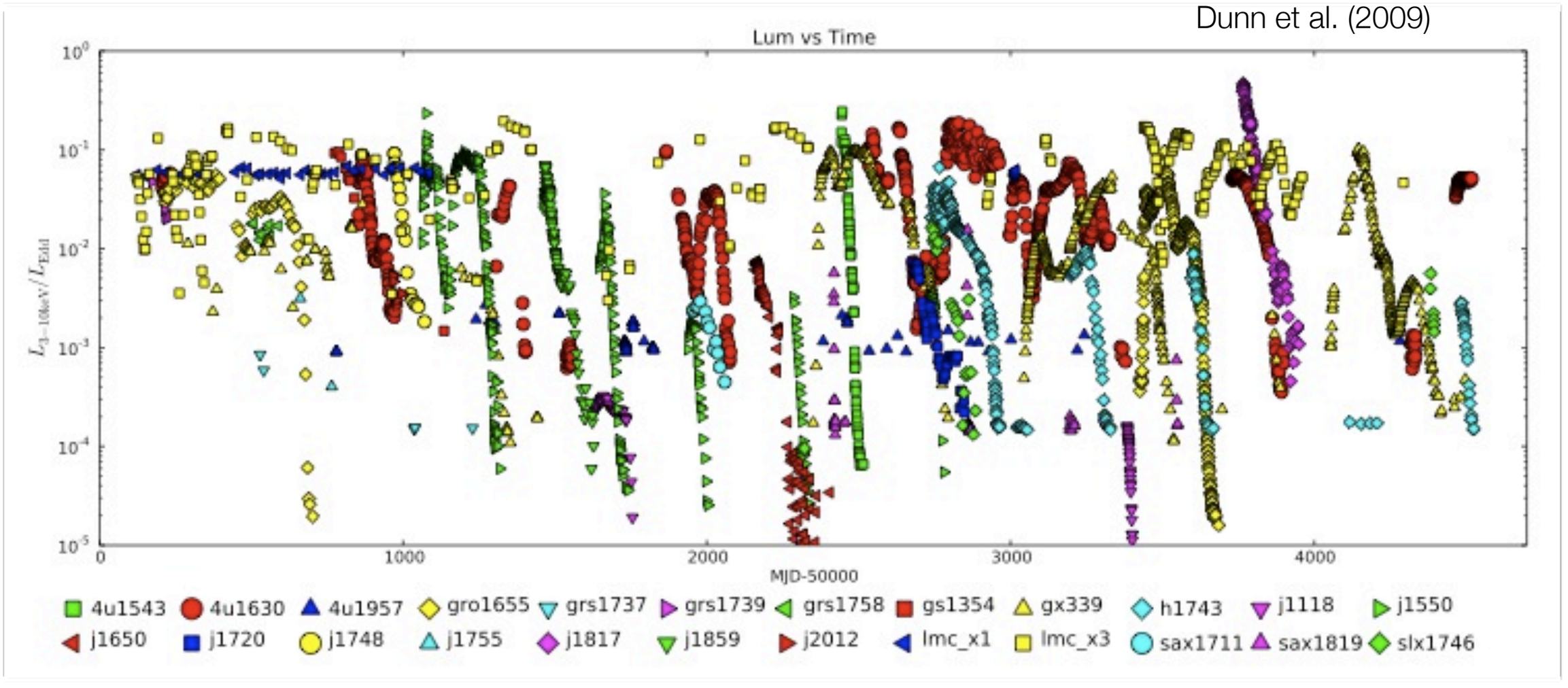
Timing Properties of Black-Hole X-ray Binaries

Tomaso M. Belloni
(INAF - Osservatorio Astronomico di Brera)

WIDEBAND X-RAY ASTRONOMY: FRONTIERS IN TIMING AND SPECTROSCOPY *PUNE* JAN. 2011

Complete RXTE dataset on BHT

Dunn et al. (2009)



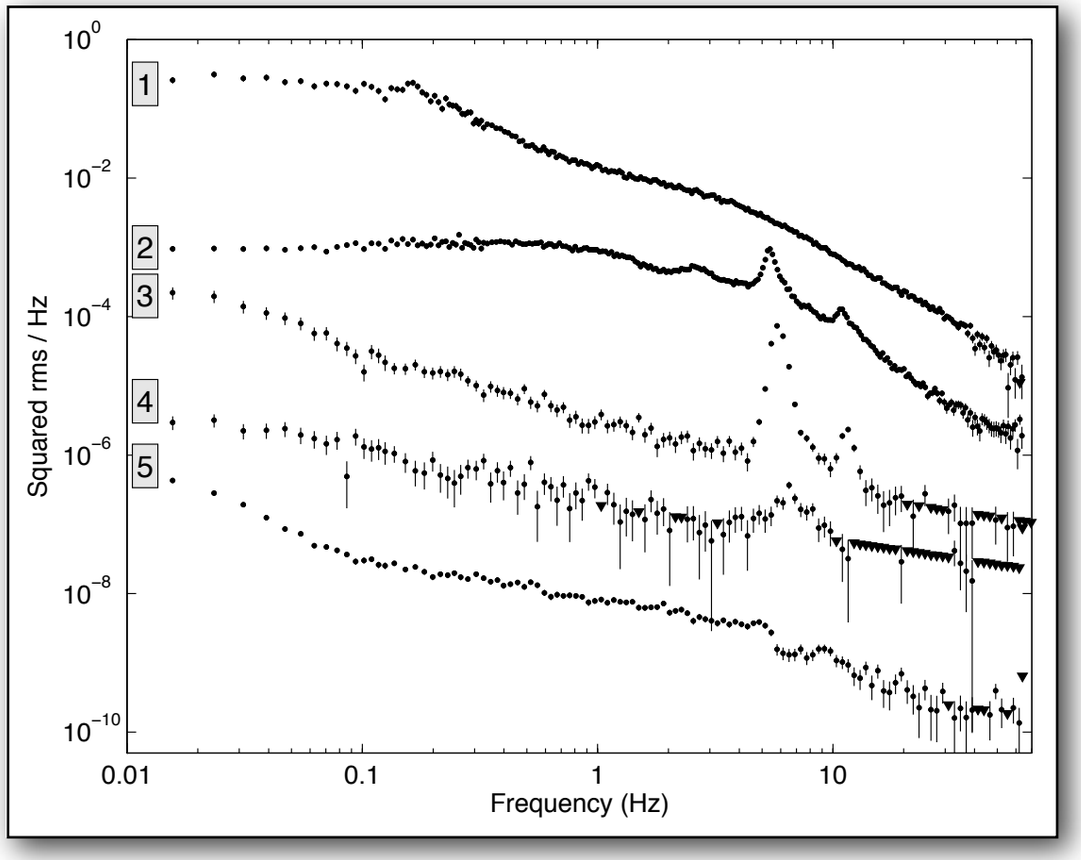
Timing BHB: is it important?

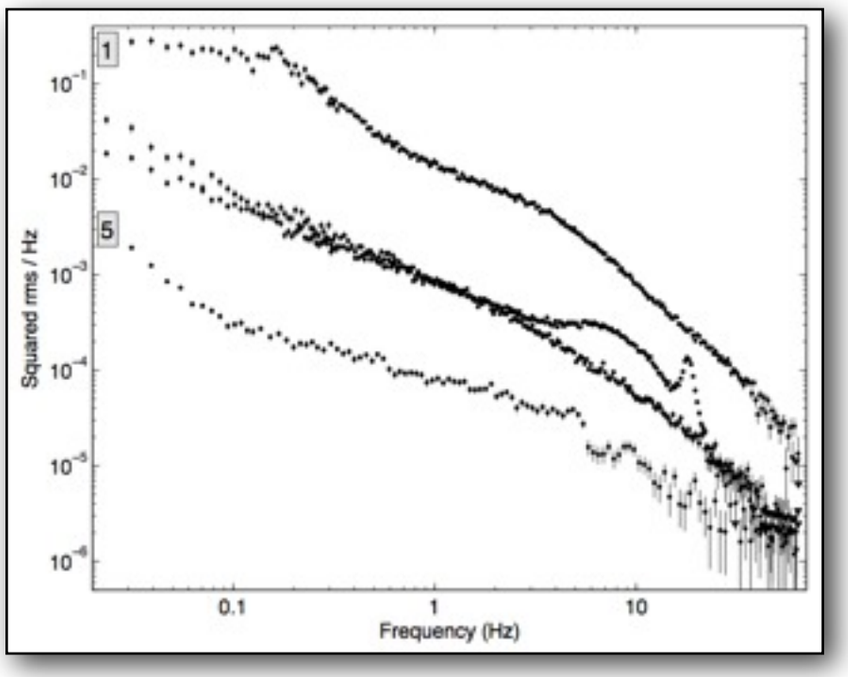
- It can give us insight on the physics of accretion (states, noise)
- it gives fundamental frequencies (QPO, noise)
- it is linked to the accretion/ejection connection (QPO, noise)
- it can give disk inner radii (HFQPO)
- GR effects in strong field (HFQPO, QPO)

Five basic types of PDS observed

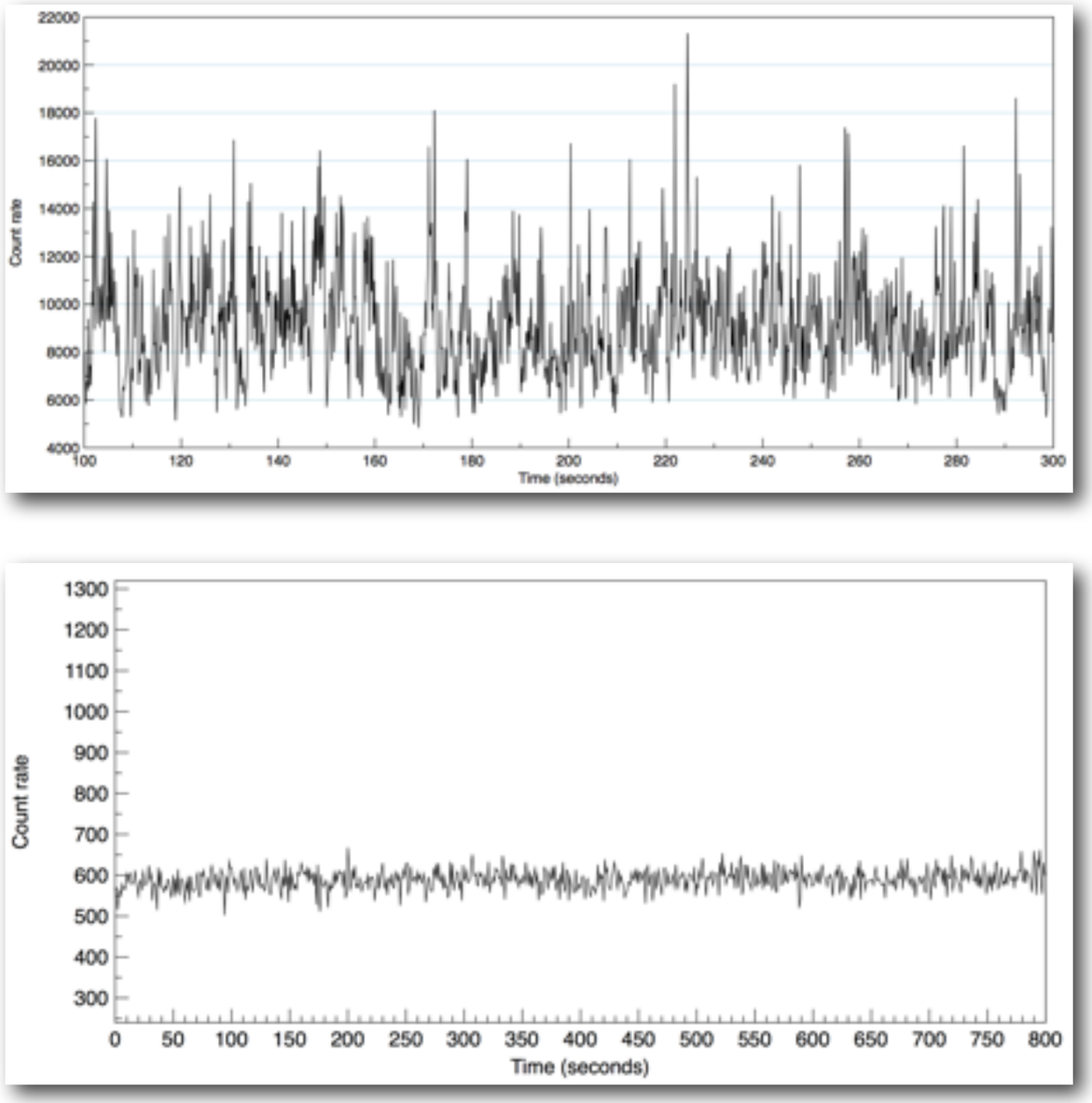
- Cover most of the observations
- There are outliers

