QPOs in AGN

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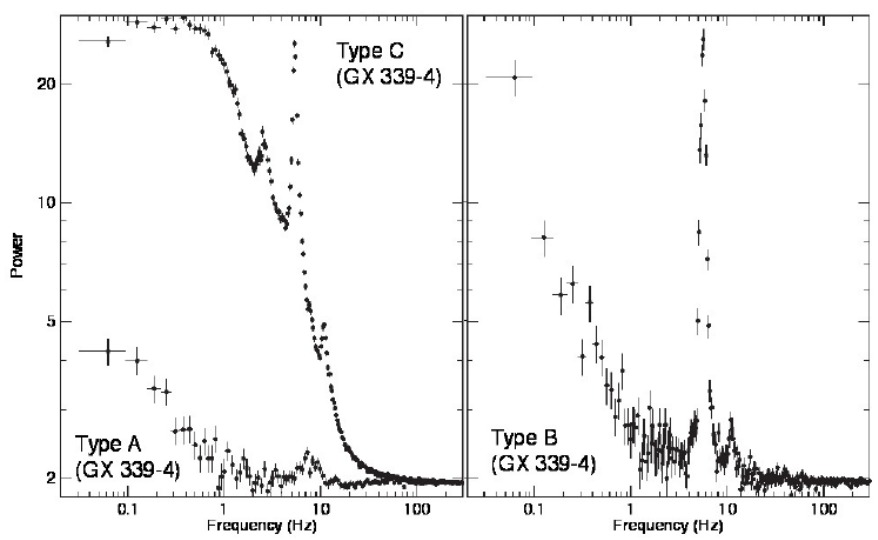
RAS
10/04/15

Cambridge X-Ray Astronomy

QPOs in BH-XRBs

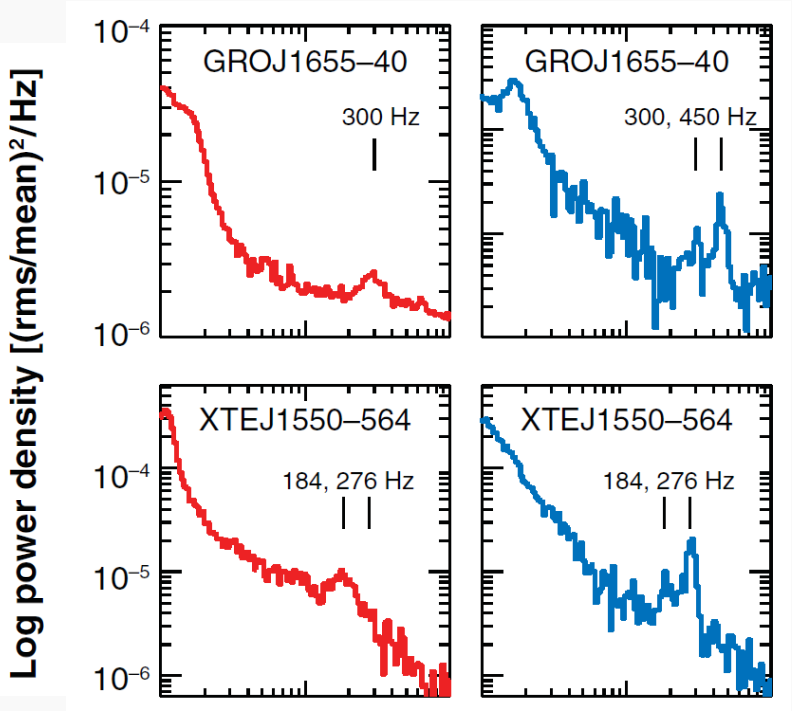
LFQPOs



SIMS: A + B
HIMS: C
LHS: C
HSS: C

Motta + 2011
See also Belloni & Stella 2014

HFQPOs

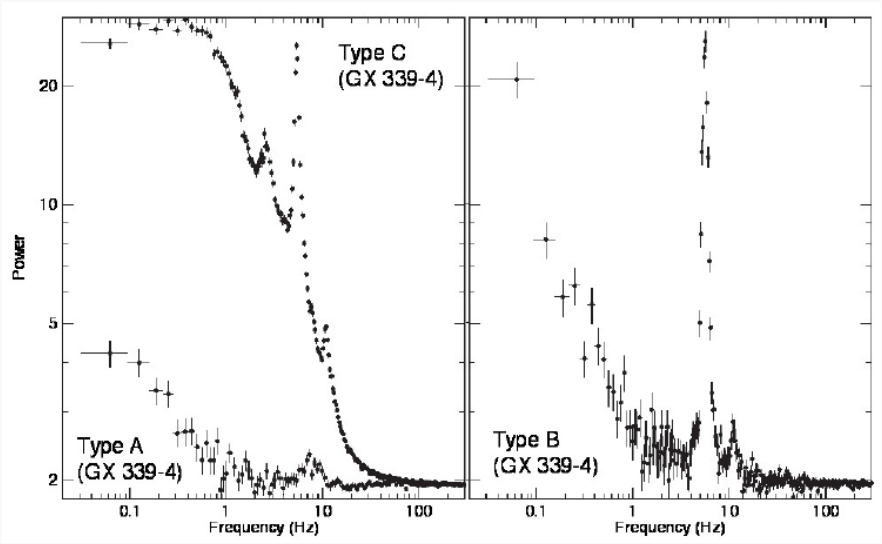


VH/I states

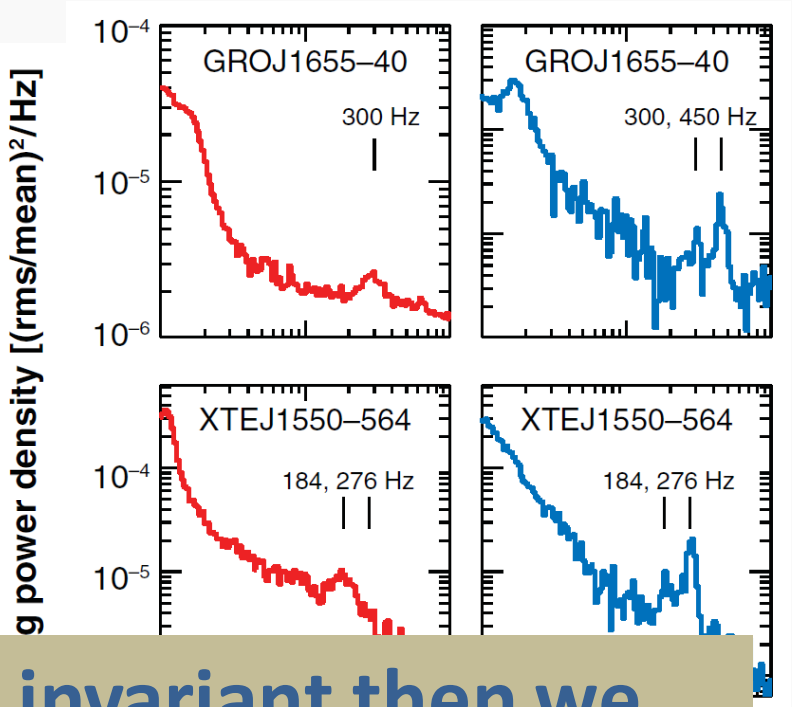
Remillard & McClintock 2006

QPOs in BH-XRBs

LFQPOs



HFQPOs



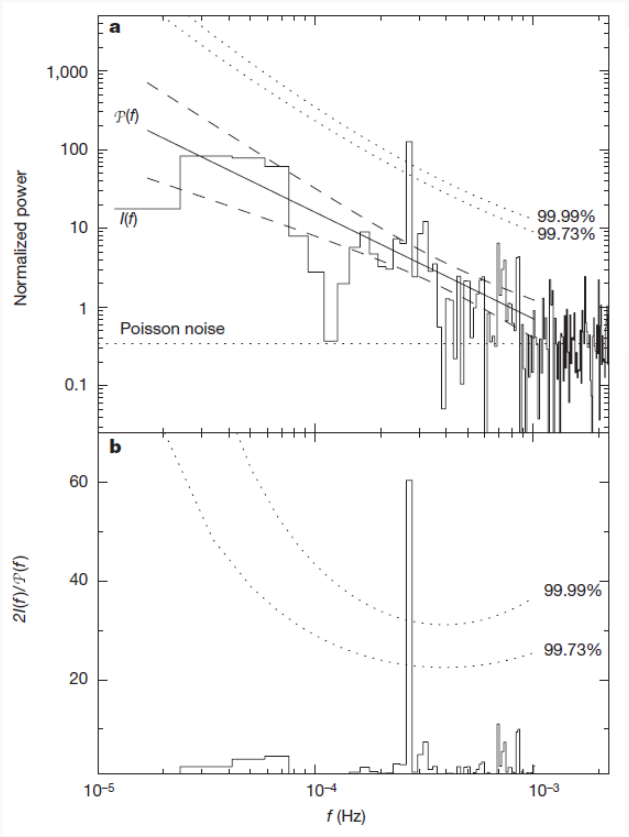
If accretion process is scale invariant then we expect to see both HF and LF QPOs in AGN

