

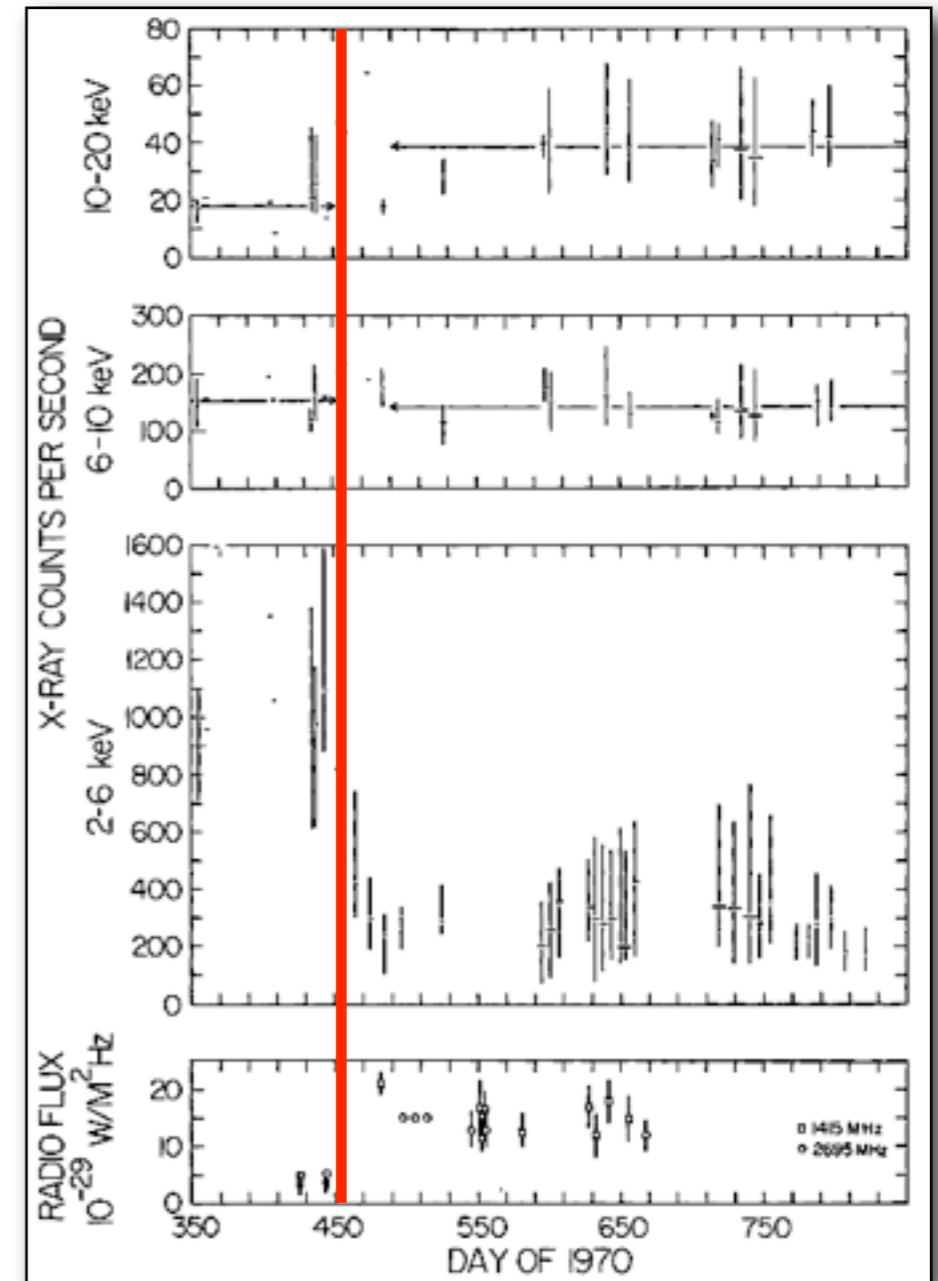
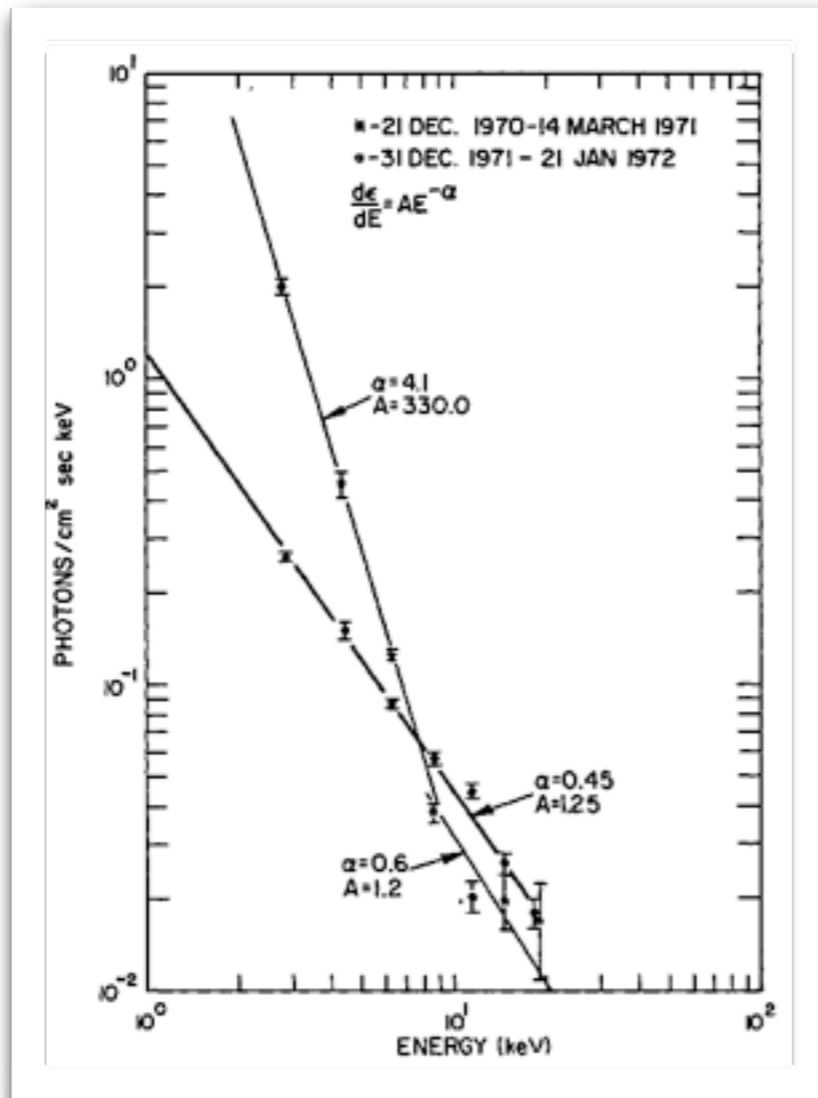


States and state transitions in X-ray binaries

Tomaso Belloni
(INAF - Osservatorio Astronomico di Brera)

Accretion onto stellar-mass black holes

- The notion of separate states is very old
- High and low state from Uhuru



Tananbaum et al. (1972)

Two very successful models

High state

Black Holes in Binary Systems. Observational Appearance

N. I. Shakura

Sternberg Astronomical Institute, Moscow, U.S.S.R.

R. A. Sunyaev

Institute of Applied Mathematics, Academy of Sciences, Moscow, U.S.S.R.

Received June 6, 1972

Received June 6, 1972

Institute of Applied Mathematics, Academy of Sciences, Moscow, U.S.S.R.

Low state

Comptonization of X-rays in Plasma Clouds. Typical Radiation Spectra

R. A. Sunyaev and L. G. Titarchuk

Space Research Institute, USSR Academy of Sciences, Profsoyuznaja 84/32, Moscow 117810, USSR

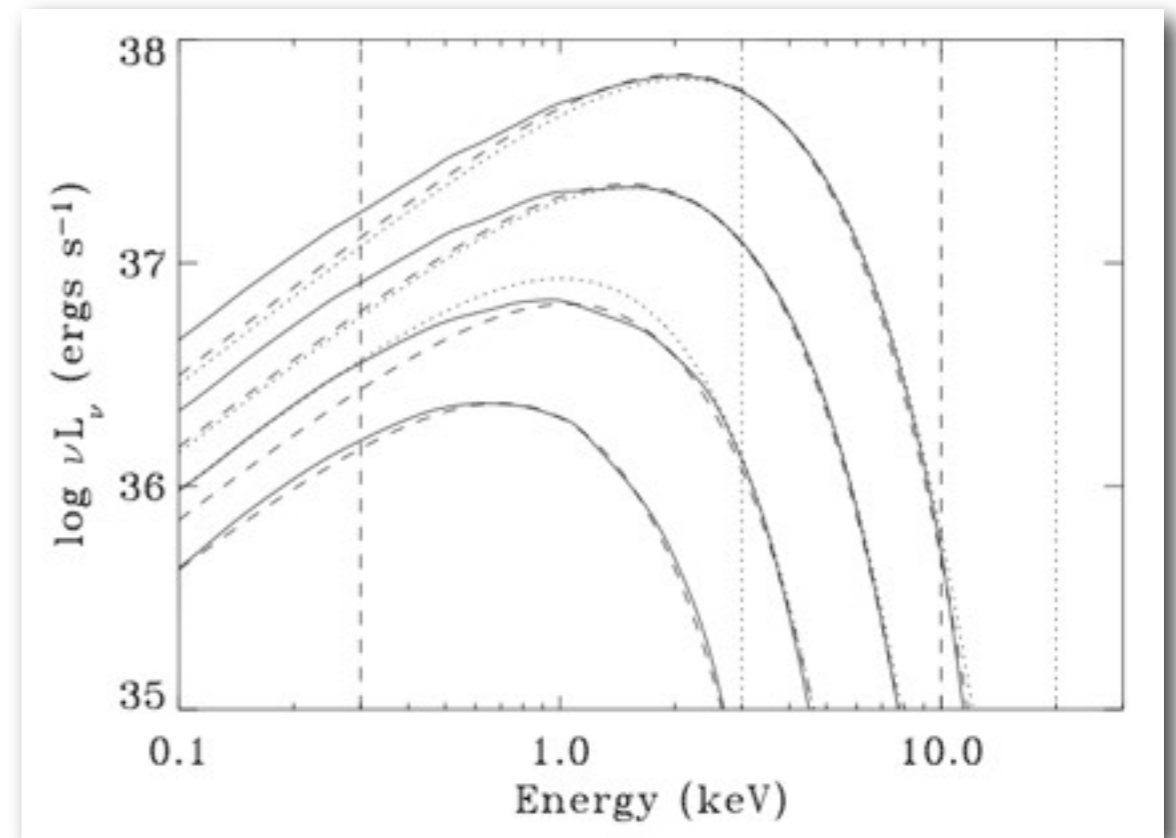
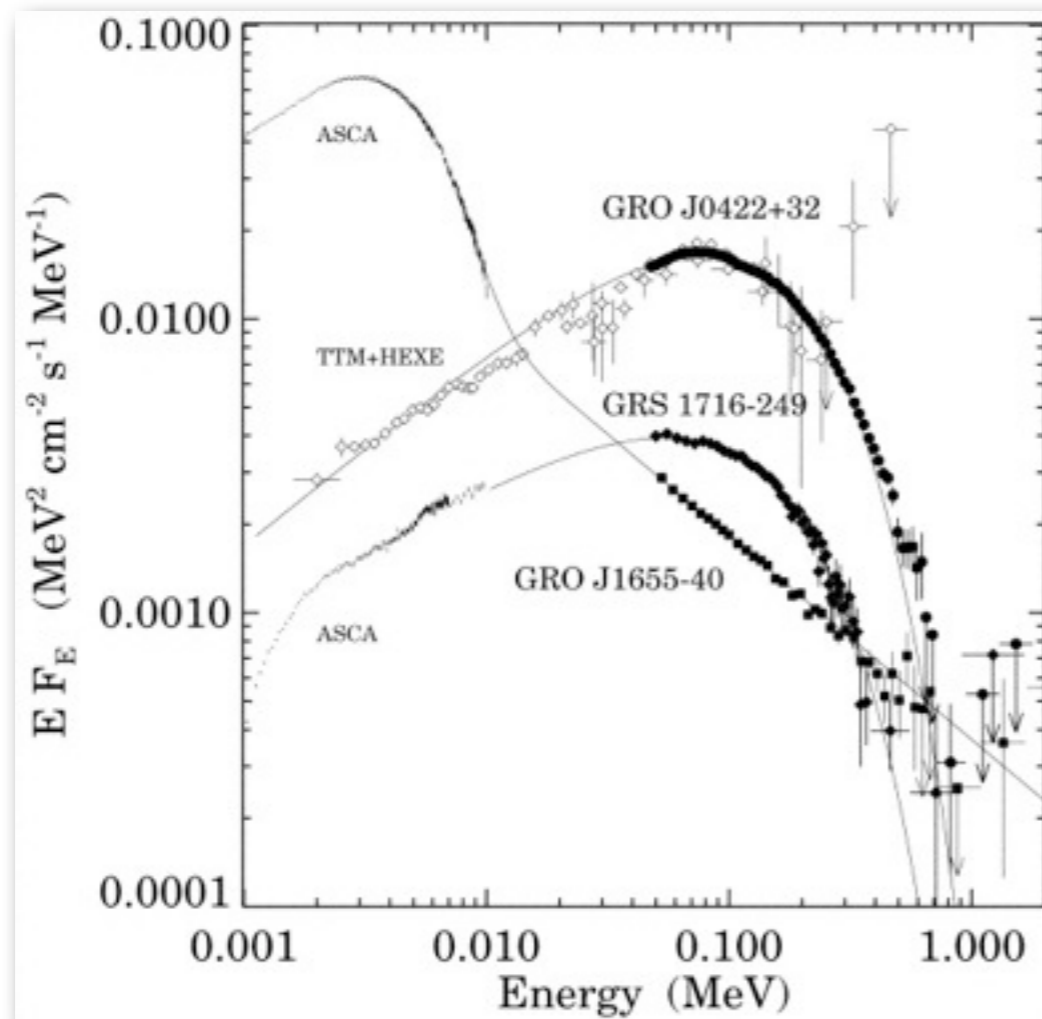
Received March 30, 1979

Received March 30, 1979

Soft state

- Thin disk model a spectacular success
- Still an additional component is present (always?)

Grove et al. (1998)

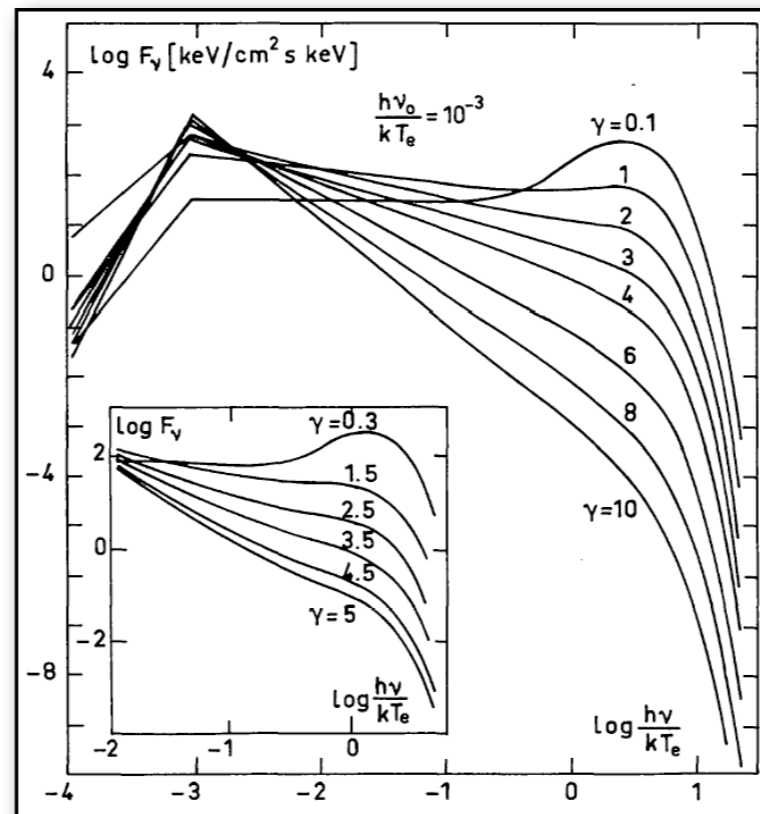


Davis et al. (2005)

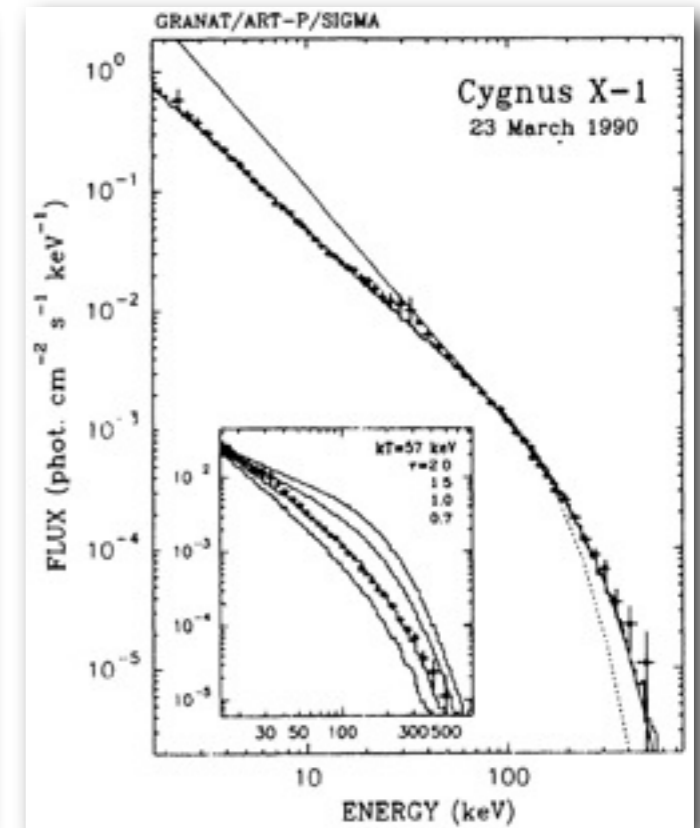
- A quiet disk

Hard state

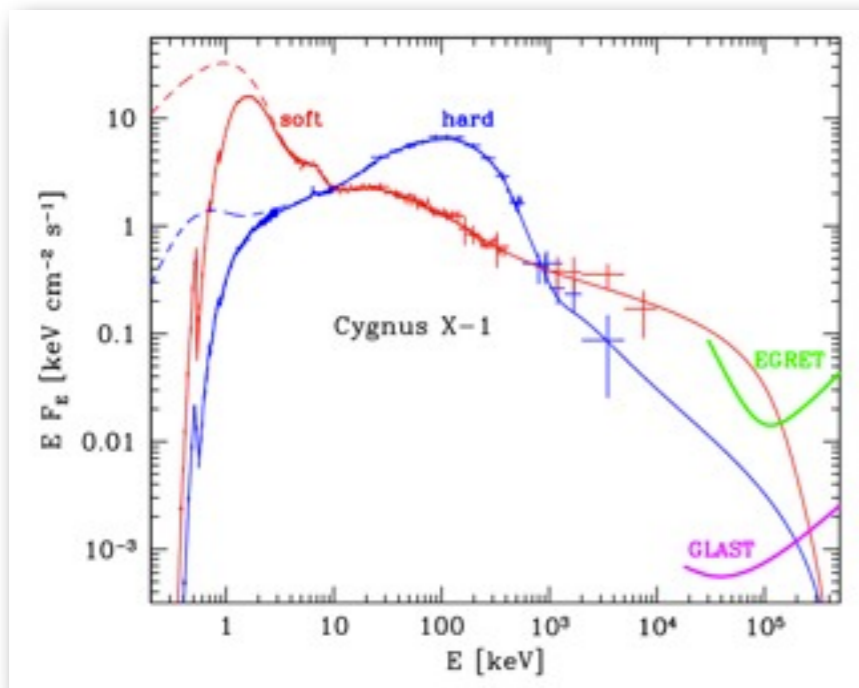
- Lots of complications
- Hybrid models
- Jet models