Belloni (2010)



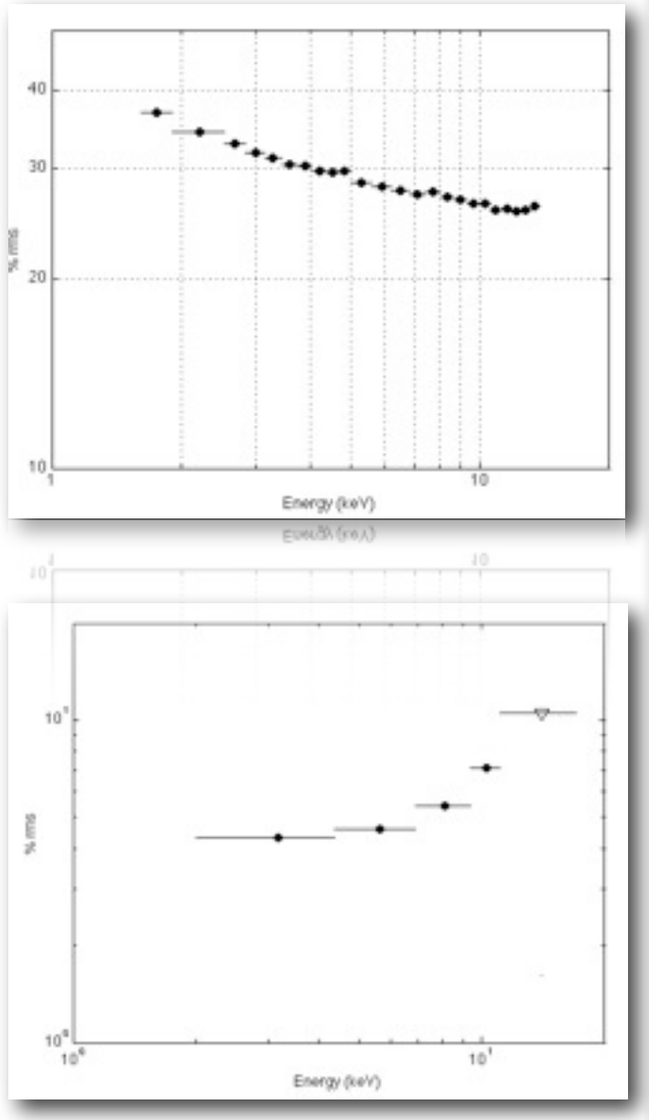


Noise components

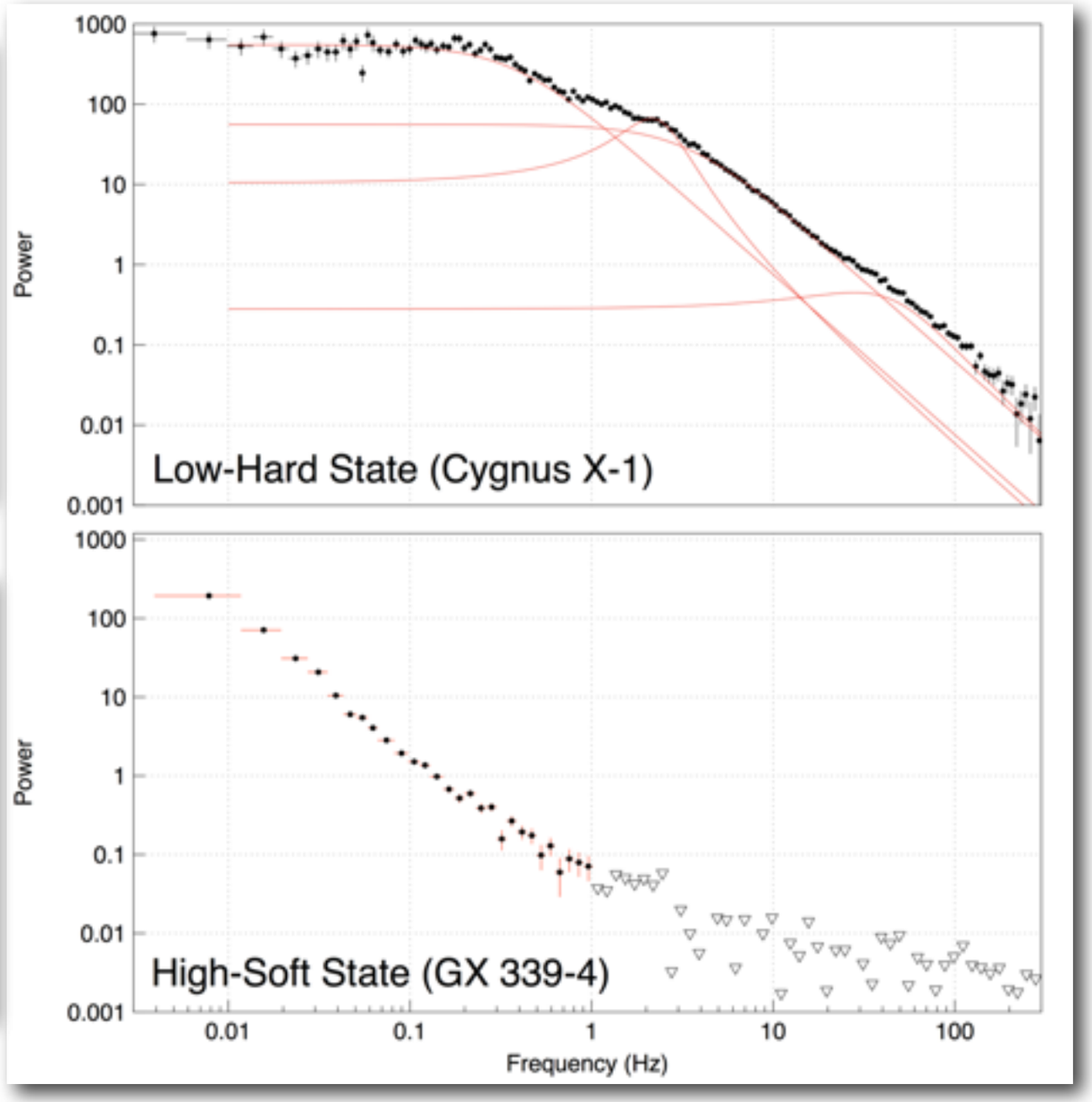


- Hard to ignore - strong differences (1-3% vs. 30-40% rms)

An important difference: energy dependence



1 keV 10 keV

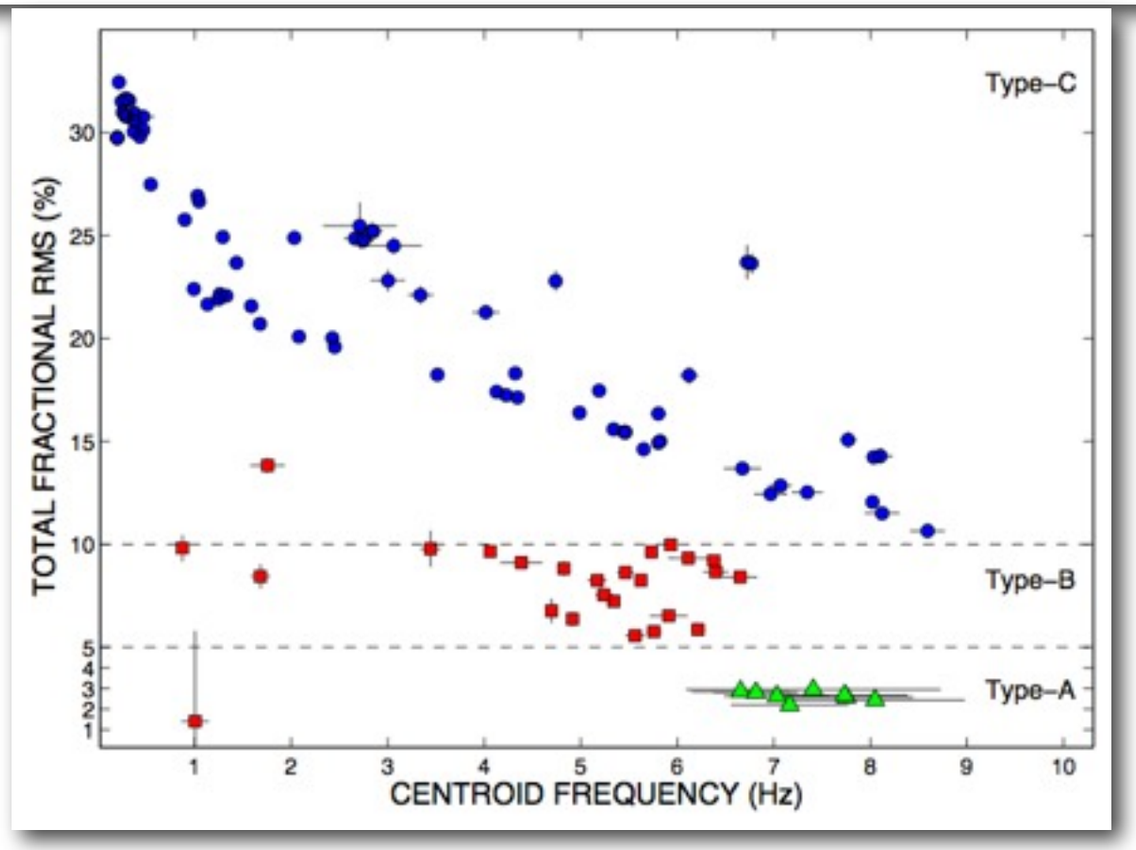


- Difference often ignored - also intermediate states

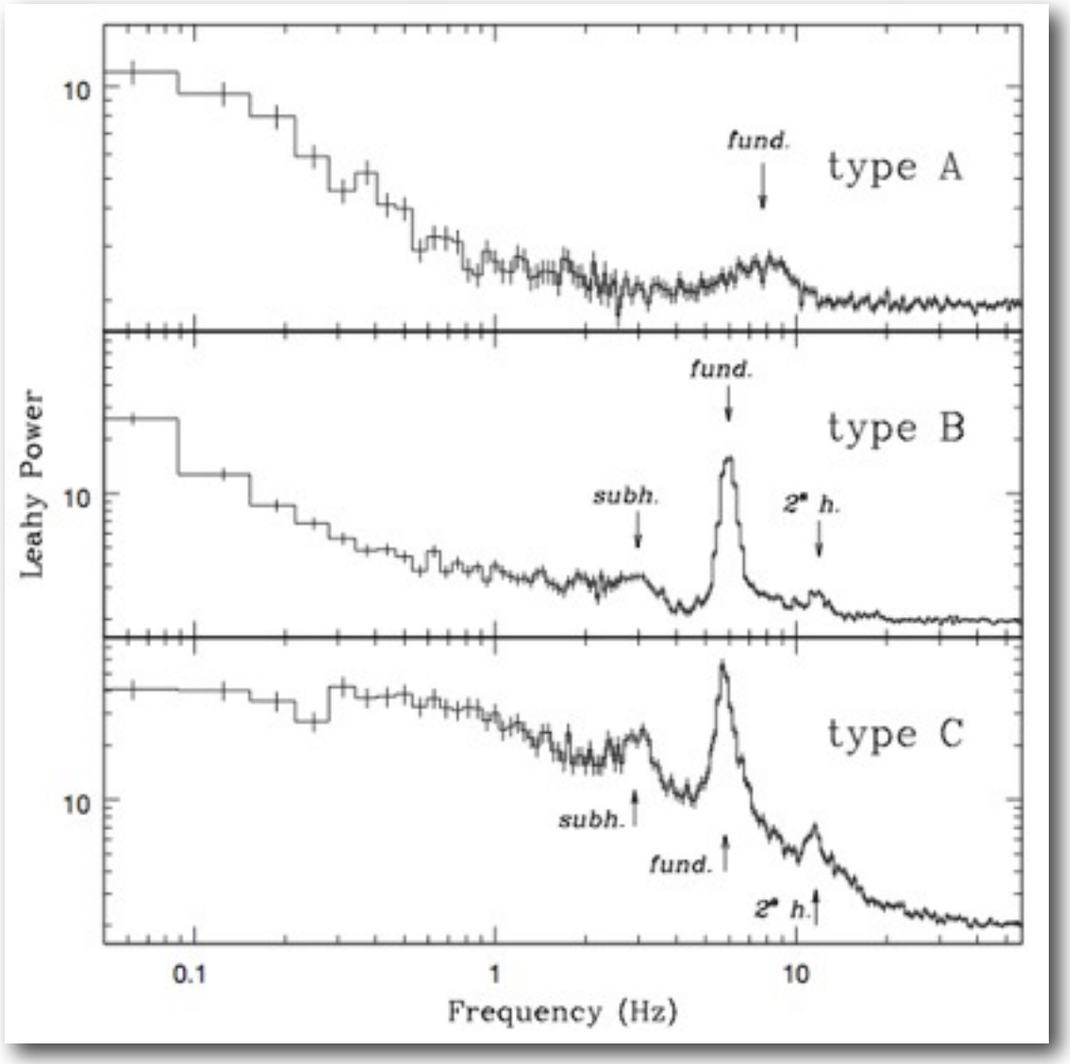
Low-frequency QPO - the ABC paradigm

Motta et al. (2011)