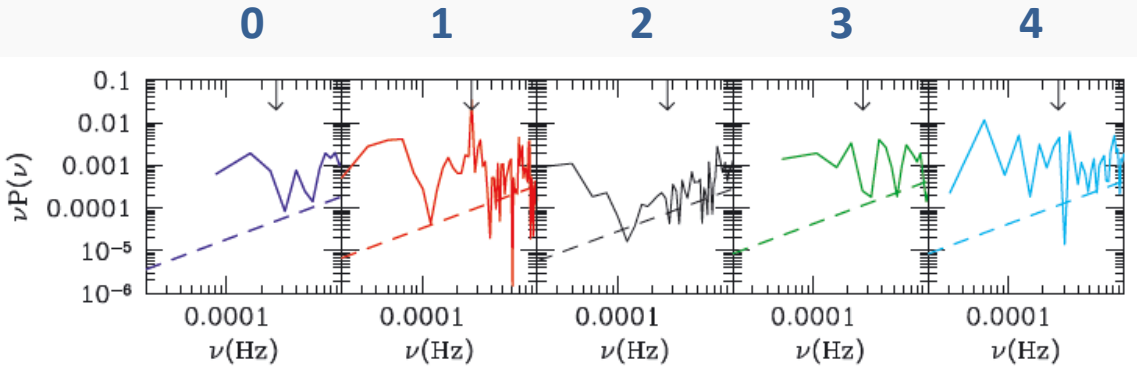
Motta + 2011
See also Belloni & Stella 2014

Remillard & McClintock 2006

QPO in RE J1034+396 (NLS1)

Ob 1: 90 ks



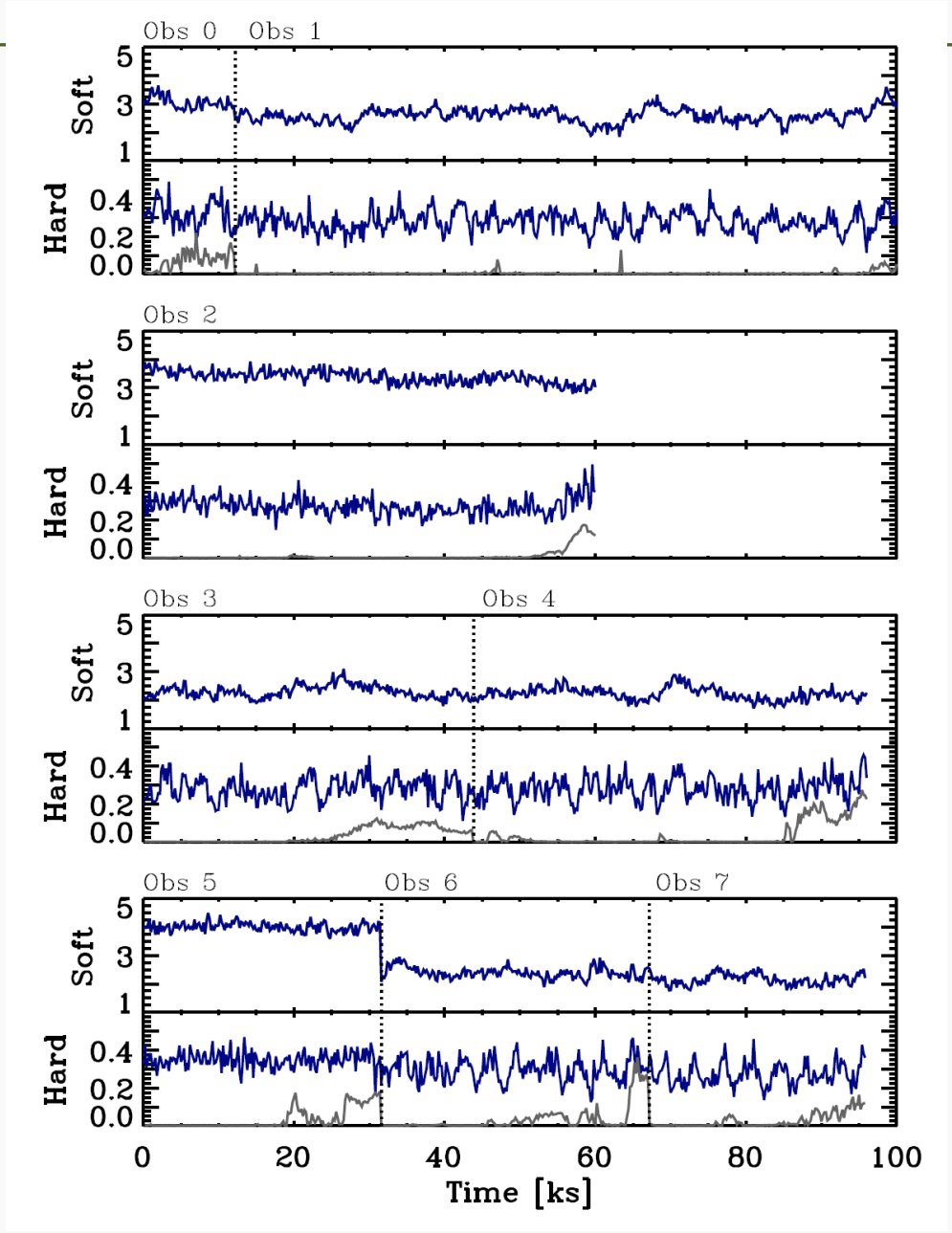


- 2.6 x 10^{-4} Hz (1 hour)
- Only seen in Obs 1 (0.3-10 keV)
- No QPO in 0.3-10 keV band (M11)
  - **Evidence for its presence in covariance spectra**

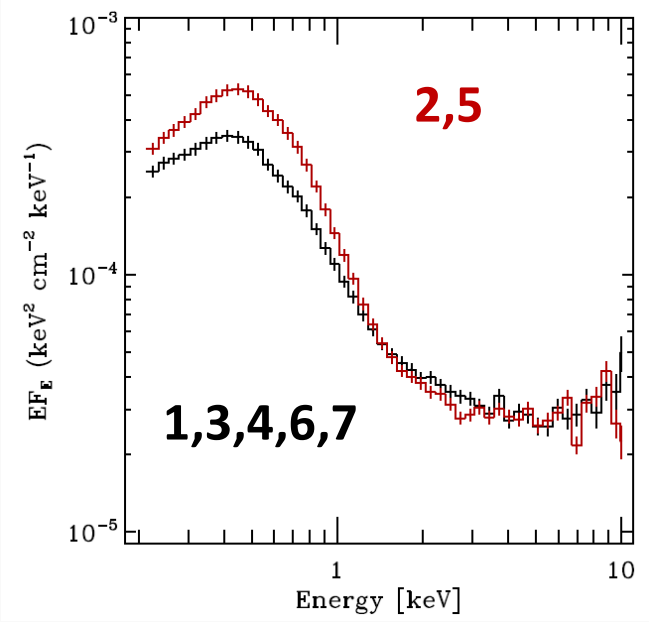
Gerlinski + 2008
See also Vaughan 2010

Middleton + 2011

XMM observations (0.3-0.8 and 1-4 keV)



