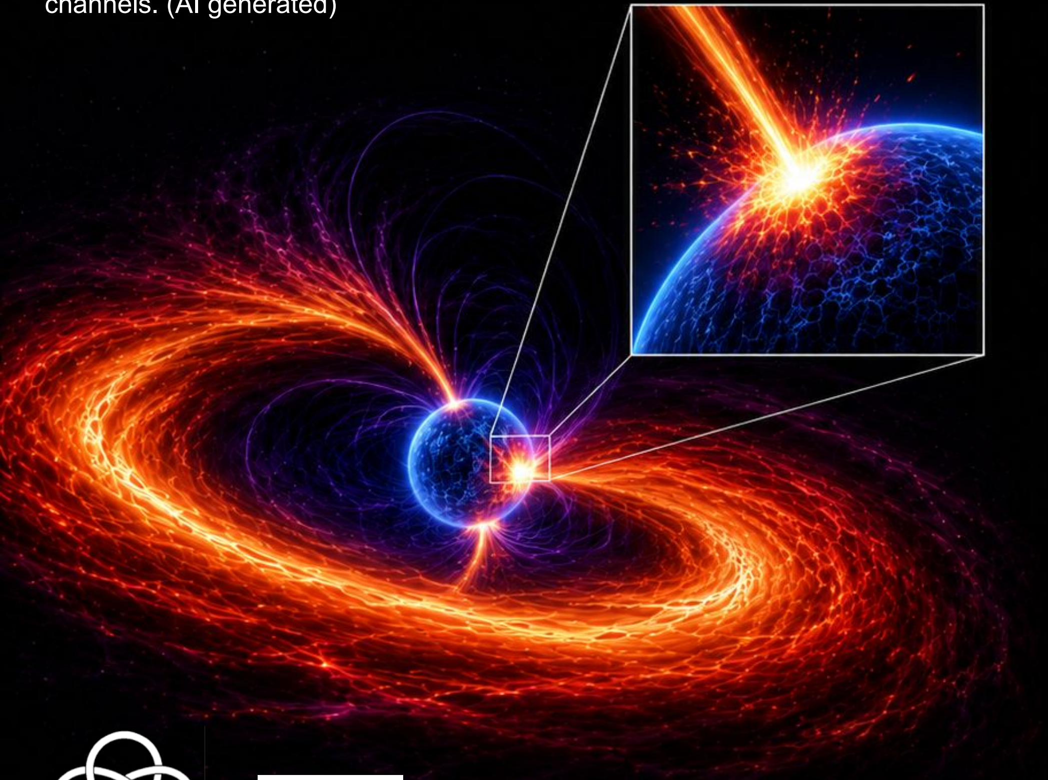
Artistic impression of the matter falling into the Neutron Star via different channels. (AI generated)



The many tones of accretion-To the memory of Tomaso Belloni.

7-11th September, 2026, Cefalu, Italy

QPOs to track the Disk Restoration signatures after Type-I X-Ray Bursts from 4U 1636−536.

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To the memory of Tomaso Belloni

This talk uses a timing framework — Lorentzian fitting of power spectra — that Tomaso Belloni helped build into the language of our field (Belloni, Psaltis & van der Klis 2002). It's fitting to bring that framework back to the source he also studied, 4U 1636−536 (Belloni et al. 2007), in his memory.

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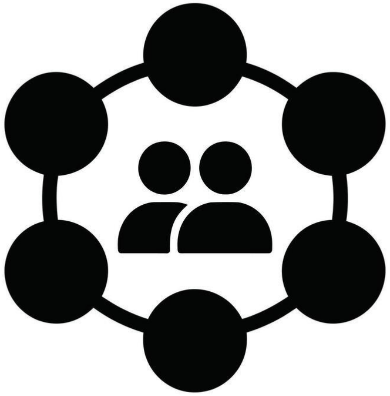

The Talk-Flow

1

2

3

4

Motivation & Methodology

- Question that drives the work
- Source selection
- Data selection and processing

Main Results

- Results worth to be noted.
- Evidences that supports the results

Connecting the dots

1. How do we connect the results to our existing Knowledge.
2. Is our result consistent to the previous findings?

Future Prospects

- What more we can do further from this work.
- Limitations.

