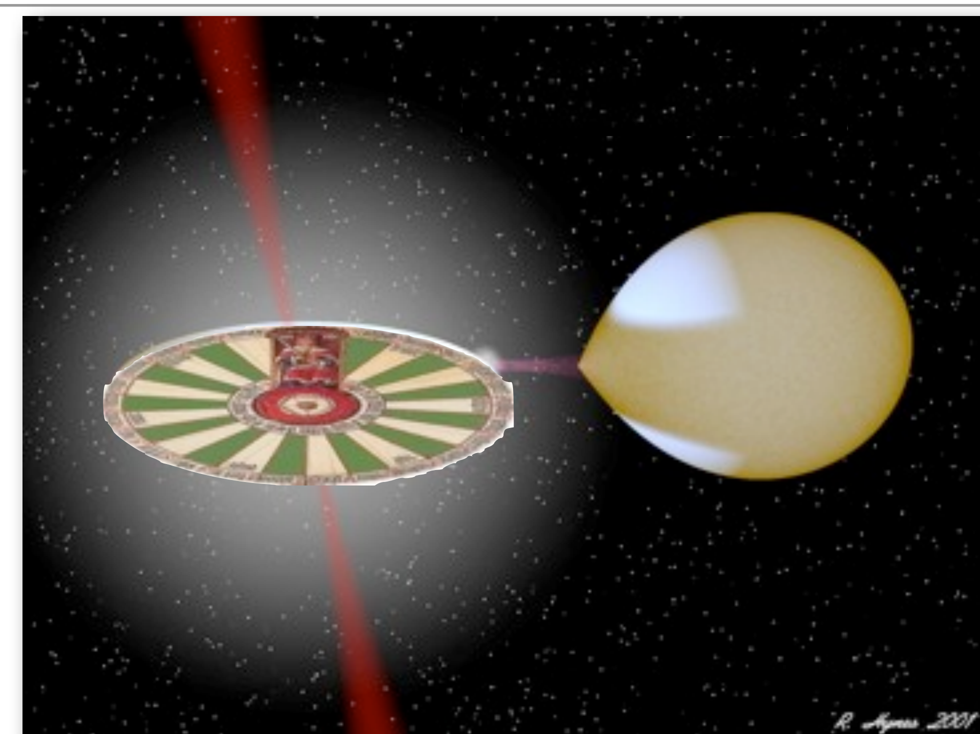
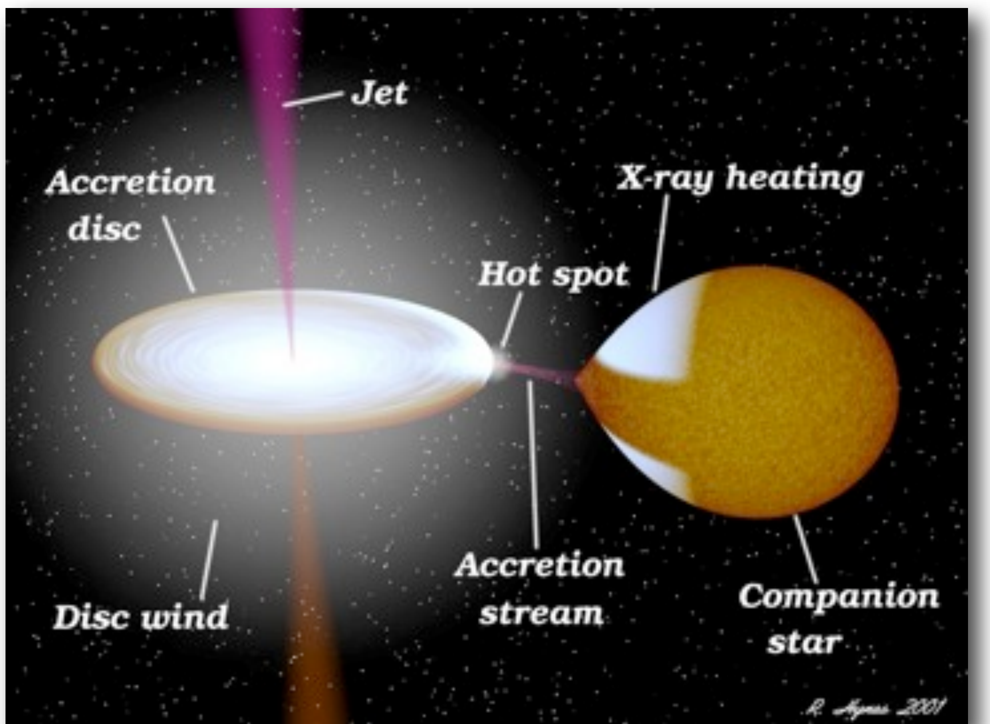
Blæc hol X-ray binary variability

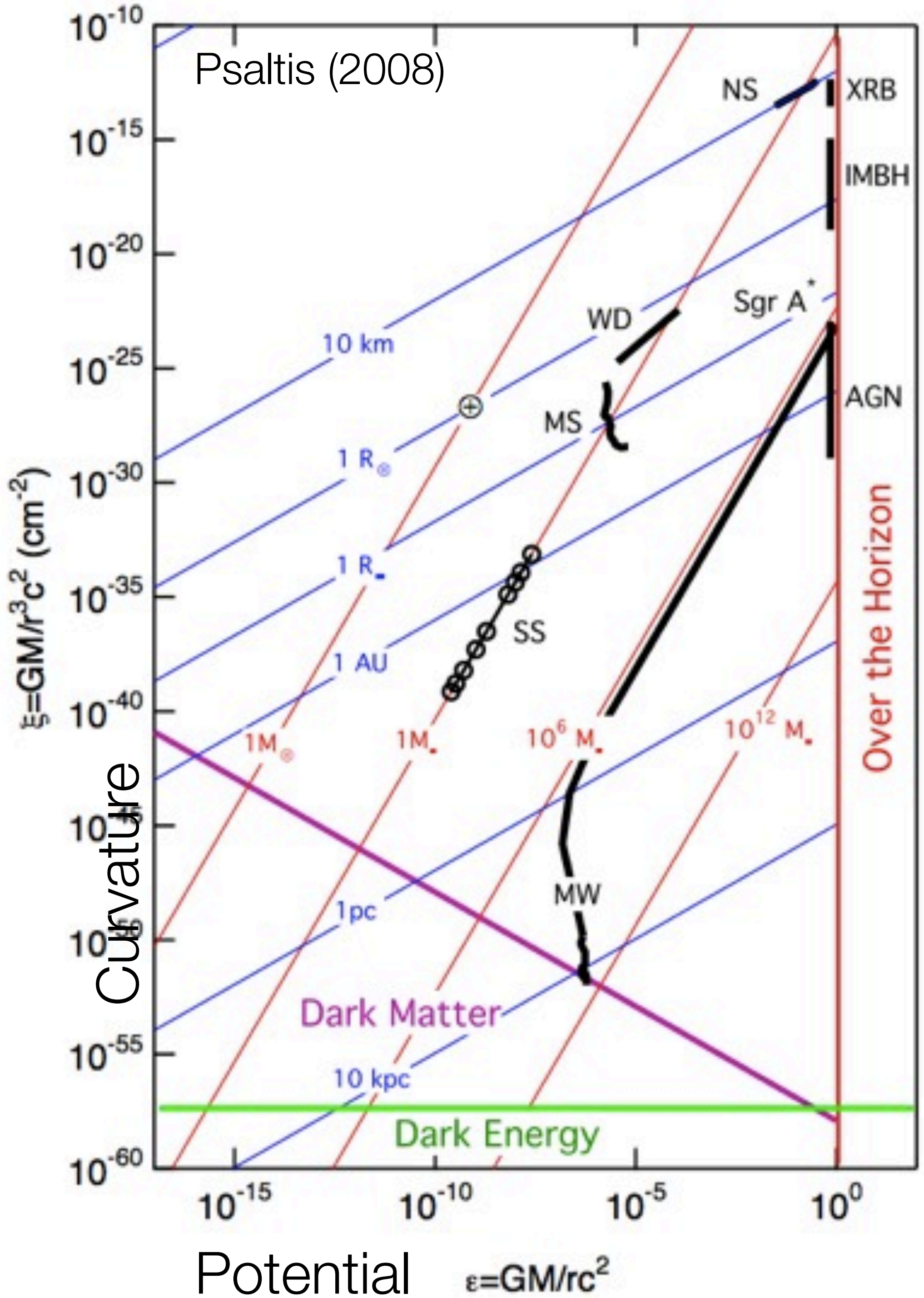
Tomaso Belloni
(INAF - Osservatorio Astronomico di Brera)



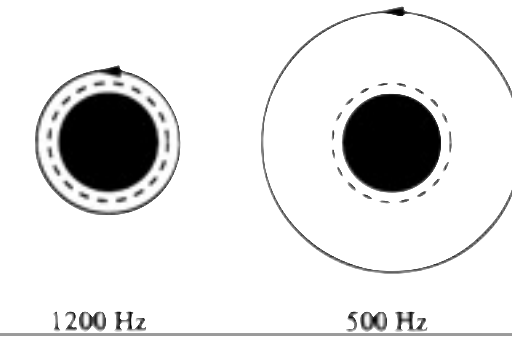
THE PROMISE OF X-RAY BINARIES

- The path to General Relativity through accretion
- The path to accretion through General Relativity





CHARACTERISTIC TIME SCALES



GR + OBJECT

- Neutron stars: spin frequency
- Keplerian frequency
- Relativistic precessions:
  - Periastron precession
  - Lense-Thirring precession

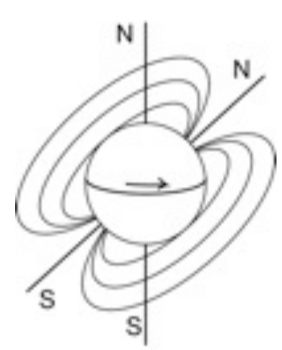
ACCRETION

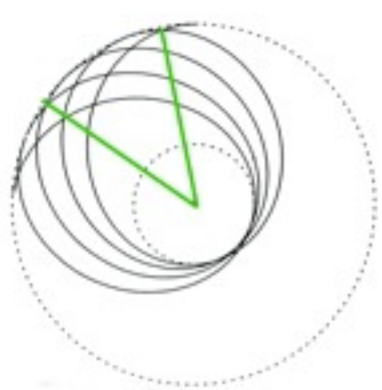
- Radial light-crossing
- Radial sound-crossing
- Free-fall
- Viscous
- Thermal

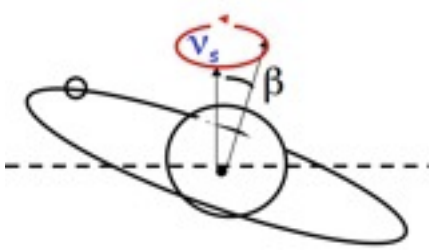
Importance of ISCO:

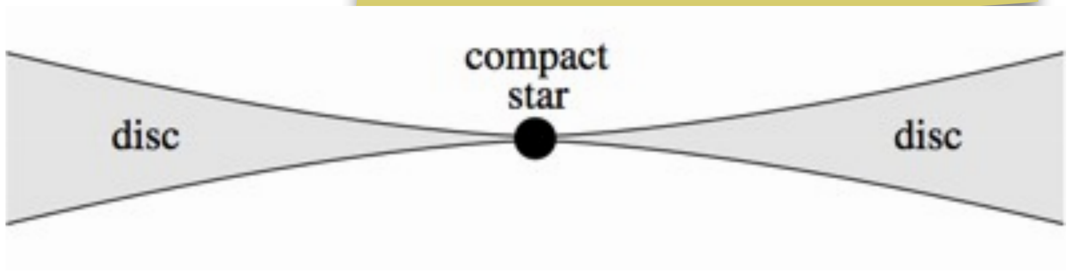
ISCO itself - GR
black hole spin

no particle, but
accretion disk





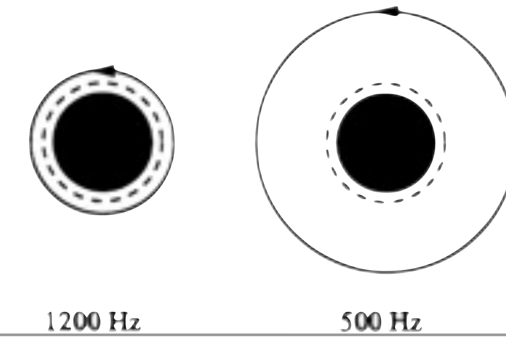




STRONG GRAVITY

All frequencies increase with decreasing radius

Immersed into a variable accretion disk



- Keplerian frequency

100-1000 Hz

ermost Stable Circular Orbit (ISCO) - *Black hole spin*

Timing and spectral approach

- Periastron precession

100-700 Hz

Weak limit: Mercury, Double Pulsar

Need timing

- Lense-Thirring precession

1-50 Hz

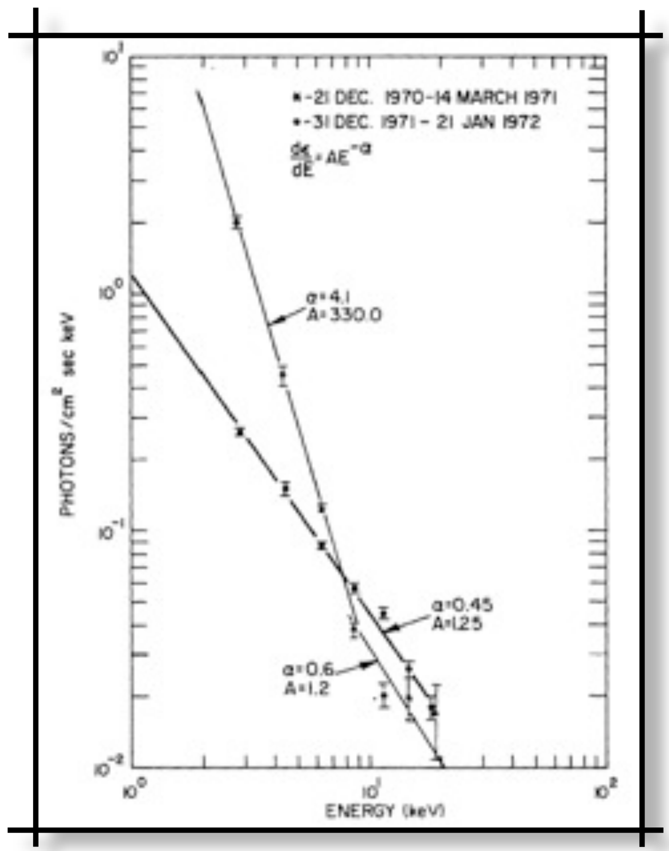
Weak limit: Gravity Probe B

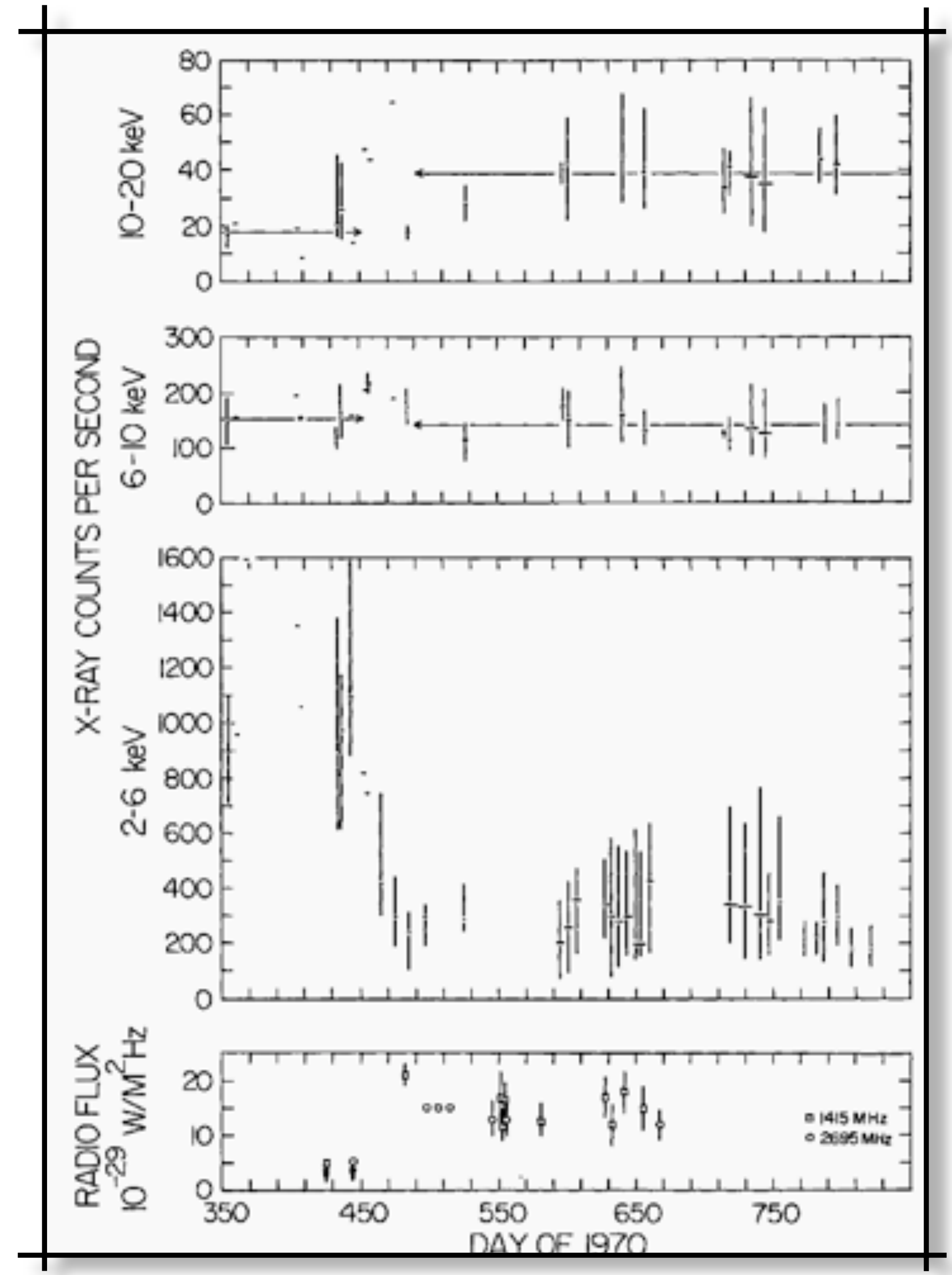
Need timing

EARLY HISTORY: LARGE VARIABILITY

- In the beginning.. Cyg X-1
- Strong spectral changes
- Radio correlation
- Long time scales here

