

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

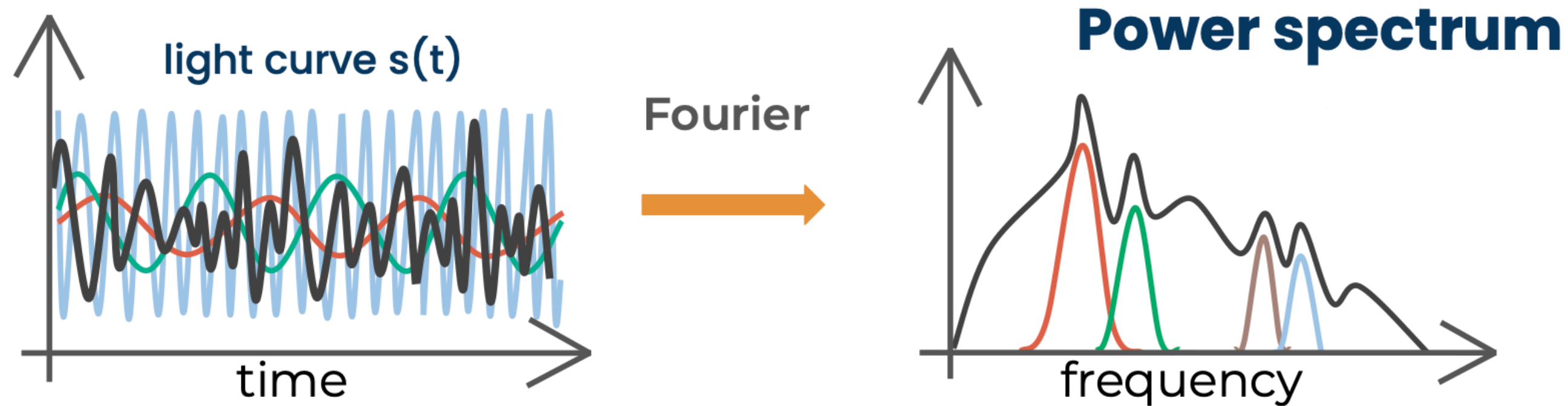
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In collaboration with
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NewAthena Rising 04/06/26



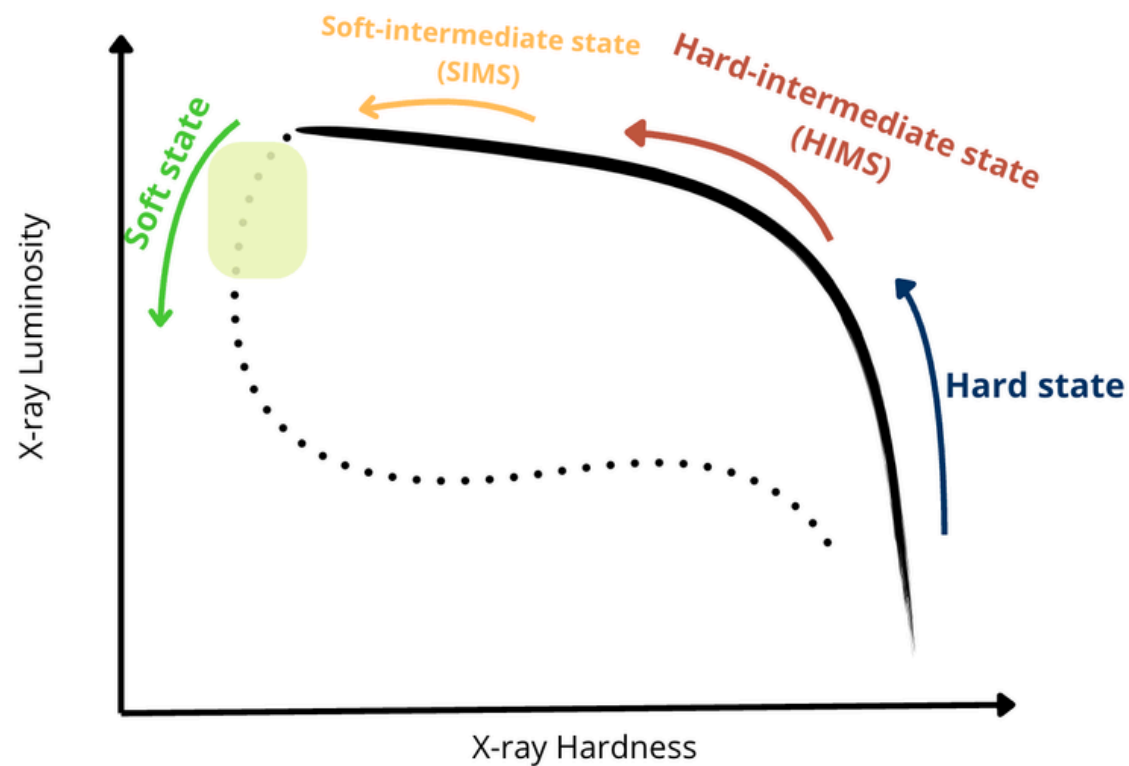
Why timing matters in BHXBs



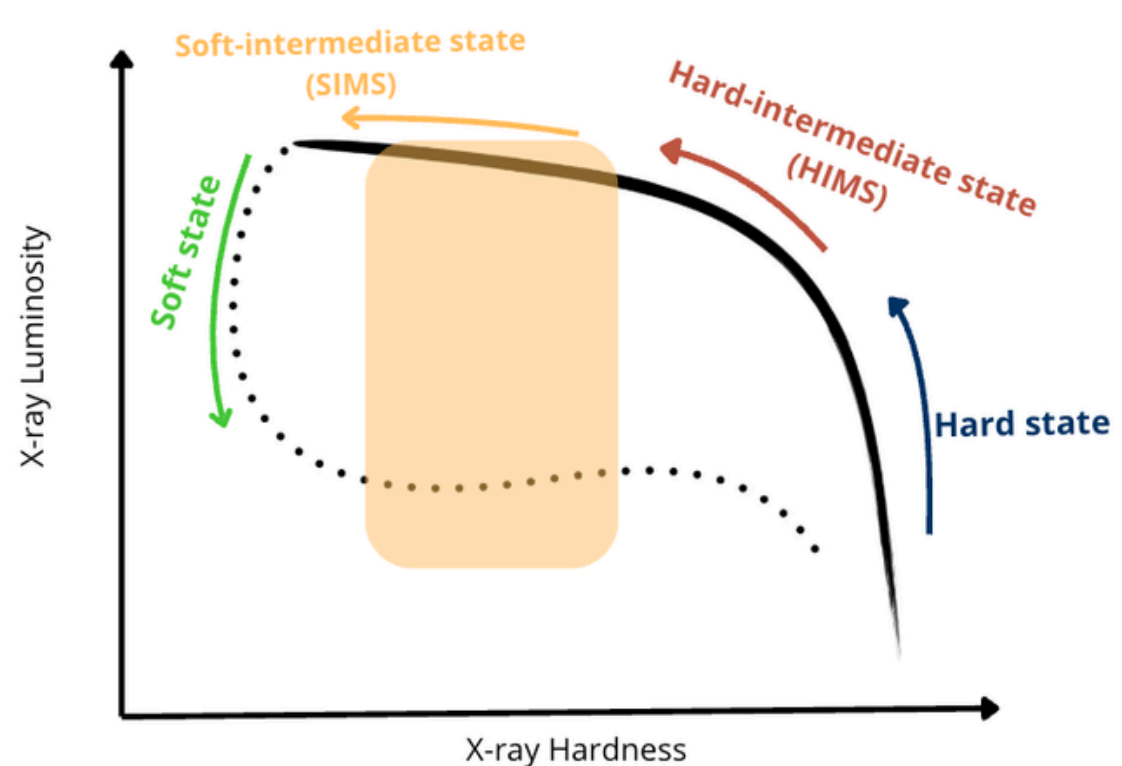
Valentina Pairano

- **Power spectrum** $P(\nu) = A|X(\nu)|^2$
- **the integral of the PSD over a given interval of temporal frequencies give the root mean square (rms) variability amplitude**