Sunyaev & Titarchuk (1980)



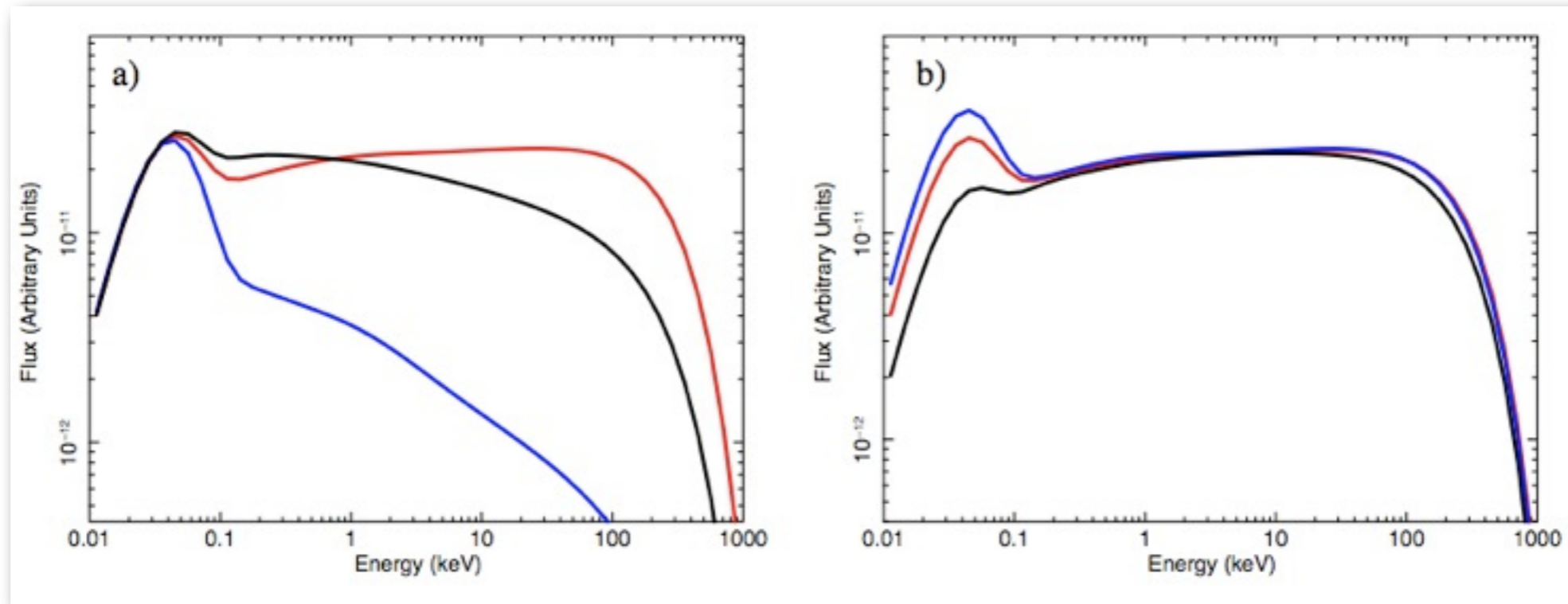
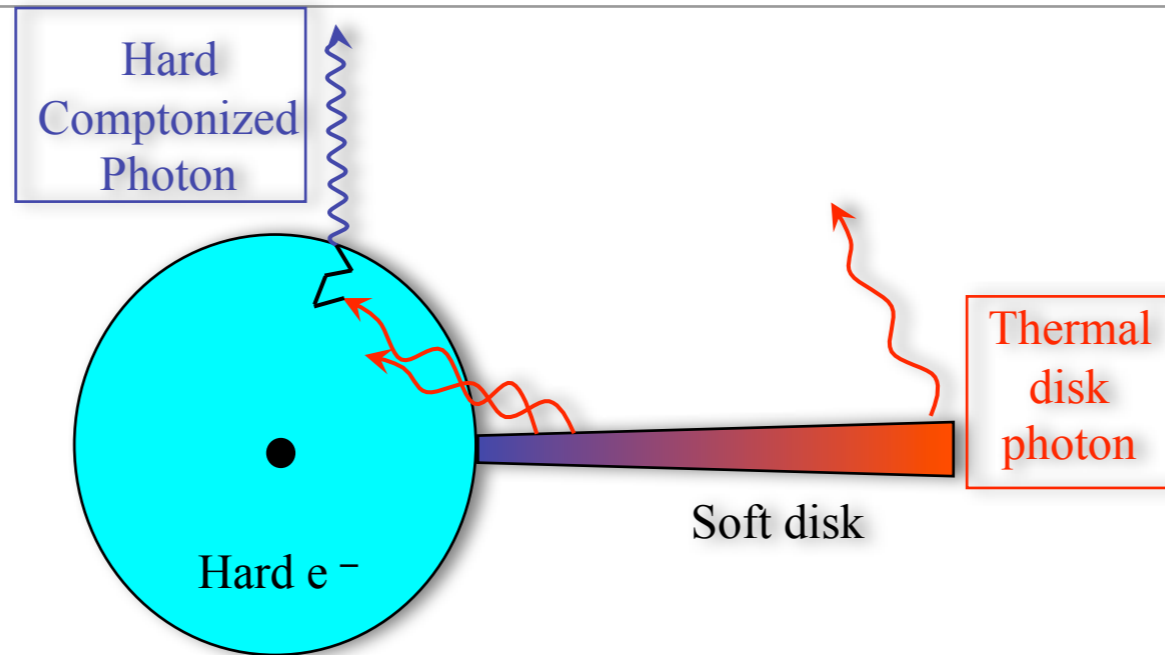
Sunyaev & Trümper (1979)



Zdziarski & Gierliński (2004)

- A restless flow

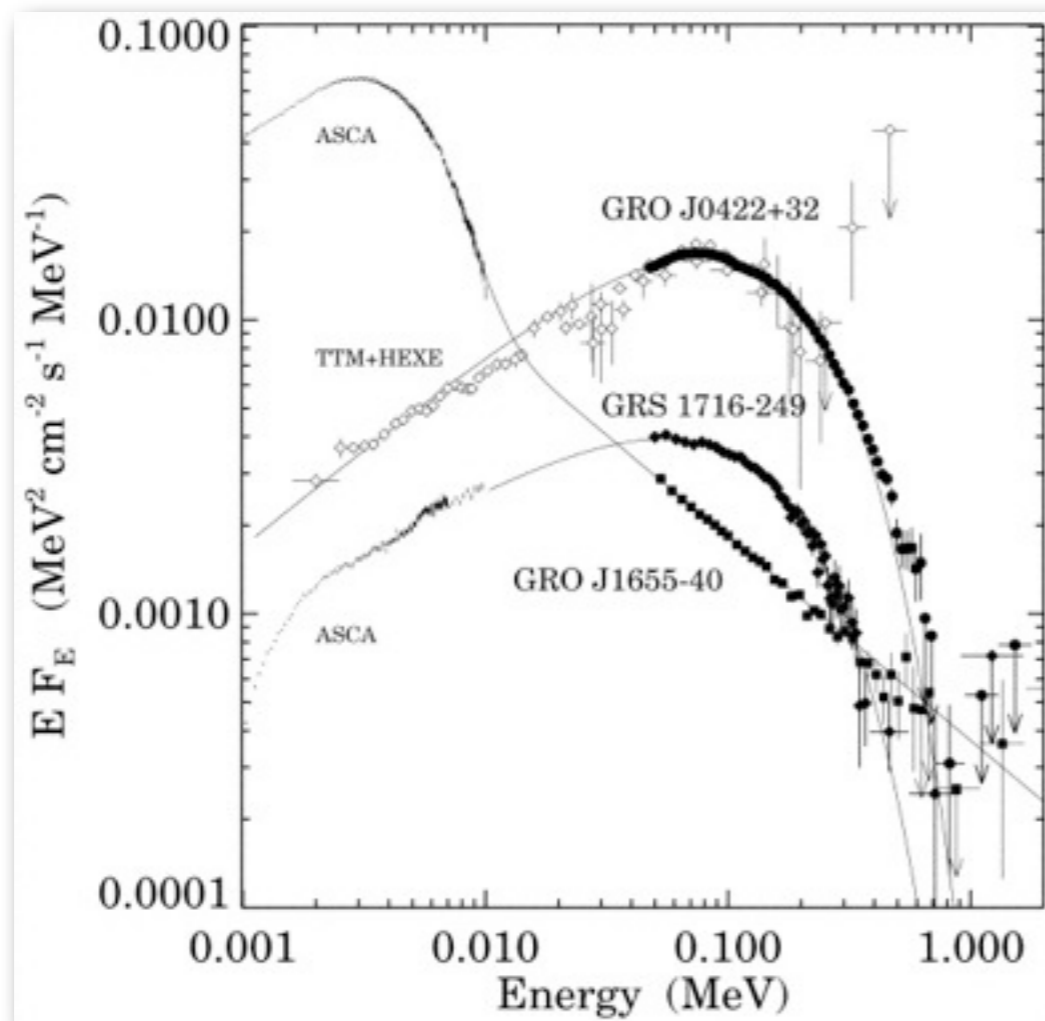
Geometry unclear



Petrucci (2009)

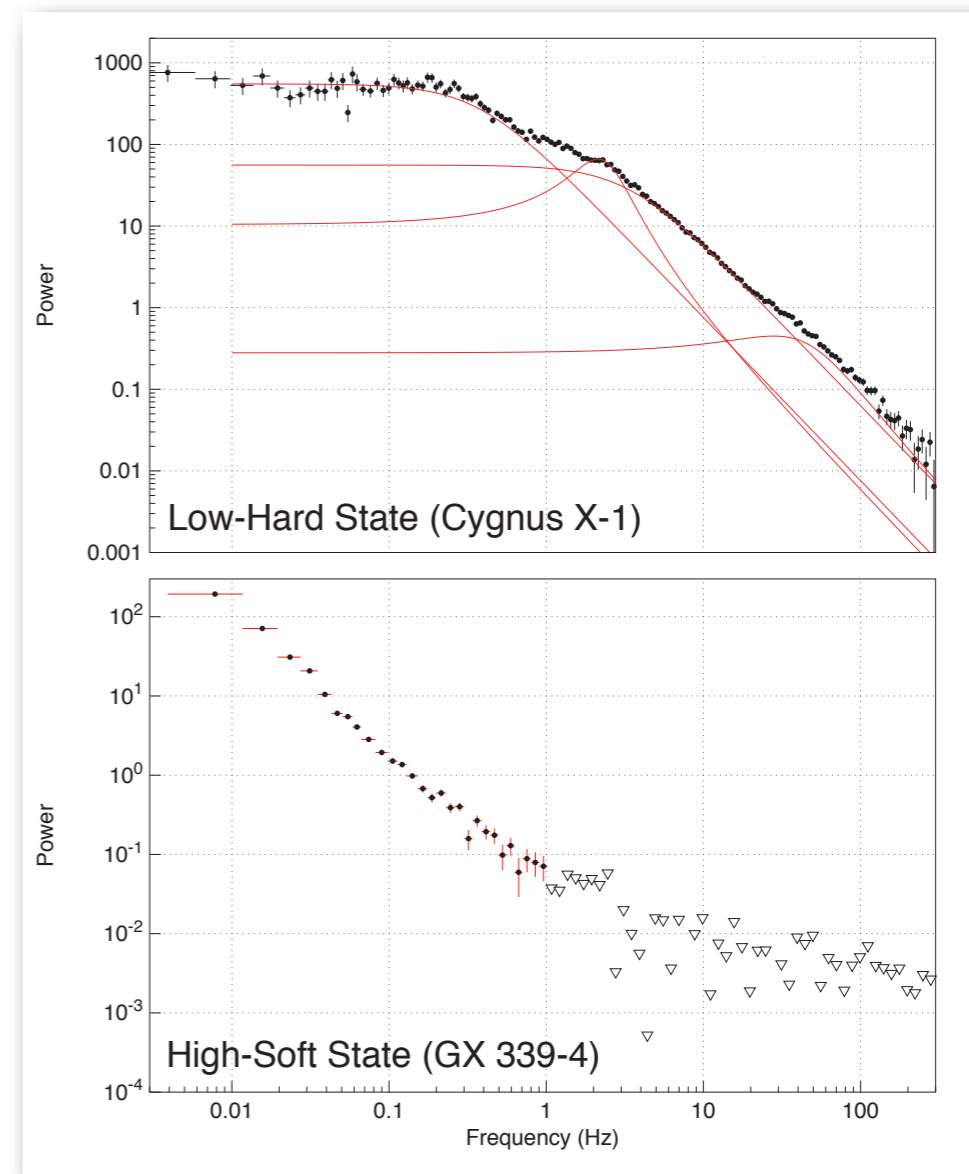
How do you go from one to the other?

Spectra



Grove et al. (1998)

Timing



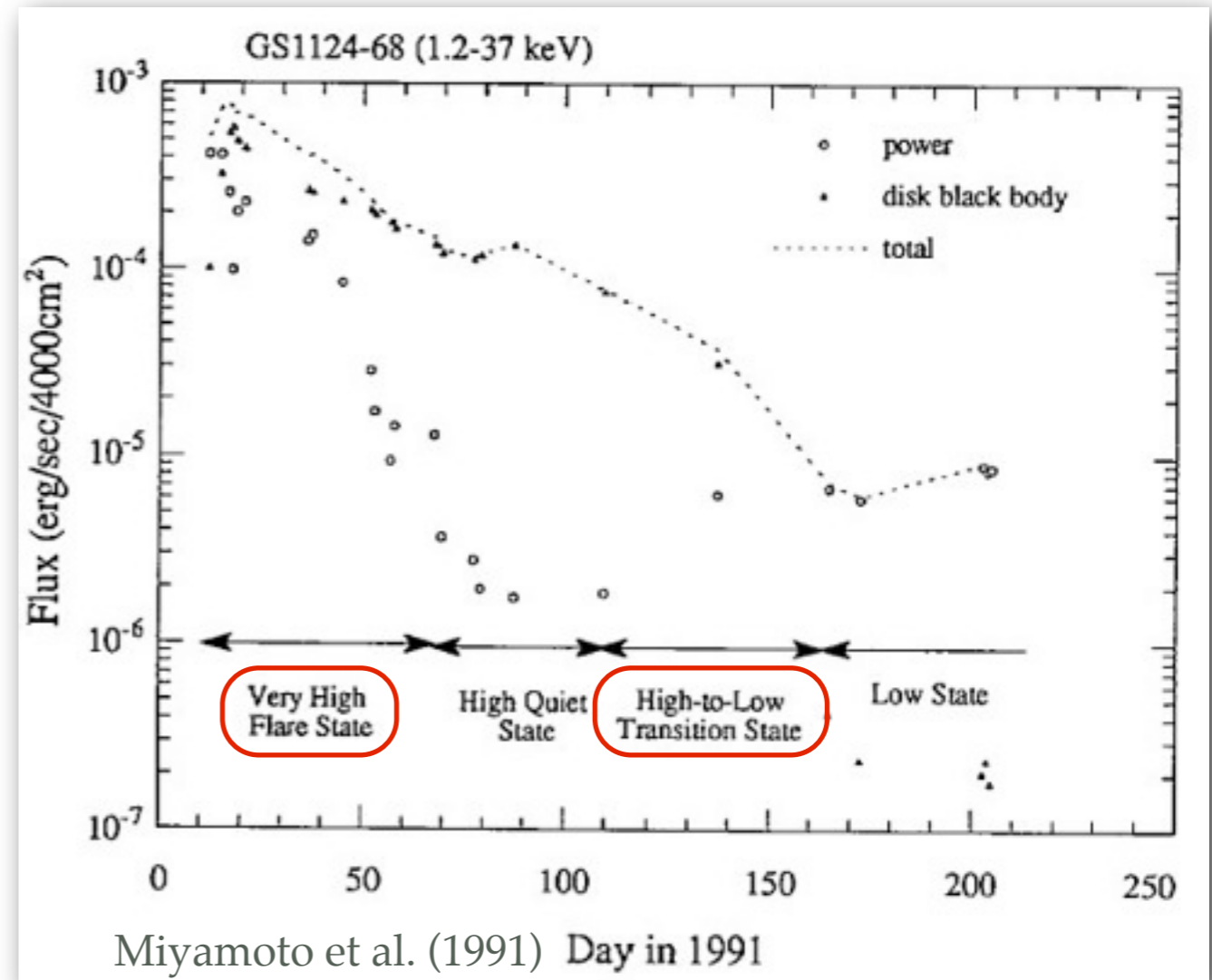
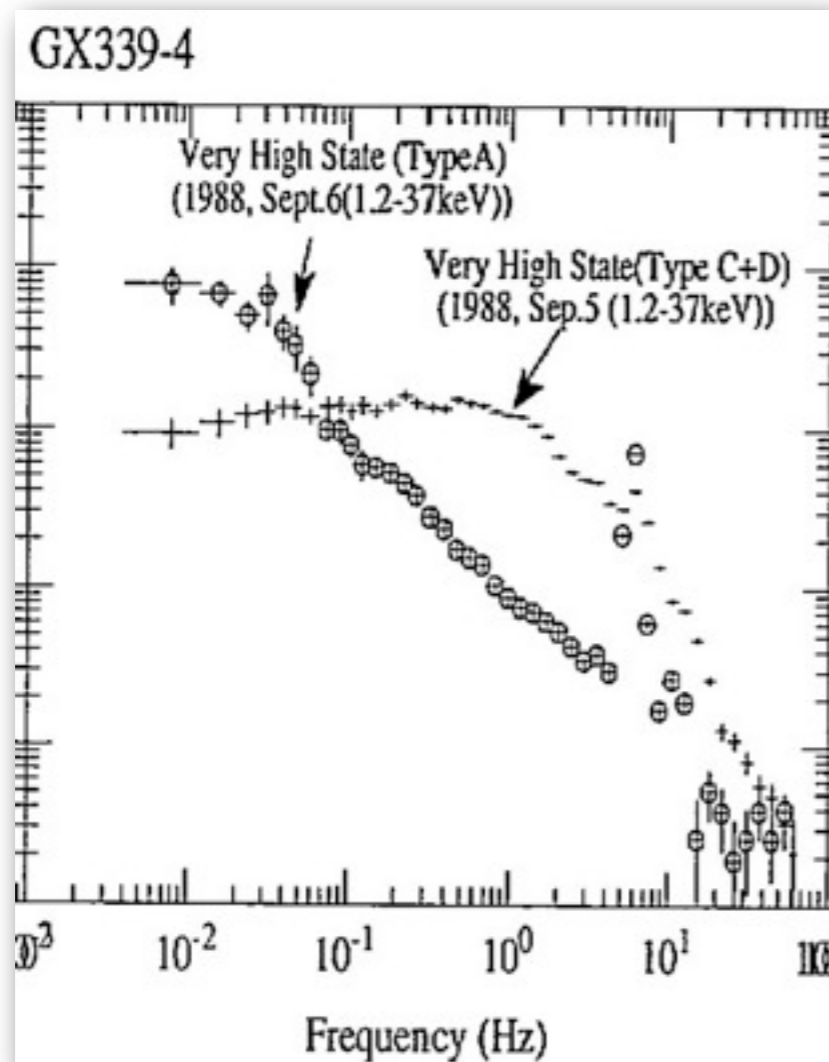
Belloni (2010)