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Motivation & Methodology

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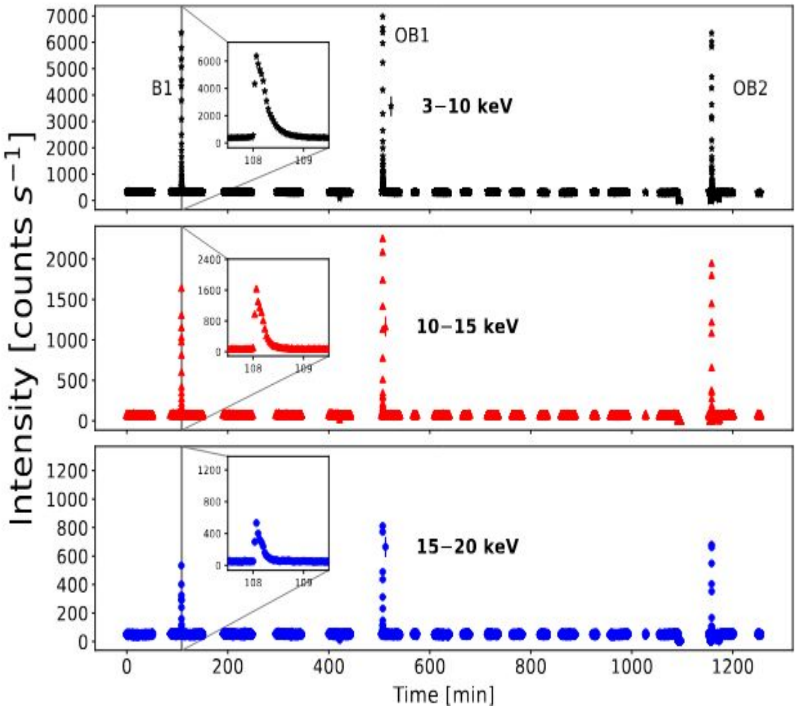
Type-I Thermonuclear Burst

- Unstable thermonuclear burning of accreted H/He on the neutron-star surface, observed as a **rapid rise (≲1-10 s)** followed by a **cooling decay over ≈10–100 s** in the X-ray light curve.

- Releases **~10^{39}–10^{40} erg** of energy in a few tens of seconds, with peak luminosities reaching a substantial fraction of the **Eddington limit**, producing intense radiation capable of perturbing the inner accretion disk.



Chattopadhyay et al. 2025 DOI: 10.3847/1538-4357/adf63a

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kHz Quasi-periodic Oscillations

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What are kHz QPOs?

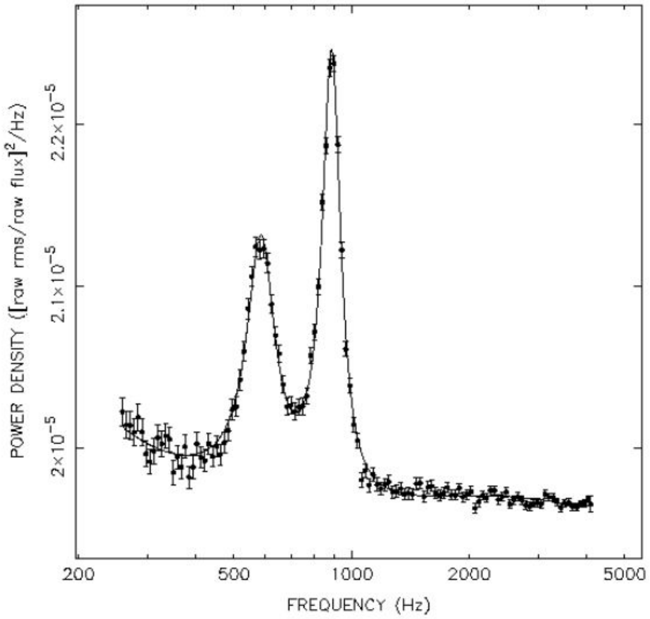
Rapid (~400–1200 Hz) quasi-periodic modulations in the X-ray light curves of NSLMXBs, seen as narrow peaks in the power spectrum (PDS).

Where do they originate?

From the **innermost accretion flow**, close to the neutron star, near the inner disk edge or boundary layer, where dynamical timescales are shortest.

Why are they important?