Tananbaum et al. (1971)

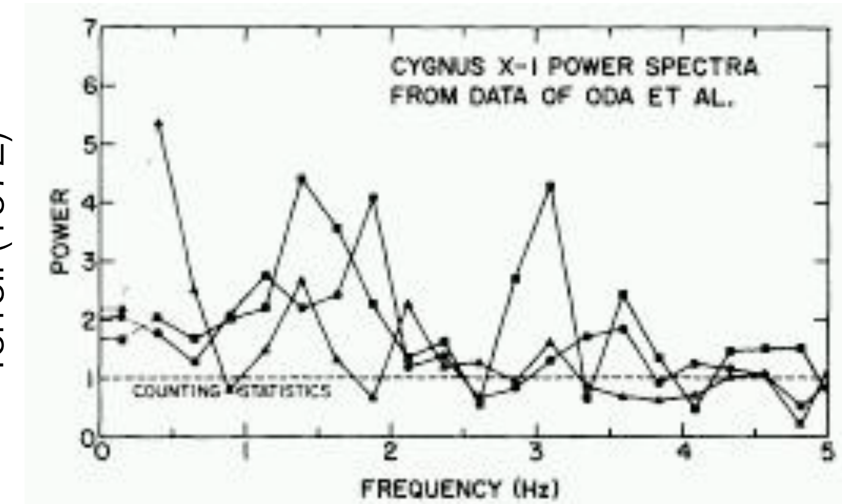




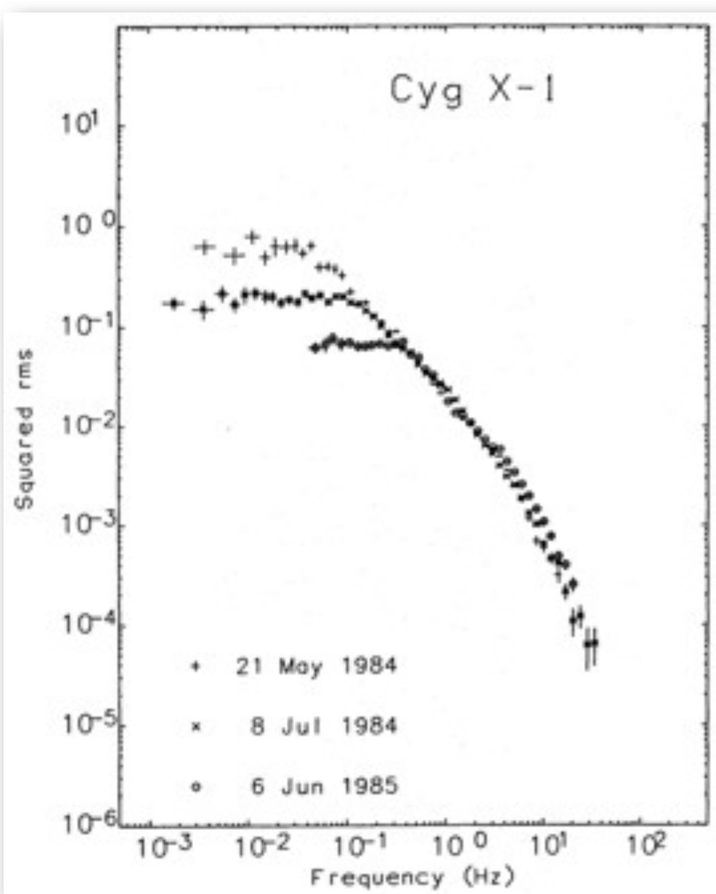
EARLY HISTORY: FAST VARIABILITY

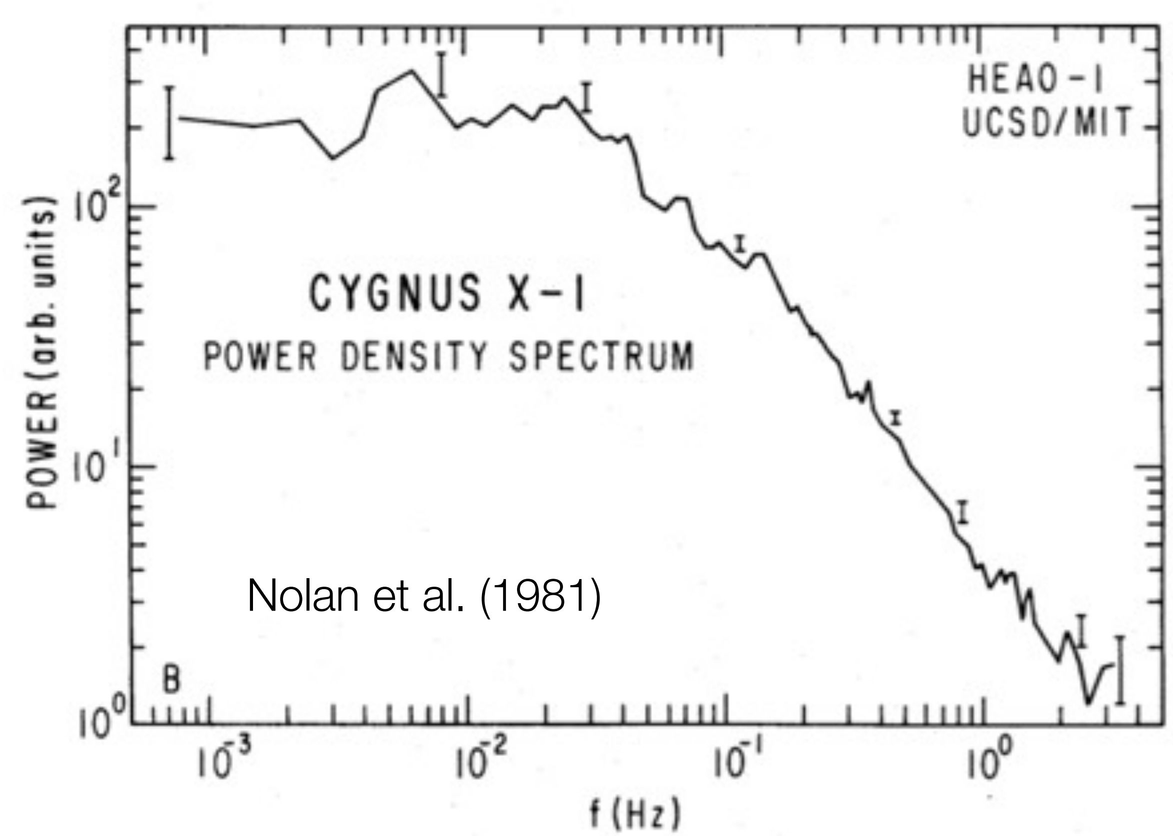
- In the beginning.. Cyg X-1
- Fast aperiodic variations
- Difficult to follow with small instruments

Terrell (1972)



Belloni & Hasinger (1990)



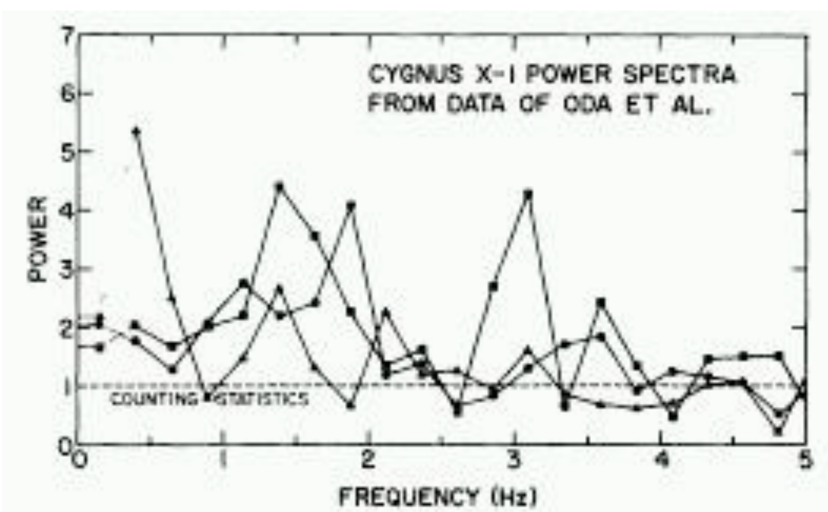


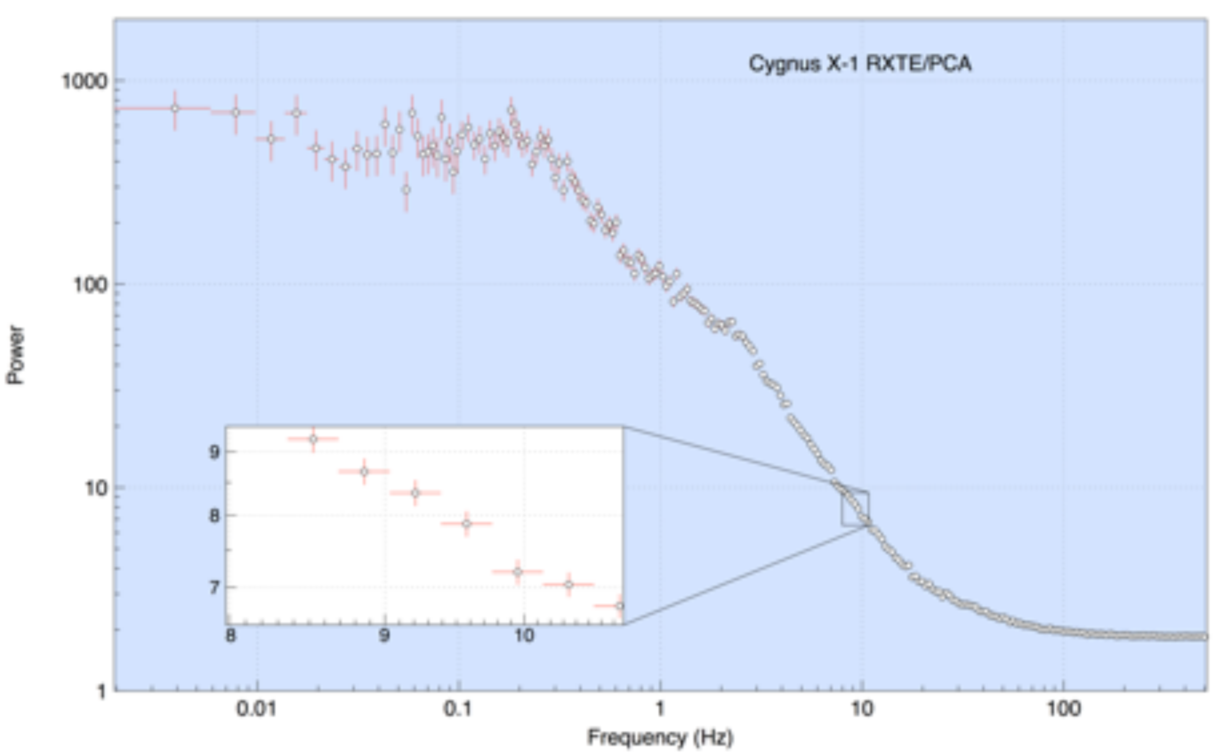
Nolan et al. (1981)

