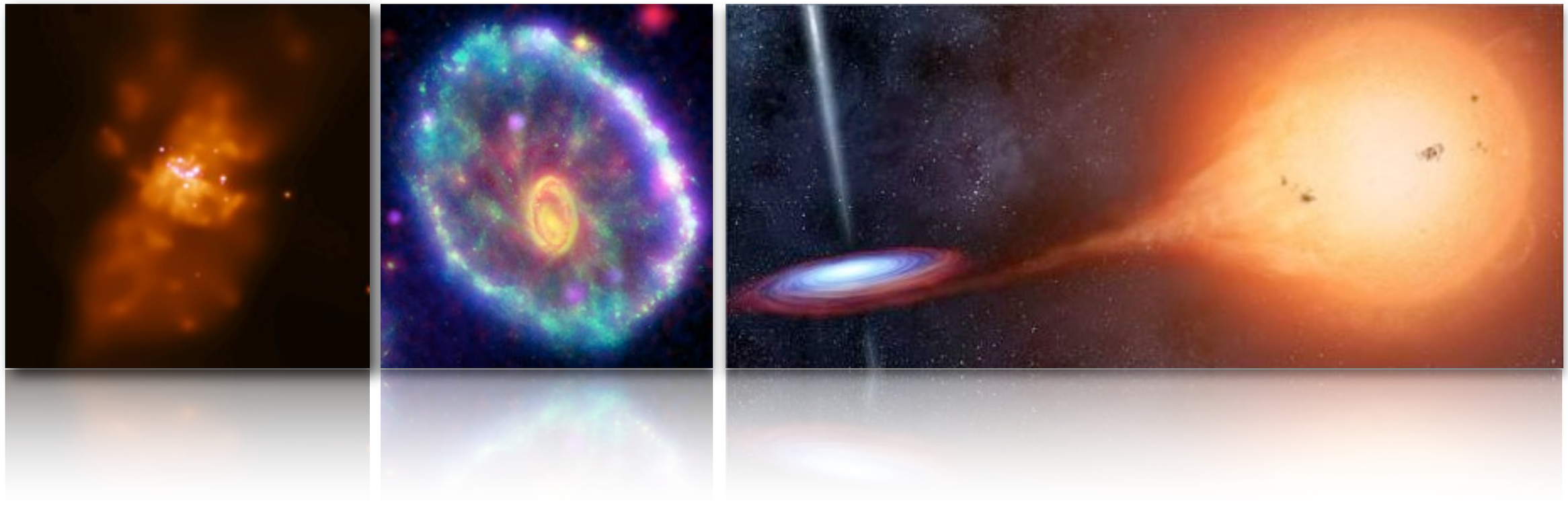
Black-hole states in external galaxies

Tomaso Belloni (INAF - Osservatorio Astronomico di Brera)

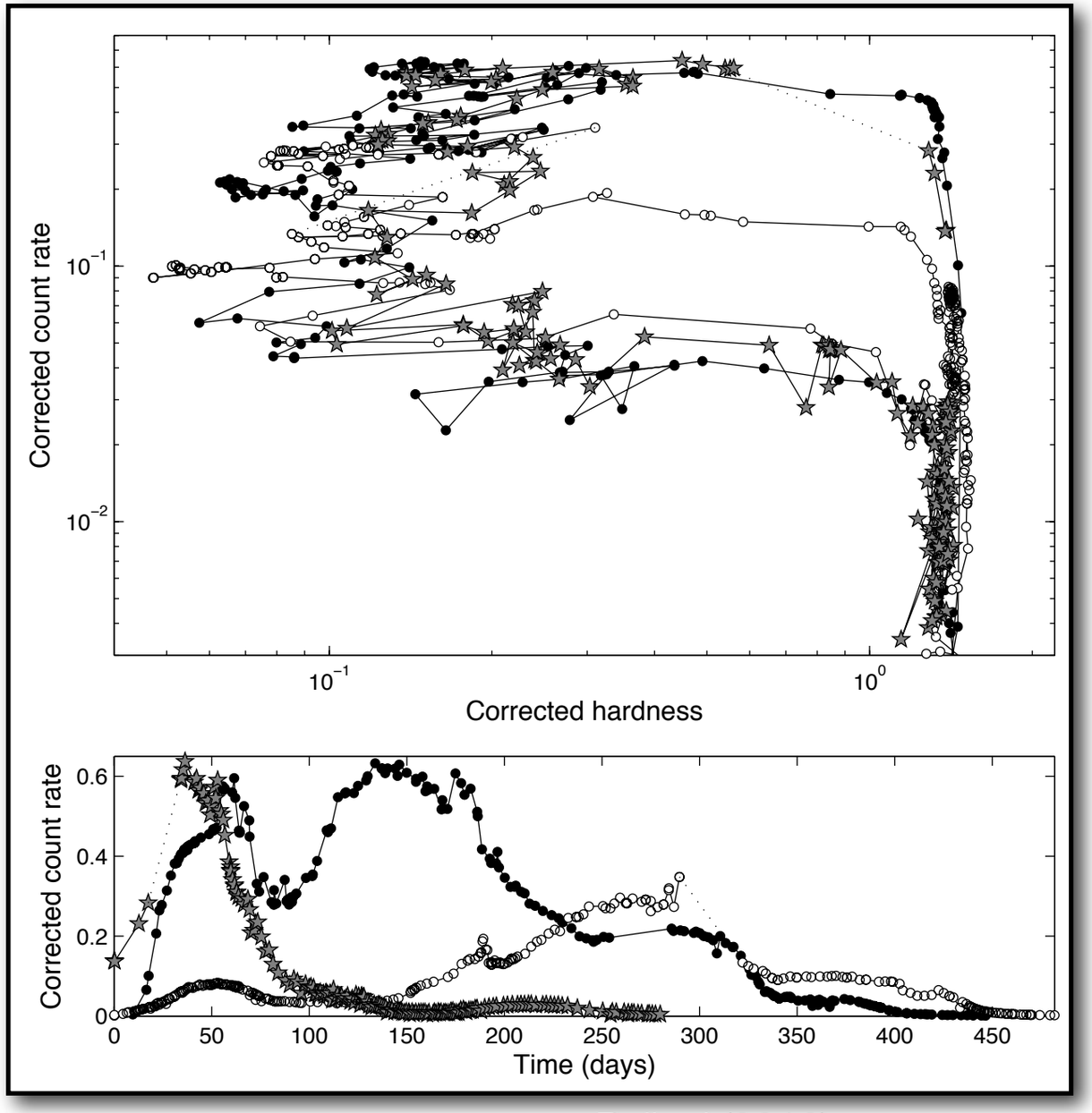


OPENING STATEMENT

- I am agnostic
- I have done limited work myself on ULXs
- I have done quite some work on Galactic X-Ray Binaries
- Phenomenology in our Galaxy
- Crude estimators: ideal for ULXs
- A glimpse at the situation for ULXs

TIMING/SPECTRAL STATES

- Light curves are intractable
- Hardness-Intensity diagrams



Belloni (2010)

TIMING/SPECTRAL STATES

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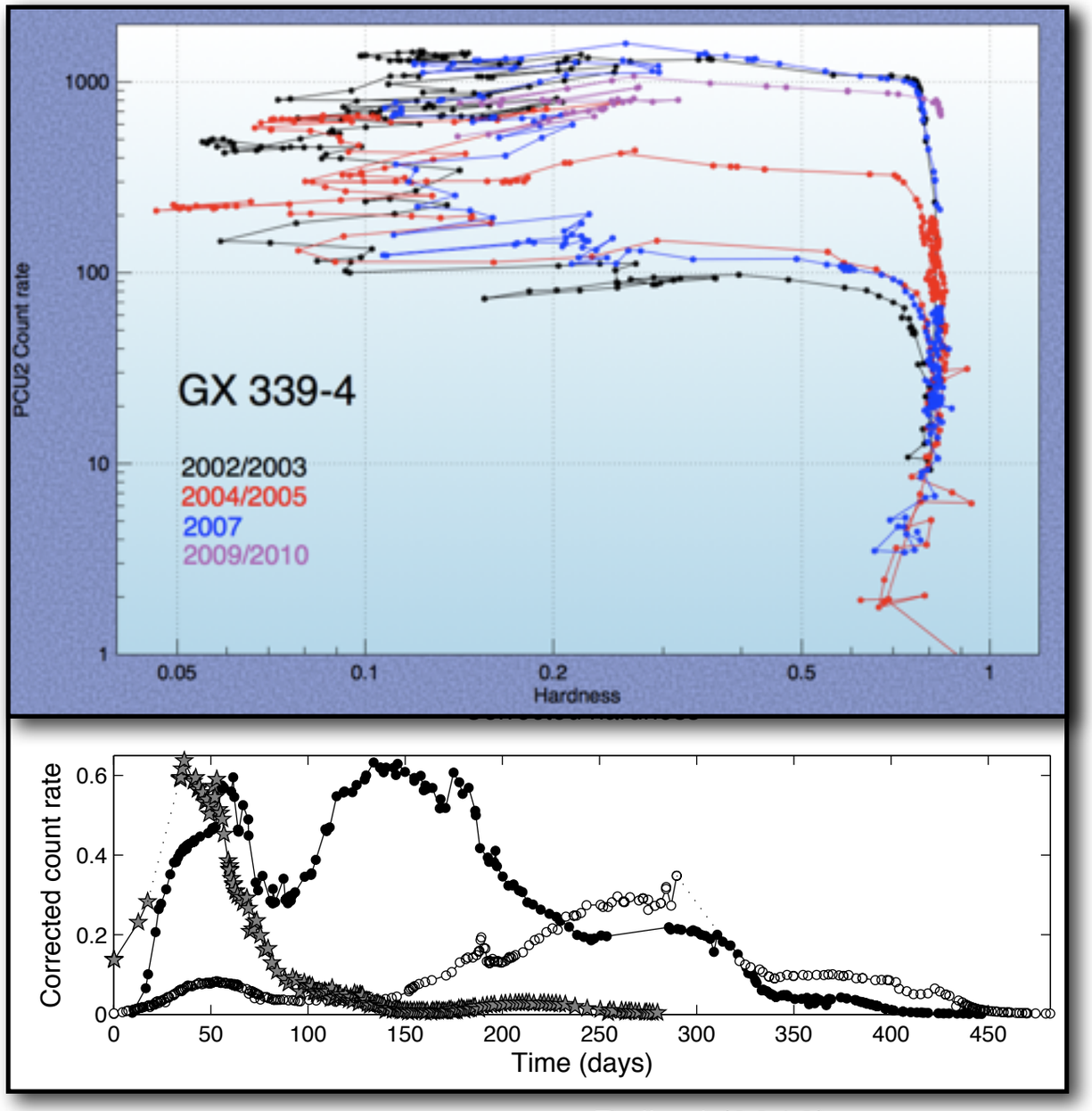
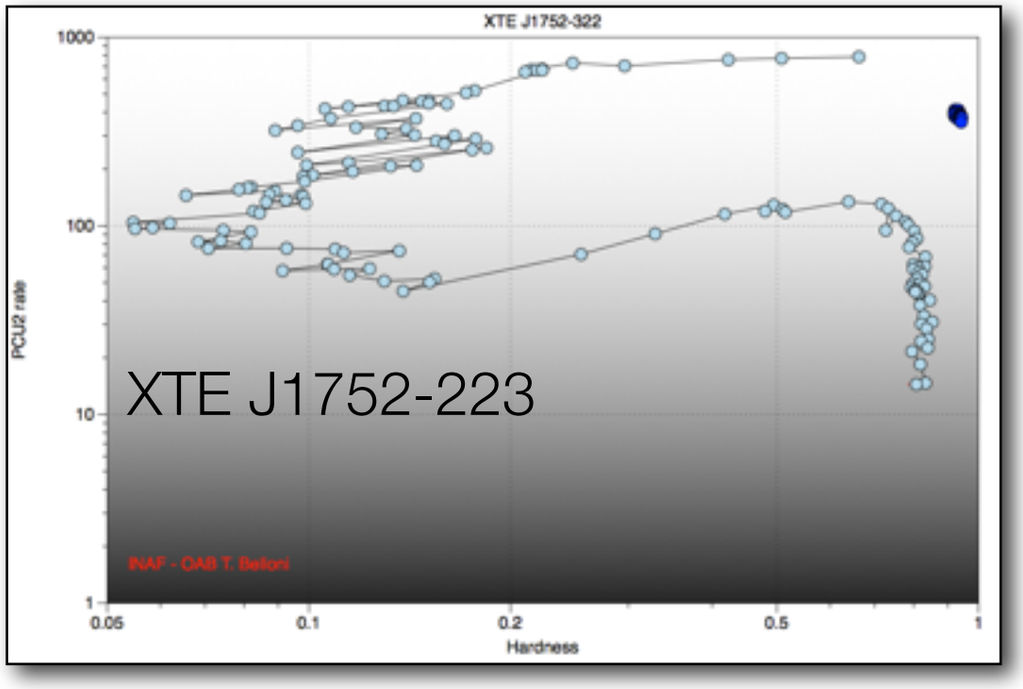
- Hardness-Intensity diagrams