Their frequencies are comparable to the **local Keplerian orbital frequency**, so changes in the **inner disk radius** directly affect the kHz QPO.



van der Klis, et al. 1997, ApJ, 481, L97

$$\nu_{kHz} \approx \nu_K(r_{in})$$

$$\nu_K(r) = \frac{1}{2\pi}\sqrt{\frac{GM}{r^3}}$$

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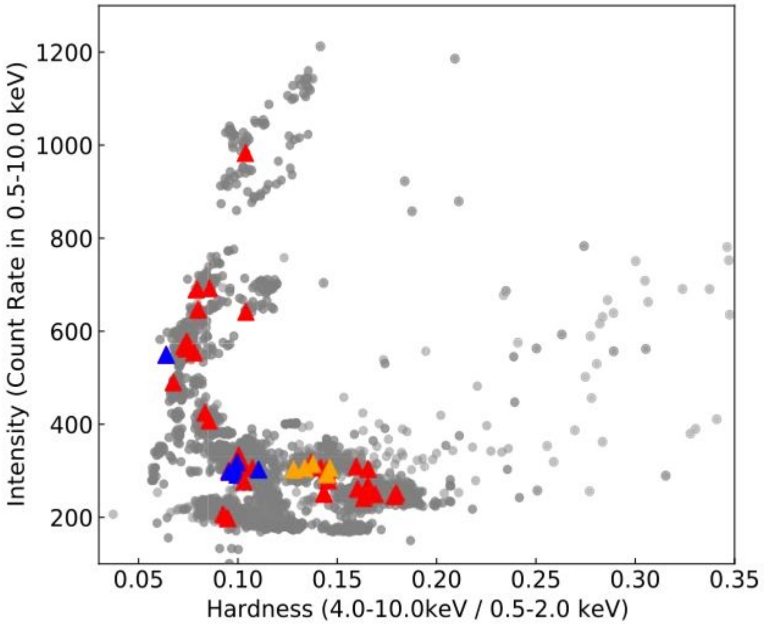
Can the impact of Burst be detected using kHz QPOs?

- **kHz QPOs originate in the innermost accretion flow**, and are sensitive to the inner disk radius.
- **Type-I bursts originate on the neutron-star surface**, releasing intense radiation on short timescales.
- **Key idea:** if burst radiation perturbs the inner disk, its effect should be **imprinted on the kHz QPO properties**.

What is the observational evidences that in support or against to this idea?

4U 1636-536

Ideal Laboratory for testing the hypothesis.



Distribution of Type-I Burst across the HID track. Güver et al. 2022

- **Persistent atoll source and prolific Type-I X-ray burster** *(van Paradijs et al. 1990; Galloway et al. 2006)*
- **Well-studied kHz QPOs spanning ~600–1200 Hz** *(van der Klis et al. 1997; Di Salvo et al. 2003; Belloni et al. 2007)*
- **Spin frequency: 581 Hz (from burst oscillations)** *(Strohmayer & Markwardt 2002)*
- **Extensive RXTE / NICER / AstroSat observational coverage** *(RXTE: van der Klis et al. 1997; Di Salvo et al. 2003; NICER: Güver et al. 2022; AstroSat: Chattopadhyay et al. 2025)*
- **Type-I bursts observed across the HID track** *(Güver et al. 2022)*

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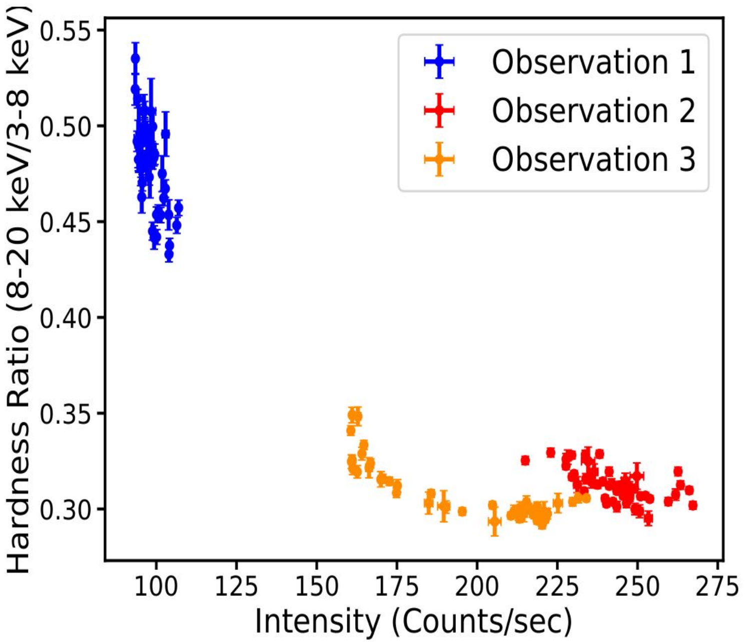
Observations

- LAXPC data has been used due to its high temporal resolution.
- All the PCU units has been used .

