

Timing and spectral analysis of the 2025 outburst of 4U 1630–47 with NICER

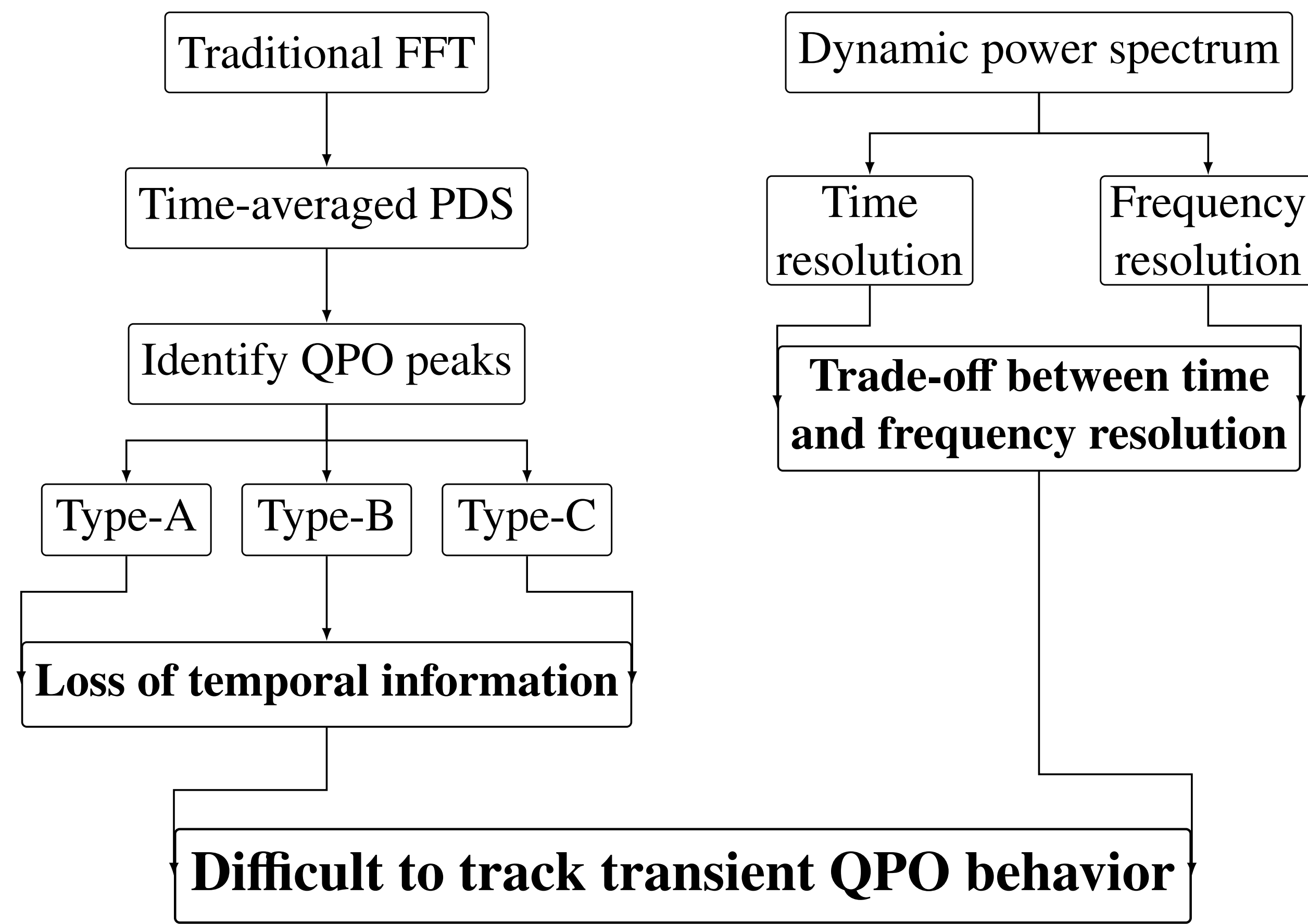
Haifan Zhu¹ Mariano Méndez¹ Xiao Chen² Wei Wang³