	A	B	C
ν	6.5-8 Hz	0.8-6.4 Hz	0.2-9 Hz
Q	1-3	$\geqslant 6$	$\geqslant 10$
rms	$\leqslant 5\%$	$5-10\%$	$\geqslant 10\%$
noise	weak red	weak red	strong flat-top



Casella et al. (2004)



A lot more (see Motta et al. 2011)

ABC or BC? Difference is important

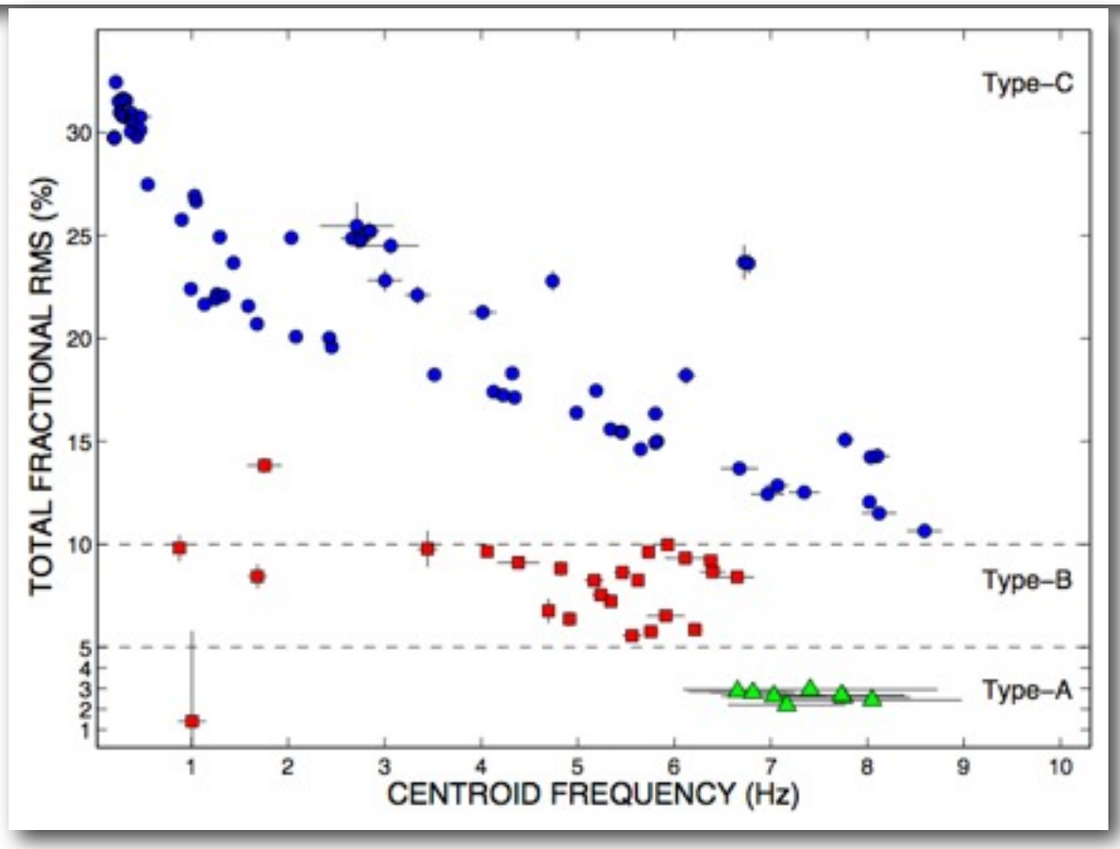
Motta et al. (2011)

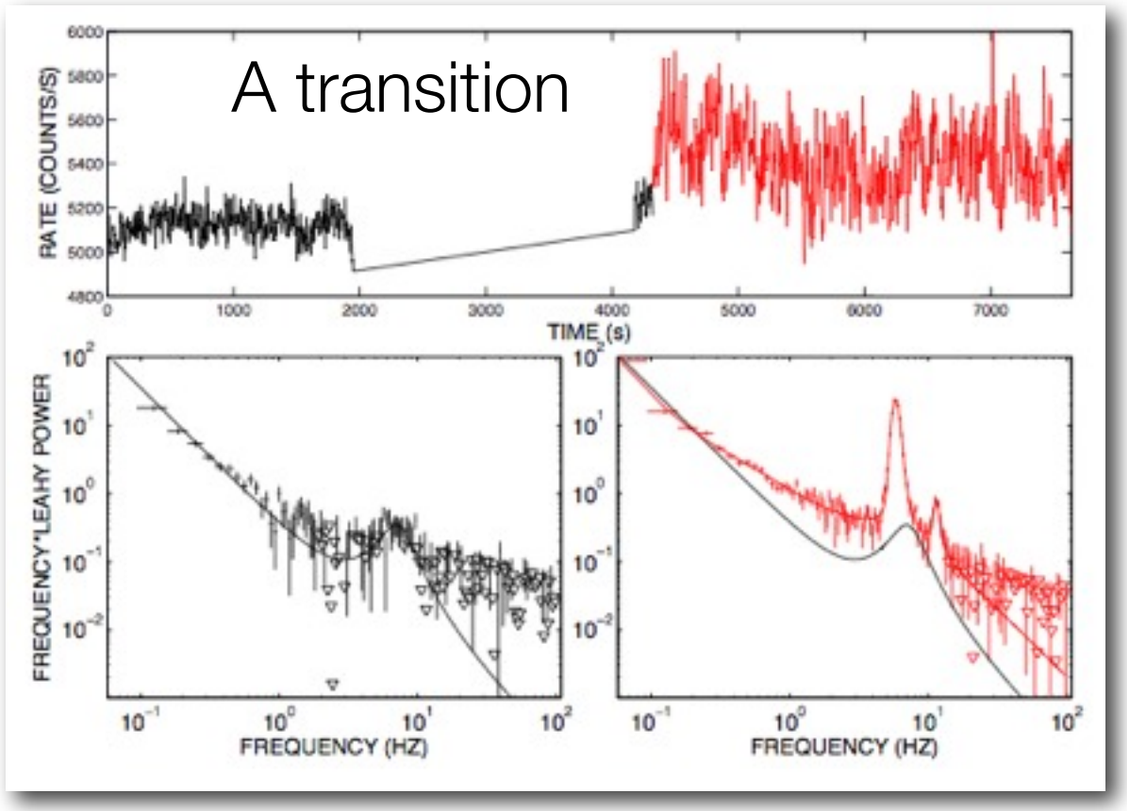
	A	B	C
ν	6.5-8 Hz	0.8-6.4 Hz	0.2-9 Hz
Q	1-3	$\geqslant 6$	$\geqslant 10$
rms	$\leqslant 5\%$	$5-10\%$	$\geqslant 10\%$
noise	weak red	weak red	strong flat-top

A continuum of properties?

Do type-C QPO also appear in the soft states?

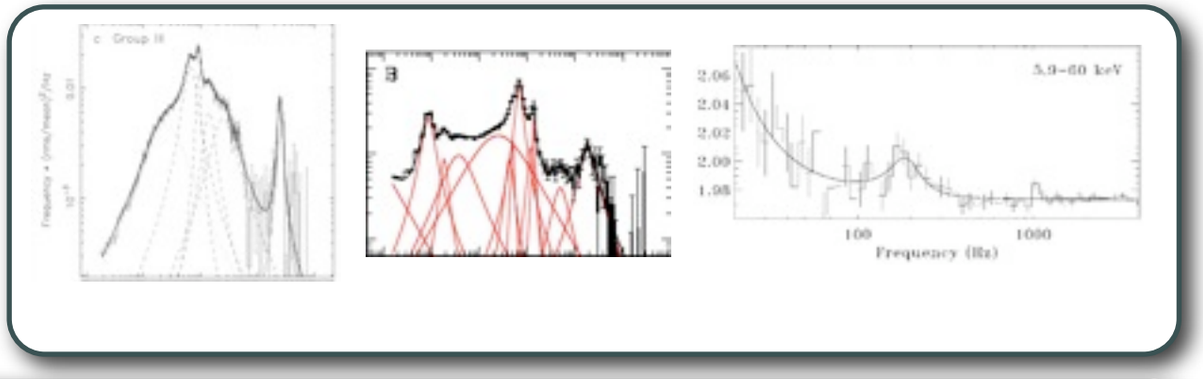
Many more details

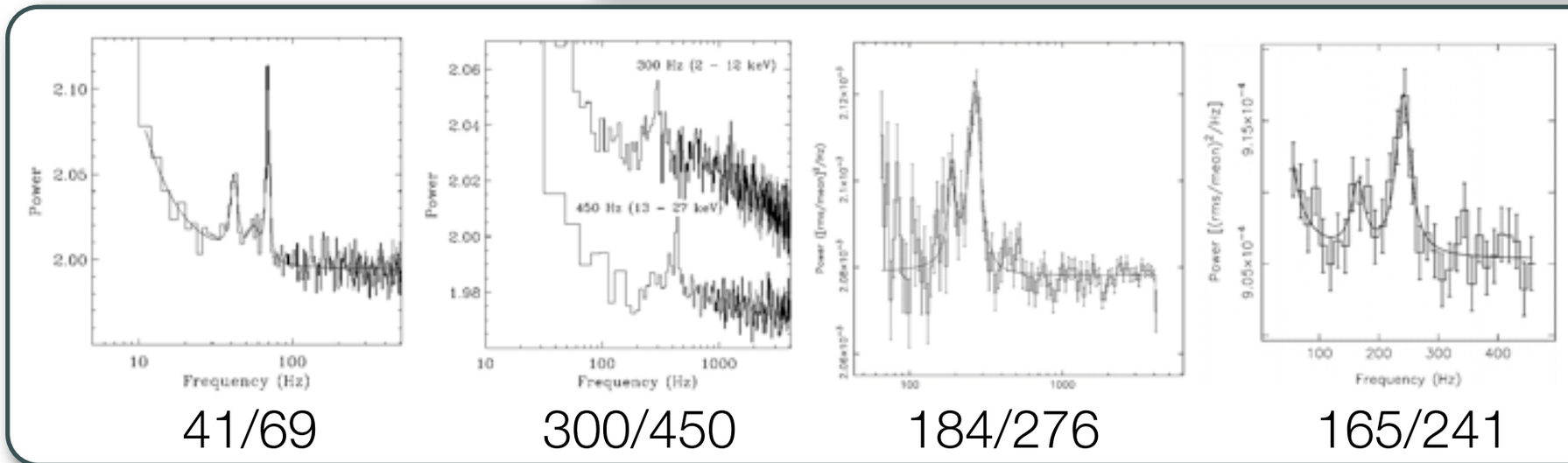




High-Frequency QPOs

- 30-450 Hz
- Very few detections
- Ratios?
- BH mass?
- Resonance model
- Too few points...