PHOTONS ARE EVERYTHING

- Sensitivity linear with flux
- Imaging reduces background only

$$n_\sigma \propto \frac{S^2}{S+B}$$

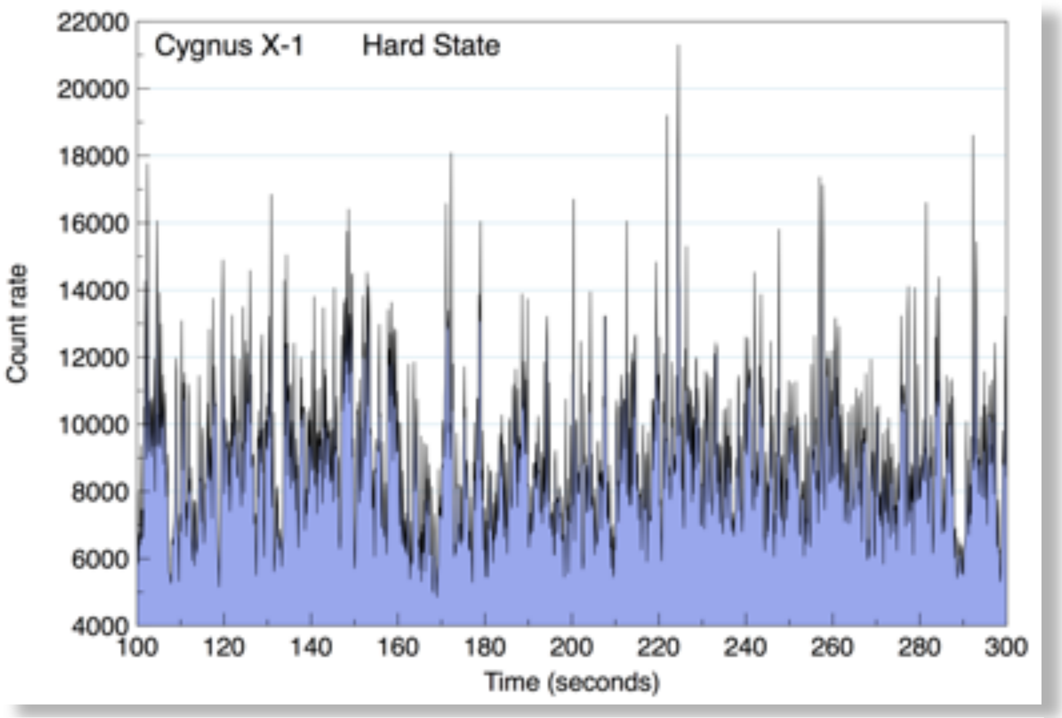


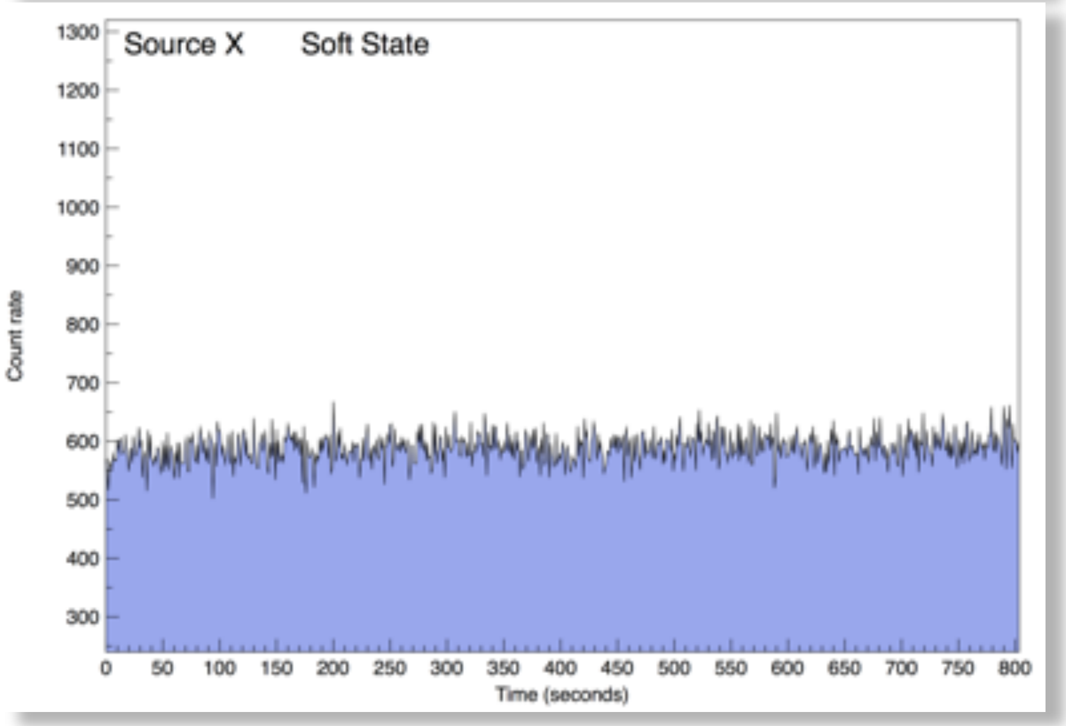


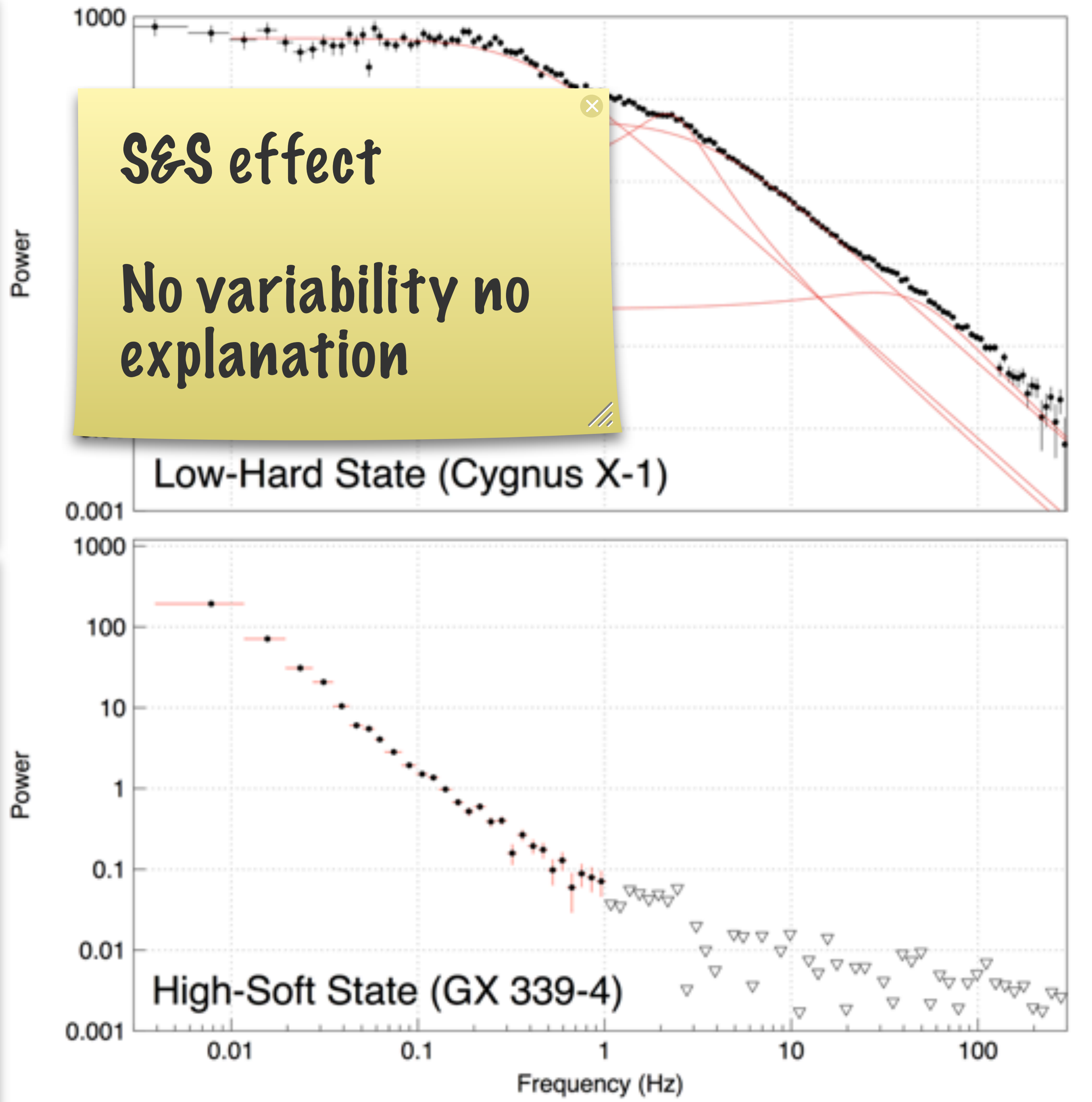
Uhuru 0.16 m^2

Rossi XTE 6500 cm^2

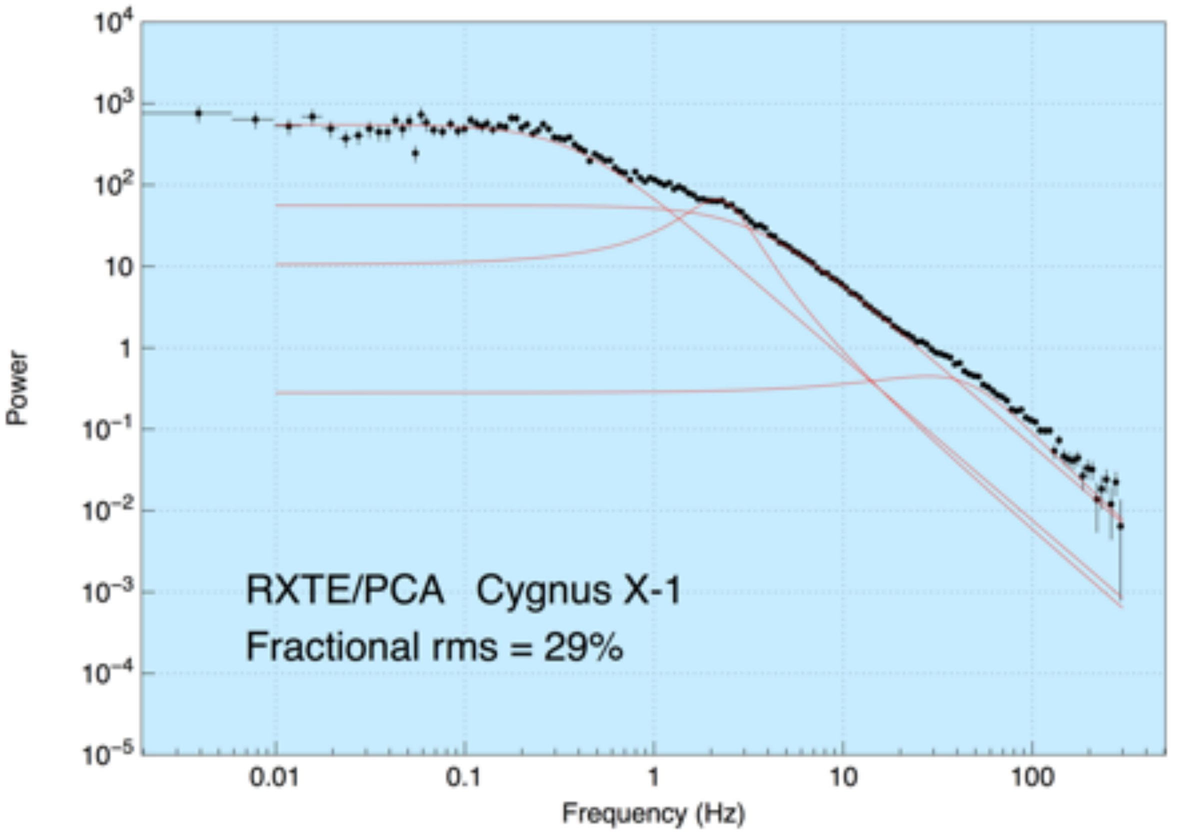
TO VARY OR NOT TO VARY?





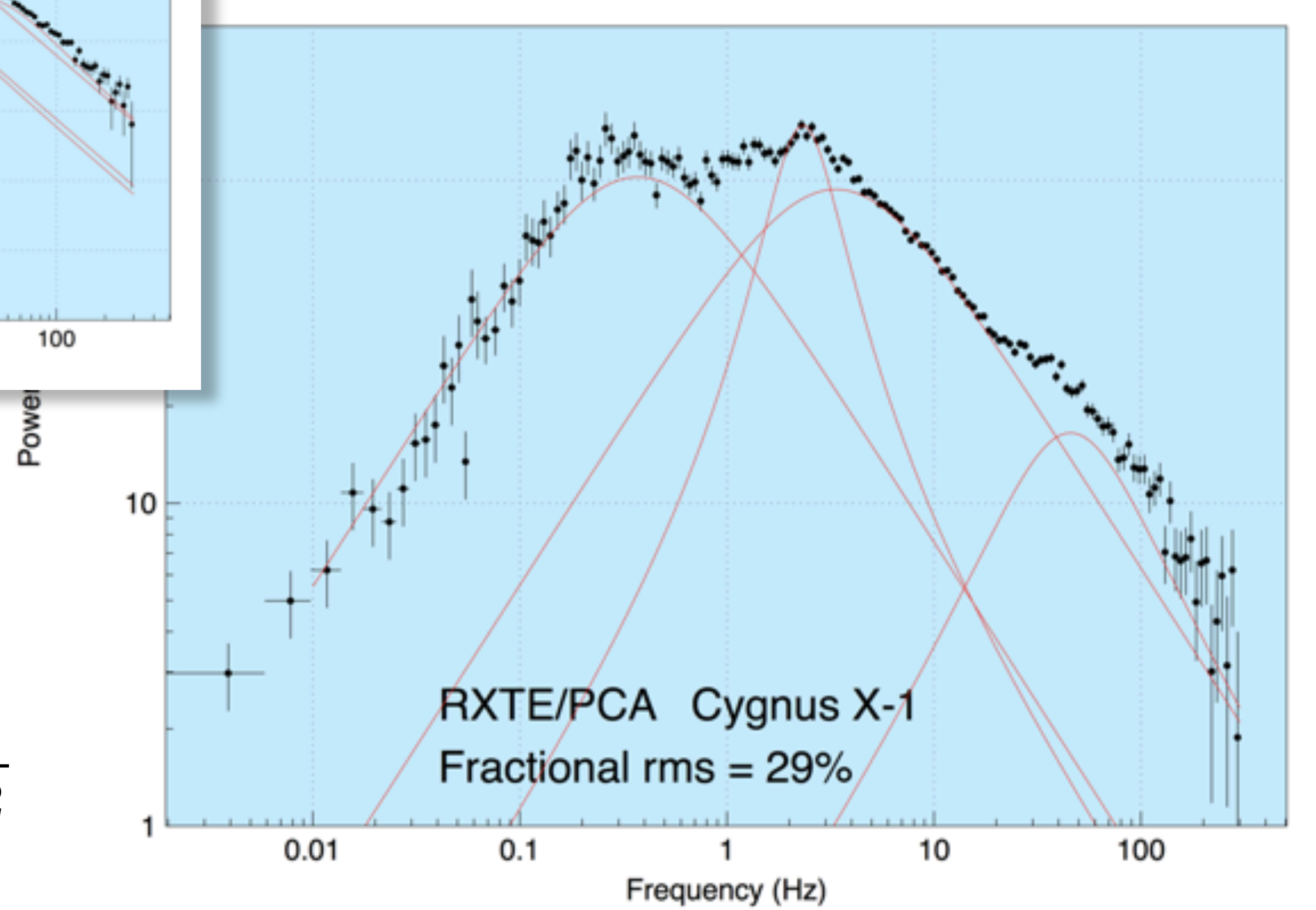


VARIABILITY COMPONENTS



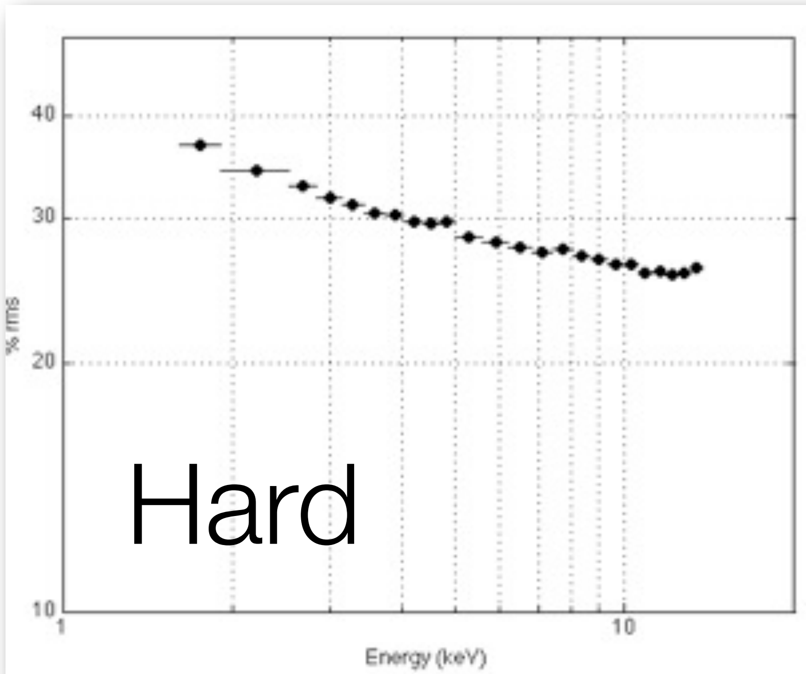
Lorentzians

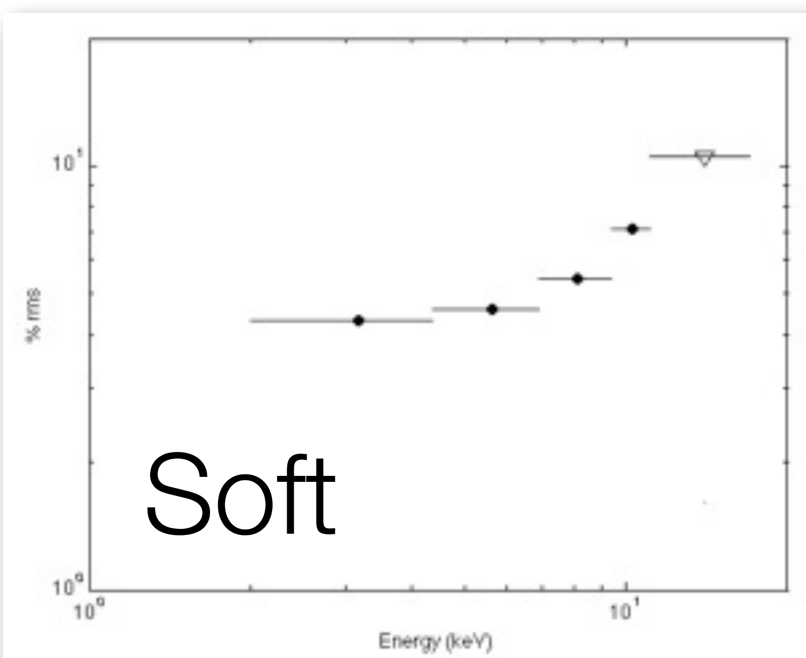
$$P(\nu) = N \frac{1}{\nu_b^2 + \nu^2}$$