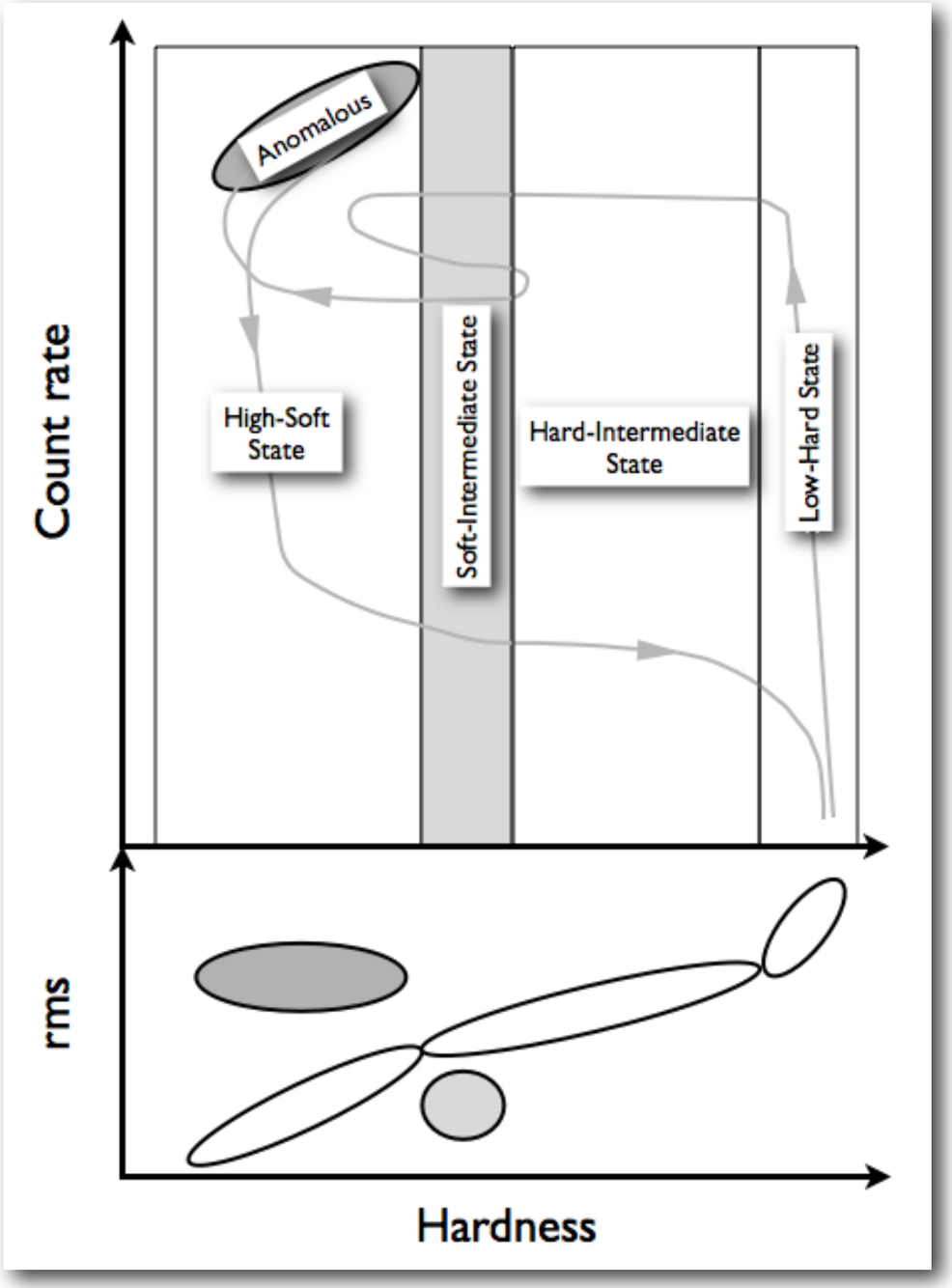




Belloni (2010)

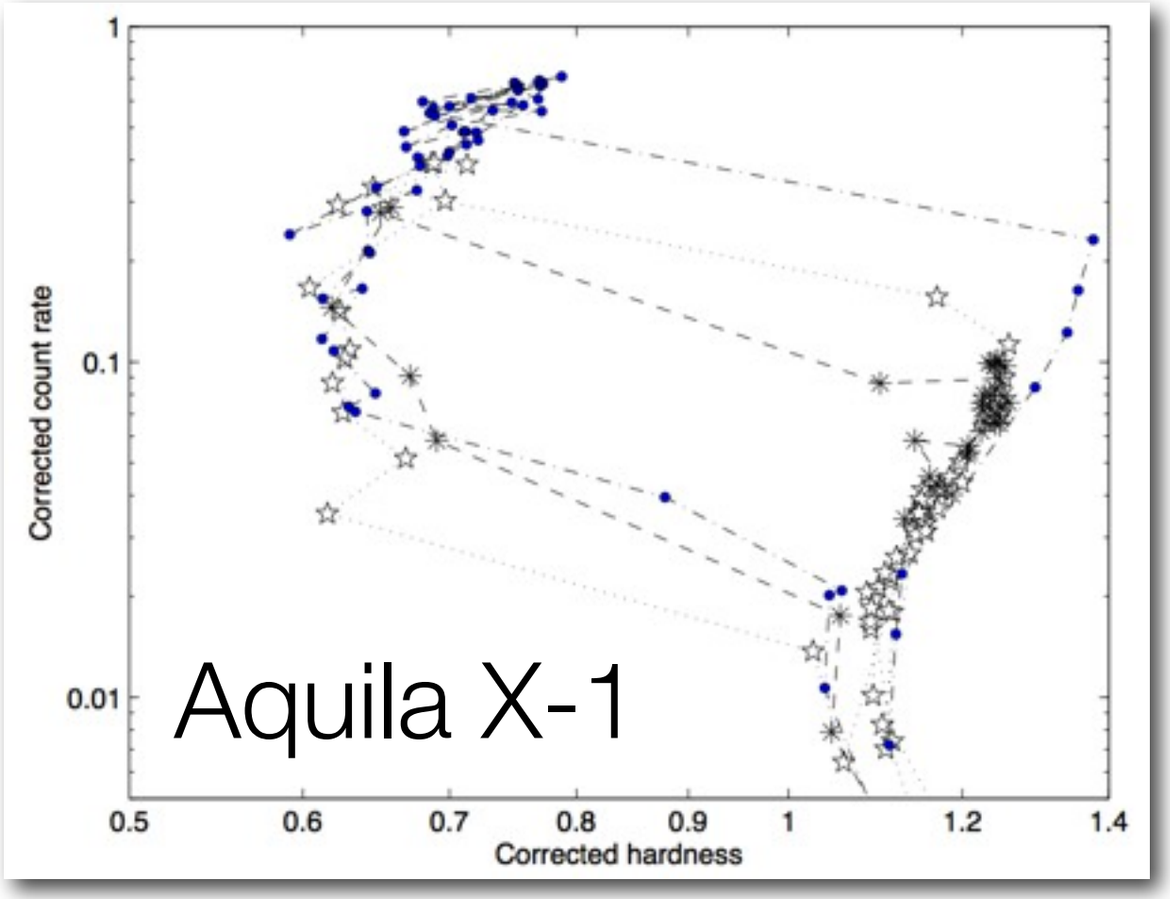
THE STATE PARADIGM

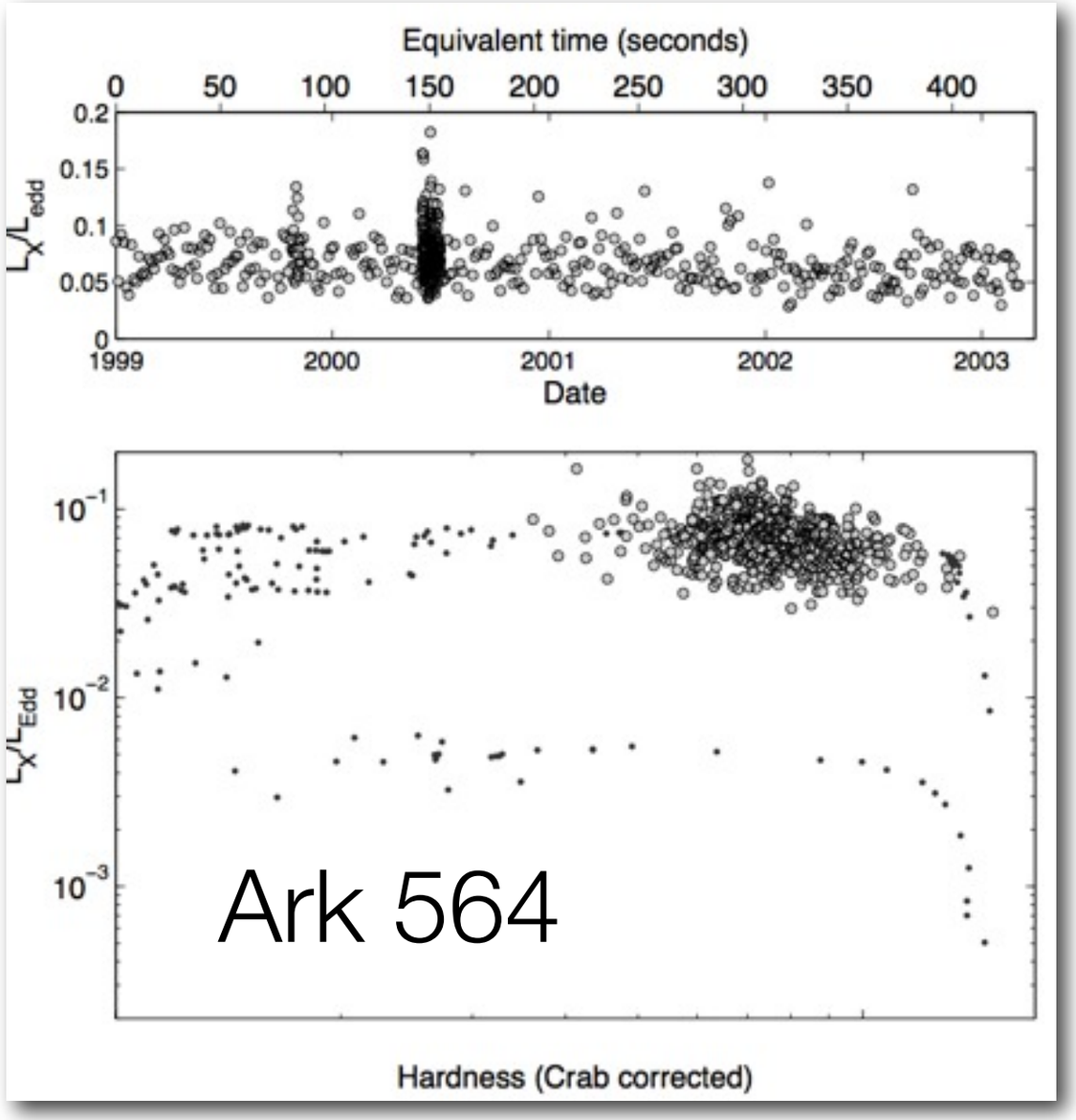
- Four separate states
- Transitions are fast (time scales)
- States are identified by: hardness
- States are identified by: variability
- Source evolution (for most sources)
- Extended to other systems



Belloni (2010)

