

Revealing the origin of the X-ray variability in Sco X-1

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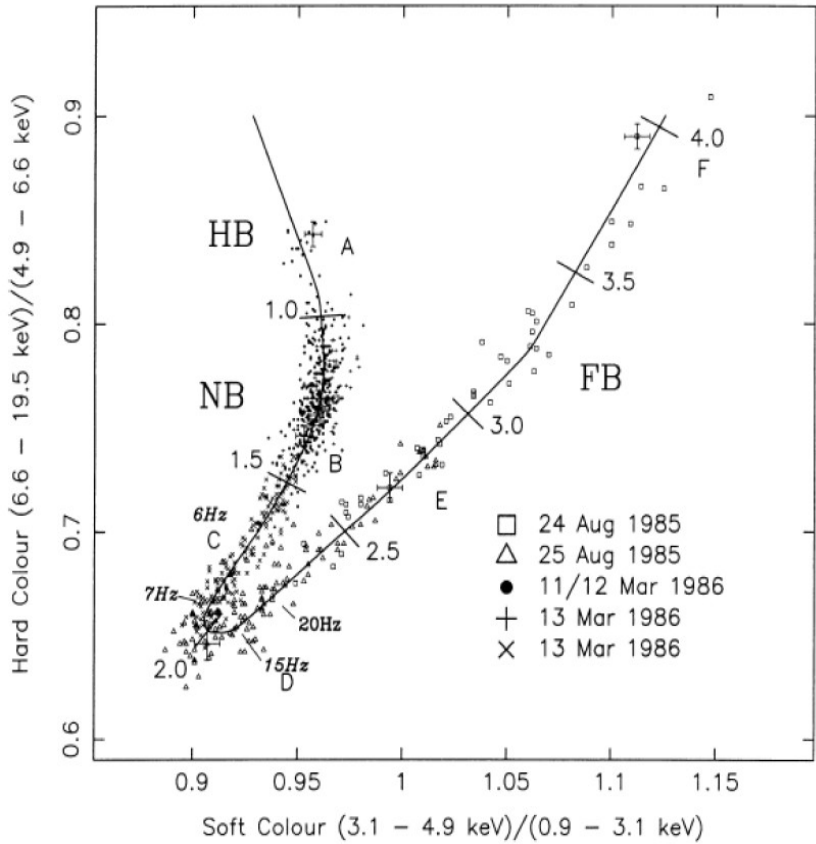
Outline

- X-ray Variability in NS LMXBs
- Revealing the origin of the variability
- Discussion and conclusion