¹Kapteyn Astronomical Institute

²Southern University of Science and Technology

³Wuhan University

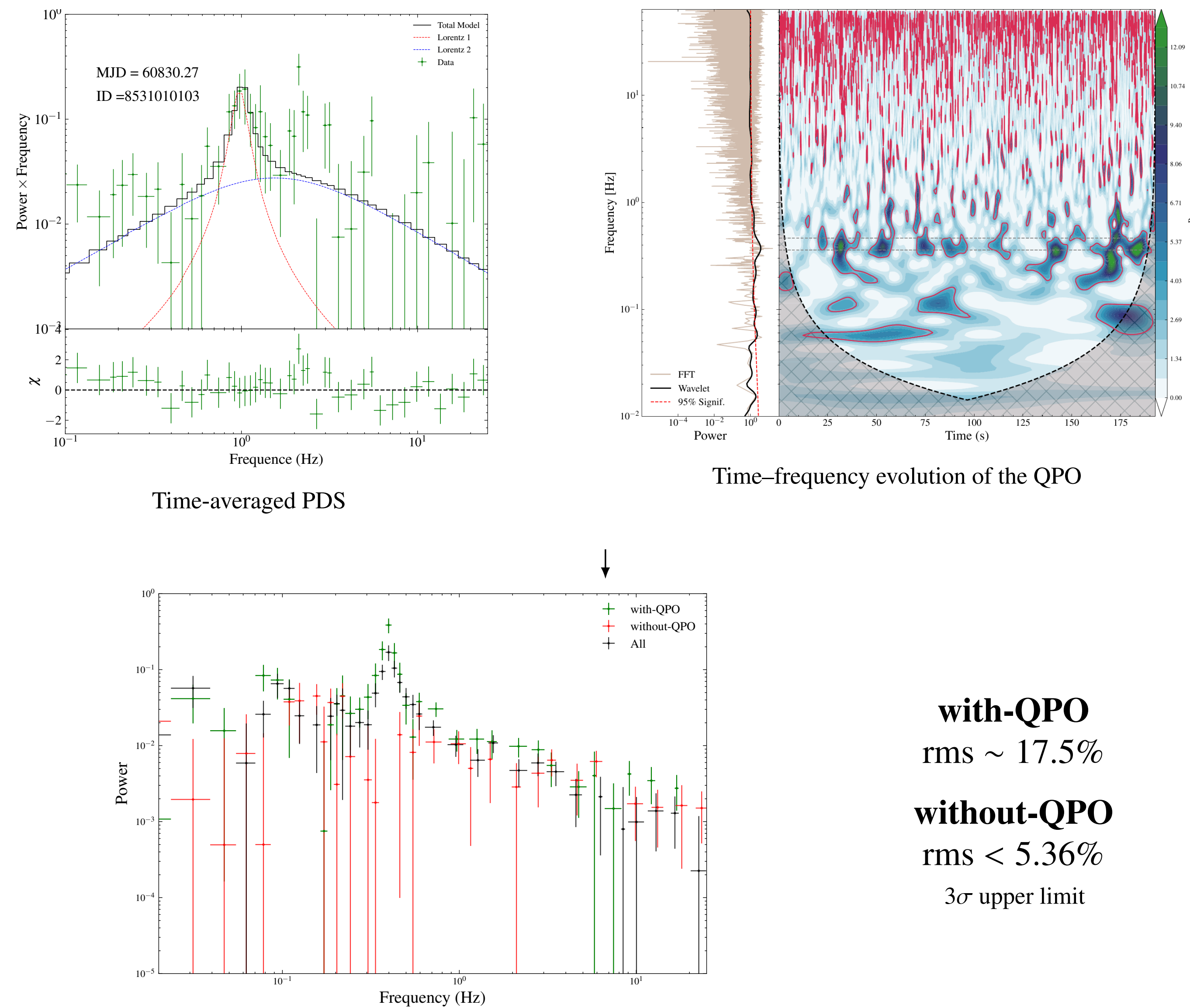
Method Introduction



Wavelet Analysis

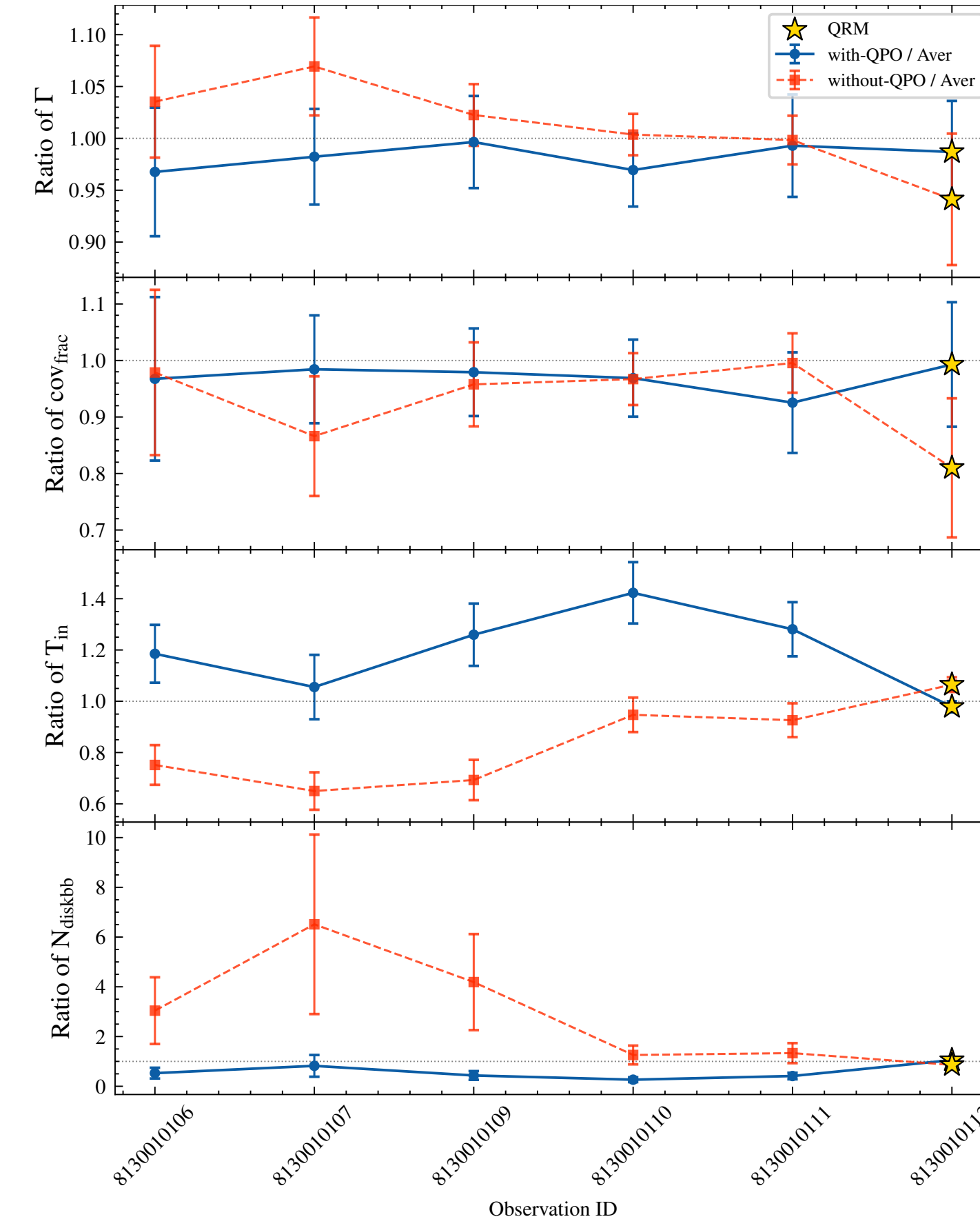
$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \Psi^* \left[\frac{(n' - n)\delta t}{s} \right]$$

Wavelet analysis tracks the temporal evolution of the QPO power.



The QPO is intermittent within a single observation.

Spectral Changes Associated with the QPO



with-QPO

T_{in} higher

N_{diskbb} lower

Γ and covering fraction show much weaker changes

The clearest spectral changes are associated with the disk.