NEUTRON STARS & ACTIVE GALACTIC NUCLEI

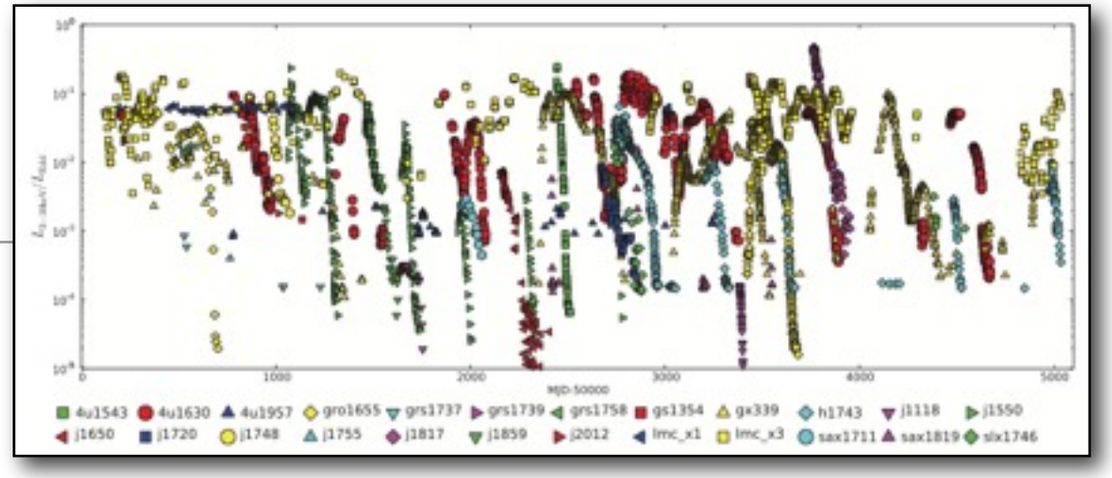


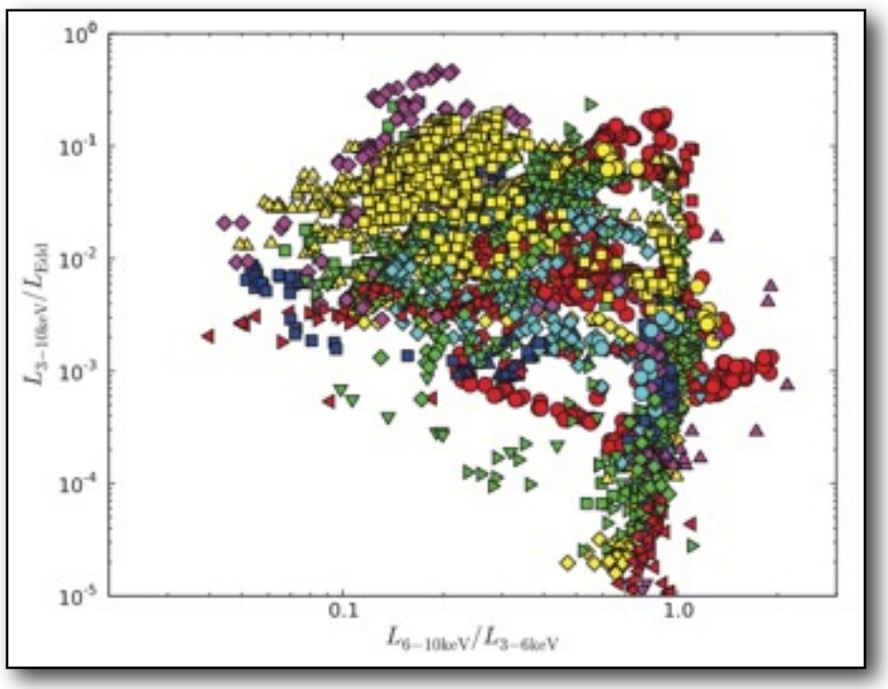


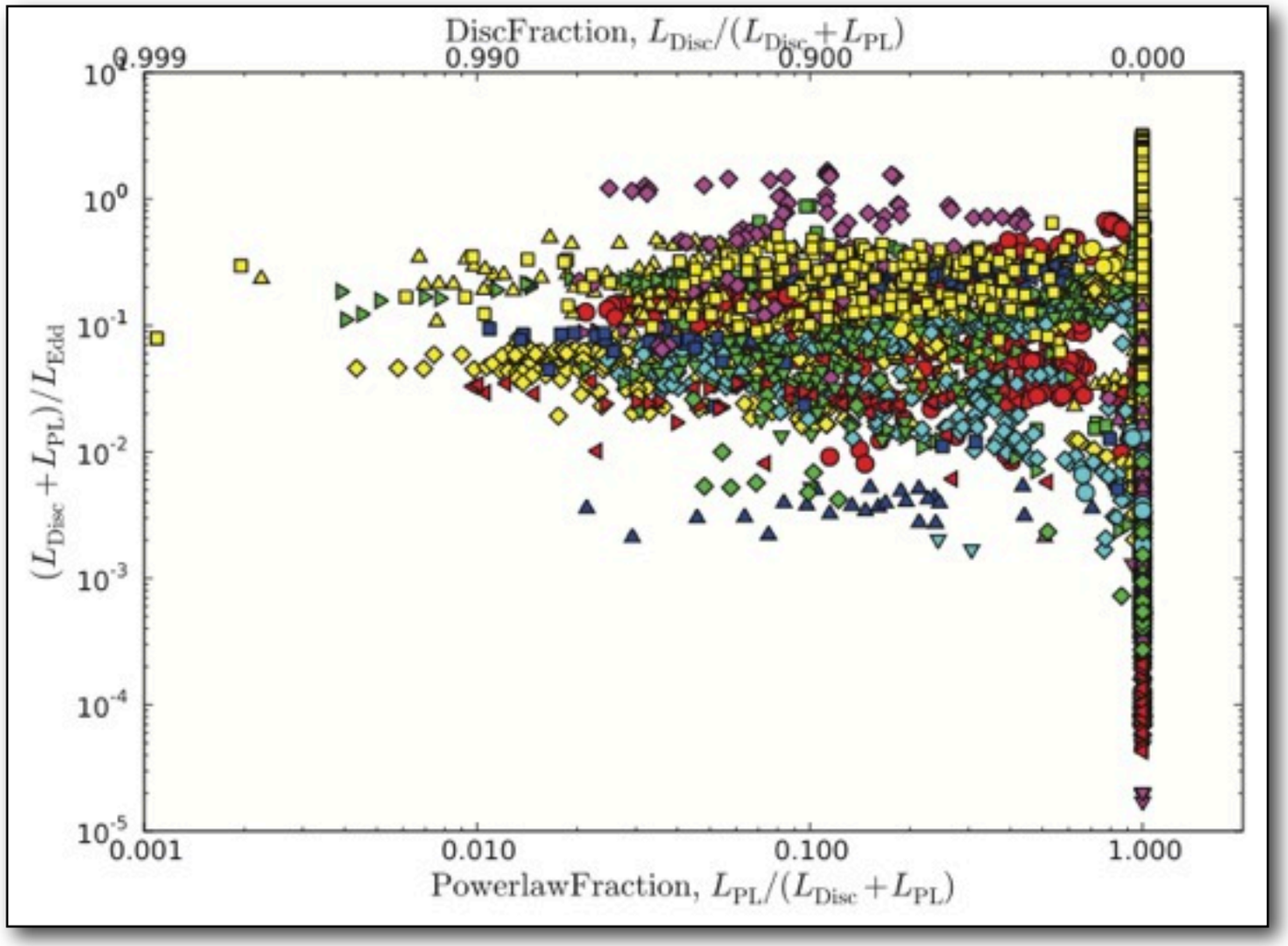
Belloni (2010)

THE BOOK OF BINARIES

- Transients in RXTE archive
- Disk/fraction-luminosity



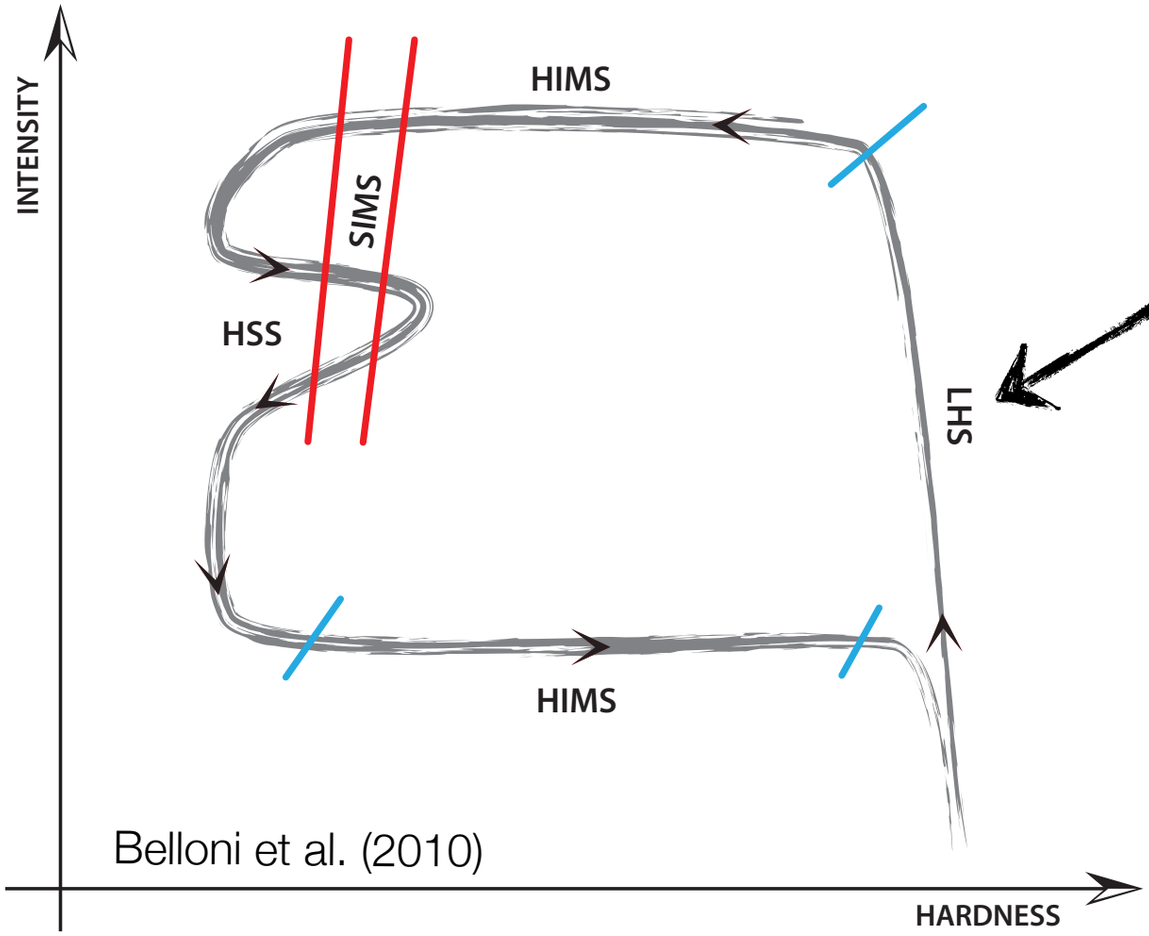




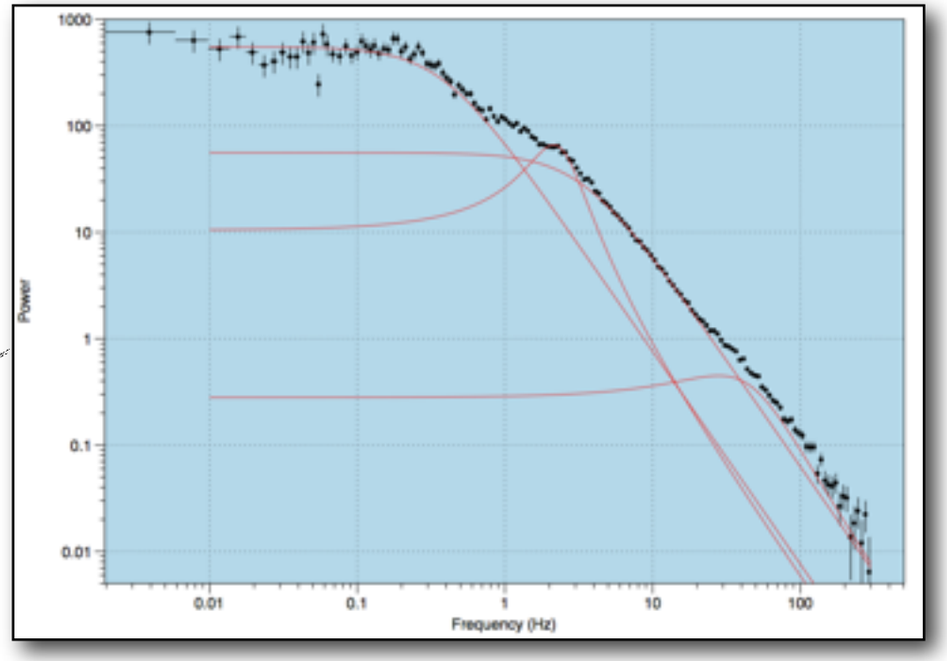
Dunn et al. (2010)