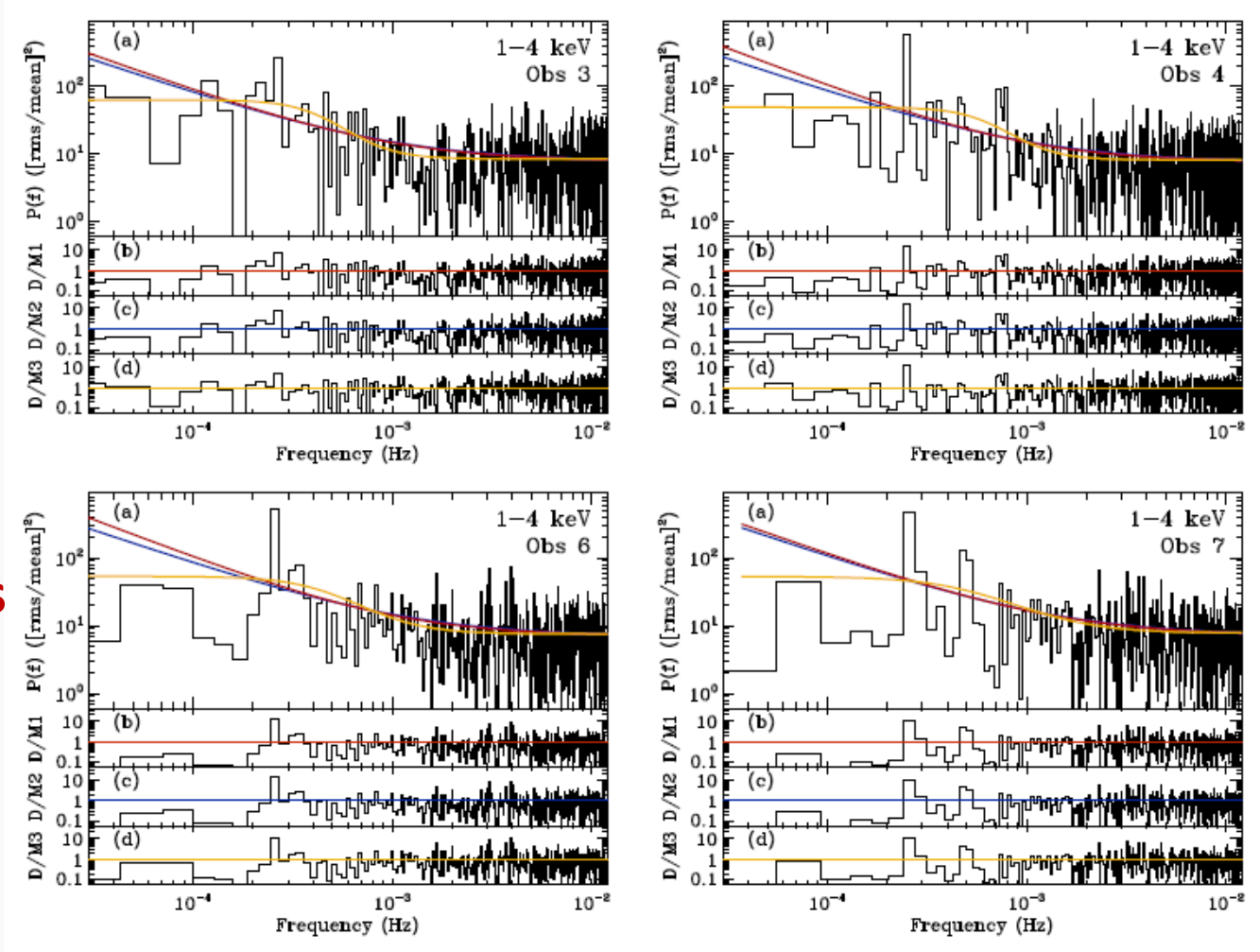
2007



2011

QPO present in 1-4 keV band in the 5 low flux/ spectrally-harder observations

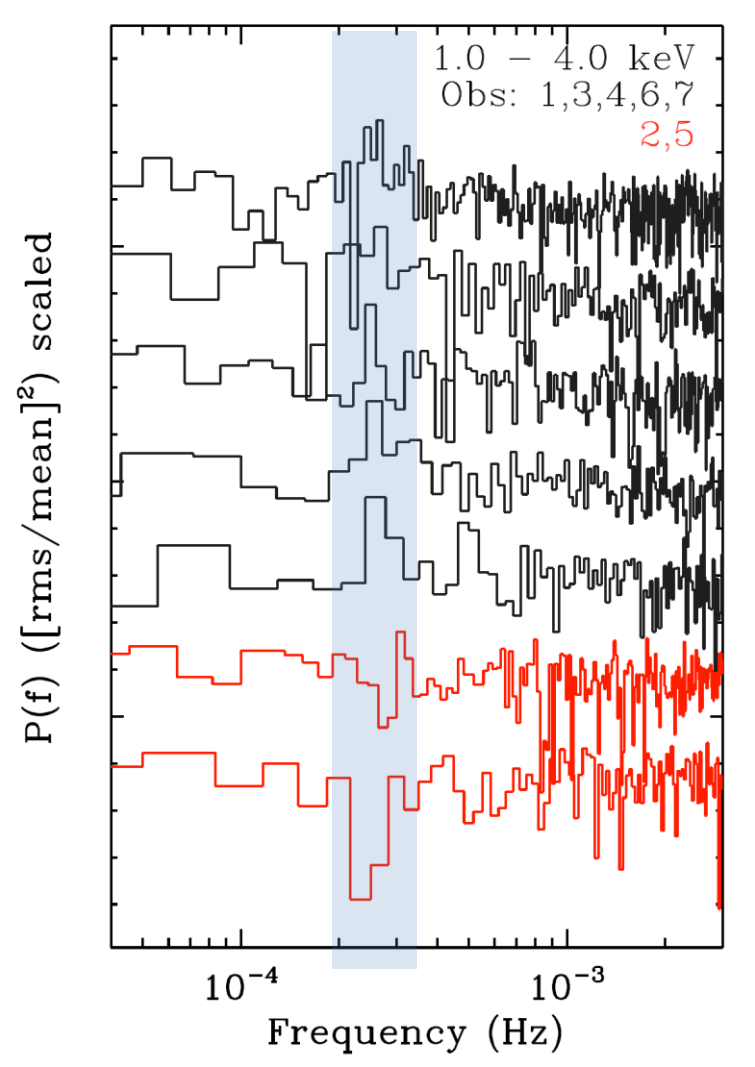
~6 % rms



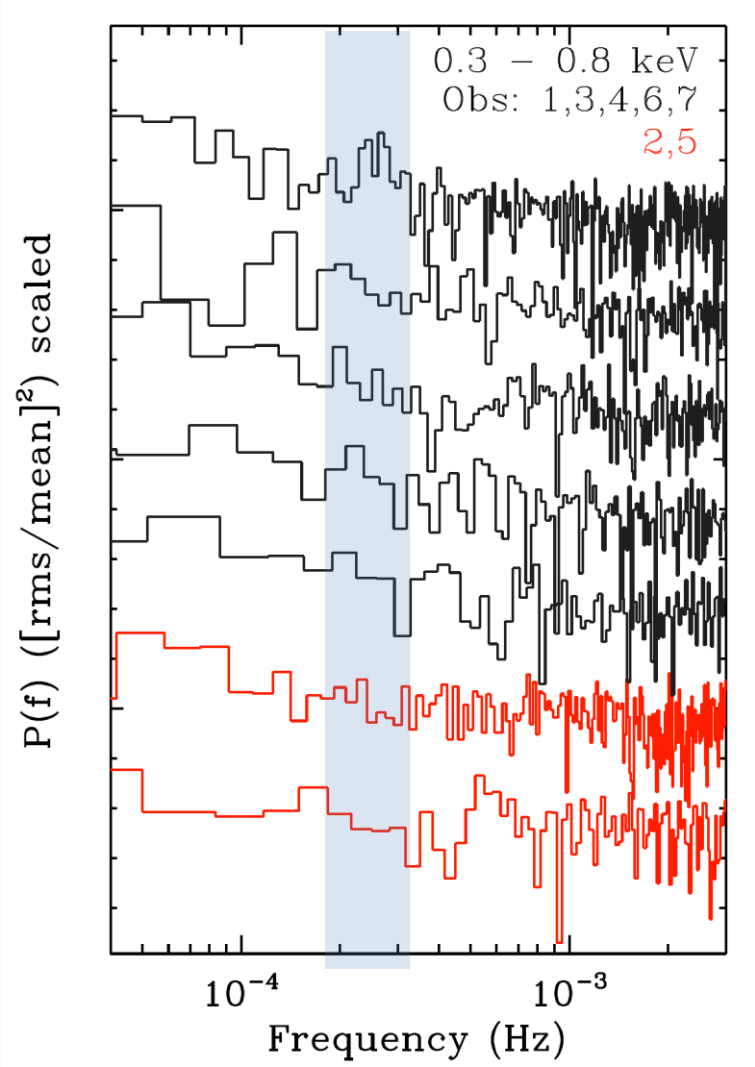
WA, Markeviciute, Kara, Fabian, Middleton, 2014, MNRAS , 445, 16