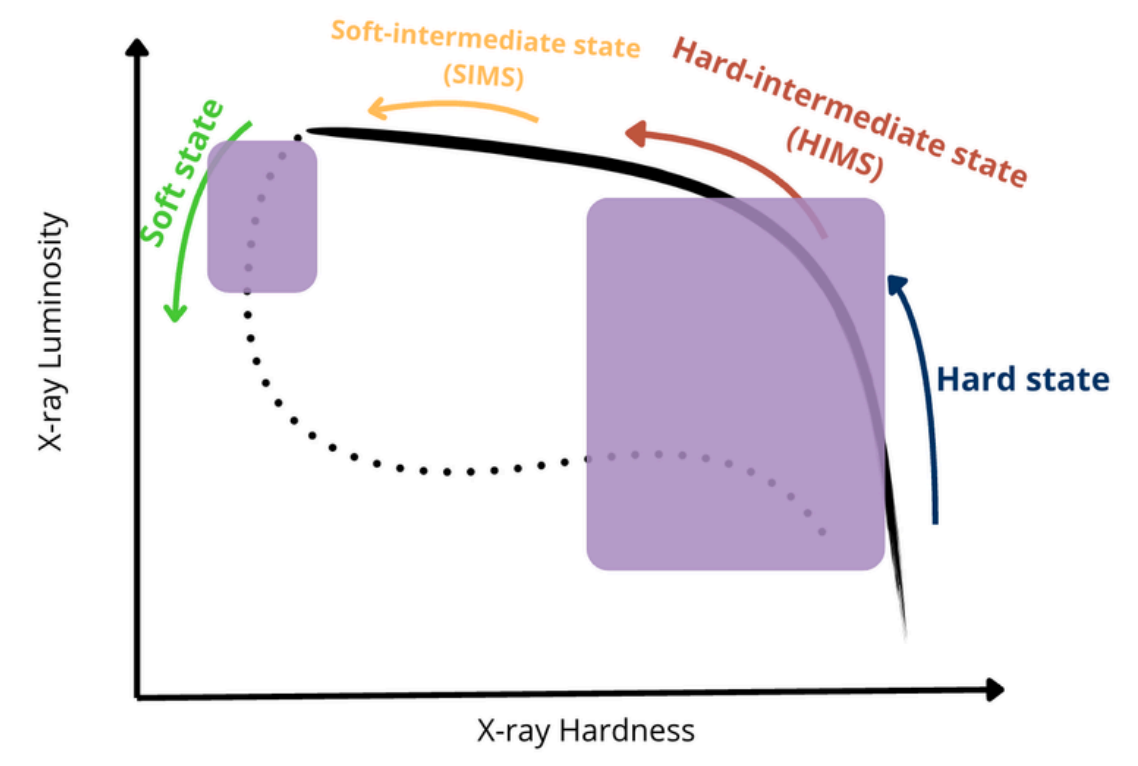
Low-frequency QPOs as state tracers



Type-A QPOs

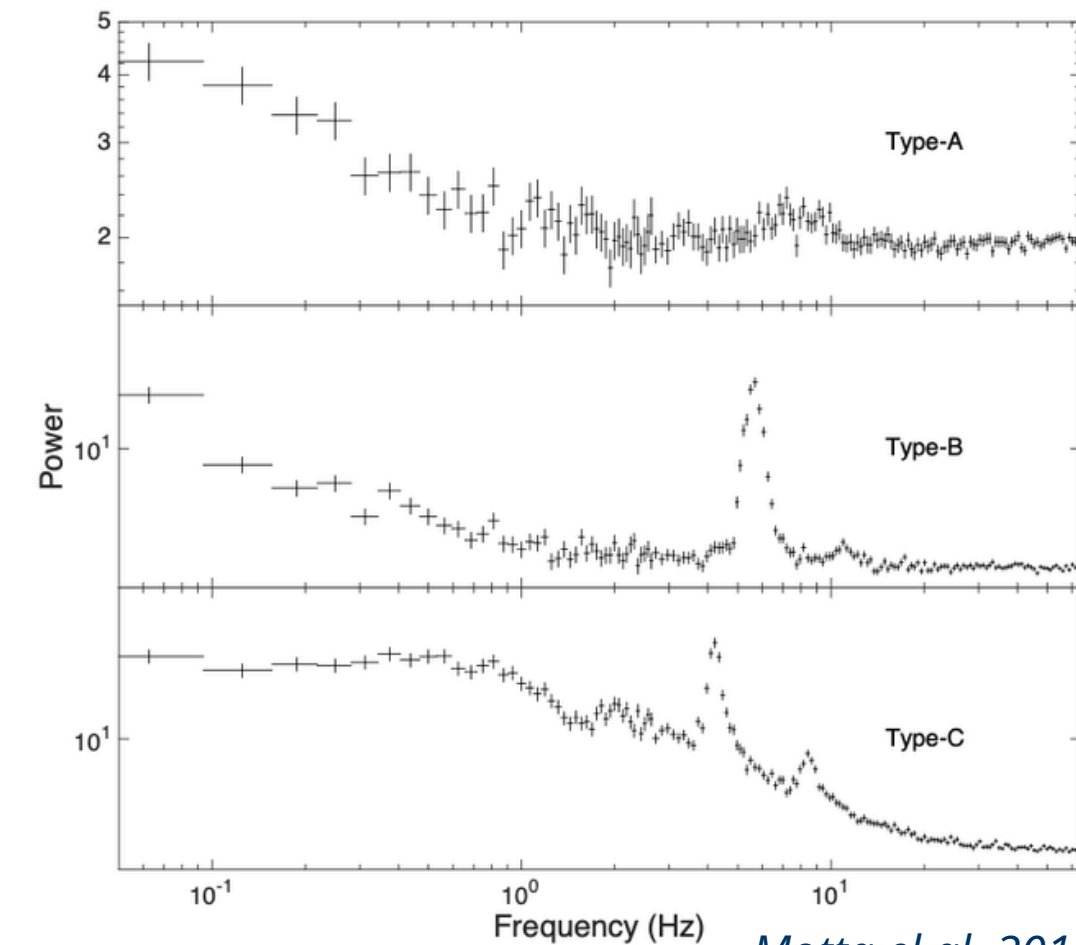


Type-B QPOs



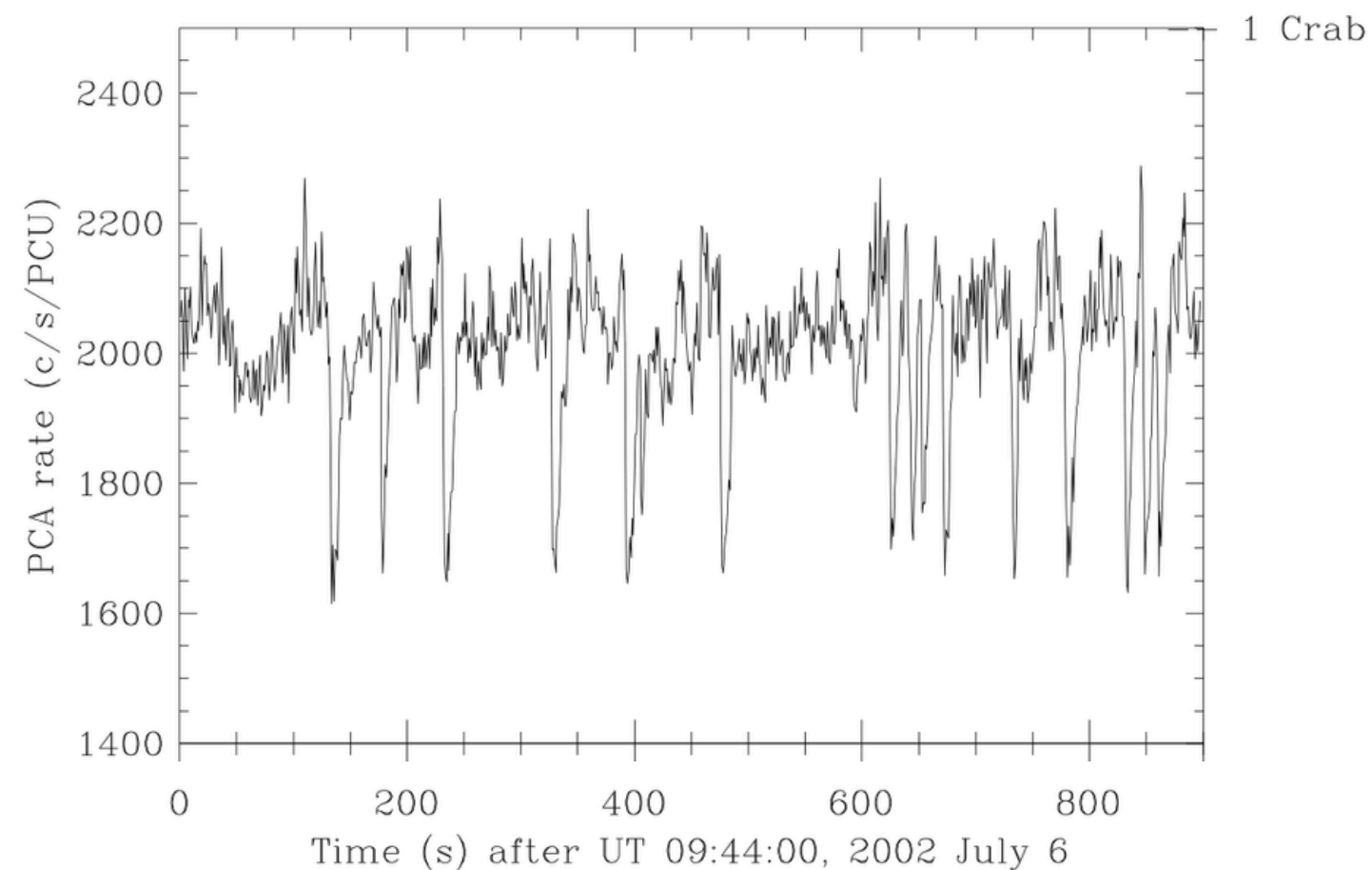
Type-C QPOs

- **Type A:** few percent rms, and broad ($Q=v/\text{FWHM} \leq 3$) peak around 6-8 Hz
- **Type B:** 5% rms, and narrow ($Q=v/\text{FWHM} \geq 5$) peak around 4-7 Hz
- **Type C:** up to 20% rms, narrow ($Q=v/\text{FWHM} \geq 10$) and variable peak at frequencies 0.1-15 Hz



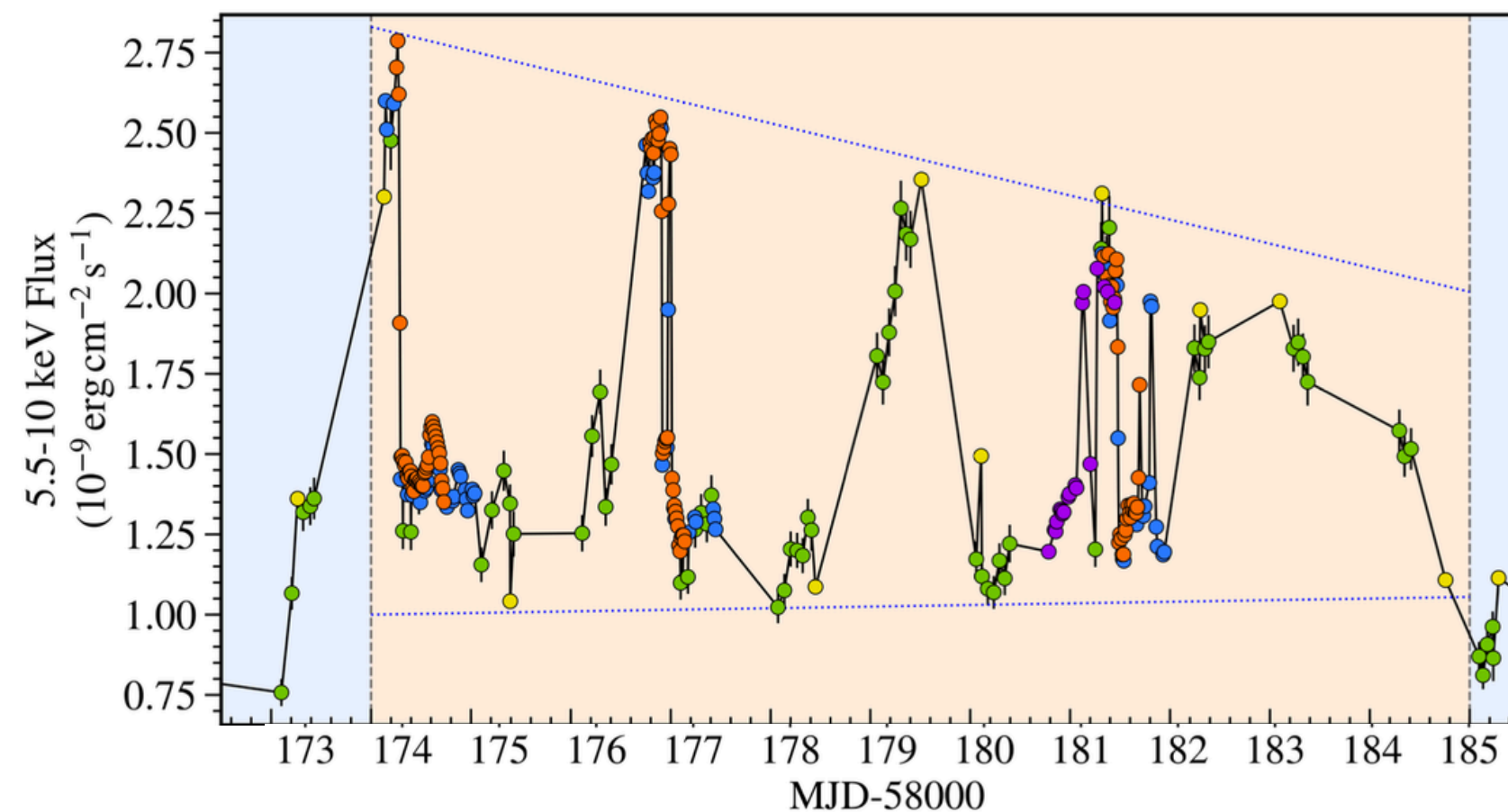
Flip-Flop

Dips



Park et al. (2004)

Flip-Flop



Bogensberger et al. (2020)

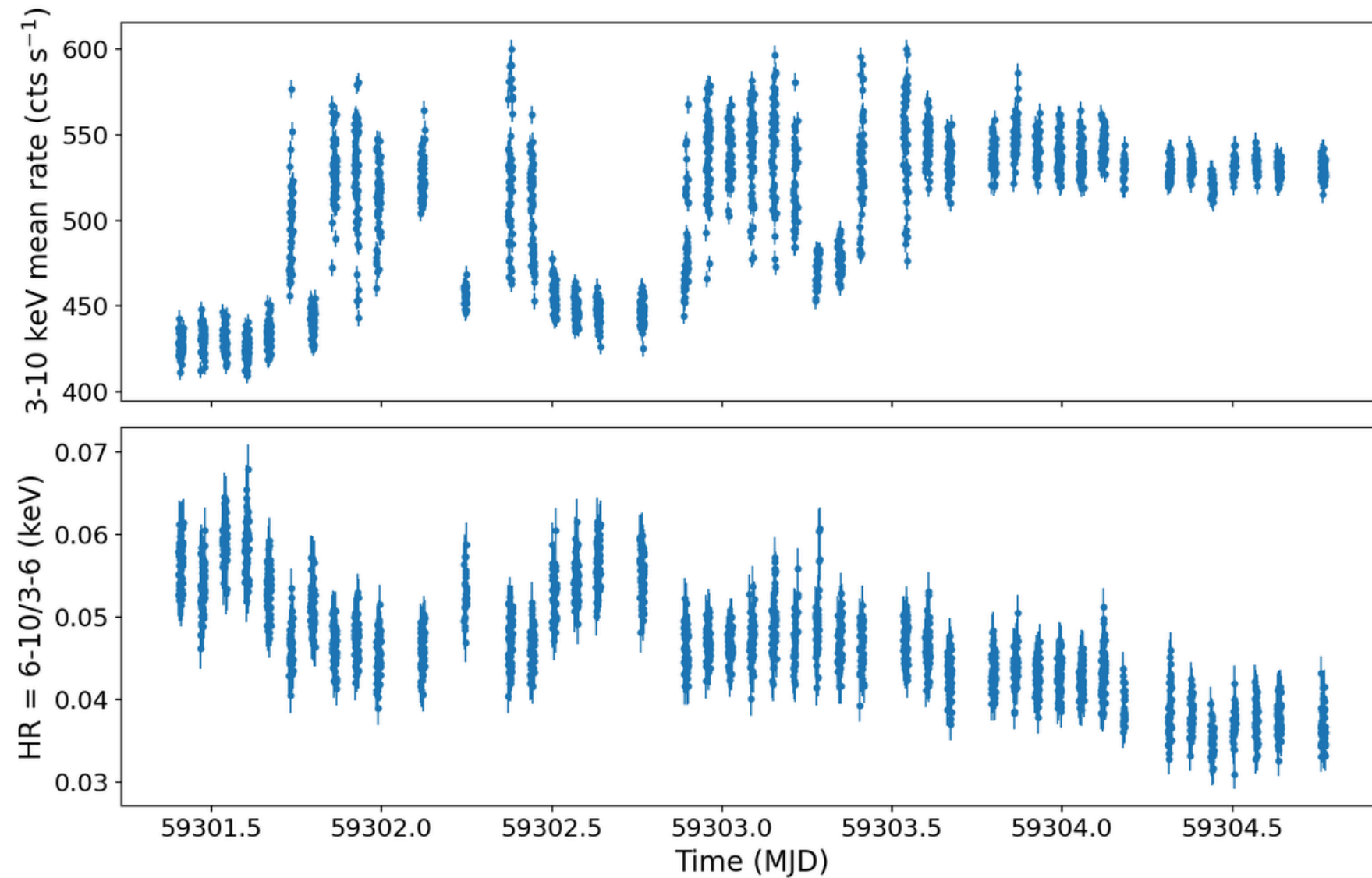
- During a dipping event, the source briefly drops to a dimmer flux

- During a flip-flop event, the source spends significant time in both states and very little moving between them