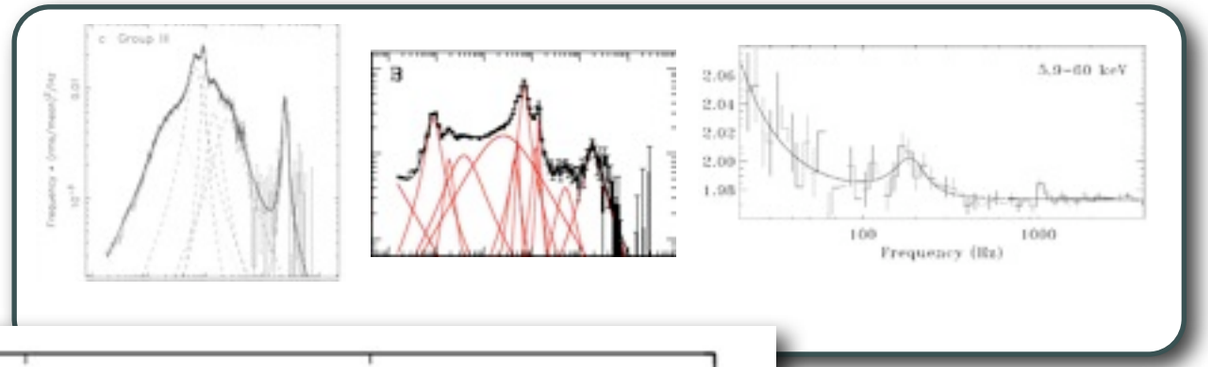


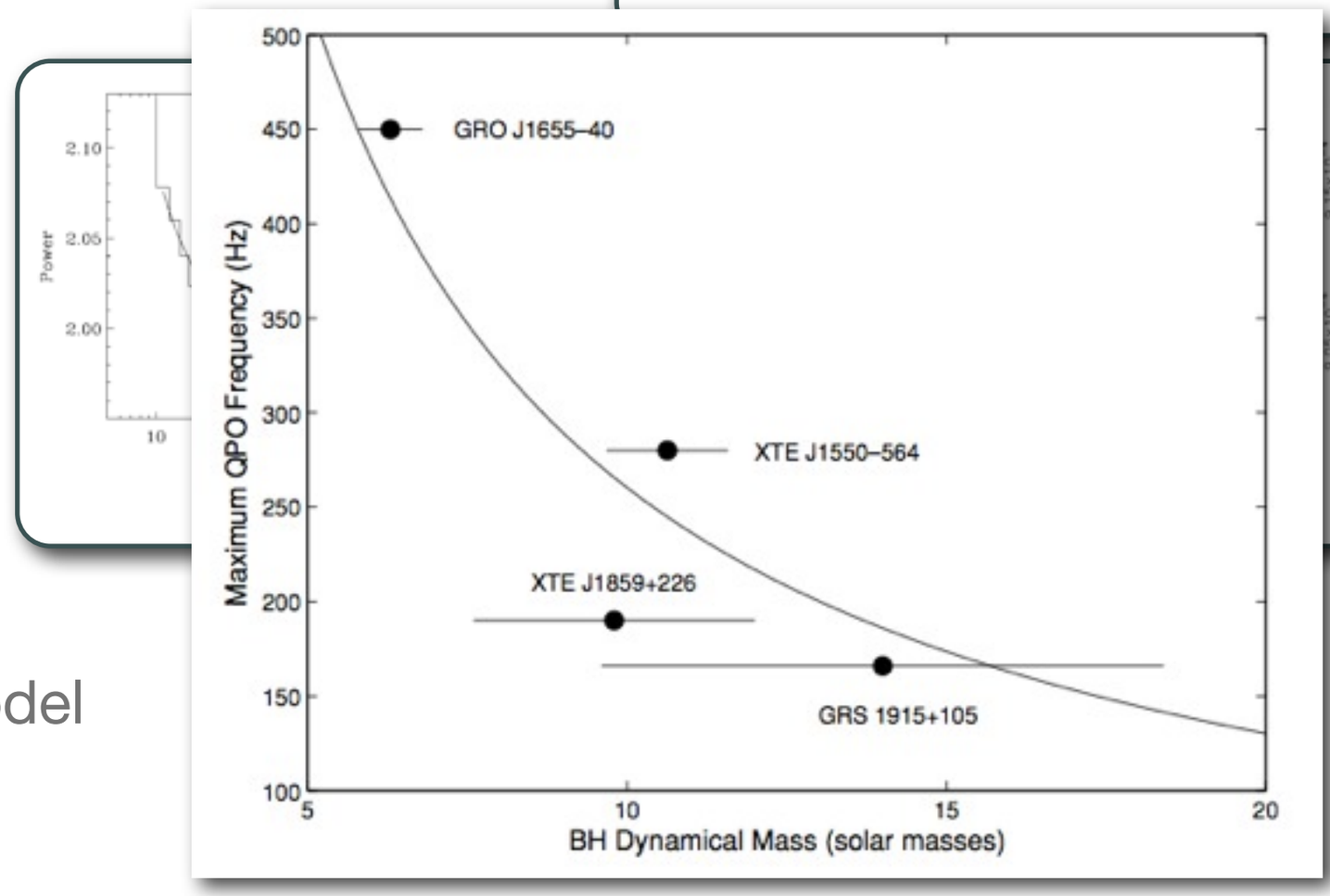


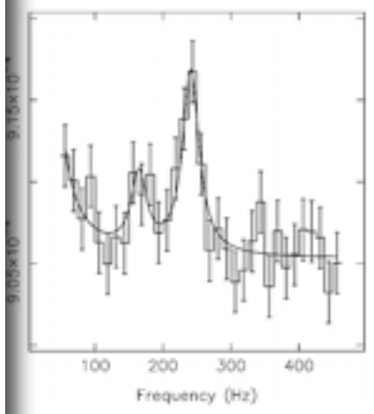
41/69 300/450 184/276 165/241

High-Frequency QPOs

- 30-450 Hz
- Very few detections
- Ratios?
- BH mass?
- Resonance model
- Too few points...