Selection Criteria :

- Simultaneous presence of the Type-I TNB and kHz QPOs.
- Only 3-observation successfully pass the above condition.
- This totally gives us 7 bursts in to initial consideration.



State of the system in the three different observation which is taken for the analysis . Bin time is 1024 sec. Only persistent counts has been used .

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Why only 3 bursts?

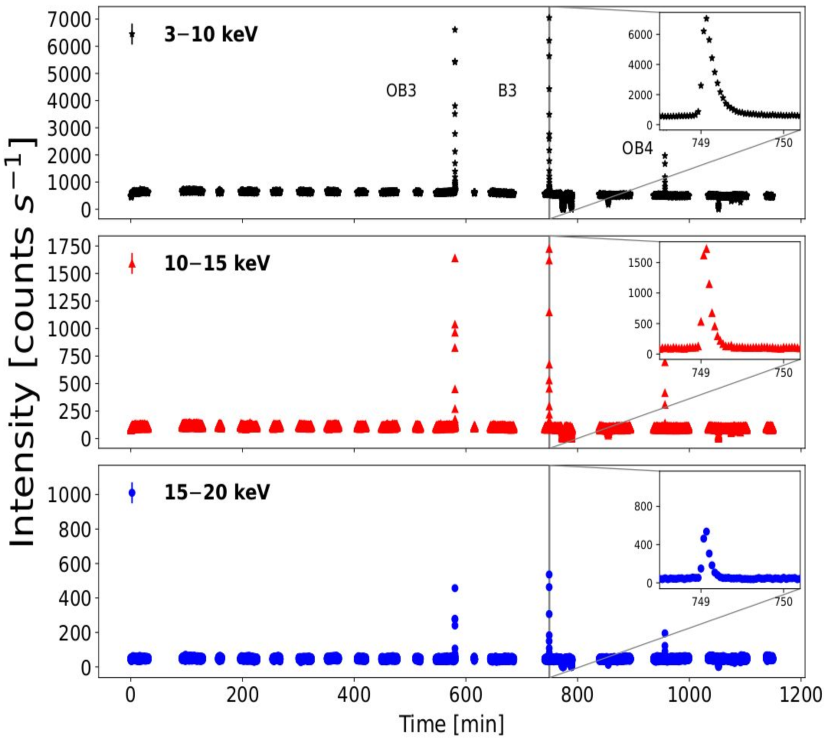
The many tones of accretion-To the memory of Tomaso Belloni.

- Burst emission (~120 s) excluded; pre-burst (-200 s) and post-burst (+200 s onward) windows defined, with post-burst divided into ~200 s segments.
- Only 3 bursts have enough data (>200 s) on both sides to meet this criterion

200 sec (pre decided ?)

$$\frac{S}{N} = \frac{r^2 N_{ph}}{2\sqrt{\Delta f \ T}}$$

- Significance depends on photon number and segment length: 5 s segments are Poisson-noise-dominated and unreliable 100 s segments carry ~20× more photons → roughly ~4–5× higher SNR (∝ √T)