Spectral and Timing properties

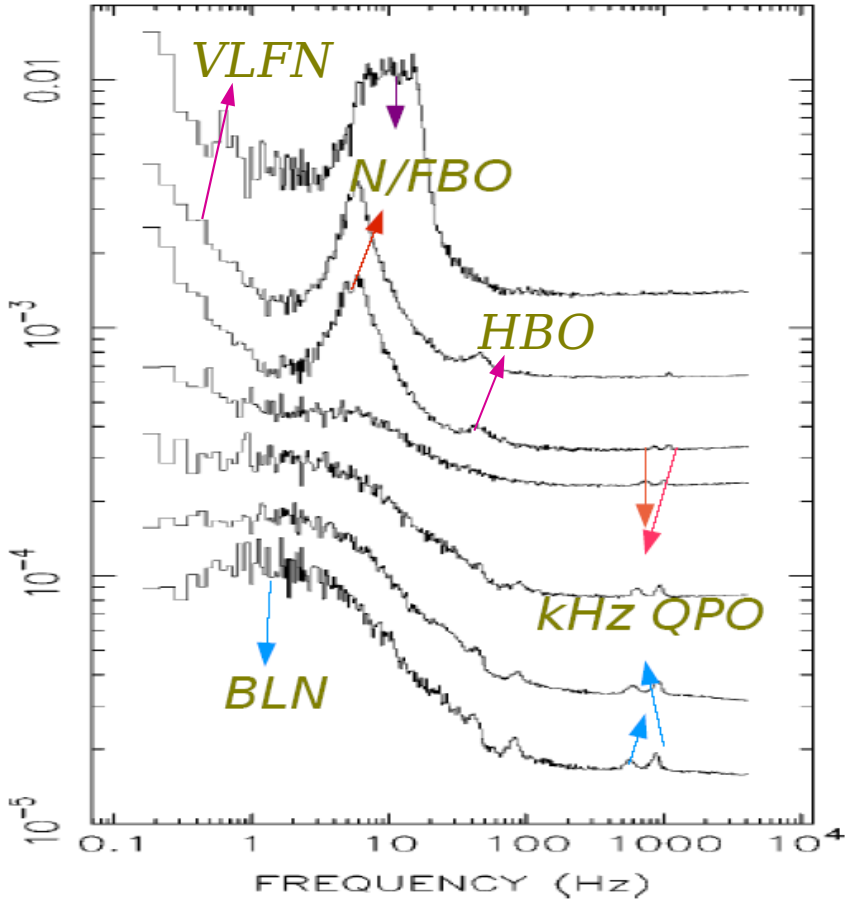
color-color diagram

power density spectra



Dieters & van der Klis 2000

VLFN: Very Low Frequency Noise
HBO: Horizontal Branch Oscillation
KHz QPO: kilohertz Quasi-Periodic Oscillation