Lack of sources: GINGA



- More sources (transients), more states
- Very High State - Intermediate

Intermediate energy spectrum

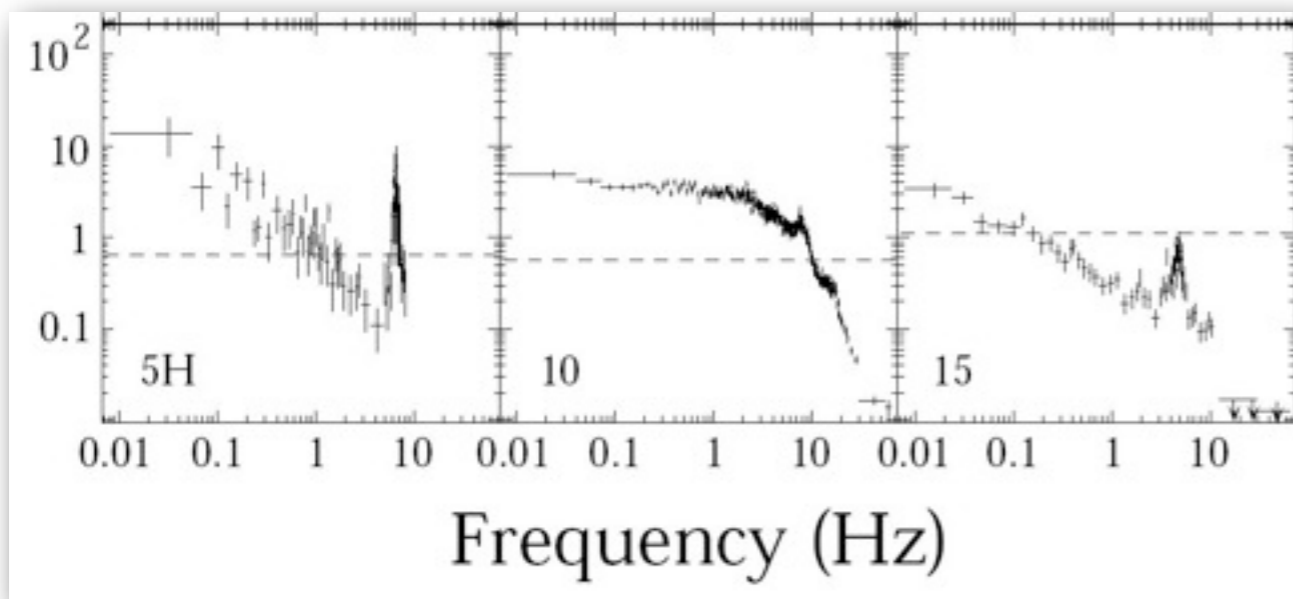


Miyamoto et al. (1991) Day in 1991

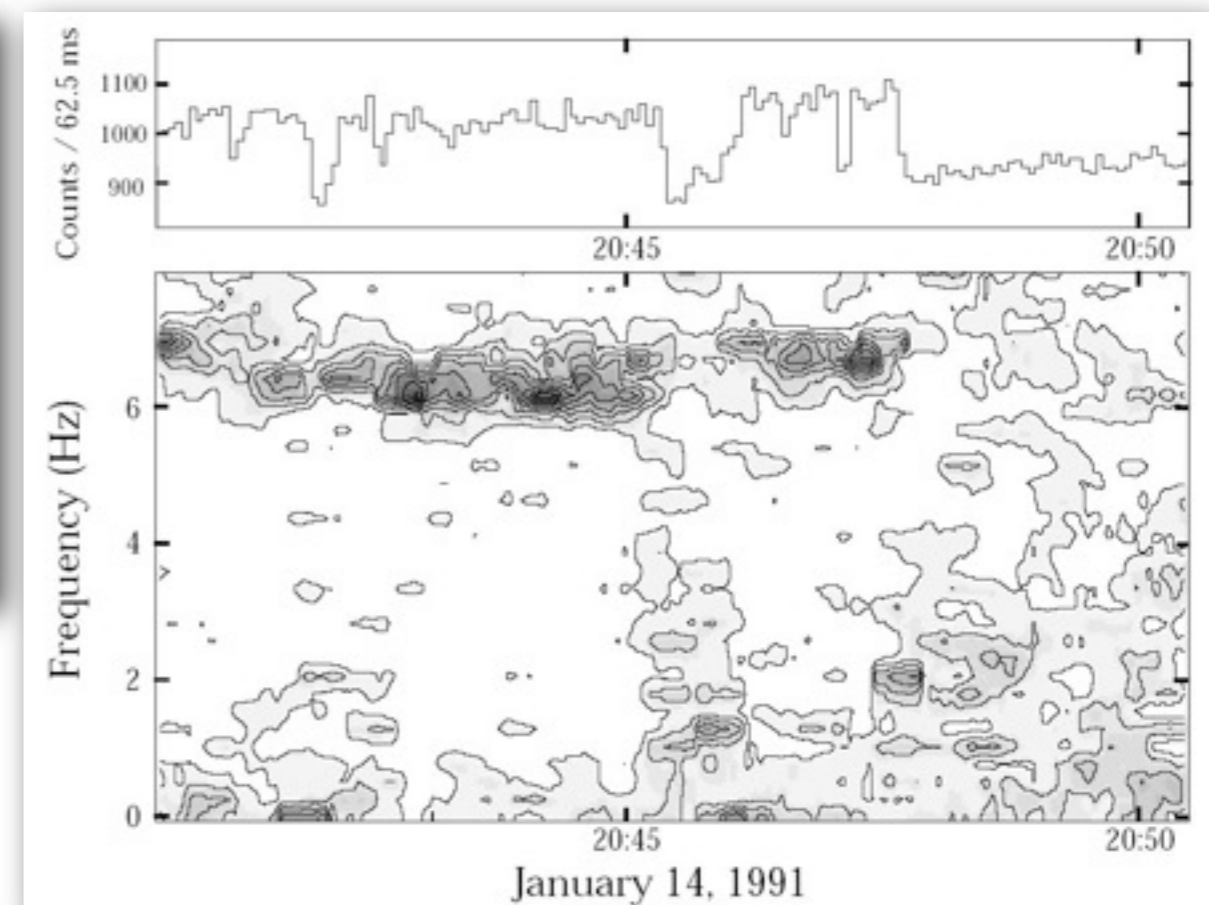
Interesting timing (finally)



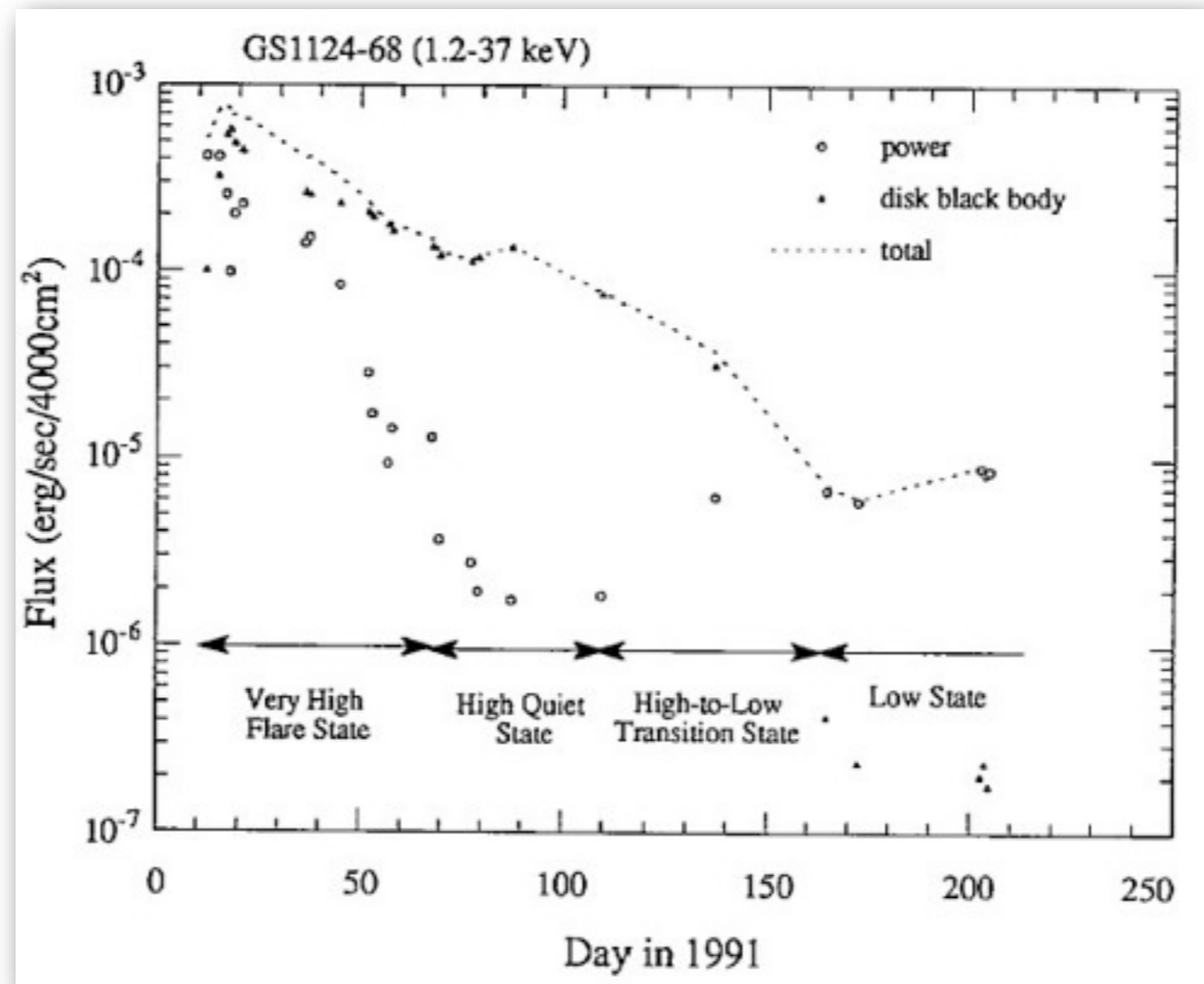
- Two flavors of QPOs?
- Unfortunately, the coverage was not enough



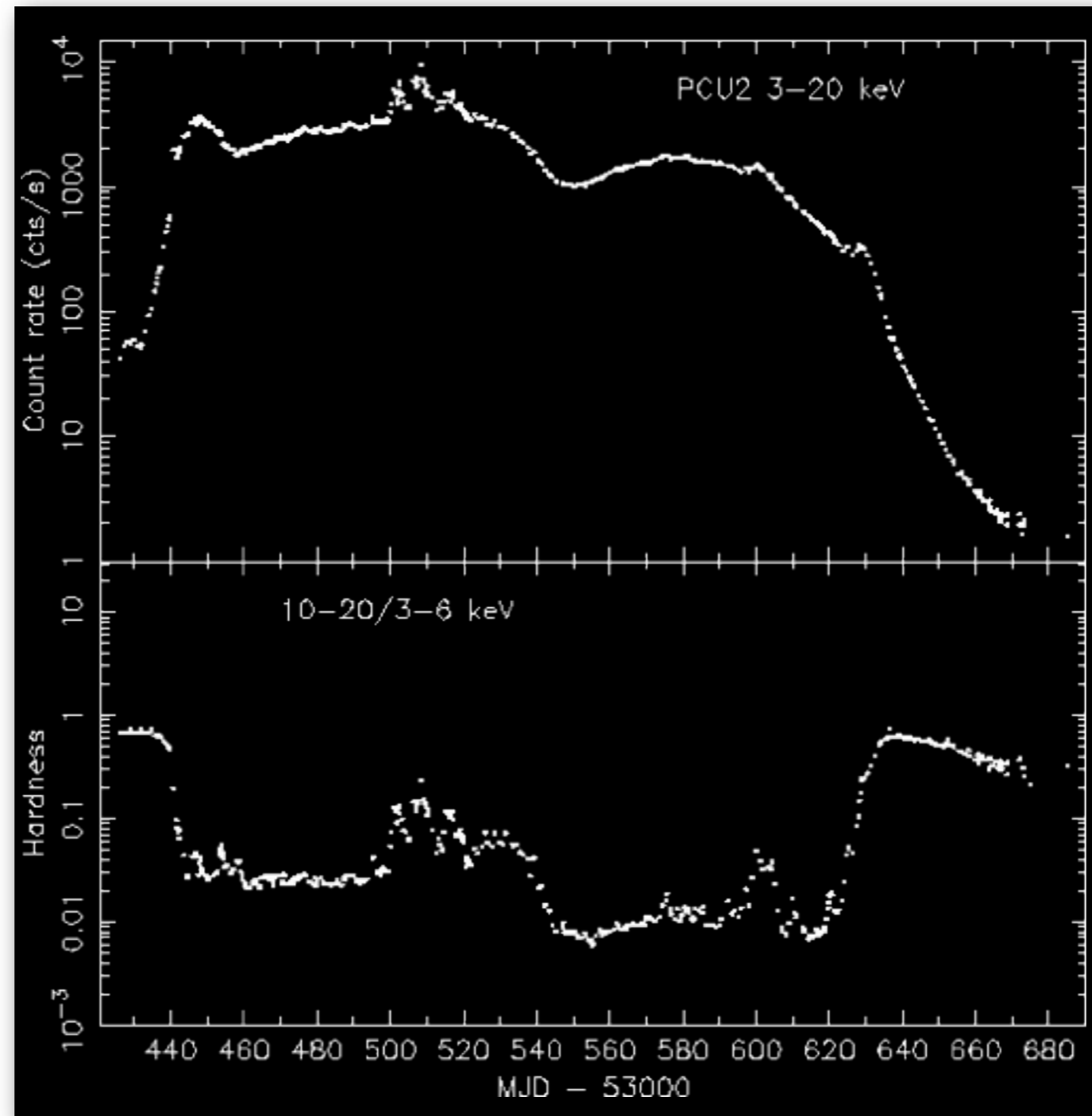
Takizawa et al. (1997)



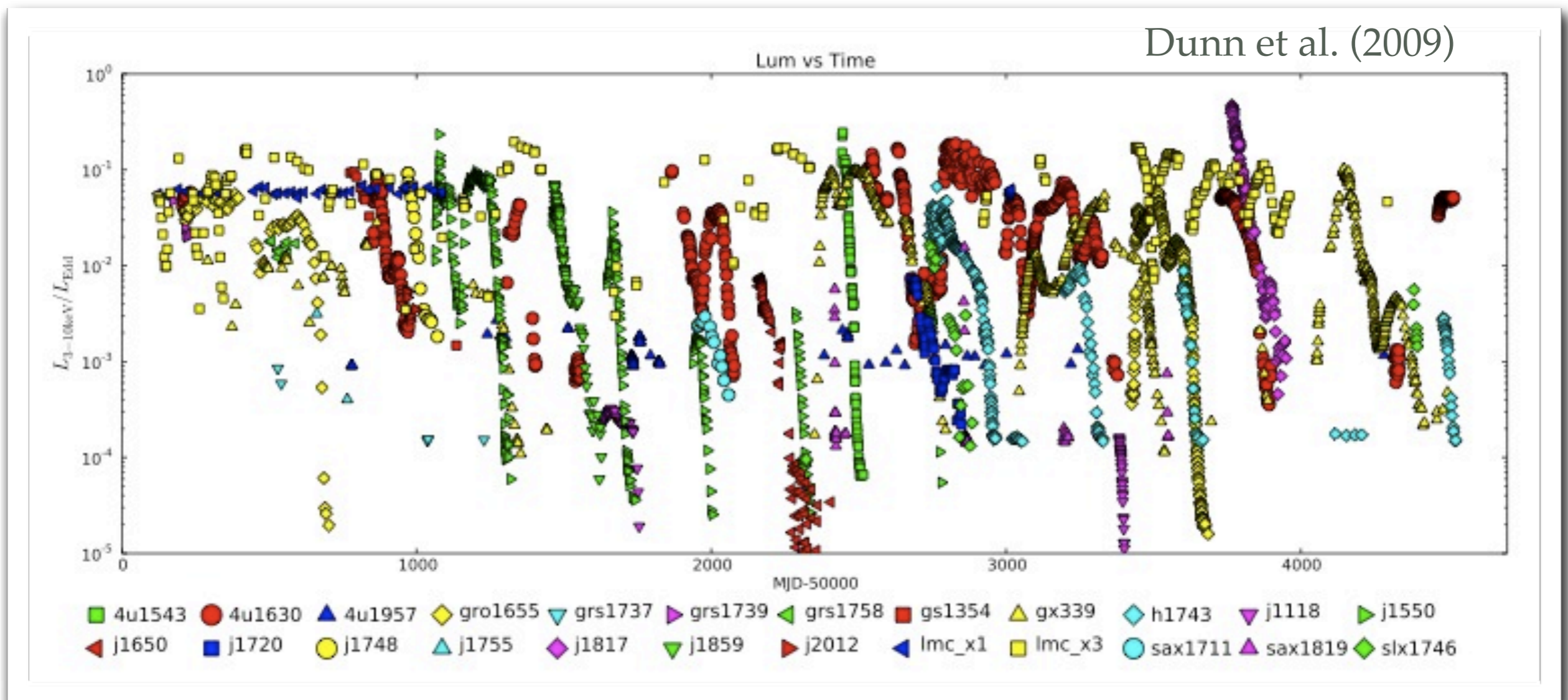
Lack of coverage: RXTE



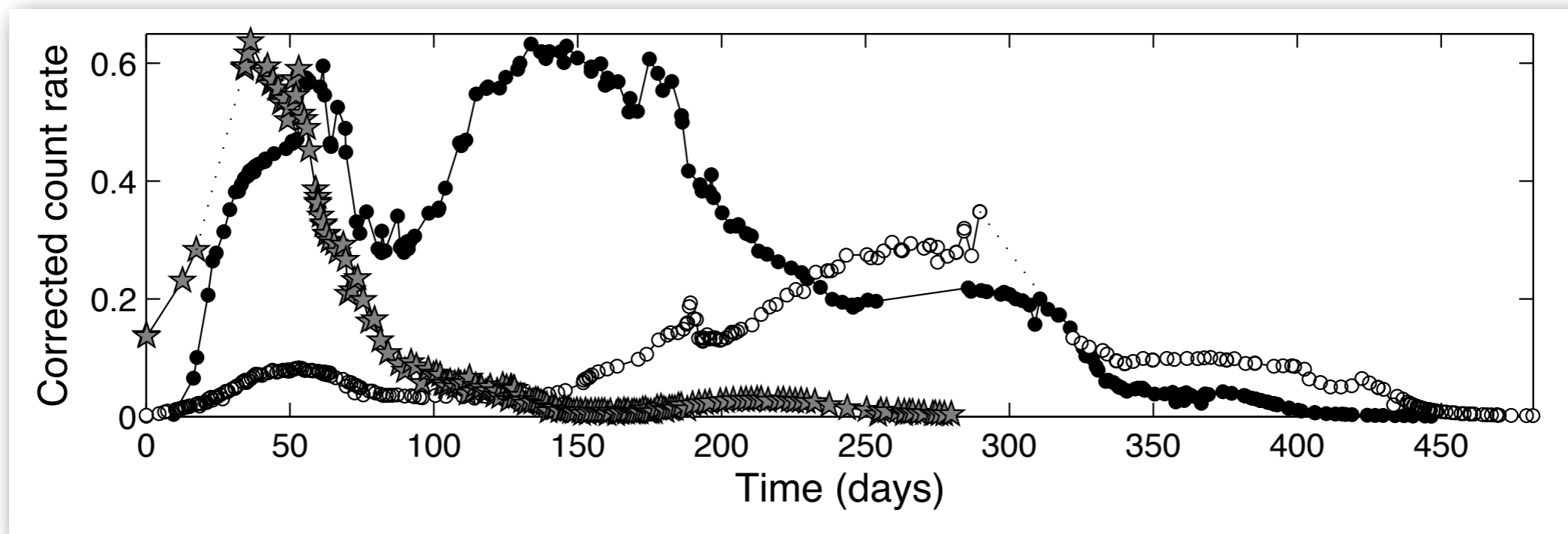
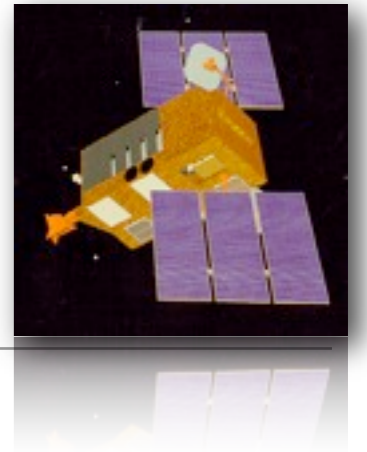
Lack of coverage: RXTE