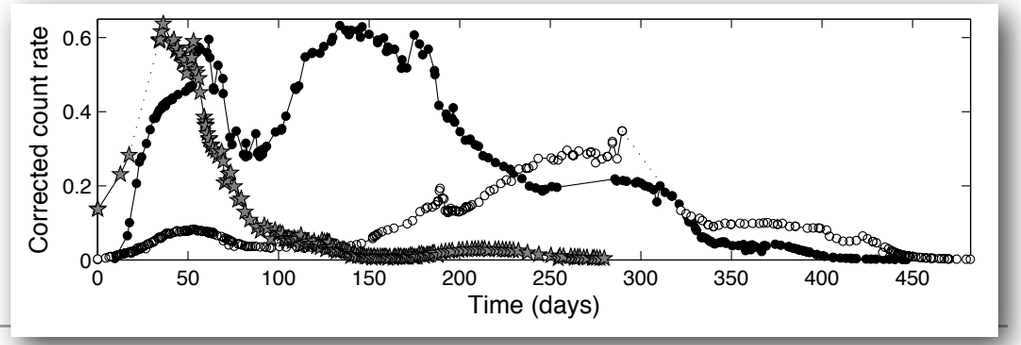




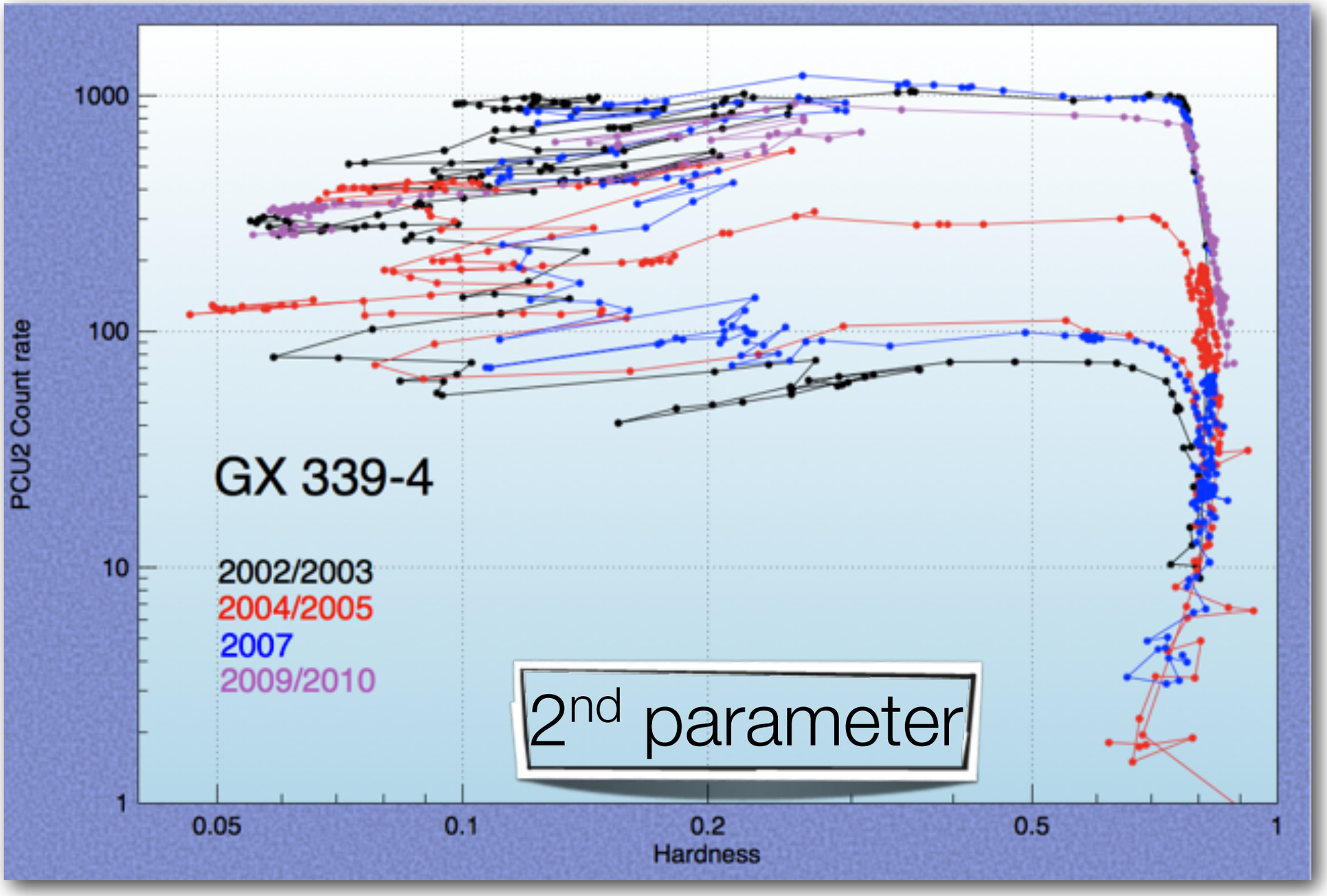


165/241

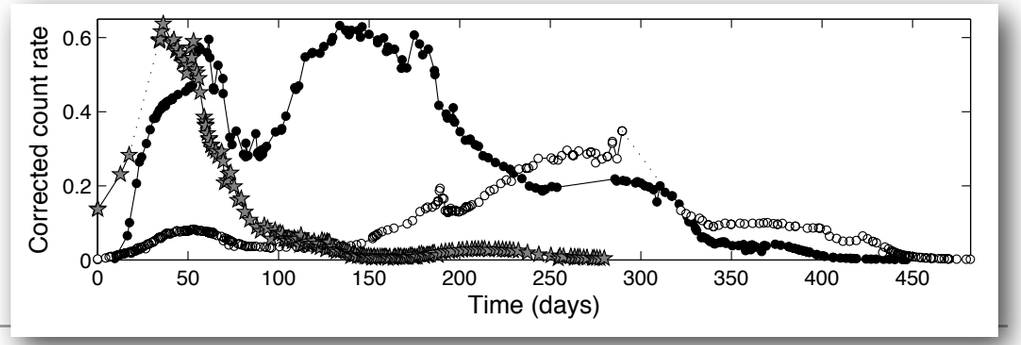
Evolution and source states



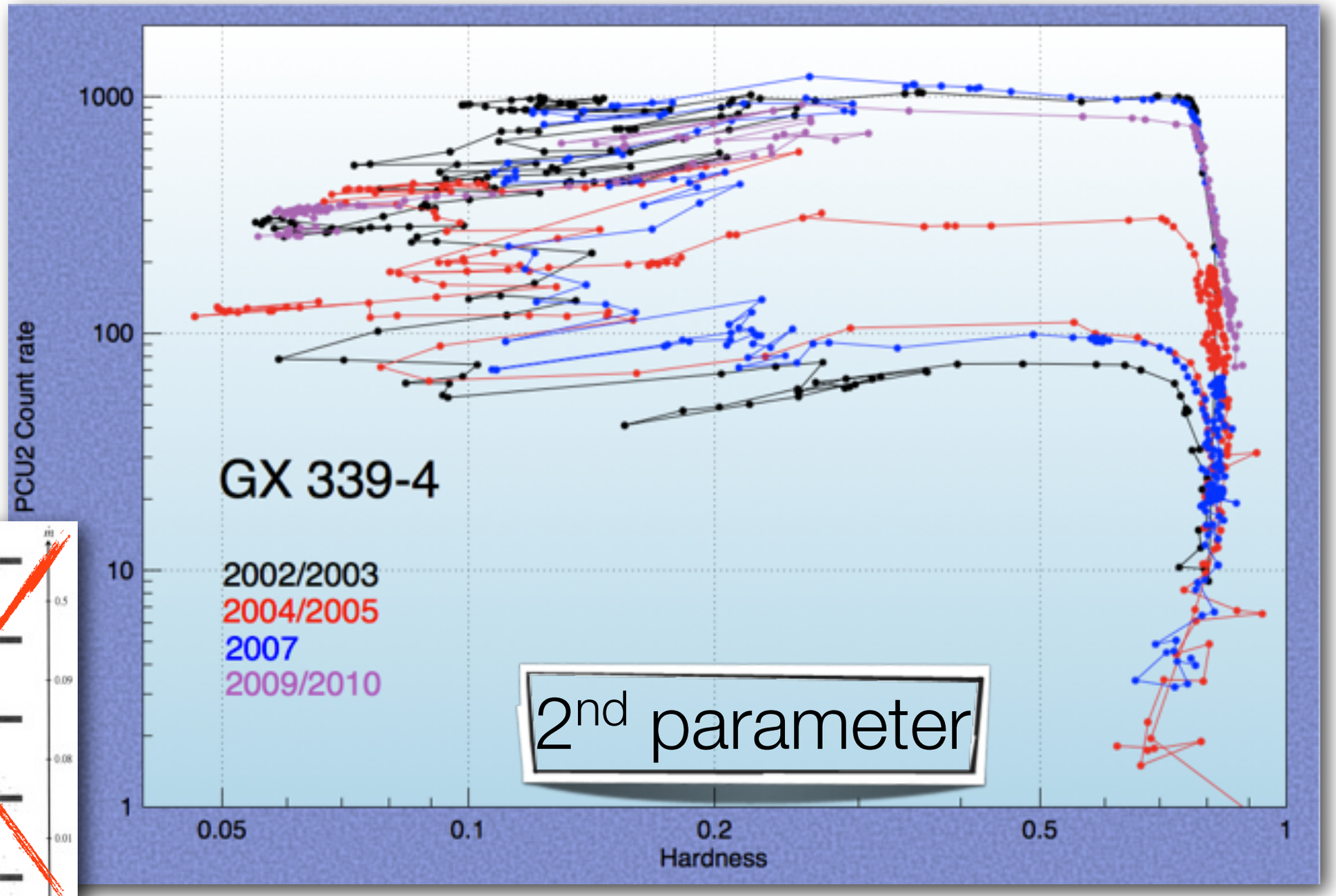
Belloni (2010)

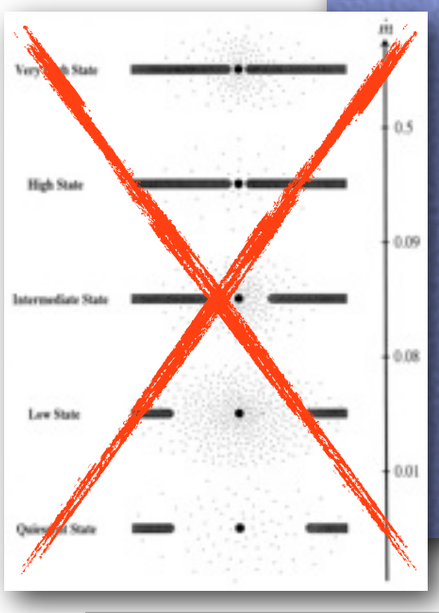


Evolution and source states



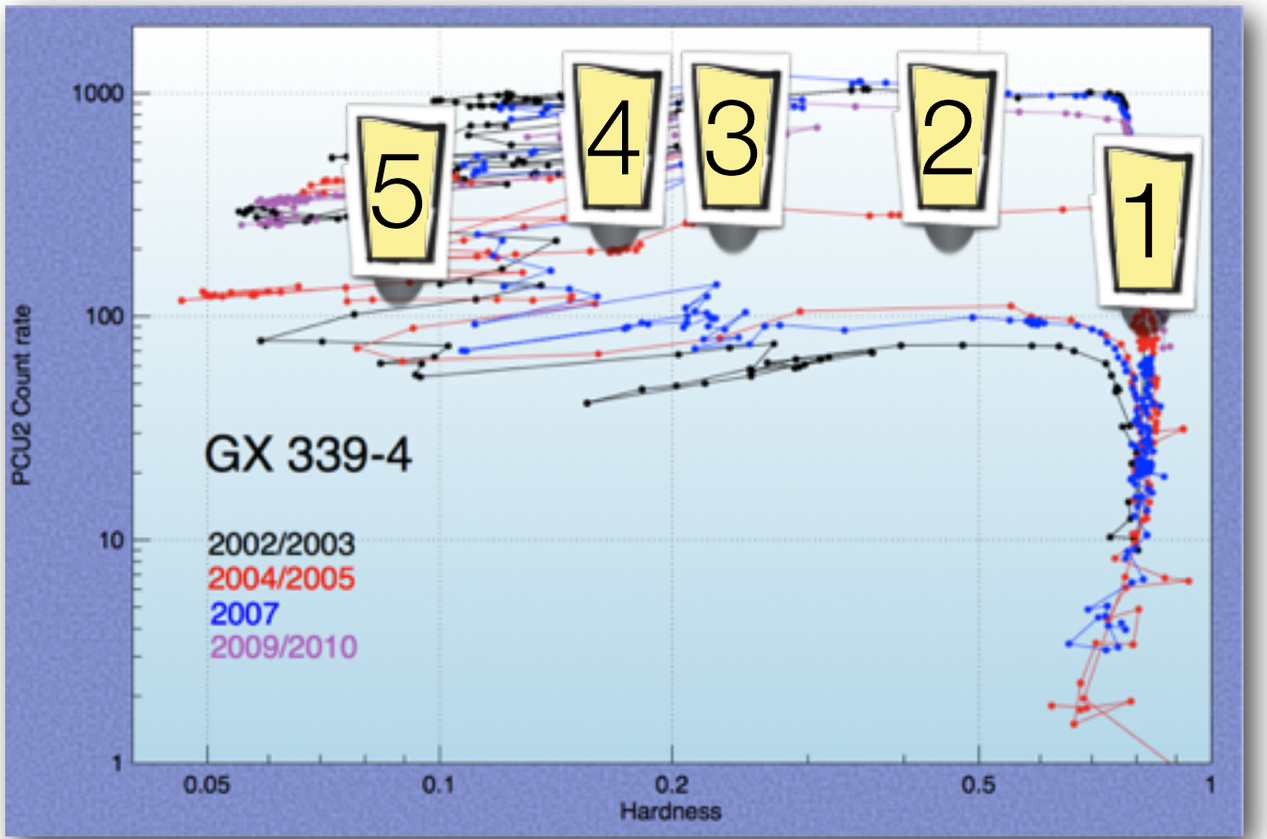
Belloni (2010)

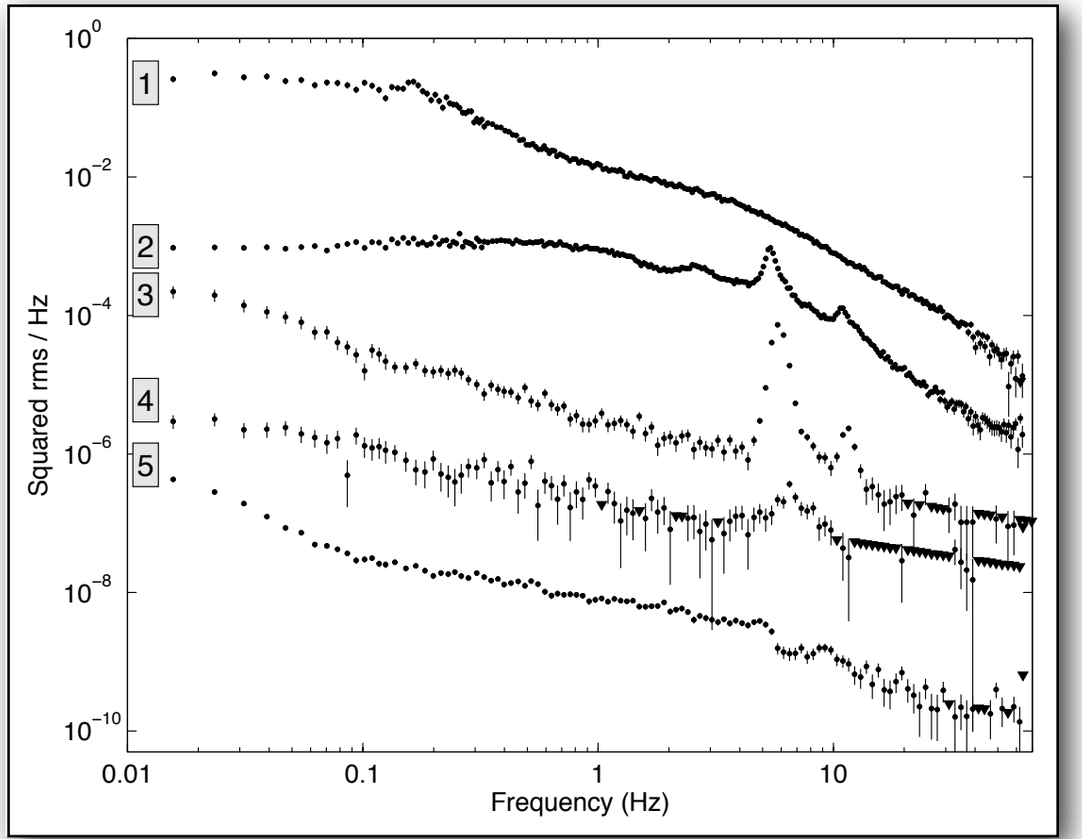




Evolution and source states

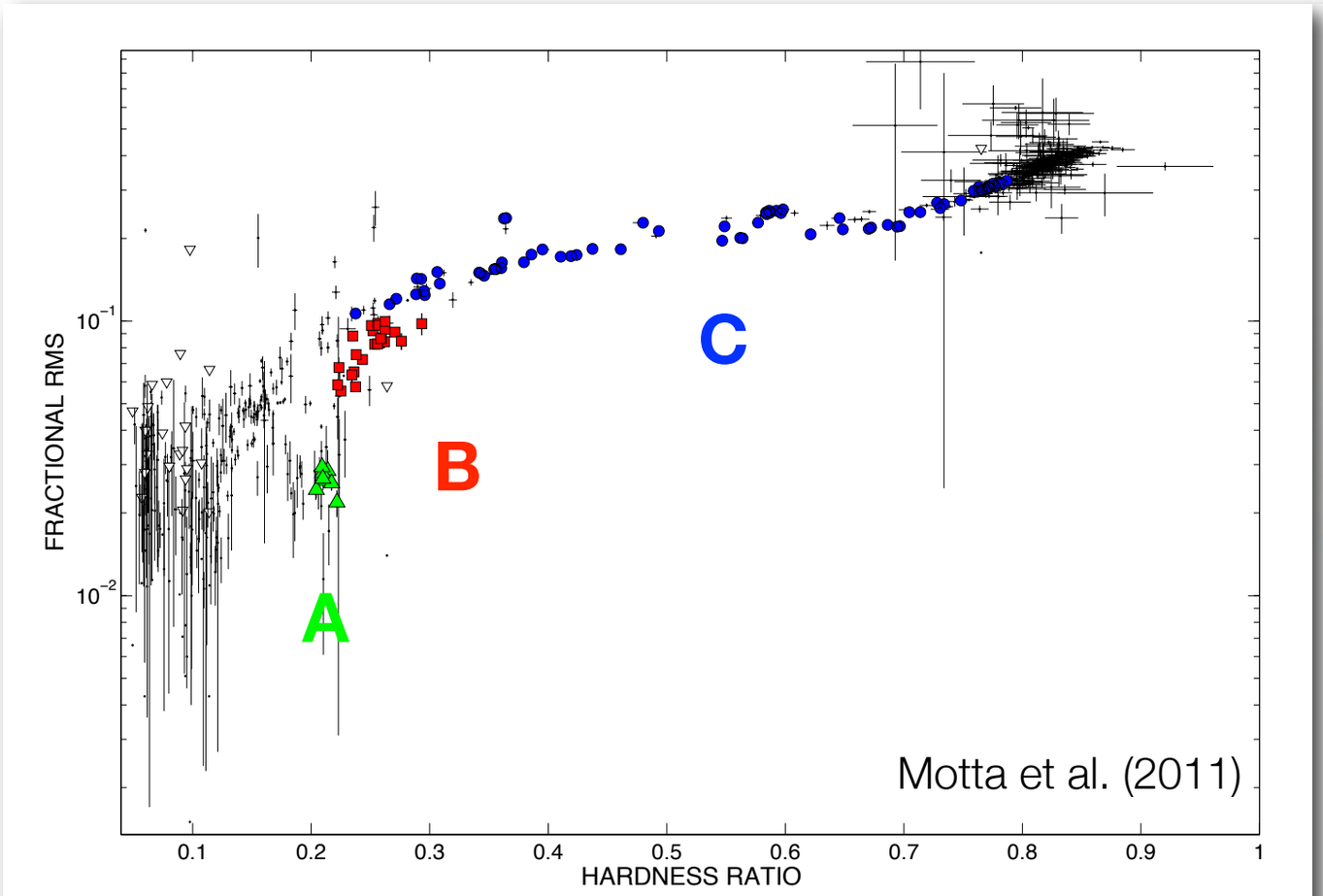
Belloni (2010)