HHT Phase Decomposition

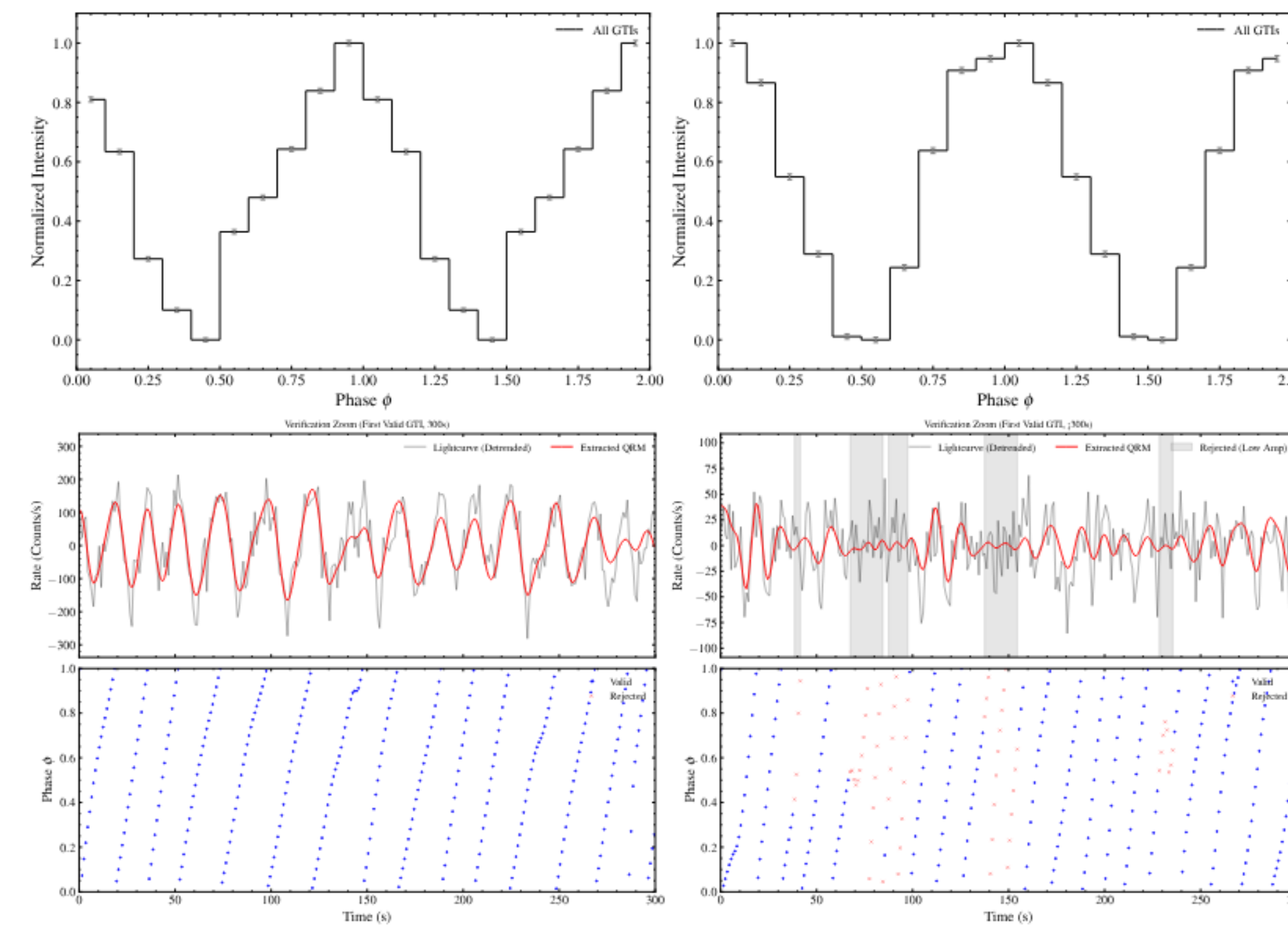
$$x(t) = \sum_{j=1}^n c_j(t) + r_n(t)$$

CEEMDAN decomposition

$$z_j(t) = c_j(t) + iH[c_j(t)] = a_j(t)e^{i\phi_j(t)}$$

Instantaneous amplitude and phase

The instantaneous phase allows us to track a non-stationary QRM cycle without assuming strict periodicity.



Extract QRM

CEEMDAN isolates the QRM-related IMF.