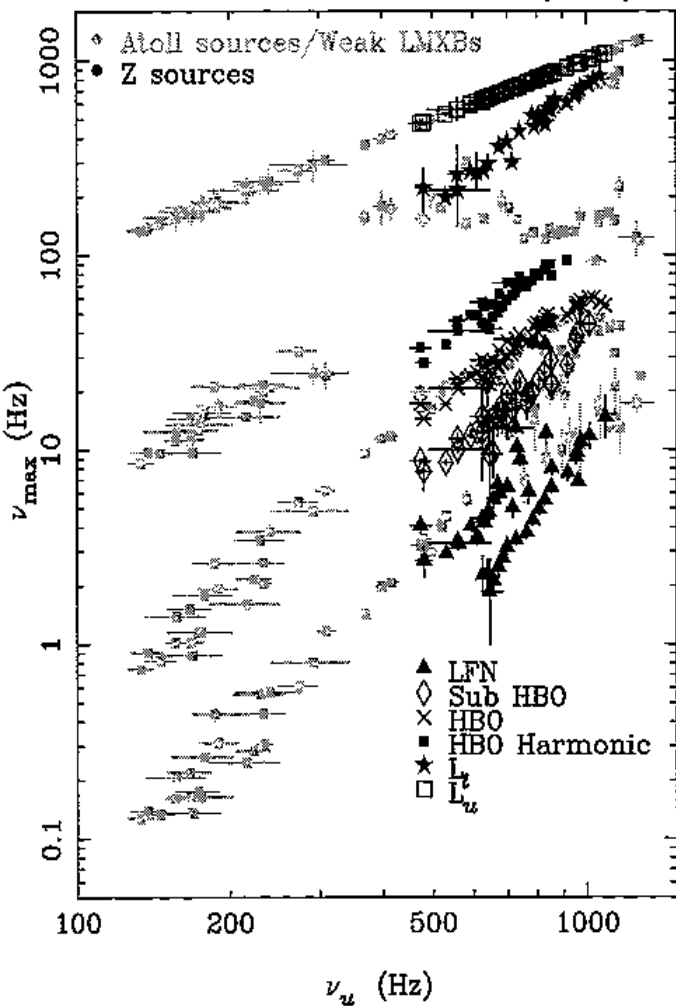


van der Klis & Wijnands 1997

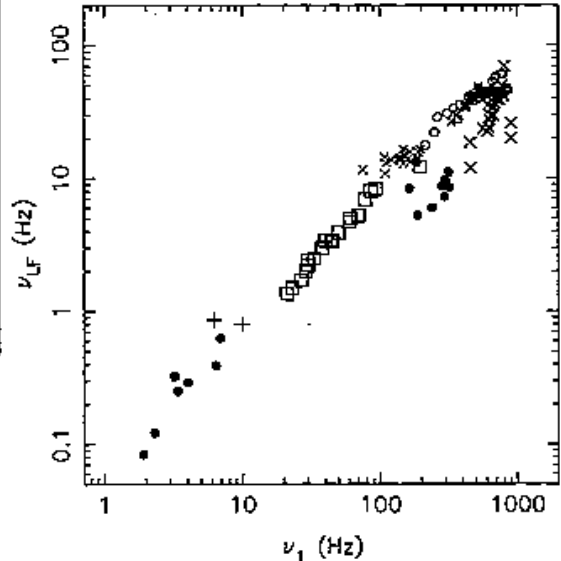
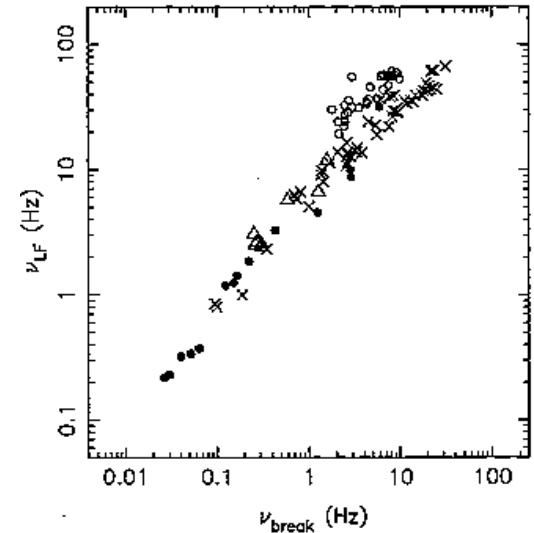
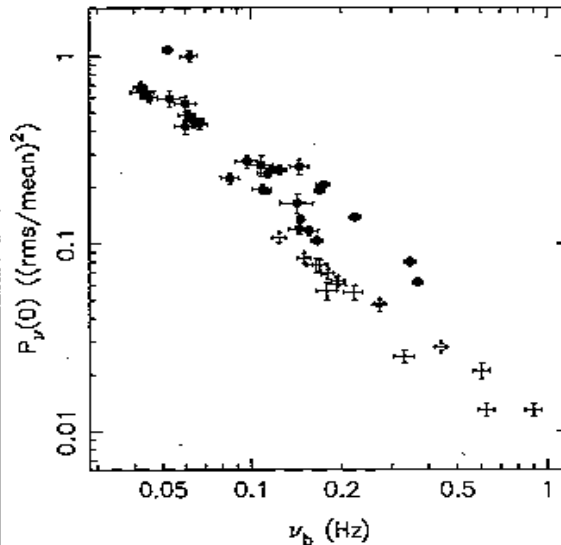
BLN: Band-Limited Noise
N/FBO: Normal/Flaring-Branch Oscillation