Energy resolved PSDs

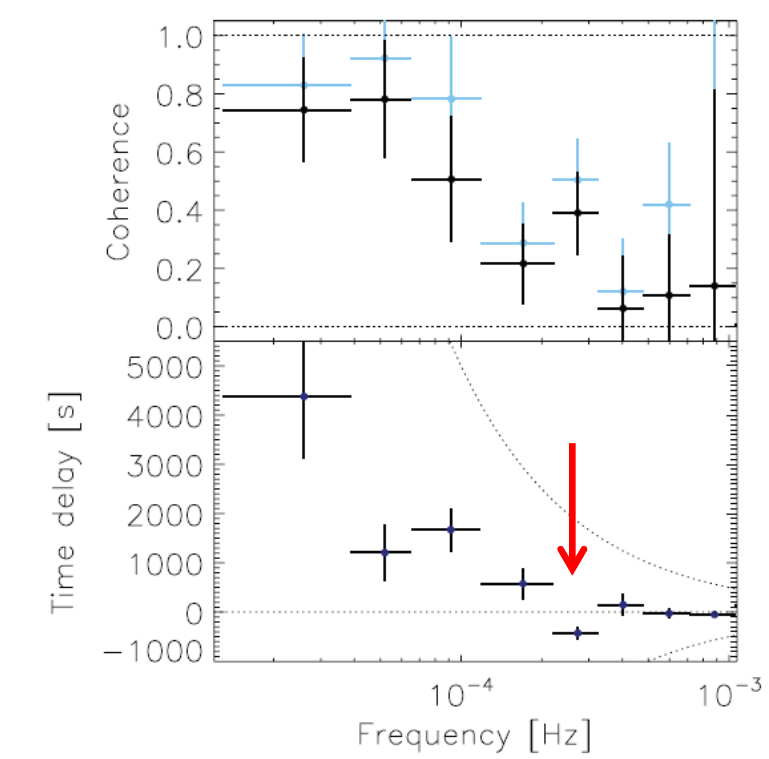
HARD

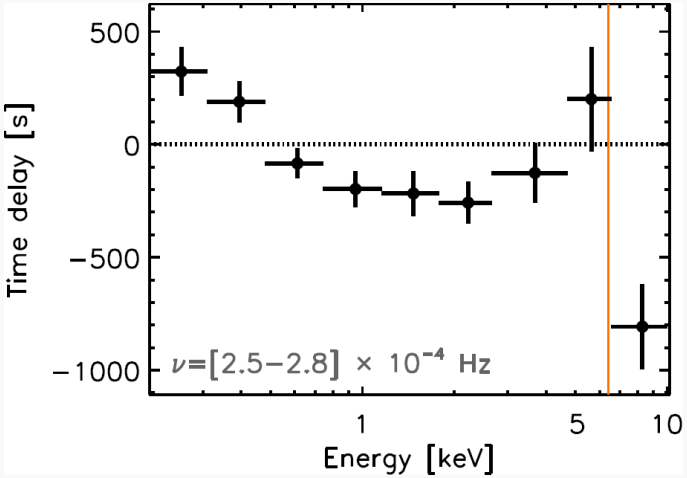


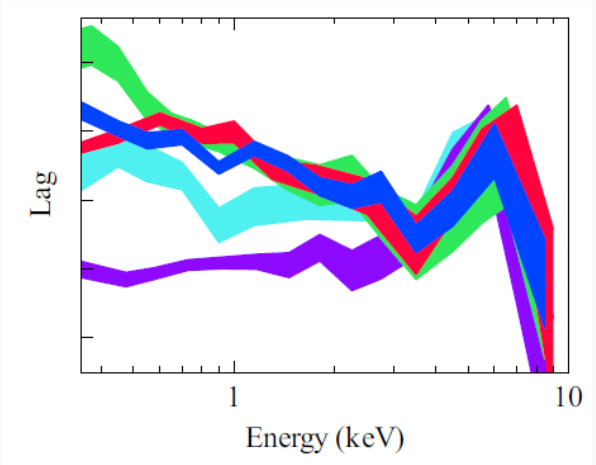
SOFT



RE J1034+396 time lags





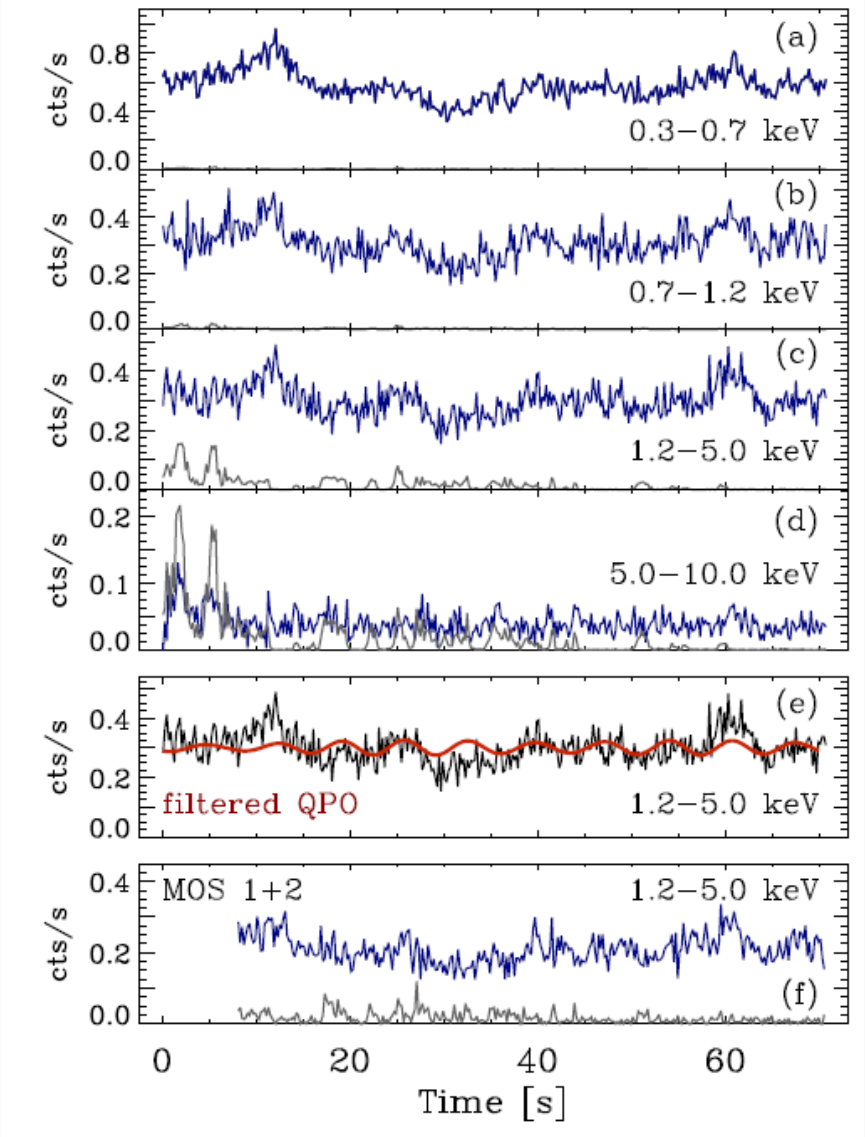


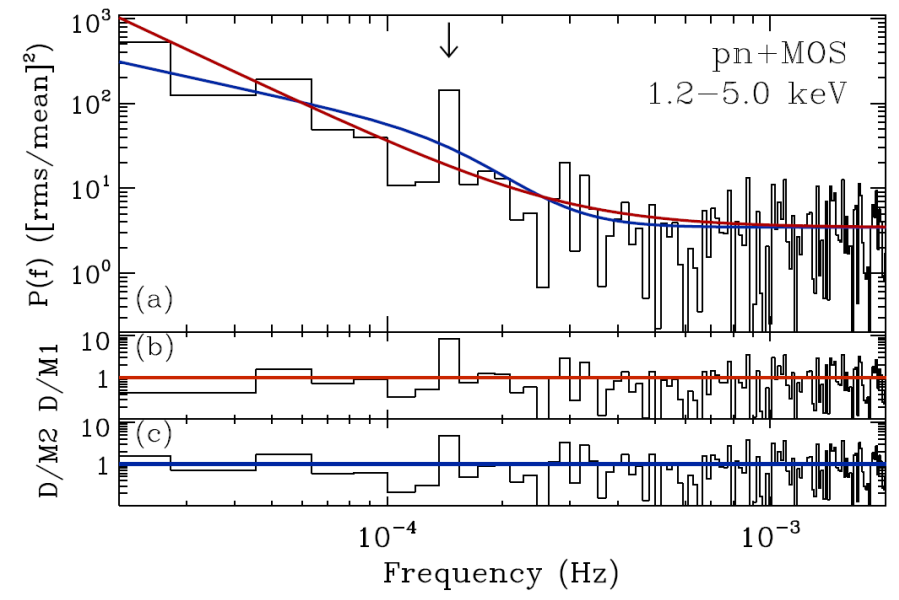
Soft lag at f QPO
(see also Zoghbi + 2011)