Complete RXTE dataset on BHT

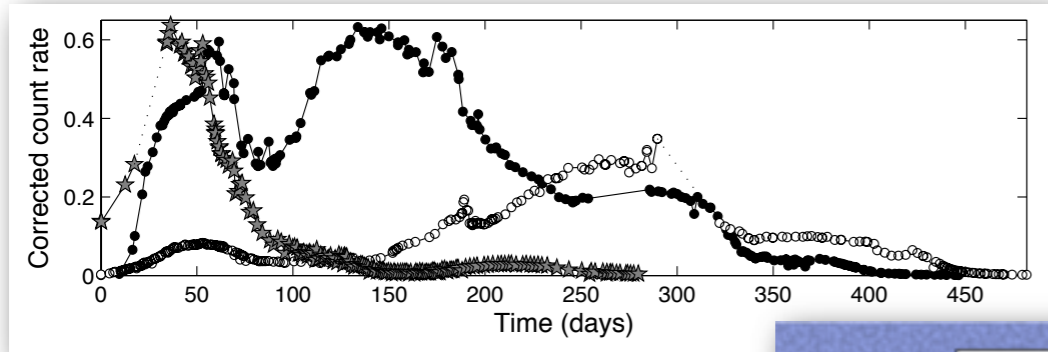


Time evolution is apparently intractable

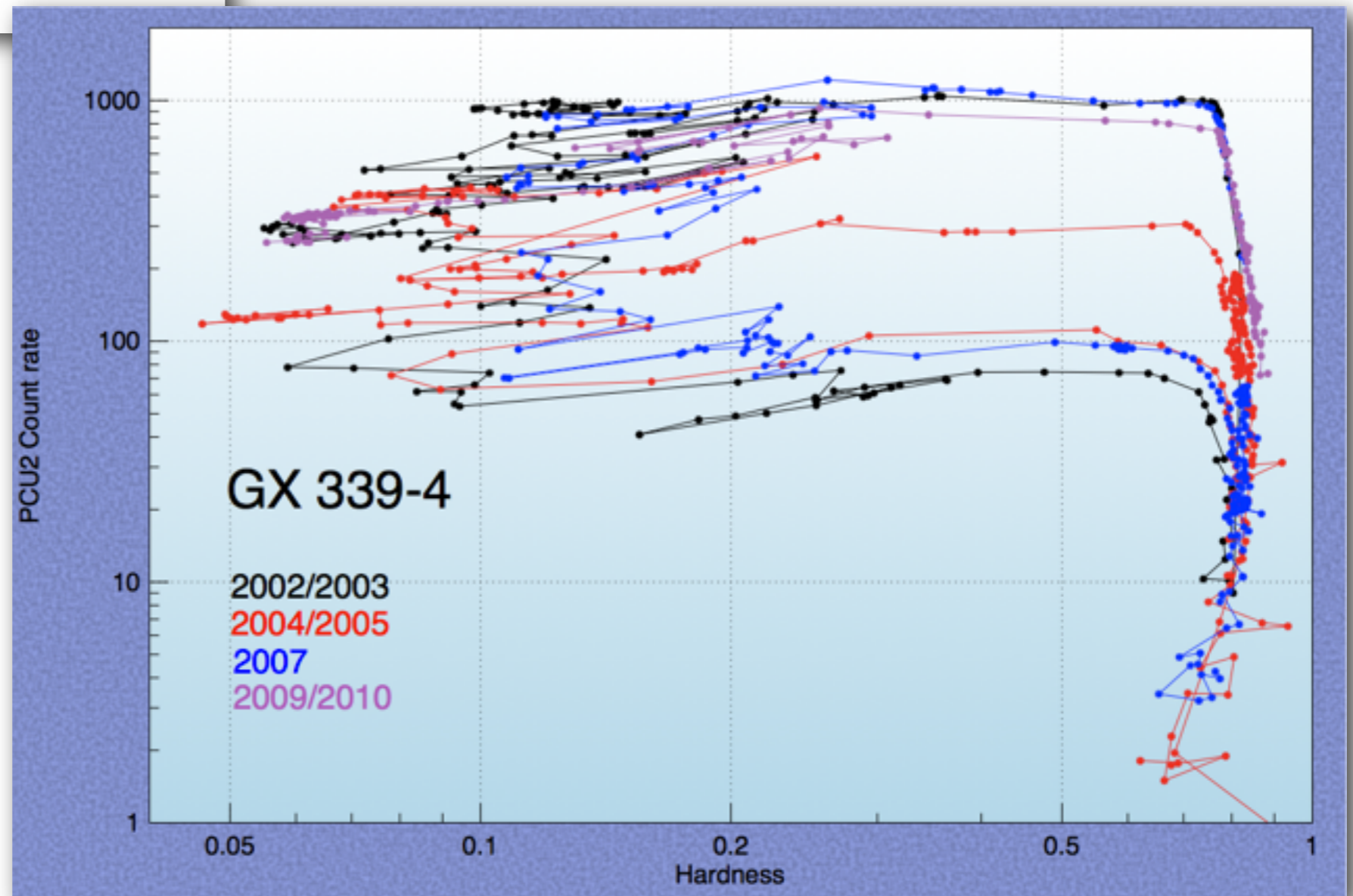


Belloni (2010)

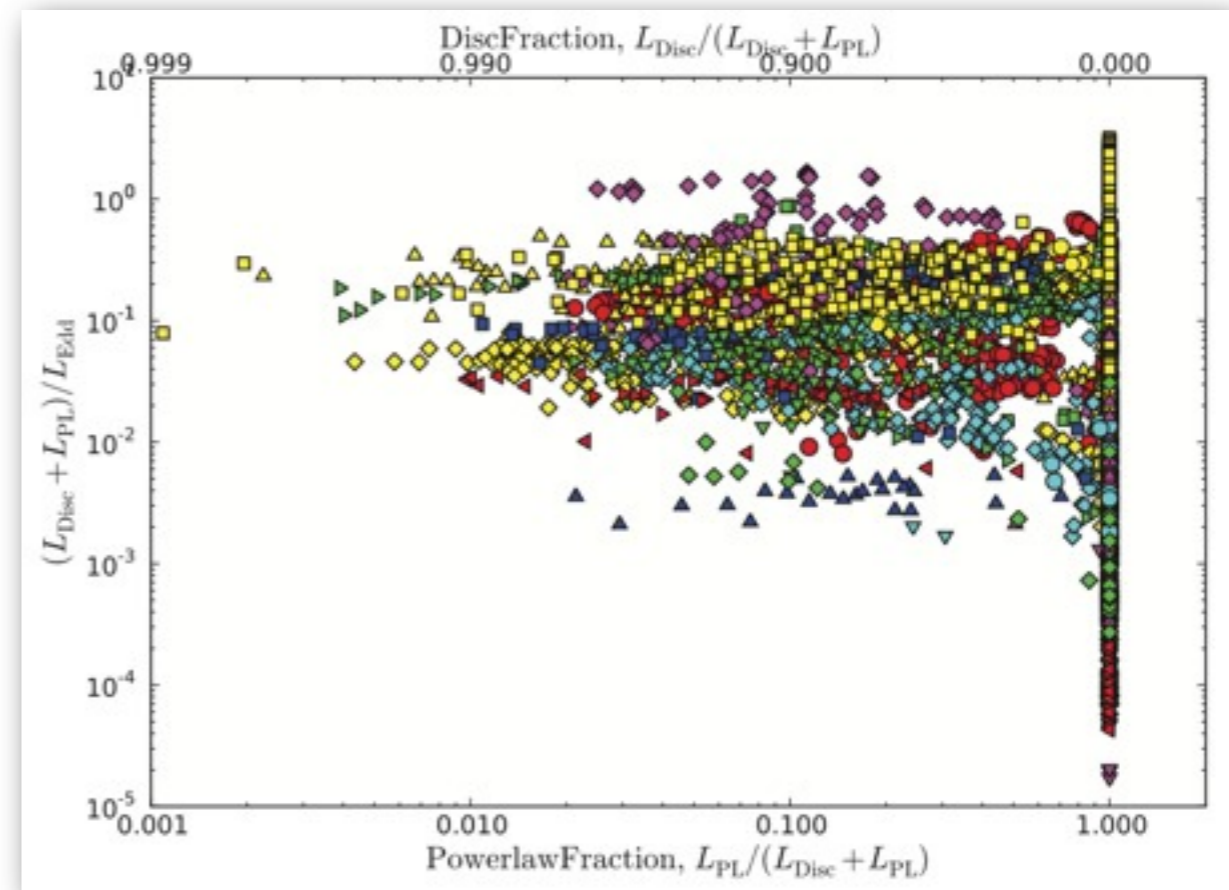
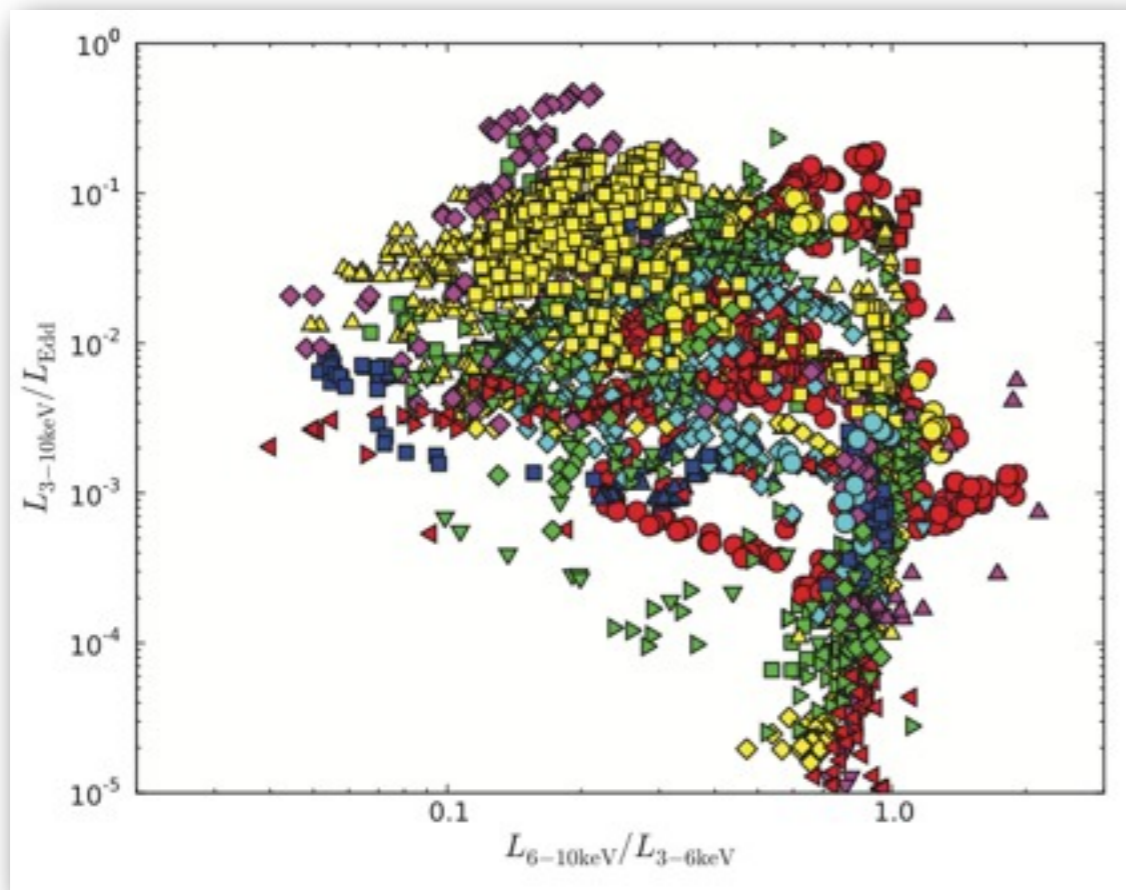
Time evolution is apparently intractable



Belloni (2010)

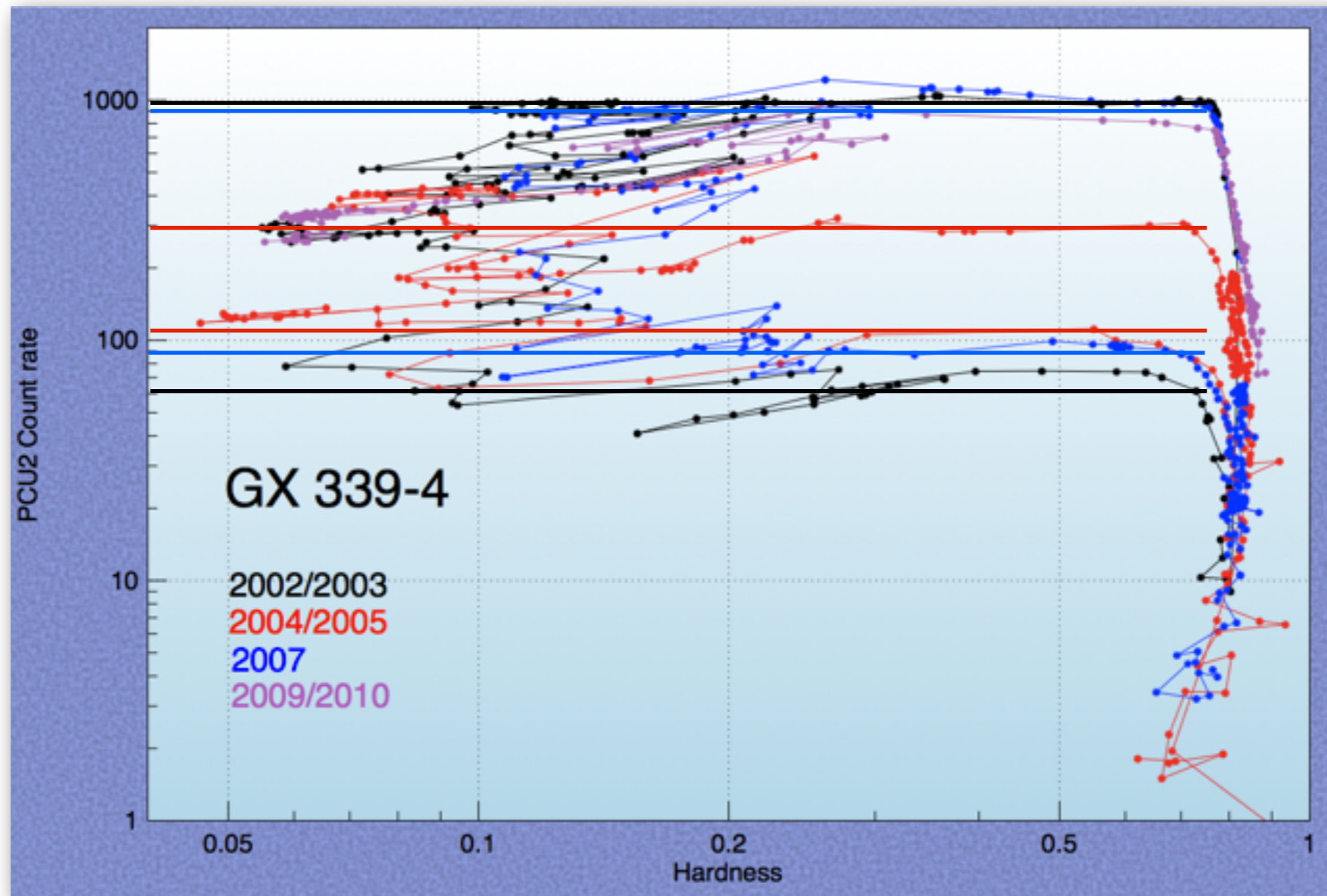


Model independent (as it must be)

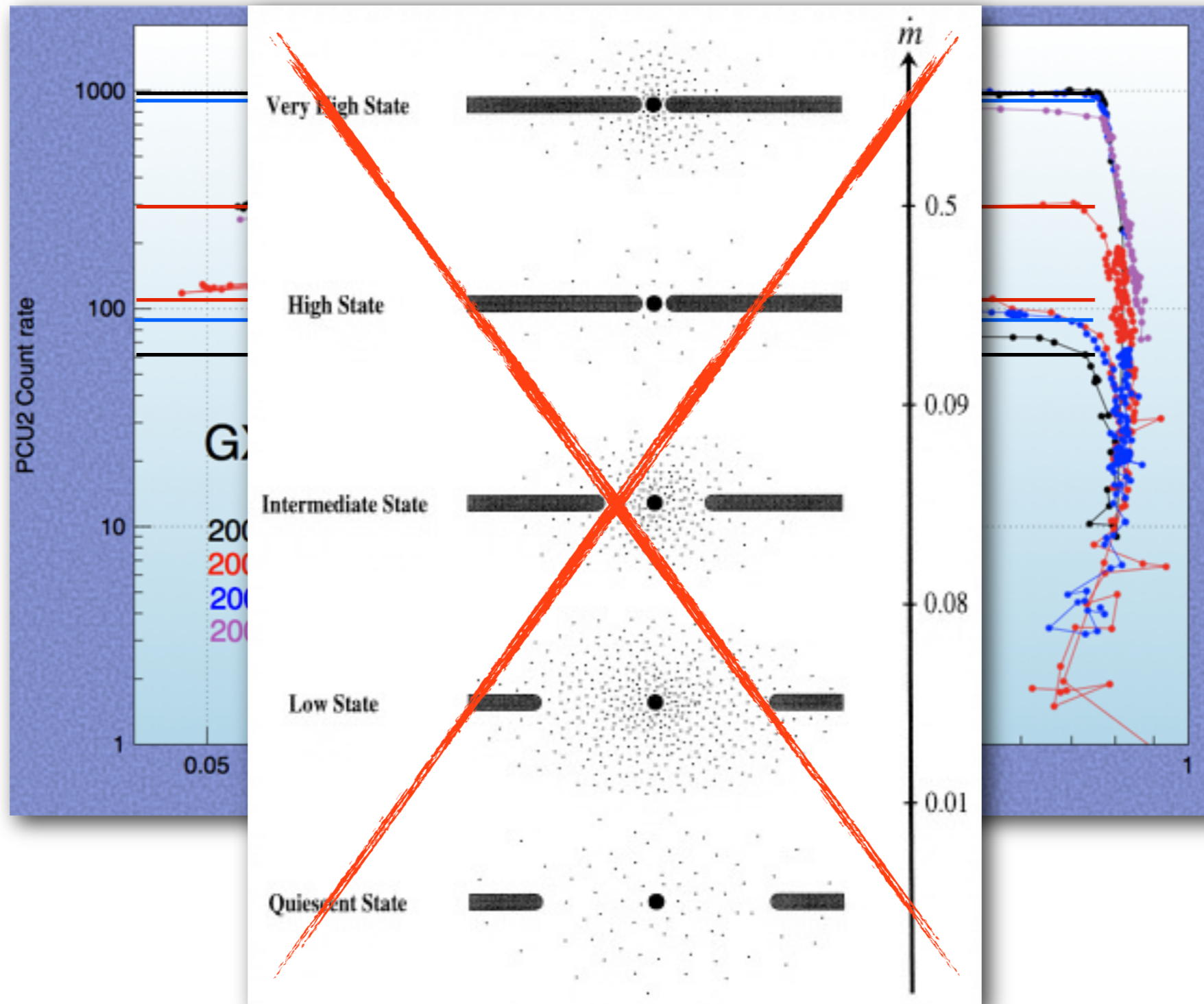


Dunn et al. (2010)