Z sources compared with other LMXBs

(b) HB | NB | FB



van der Klis 2006



Belloni et al. 2002
 Wijnands & van der Klis 1996
 Psaltis et al. 1996

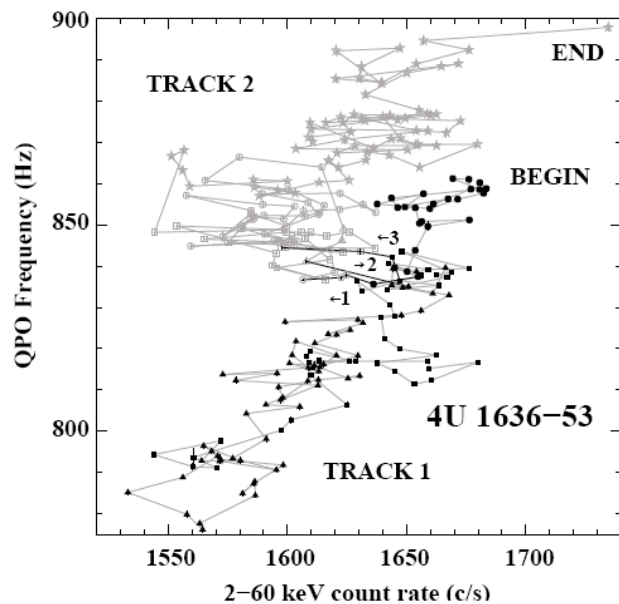
filled circles: *black-hole candidates*

open circles: *Z sources*

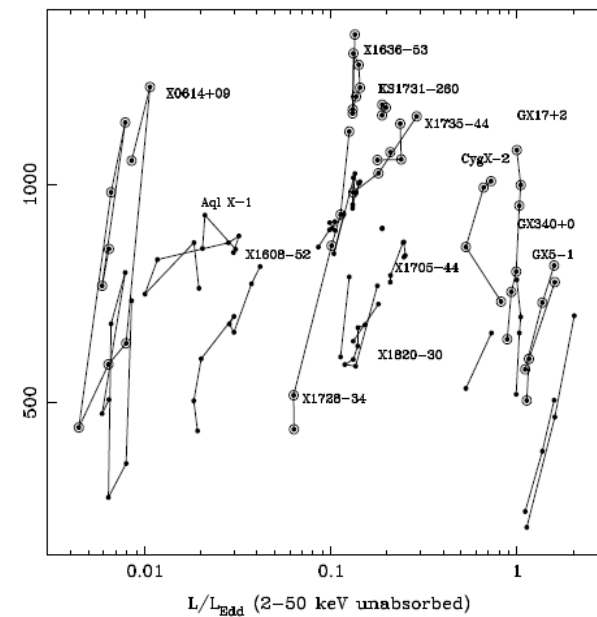
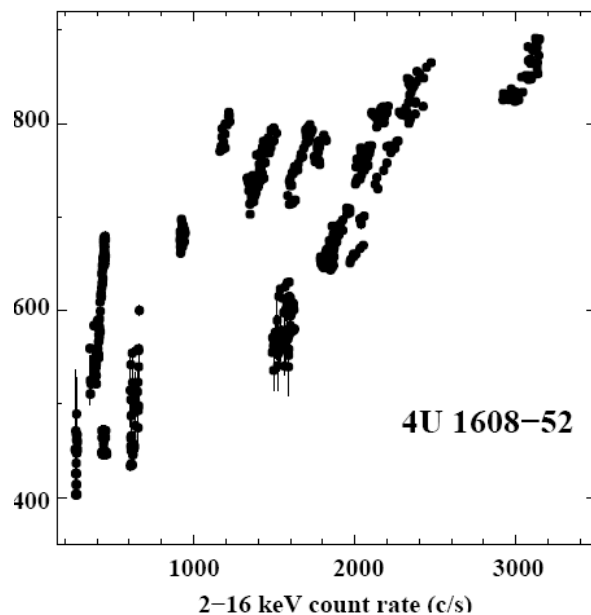
crosses: *atoll sources*

These relations suggest similar origins of BLN etc. across LMXBs.

“parallel-track” phenomena



Méndez et al. 1999



Ford et al. 2000

On the time scale of hours corresponding to each track, the frequency of the kHz QPOs is believed to correlate with the mass accretion rate.

On longer timescales, and across sources, the relation between kHz QPO frequency and luminosity is lost.

The idea

- Study the kHz QPO frequency variation on the coherence timescale of a certain variability component at a lower frequency.

For example, study the correlation between the X-ray flux on the timescale of a certain variability component and the kHz QPO frequency.

- Compare the correlation with that corresponding to the “parallel-tracks”

In this way, we reveal the clues to the origin of the X-ray variability of Sco X-1, therefore the origins of the same components across LMXBs.

