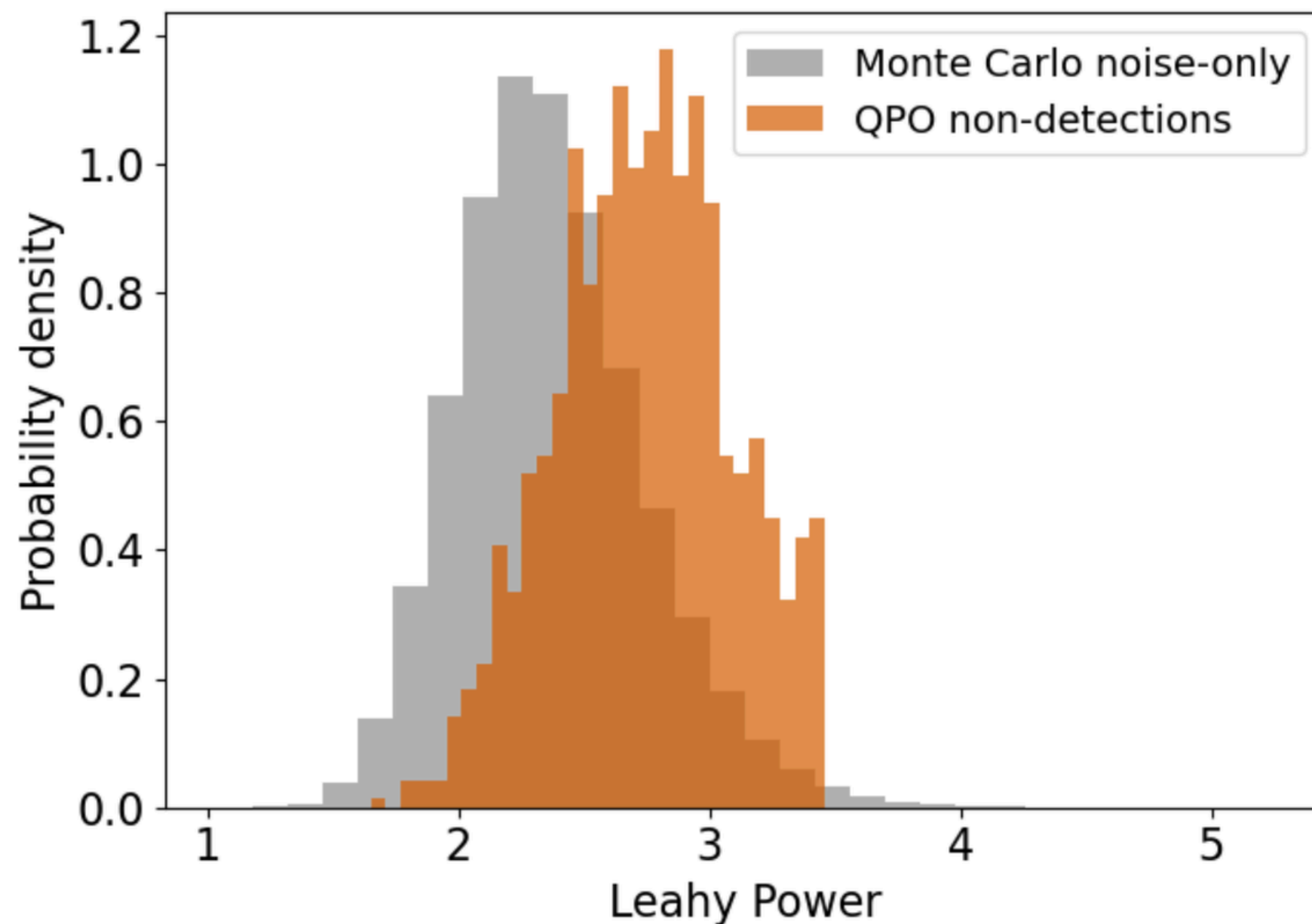
QPO detections in the DPS



- The detection map shows that significant QPO detections cluster in specific parts of the transition

Is the QPO really disappearing?

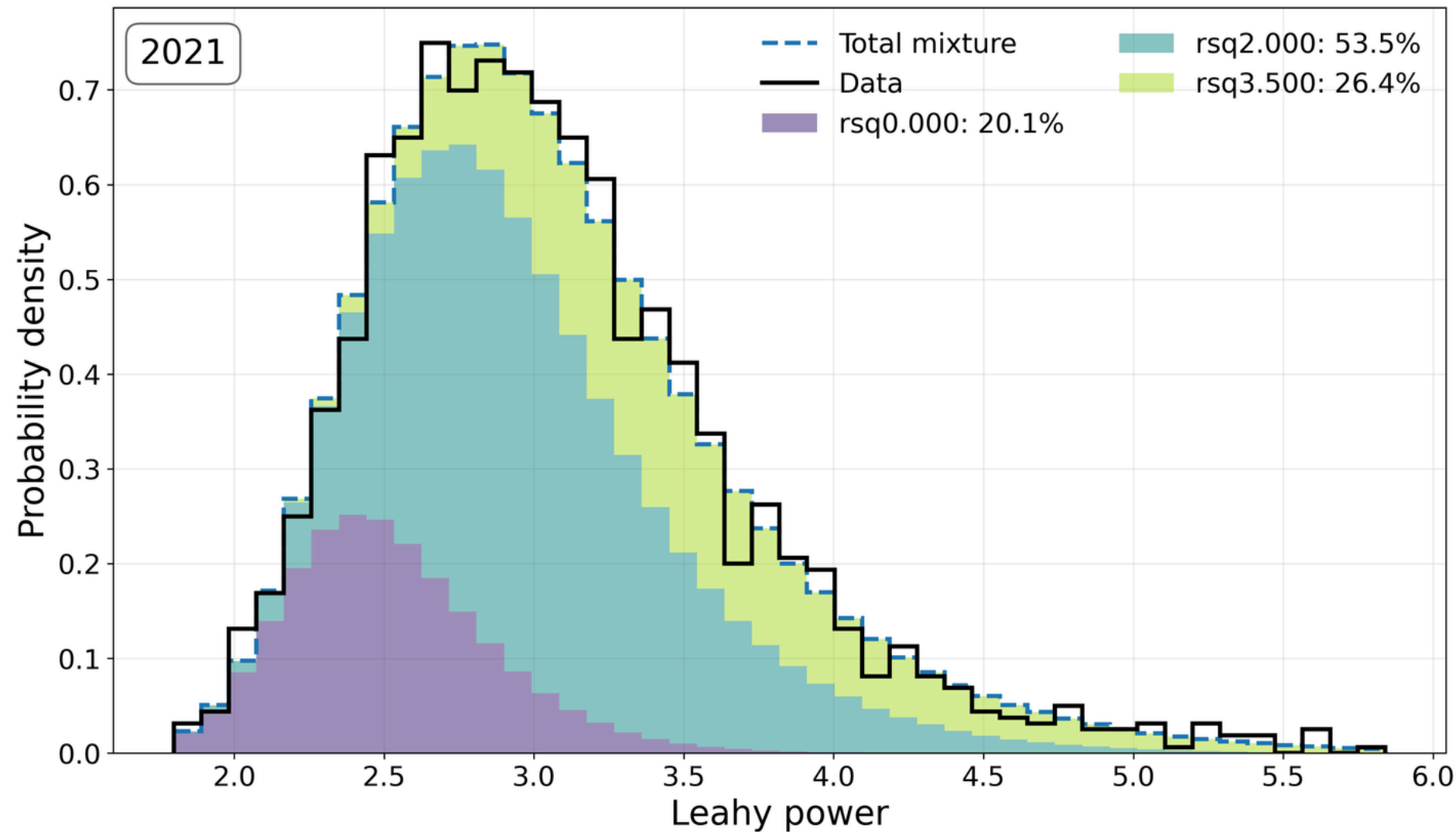
- We compare the QPO non-detection segments with Monte Carlo noise-only simulations