Markeviciute, WA, et al, *in prep*

Uttley et al 2014

A QPO in MS 2254.9-3712 (NLS1)



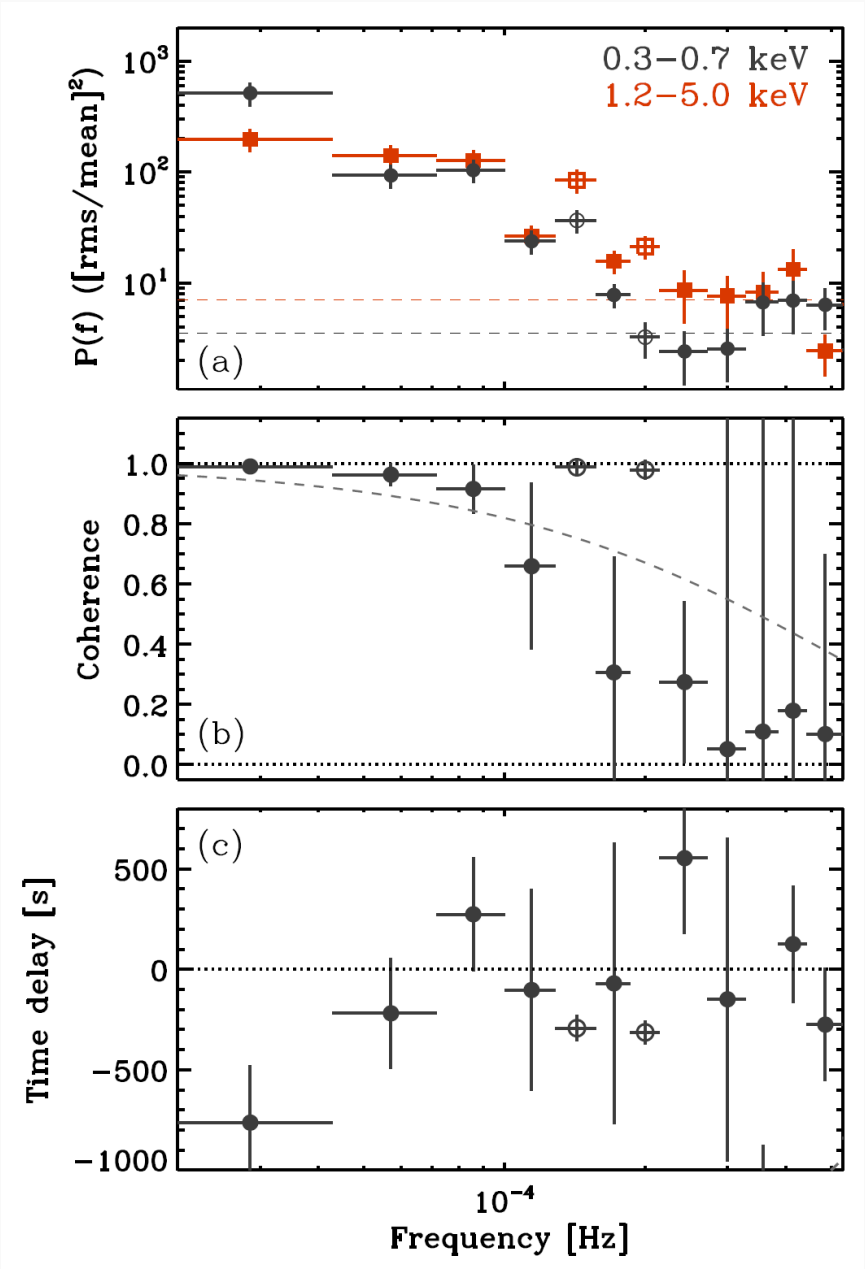


$$P(\nu) = N\nu^{-\alpha} + C$$

p_{LRT} = 0.0012
p_{SSE} = 0.001
p_{R} = 0.001

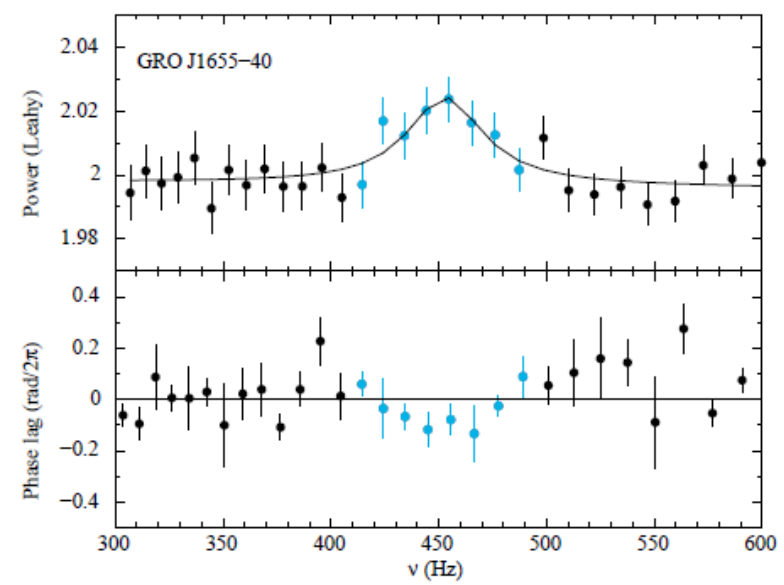
$$P(\nu) = \frac{N\nu^{\alpha_{low}}}{1 + (\nu/\nu_{bend})^{\alpha_{low}-\alpha_{high}}} + C$$