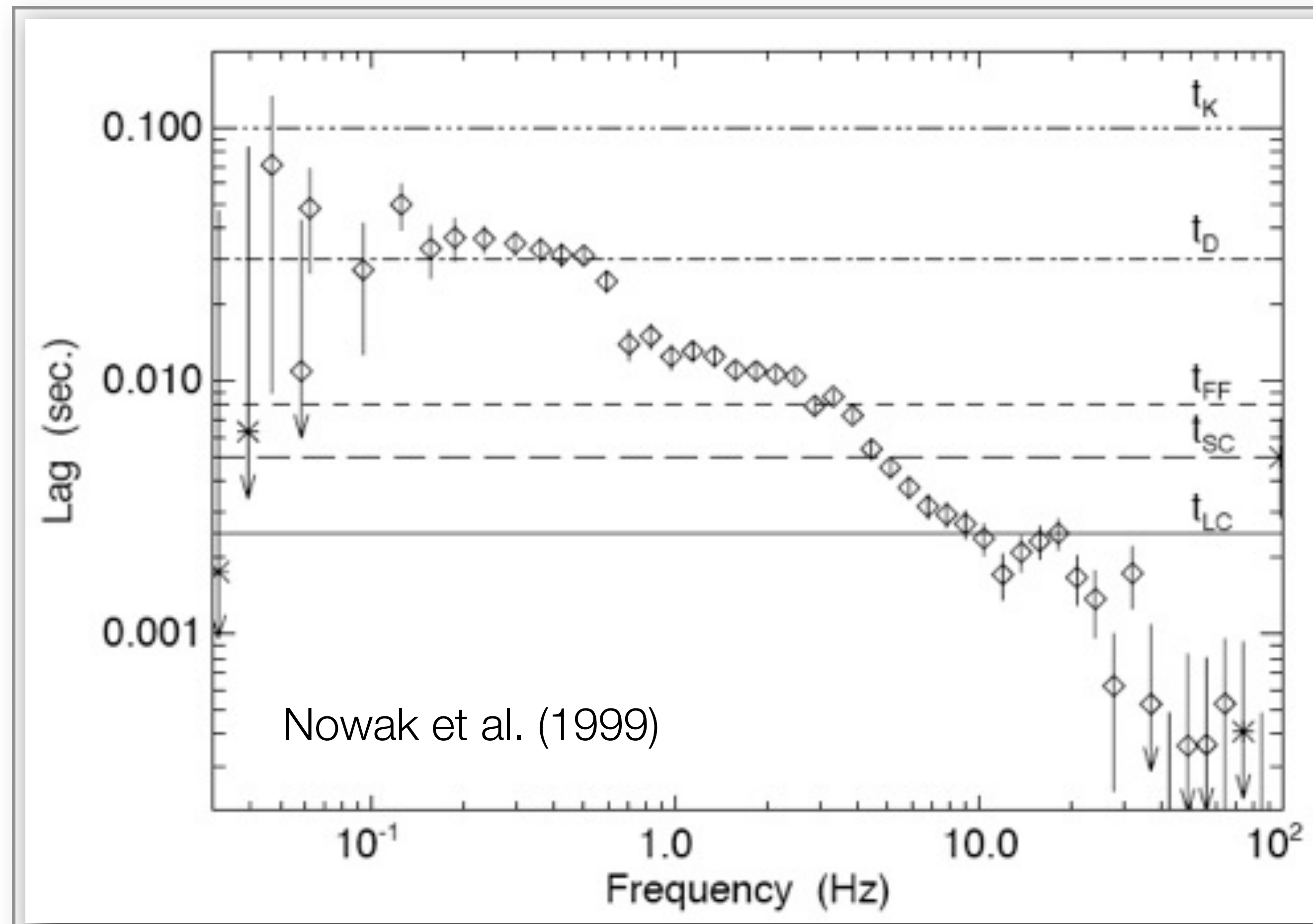


$$P(\nu) = N \frac{\nu}{\nu_b^2 + \nu^2}$$

ENERGY DEPENDENCE AND LAGS

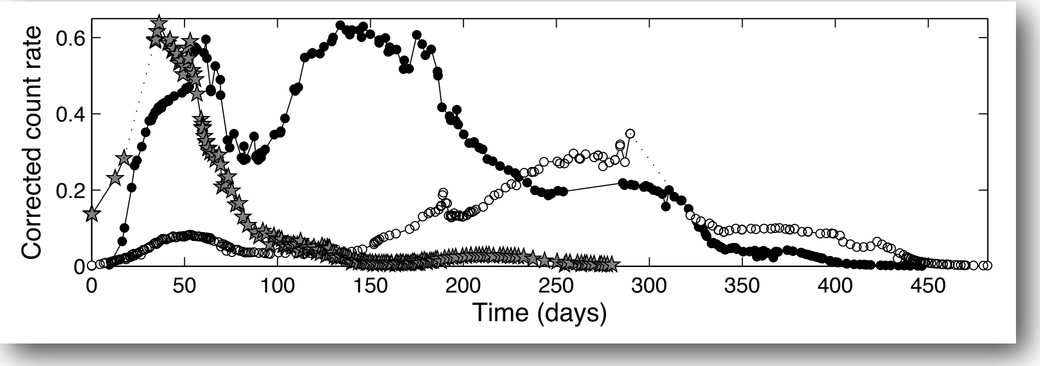




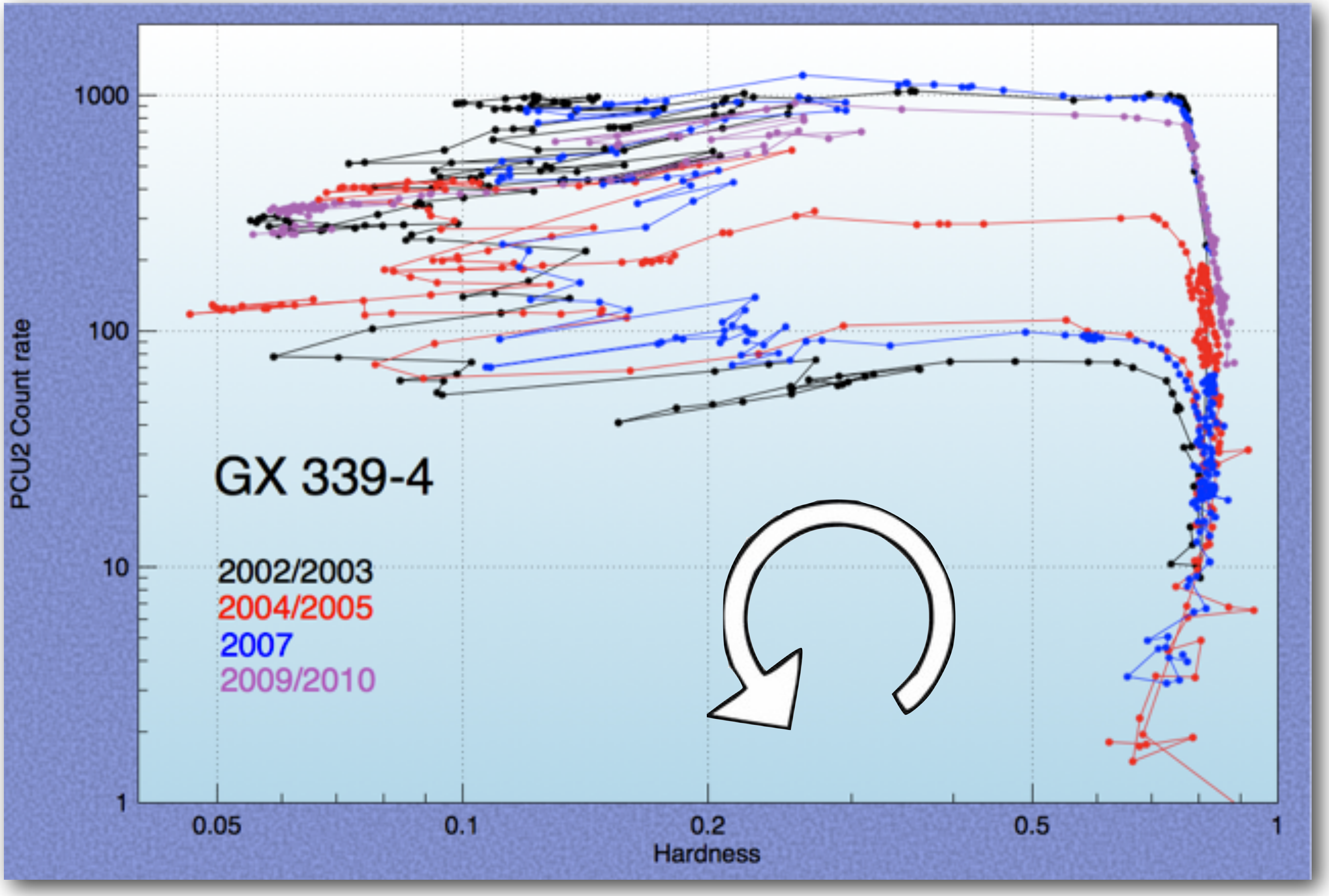


Time/phase lags between energies from Fourier spectrum

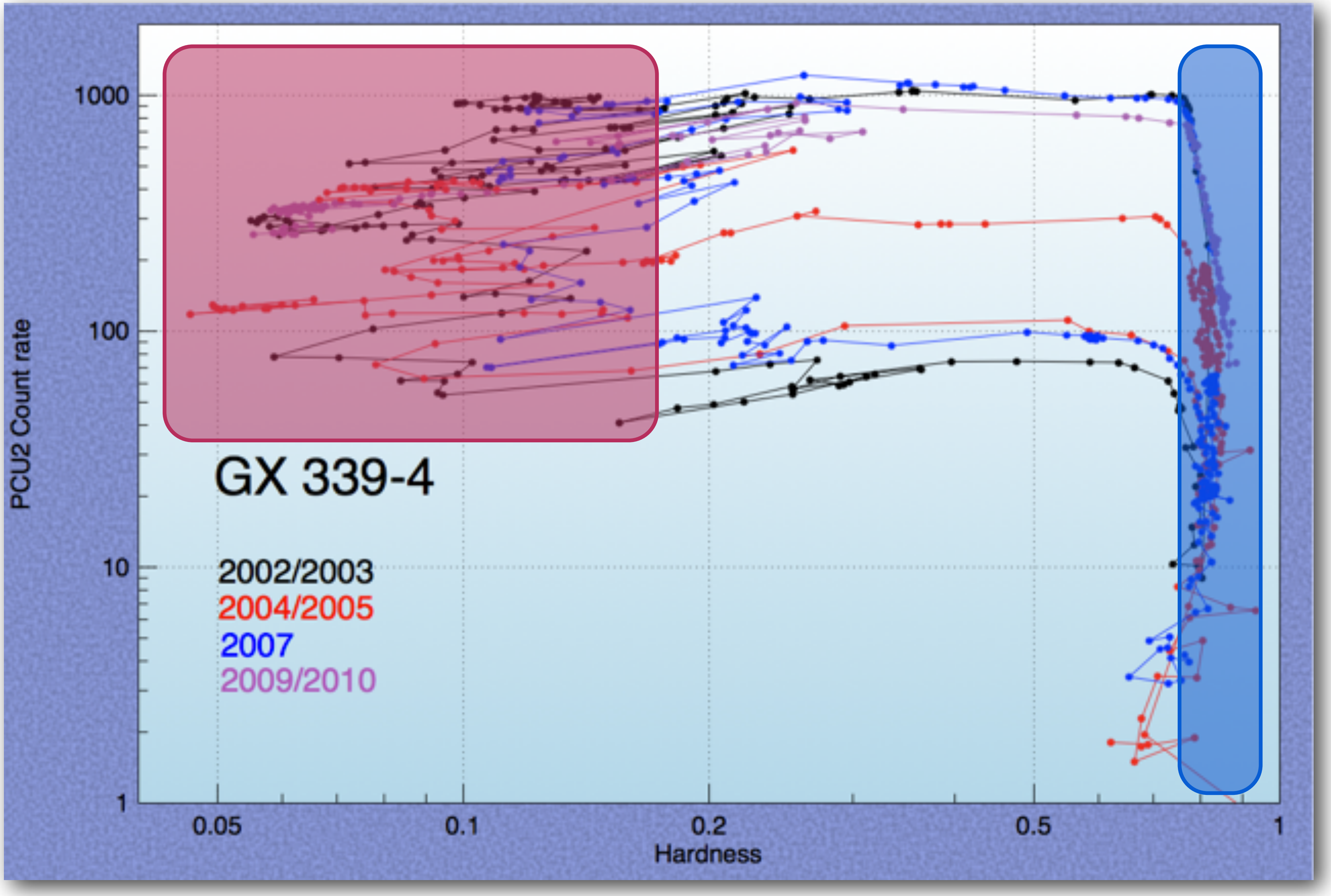
EVOLUTION OF TRANSIENTS



Hardness-Intensity Diagram (HID)



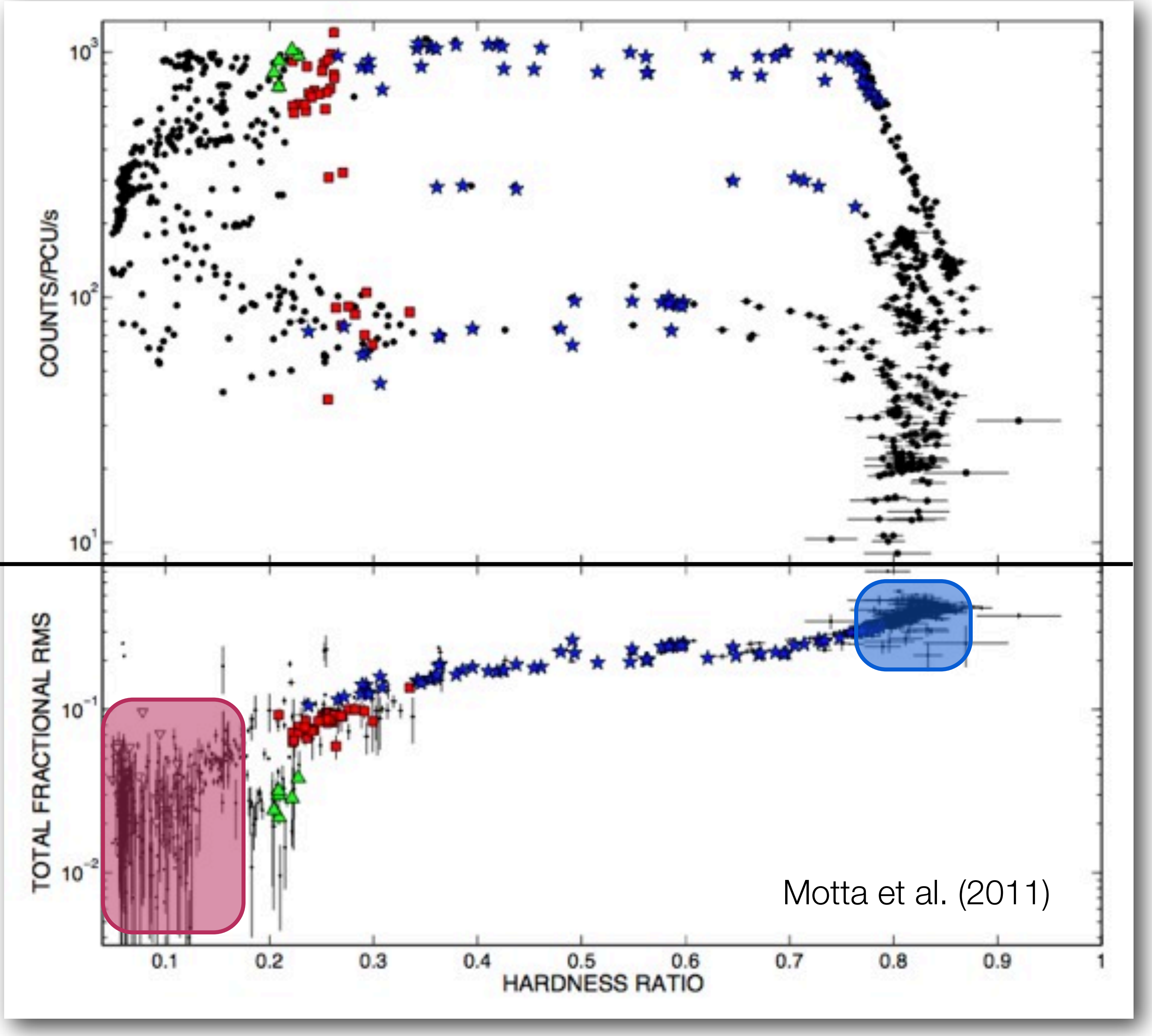
HARD/VARIABLE & SOFT/QUIET



HARD/VARIABLE & SOFT/QUIET

HID

Hardness-Rms Diagram

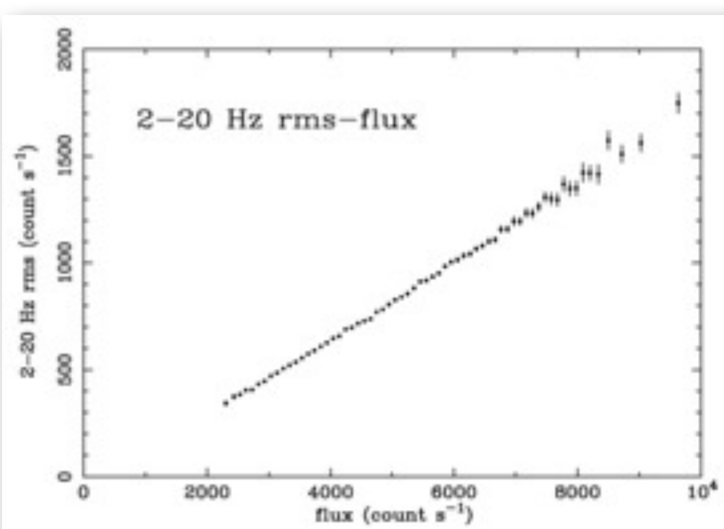


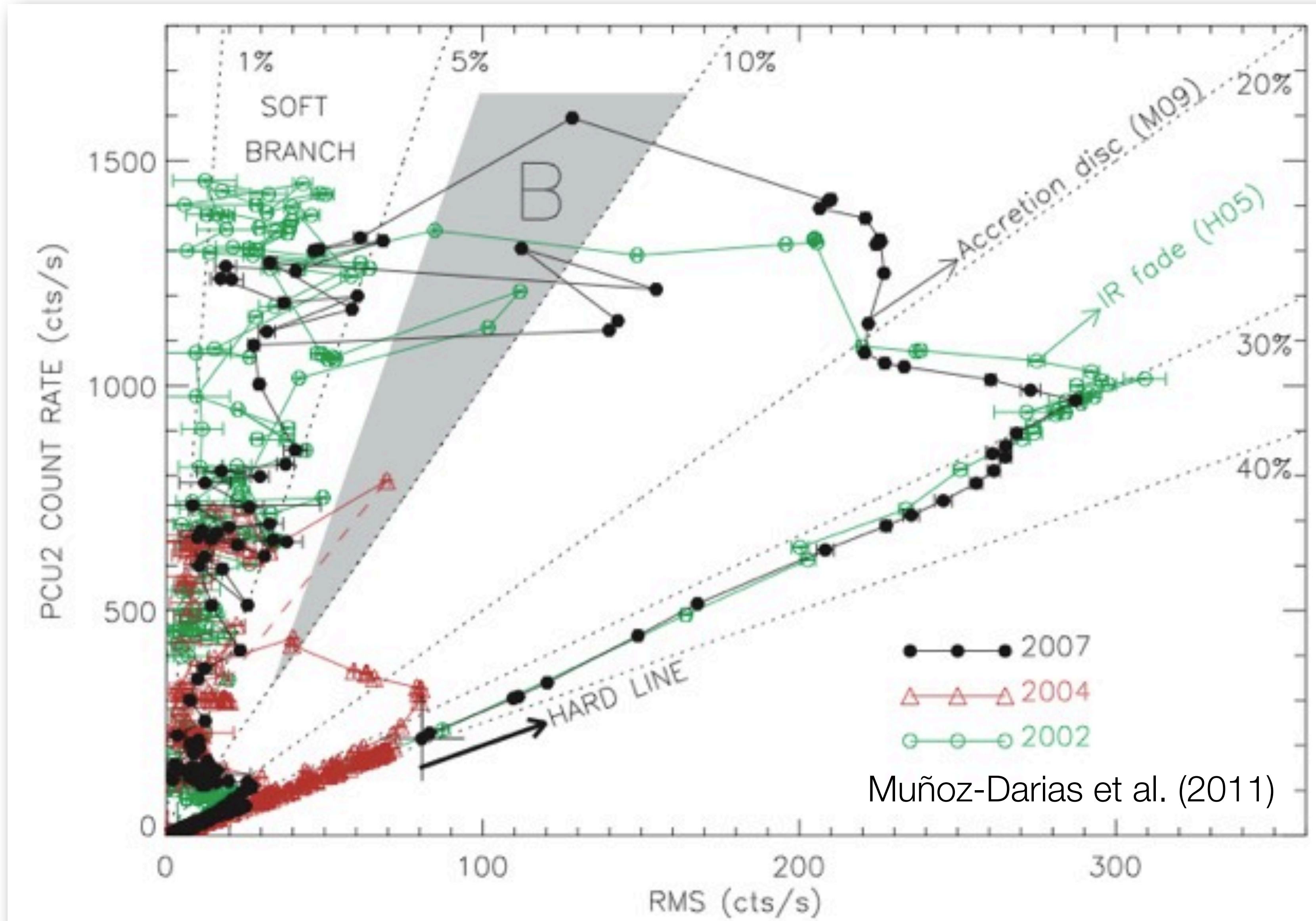
RMS-INTENSITY DIAGRAM

rms-flux

Gleissner et al. (2004)

Uttley, McHardy & Vaughan (2005)





Muñoz-Darias et al. (2011)

MISSING..