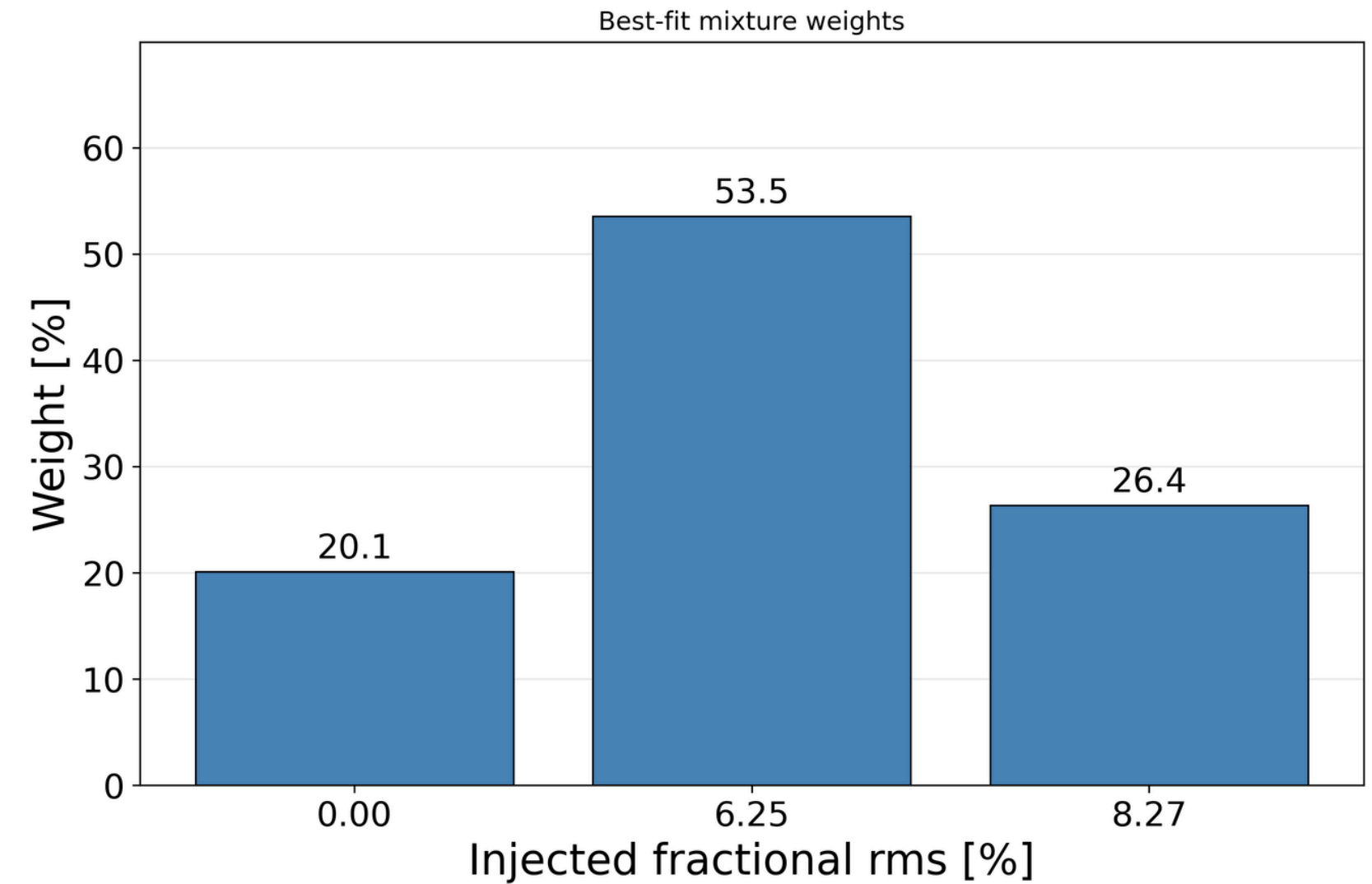
KS statistic: 0.42
p-value: 9.81e-199

- We may be missing weak QPOs because of limited statistics
- We cannot conclude that the QPO truly disappears during the flip-flops

Is the QPO really disappearing?

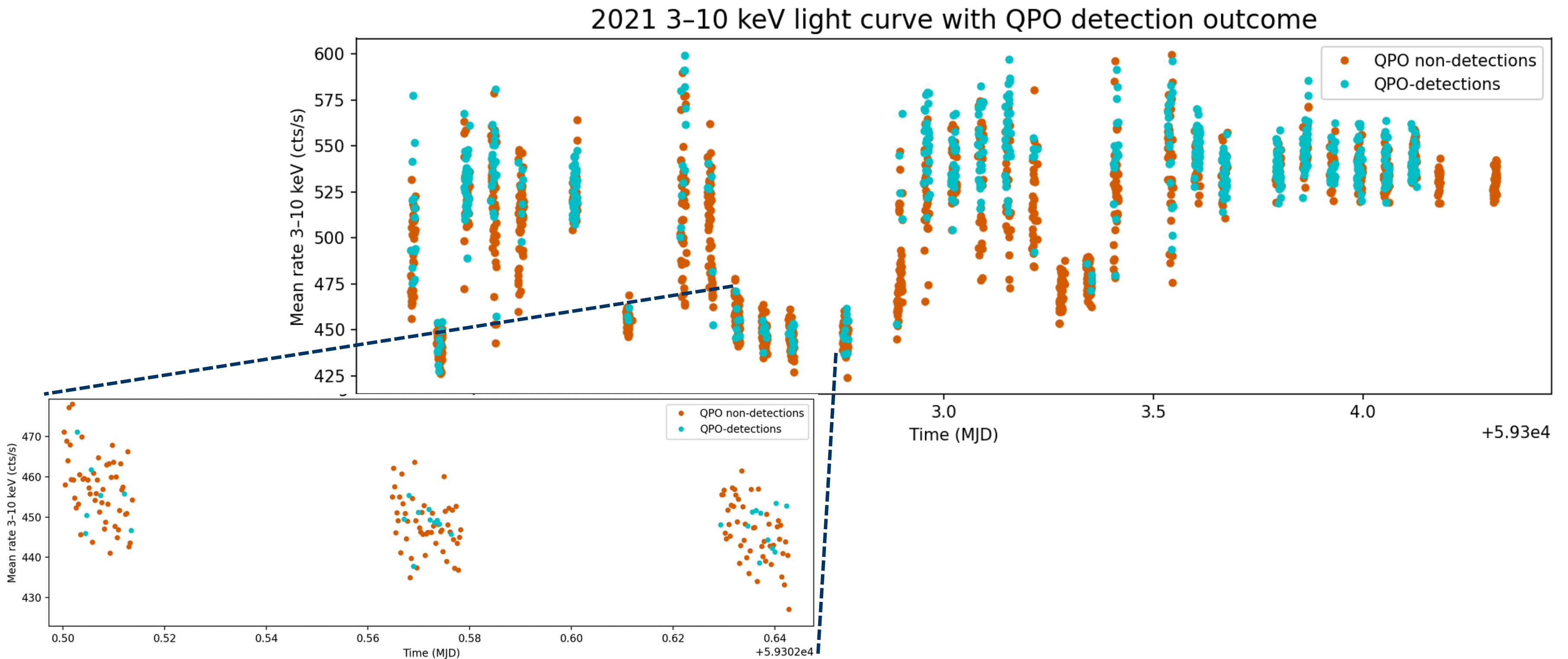


- KS: 0.007
- p-value: 0.999



- results suggest that on timescales of 20 seconds the QPO either turns off or changes amplitude

QPOs “Switches” Are Not Simply Flux-Driven



- At the current threshold there is no a clear correlation between flip-flops (count rate change) and changes in the power spectrum (spectral changes)

Conclusion and Future Work

- **GX 339–4 shows rapid flip-flop-like variability during the hard-to-soft transition**
- **Our results suggest that on timescales of 20 seconds the QPO either turns off or changes amplitude during flip-flops**
- **No one-to-one correlation between flip-flops flux states and QPOs switches**
- **Next steps: testing QPOs detections against red noise, statistical analysis of the 2024 outburst**