Alston + 2015, MNRAS, 449, 467



Cross-Spectral products between soft (0.3-0.7) and hard (1.2-5.0) bands

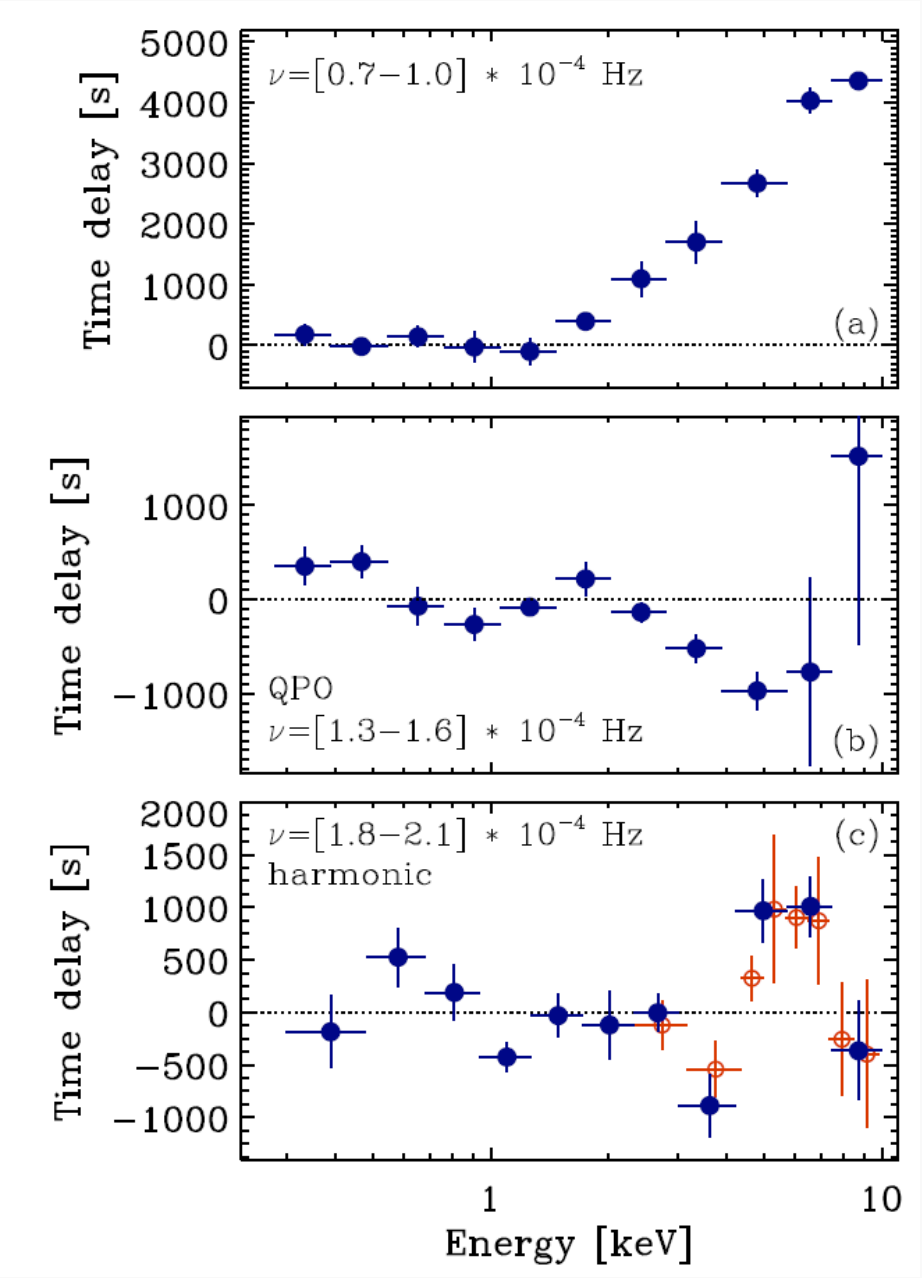
Soft lags observed in some BHB HFQPOs



Mendez + 2013

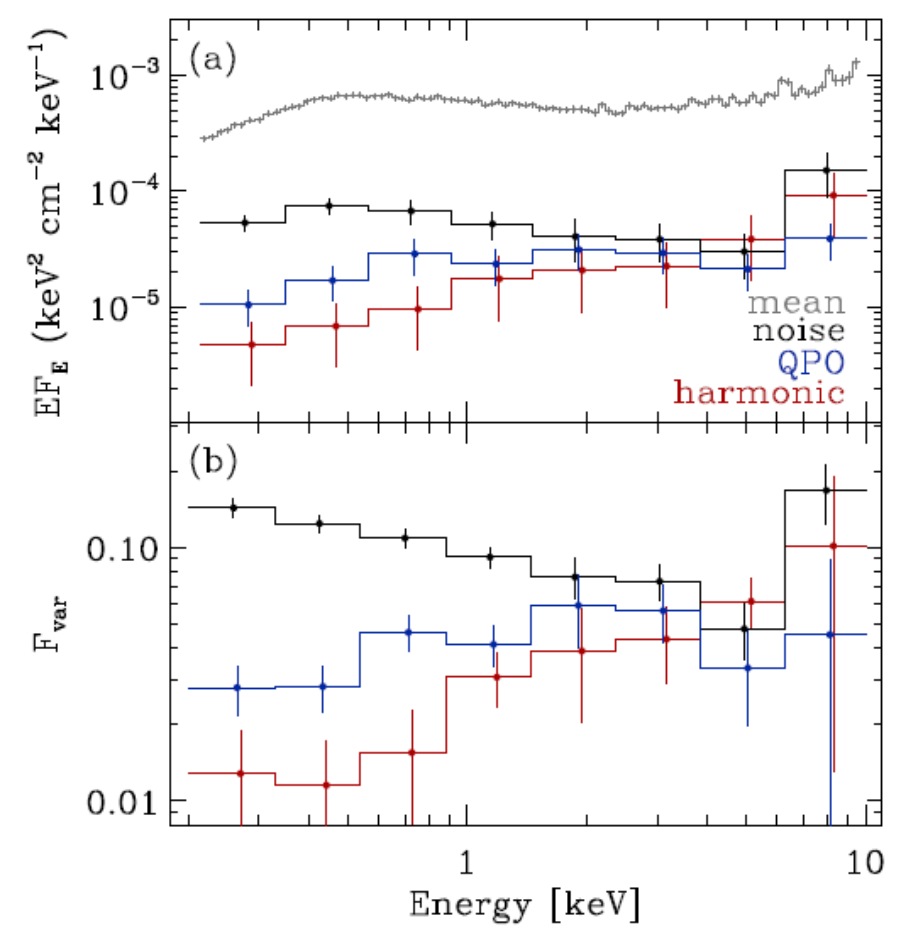
Time delays as a function of energy at a given frequency

Positive lag indicates lag of comparison band vs total energy band (minus comparison band)



Alston + 2015, MNRAS, 449, 467

Mean and *rms*-spectra

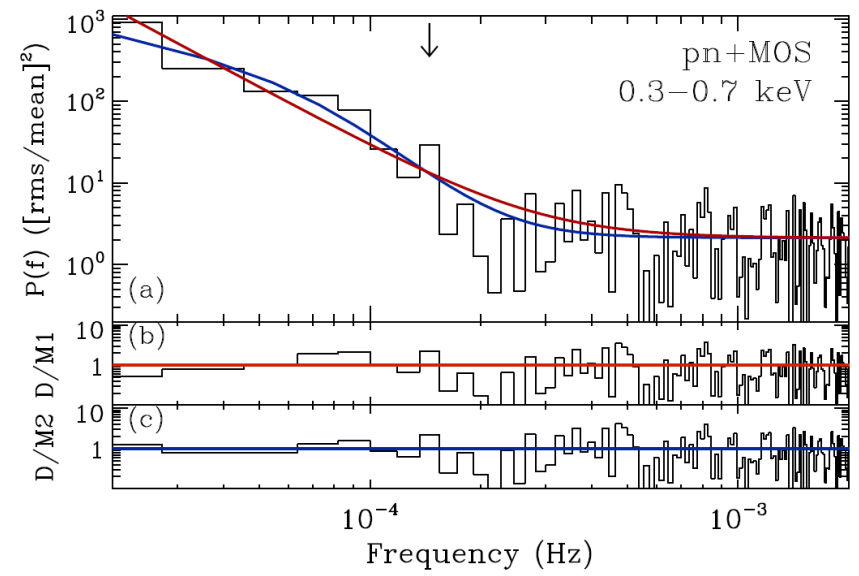


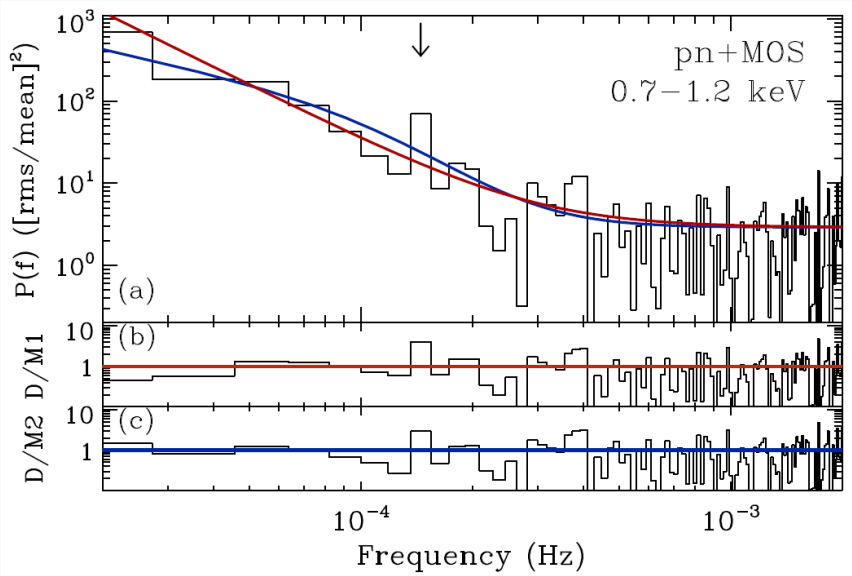
Mean spectrum well described by two absorbed PL (Γ~2.8; 1.5) plus neutral reflection