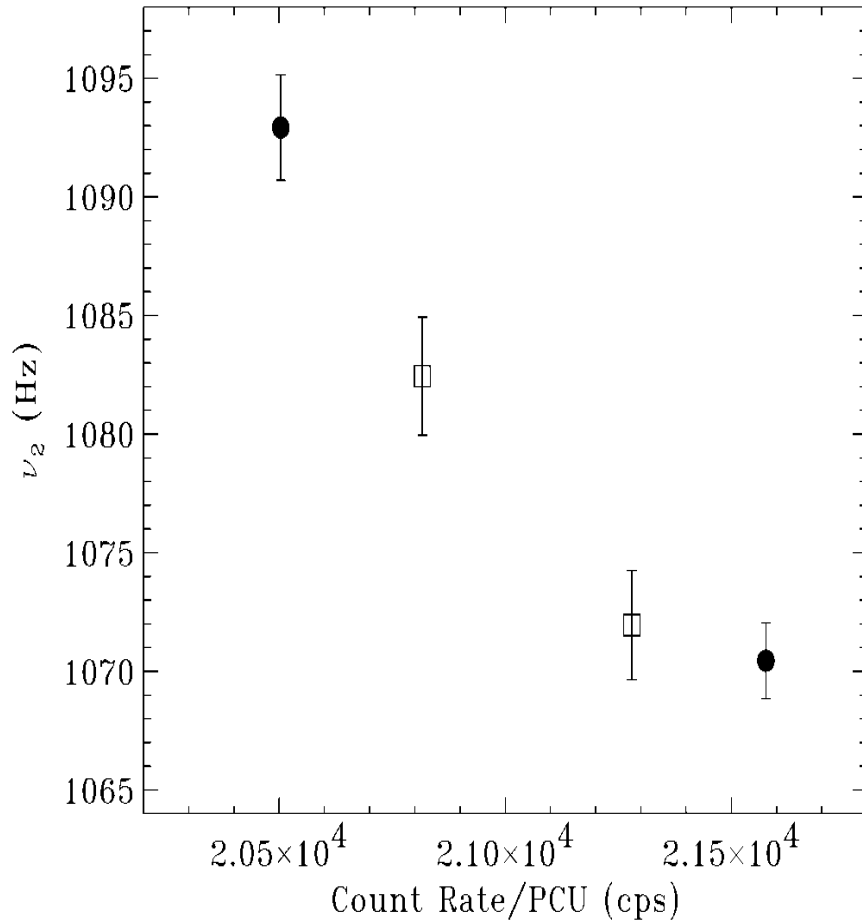
Why Sco X-1 ?

- the brightest persistent X-ray source

Variability components generally have similar fractional rms amplitude among sources on the same state. The best sources for the study of a certain variability component are the brightest sources.