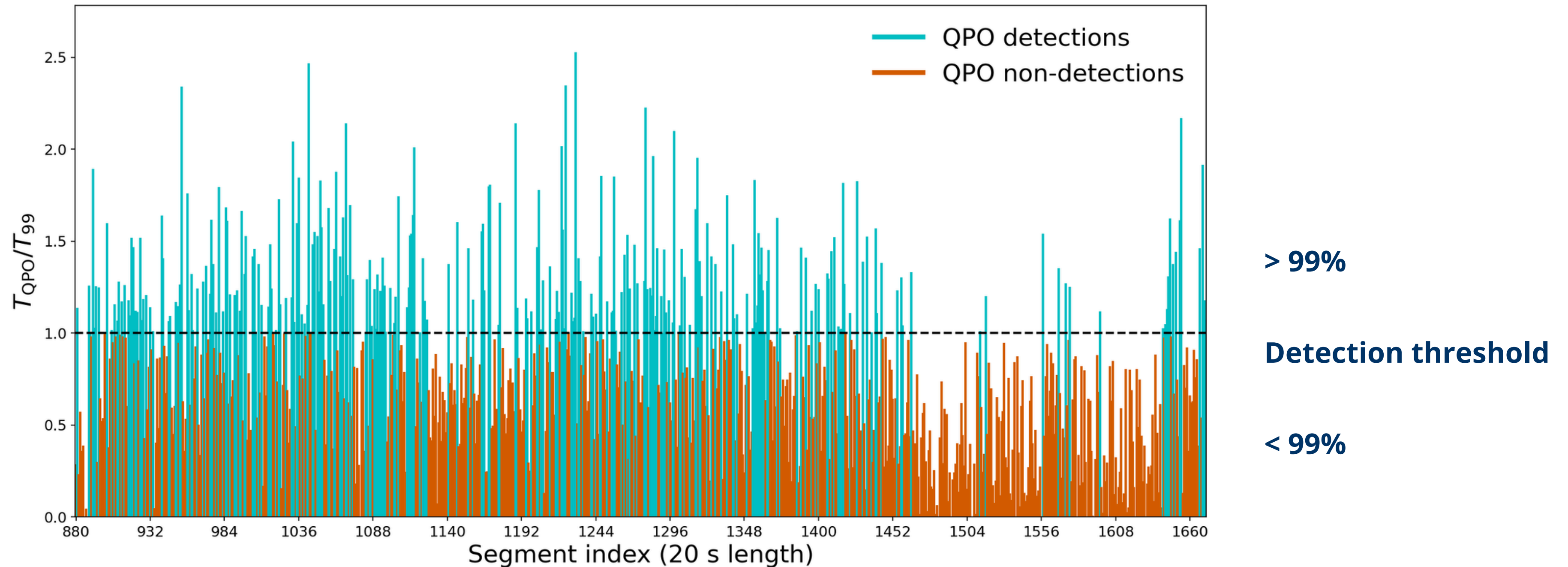


Thank you for your attention

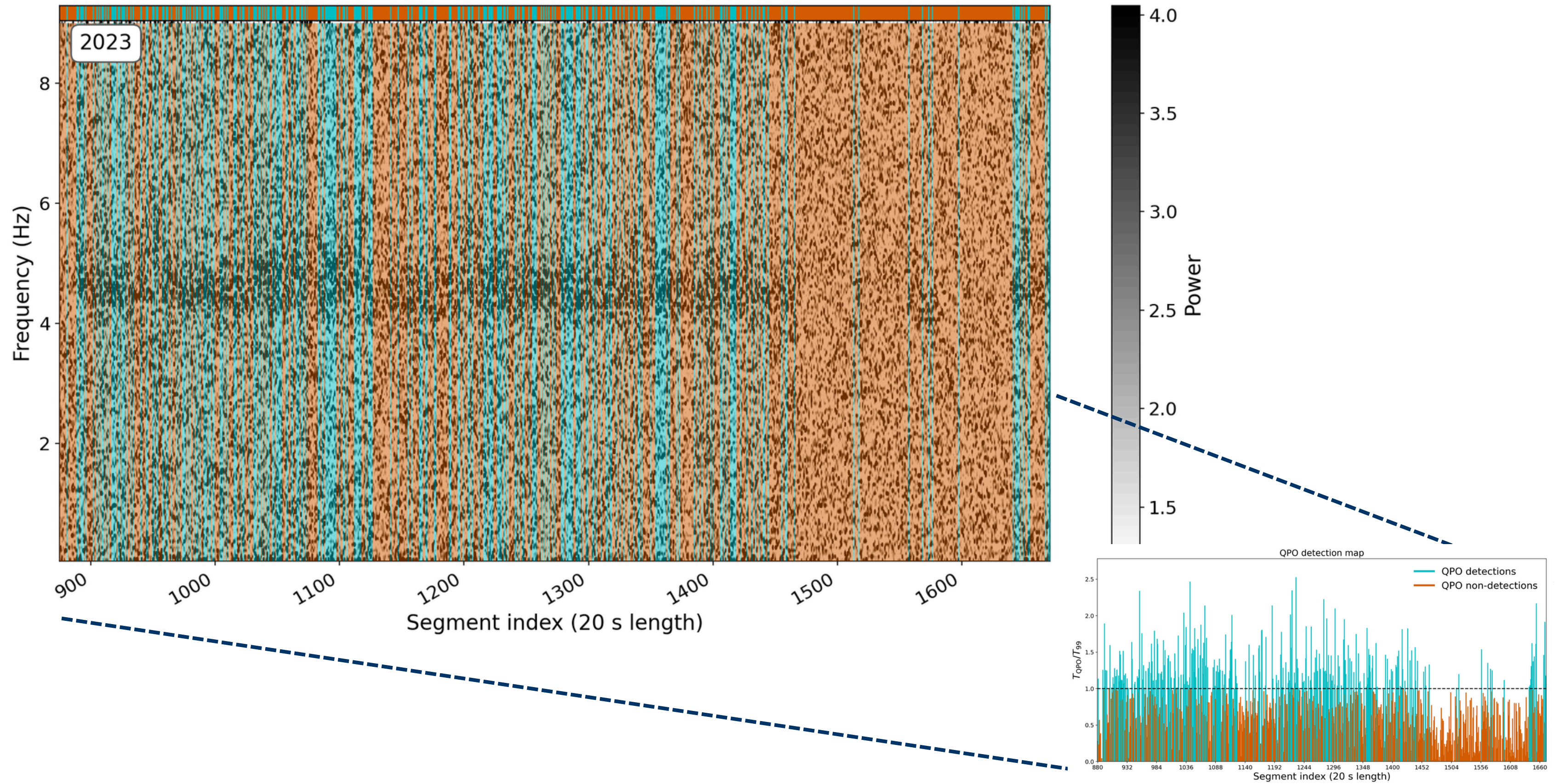
federico.ferretti@uniroma3.it

QPO time-resolved detection map

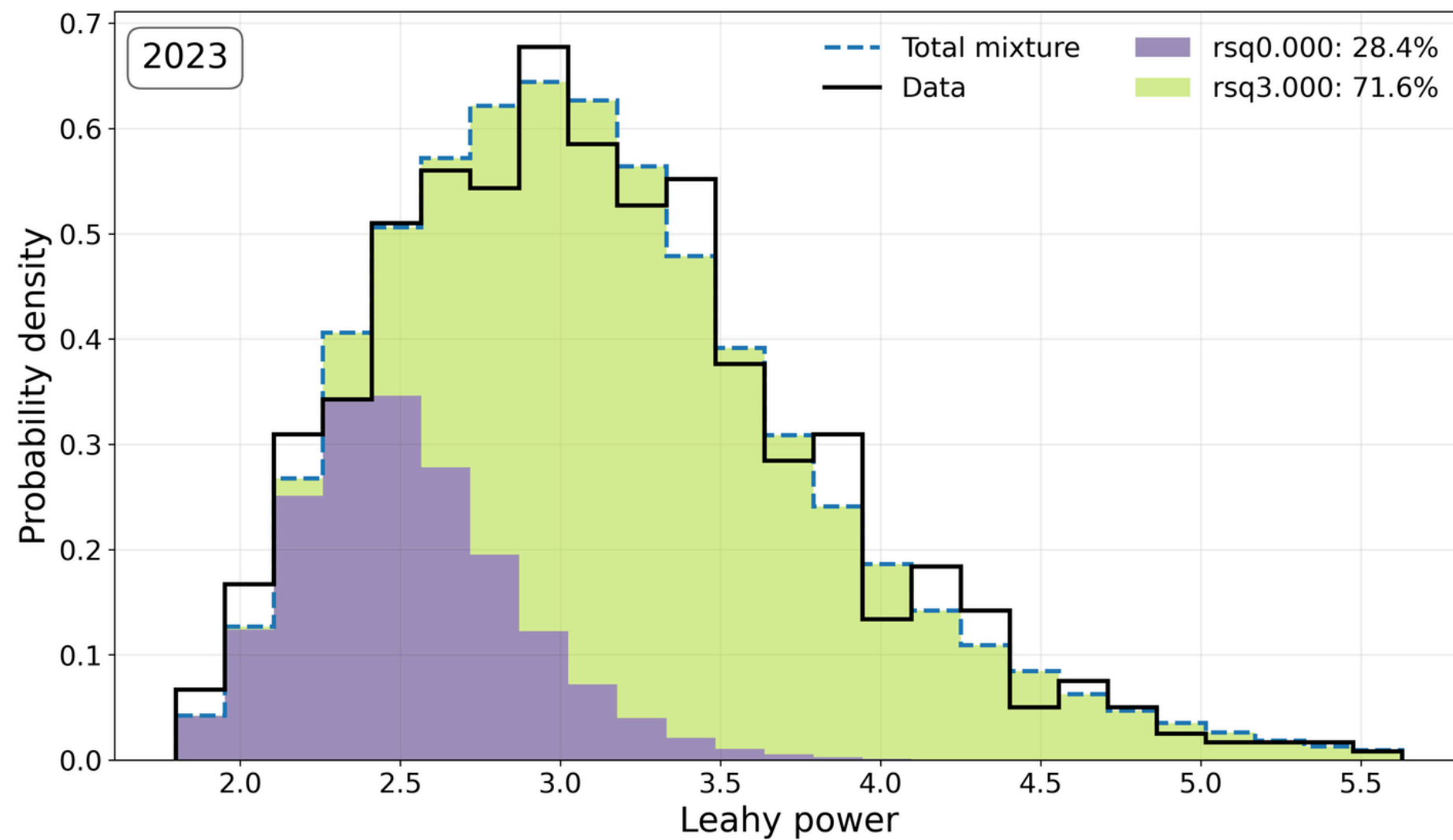
2023 outburst QPO detection map



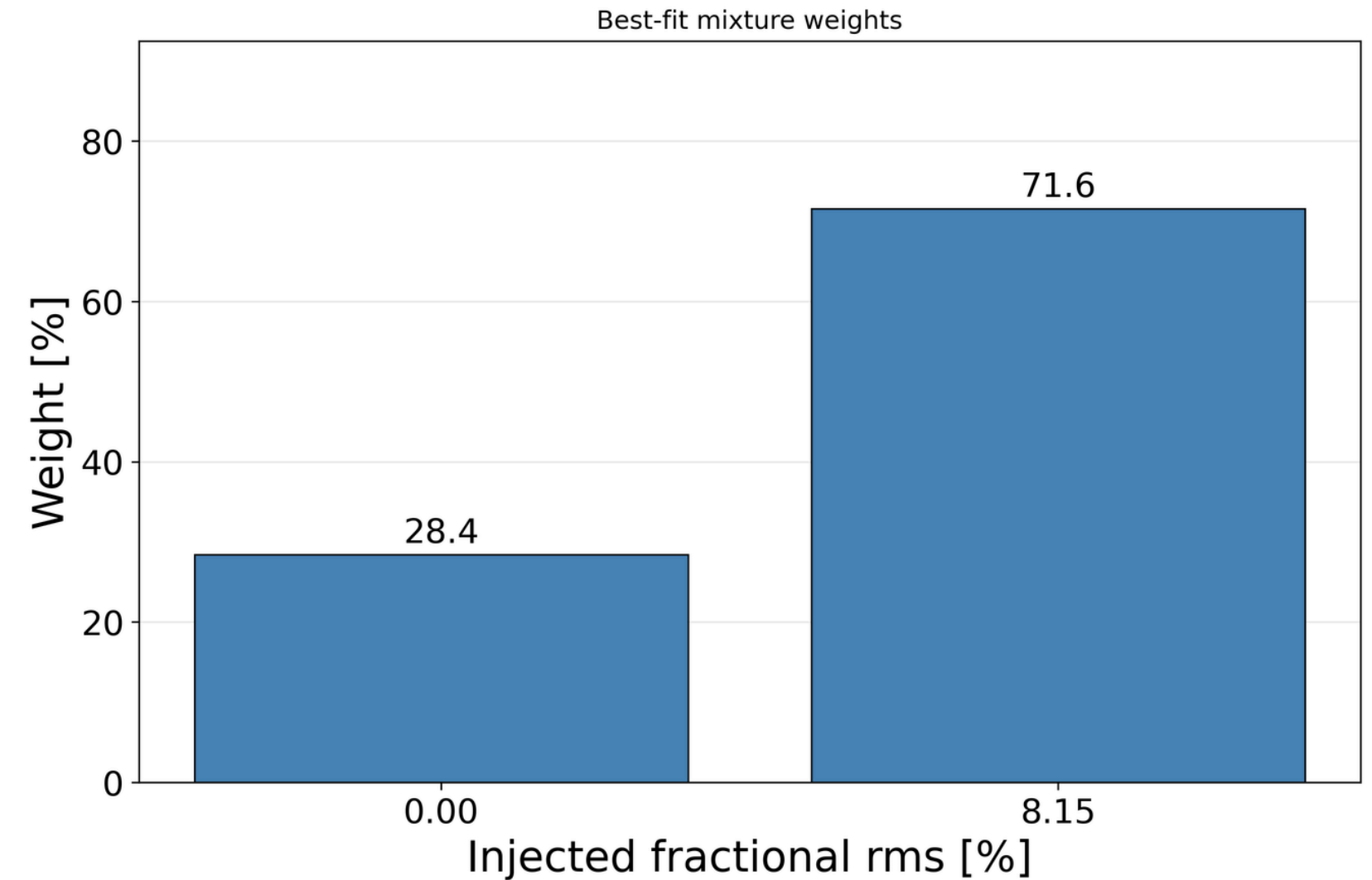
QPO detections in the DPS



Is the QPO really disappearing?