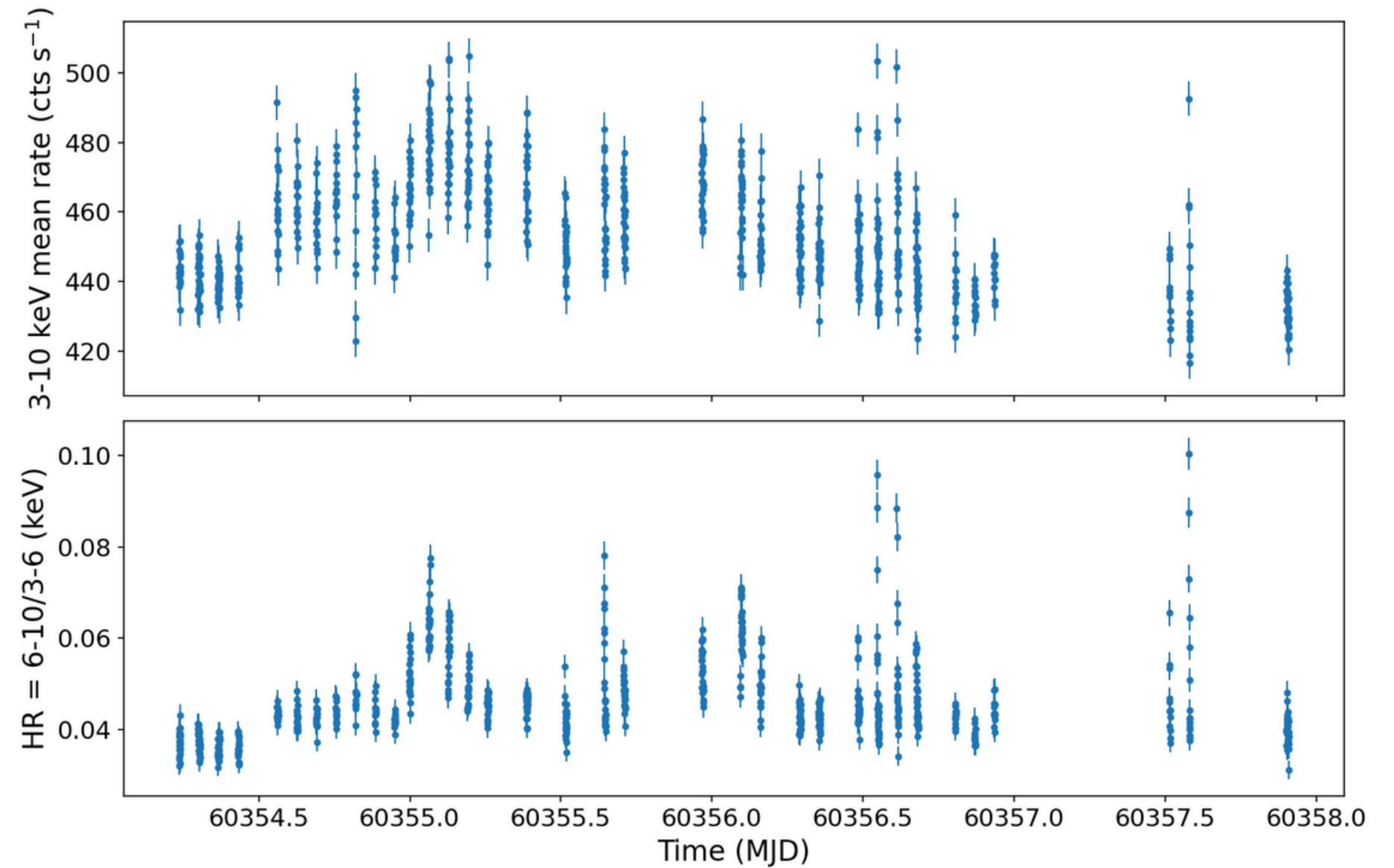
Fast variability during the transition

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



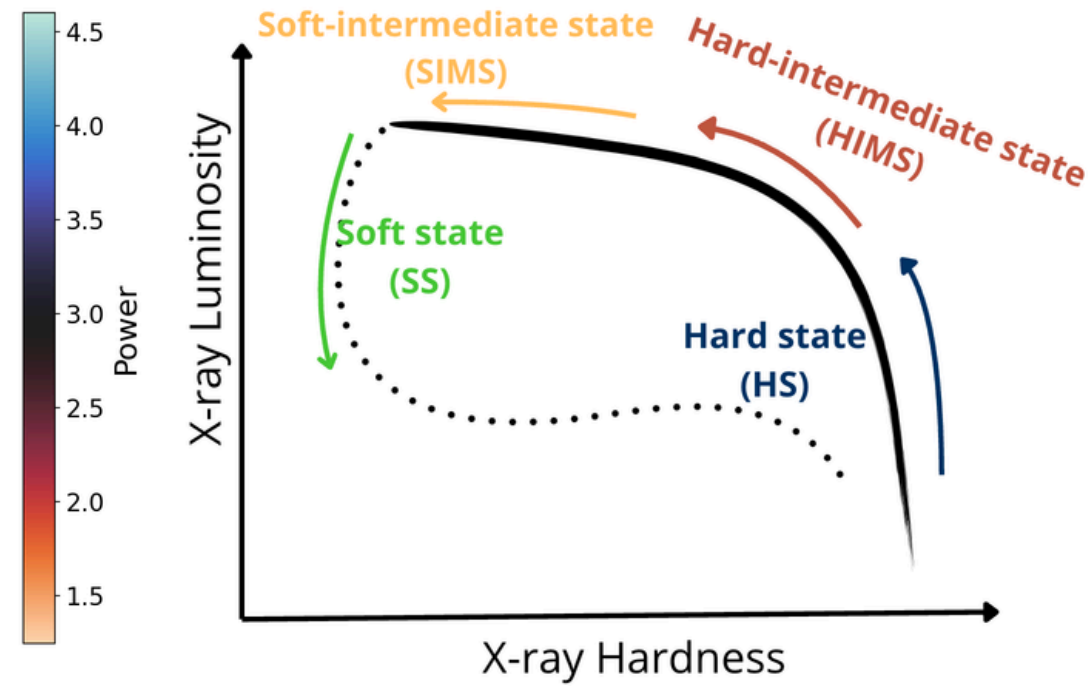
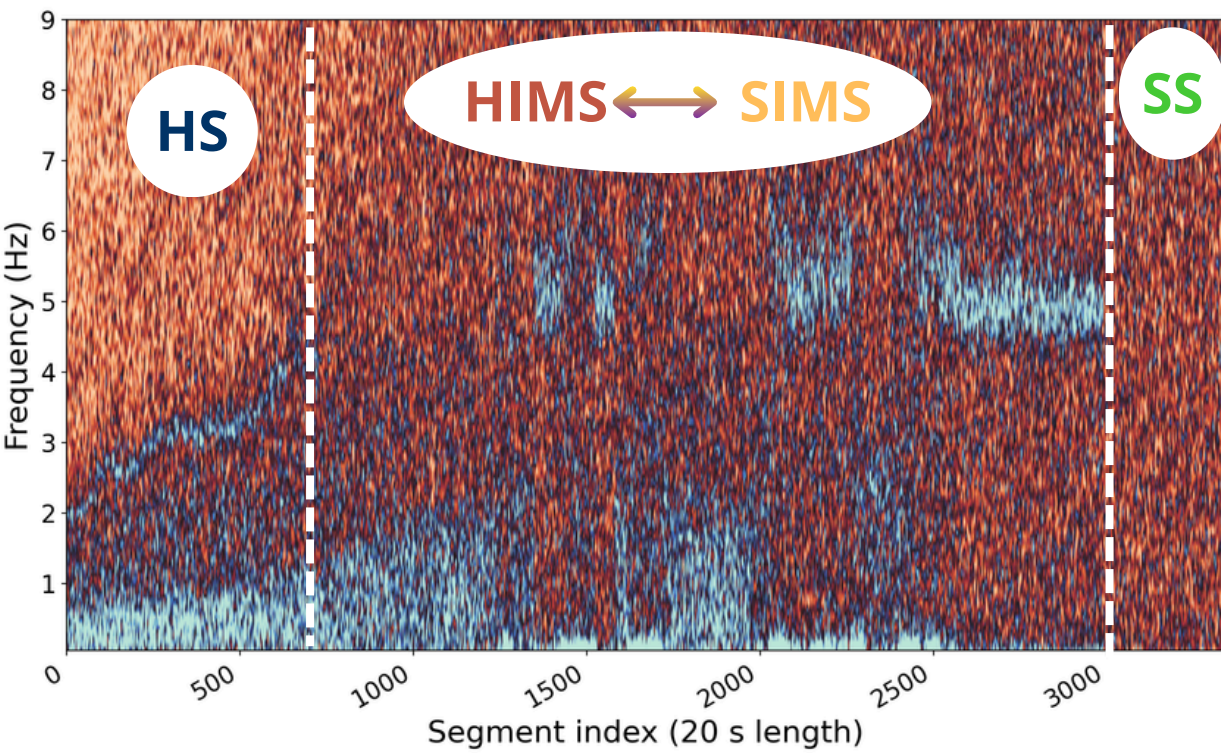
Outburst 2024



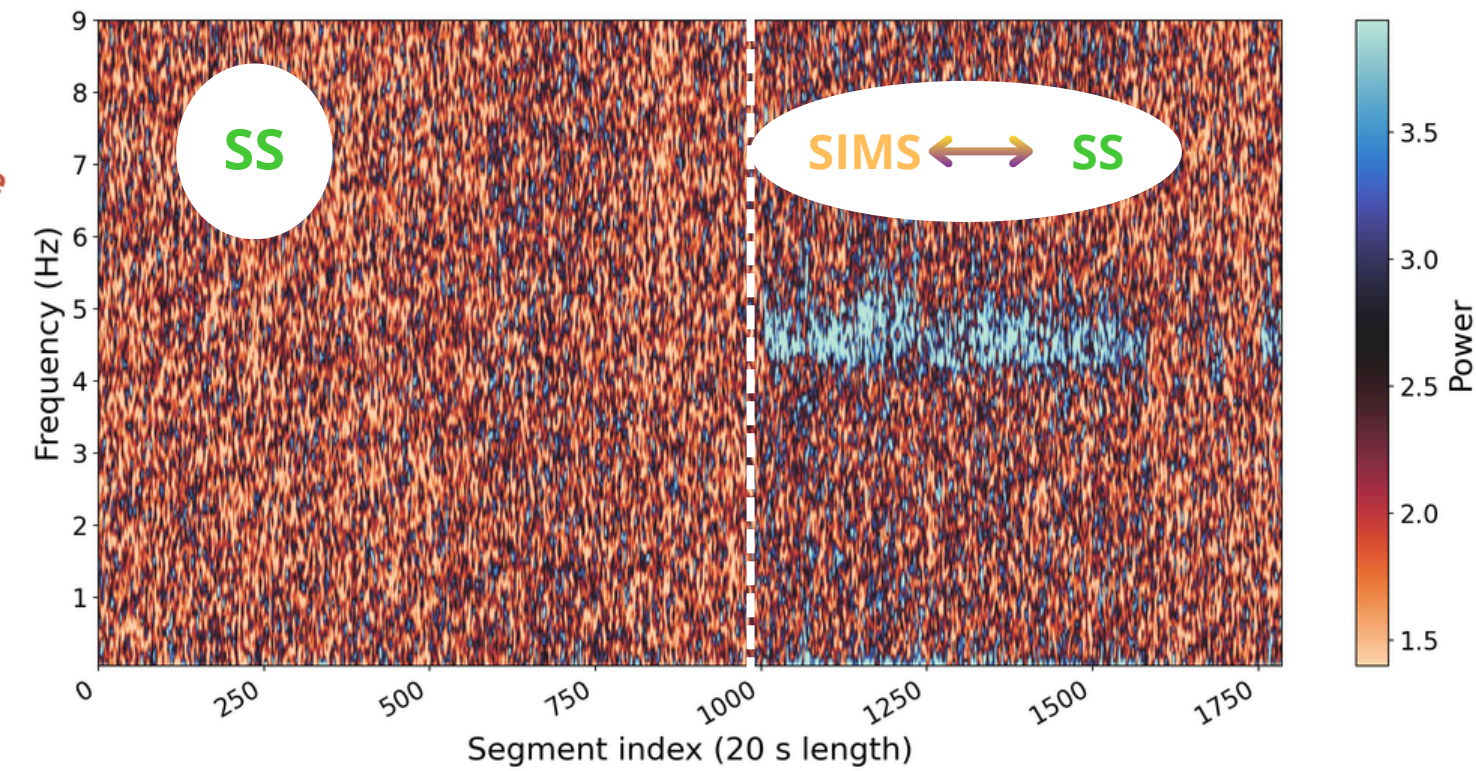
- The 3–10 keV NICER light curves show rapid count-rate changes together with hardness evolution

GX 339-4: Dynamical power spectrum

Outburst 2021

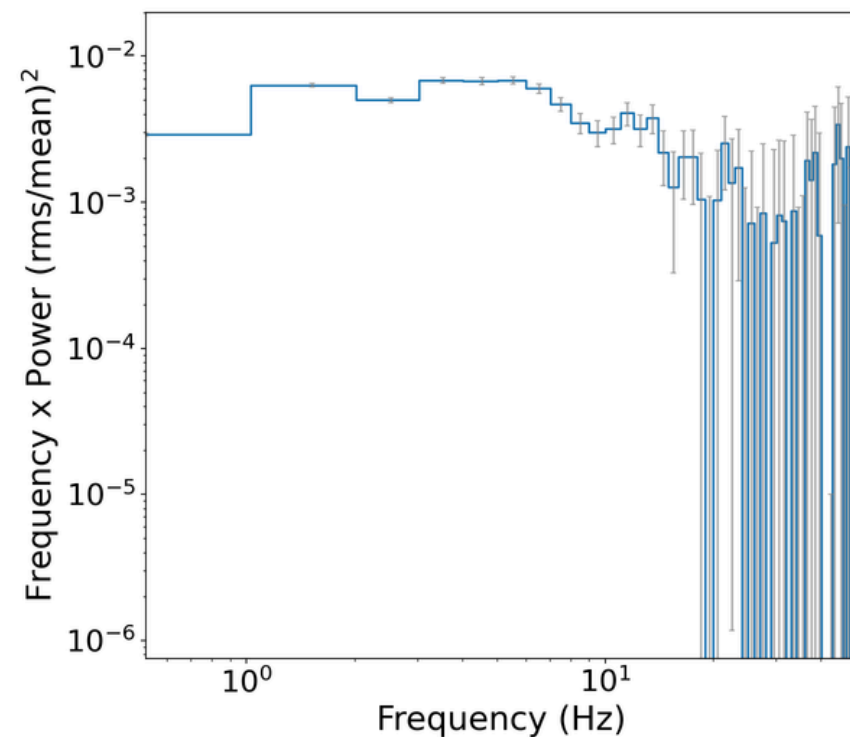


Outburst 2024

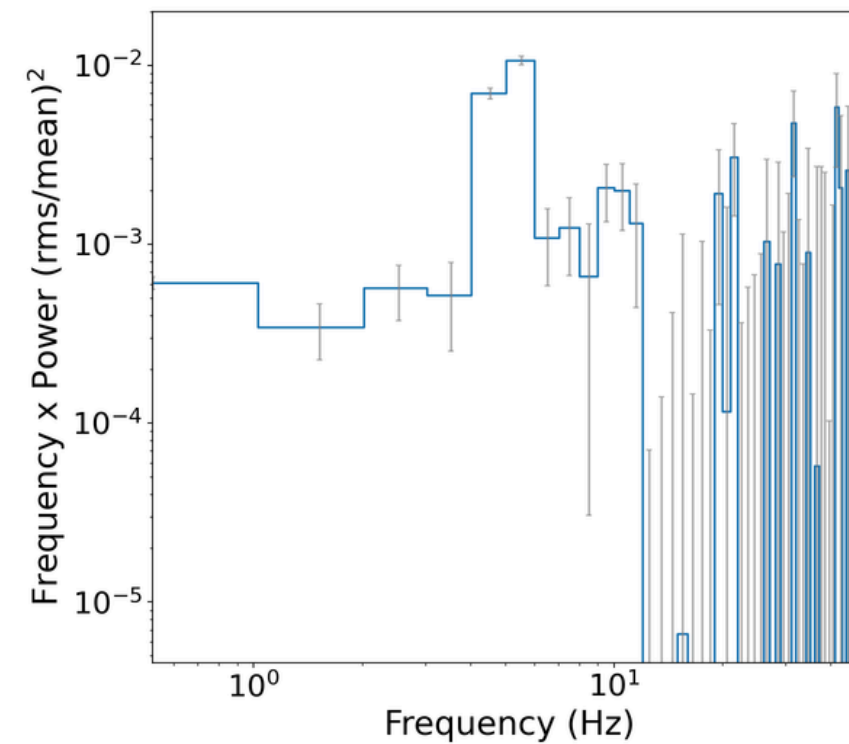


Computed from 3–10 keV lightcurves (0.01 s binning, 20 s segments) considering only the hard-to-soft transition (Buisson et al. 2025)