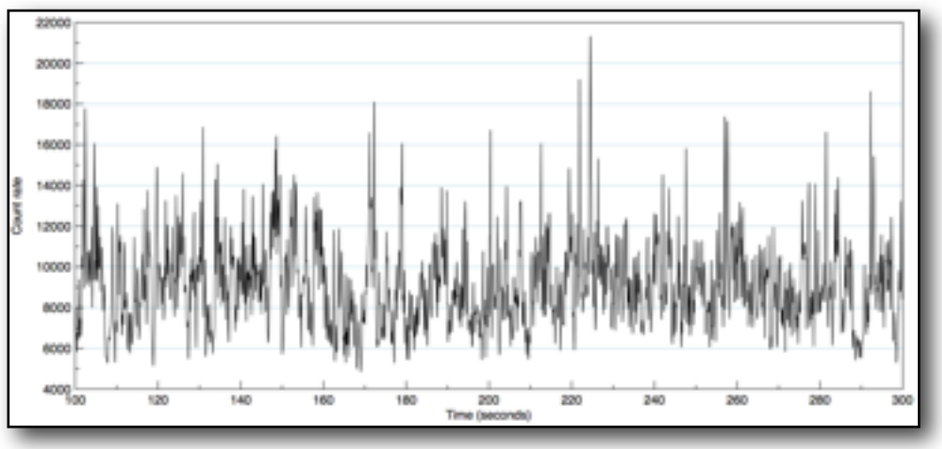
VARIABILITY

- Hard state: 30-40% variability



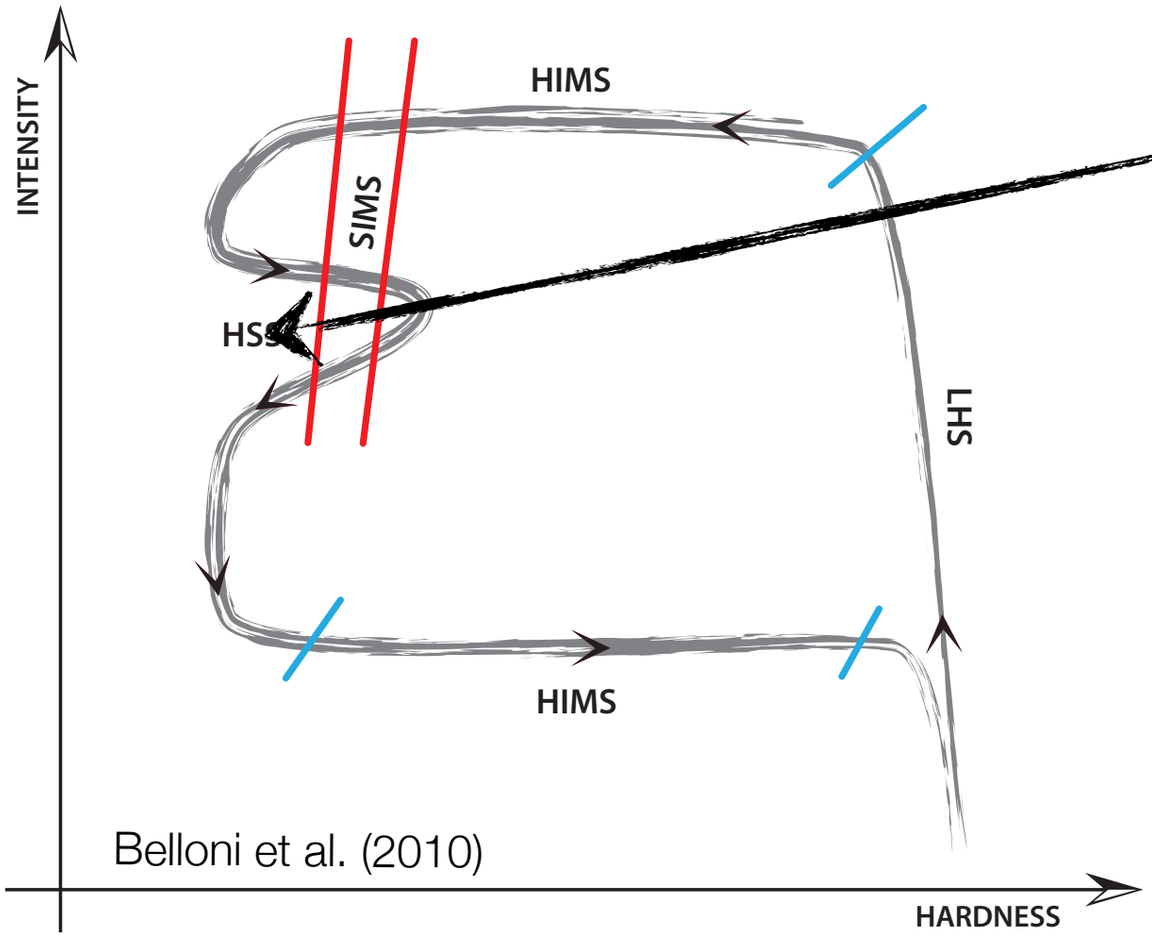
Belloni et al. (2010)



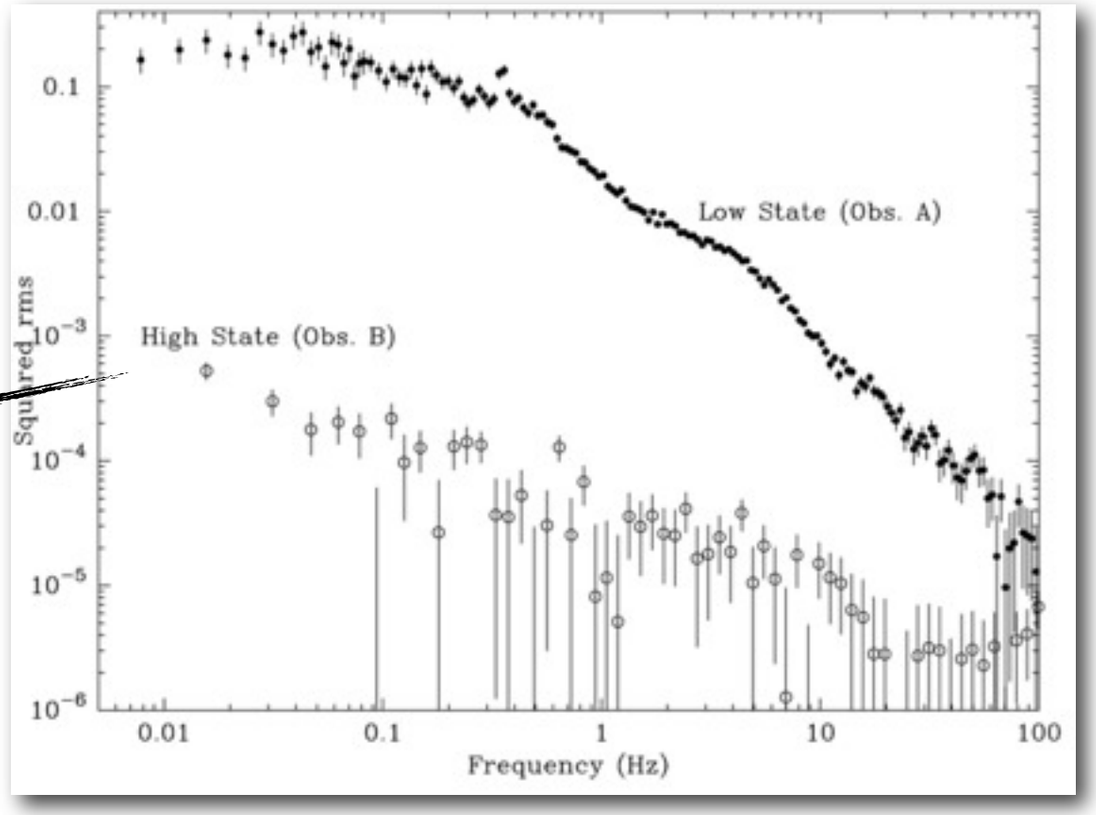


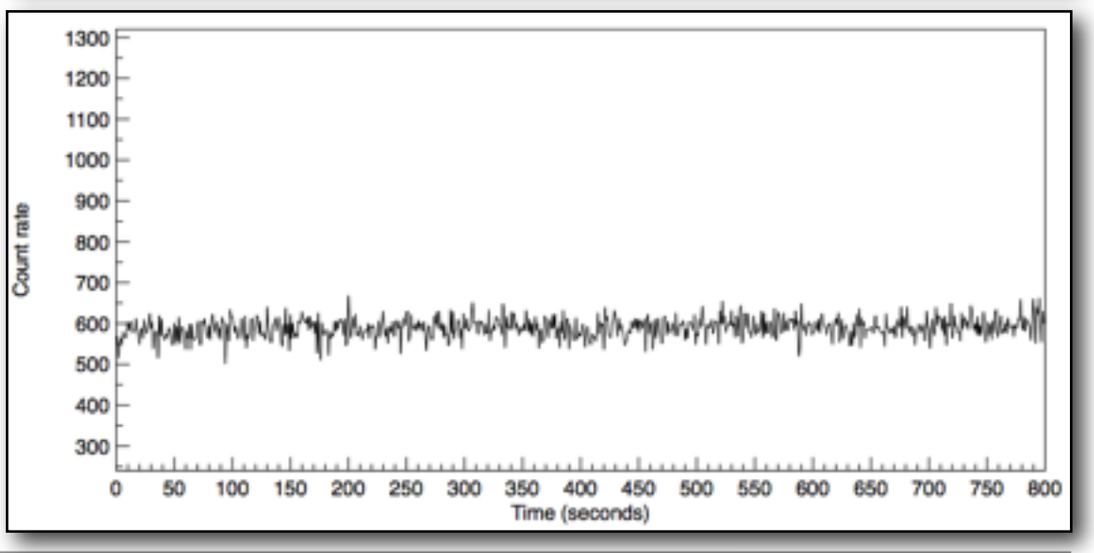
VARIABILITY

- Soft state: ~1-2 % variability



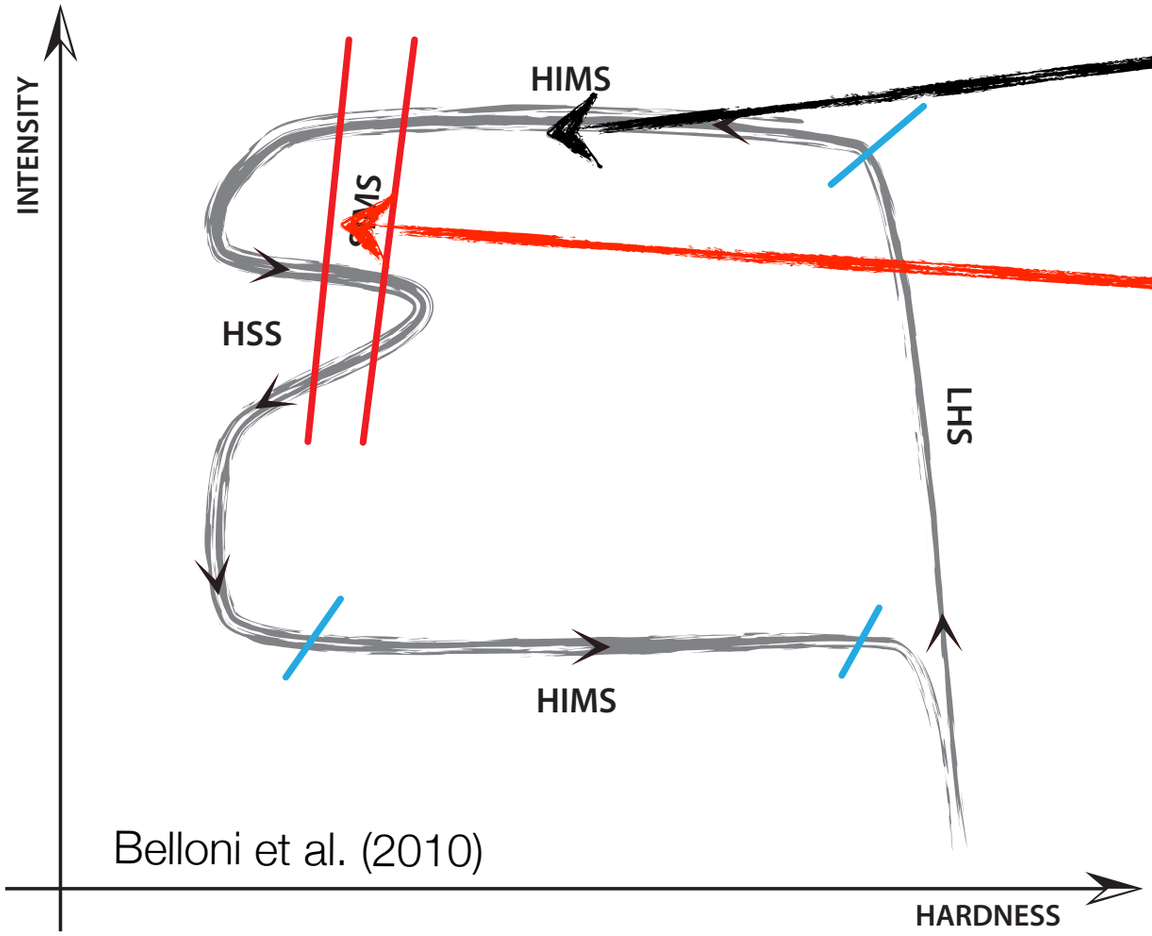
Belloni et al. (2010)