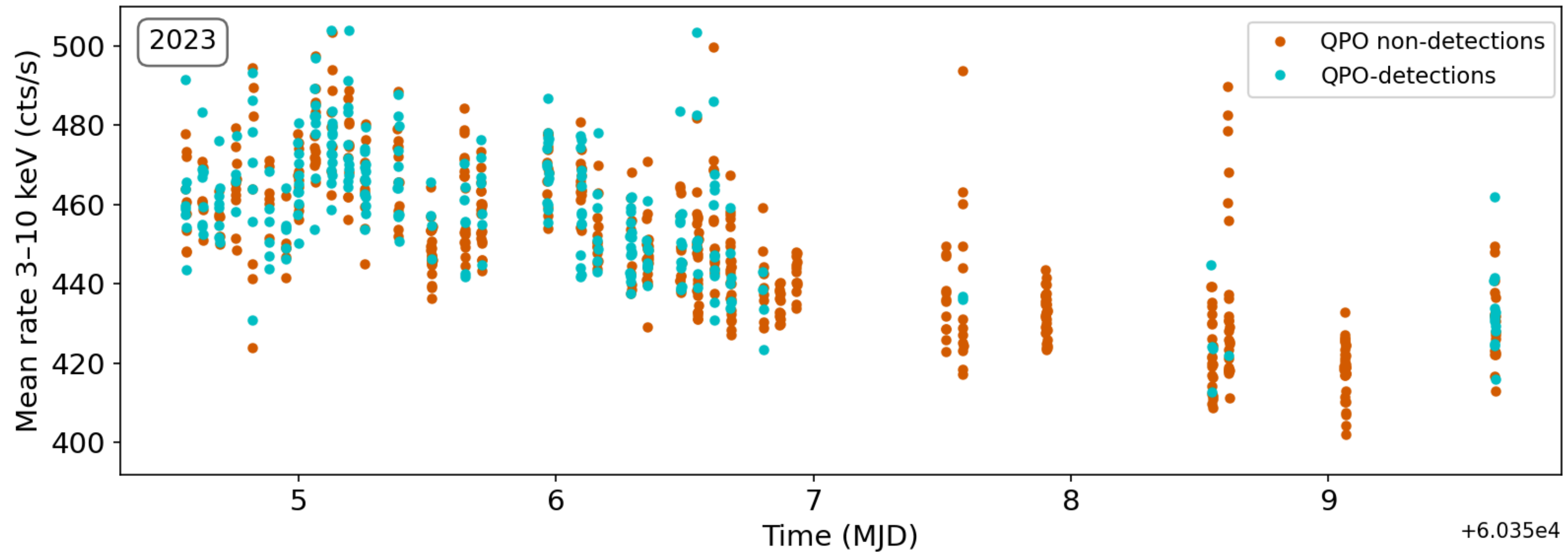


- **KS: 0.007**
- **p-value: 0.999**

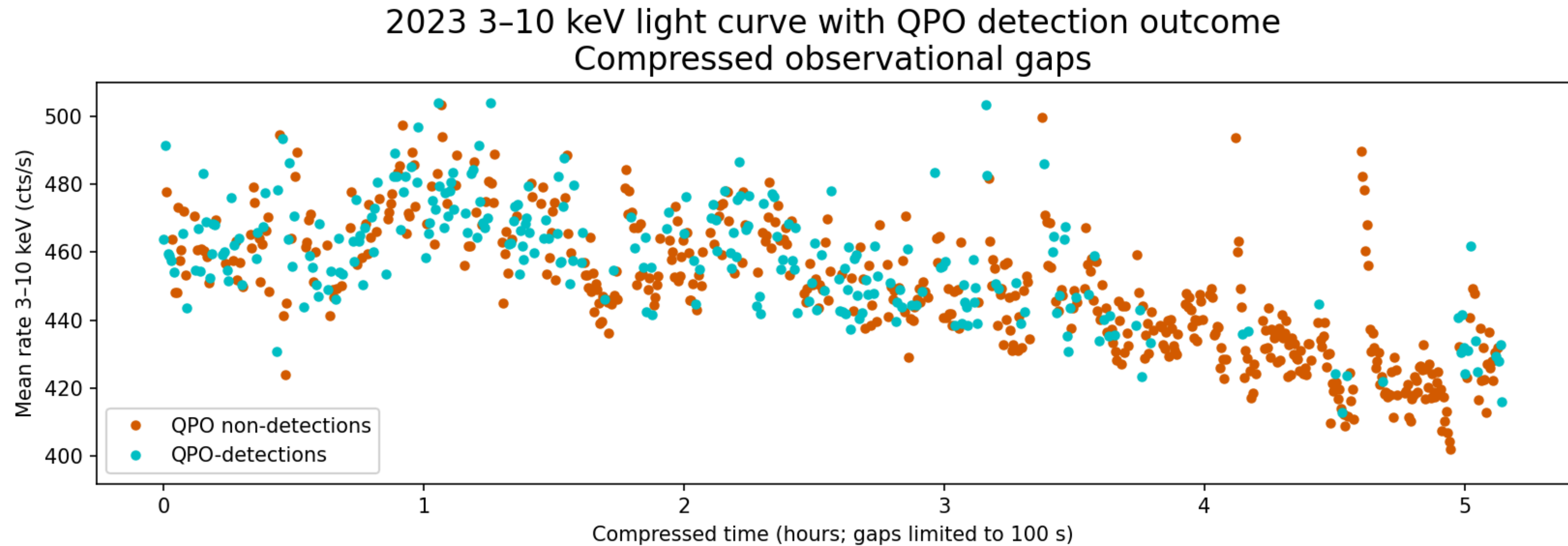


- **results suggest that on timescales of 20 seconds the QPO either turns off or changes amplitude**

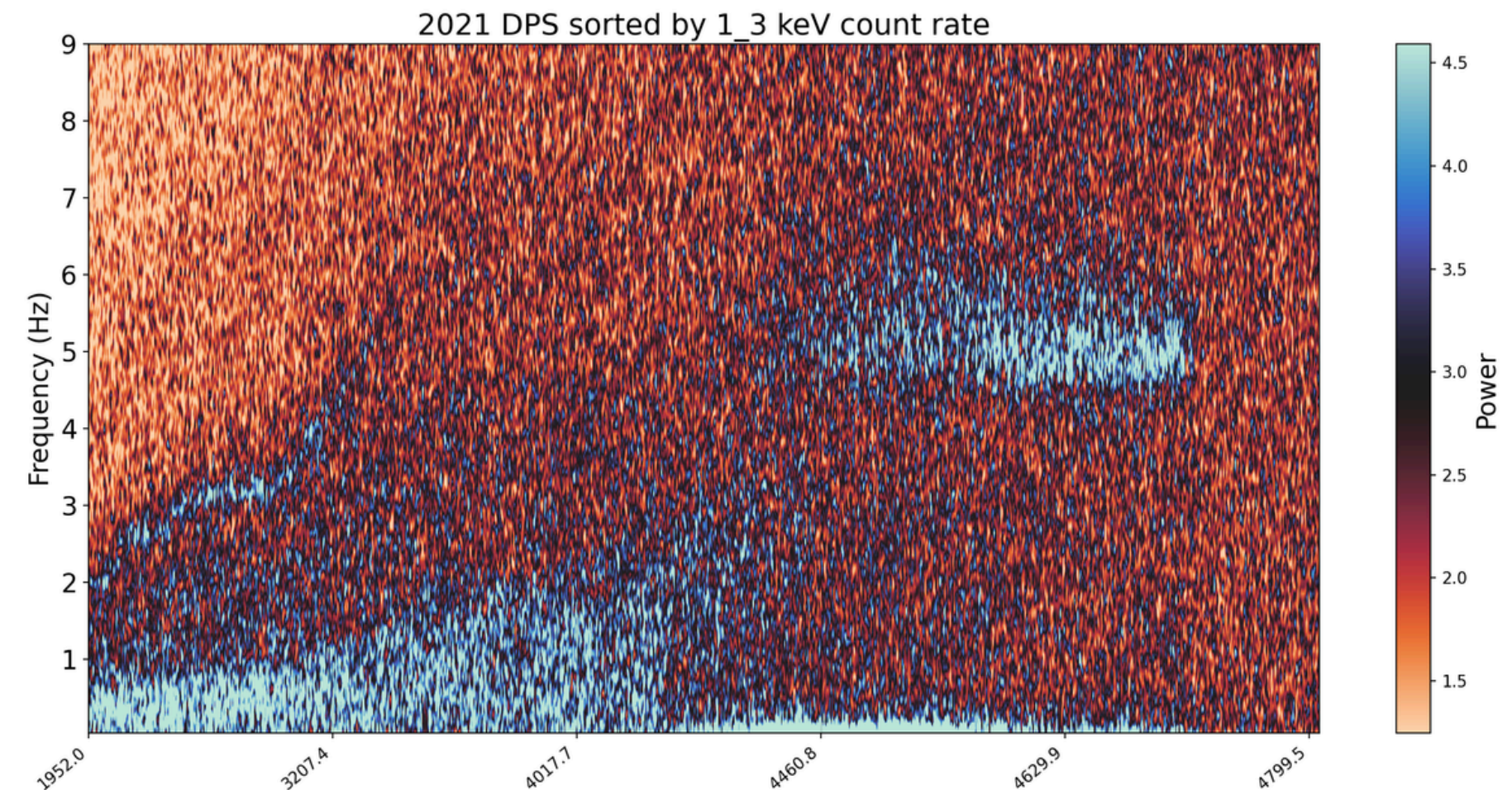
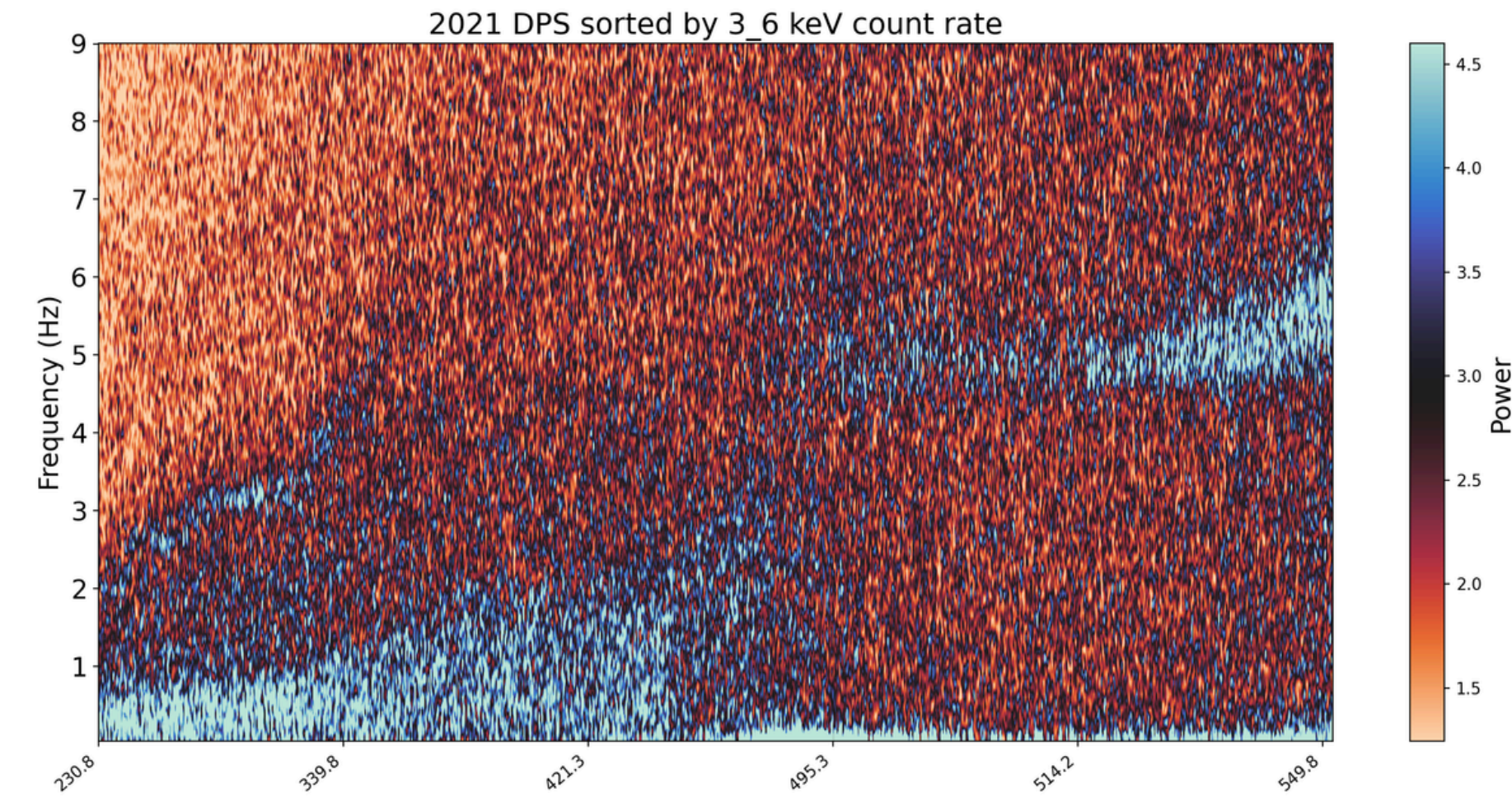
QPOs “Switches” Are Not Simply Flux-Driven