Obs 3

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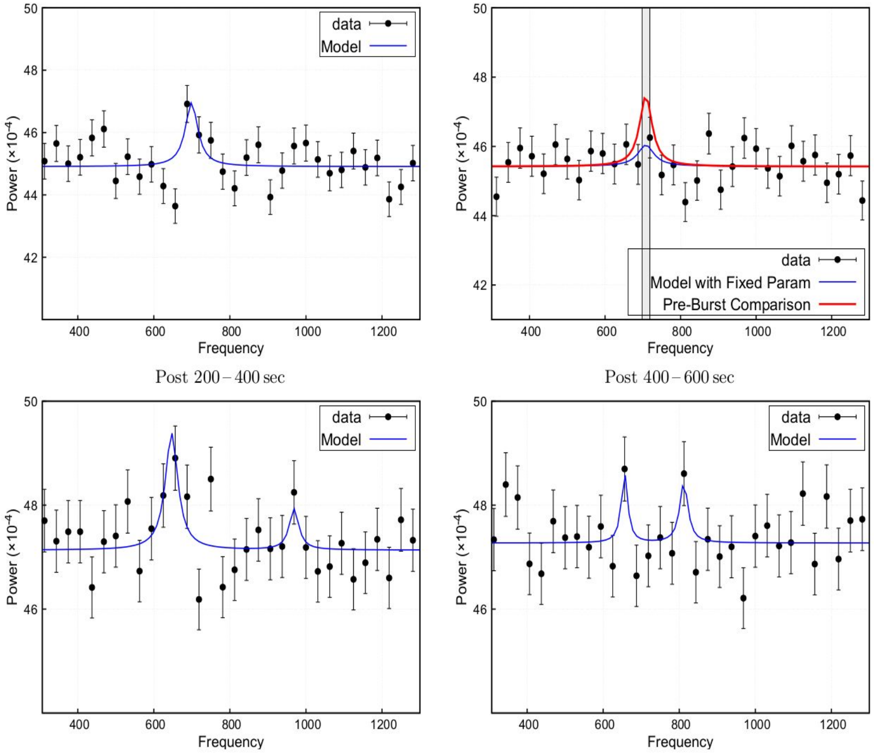
Main Results

Power density spectrum

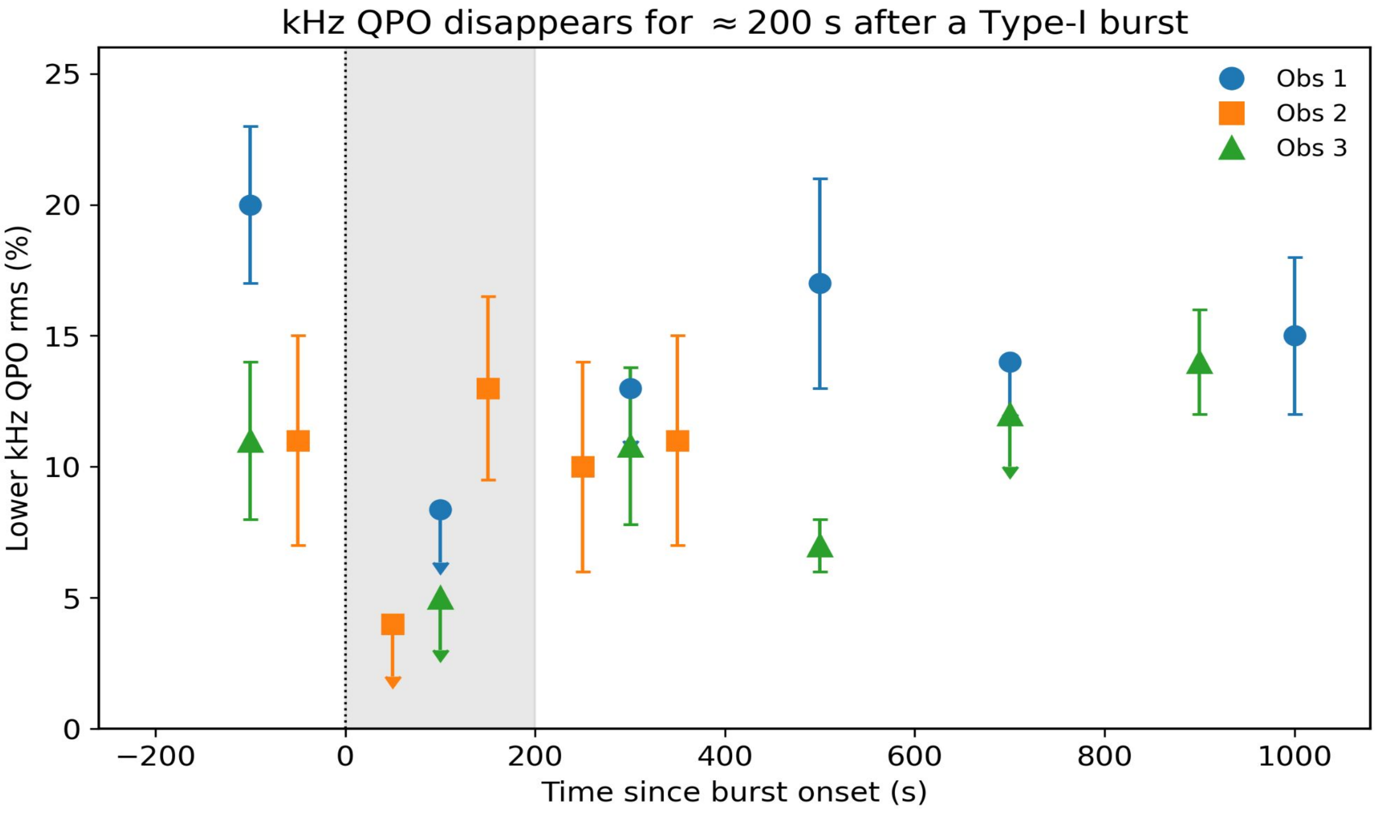
- rms-normalized PDS up to 2000 Hz computed in ~200 s segments.
- PDS fitted with single/multiple Lorentzians plus a constant. (Belloni, Psaltis & van der Klis (2002))
- When no peak is detected, Lorentzian frequency and width are fixed to the nearest segment with a detected QPO to estimate rms.