Track phase

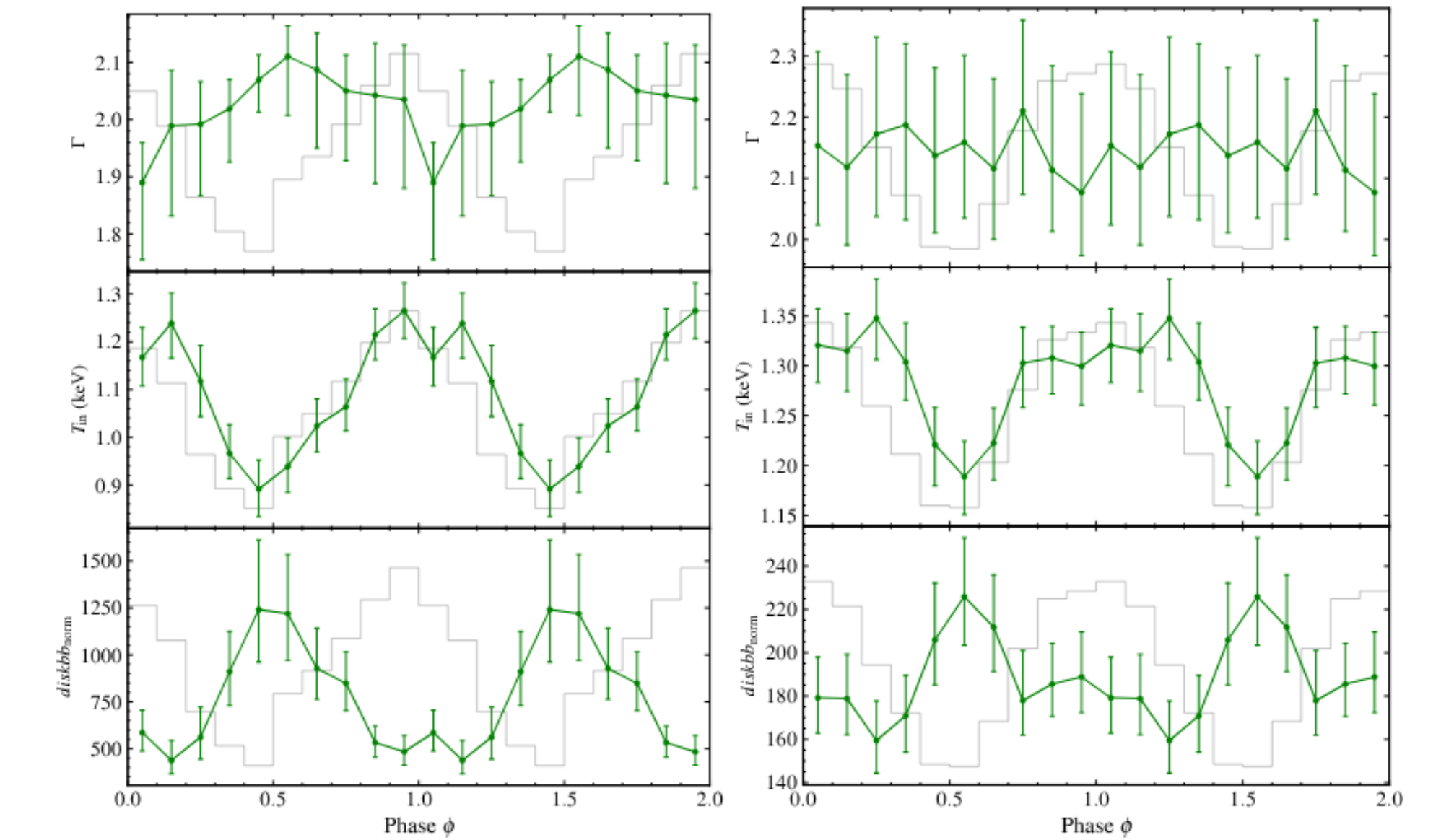
Hilbert transform gives $\phi(t)$ continuously.

Tag photons

Each photon is assigned to a QRM phase bin.

Low-amplitude intervals are excluded to avoid noise-dominated phase estimates.