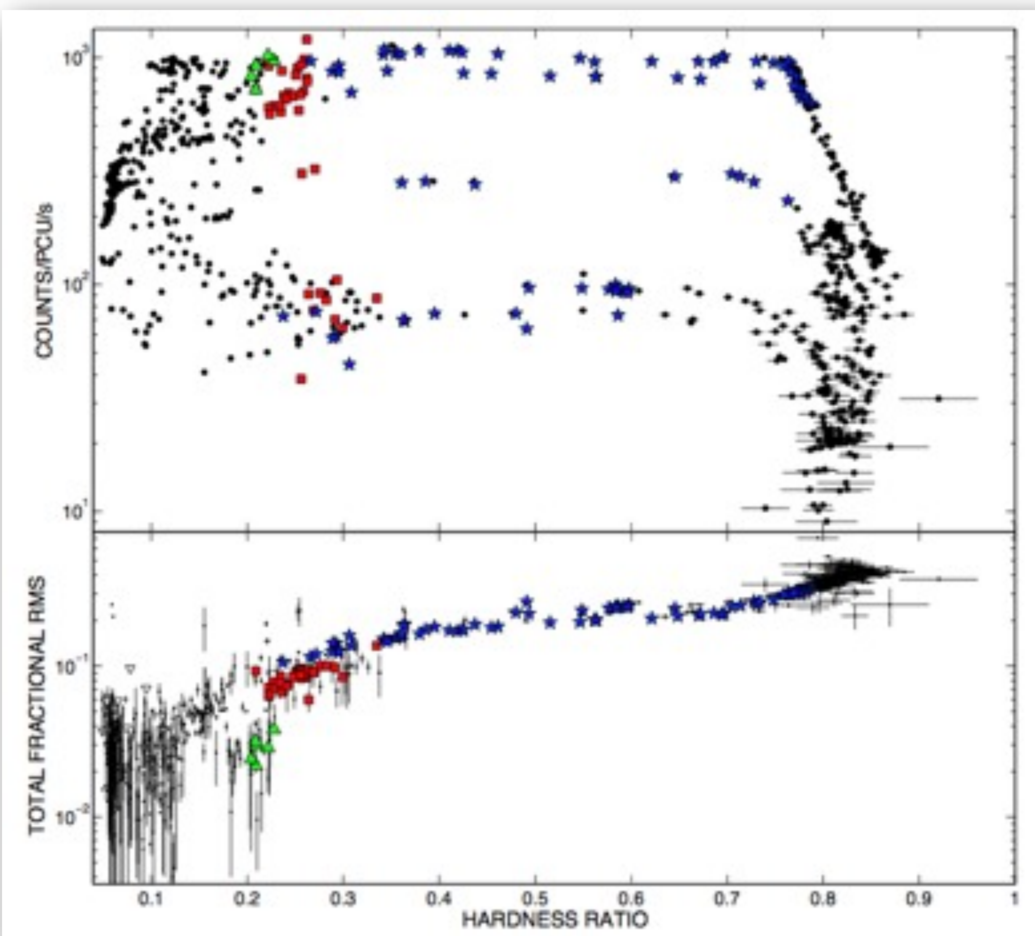
Where are the good frequencies?

What happens in the middle of the diagrams?

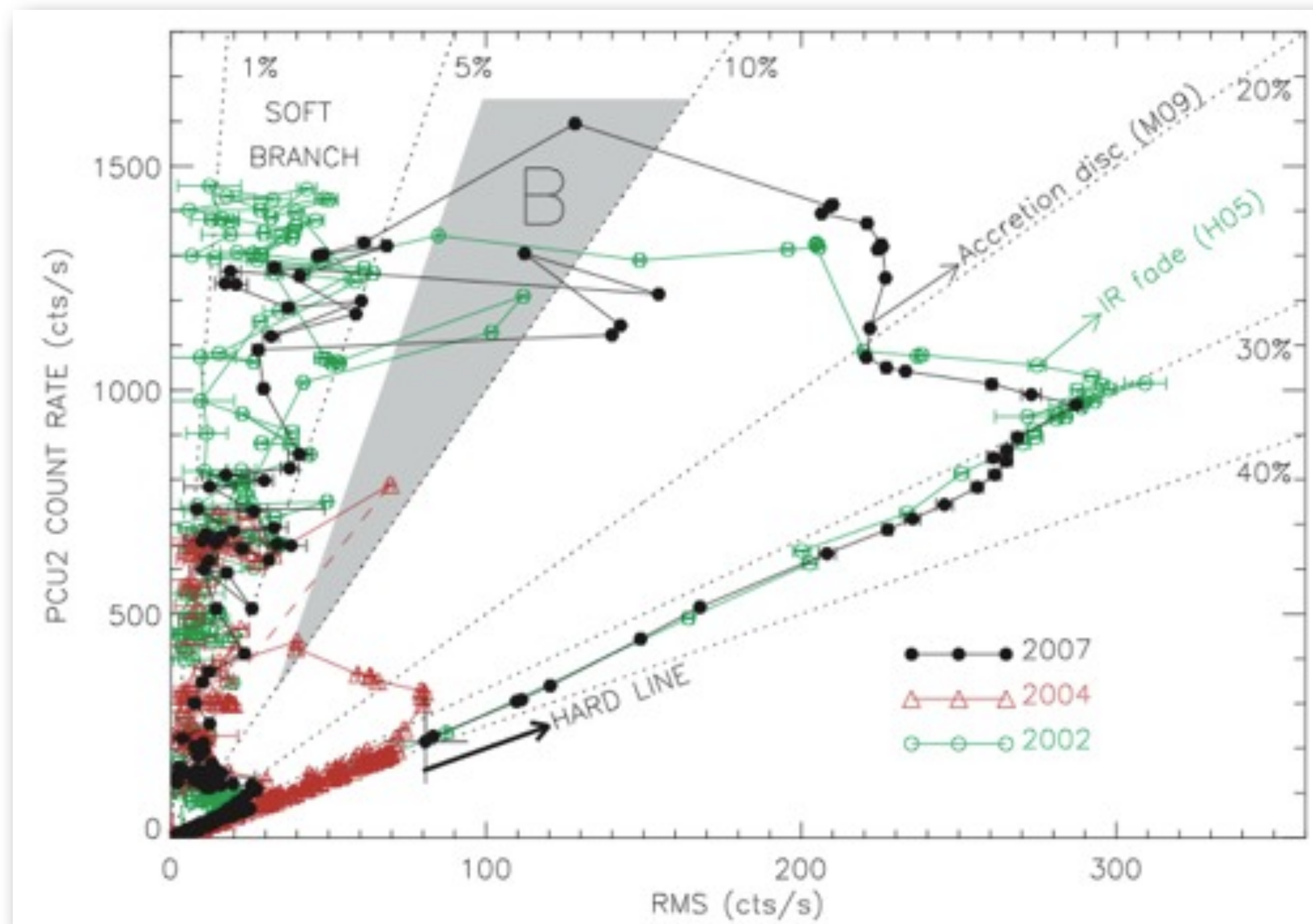
INTERMEDIATE STATES: QPOs

- Intermediate spectrum
- Intermediate rms

Transitional states



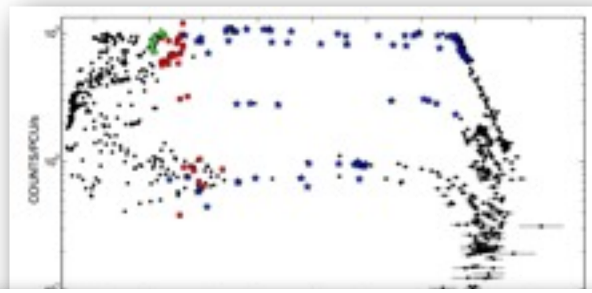
Motta et al. (2011)

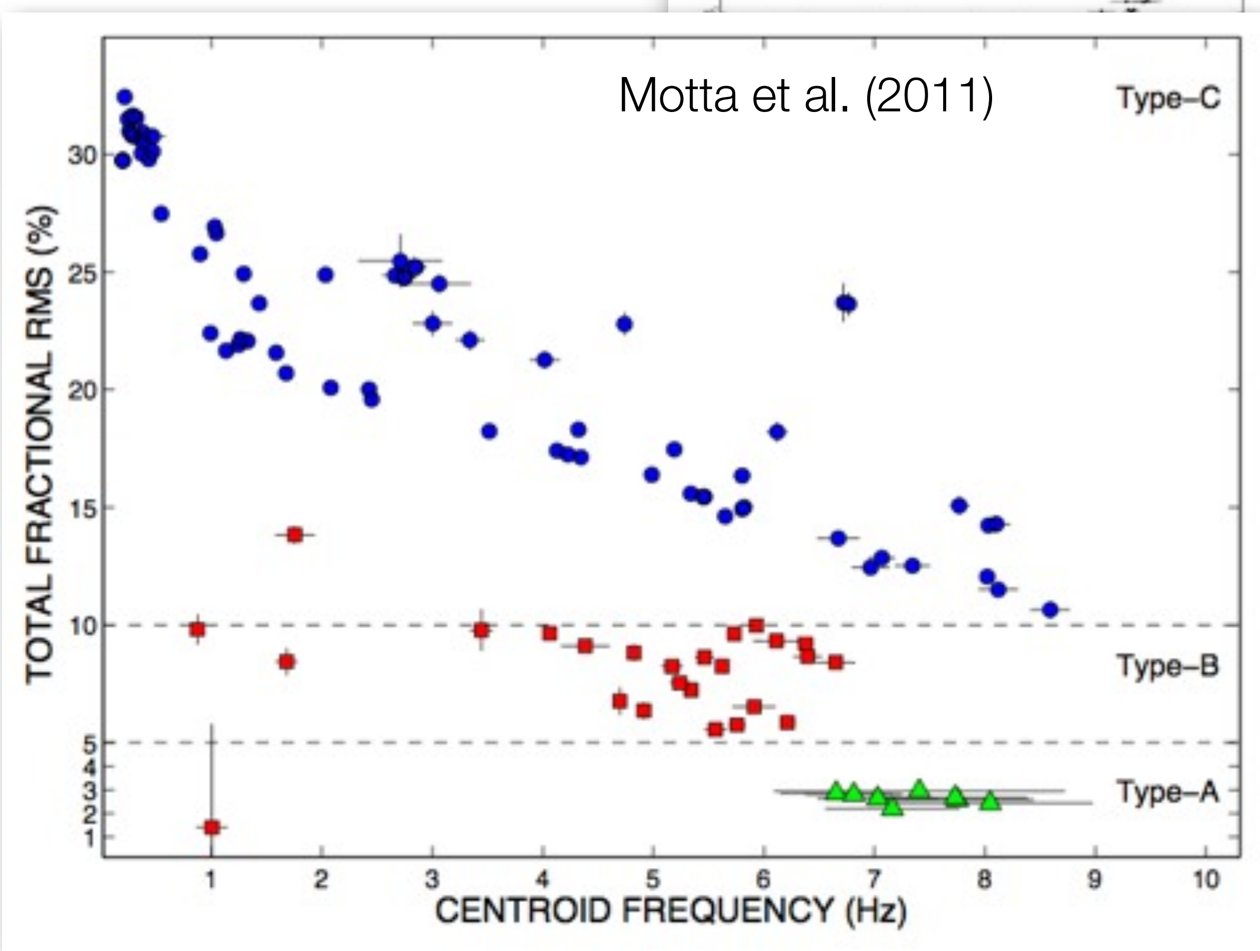


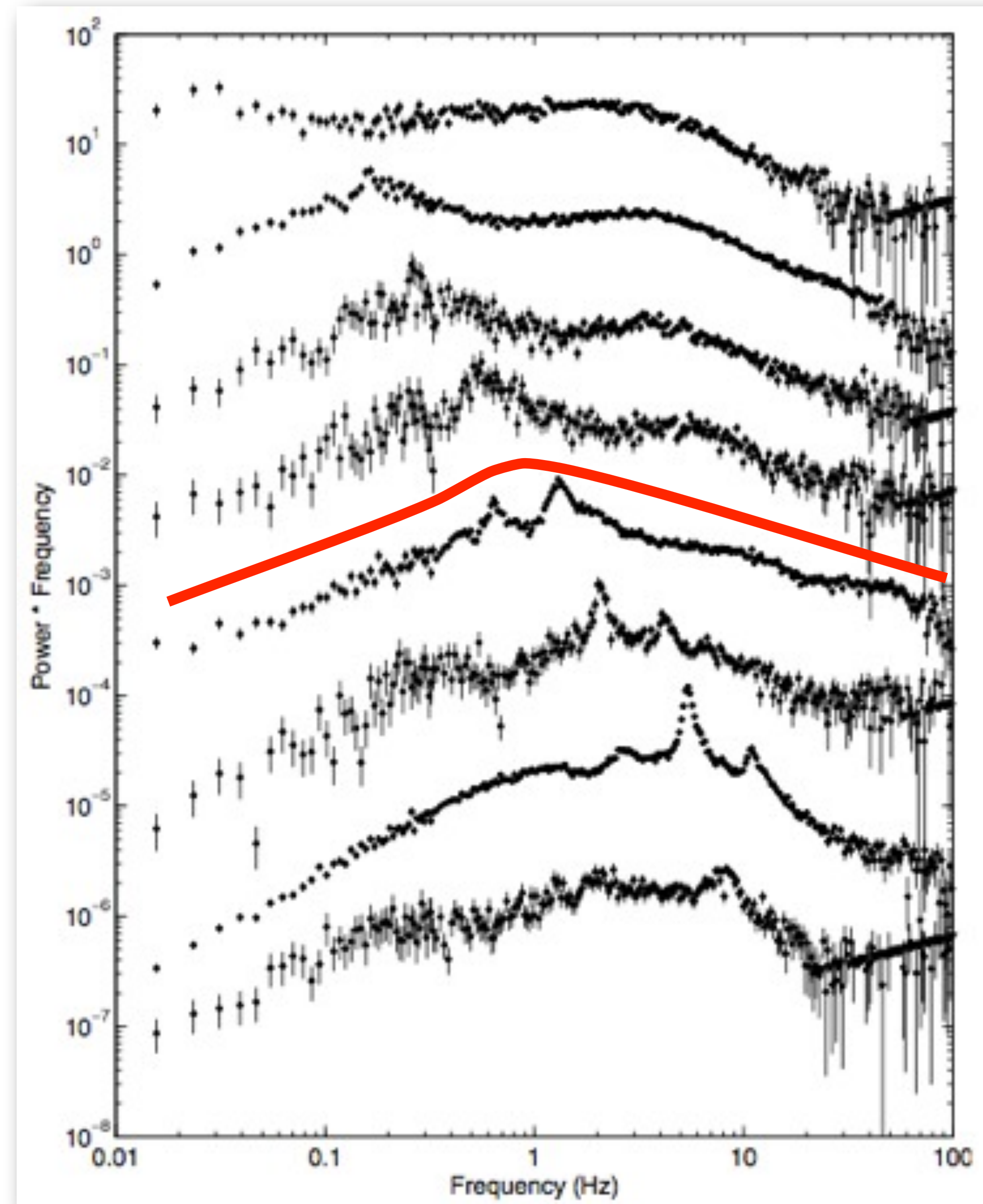
Muñoz-Darias et al. (2011)

HARD-INTERMEDIATE: QPO + NOISE

- Smooth evolution of properties - harmonics
- Frequencies increase
- Variability decreases