Hard QPO spectral variability observed in BHBs and RE J1034 (e.g. Belloni 2010 review)

Alston + 2015, MNRAS, 449, 467

Structure seen at f_{QPO} in softer bands





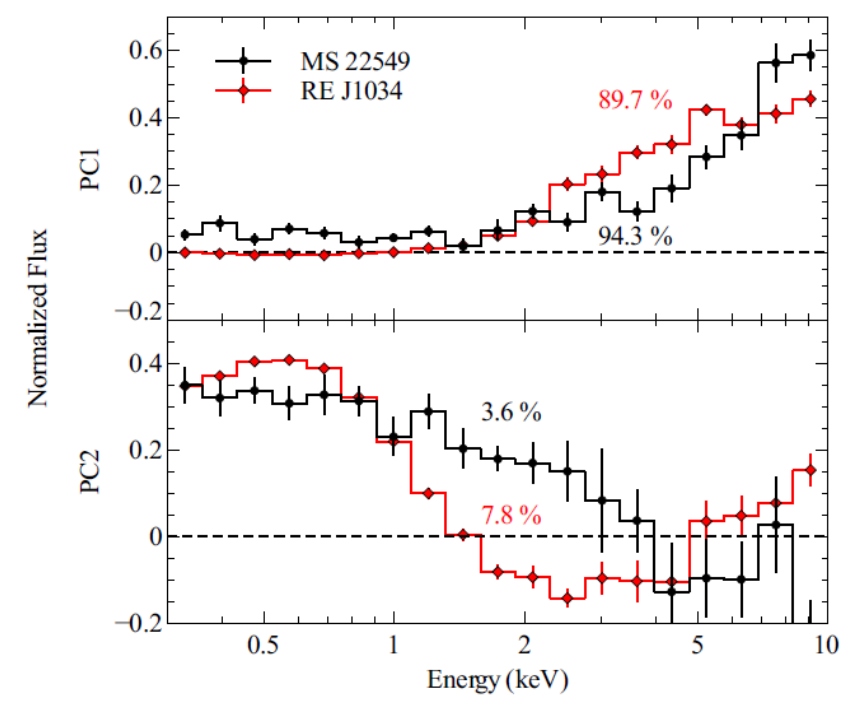
Reprocessing of hard band QPO variability?
Soft lags observed

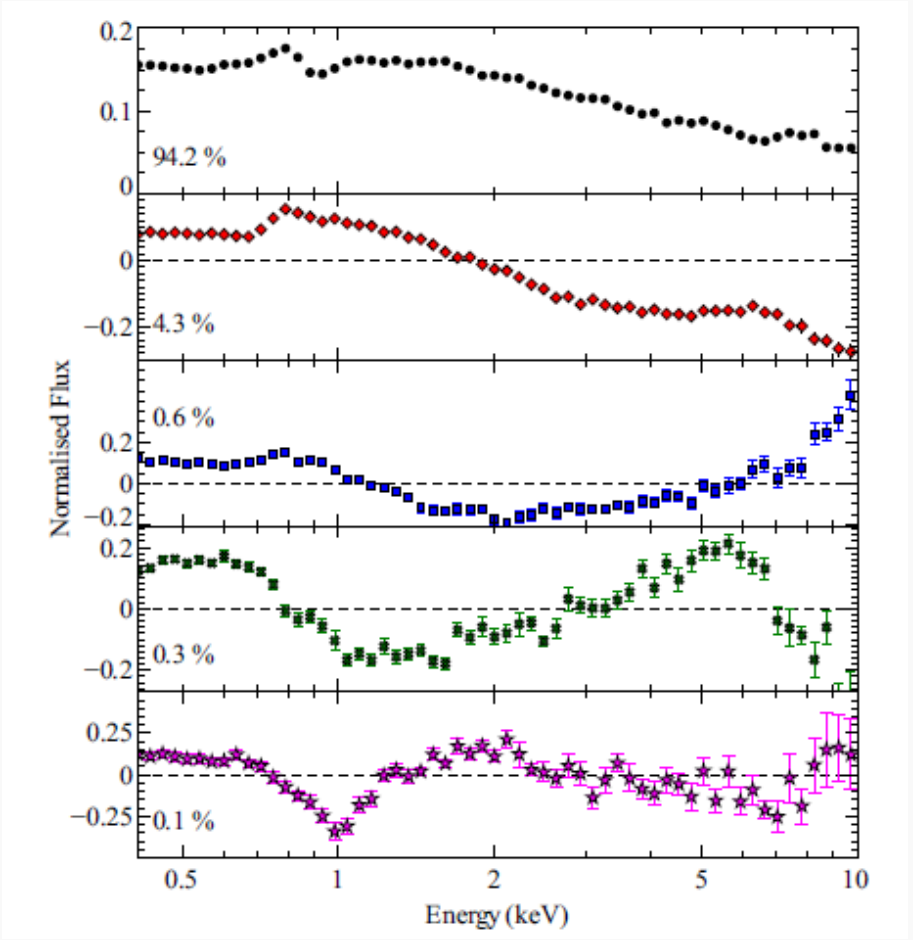
Same primary continuum QPO?
No lag with 1.2-5 observed

Alston + 2015, MNRAS, 449, 467

Principle components analysis (PCA)

NGC 4051



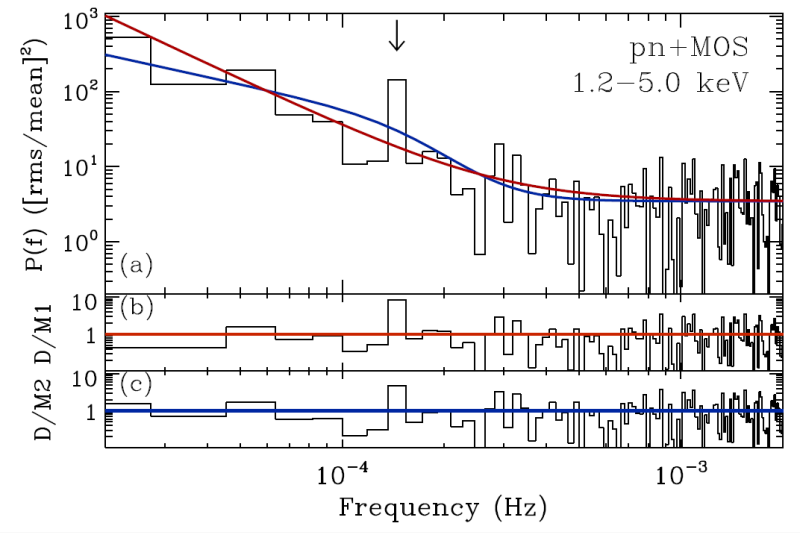


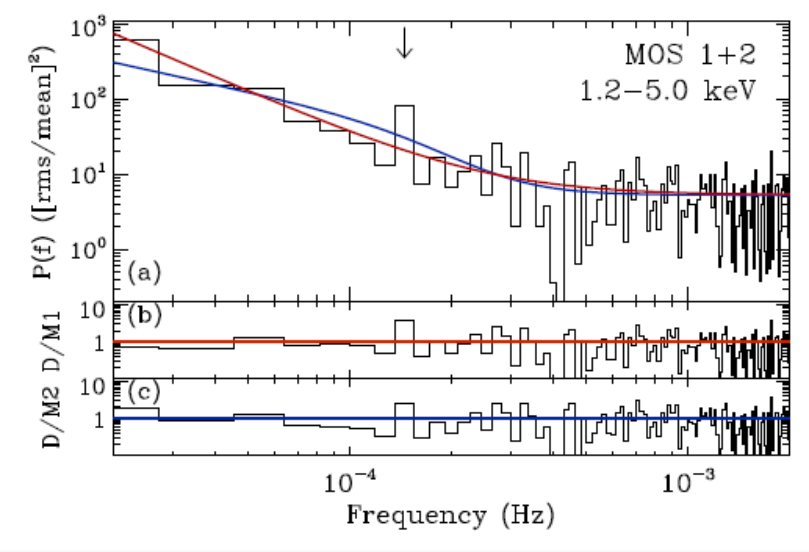
Spectrum is broken down into set of variable components.