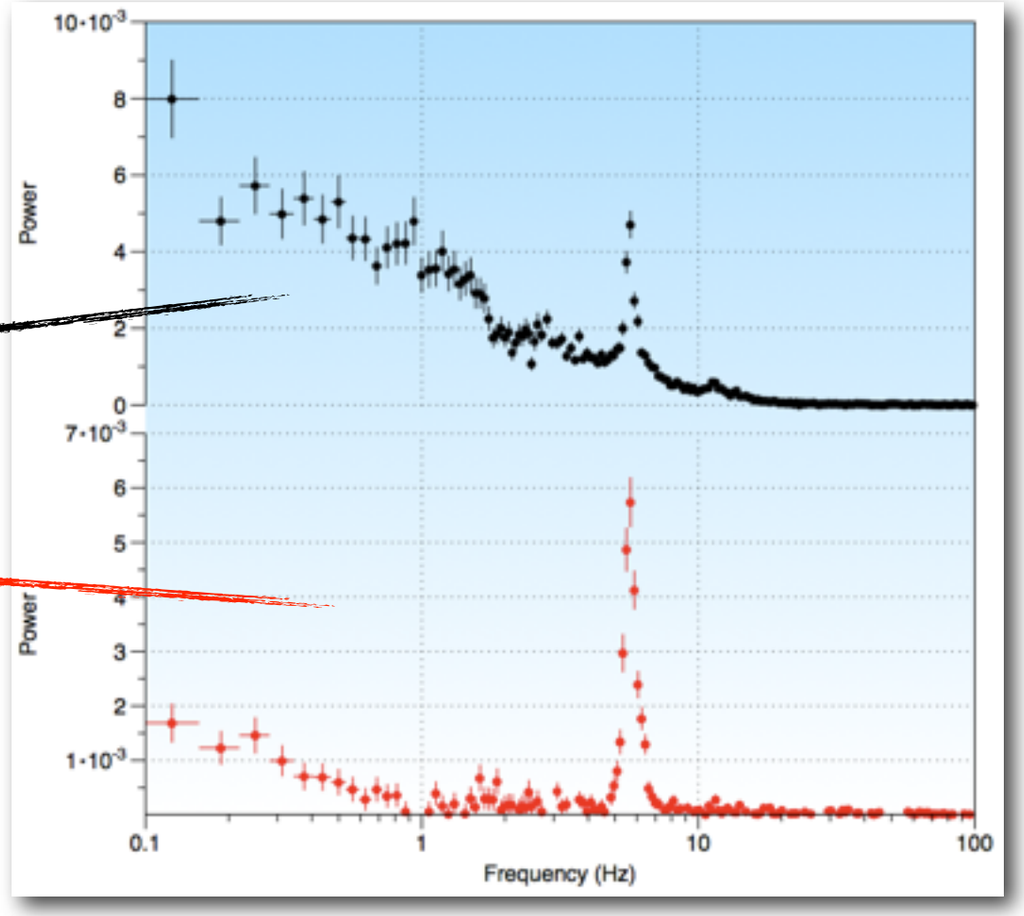


INTERMEDIATE STATES: QPO

- Two (three) flavors

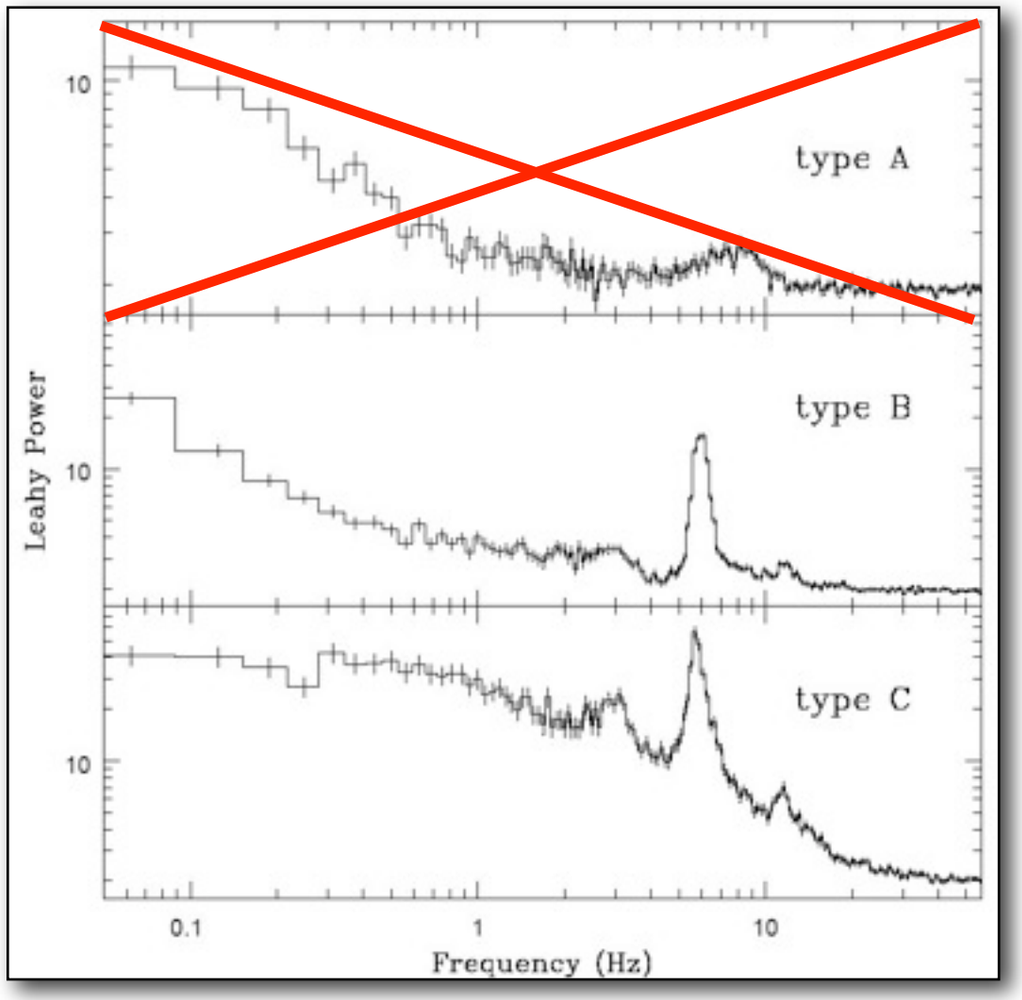


Belloni et al. (2010)



QPO FLAVORS

- Different behaviours



Casella, Belloni & Stella (2004)

TABLE 1
SUMMARY OF TYPE-A, -B AND -C LFQPOS PROPERTIES

Property	Type C	Type B	Type A
Frequency (Hz)	∼0.1-15	∼5-6	∼8
Q (ν/FWHM)	∼7-12	$\gtrsim$6	$\lesssim$3
Amplitude (%rms)	3-16	∼2-4	$\lesssim$3
Noise	strong flat−top	weak red	weak red
Phase lag @ν_{QPO}	soft/hard	hard	soft
Phase lag @$2\nu_{QPO}$	hard	soft	...
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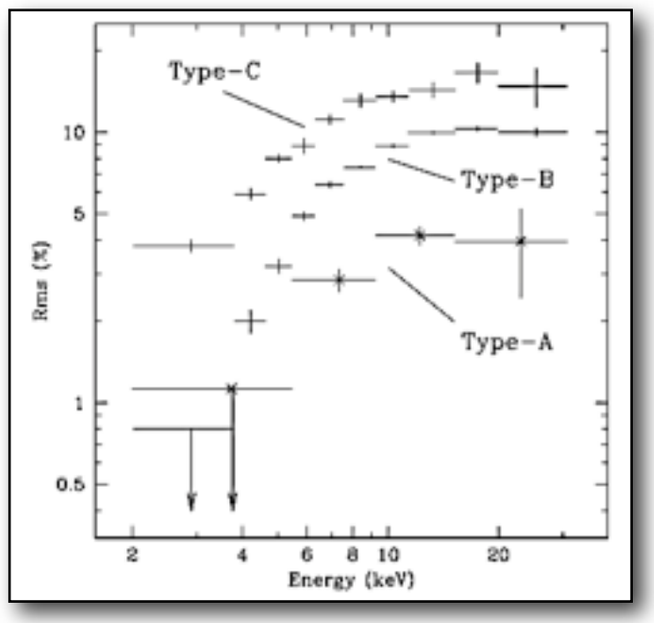
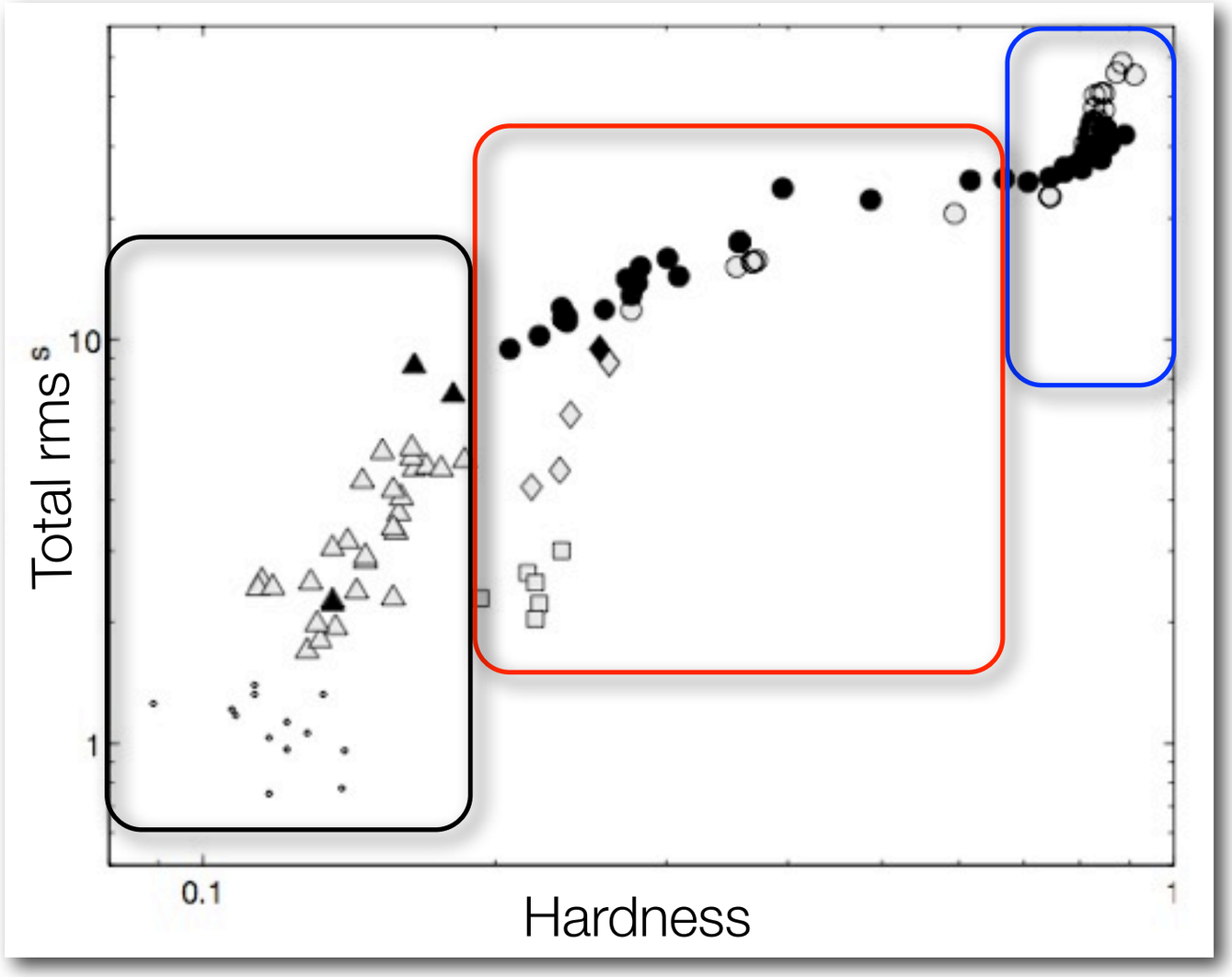