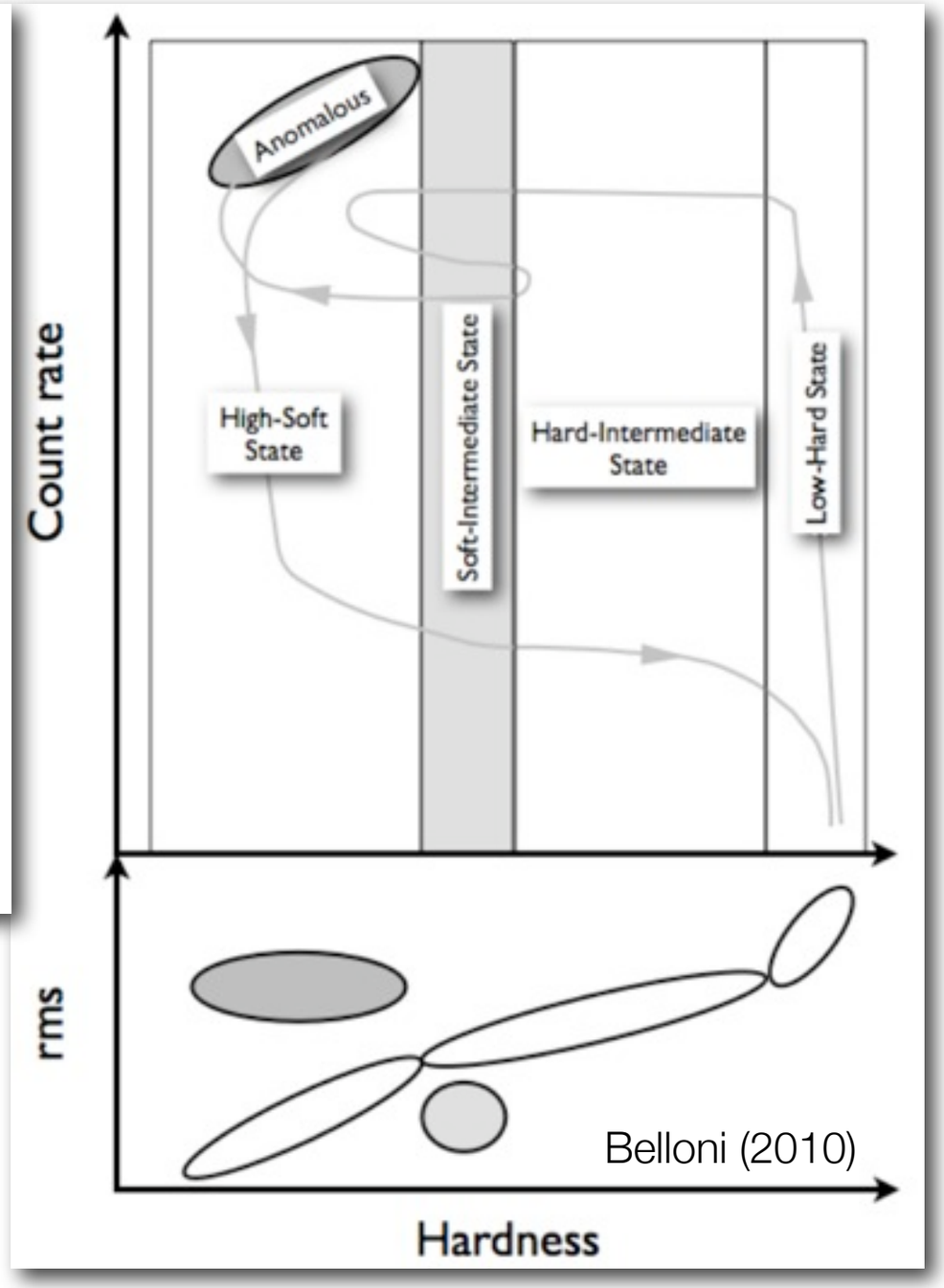




- PDS distribute along the HID
- Strong variations define states

Evolution and source states

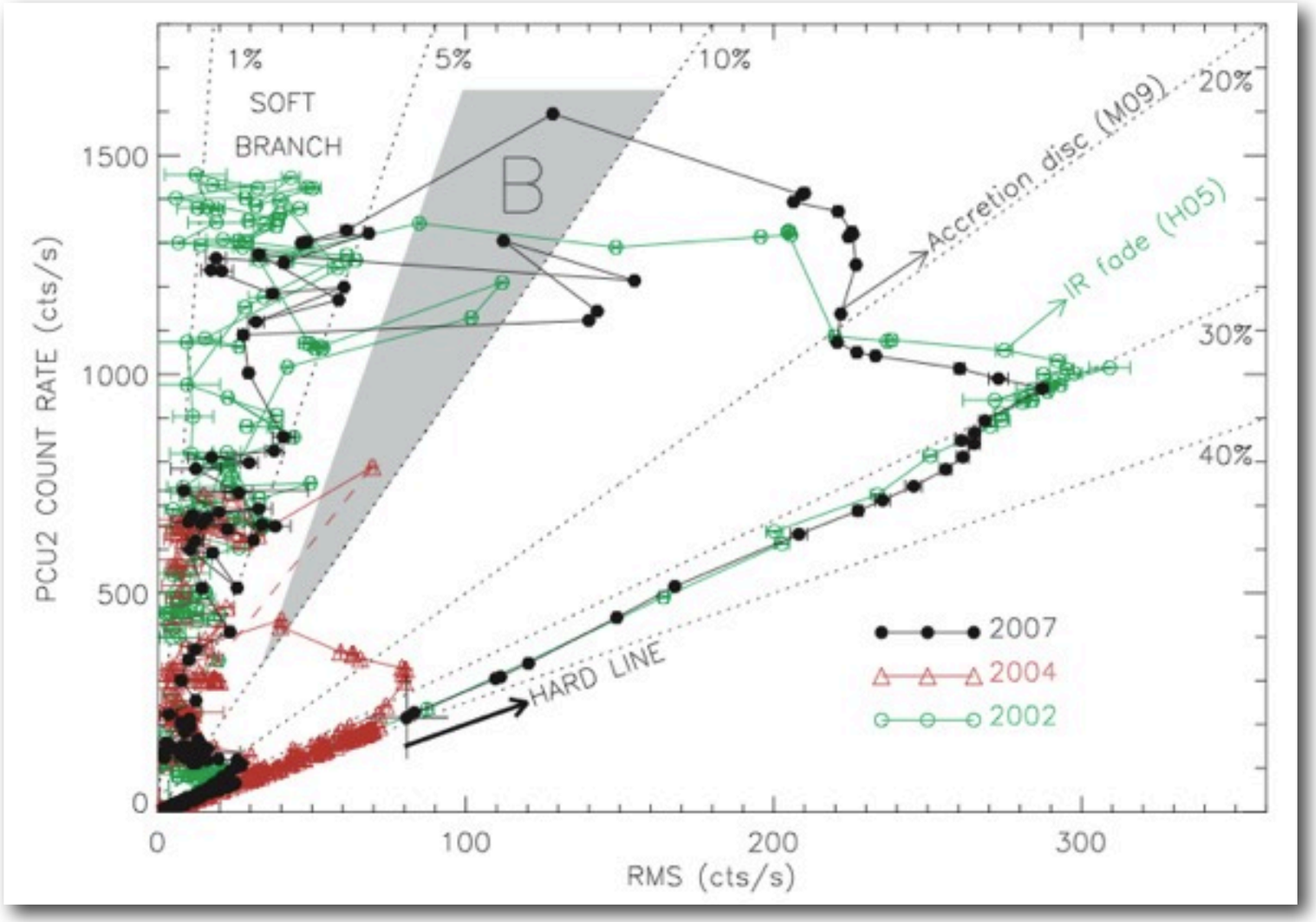




- HRD in addition to HID
- Here there is no hysteresis

An additional diagram: VD

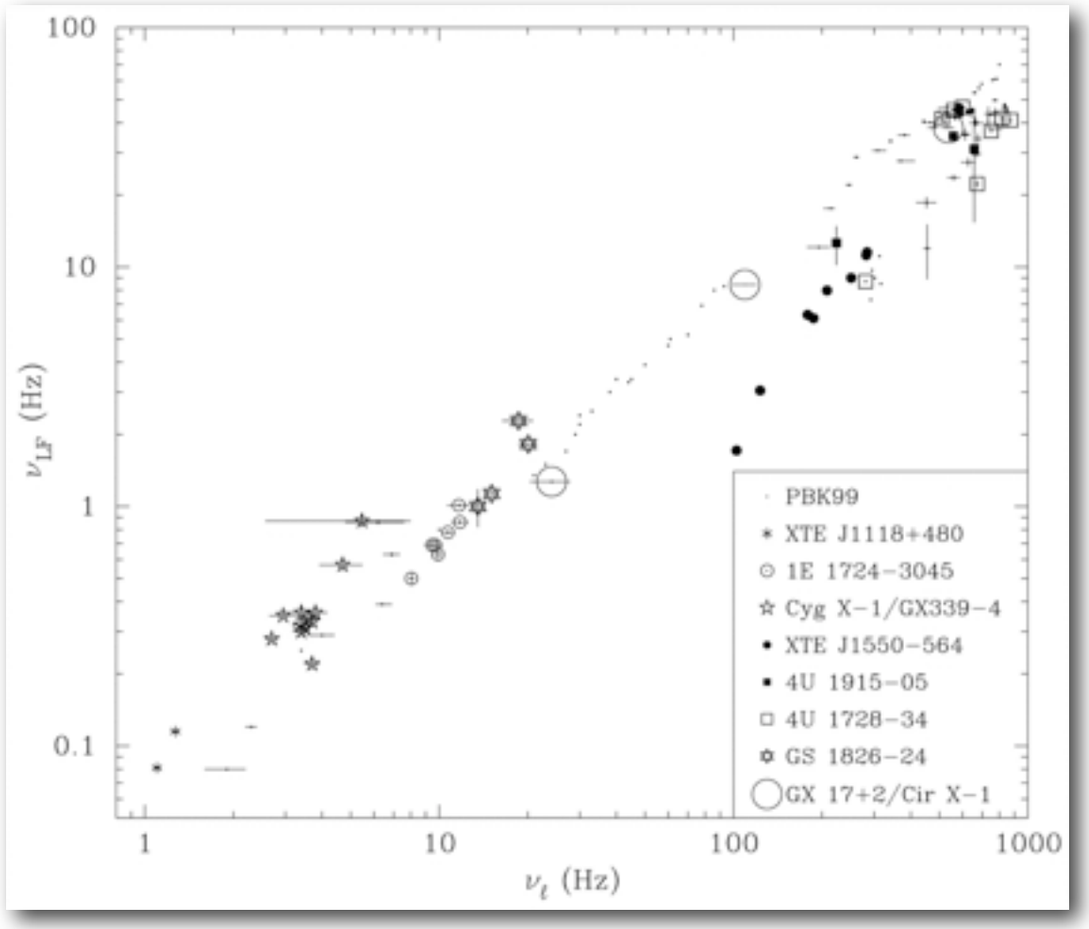
Muñoz-Darias et al. (2011)