Alston + 2015, MNRAS, 449, 467

Parker + 2014

QPO identification





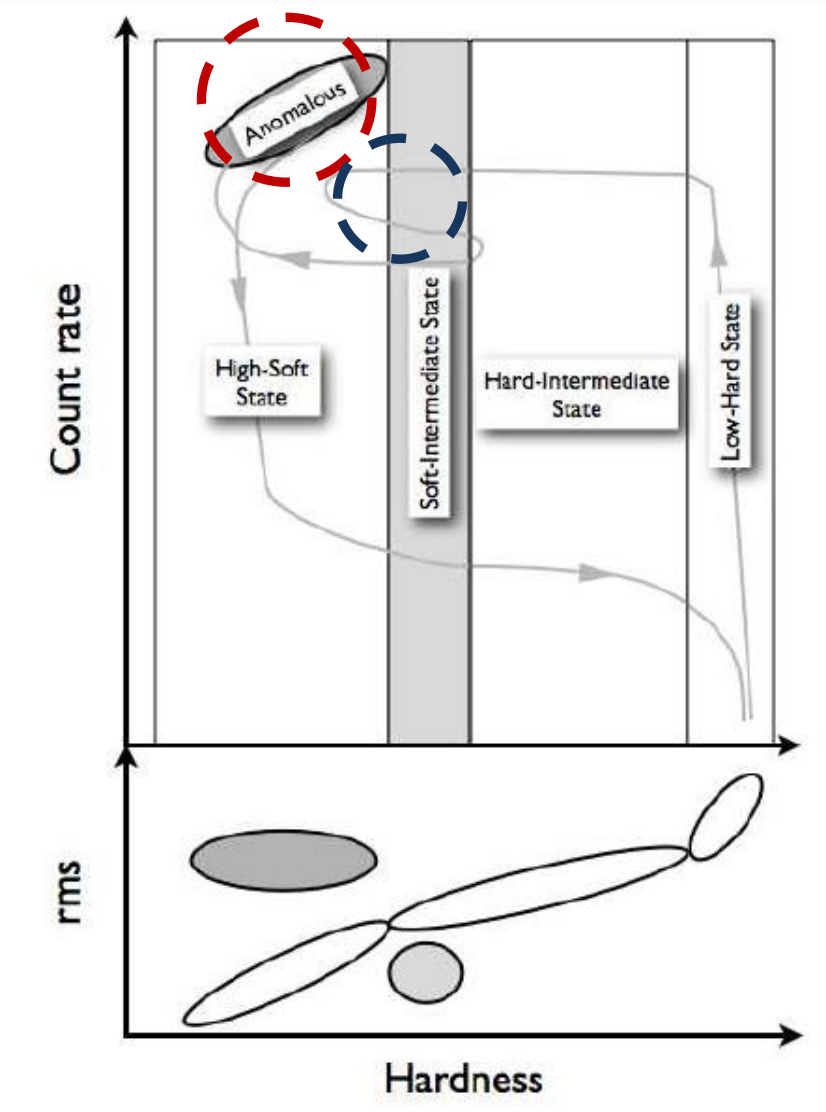
- M_{BH} ~ 0.4-1 x 10^7 M_{sun}
- Broadband noise present
- High coherence in BB noise
- 3:2 harmonic (maybe)
- ~5 % rms
- Consistent with HFQPOs observed in BHBs
- LFQPO: M_{BH} < 1 x 10^6 M_{sun}

AGN have more counts per characteristic timescale than BHBs. Better probe of QPO mechanism

Comparisons with XRBs

RE J1034+396

- m_E = 1-4
- 67 Hz QPO in GRS 1915 (Middleton & Done 2010)
- But soft lag seen in 35 Hz QPO (Mendez et al 2013)

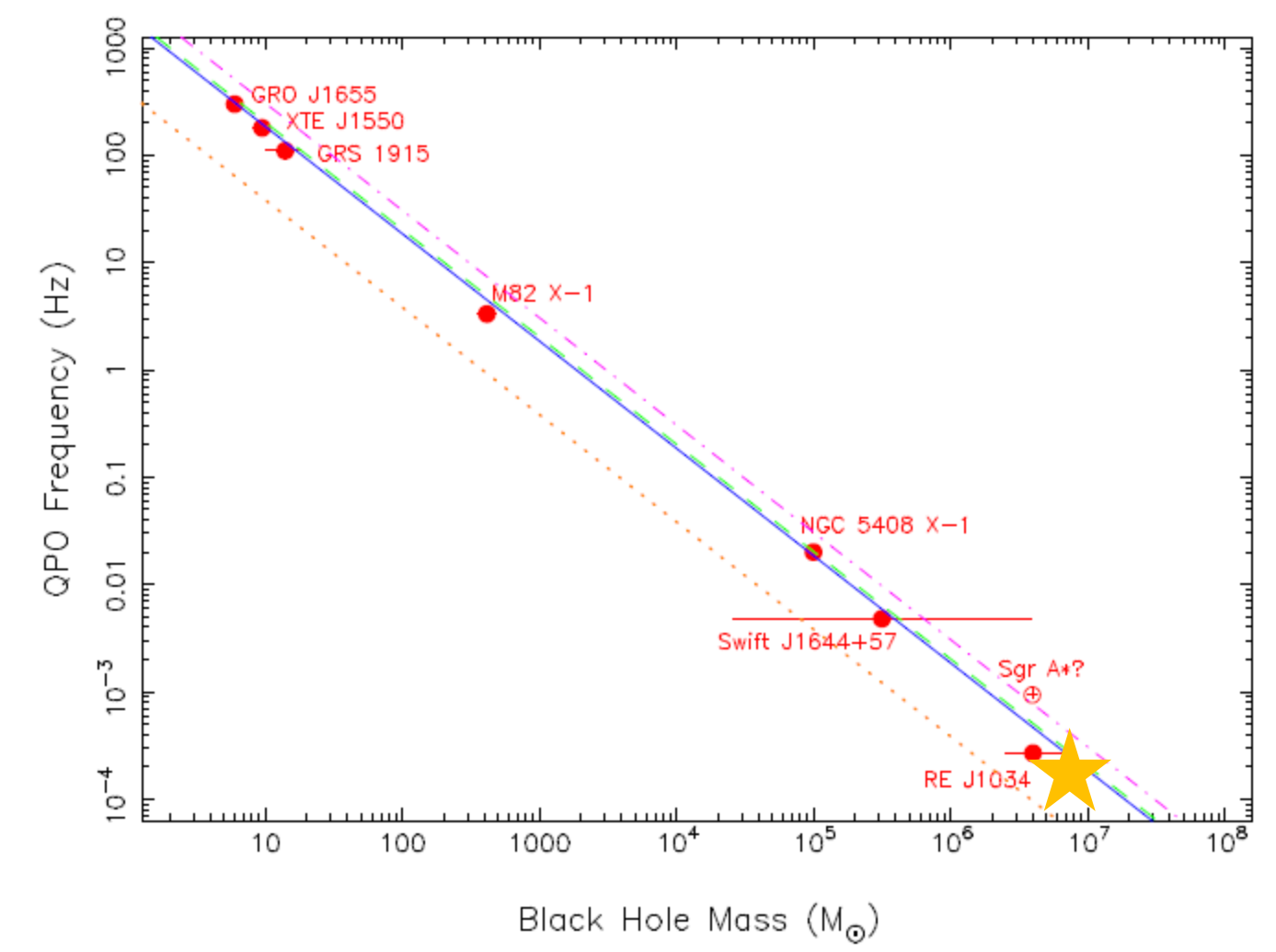


MS 22549-3712

- m_E = 0.25-1
- ~100 Hz for 10 Msun BHXRB

Summary

- QPOs important probe of the inner accretion flow
  - More counts/timescale in AGN
- 1 hr QPO detected in 5 low-flux/spectrally harder observations of RE J1034+396
- 2 hr QPO detected in MS 2254.9-3712
  - Shows similar spectral-timing properties to RE J1034
  - Consistent with being HFQPO
- Reverberation lag seen at f_{QPO}
  - Constraint for QPO models
- Both accreting at m_E – consistent with very high and intermediate states in BH XRBs



f ~ 1/M

Zhou + 2014

PG 1116+215: another QPO detection?