Hysteresis effect



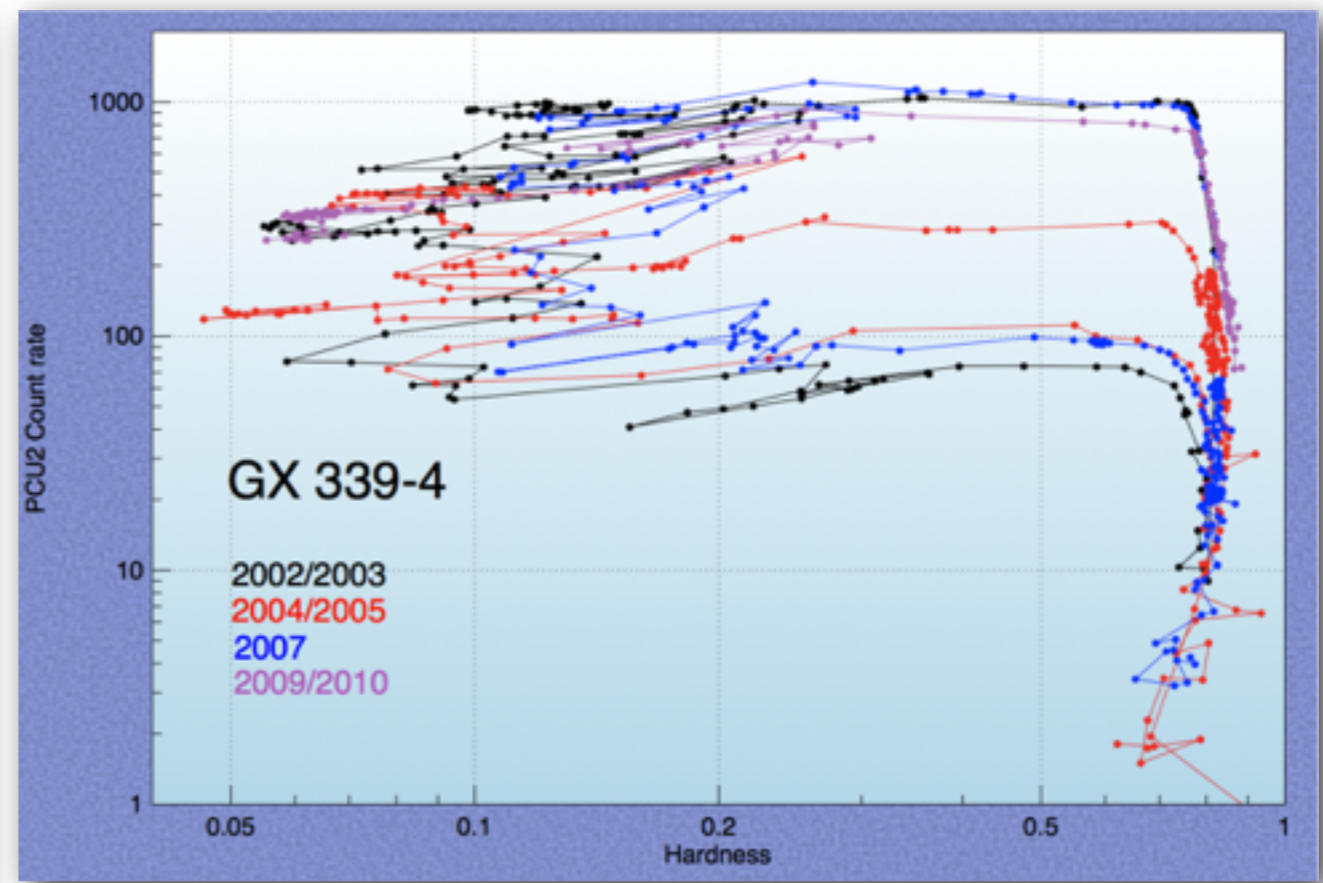
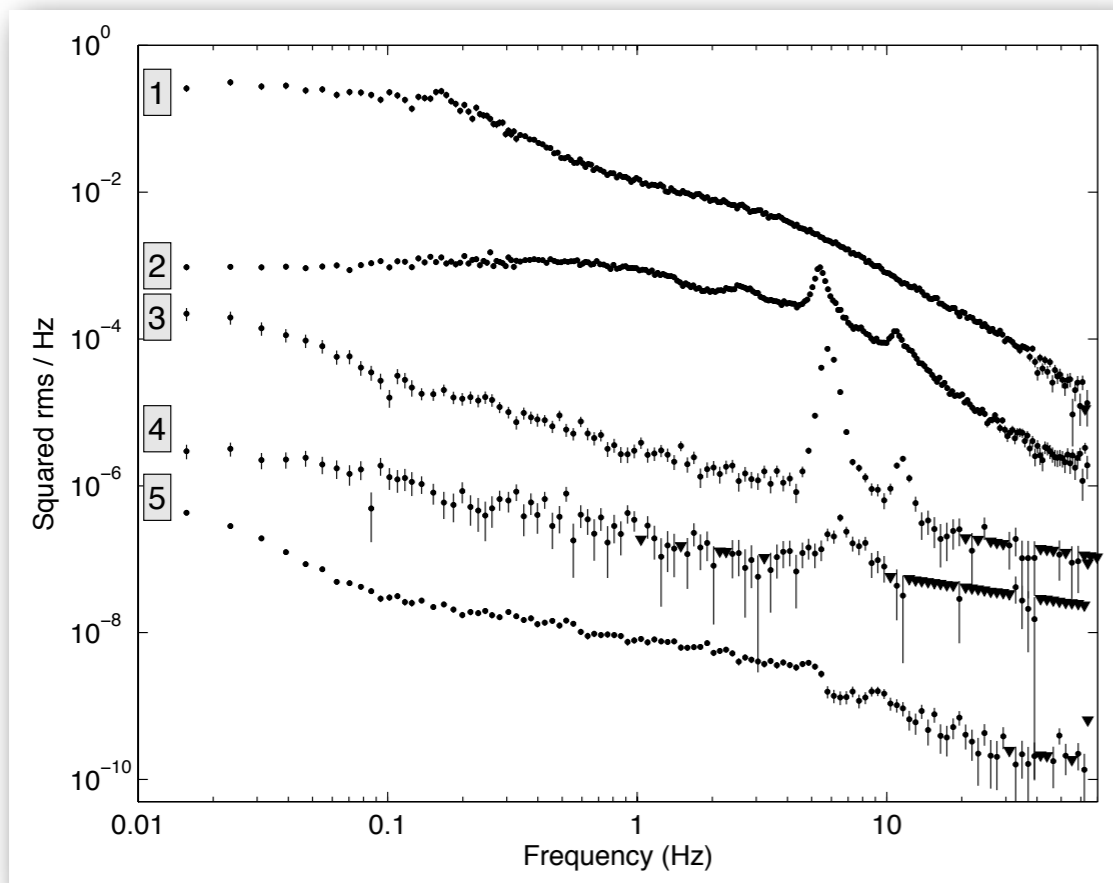
Hysteresis effect



Outburst evolution

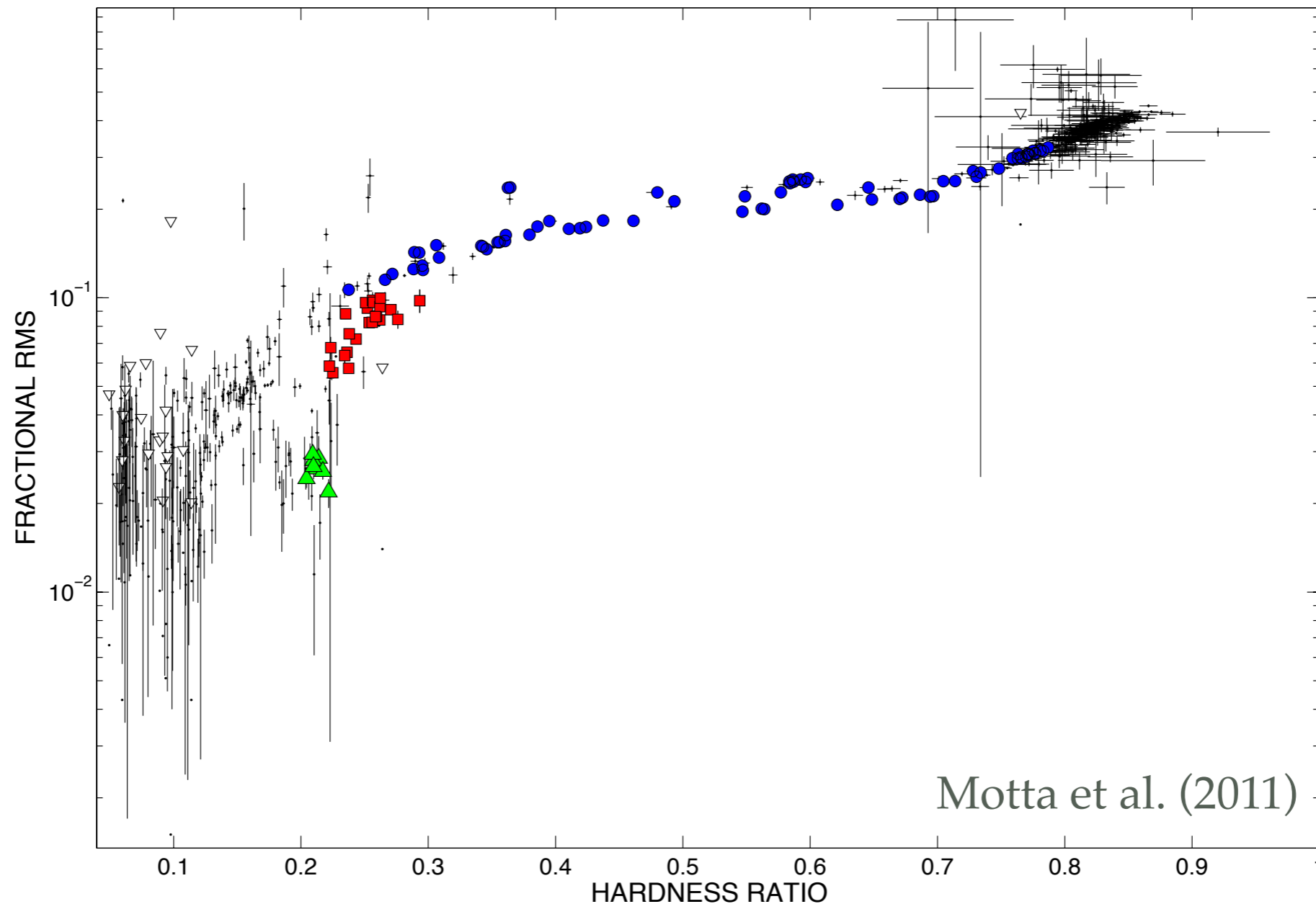
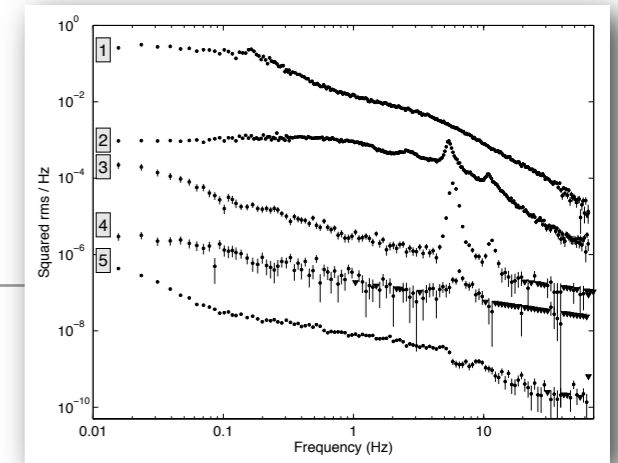


- So there is a nice evolution: what about states?
- Need to see sharp changes
- Fast time variability is and must be a guide



A look at timing features

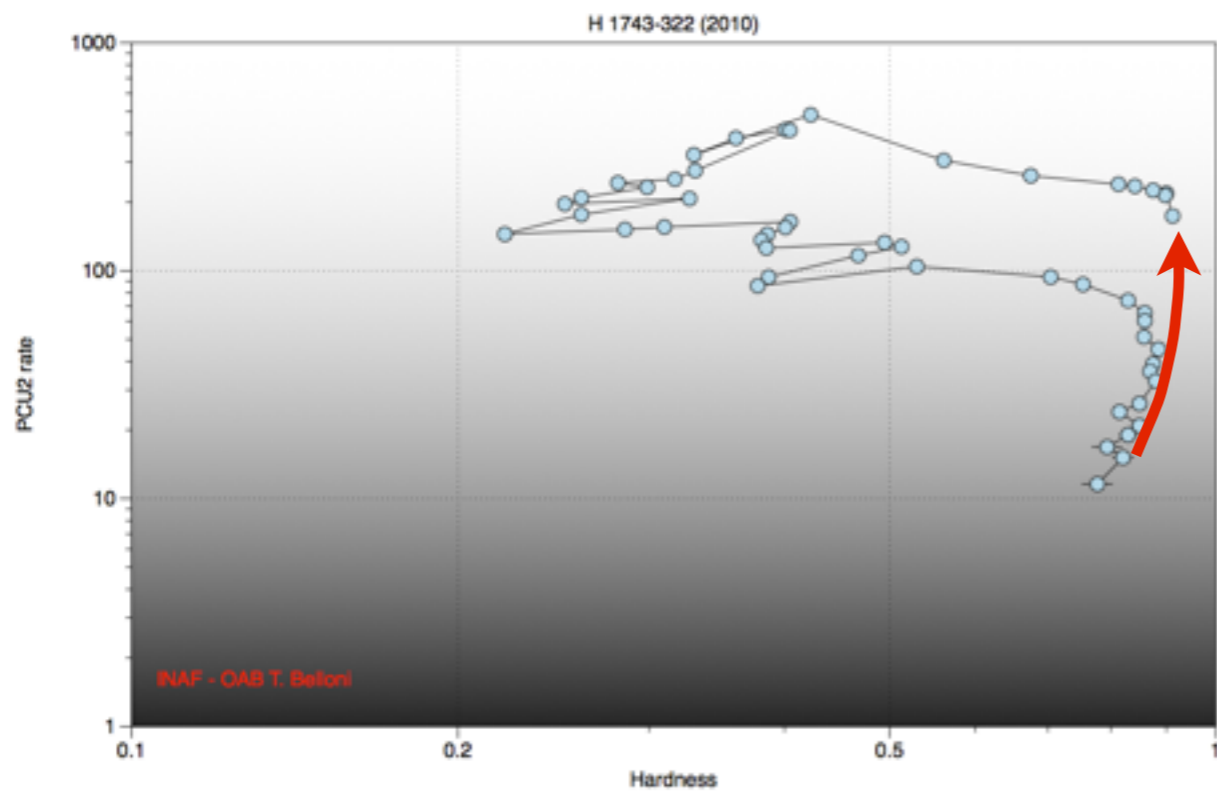
- A second diagram: Hardness-Rms (HRD)



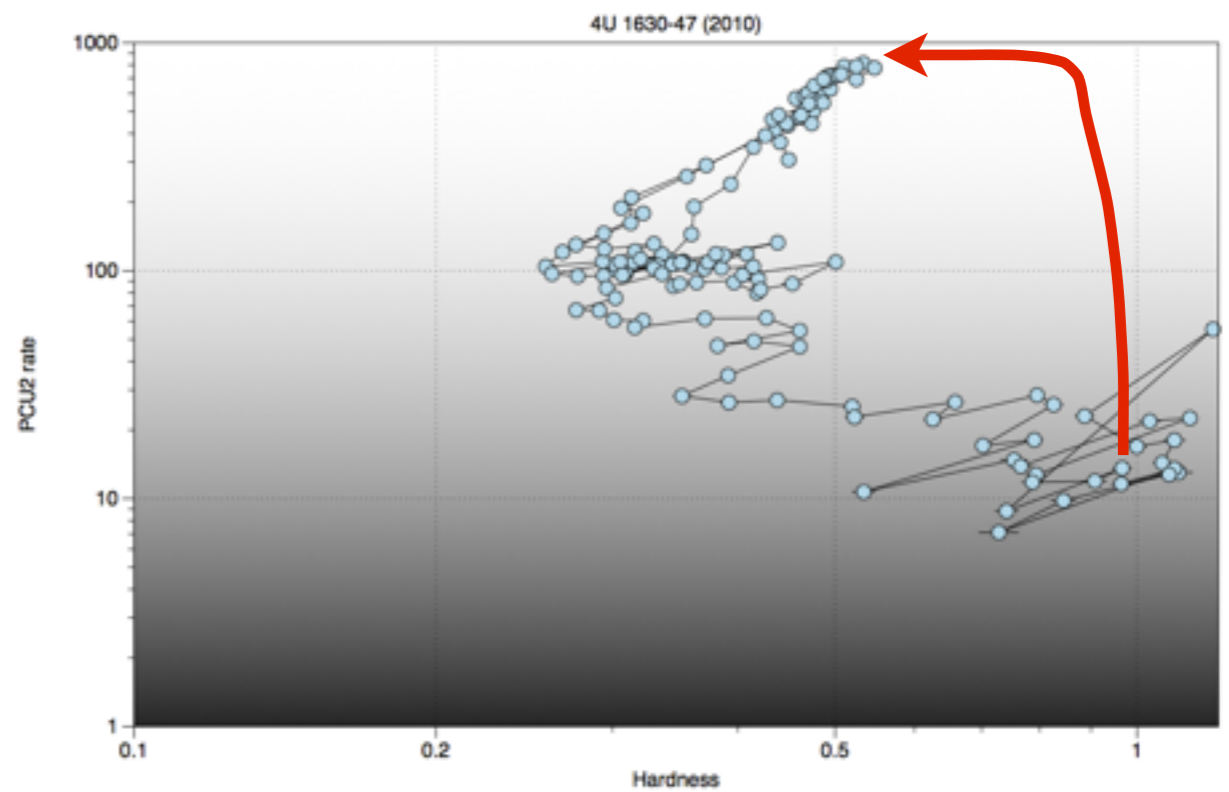
Motta et al. (2011)

Time evolution

- Some sources behave well, some do not - states are the same
- First branch(es) missing - fast?