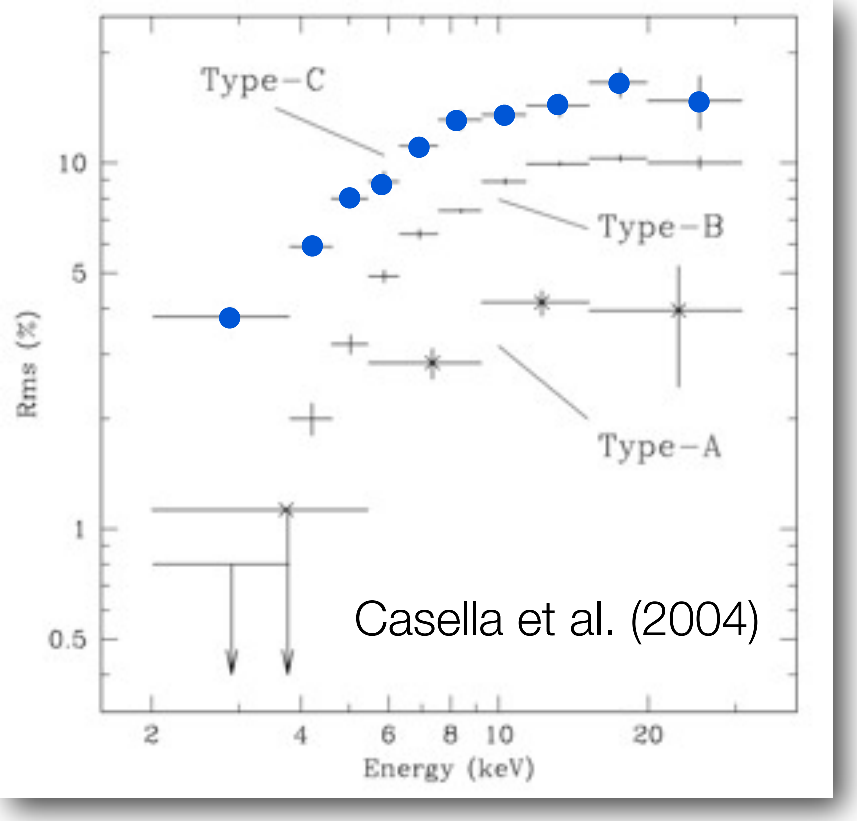


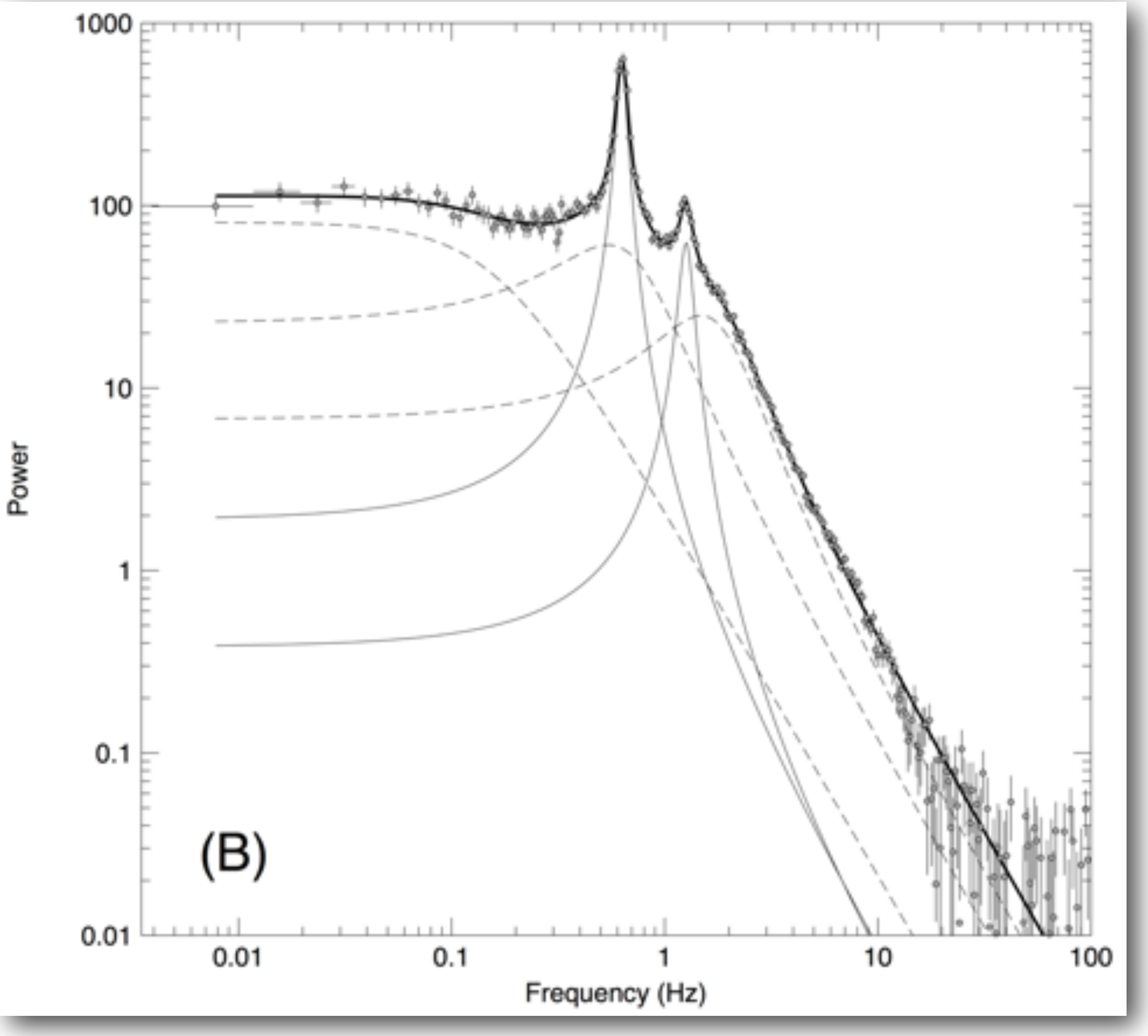


Belloni (2010)

SAME COMPONENTS - Radius connection?

- Frequency-modulated oscillation?
- Frequency range for Lense-Thirring
- Complex lags
- Hard oscillations

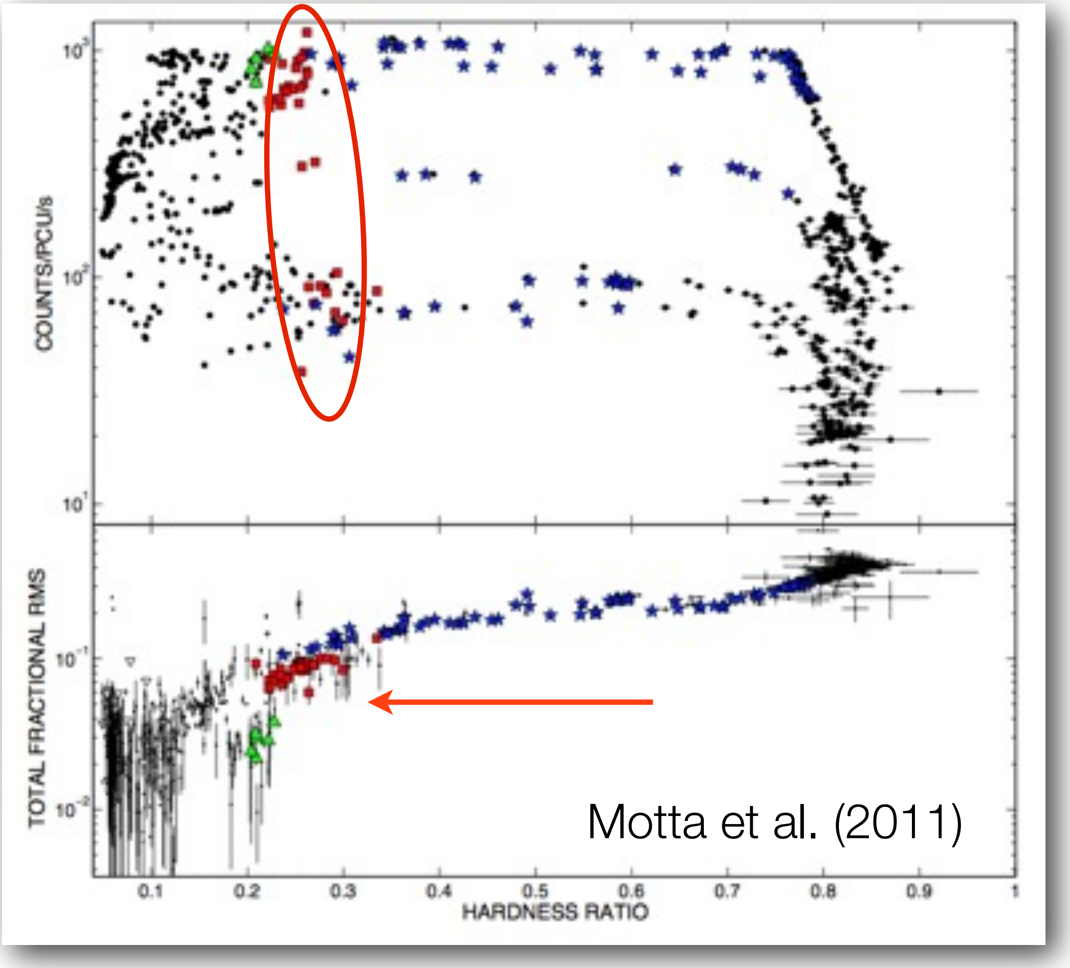


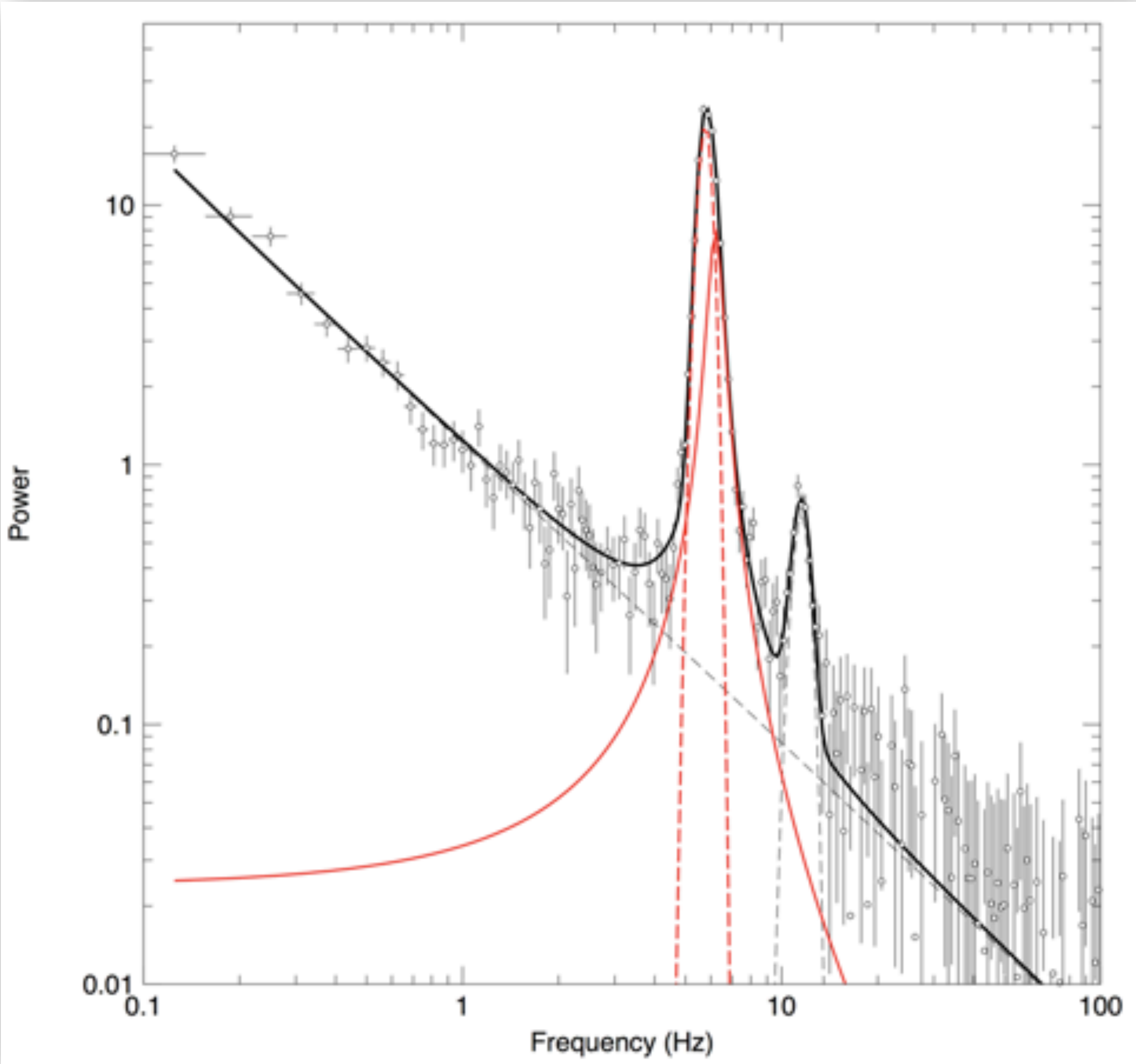


Ratti & Belloni et al. (2011)

A PECULIAR OSCILLATION

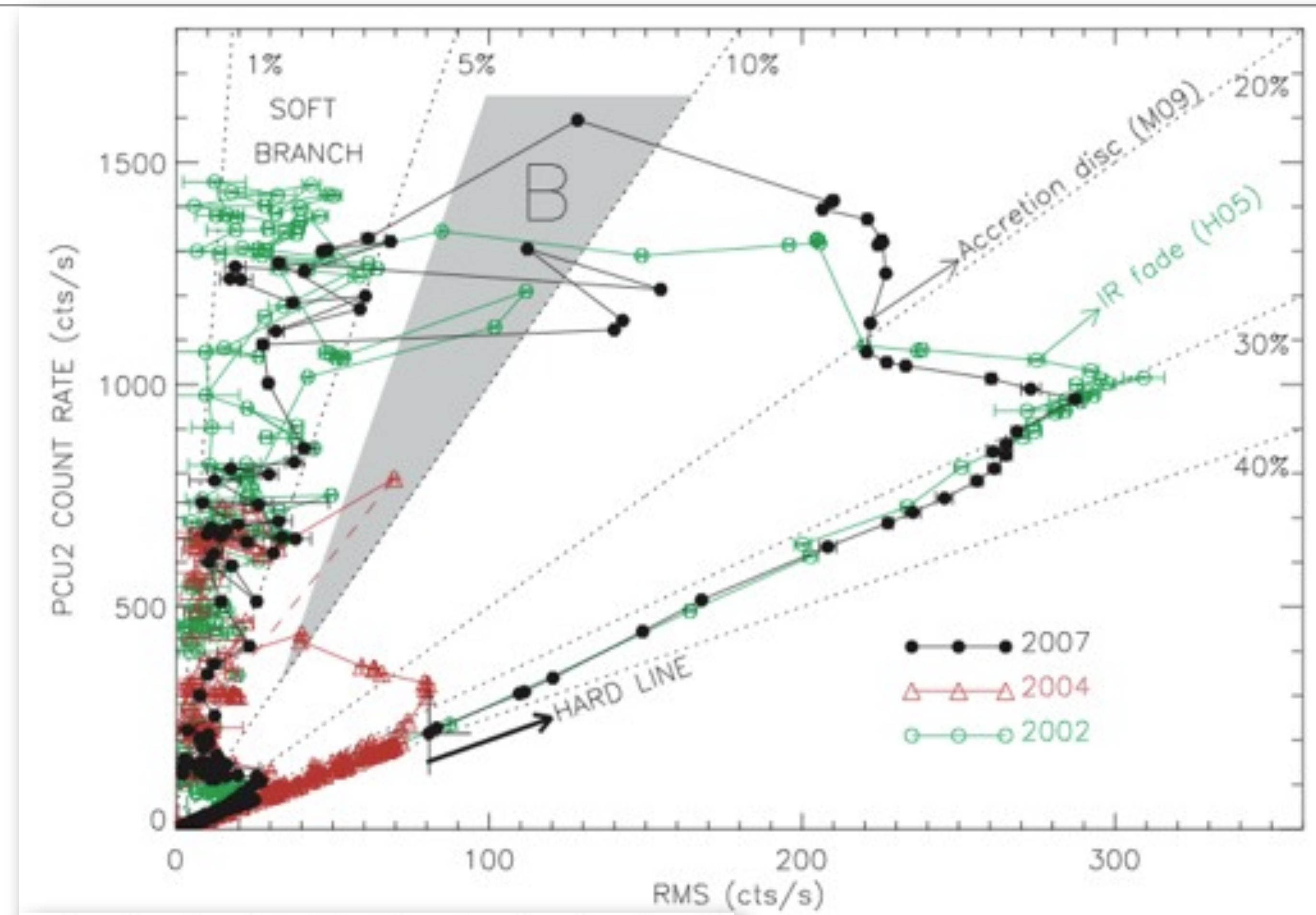
- Limited frequency range
- Less rms: no flat-top noise
- Not Lorentzian?