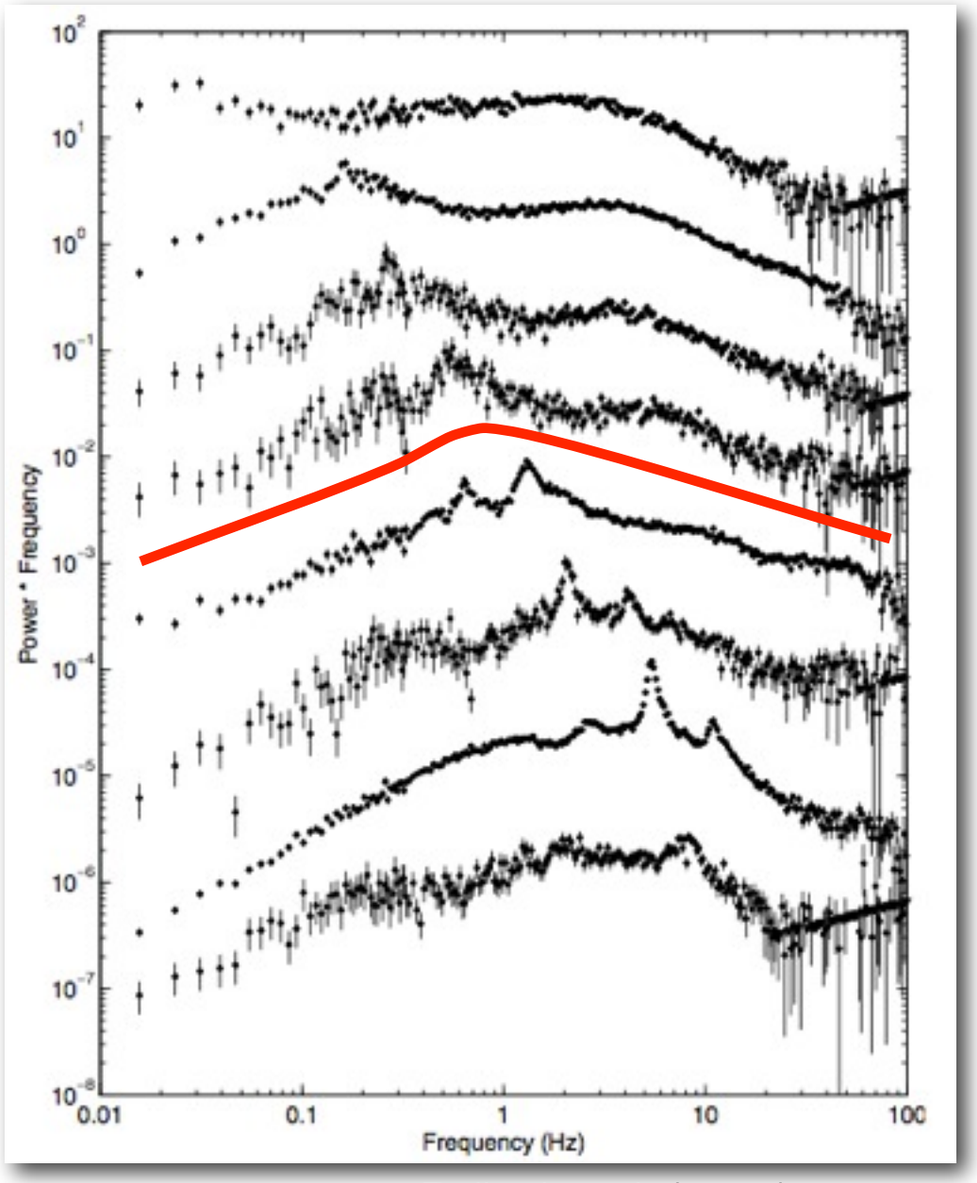
- The third diagram - rms not fractional
- No energy information!

Correlations

(Almost) everything is correlated!



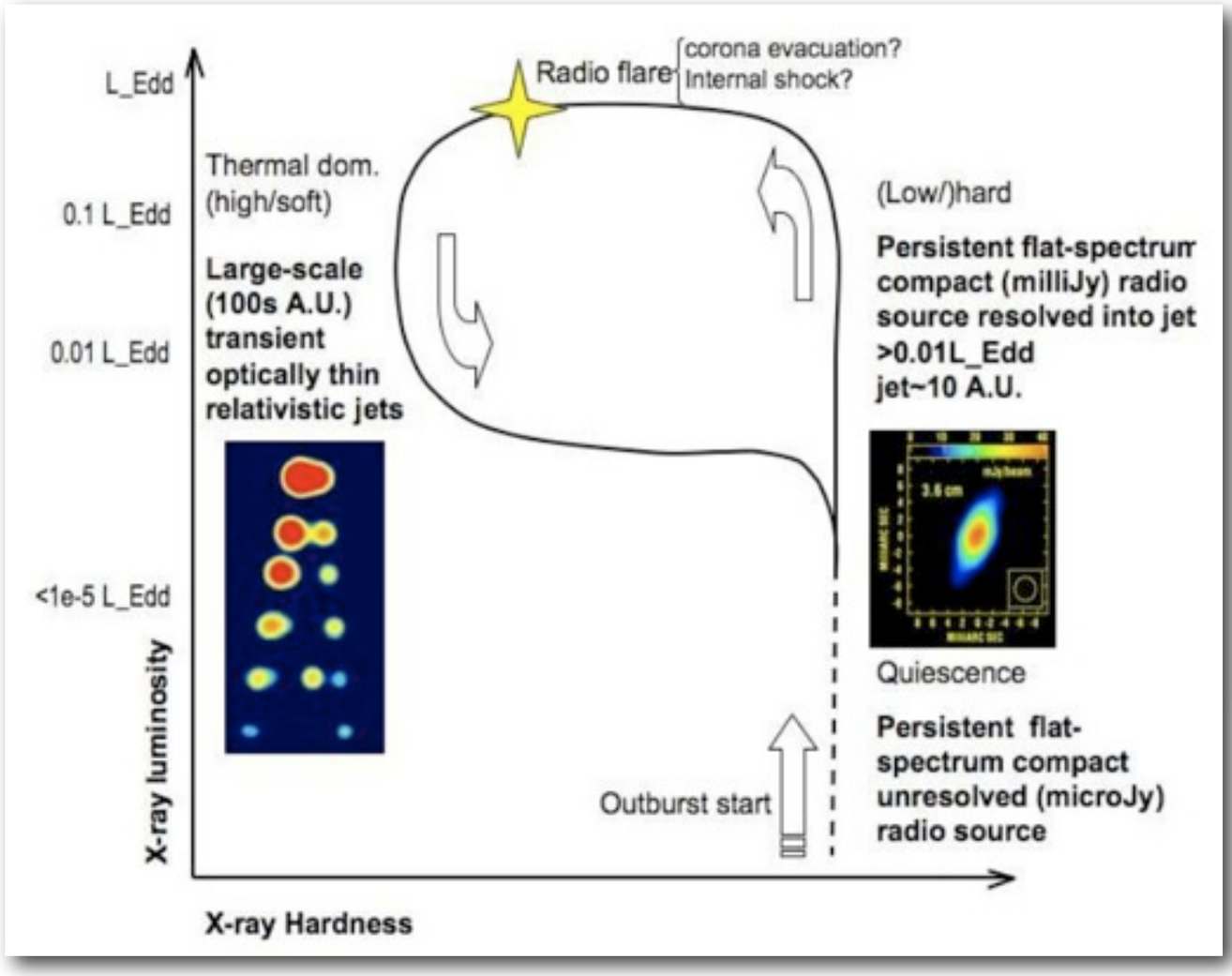
Belloni, Psaltis & van der Klis (2005)



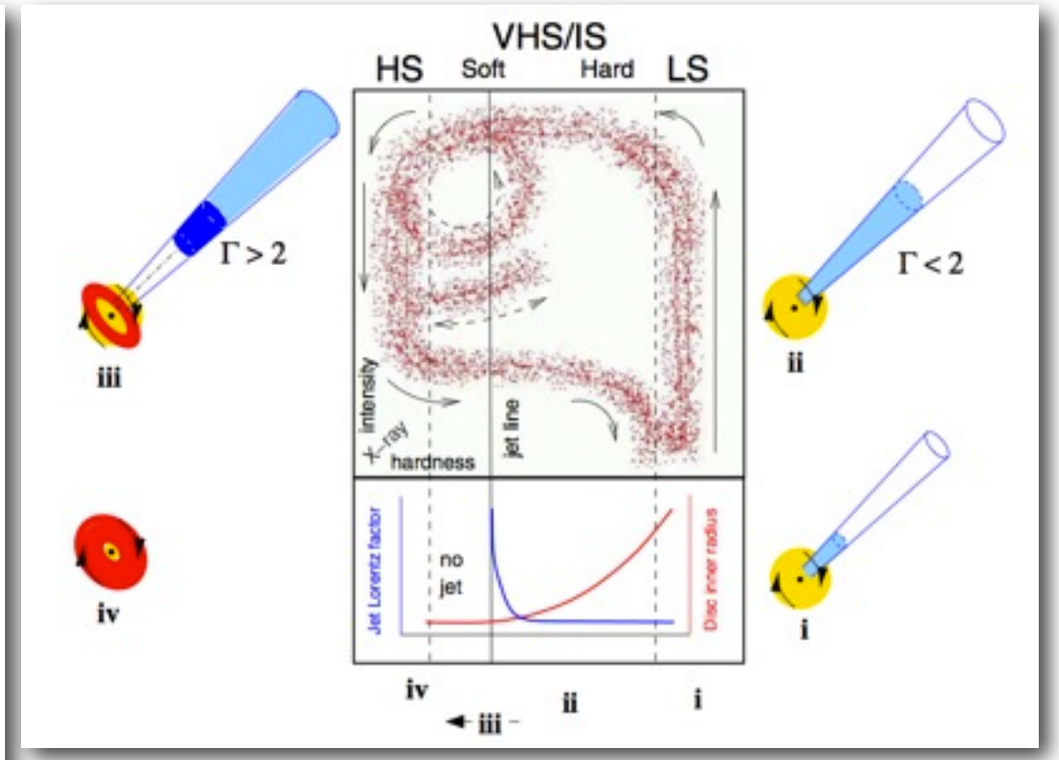
Belloni et al. (2005)

Connection with radio jets

Gallo (2010)



Fender, Belloni & Gallo (2004)

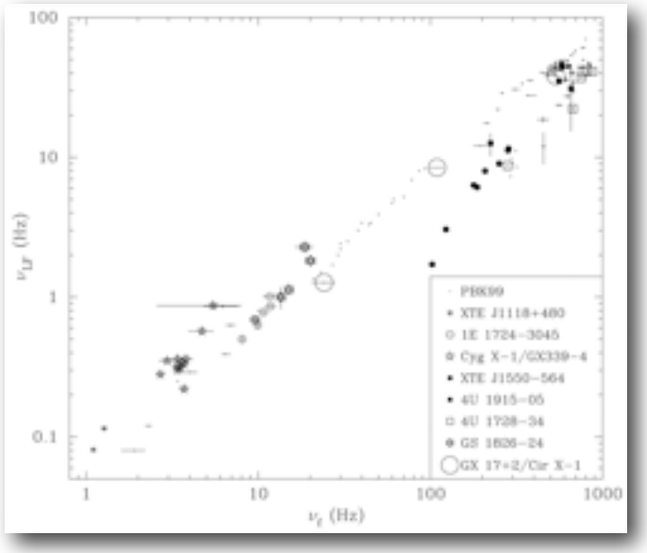


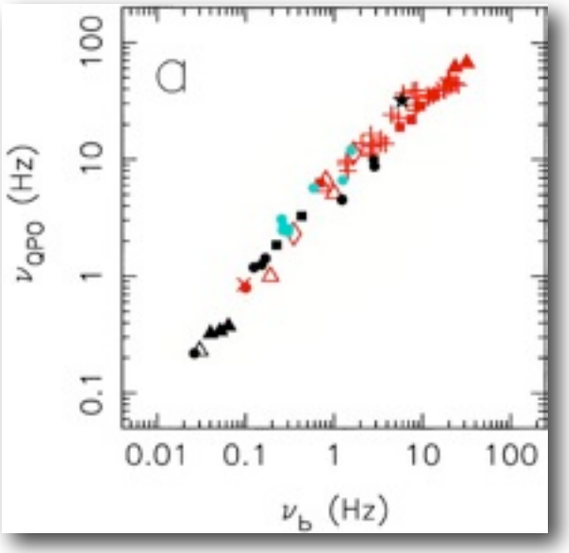
- Radio emission goes with it - ejections close to transitions
- Some variability from the jet itself?