H 1743-322

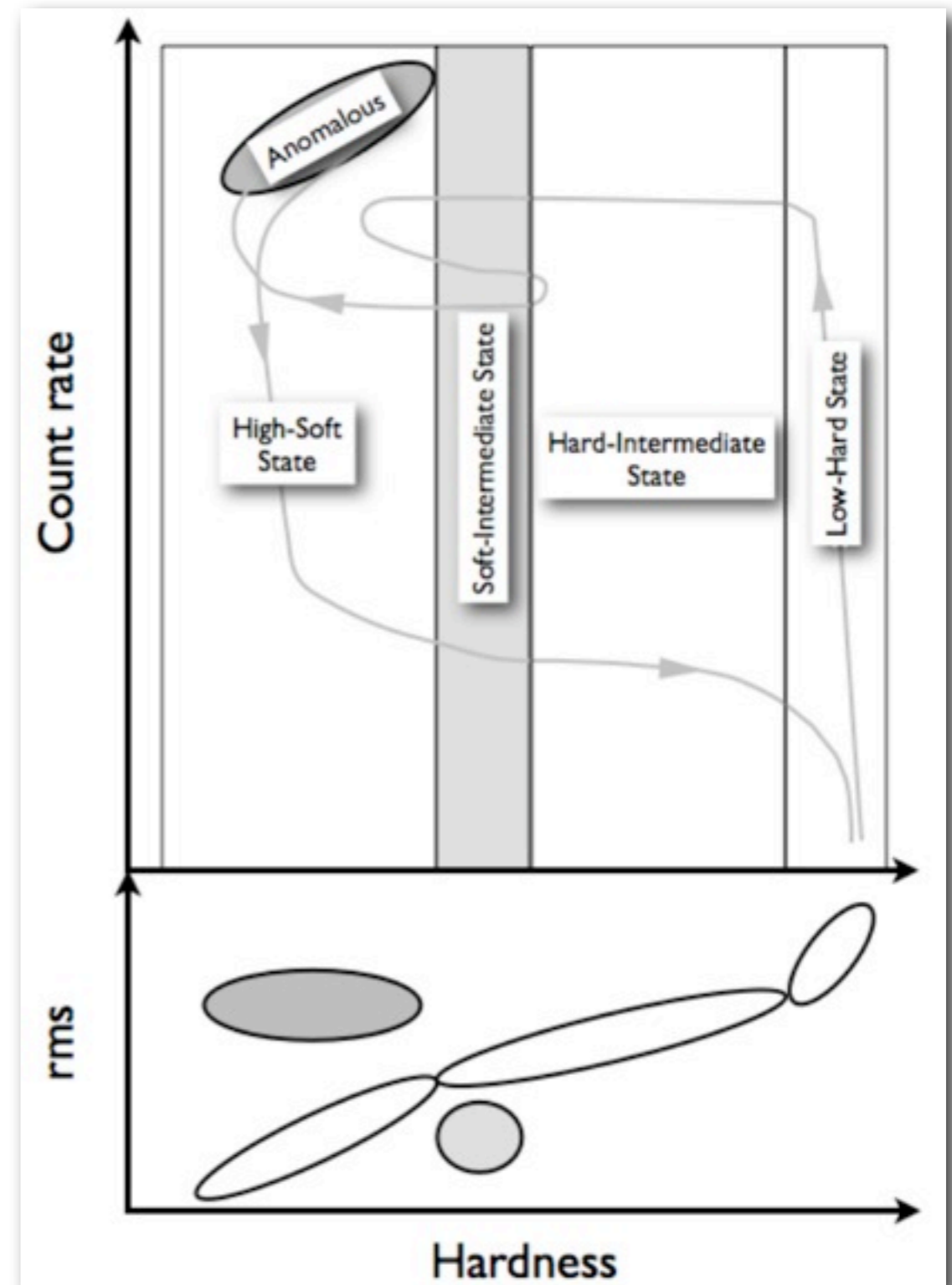


4U 1630-47

A state classification

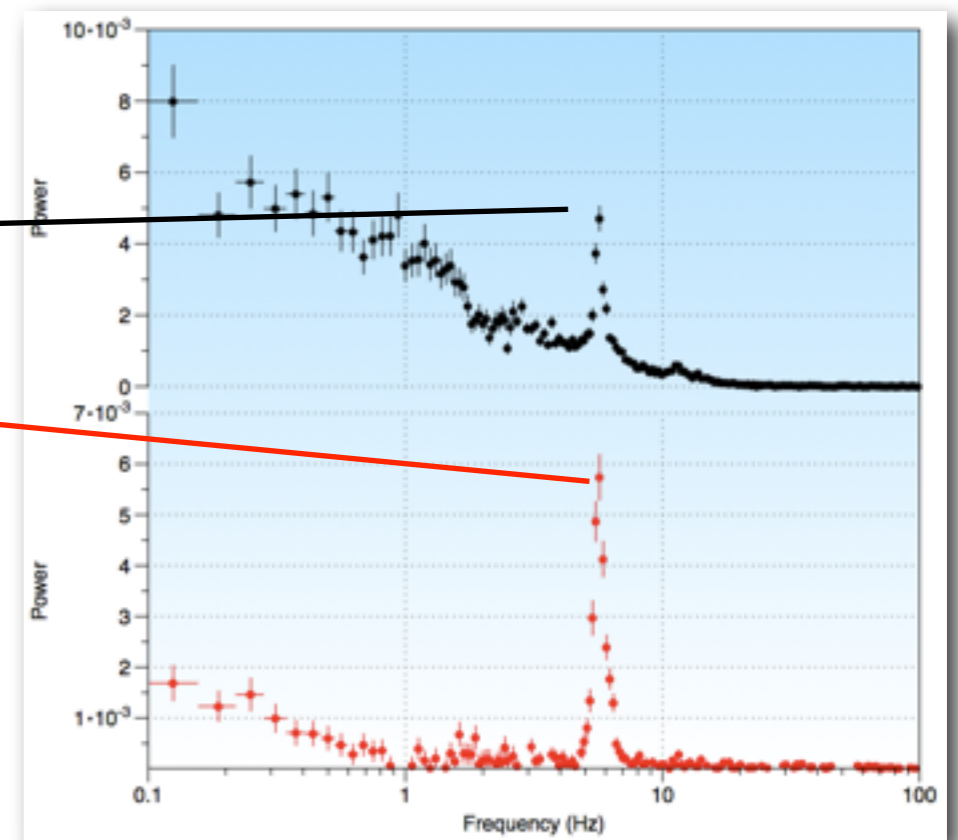
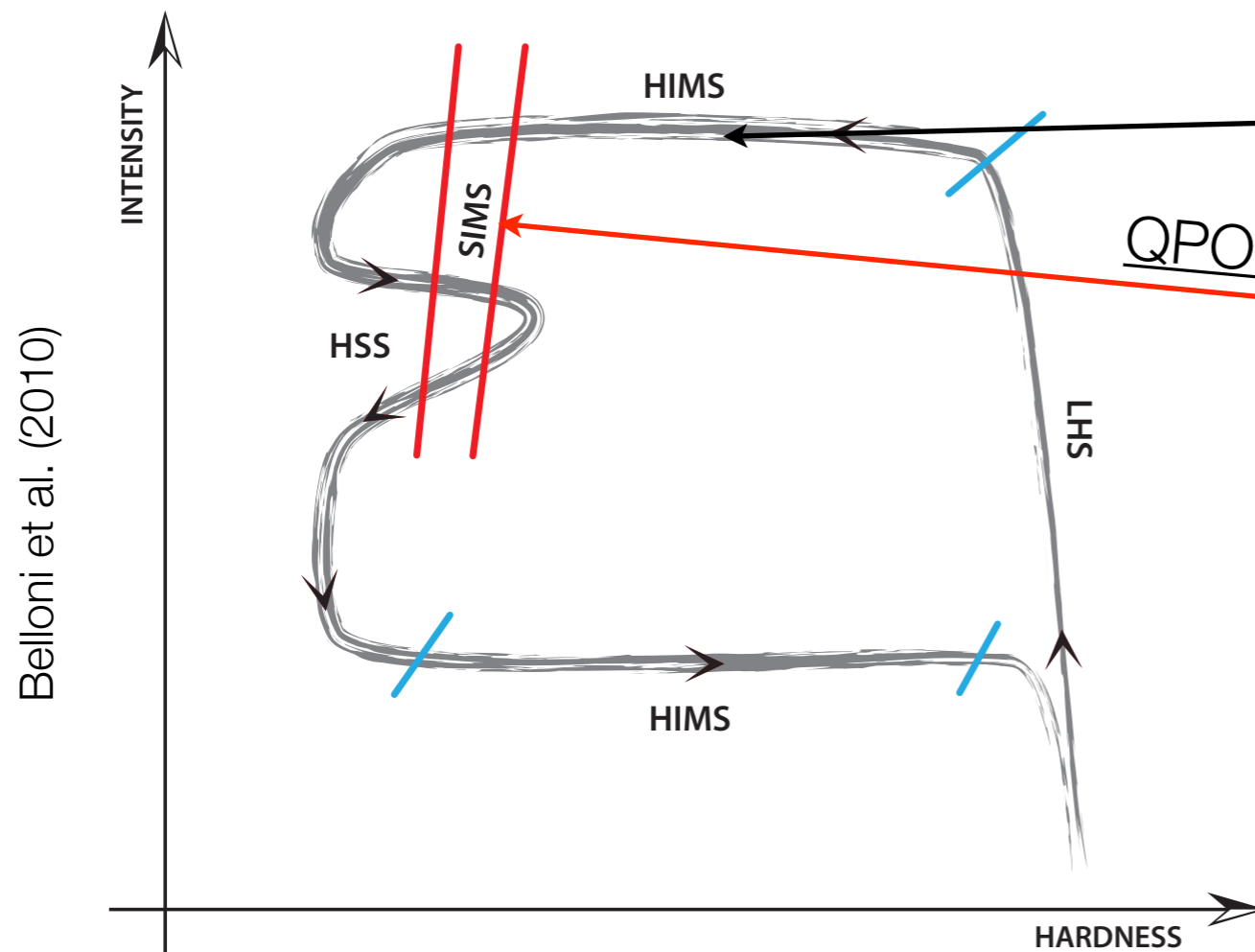
Belloni (2010)

- The spectral evolution is continuous
- Timing changes define states
- Hard State: strong variability
- HIMS: C-QPO + noise
- SIMS: AB-QPO + PL
- HSS: weak variability



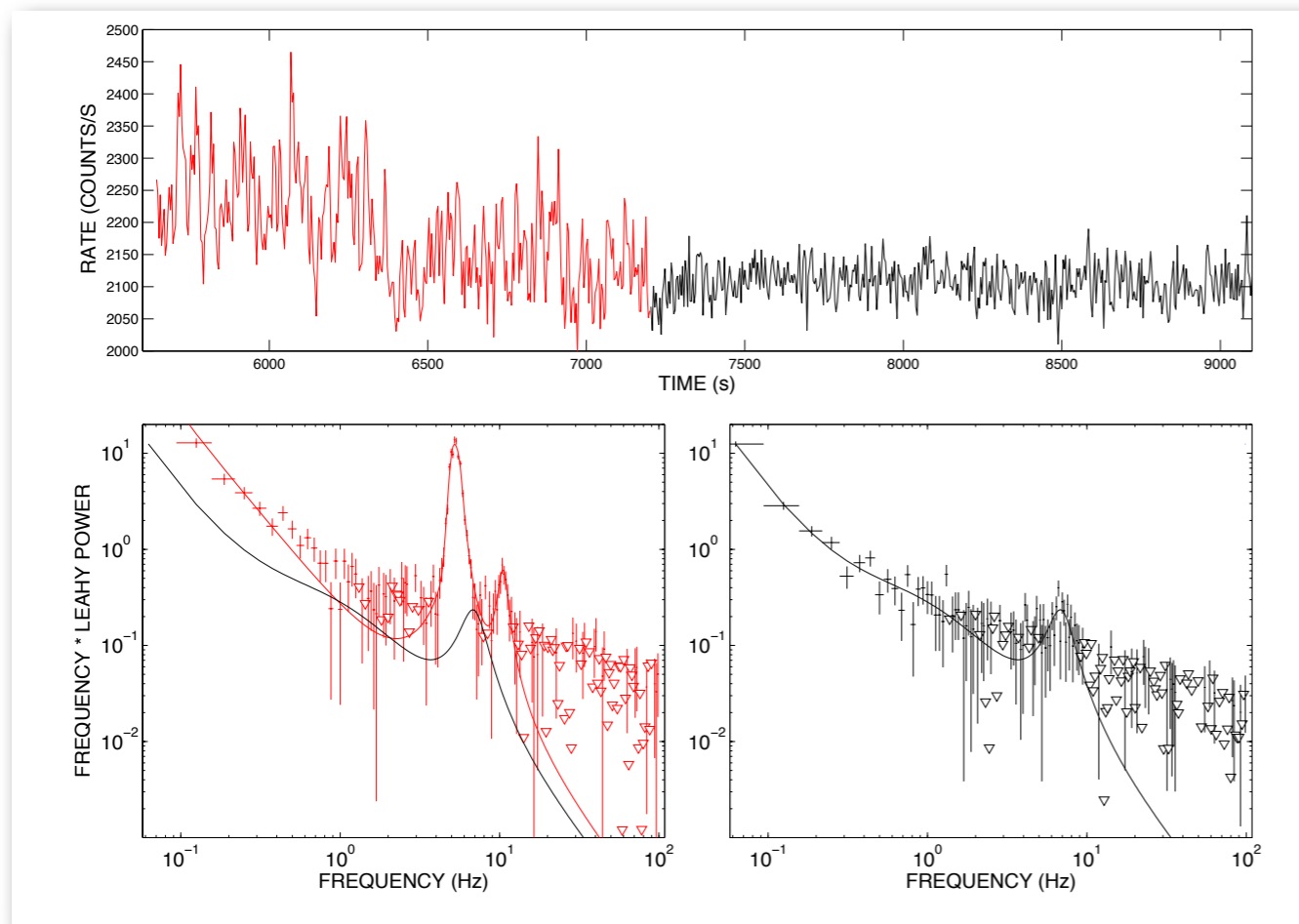
The QPO transition

- The HIMS-SIMS transition is the sharpest and most crucial
- Little spectral changes below 20 keV

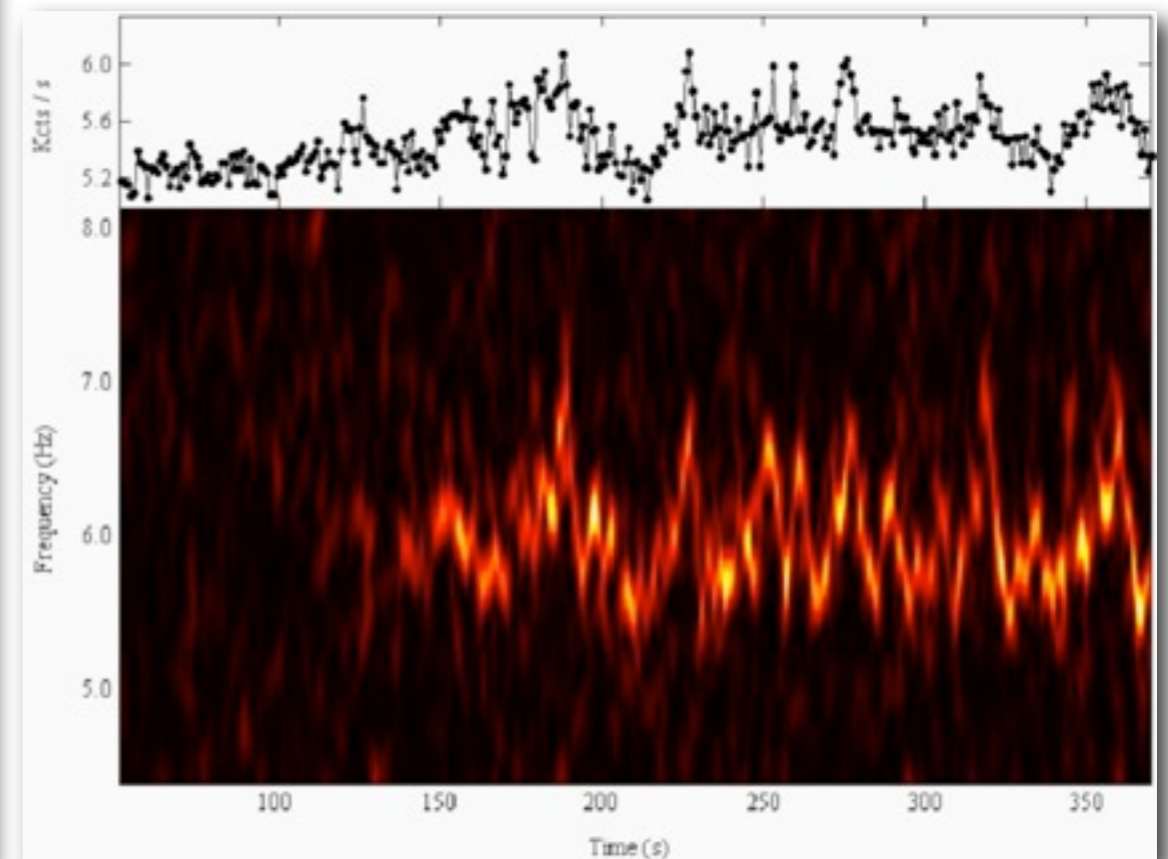


The QPO transition: FAST!