OVERALL VARIABILITY

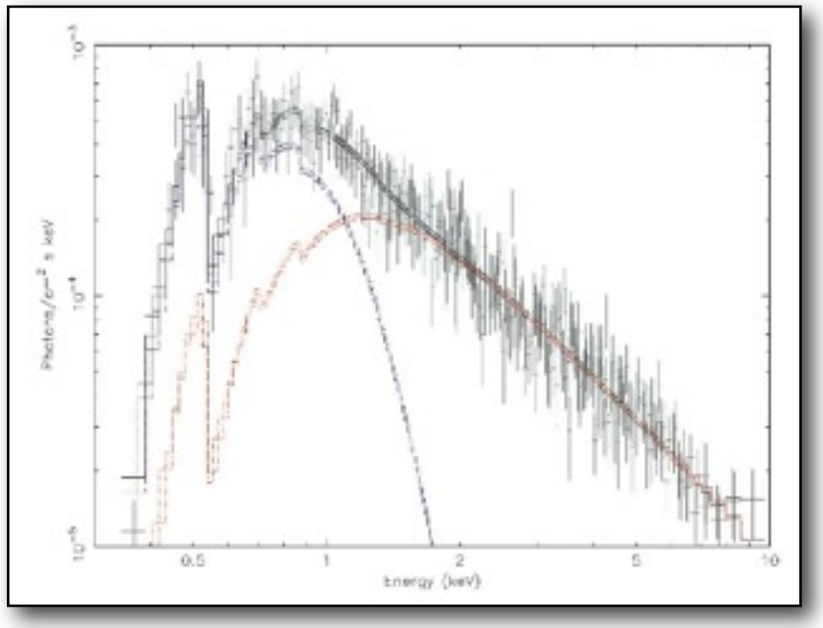
- States are well defined here



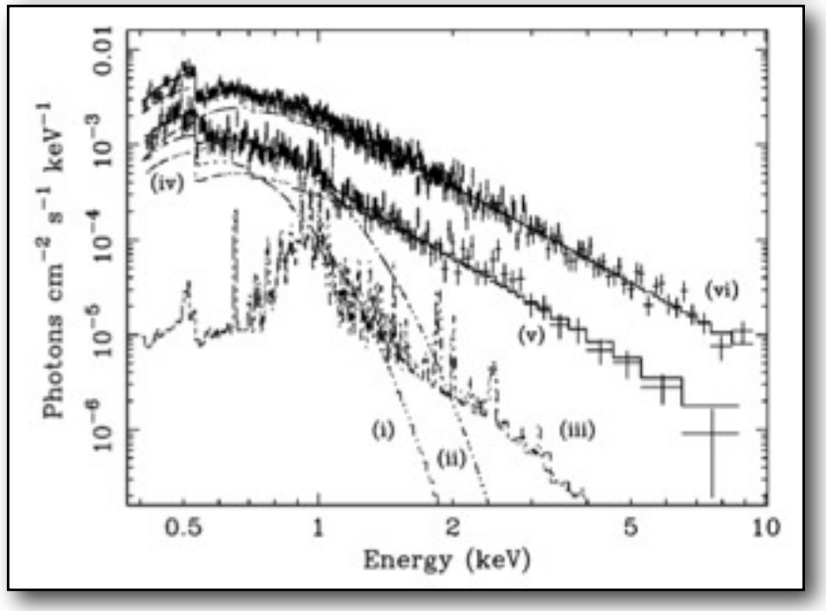
Belloni et al. (2005)

ULX: SPECTRAL APPROACH

- What do we expect?
- Mostly comparison with Galactic models
- Find thermal disk, estimate mass
- Detect spectral transitions
- Use complex thermal models
- We have many systems: we can use them



Miller et al. (2003)



Dewangan et al. (2004)

ULX: SPECTRAL APPROACH

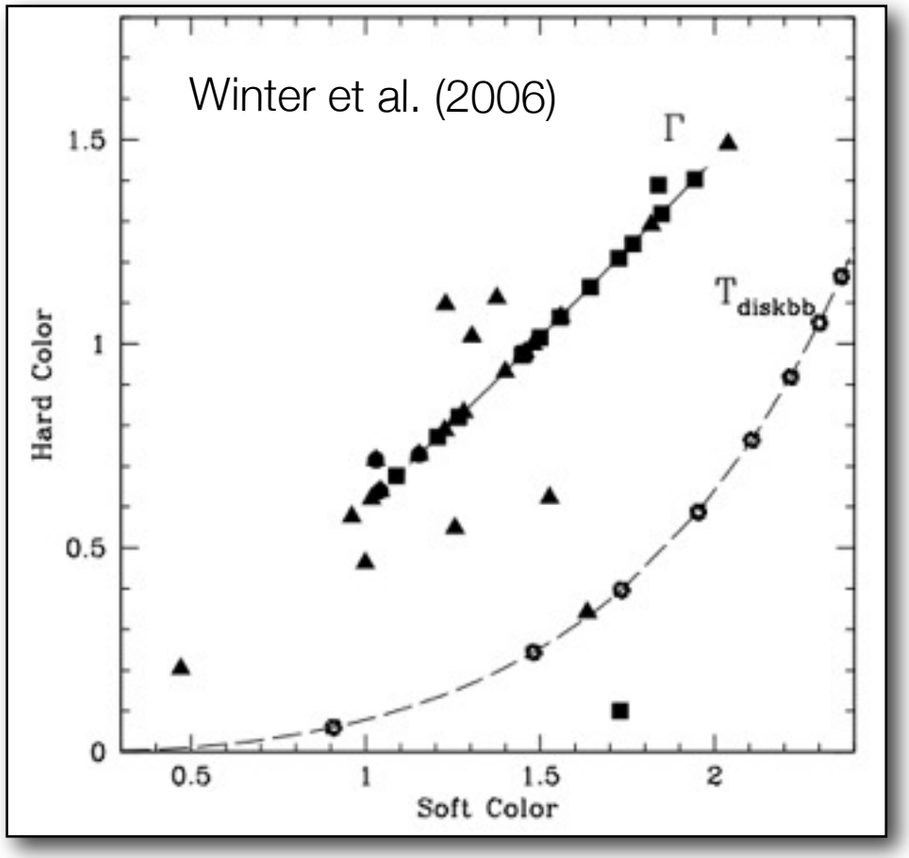
- Correlations between parameters
- Spectral transition observed

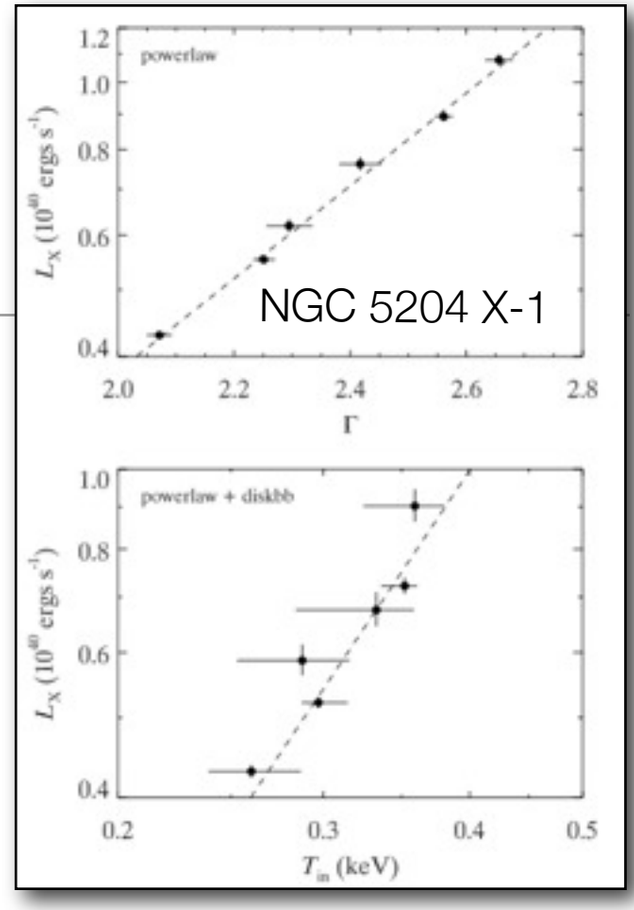
M 82: Ji et al. (2010)

Hol II X-1: Dewagan et al. (2004)

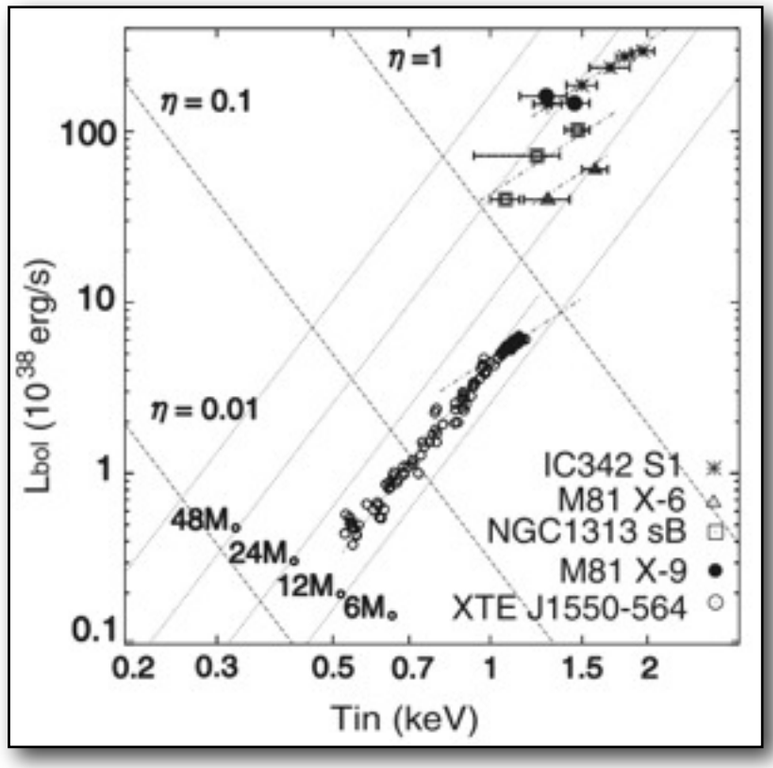
- Diagrams
- Ultra-luminous state

Gladstone et al. (2009)





Feng & Kaaret (2009)

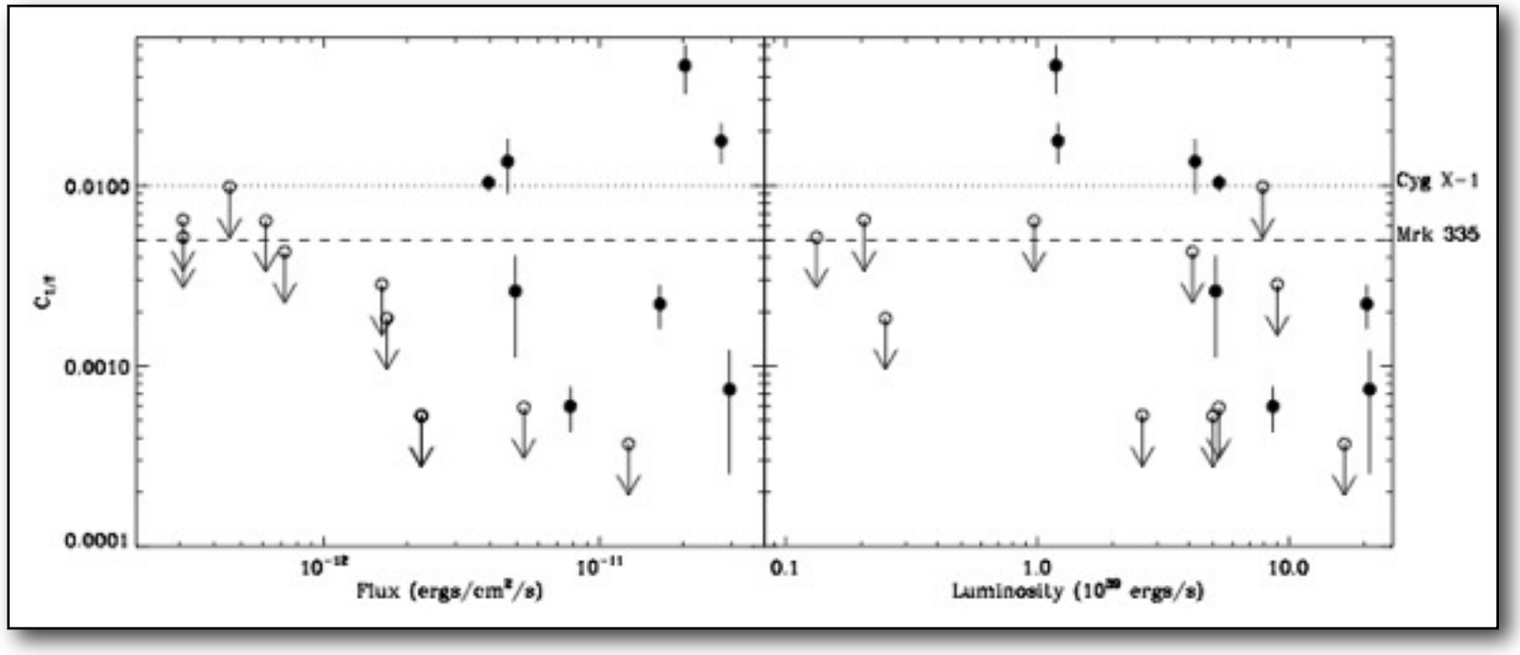


Tsunoda et al. (2006)