- Consistently, QPO appears in the pre zone .
- Post 0-200 sec zone NO significant peak is observed.



Obs 3

RMS variation



QPO rms amplitude is dropped by 5-6 % in the immediate post 0-200 sec and gradually recovers from segment to segment.

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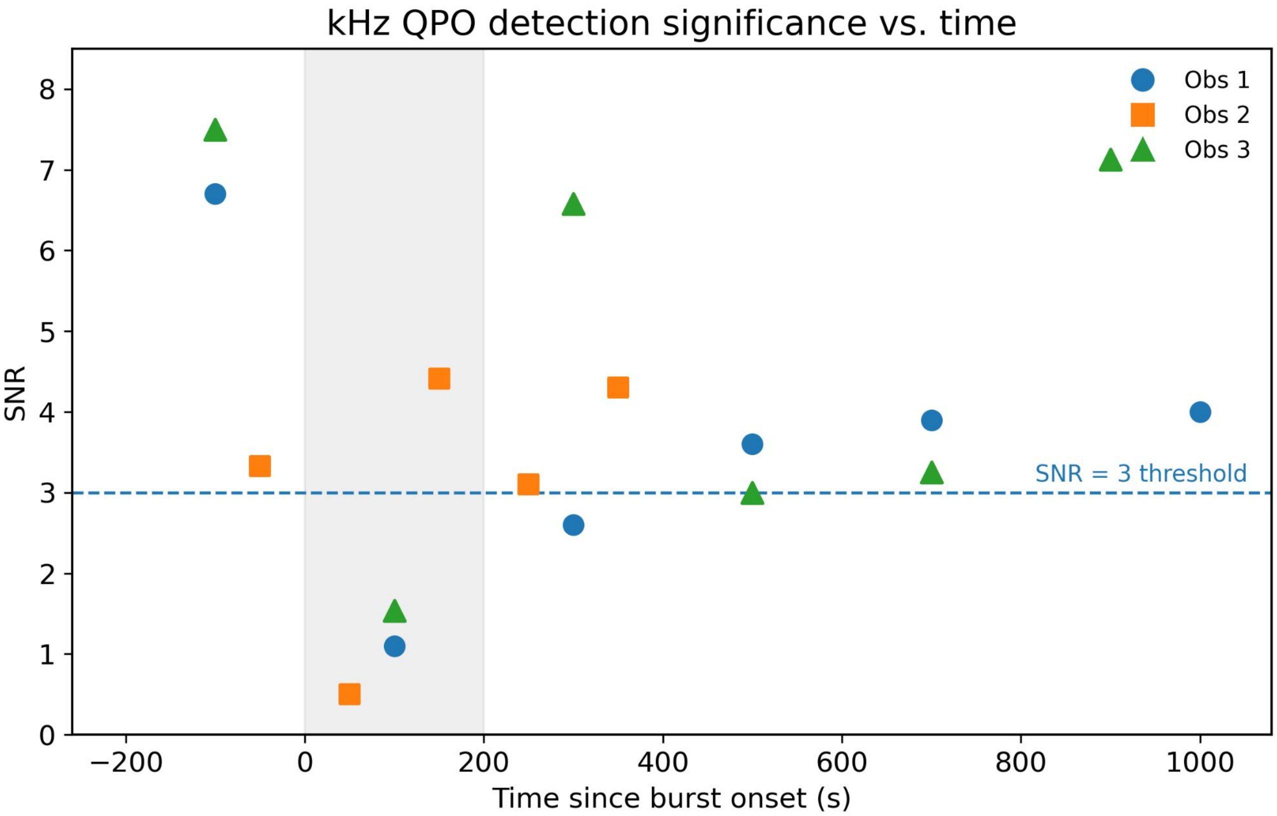
SNR of the observed peaks