Models

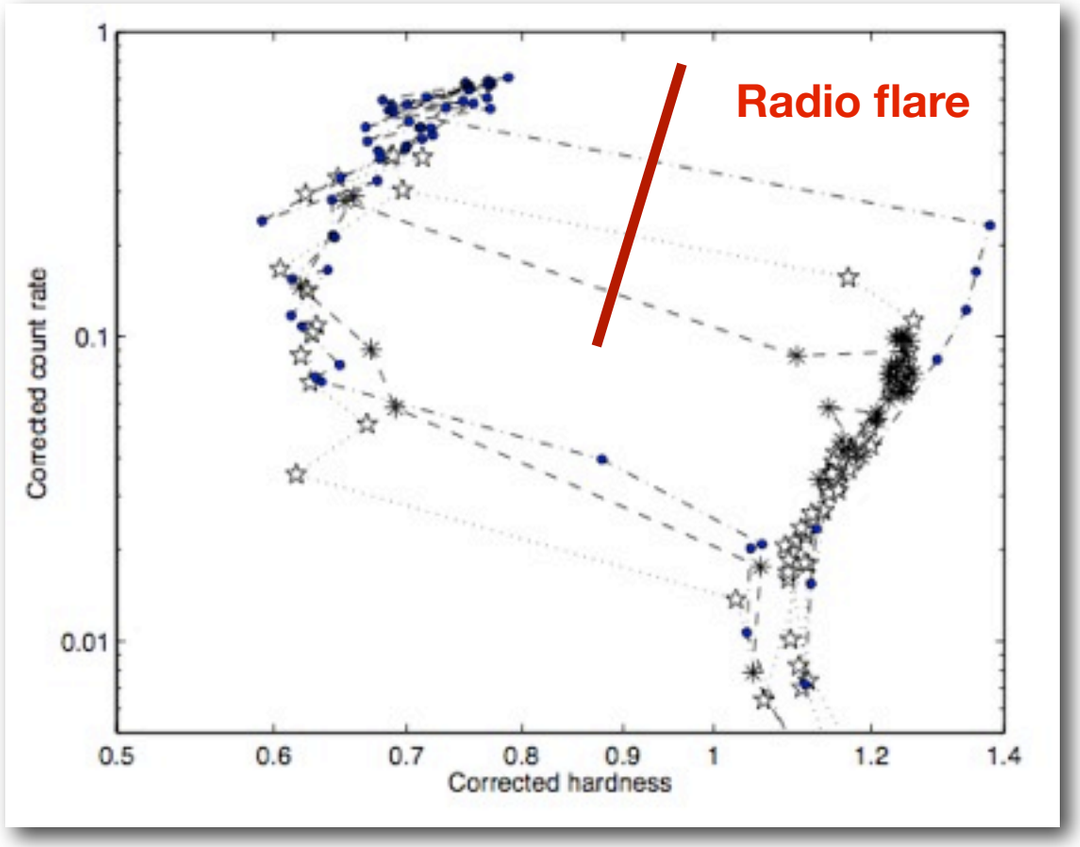
- Strong noise: fluctuating-accretion model — Arévalo & Uttley (2006)
- Type-C QPO: GR model - complete model — Stella & Vietri (1998) — Ingram & Done (2011)
- Type-B QPO: ?
- HFQPO: GR models - relativistic precession (need more data)
- Yet, all these are related

Wijnands & van der Klis (1999)
Psaltis, Belloni & van der Klis (1999)
Belloni, Psaltis & van der Klis (2002)

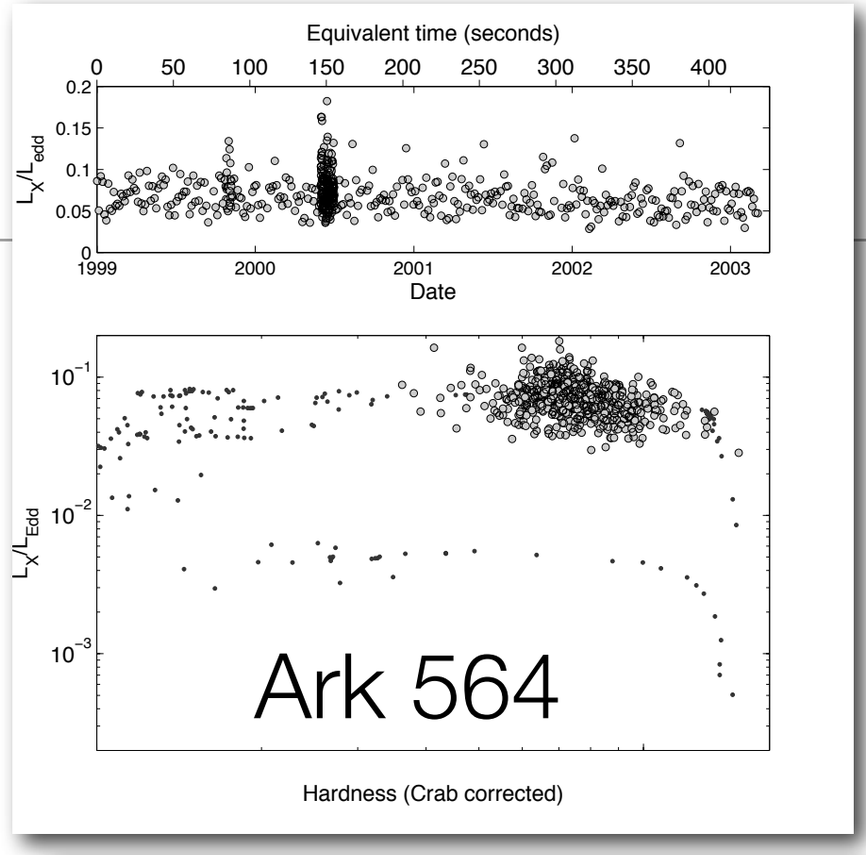


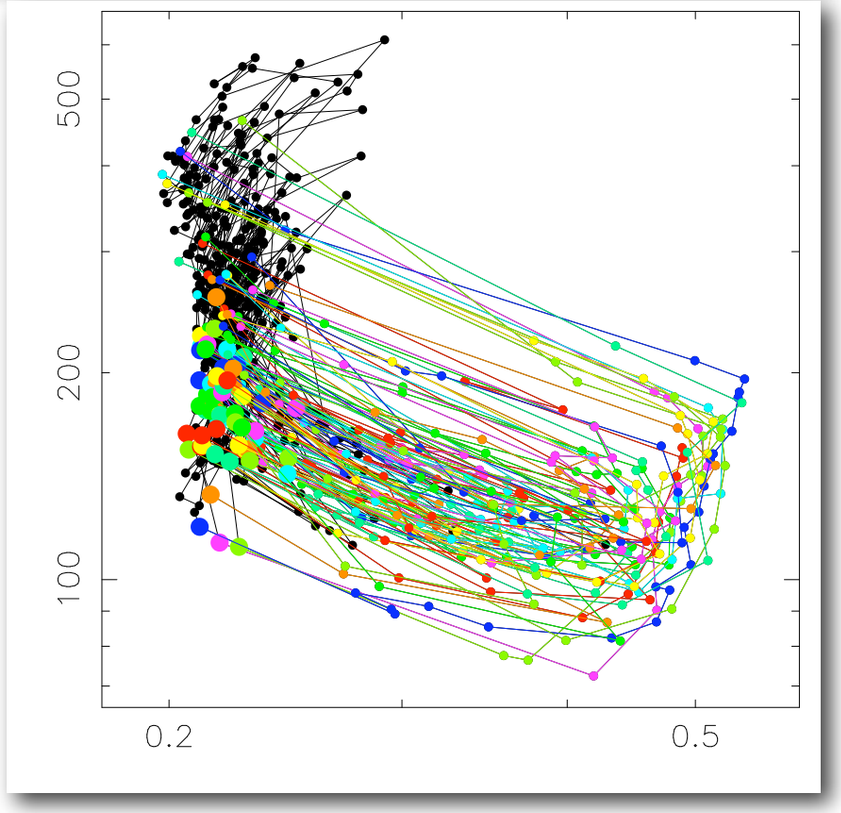


Other sources



Aql X-1

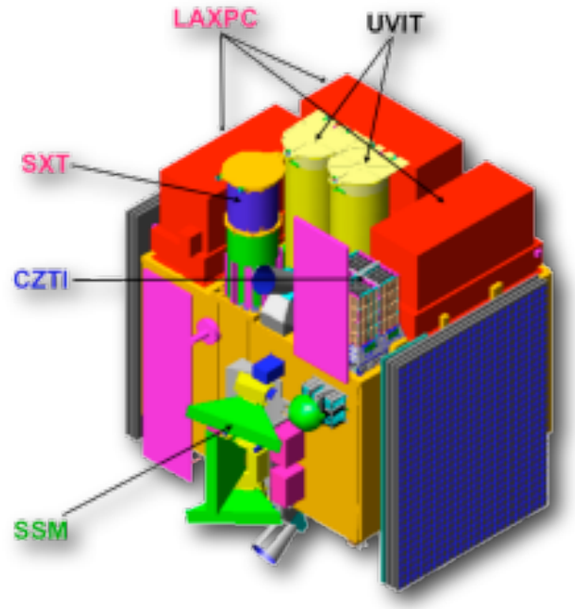




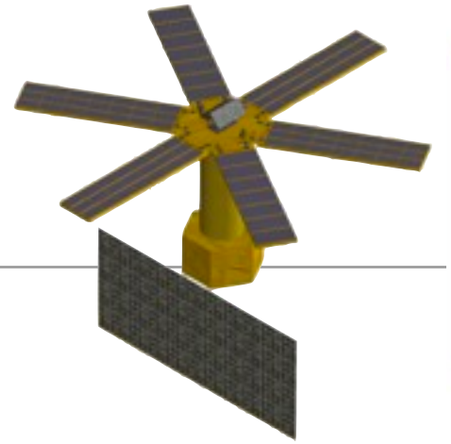
4U 1636-53

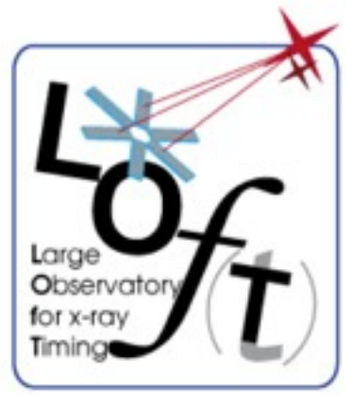
The near future: ASTROSAT

- Excellent capabilities
- Advantages over RXTE
- High-energy response
- Soft-energy response
- UV coverage
- **Observational strategies are crucial**



The next future: LOFT





- Proposed to ESA M3 call
- **L**arge **A**rea **D**etector (12 m^2) + **W**ide **F**ield **M**onitor

Parameter	Requirement	Goal
LAD		
Energy range	2–30 keV (nominal) 2-50 keV (expanded)	1–40 keV (nominal) 1–60 keV (expanded)
Effective area	12.0 m^2 (2-10 keV) 1.3 m^2 (@30 keV)	15 m^2 (2-10 keV) 2.5 m^2 (@30 keV)
Energy resolution (FWHM, @ 6 keV)	<260 eV (all events) <200 eV (40% of events)	<180 eV (all events) <150 eV (40% of events)
Field of view (FWHM)	<60 arcmin	<30 arcmin
Time resolution	10 μs	5 μs
Dead time	<0.5% (@ 1 Crab)	<0.1% (@ 1 Crab)
Background	< 10 mCrab	< 5 mCrab
Maximum source flux (steady, peak)	>300 mCrab, >15 Crab	>10 Crab, > 30 Crab
WFM		
Energy range	2-50 keV	1-50 keV
Energy resolution (FWHM)	<300 eV	<200 eV
Field of view	>3 steradian	>4 steradian
Angular resolution	5 arcmin	3 arcmin
Point source localization	1 arcmin	0.5 arcmin
Sensitivity (5 σ, 50 ks)	2 mCrab	1 mCrab
Sensitivity (5 σ, 1 s)	0.5 Crab	0.2 Crab