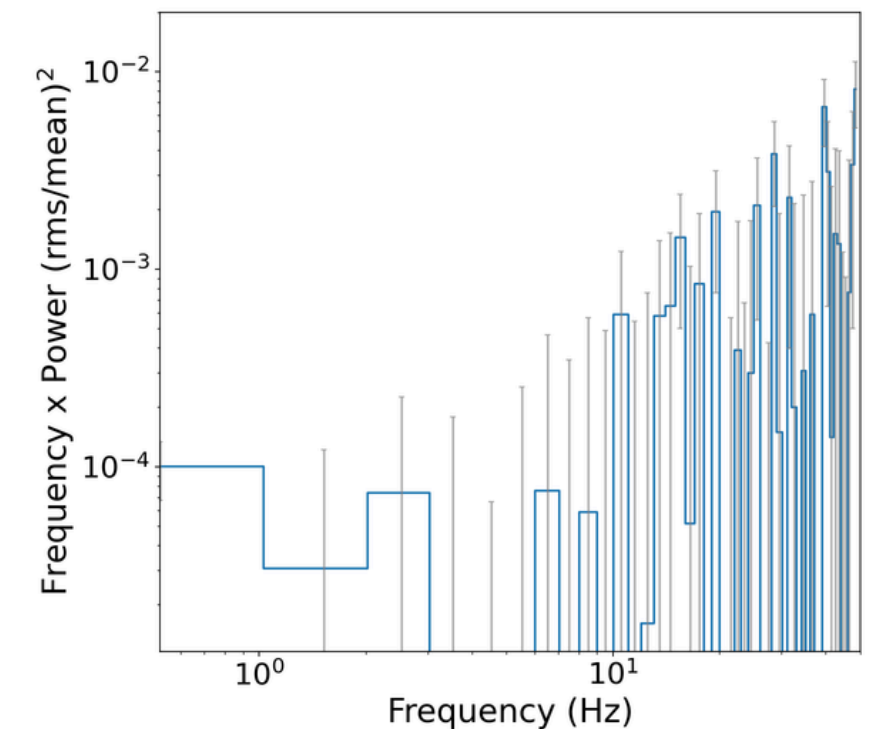
HIMS



SIMS

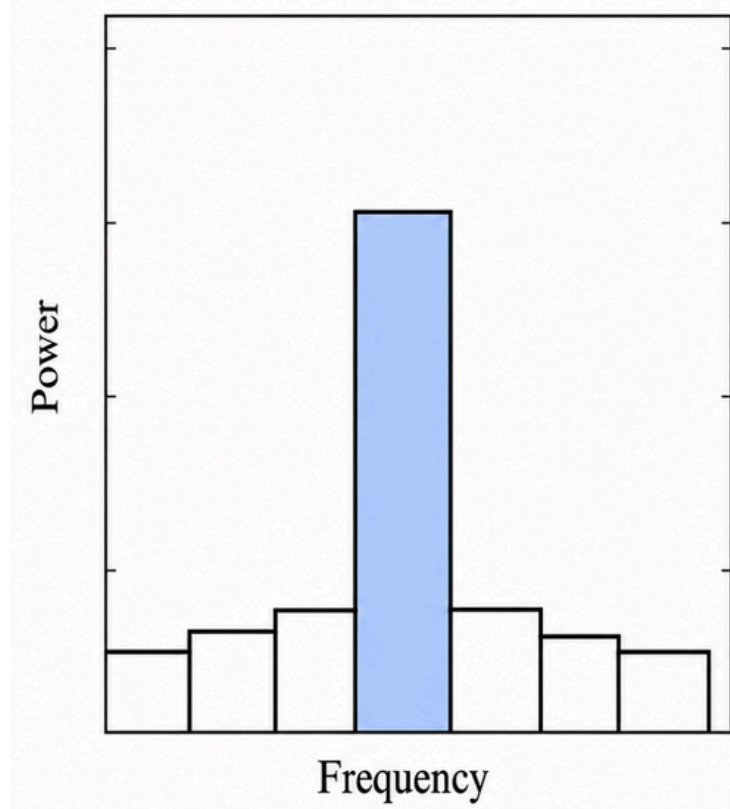


Soft state

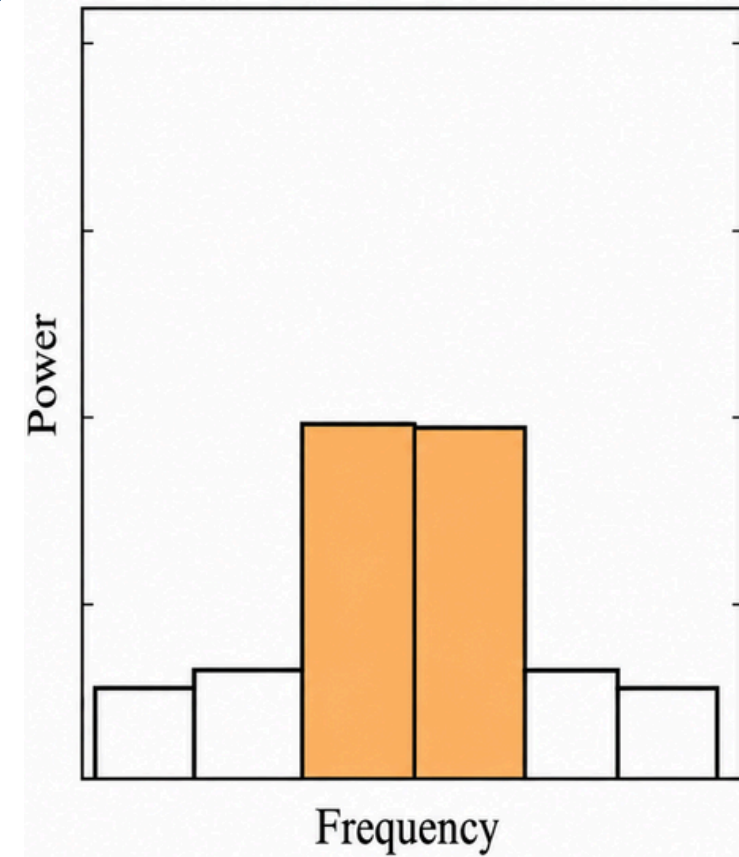


Monte Carlo significance with a “two-bin” safeguard

- 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:



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



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

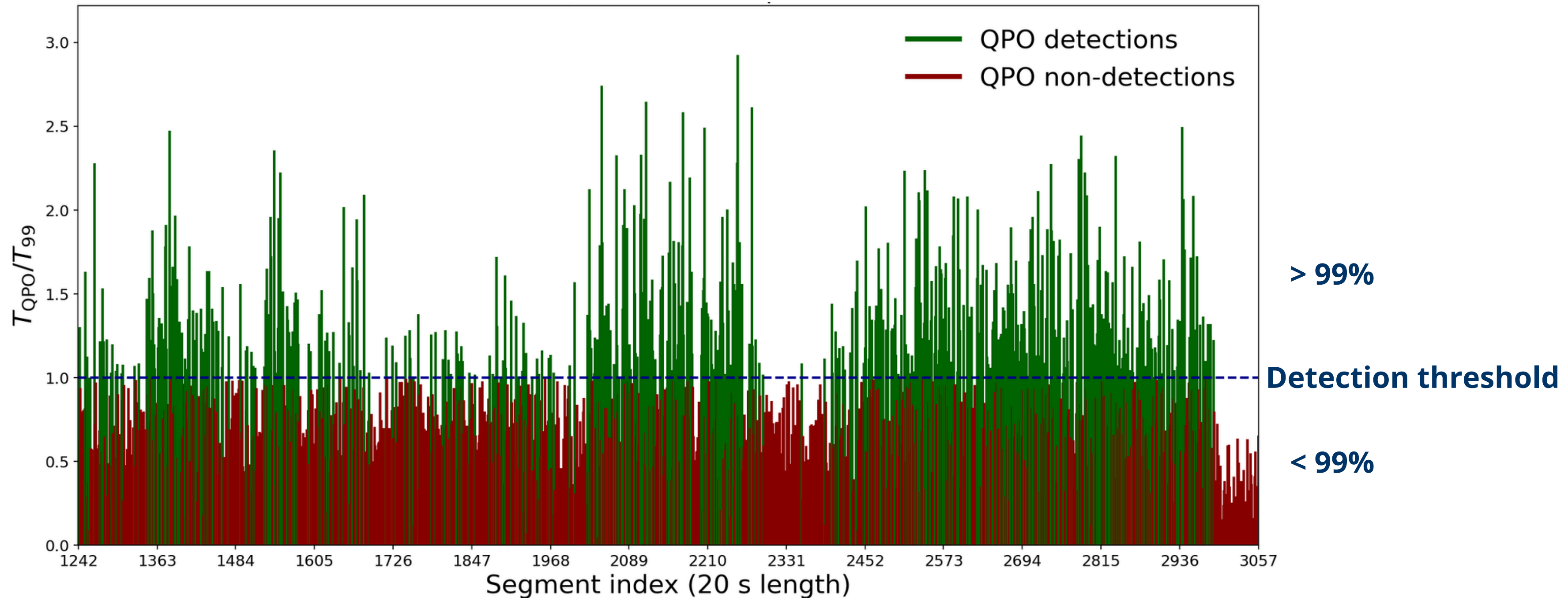
- $T_{\nu_j} = \max(S_{\nu_j}^{(1)}, S_{\nu_j}^{(2)}), \quad T_{QPO} = \max(T_{\nu_j})$

- Then we run Monte Carlo simulations, compute T for each simulated PDS, and obtain a p-value for the observed T

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

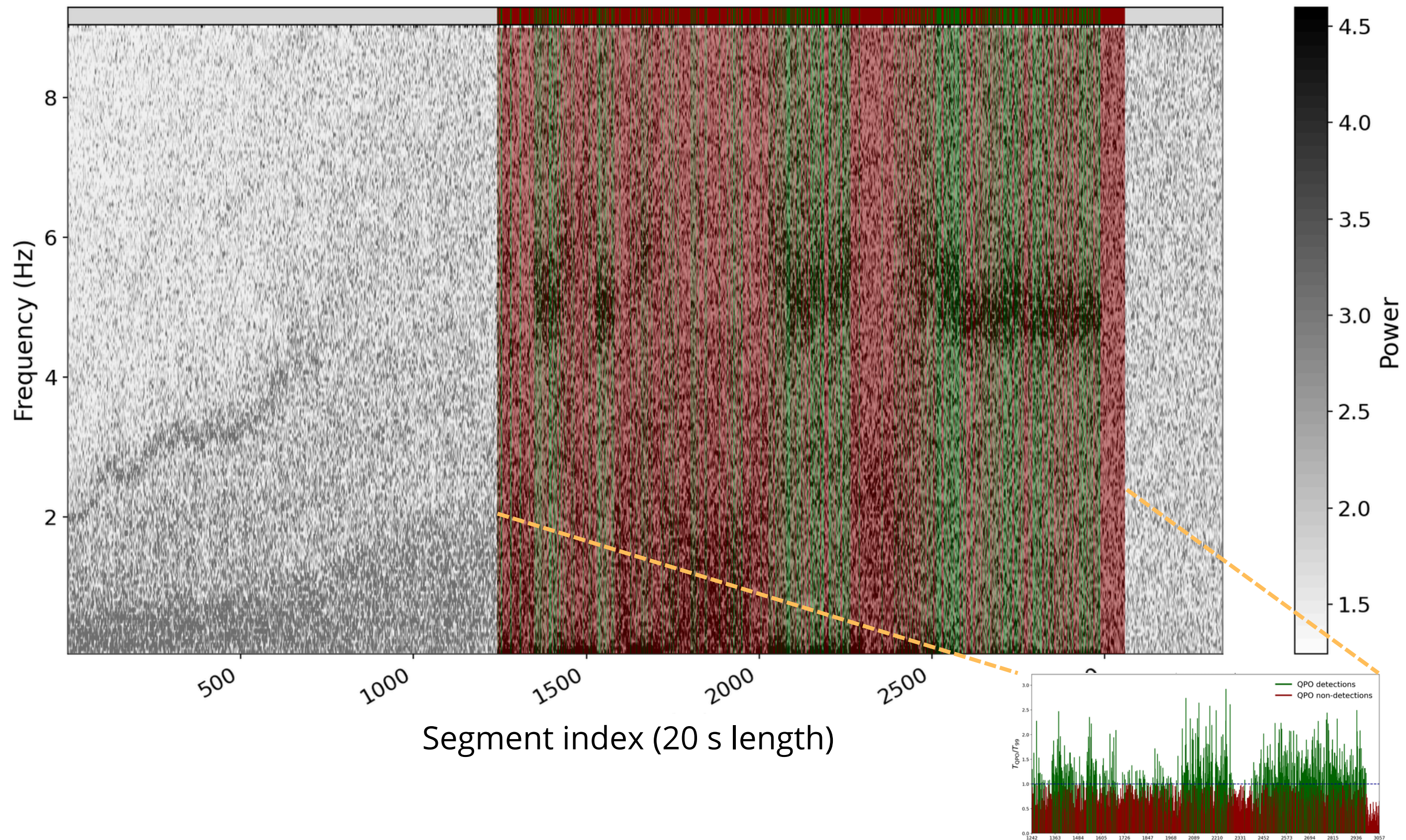
Segment-by-segment QPO detection map

2021 outburst QPO detection map



- Green segments exceed the 99% threshold; red segments do not
- 2024 outburst working in progress