X-ray Variability on long and short time scales

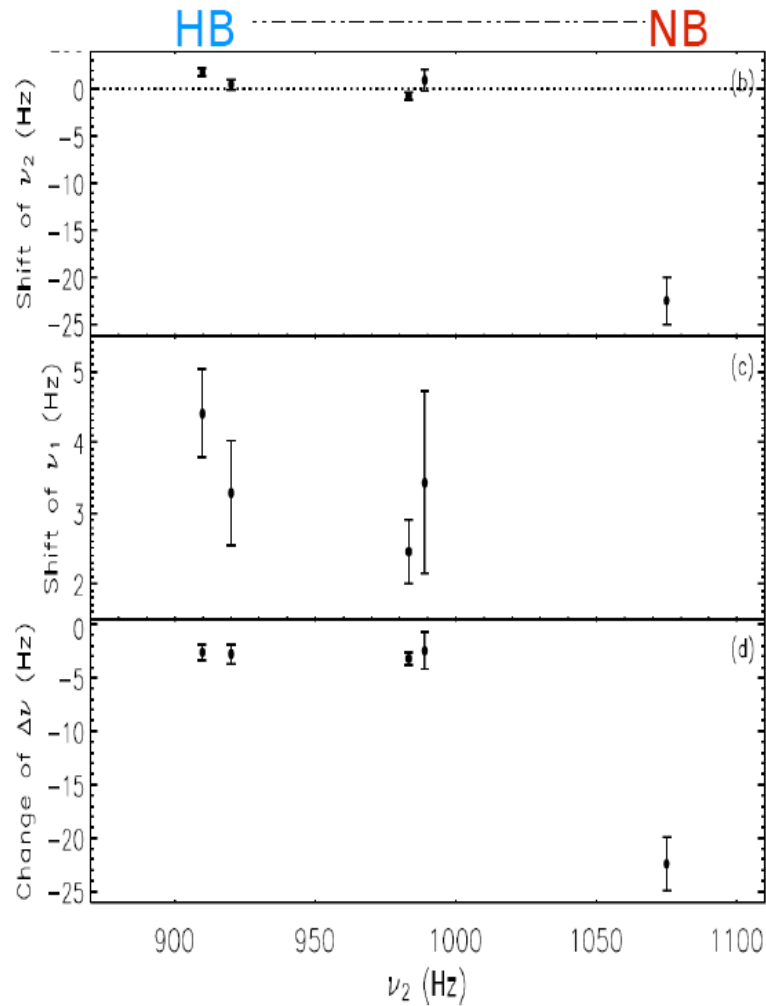
1. Hundreds of seconds -- VLFN



Yu et al. 2001

- There is an anti-correlation between the kHz QPO frequency and the VLFN flux.
- The VLFN is primarily associated with the variation of the mass accretion rate, which is associated with the variation on each parallel track.

2. Seconds -- BLN



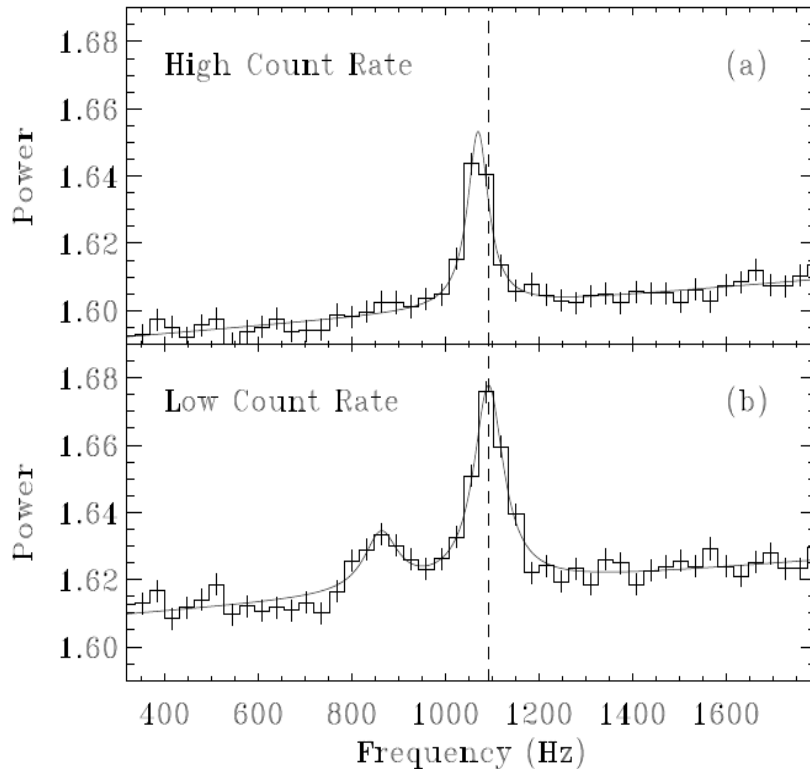
Cao & Yu 2009

- Both lower (ν_1) and upper (ν_2) kHz QPO frequency are positively correlated with the BLN flux.