ULX: TIMING APPROACH

- Systematic studies (few)

- rms-flux relation (NGC 5408 X-1)



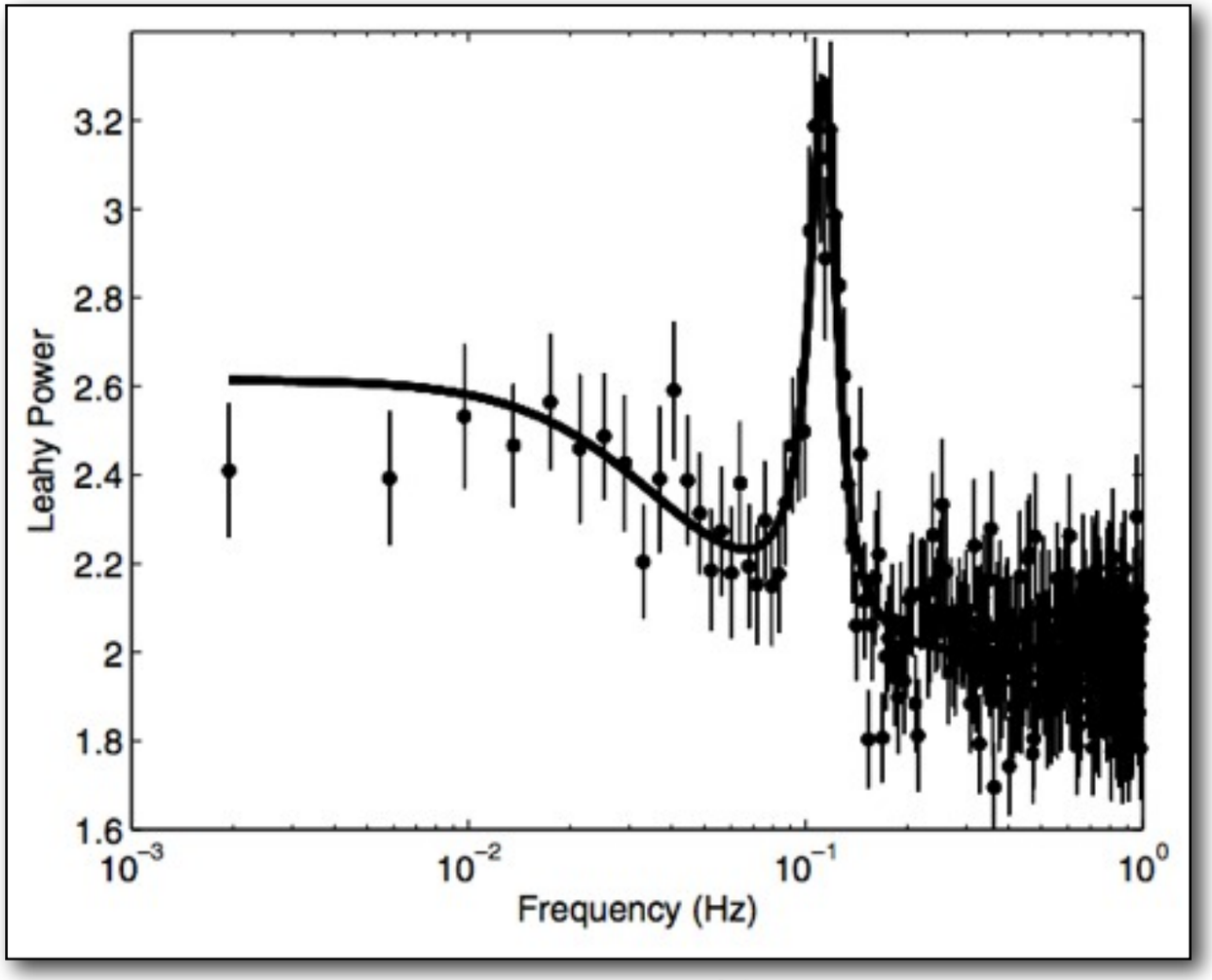
Heil et al. (2009)

- Still missing: hardness-rms diagram - variability hard to measure

- Things will get better in time

ULX: TIMING APPROACH - QPOs

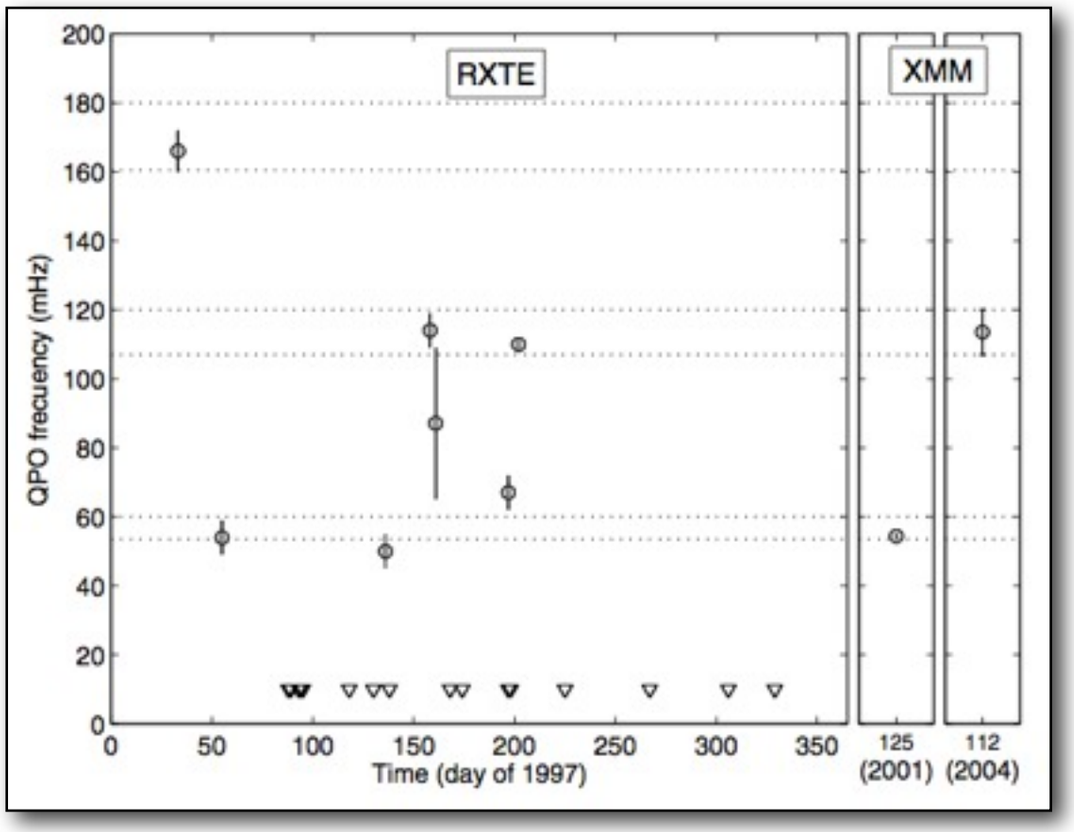
- Precise frequencies
- Typical of galactic binaries
- Direct comparison
- Relatively rare
- M82 X-1 Strohmayer & Mushotsky (2003)
- It has all required signatures

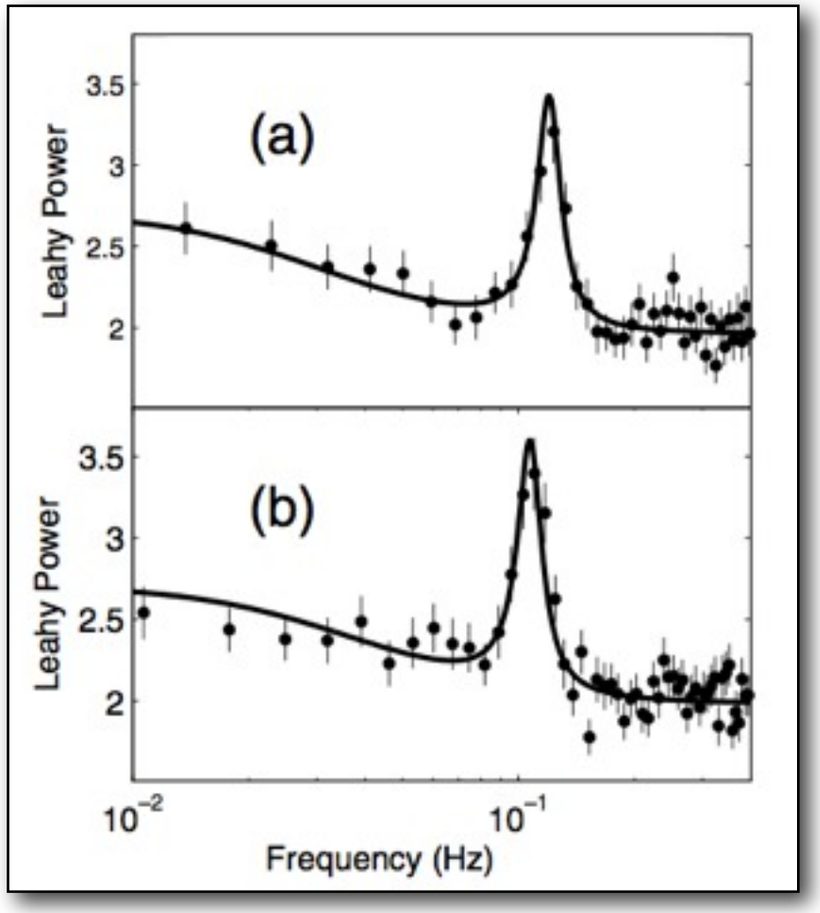


Mucciarelli et al. (2006)

ULX: TIMING APPROACH - QPOs

- Fast frequency variations
- Associated noise (22% rms)
- Long-term changes (?)





Mucciarelli et al. (2006)

ULX: TIMING APPROACH - QPOs

- Correlation?
- Which QPO?