- Sharp changes in a matter of seconds



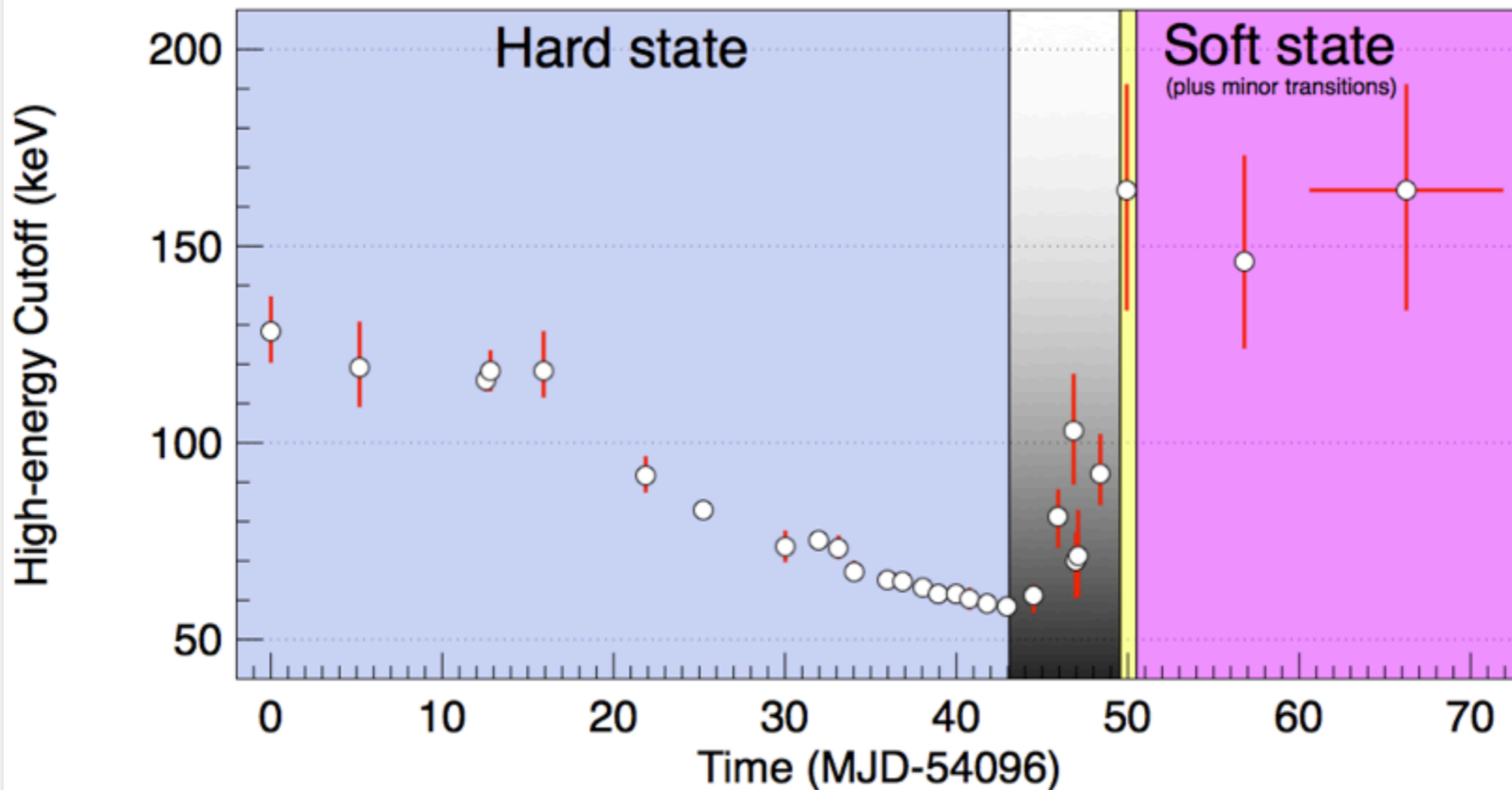
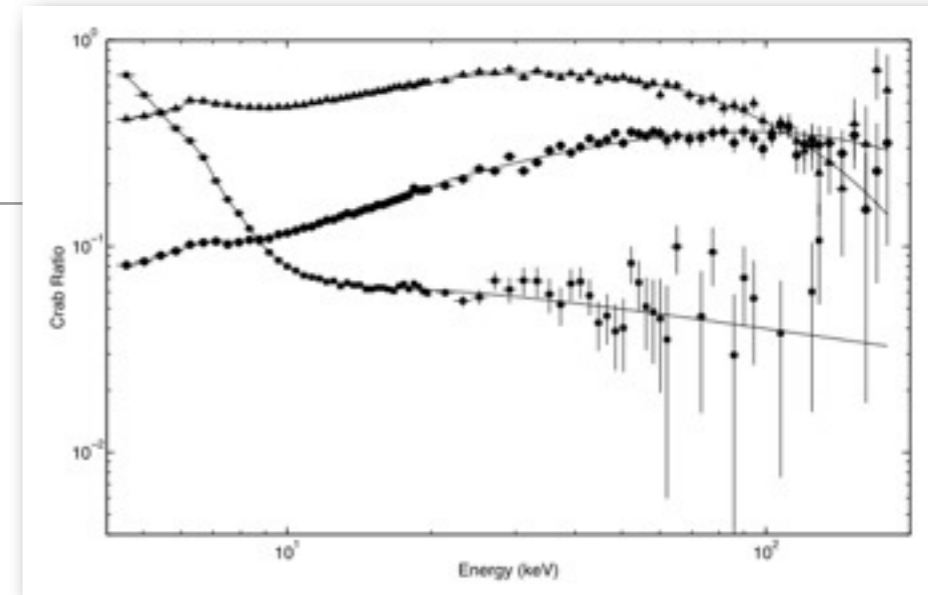
Motta et al. (2011)



Nespoli et al. (2003)

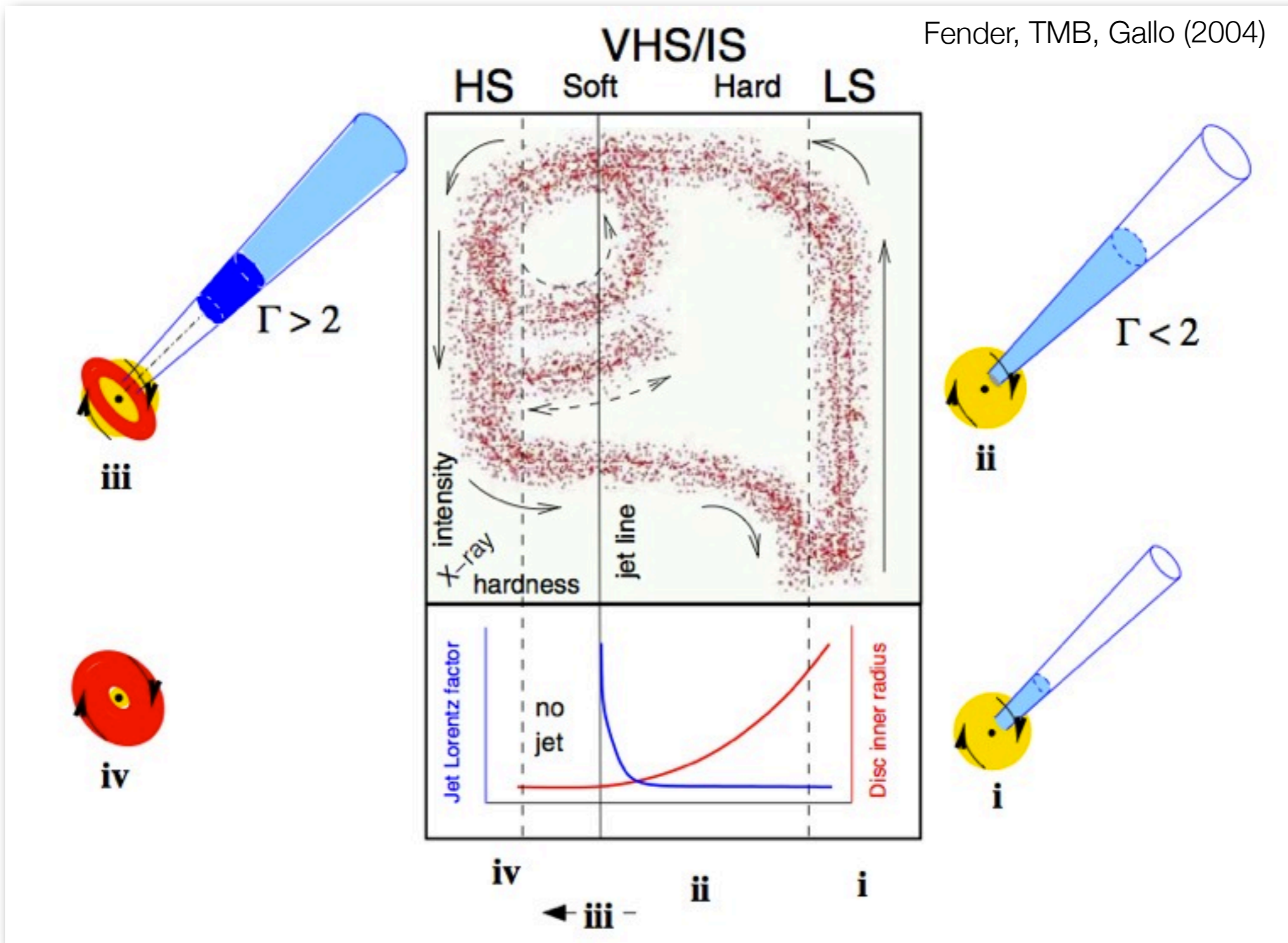
Spectral changes

- Above 20 keV, a different picture
- Strong cutoff changes



Motta, TMB, Homan (2009)

The radio jet connection



The radio jet connection

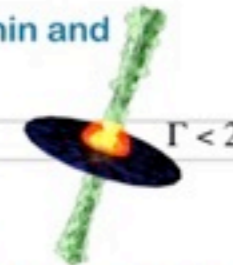
JET LINE AREA:

- 2 - 50% L_{Edd} .
- High-frequency QPOs (after).
- Type A & B QPOs (after).
- See radio ejecta (fast) each "crossing" of jet line.
- RMS drop ("The Zone") associated with ~ 0.2 Hz lowest frequency Lorentzian, close to ejecta time.



HIMS:

- Disk starts near ISCO.
- Transition starts around 2 - 50% L_{Edd} .
- Type C QPOs.
- IR drops.
- Radio starts going optically thin and variable (new ejecta?).

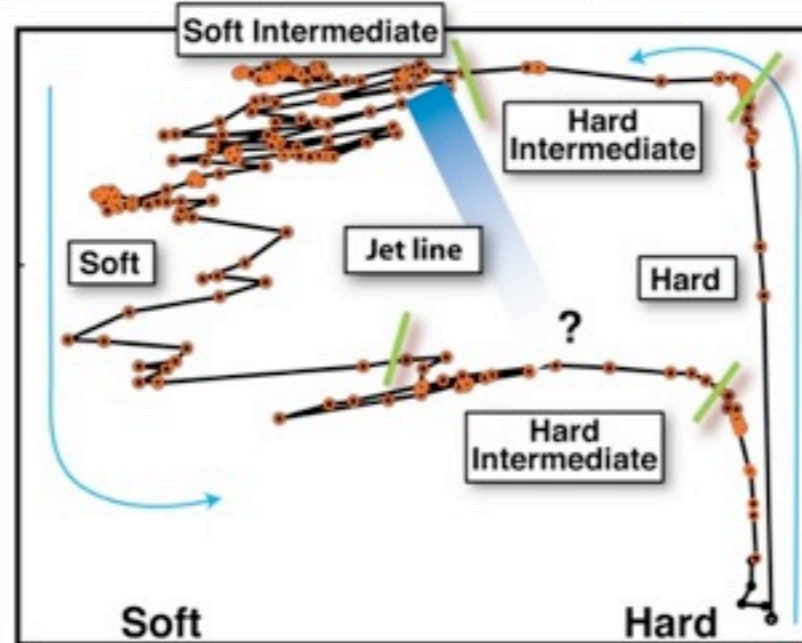


SOFT STATE:

- Optically nuclear thin jet radio emission observed initially, but quenched by at least 20-50x by full transition.
- Detected radio flux not nuclear?
- Type C QPOs.
- Non-thermal power law extending to \sim MeV.
- Thin disk ~ 0.1 - $1.0 L_{\text{Edd}}$ at ISCO.



X-ray Luminosity



Spectral Hardness
(spectral slope, soft=steep, hard=flat)

HARD STATE:

- Disk moves in to \sim few R_g by 10% L_{Edd} .
- Lorentzian/broad noise components.
- High RMS variability.
- Flat spectrum jet up to IR/opt.
- Compact jet sometimes resolved.
- Radio/IR/X-ray correlations.
- Reflection "bump".



T. Belloni
A. Celotti
S. Corbel
R. Fender
E. Gallo
M. Hanke
E. Kalemci

D. Maitra
S. Markoff
I. McHardy
M. Nowak
P.-O. Petrucci
K. Pottschmidt
J. Wilms

HIMS:

- Same as upper branch but:
- No optically thin radio flare.
 - Radio recovers close to hard state.
 - Lower flux level (hysteresis).

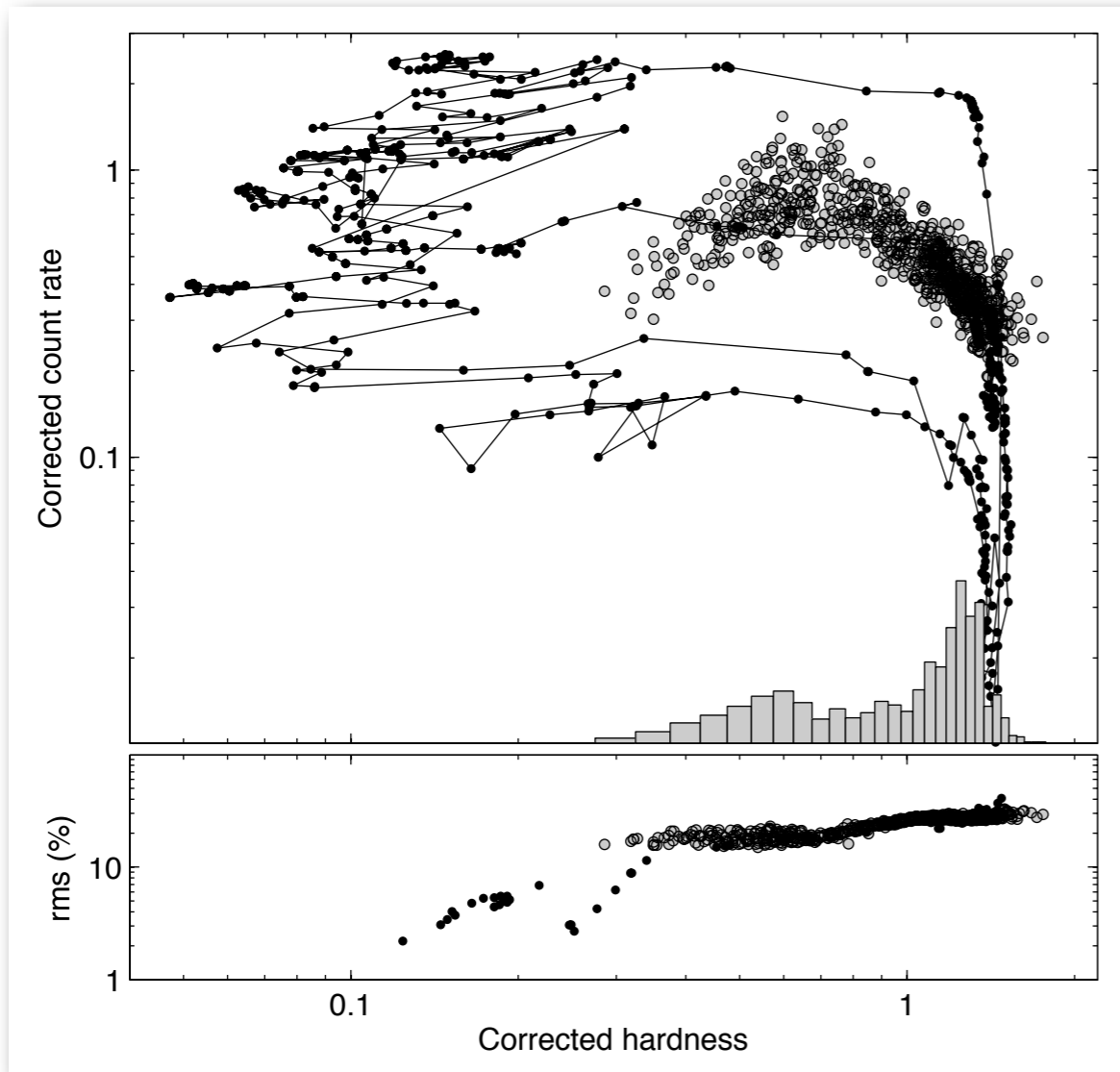
QUIESCENCE:

- Thin disk recessed to $> 10^2 R_g$
- BB component seen in UV/Optical.
- Disk 10-100x more luminous than LX. By $\sim 10^{-4} L_{\text{Edd}}$.
- No iron lines?



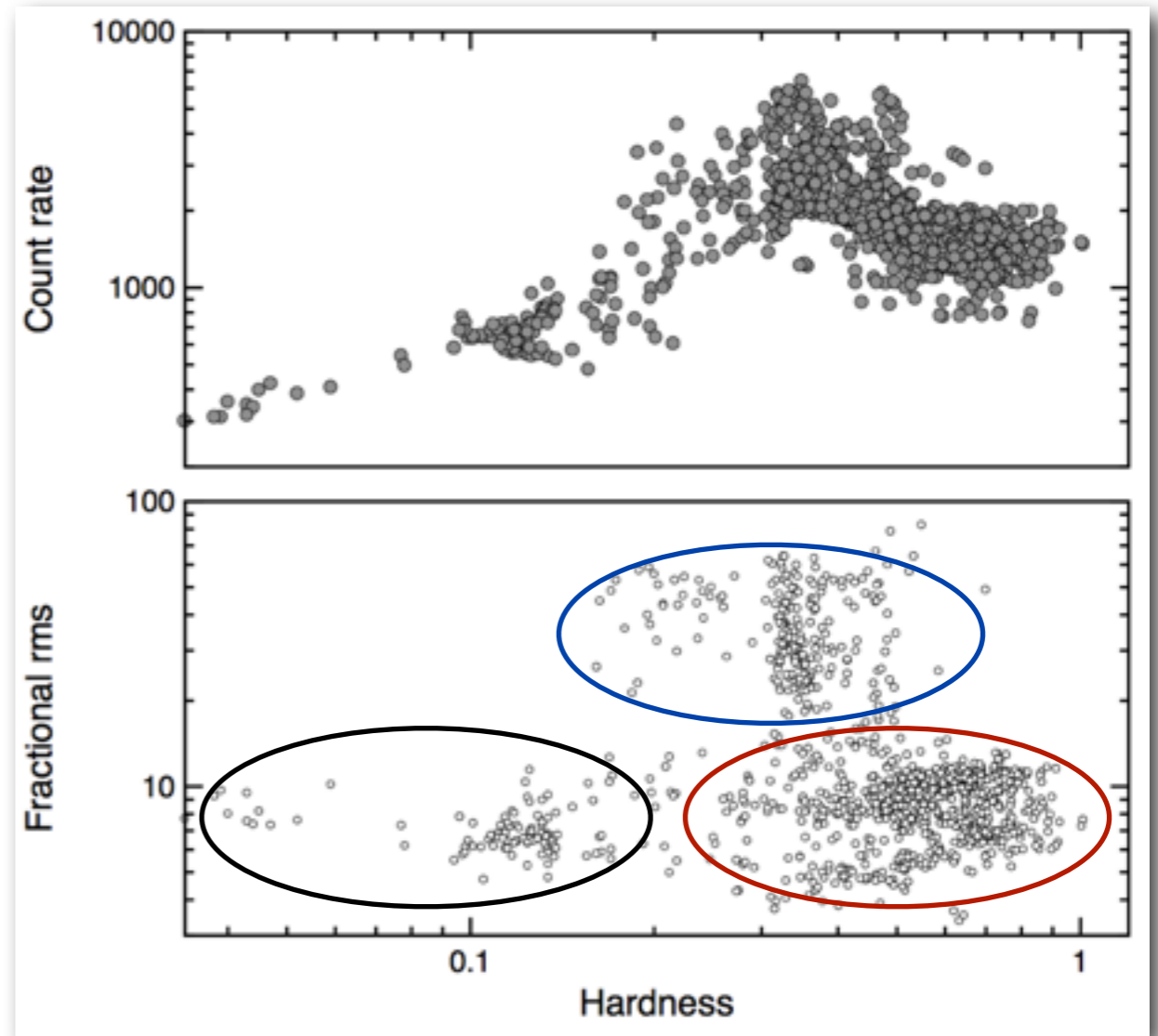
Probing the Accretion/Outflow Connection in
X-Ray Binaries and Active Galactic Nuclei