- On the BLN timescales the peak separation ($\Delta\nu$) decreases by about 2~4 Hz with increasing ν_2 , consistent with that on long time scales the source traces on the color-color diagram.

- The BLN is likely associated with the disk flux.

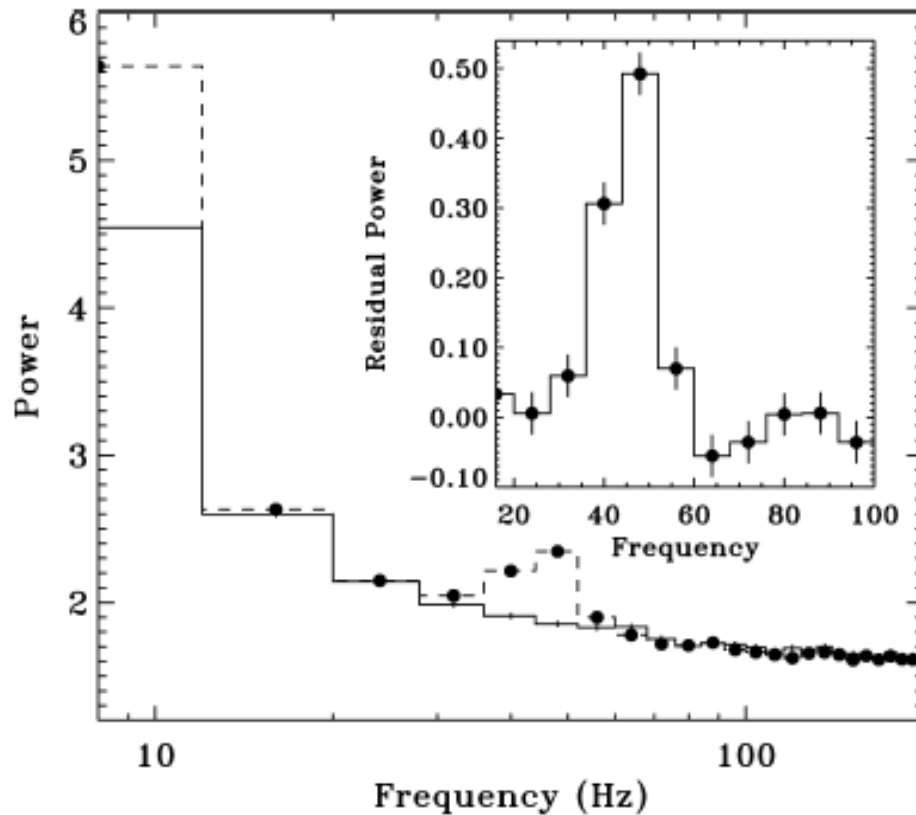
3. A hundred milliseconds -- NBO



Yu et al. 2001

- The frequency of the upper kHz QPO is anti-correlated with the NBO flux.
-
- The NBO flux probably originates from inside the inner disk radius, which exerts a radiative stress on the inner disk edge causing orbital frequency modulation.
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- Failure of the unknown mechanism for the kHz QPOs to generate the lower kHz QPO during the NBO phase of high flux.

4. Ten milliseconds -- HBO



- The HBO shows up during the NBO phase of high flux.
- Investigation of the variability on the coherence time scale of HBO is underway.

filled circles: high flux

crosses: low flux

Discussion and conclusion

- We have systematically studied the X-ray variability in neutron star LMXBs from hundreds of seconds to ten milliseconds.
- Comparing the correlation behavior with the that of the variation forming each parallel track, we provide the evidence that:

BLN corresponds to the variation of the mass accretion rate in the disk flow

NBO flux is generated inside the inner disk or on the neutron star surface

HBO shows strong coupling with the NBO

- Assuming the unified picture of neutron star and black hole variability is correct, the BLN in black hole binaries corresponds to the variation of the mass accretion rate in the disk flow (not from corona, radial flow, or jet).

Thanks !