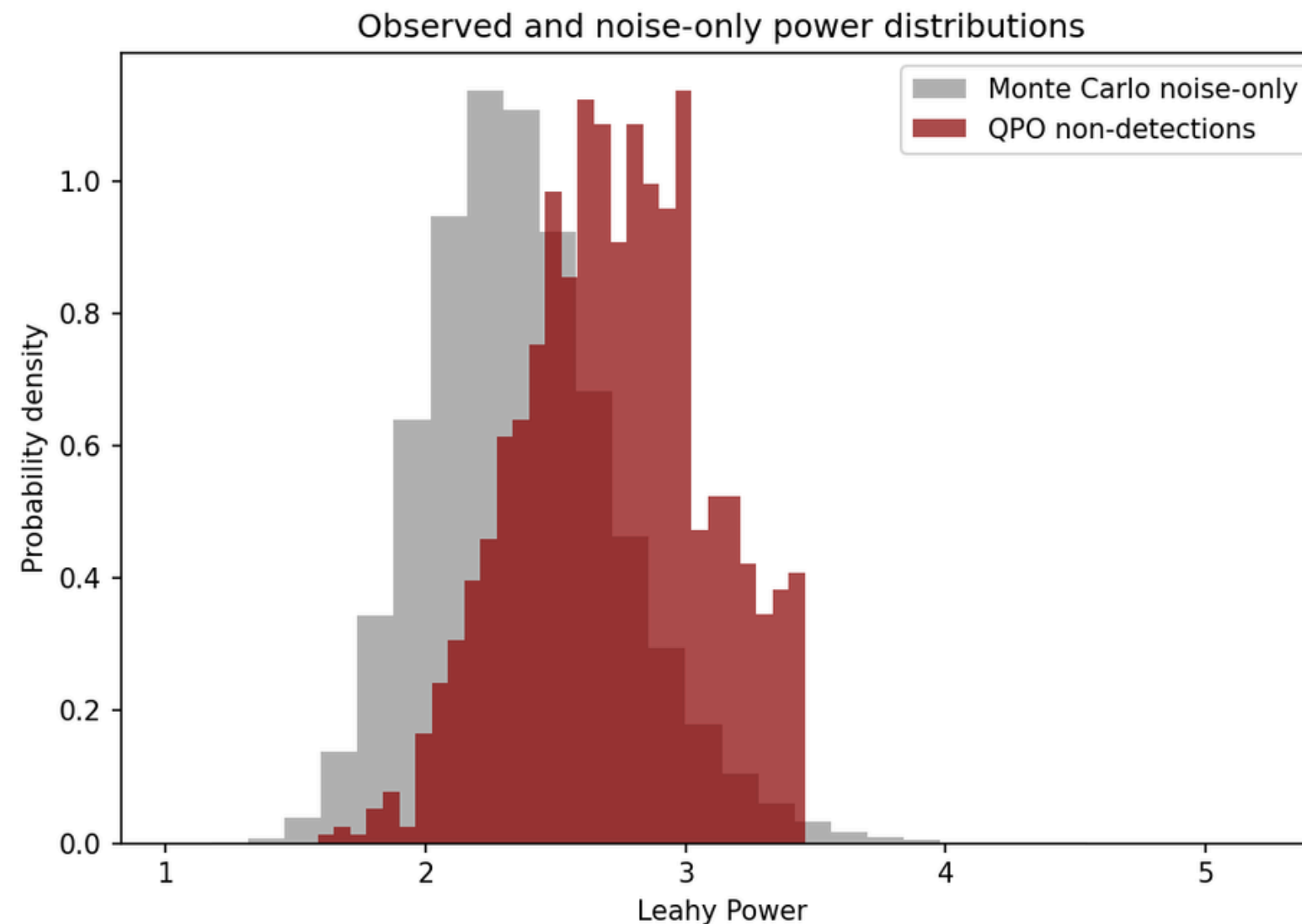
Where are the QPO detections in the DPS?



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

Are QPO really disappearing?

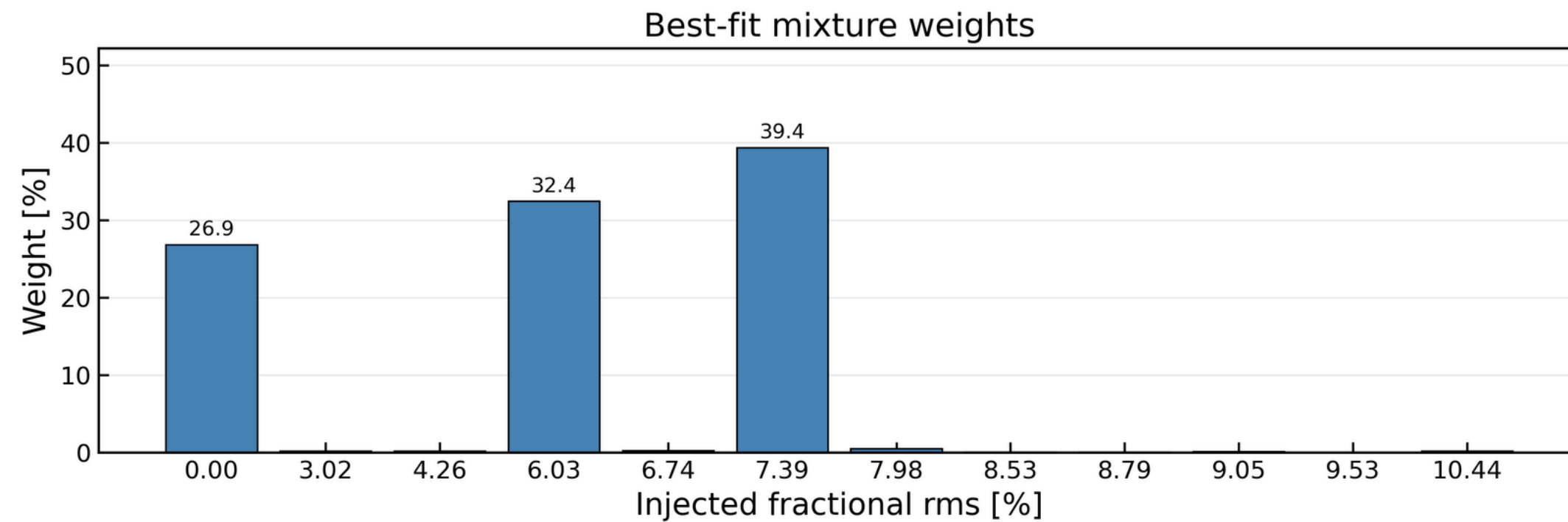
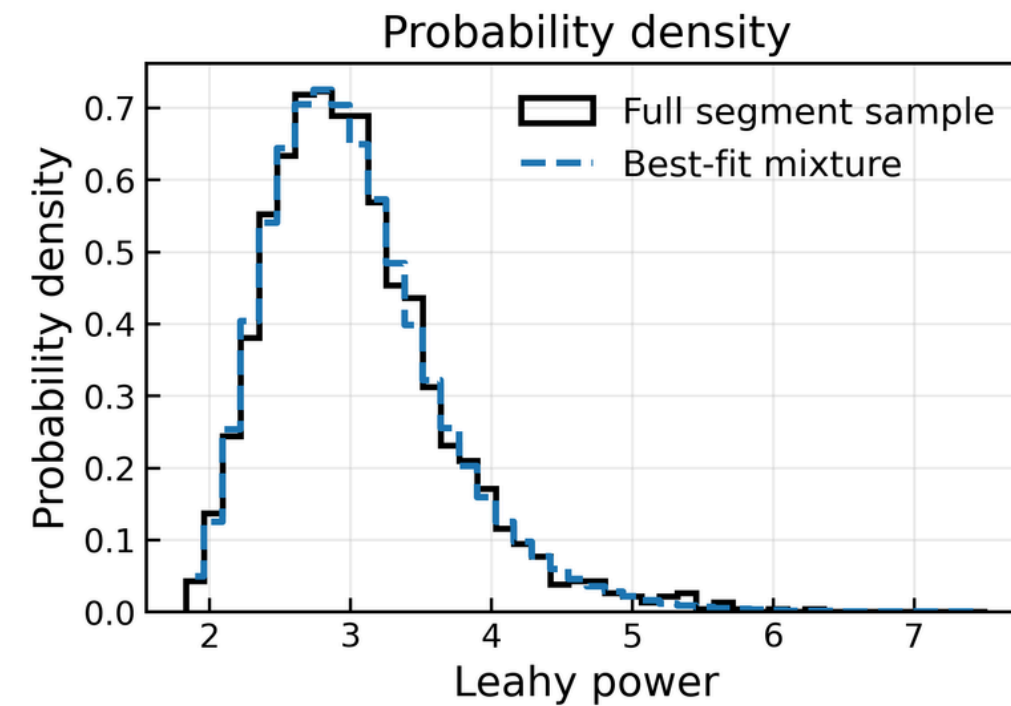
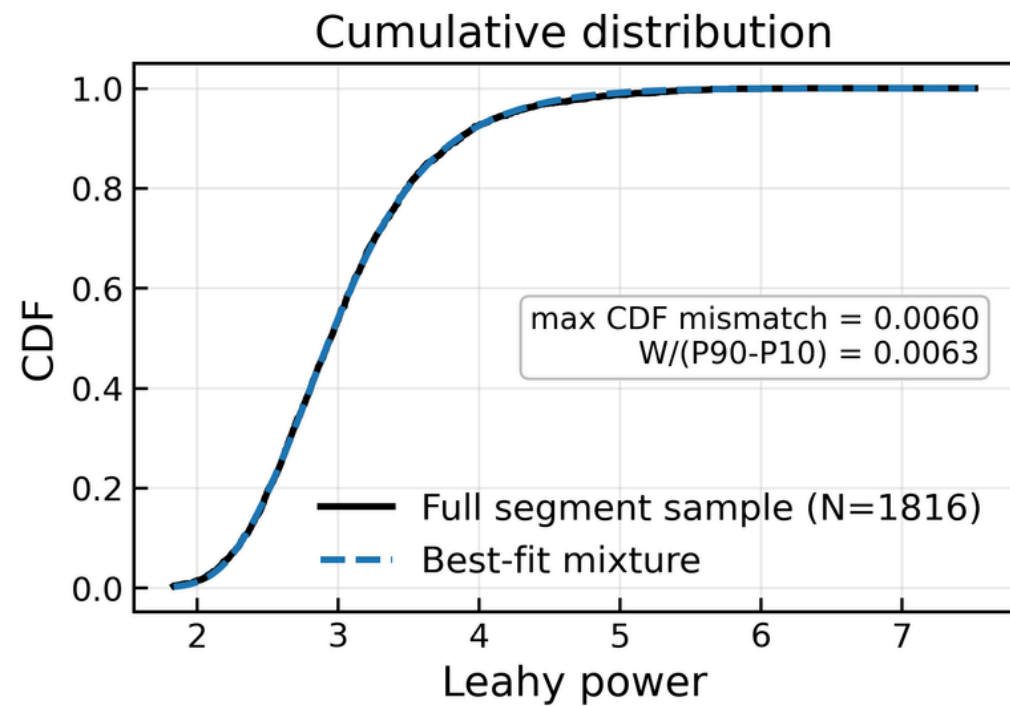
- We compare the QPO non-detection segments with Monte Carlo noise-only simulations



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

Are QPO non-detections real disappearances?