Other sources



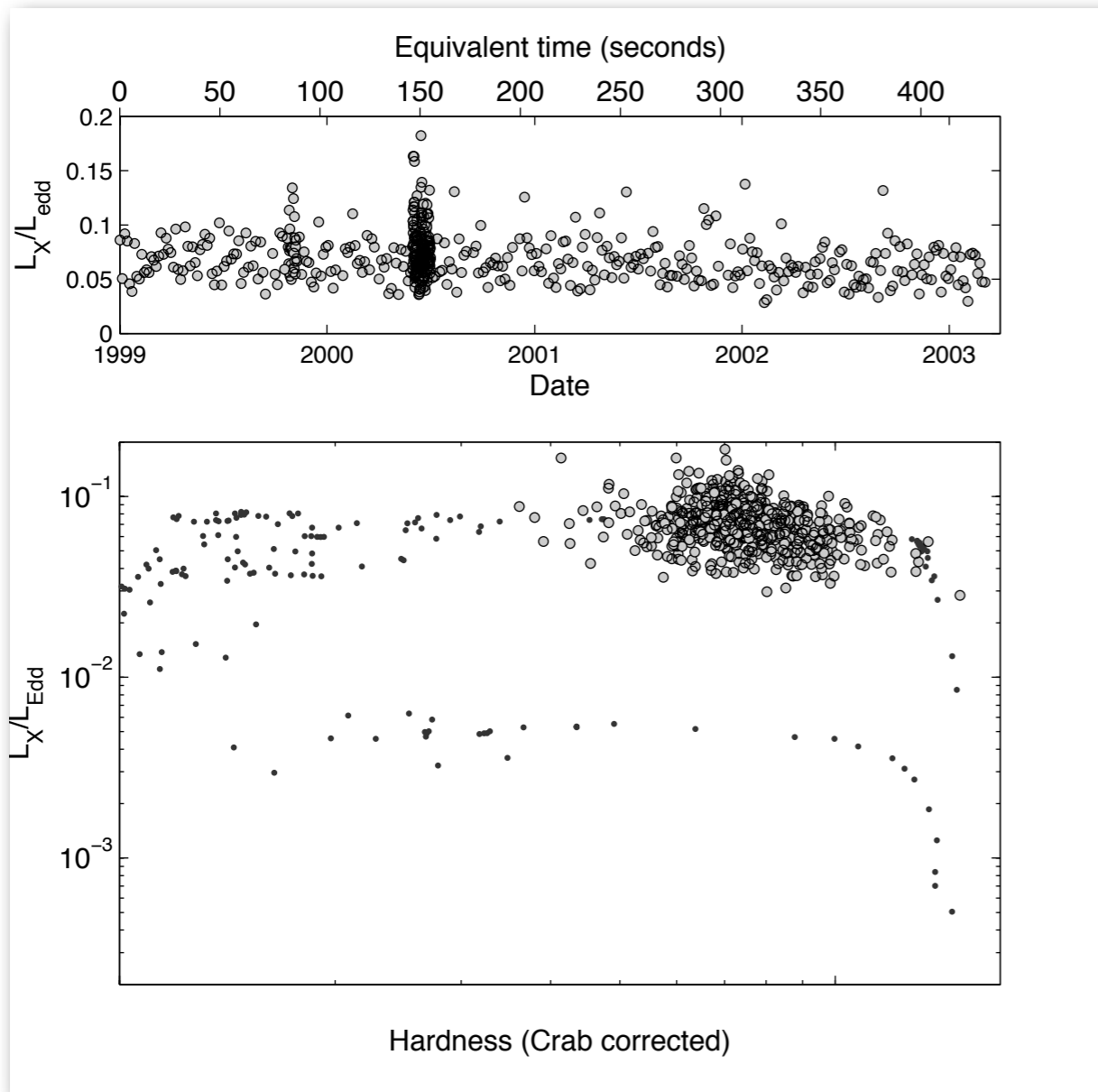
Cyg X-1

TMB (2010)



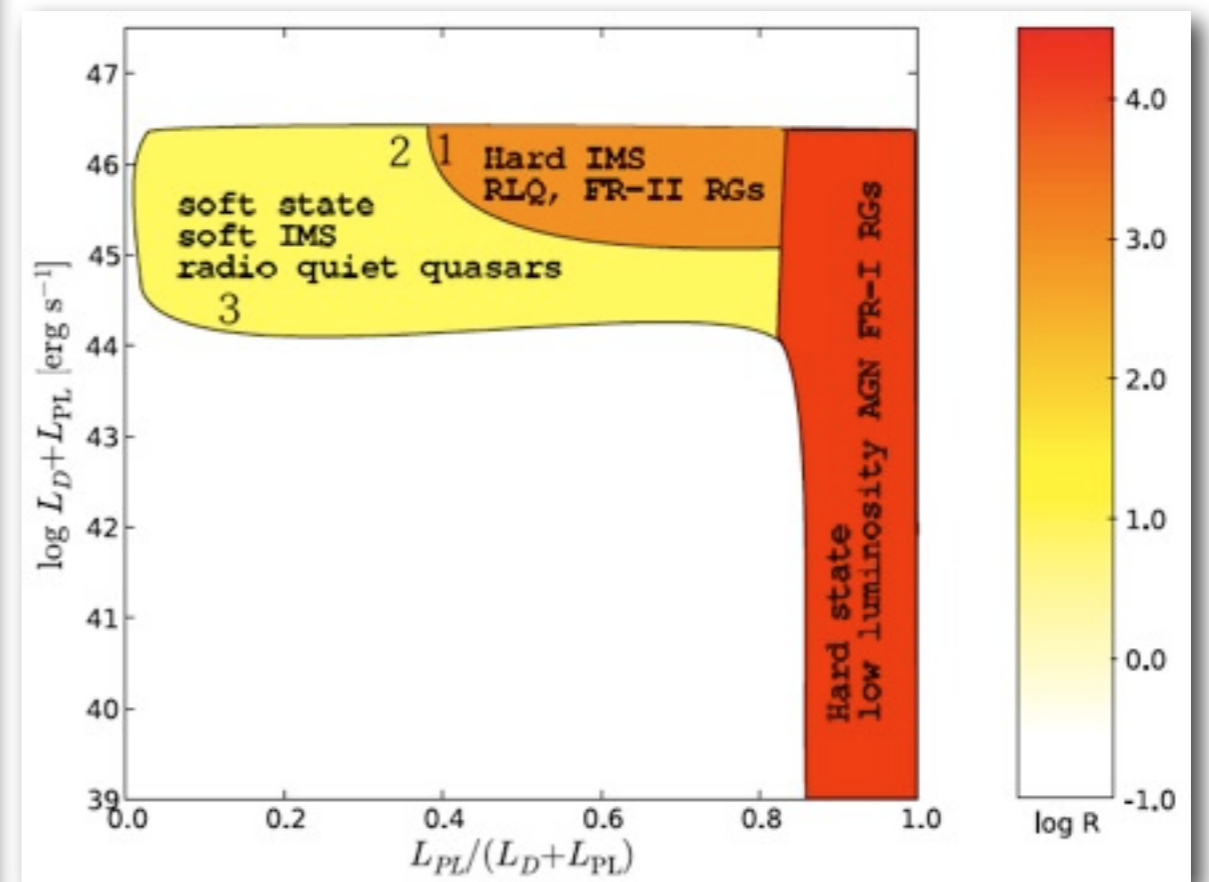
GRS 1915+105

Other sources - other time scales



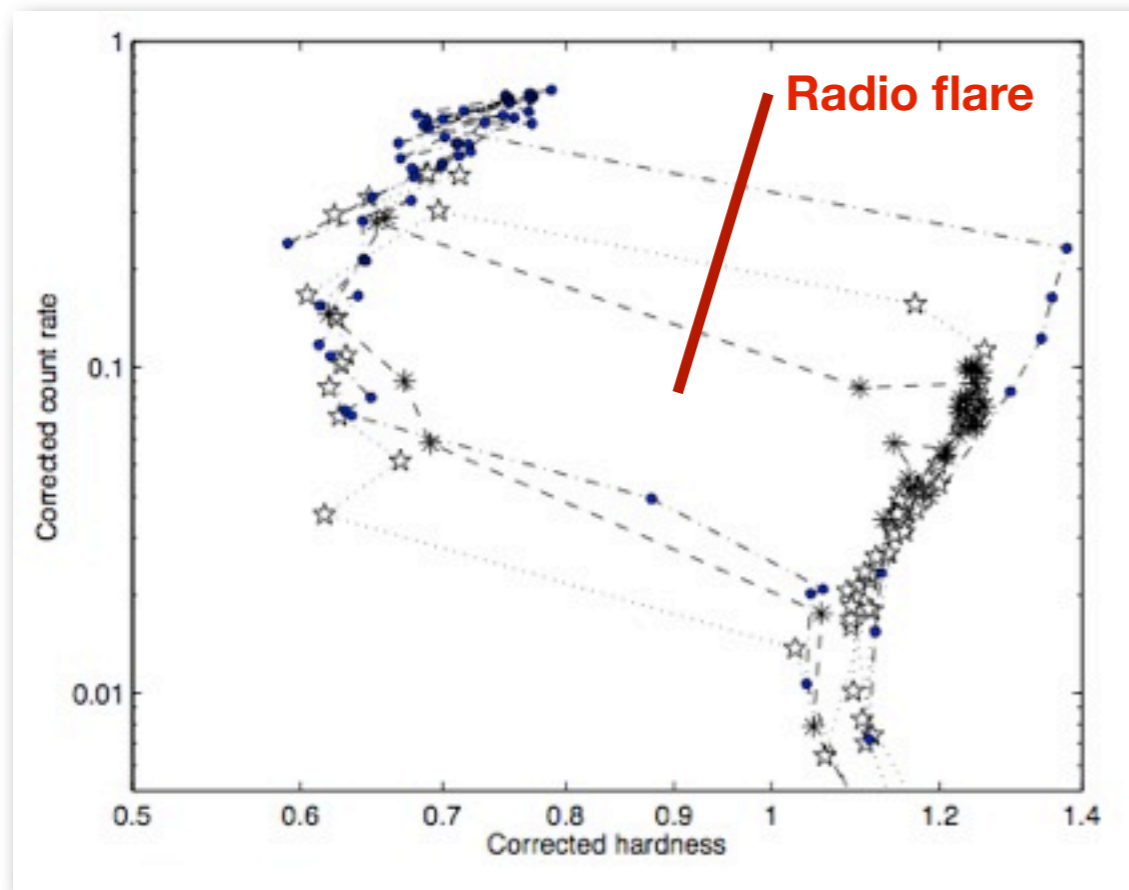
TMB (2010)

Ark 564



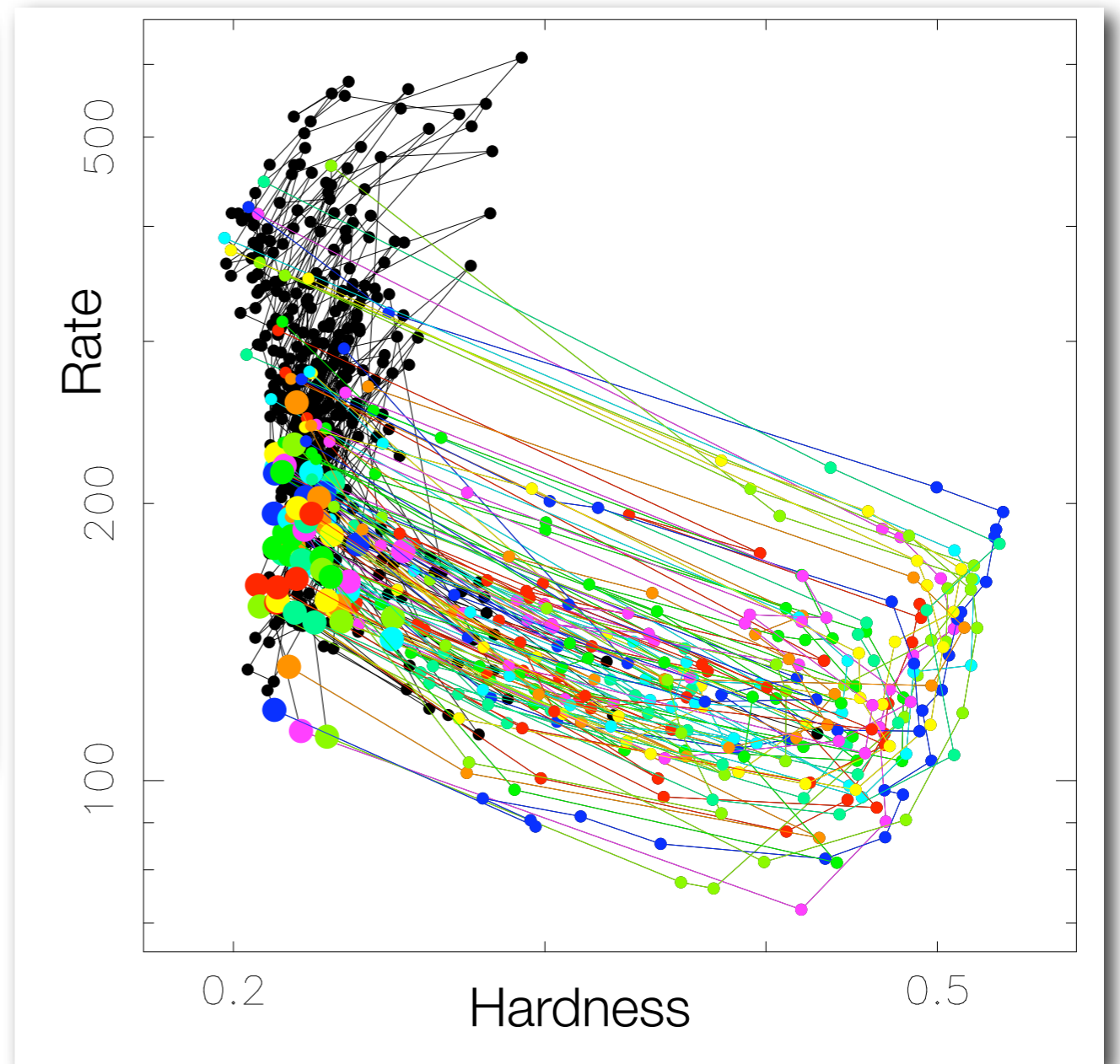
Körding et al. (2006)

Neutron-star X-ray binaries



TMB (2010)

Aql X-1

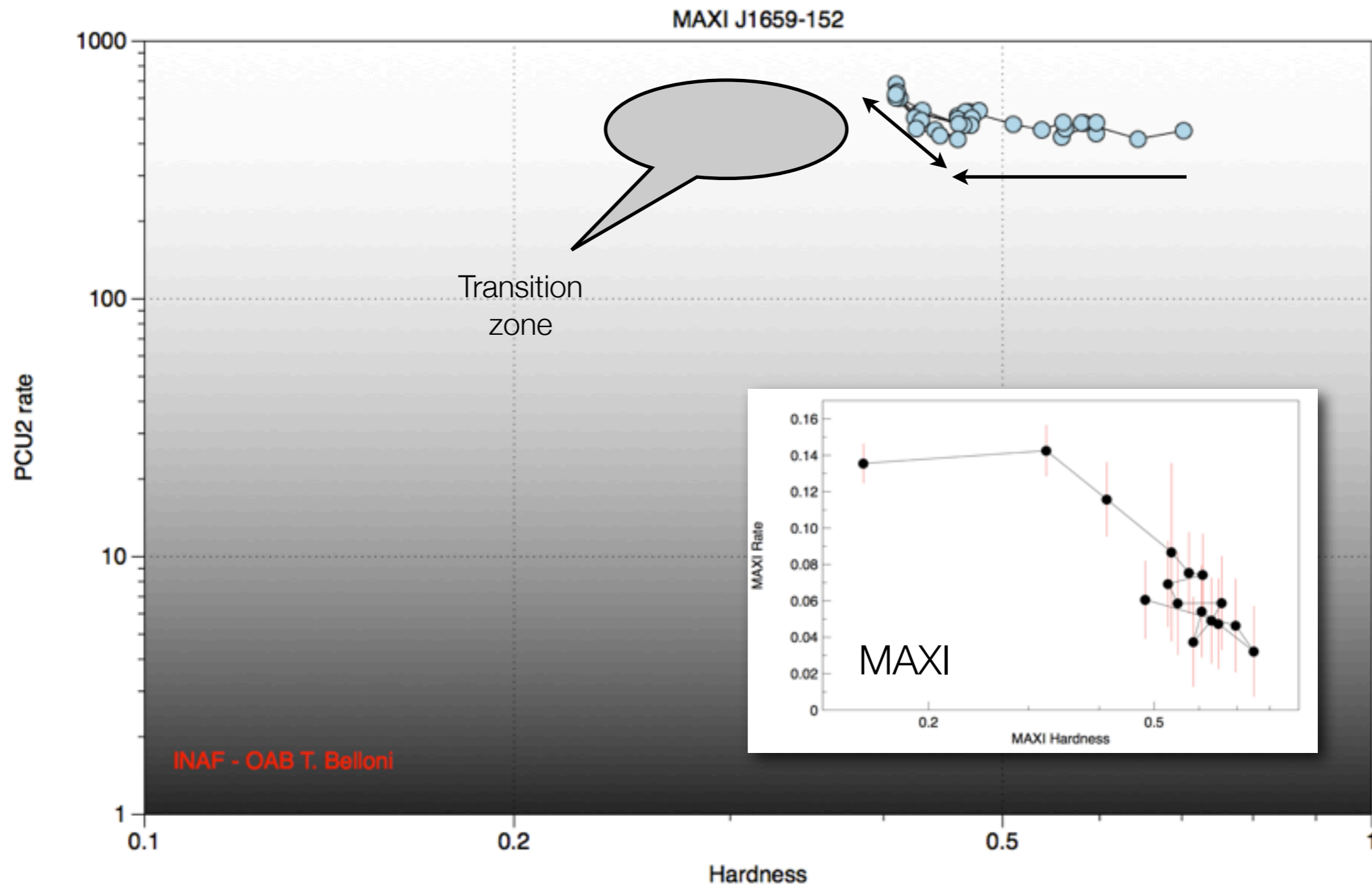


Homan et al. (2011)

4U 1636-53

New systems

- The recent transient MAXI J1659-152 as of today

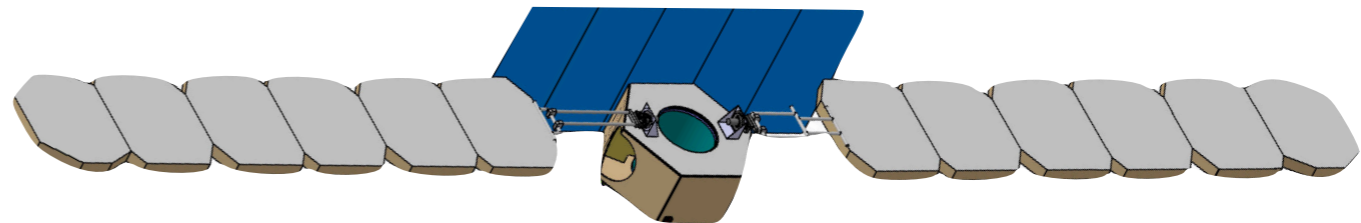


Conclusions

- We now have a very clear picture of how X-ray transients evolve
- This leads to a strong state classification based on transitions
- Never mix apples and pears. There is very little space to play here
- The radio/X-ray connection works with these states
- Timing is paramount, although we do not really know what it is (yet)
- The near future is ASTROSAT (launch early 2012)
- The far future could be

Conclusions

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LOFT