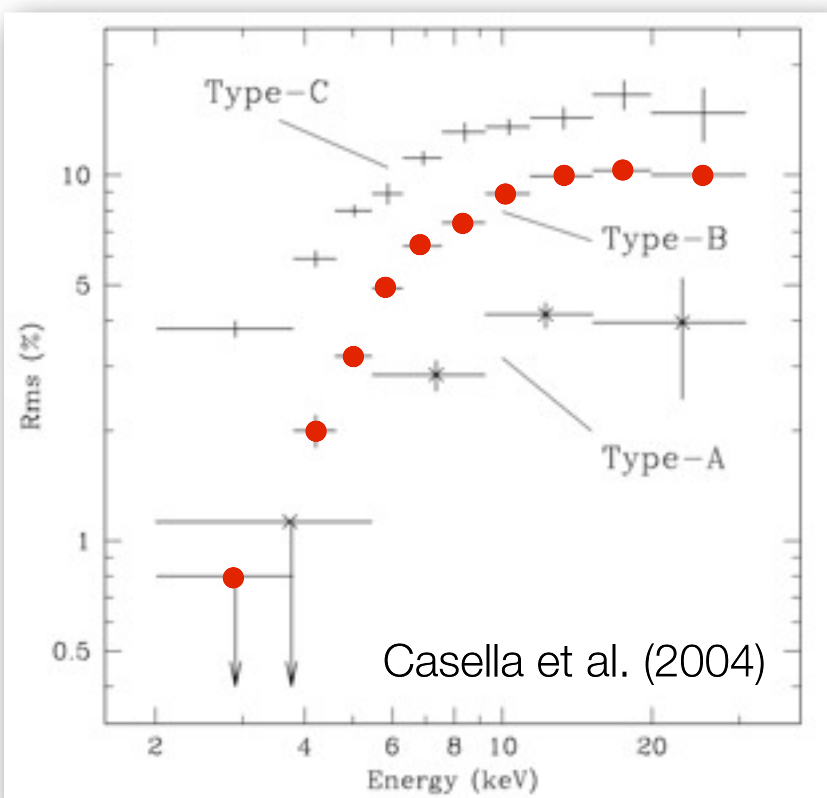


A PECULIAR OSCILLATION

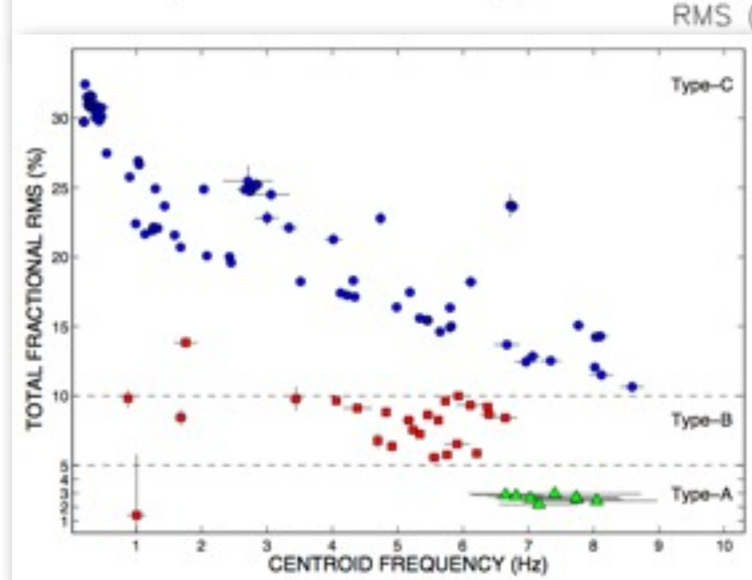
- Associated to a specific rms
- Same energy dependence
- Energy spectrum (Stiele)



Muñoz-Darias et al. (2011)



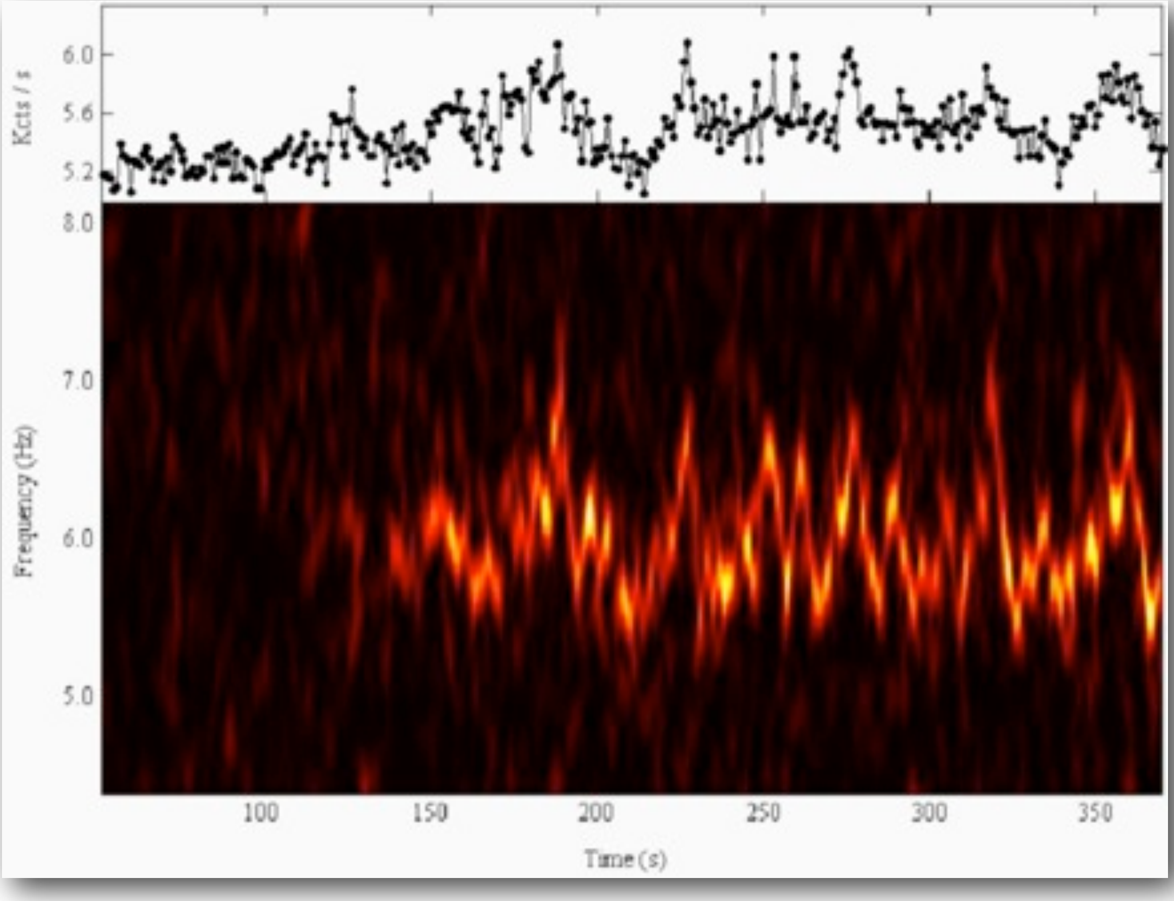
Casella et al. (2004)

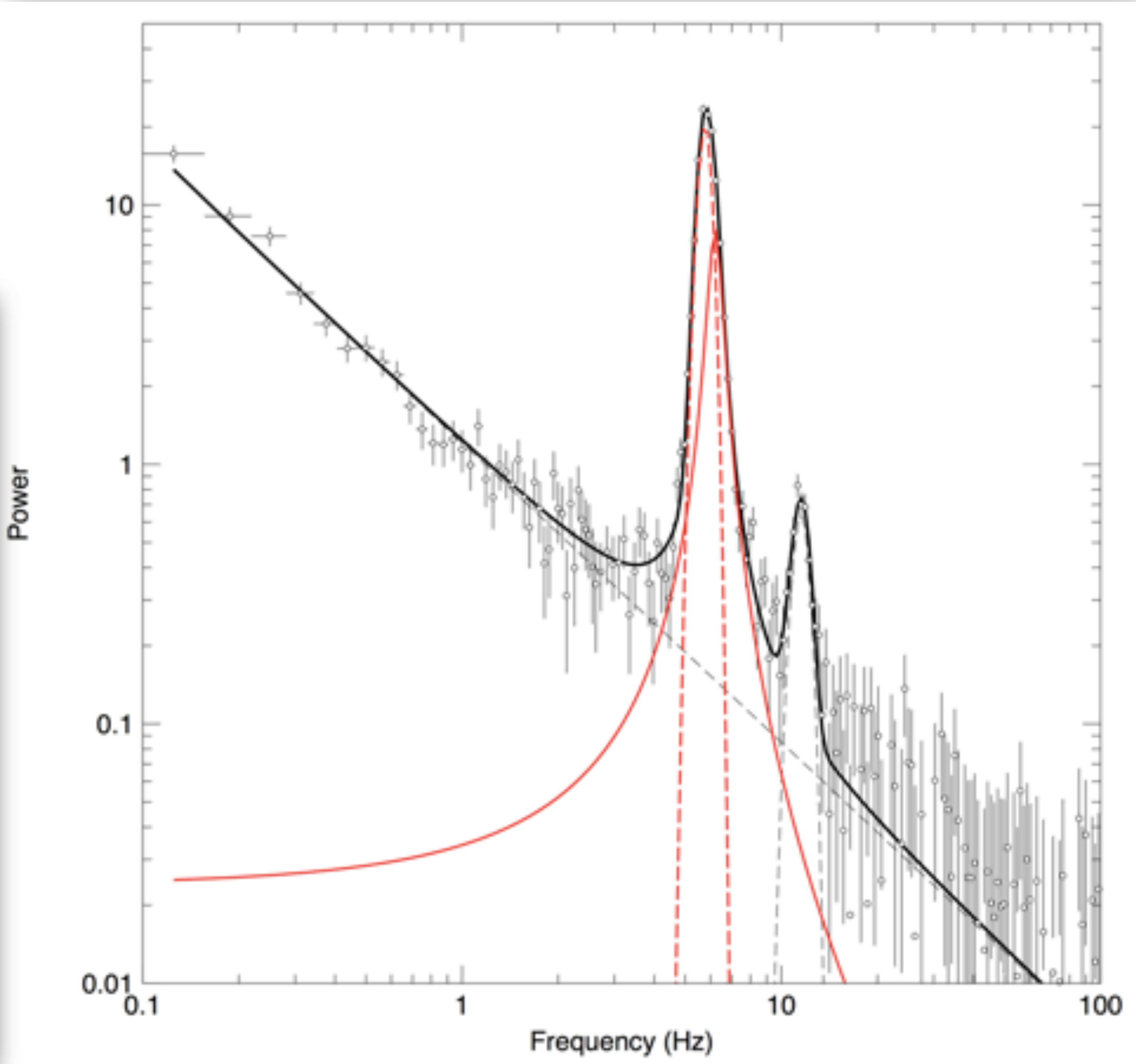


- More details: Motta's talk

NOT LORENTZIAN?

- Gaussian + wings
- Variability! And transient..

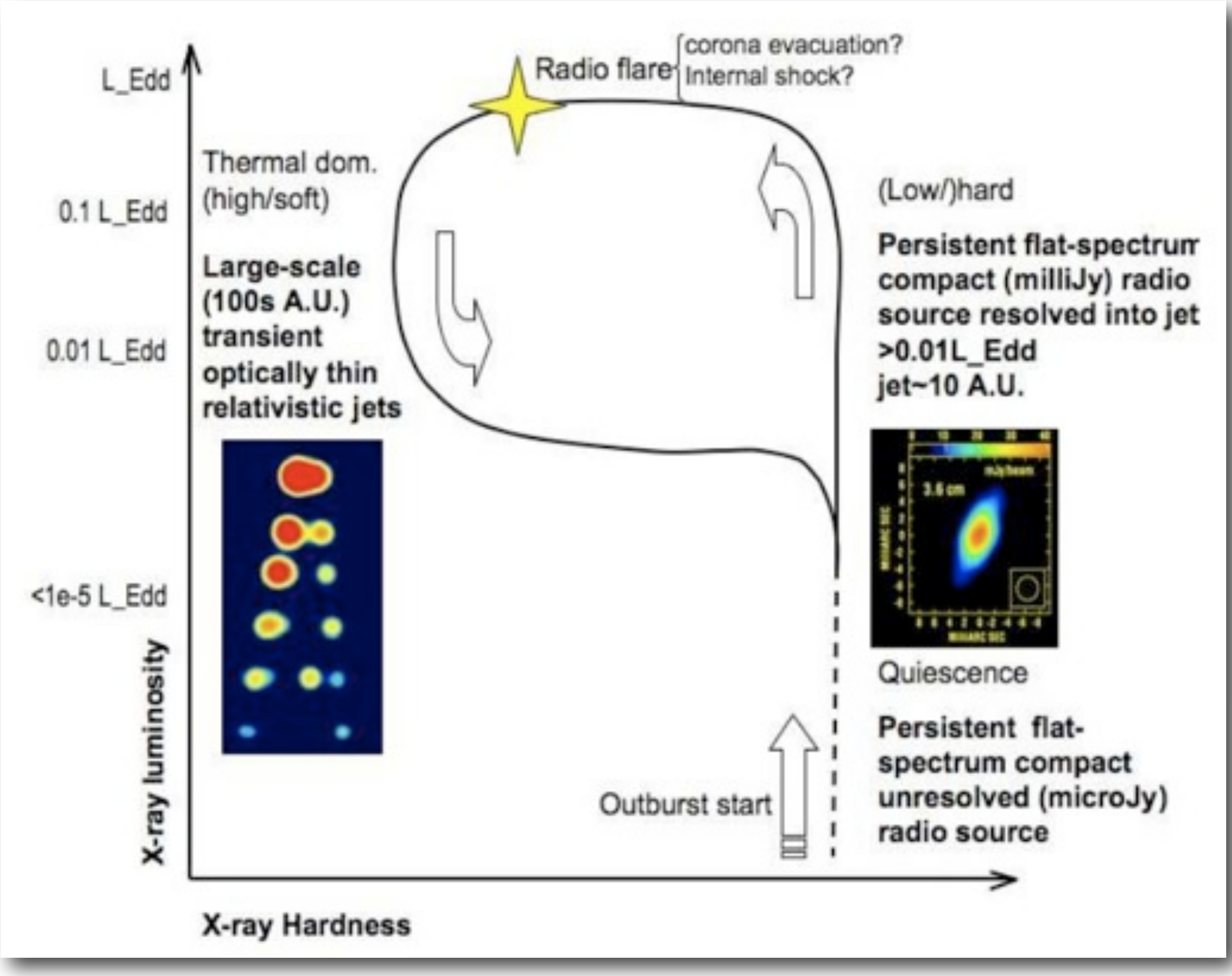




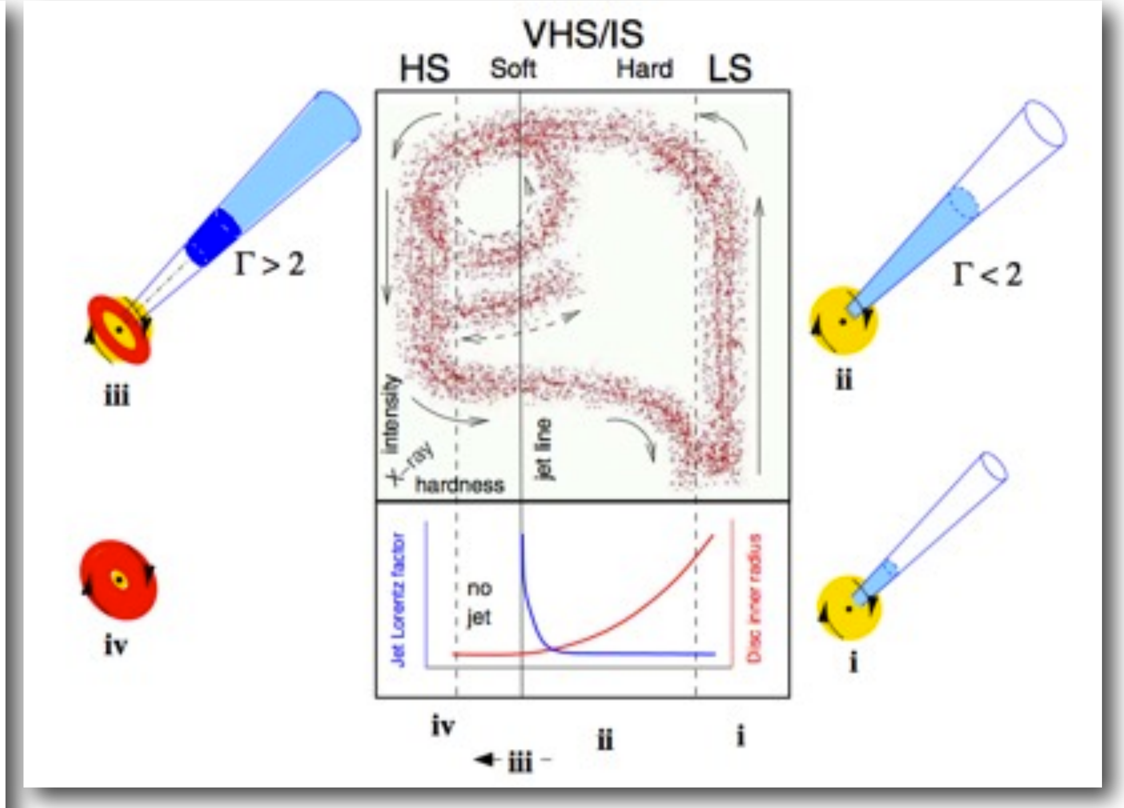
Nespoli et al. (2003)

CONNECTION WITH RADIO JETS?