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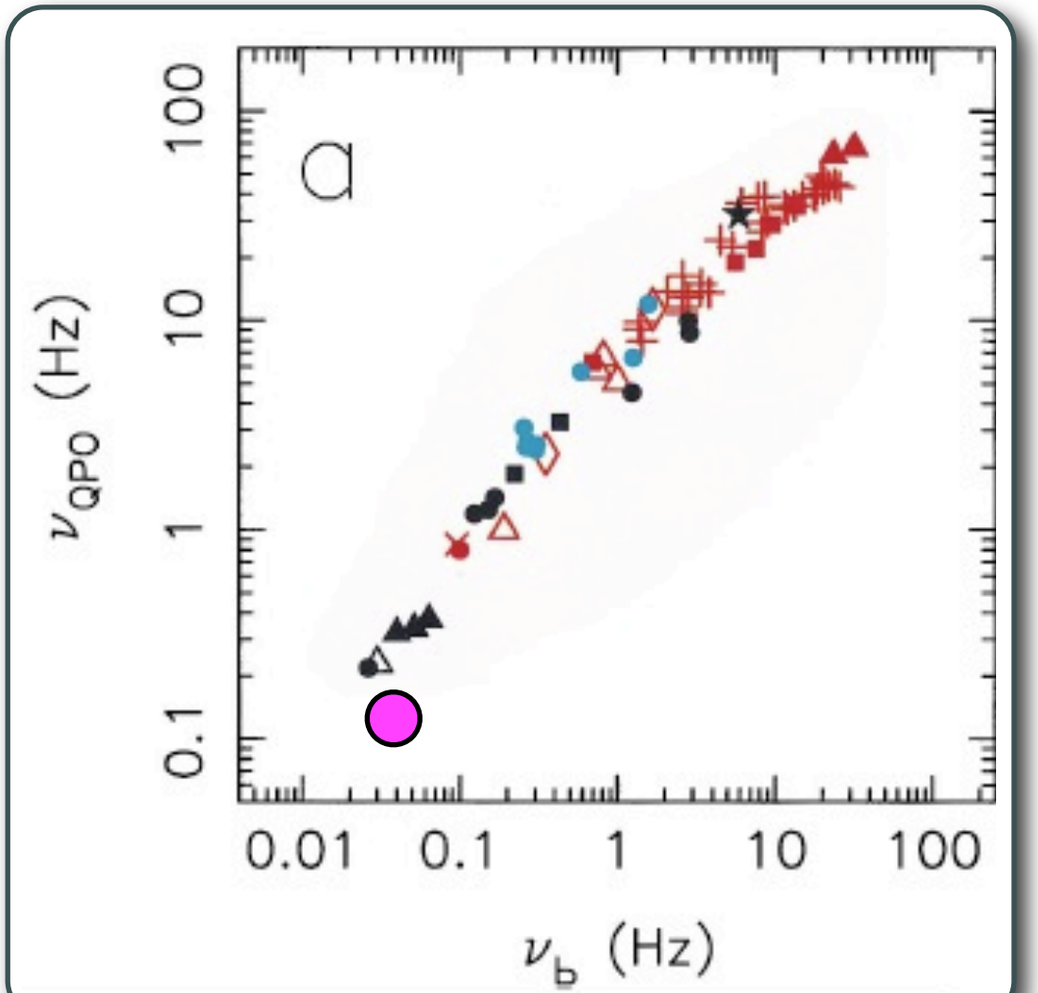
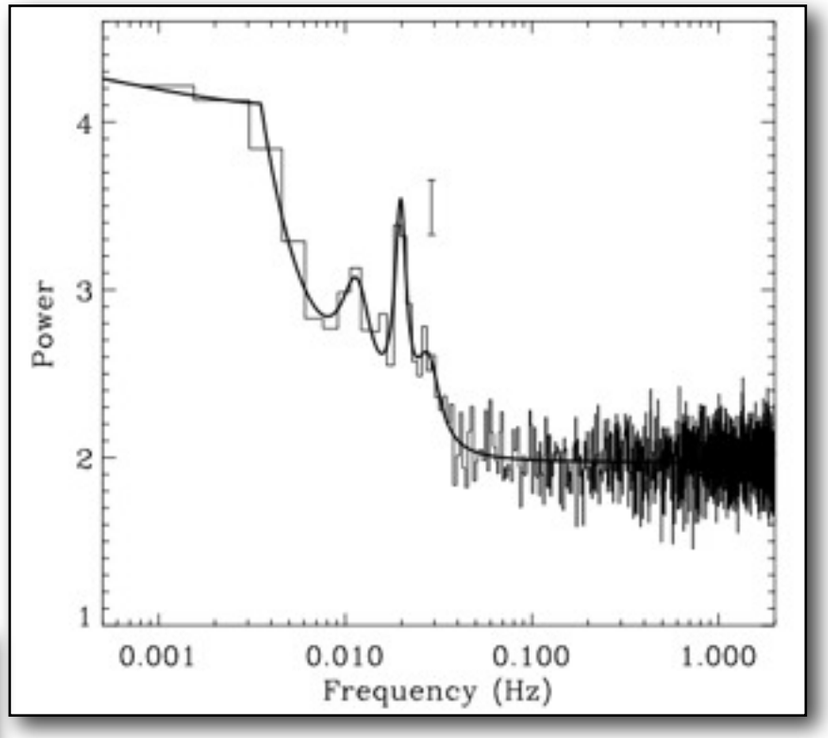


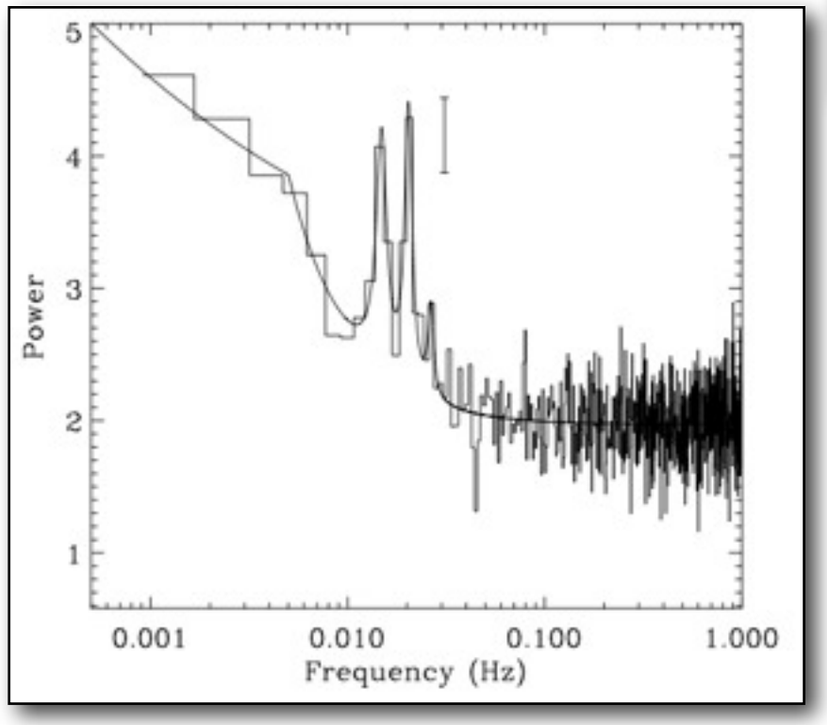
Wijnands & van der Klis (1999)

- HFQPO? Does not fit (and yet it moves..!)
- Type C: the worst type for mass estimate

ULX: TIMING APPROACH - QPOs

- NGC 5408 Strohmayer et al. (2007)
- 20 mHz QPO + break 3.5 mHz
- Two peaks?
- Watch out for ratios
- See talk by Middleton

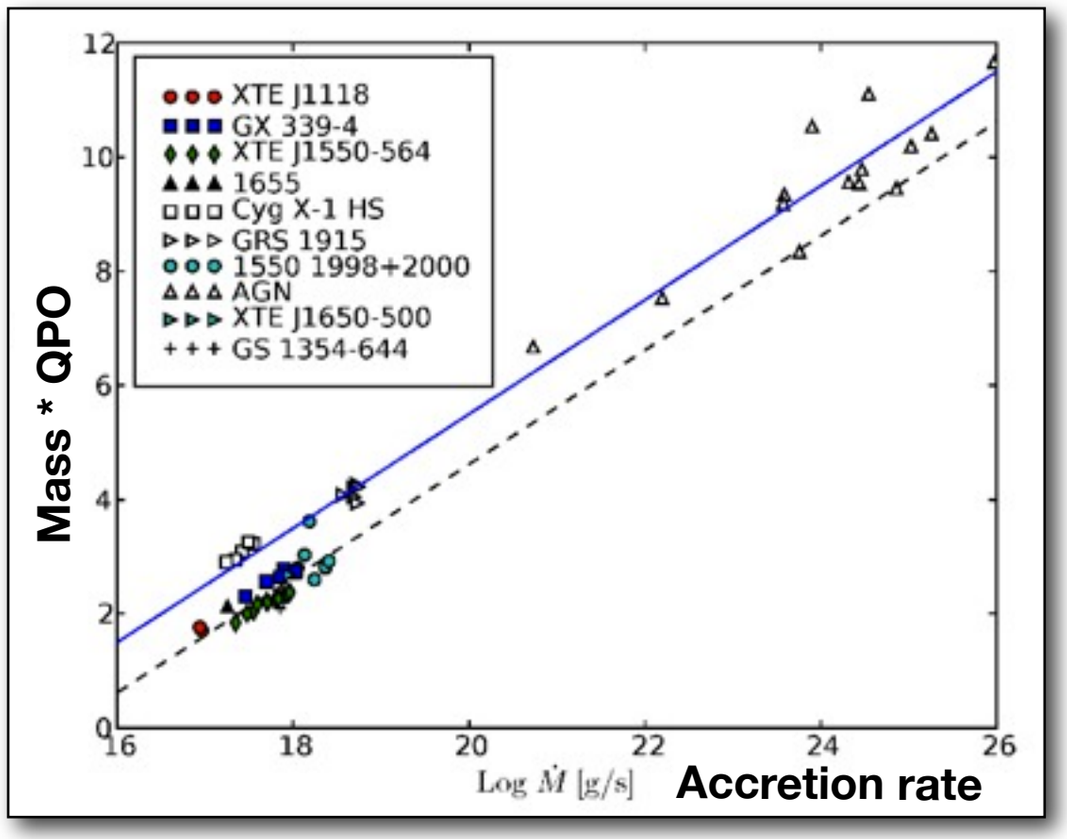




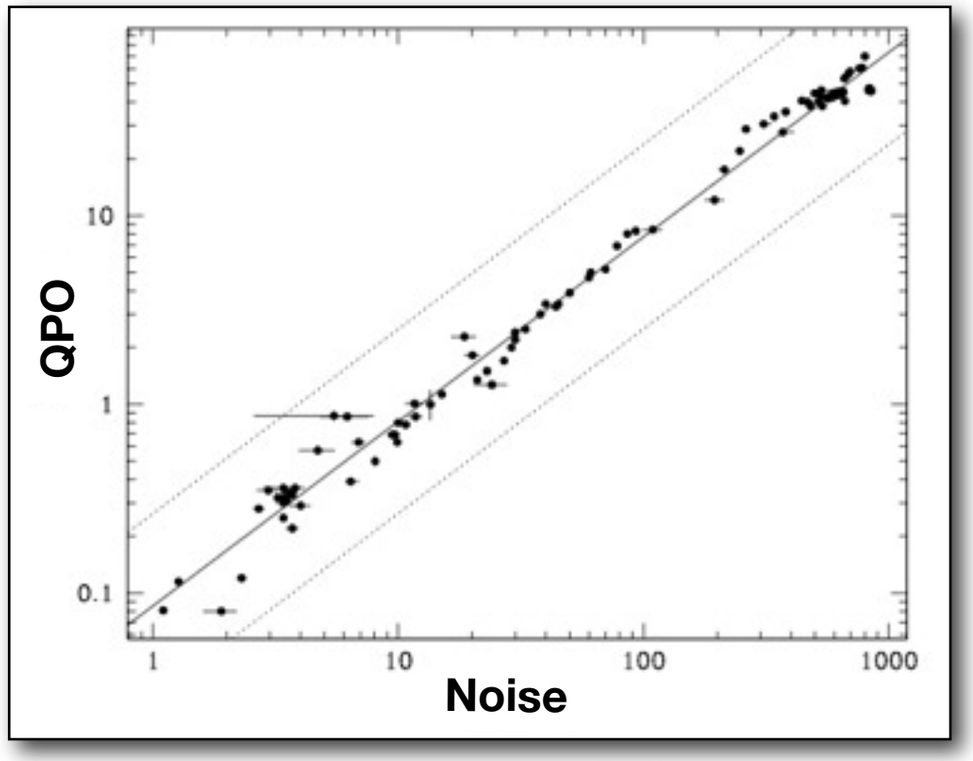
A MULTI-STEP ATTEMPT

- Using correlations:

noise ⇨ QPO
LX ⇨ Ṁ ⇨ Mass



Körding et al. (2007)



Belloni et al. (2002)

Source	ν_{QPO} (mHz)	L_X[a] (ergs/s)	BH mass ($M_\odot$) Ineff. accr.	Eff. accr.
M82 X-1 (2001)	54±1	130±13	240^{+380}_{-150}	700^{+905}_{-395}
M82 X-1 (2004)	113±2	170±17	165^{+260}_{-100}	550^{+710}_{-310}
NGC 5408 X-1	20±0.5	30±3	295^{+465}_{-180}	570^{+735}_{-320}

Casella et al. (2008)

CONCLUSIONS

- From states to ULX masses - but other options
- Spectral approach: population studies
- Timing approach: most direct way
- Your help is needed - XMM campaigns