Phase-resolved Spectral Evolution



T_{in}
positively correlated with flux

2023: $r = 0.82$
2025: $r = 0.88$

N_{diskbb}
anticorrelated with flux

2023: $r = -0.68$
2025: $r = -0.73$

Γ
no significant correlation

$p > 0.45$
in both epochs

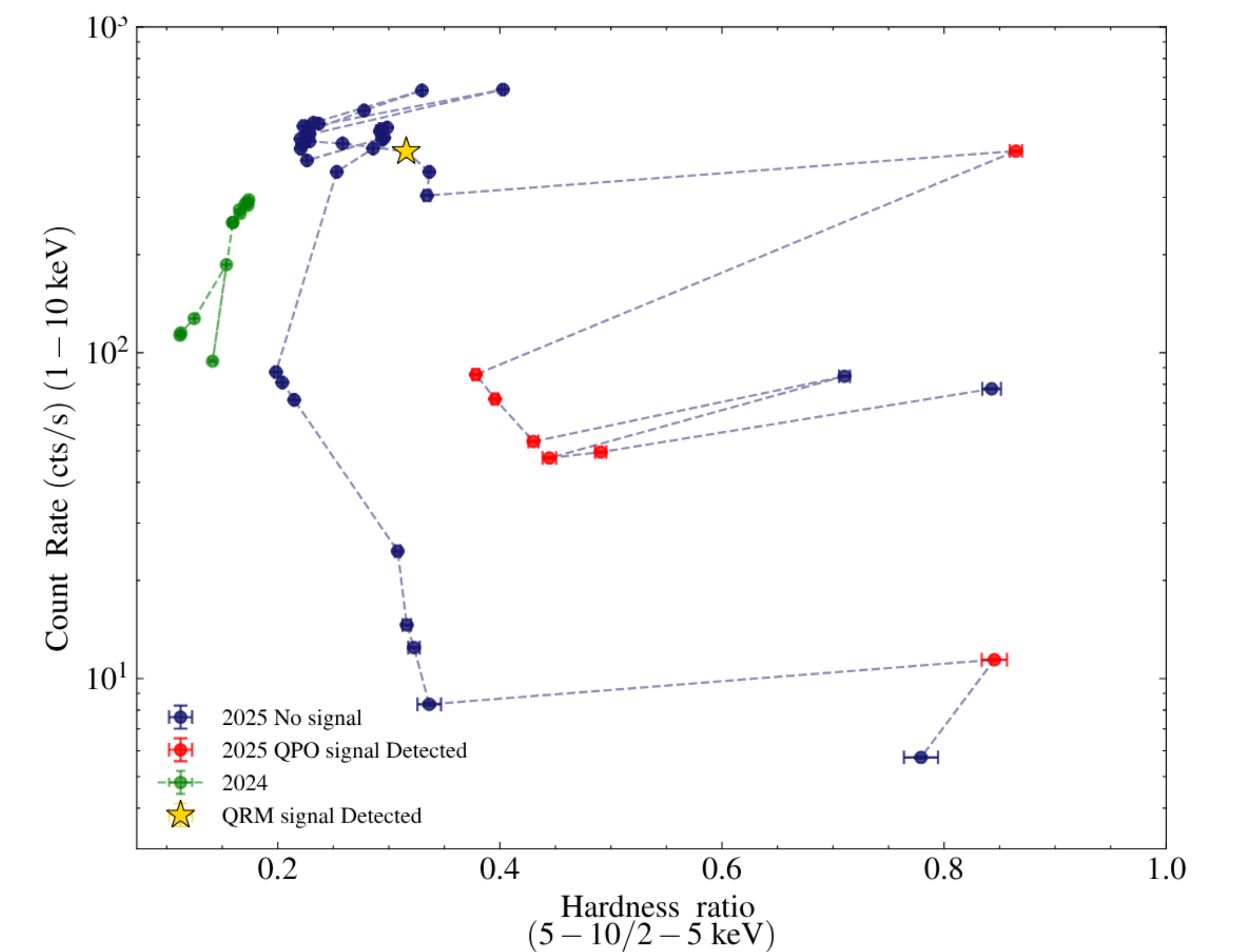
The weak 2025 QRM follows the same disk-dominated pattern as the 2023 heartbeat state.

Summary

- Type-C QPOs are intermittent within individual NICER observations.
- Their spectral variability is most clearly associated with **disk-related parameters**.
- The weak 2025 mHz QRM shows the same **disk-dominated phase evolution** as the stronger 2023 heartbeat state.

Time–frequency analysis reveals variability hidden by averaging.

Appendix: Outburst Evolution



Hardness–Intensity Diagram