QPOs “Switches” Are Not Simply Flux-Driven



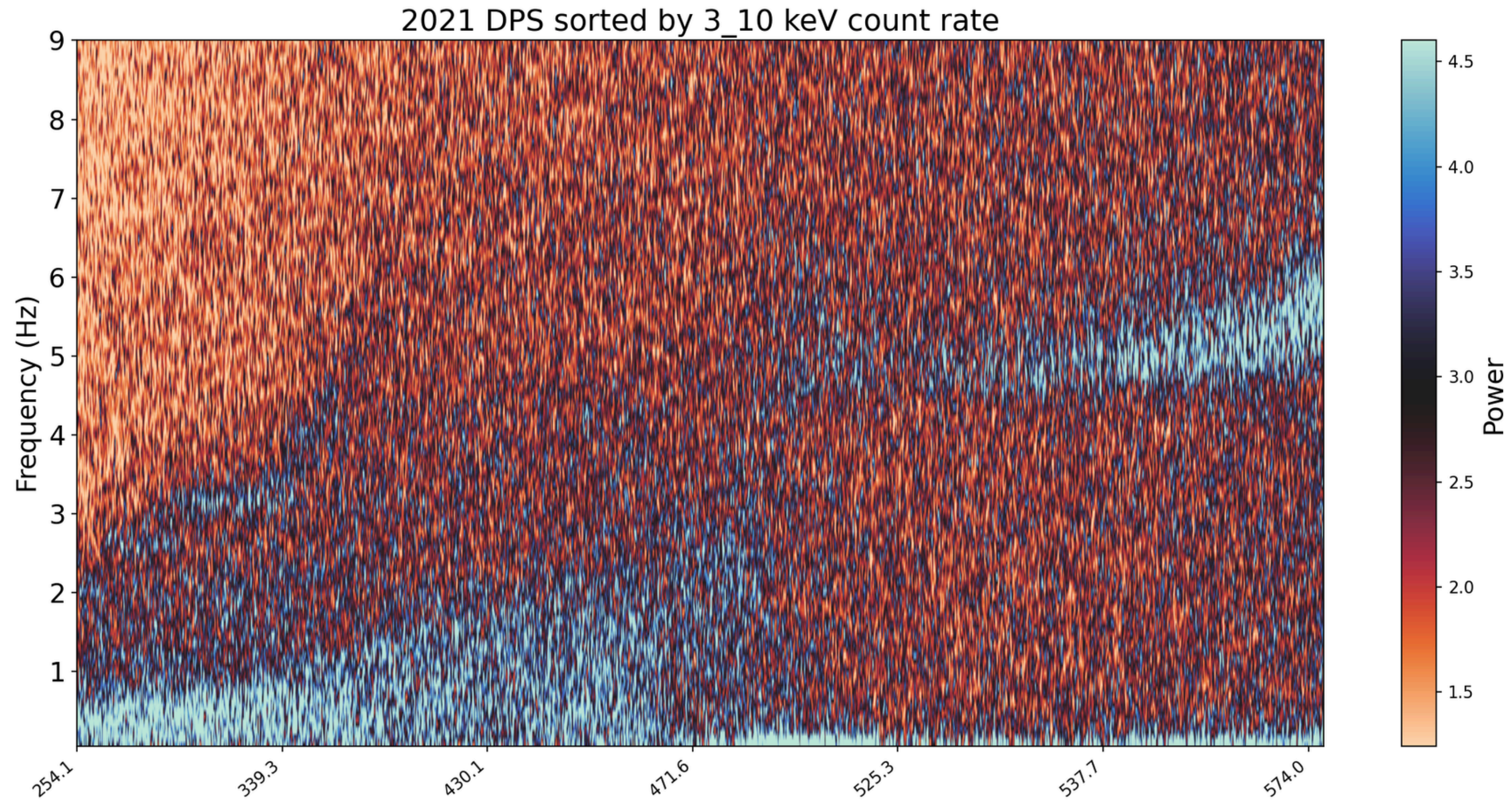
DPS sorted by count rate



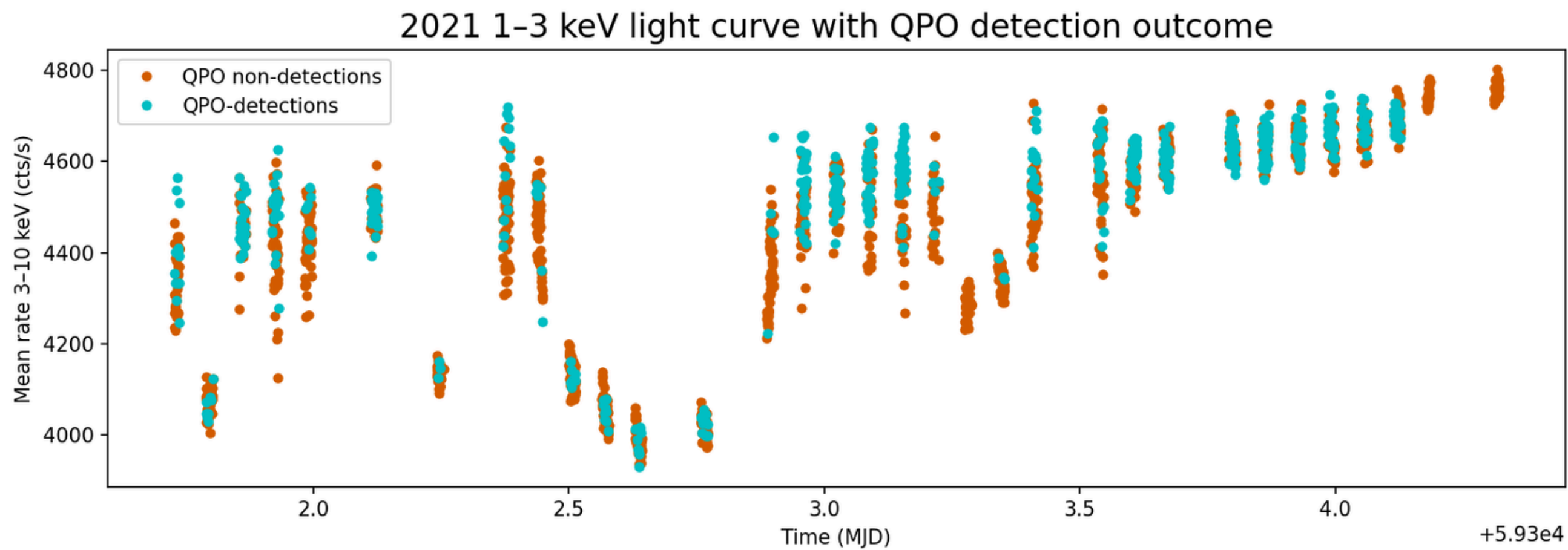
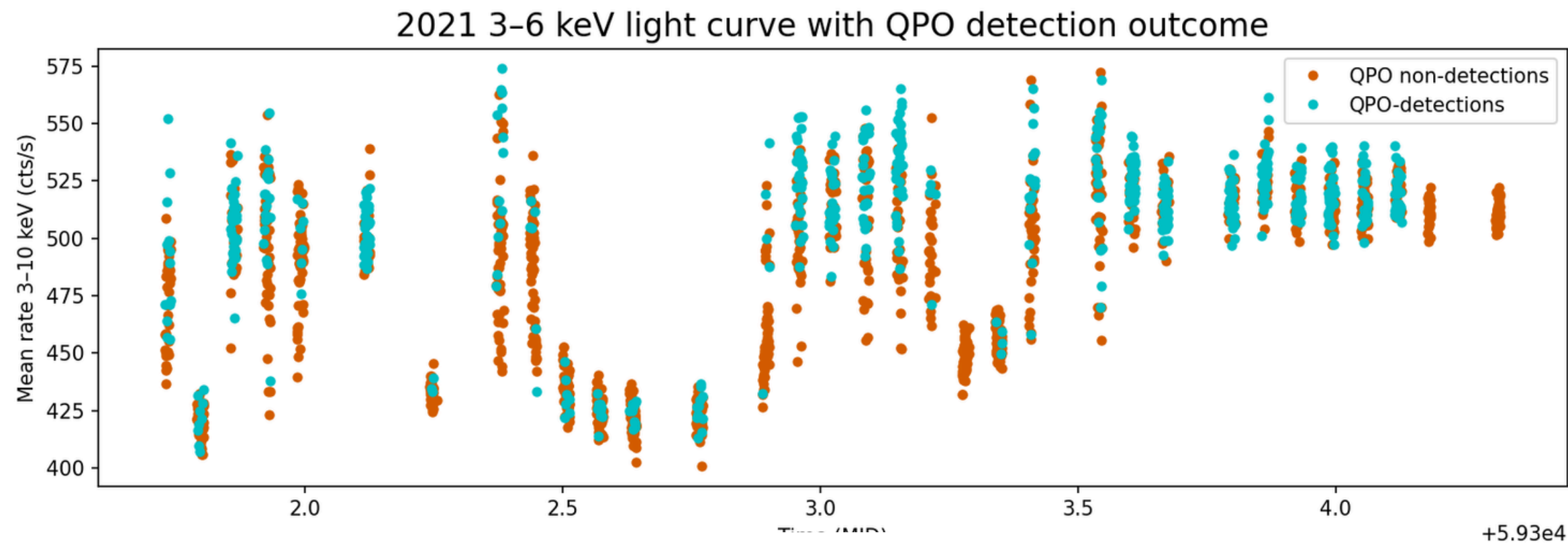
- Above a certain count rate transition from a state in which the type-B QPO is absent to one where it dominates the variability. The frequency changes with count rates (Buisson et al. 2025)