$$\mathrm{SNR} = \frac{1}{2}\left(\mathrm{rms}_{\mathrm{src}}\right)^2 C_t \sqrt{\frac{T}{\Delta\nu}}$$

$$\mathrm{rms}_{\mathrm{src}} = \left(\frac{C_s}{C_t}\right)\mathrm{rms}$$

$$C_t = C_s + C_b$$

M. van der Klis 2004; D. Barret et al. 2008

$$p_N\left(<P_{\max}\right) < 0.05$$

$$\Rightarrow \mathit{detection\ at} > 95\%$$

$$\mathit{confidence\ (after\ trials\ correction)}$$

Connecting the Dots

What can we infer from what we observed?

Revisit to Peille et al. (2014)

Peille et al. (2014) asked: Is kHz QPO disappearance during bursts *real*, or just reduced detectability from burst photons diluting the signal?

They showed: *dilution alone can't explain it in all cases → genuine burst–disk interaction*

They further found: *Most bursts recover within tens of seconds; a few show delayed recovery, ≳100 s*

kHz QPO can trace the disk's recovery signature

$t_{visc} = R^2/\nu \sim 100–200$ s, for $\nu \sim 10^{11}$ cm^2 s^{-1}, R ~ 40 km

Type-I bursts temporarily disrupt the inner flow; the kHz QPO tracks its viscous restoration on ~100–200 s

What did we ask?

Given that, kHz QPO suppression during bursts cannot be explained by dilution alone, implying a genuine burst–disk interaction.

Is there a characteristic post-burst timescale that governs the re-establishment of the inner accretion flow traced by kHz QPOs?

What we get ?

$$T_{rec} \sim 100-200\ sec$$

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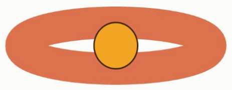
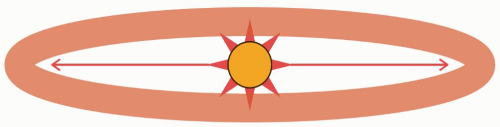
Long Story in Short:

Key Takeaways :

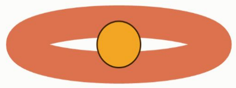
- Pre-burst kHz QPO present; post-burst QPO suppressed.
- Suppression lasts ~100 – 200 s beyond burst emission.
- Recovery is gradual, not instantaneous.
- Timescale matches inner-disk viscous response.



A. Disk close to the neutron star



B. Thermonuclear burst pushes the disk away



C. Disk restored after 100–200 s

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Future Prospects & Limitations

Limitations:

Conclusions rest on a single source and three bursts; burst-to-burst QPO behavior is known to vary (Peille et al. 2014), so the ~200 s timescale may not be universal. (further verification required)

The analysis attributes QPO disappearance purely to disk disruption, but a burst-heated or restructured corona could equally suppress/shift the QPO. Without a coronal spectral check, disk disruption and corona disruption remain observationally degenerate.

Future Prospects:

1. Spectral study of same pre-/post-burst segments as PDS analysis and Track kT_in and R_in across bursts. Prediction: R_in increases post-burst, decays back on ~160–200 s timescale.

2. Right now the whole result rests on three bursts from a single source. The obvious next step → assembling a systematic multi-source, multi-burst catalog — using archival, and future missions to see whether the ~160–200 s disruption/recovery timescale and the ~5–6% rms drop are universal features of Type-I bursts in atoll sources, or specific to 4U 1636−536.

Some Useful References:

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Thank you For Your Attention.

Questions ?