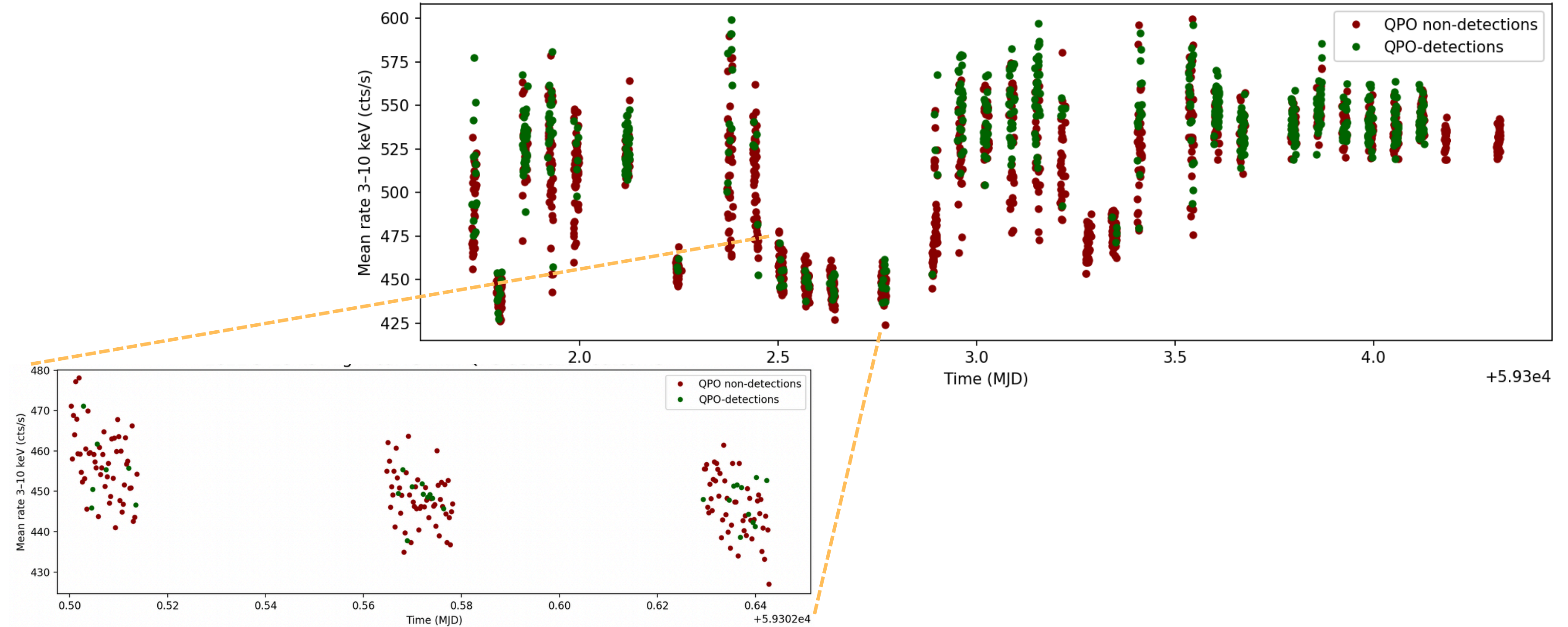


- **KS: 0.007**
- **p-value: 0.999**

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

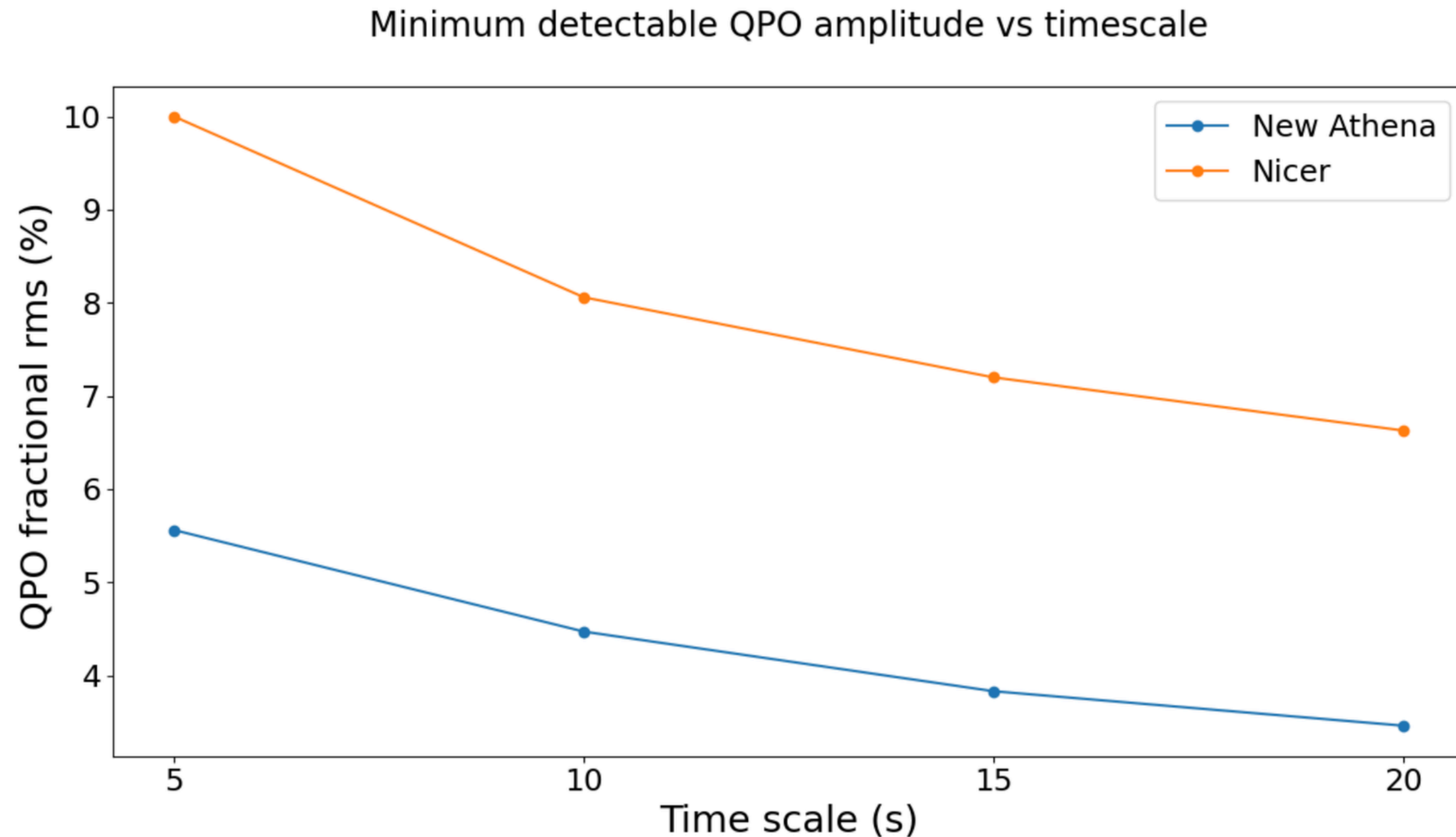
QPOs “Switches” Are Not Simply Flux-Driven

2021 3–10 keV light curve with QPO detection outcome



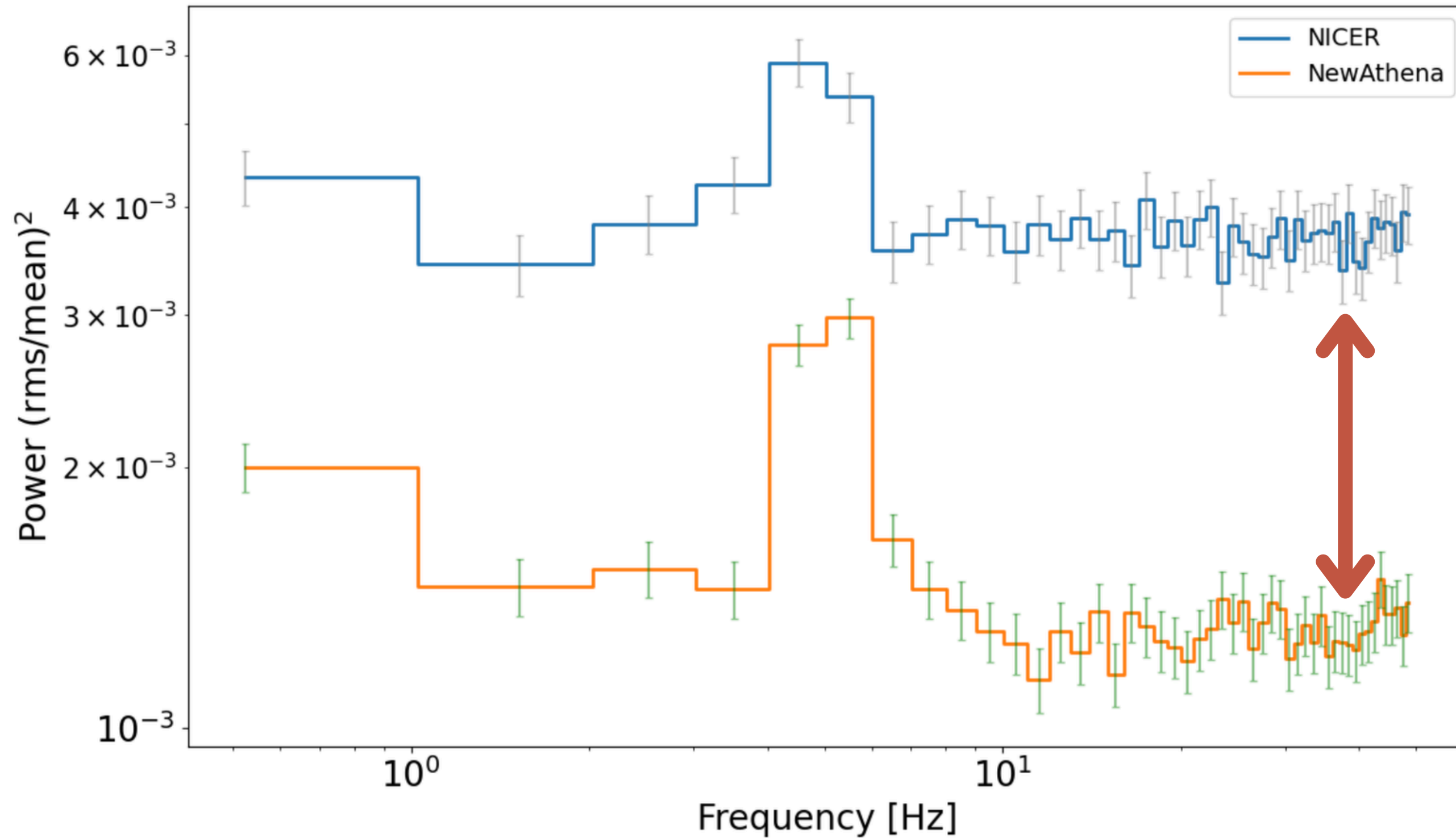
- At the current threshold there is no a clear correlation between flip-flops (count rate change) and changes in the power spectrum (spectral changes)

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?



Poisson-noise level ≈ 3 times lower with NewAthena

Conclusion and Future Work

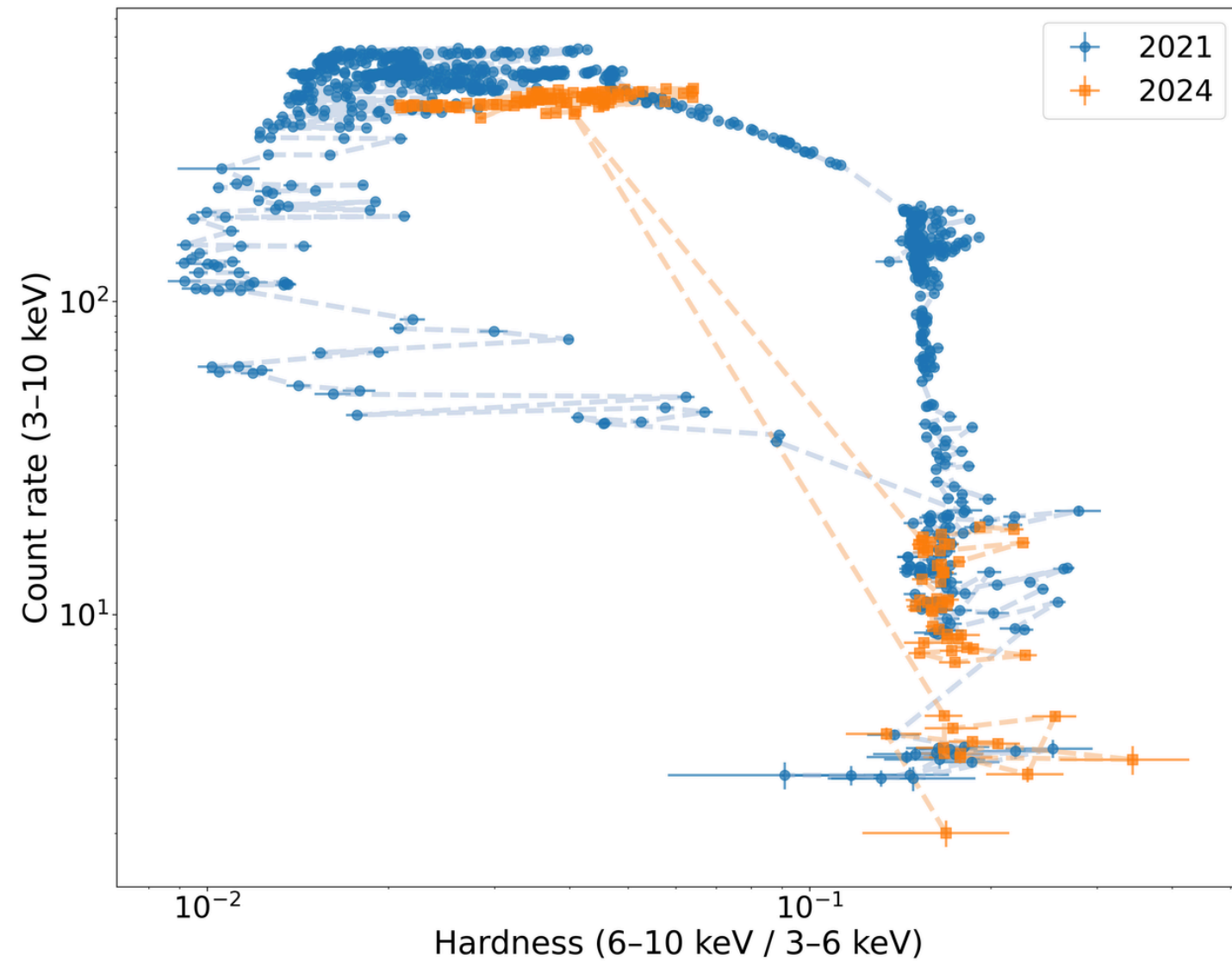
- **GX 339–4 shows rapid flip-flop-like variability during the hard-to-soft transition**
- **results suggest that on timescales of 20 seconds the QPO either turns off or changes amplitude**
- **Next step: combine Monte Carlo QPO classification with QPO-on/off spectroscopy**
- **NewAthena will allow the same test on shorter timescales and with lower Poisson-noise limitations**

Thank you for your attention

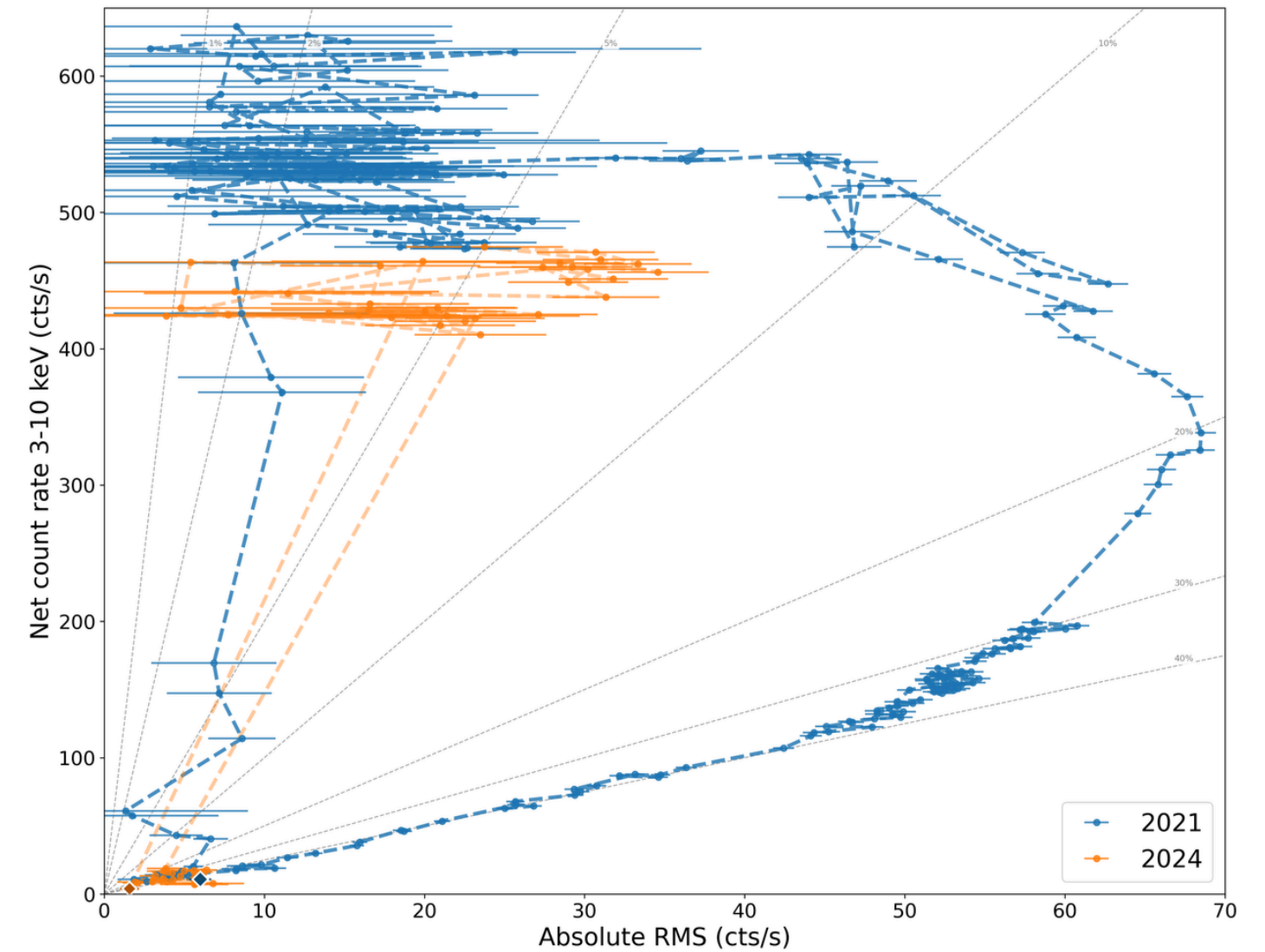
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GX 339-4: HID and RMS-Intensity Diagram