- It appears that the presence of the QPO is confined to a specific range of count rates

QPOs “Switches” Are Not Simply Flux-Driven



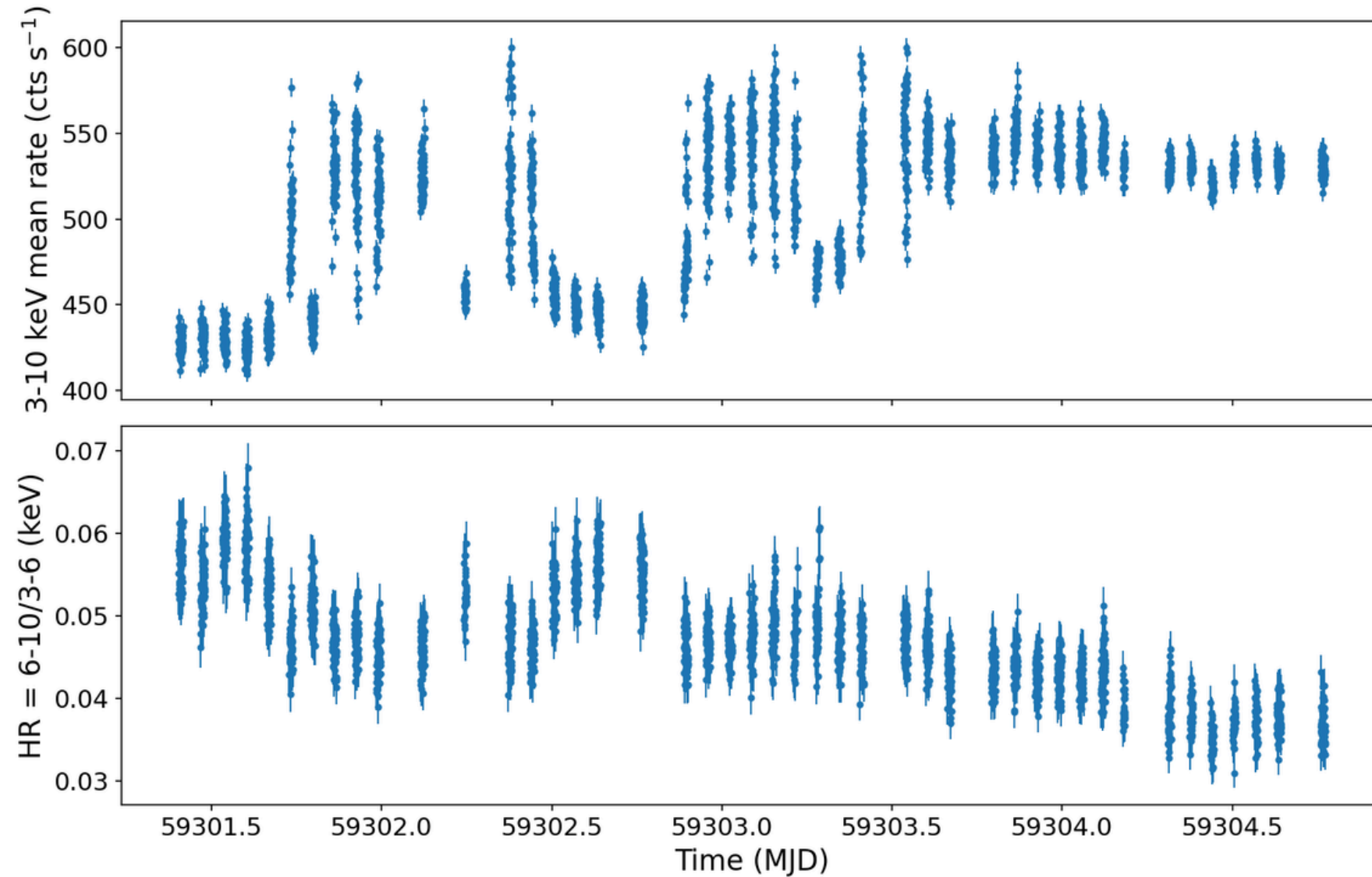
QPOs “Switches” Are Not Simply Flux-Driven



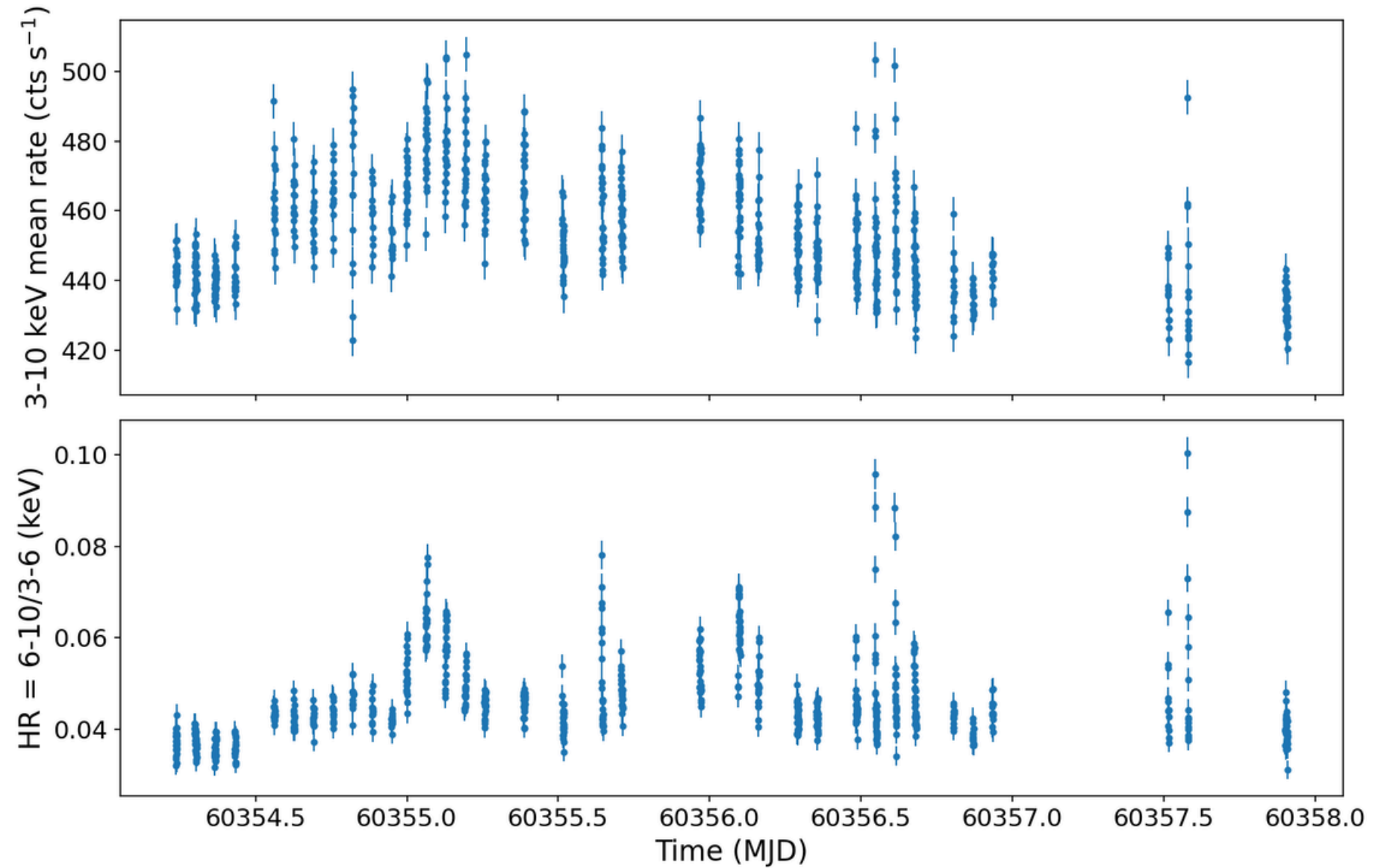
Fast variability during the transition

- GX 339-4 NICER light curves (3-10 keV, 20 s binning) and hardness ratios (6-10/3-6 keV) covering the hard-to-soft transitions

Outburst 2021

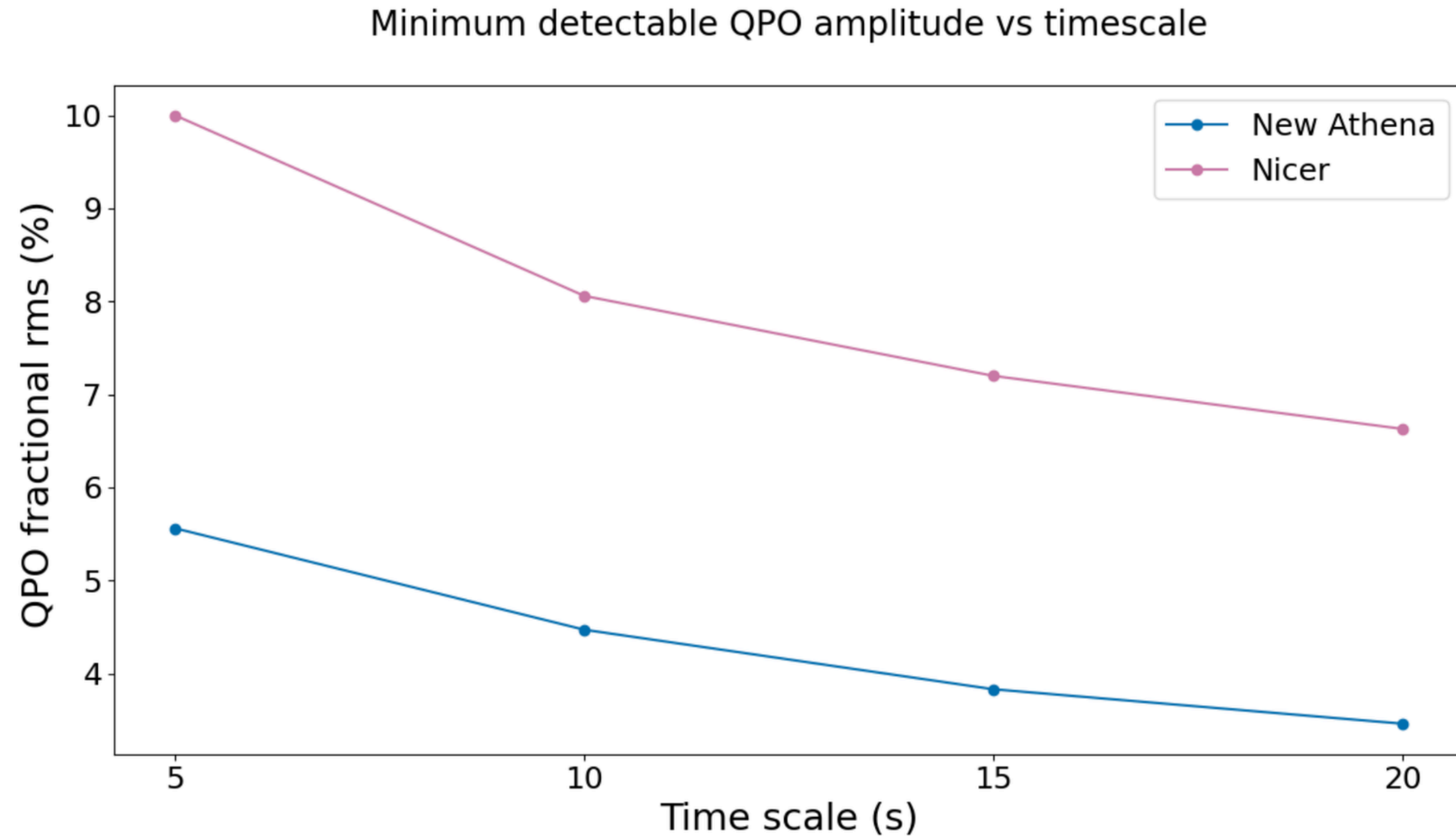


Outburst 2024



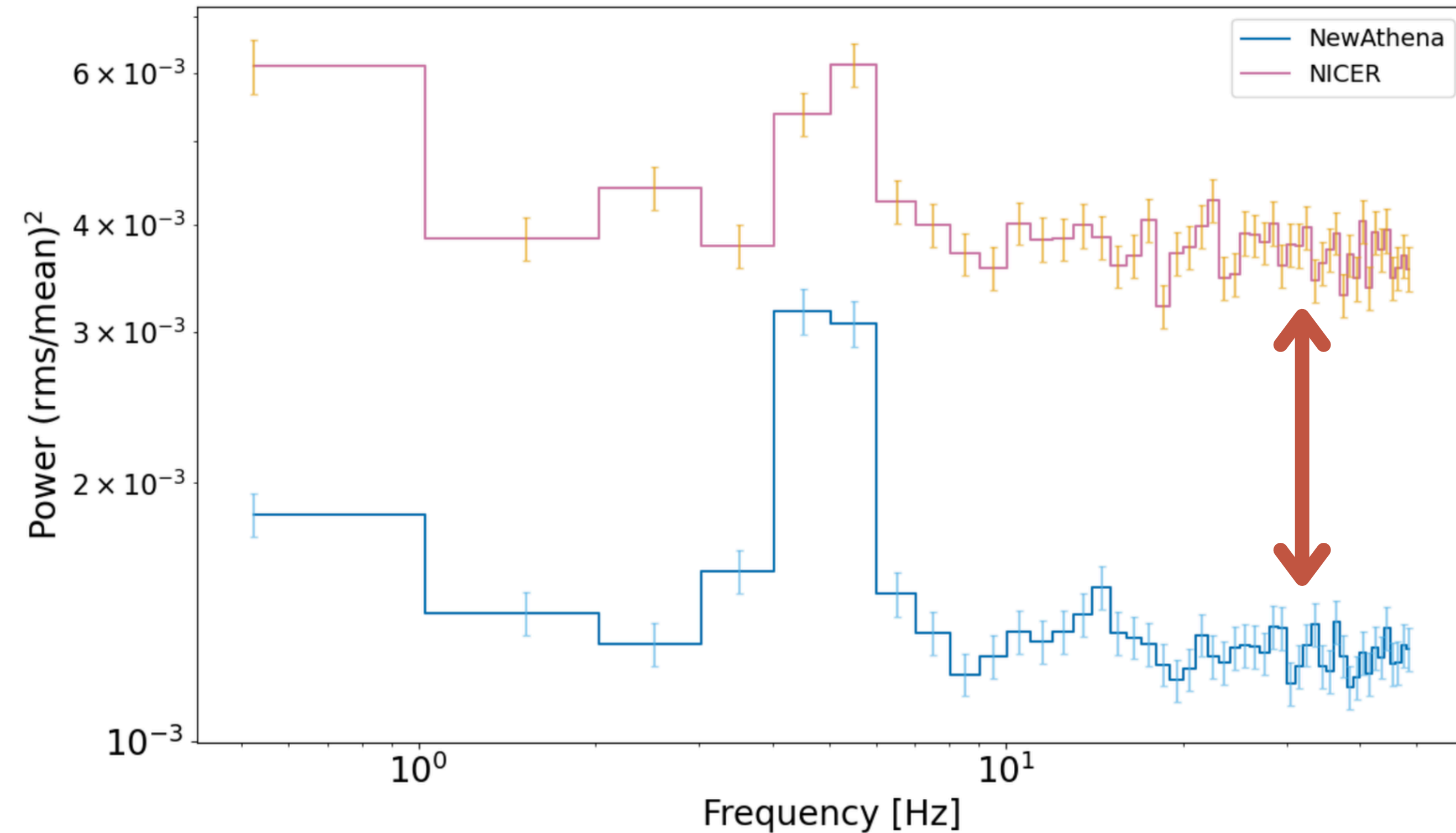
- The light curves show rapid count-rate changes together with hardness evolution

Will we do a better job with NewAthena?



- **NewAthena provides roughly a factor of two improvement in sensitivity to the QPO amplitude**