HID: 2021 vs 2024 NICER Outbursts



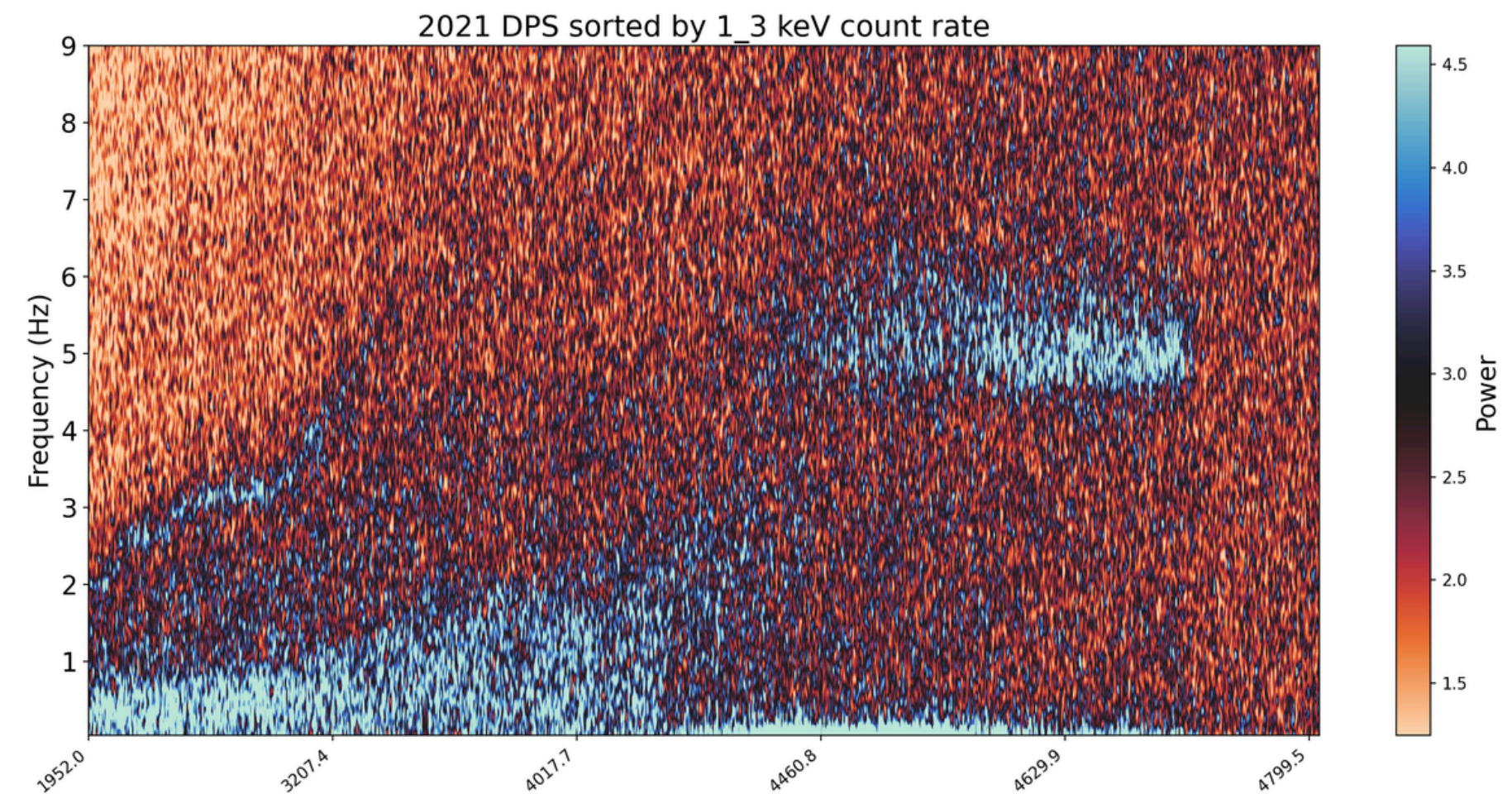
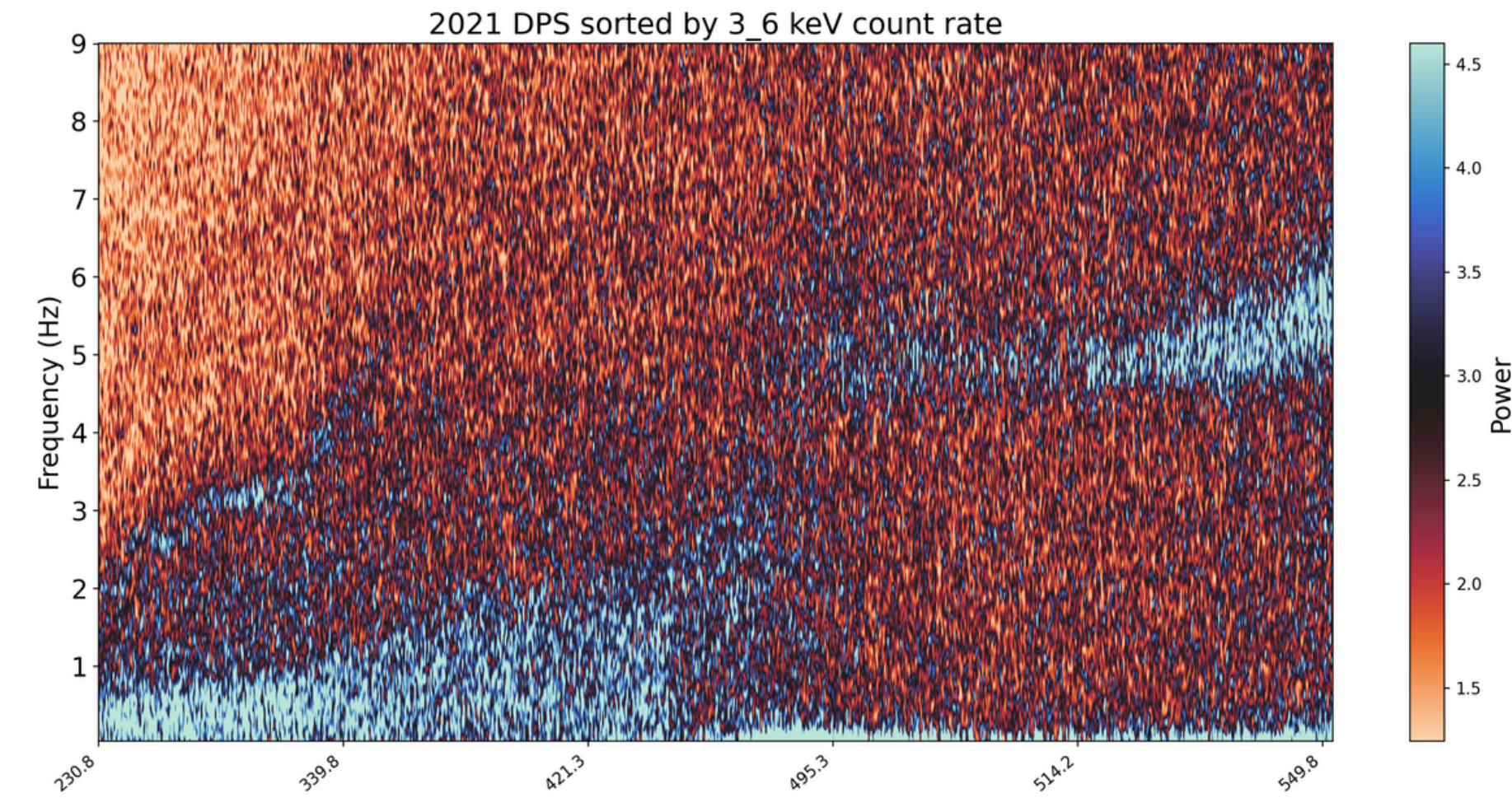
RMS-Intensity Diagram of GX 339-4 (2021 vs 2024)



- 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.

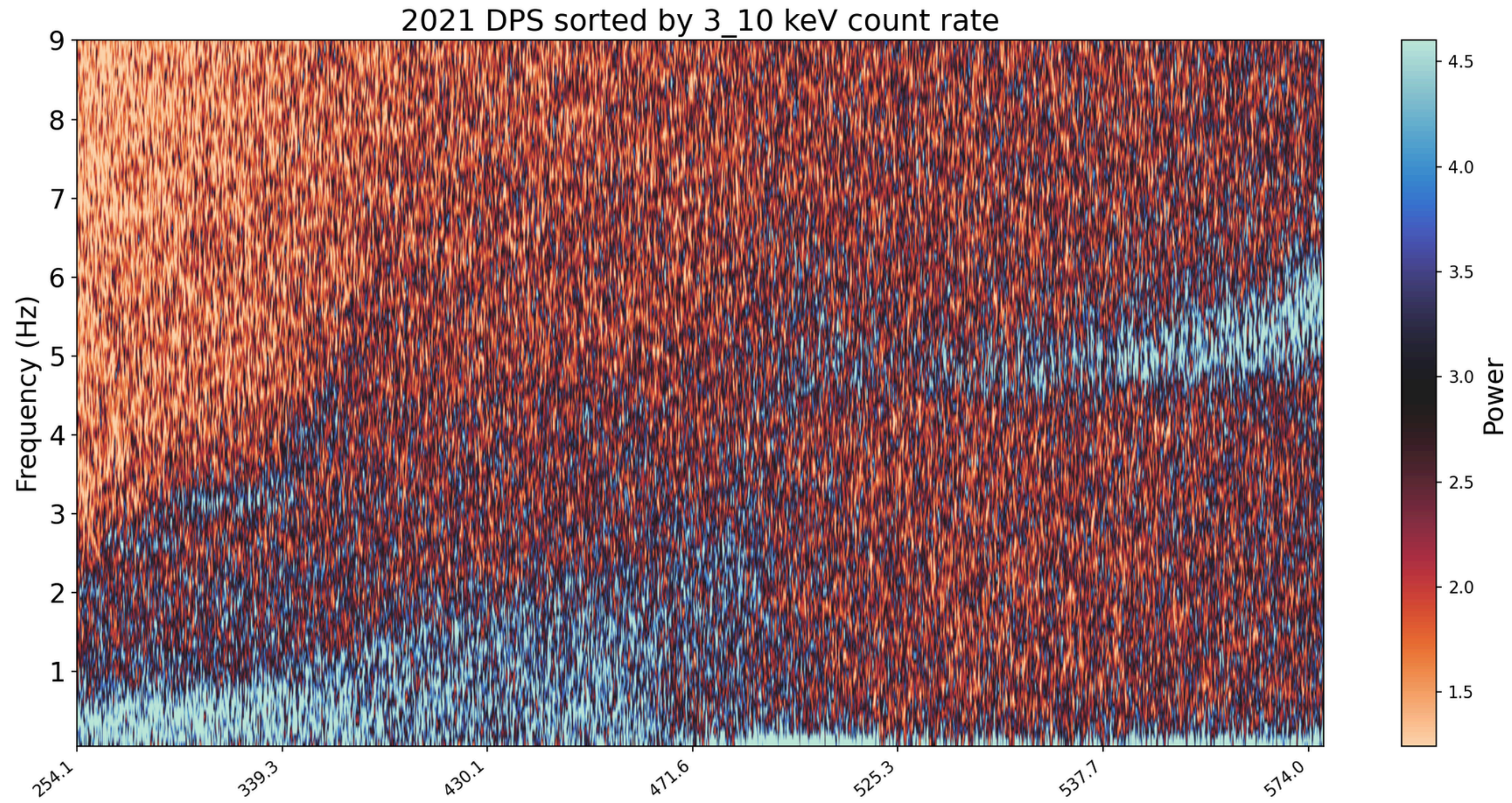
DPS sorted by count rate



- 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)

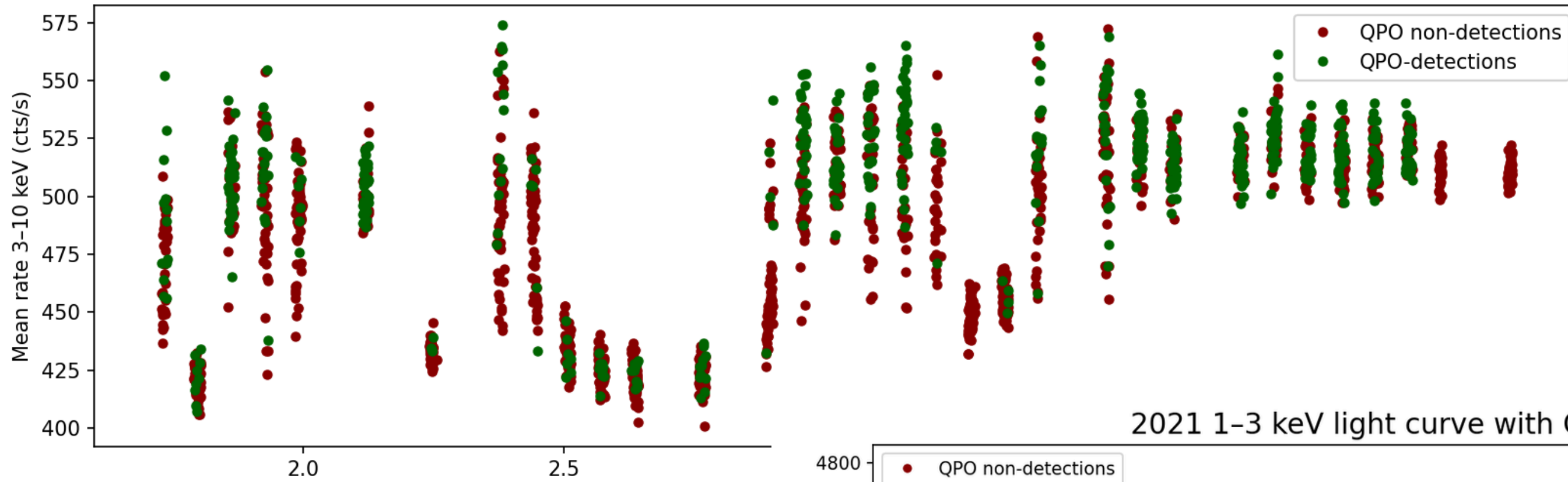
- It appears that the presence of the QPO is confined to a specific range of count rates

QPOs “Switches” Are Not Simply Flux-Driven

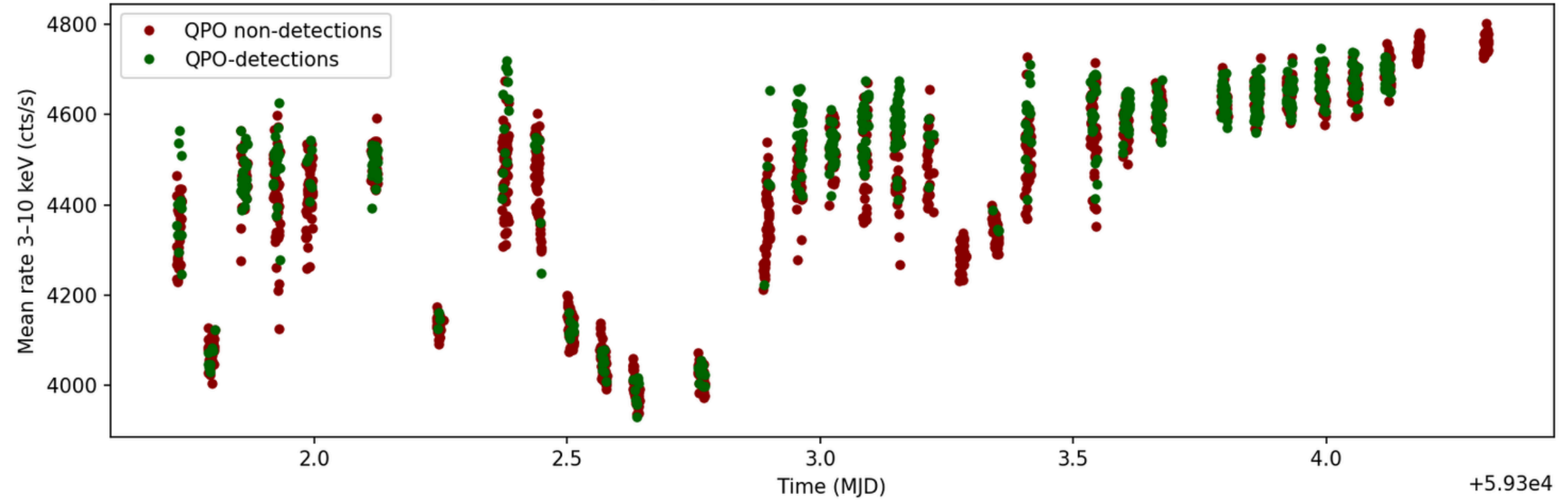


QPOs “Switches” Are Not Simply Flux-Driven

2021 3-6 keV light curve with QPO detection outcome

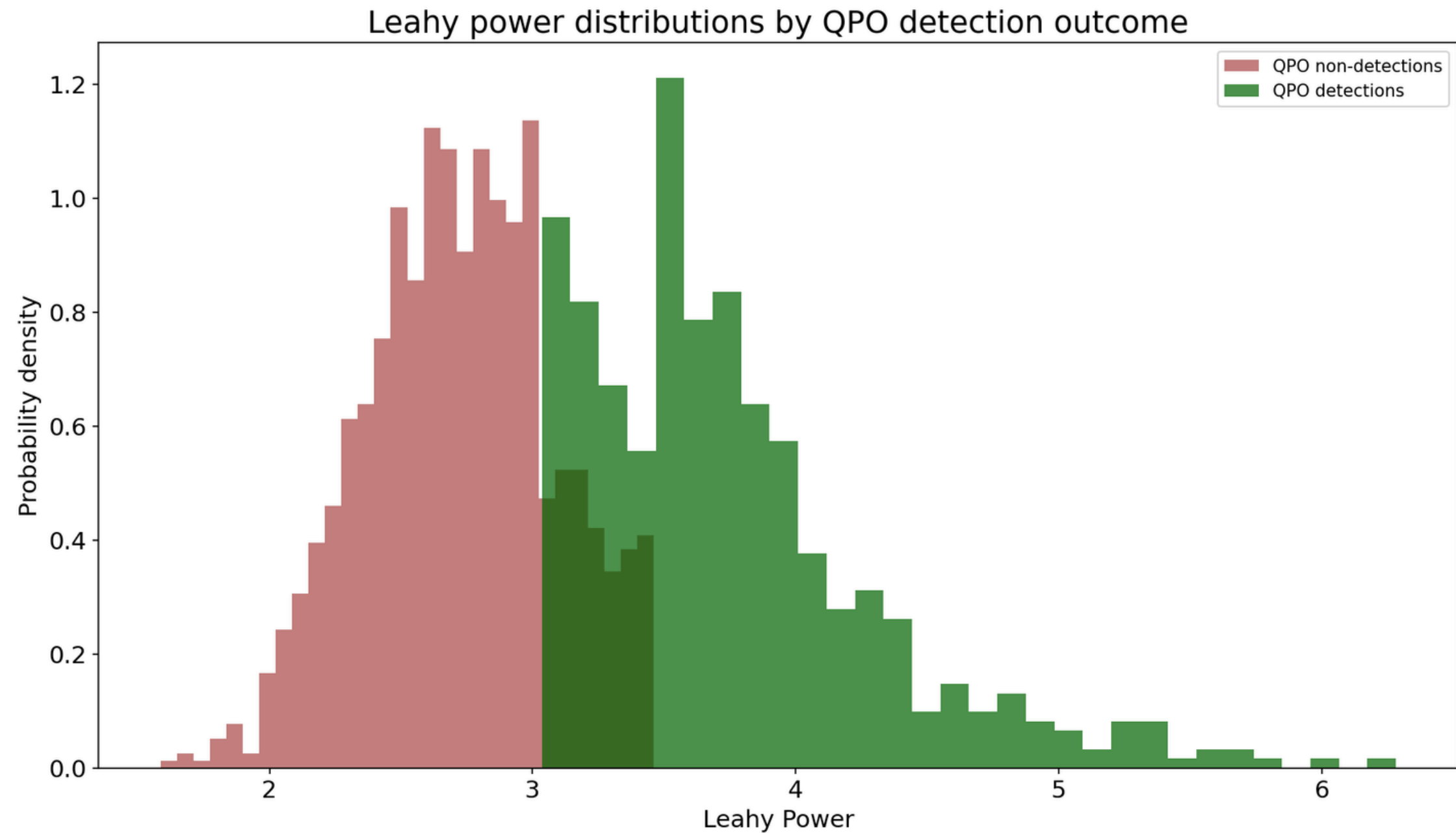


2021 1-3 keV light curve with QPO detection outcome

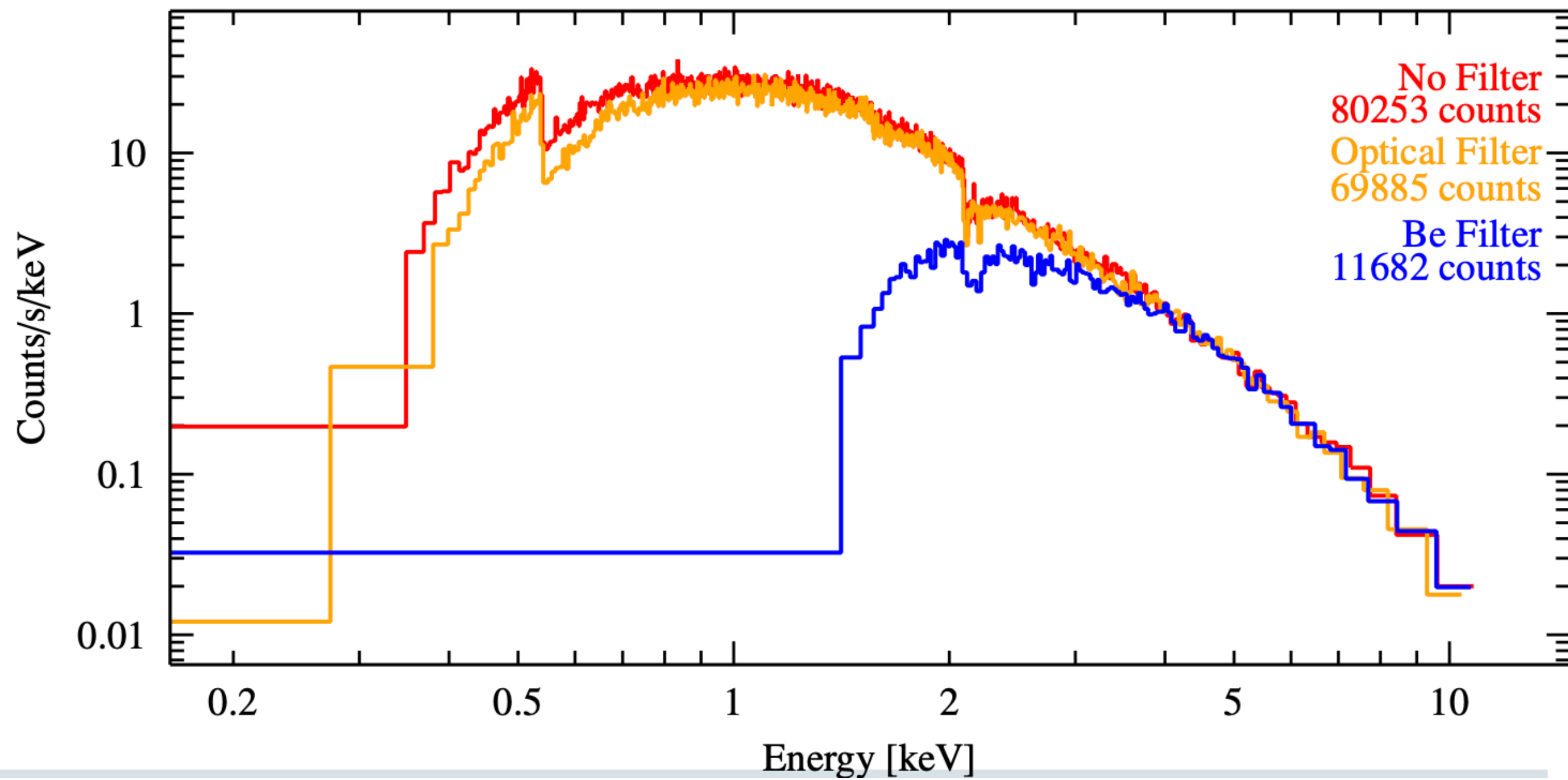


Are QPO really disappearing?

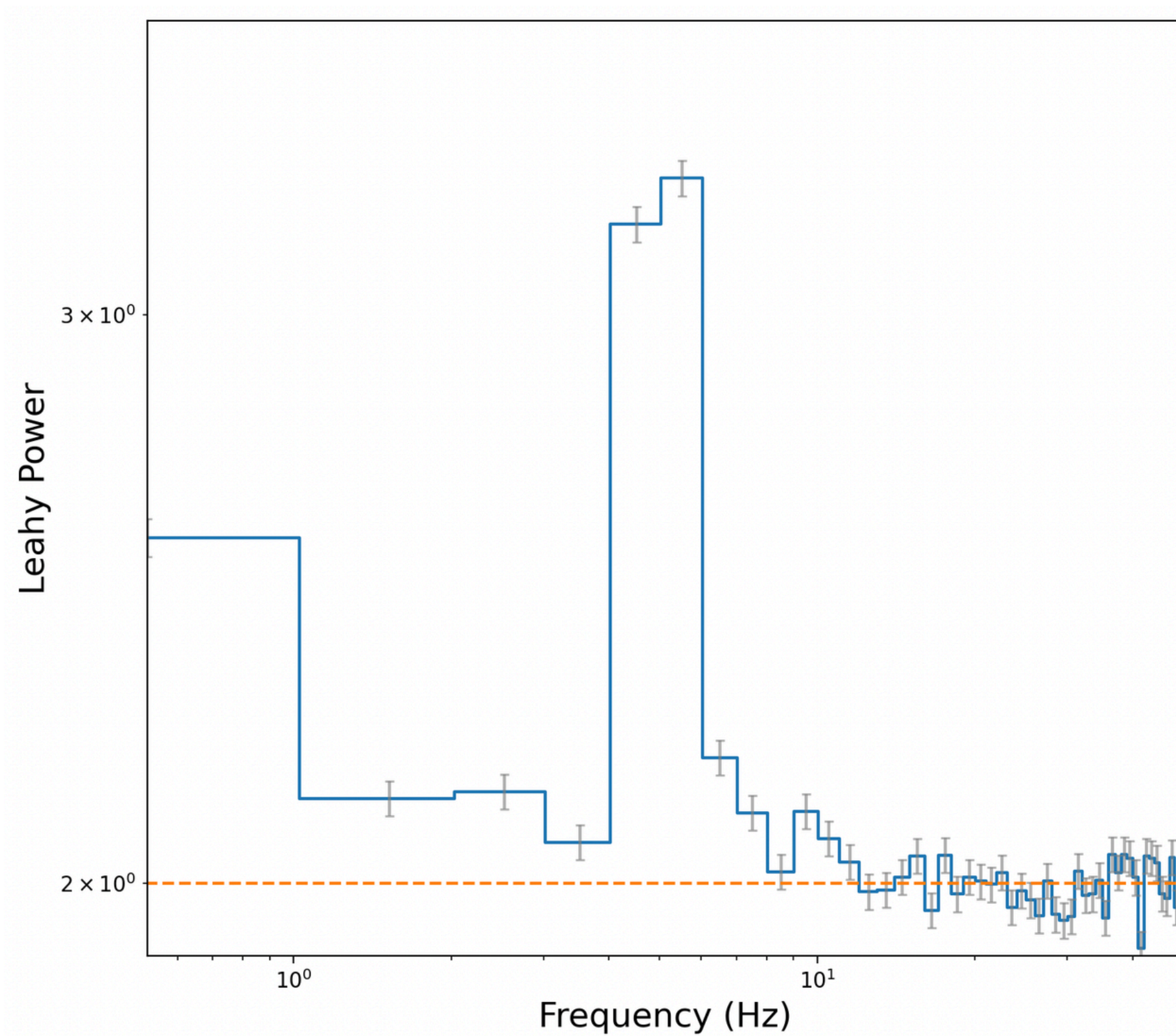
- The QPO detection map is threshold-limited by signal-to-noise
- Non-detections are not automatically QPO-off intervals
- They may include weak QPOs below the detection threshold



NewAthena Filter



Just Poisson noise?



QPO ON-OFF (99% singificance)