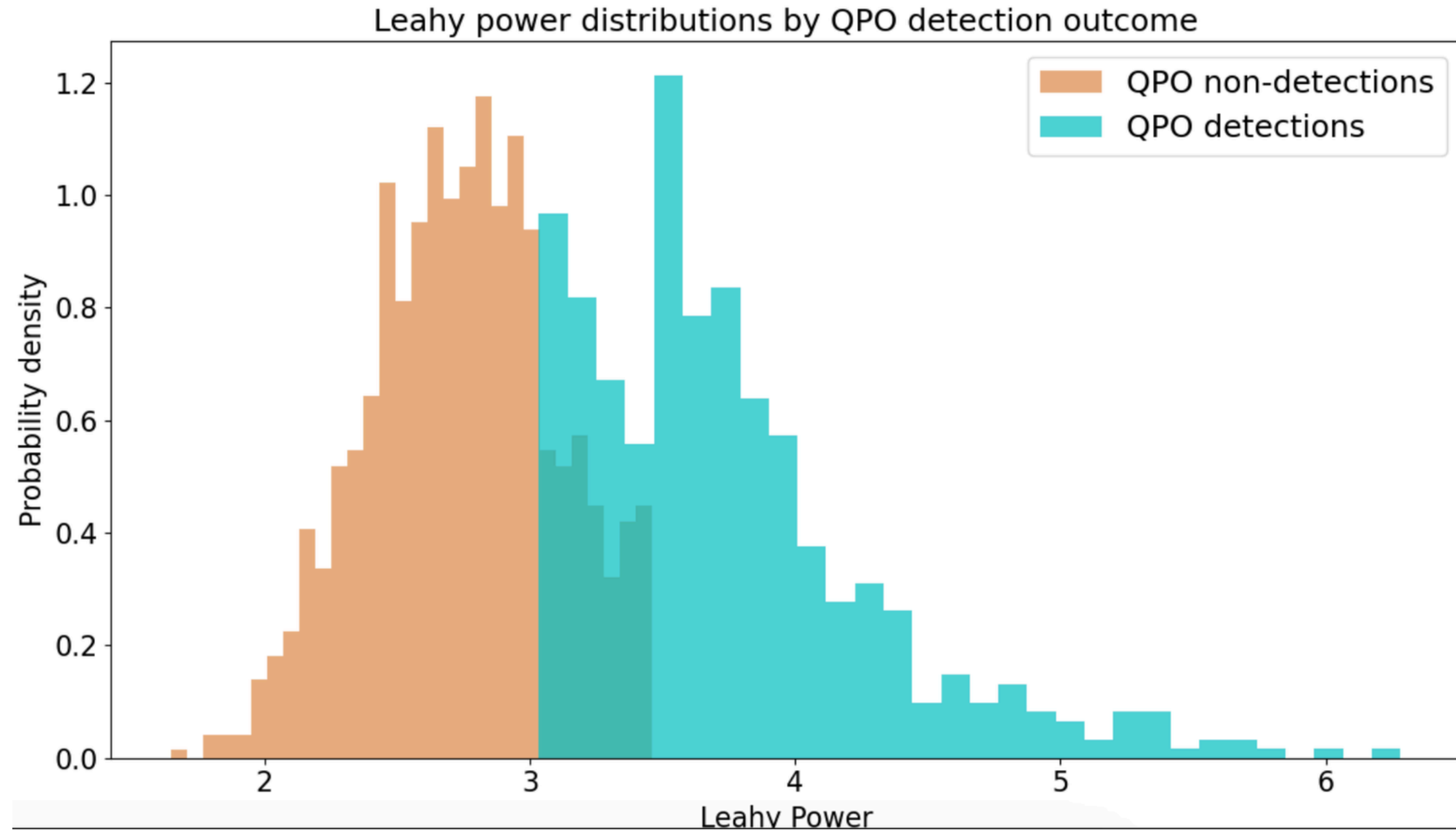
Will we do a better job with NewAthena?



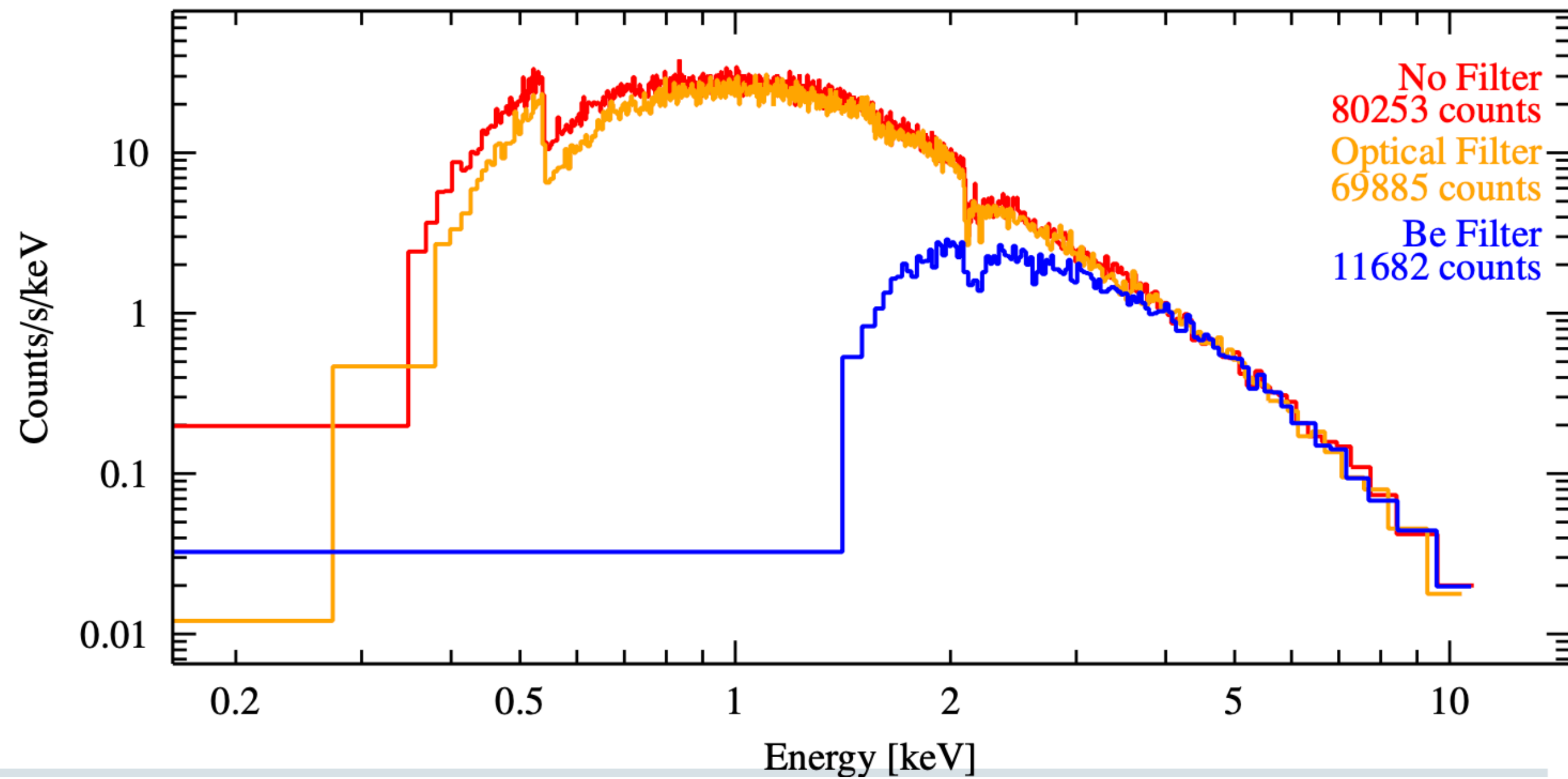
Signal-to-noise level ≈ 3 times higher with NewAthena

Are QPO really disappearing?

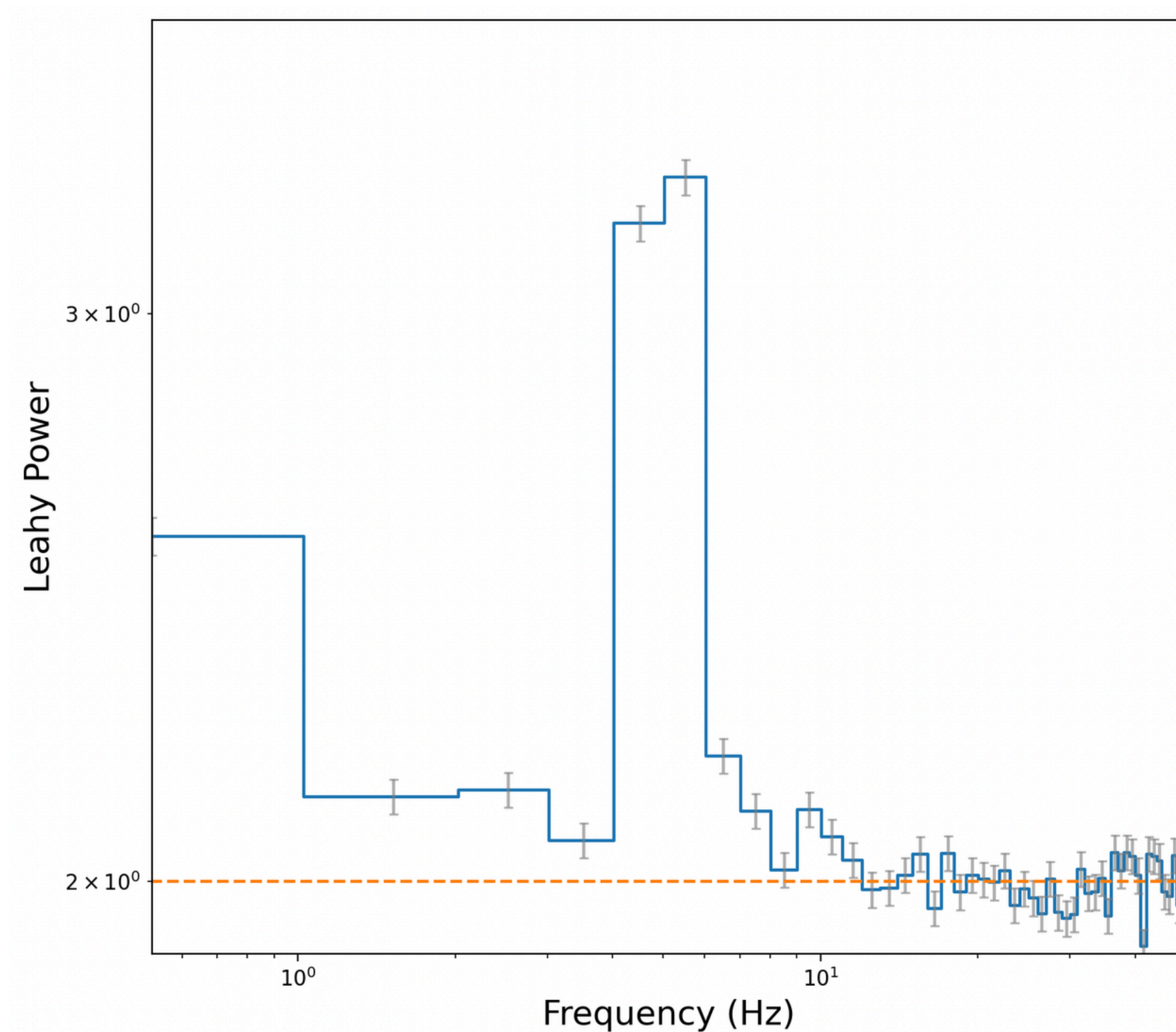
- The QPO detection map is threshold-limited by signal-to-noise
- Non-detections are not automatically QPO-off intervals
- They may include weak QPOs below the detection threshold



NewAthena Filter



Just Poisson noise?



QPO ON-OFF (99% singificance)