Gallo (2010)



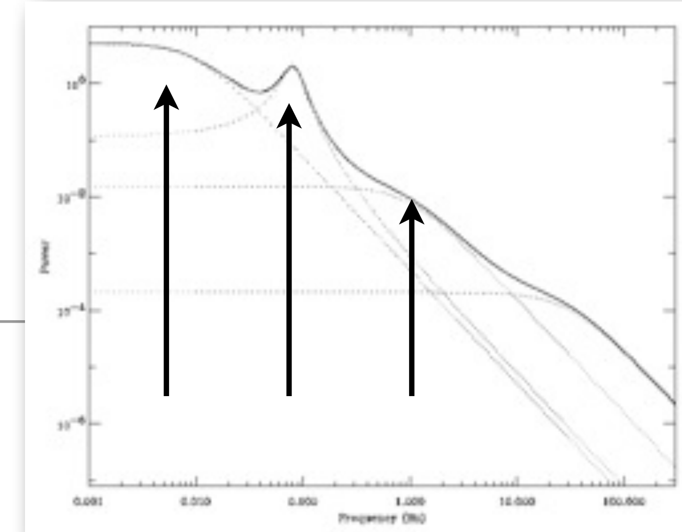
Fender, Belloni & Gallo (2004)



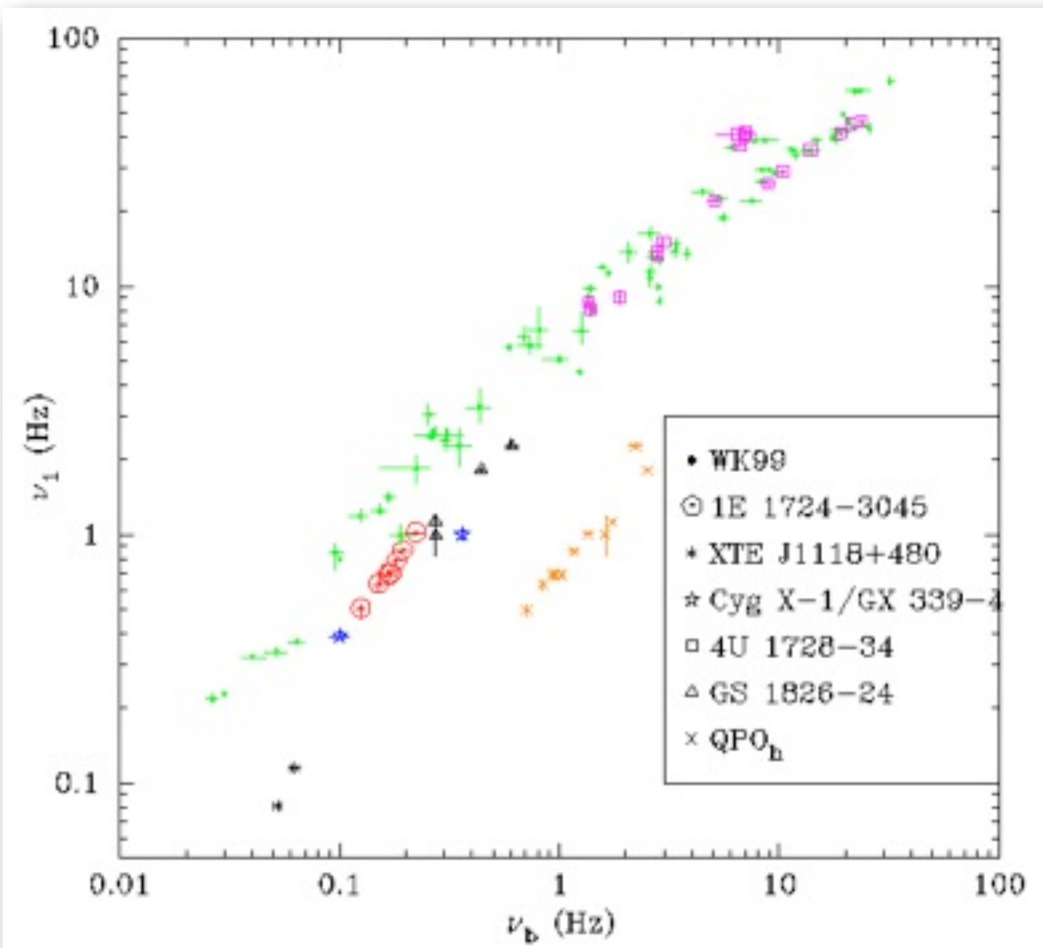
- Radio emission goes with it - ejections close to transitions
- Some variability from the jet itself?

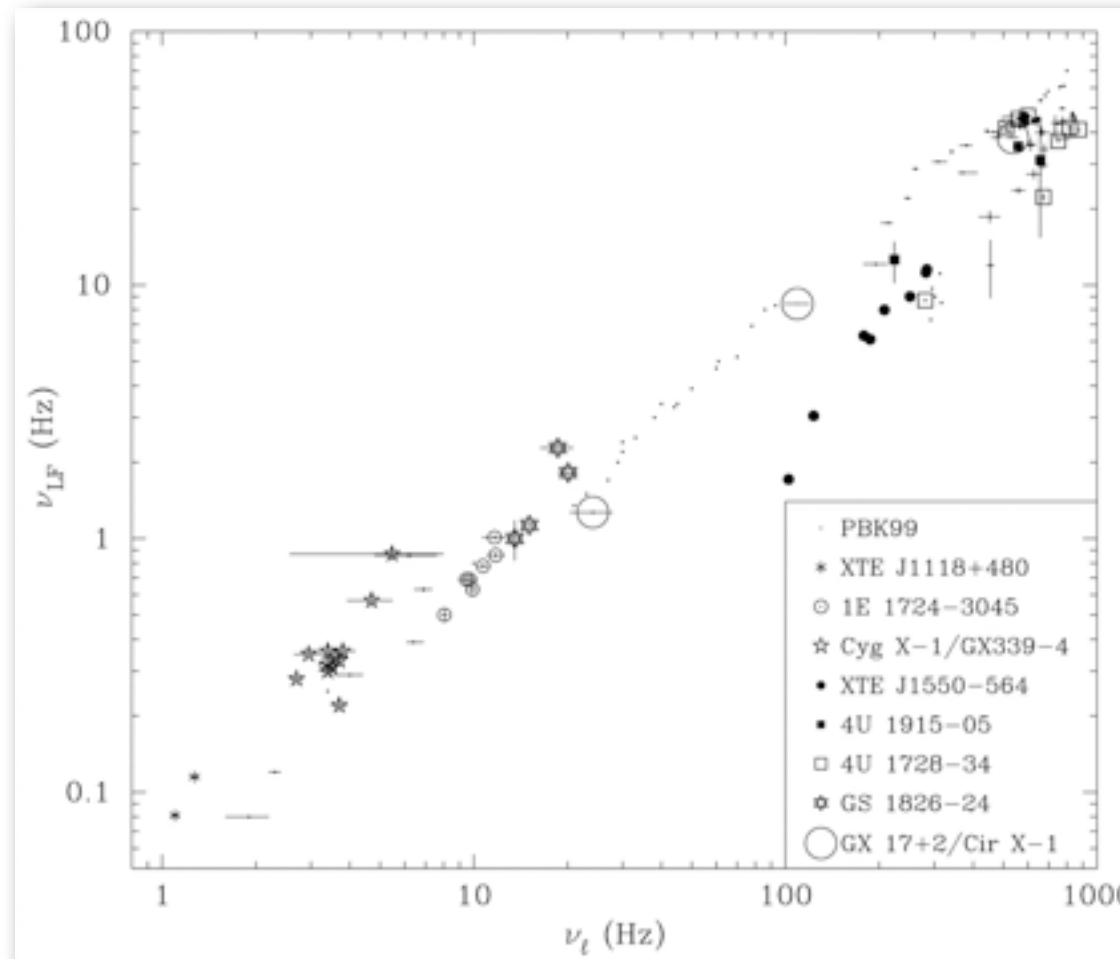
Casella's talk

FREQUENCY CORRELATIONS



- All frequencies correlate
- NS binaries follow





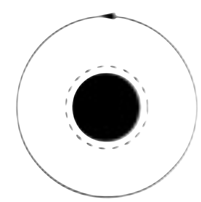
Wijnands & van der Klis (1999)

Psaltis, Belloni & van der Klis (1999)

Belloni, Psaltis & van der Klis (2002)

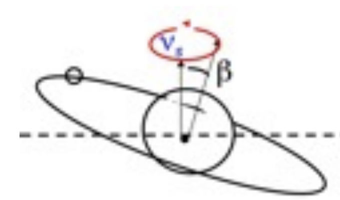
LINK TO GENERAL RELATIVITY?

- All models involve now GR frequencies
- Relativistic Precession Model Stella & Vietri (1998,1999)
  - bump 2: Keplerian

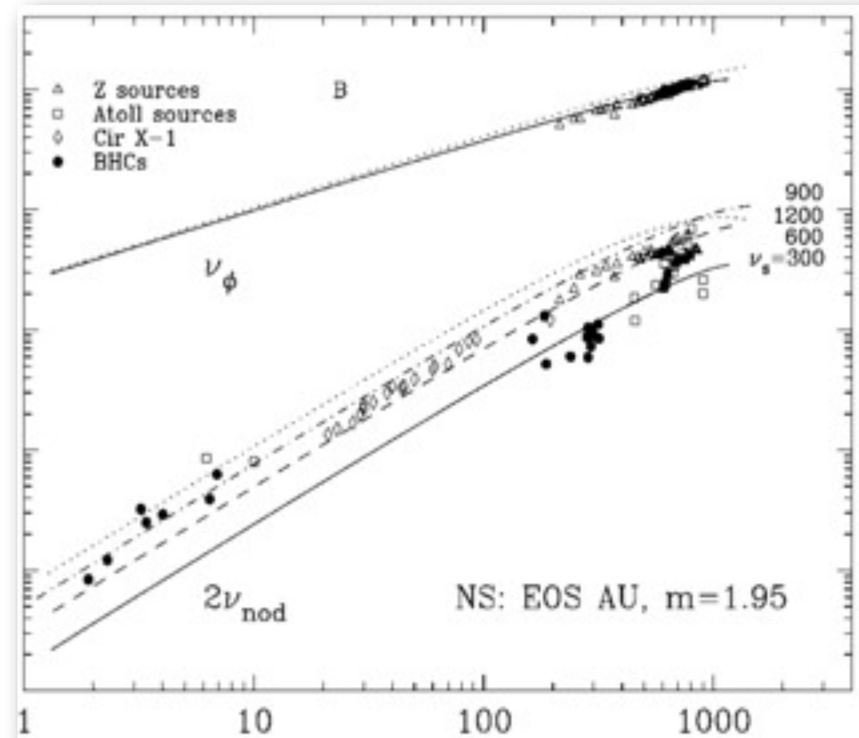


  - Bump 1: periastron precession

  - QPO: Lense-Thirring precession



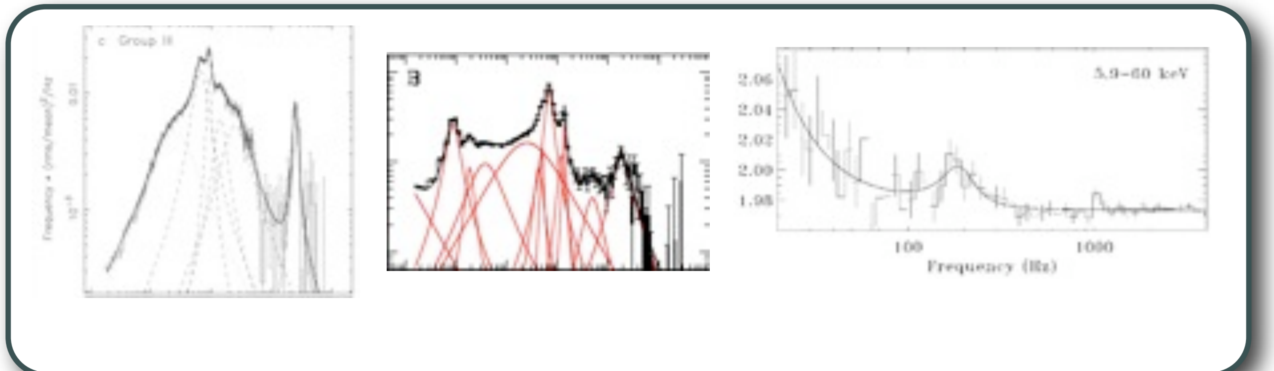
- Emission process must be added
- Type-B (peculiar) QPO does not fit

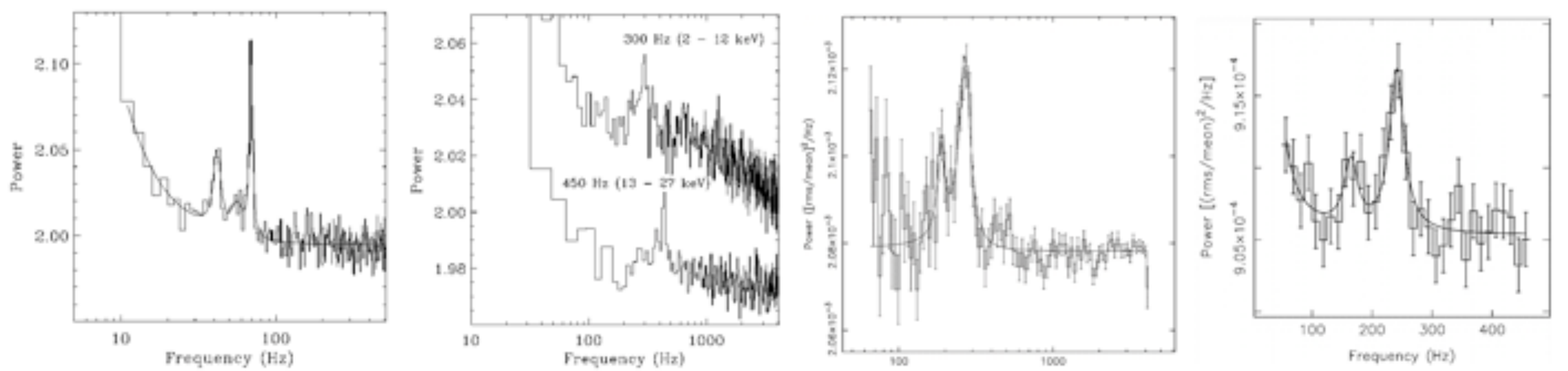


Stella et al. (1999)

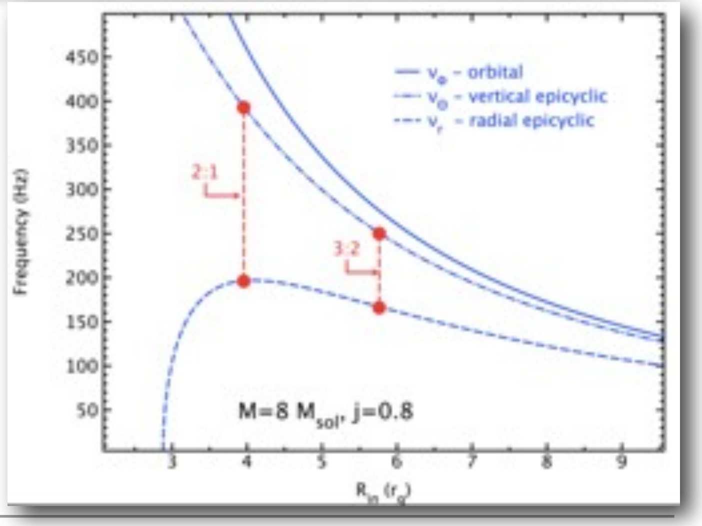
High-Frequency QPOs

- 30-450 Hz
- Very few detections
- Ratios?
- BH mass?
- Resonance model
- Too few points... some of them not even real



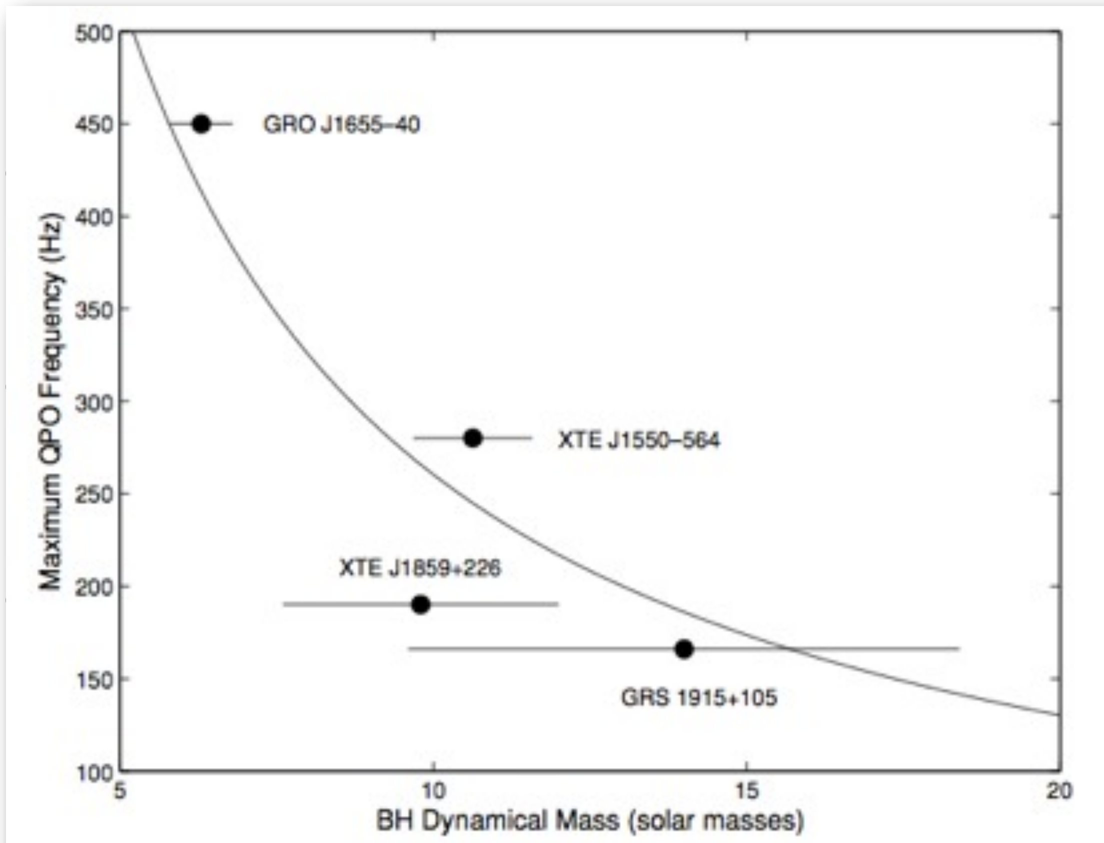


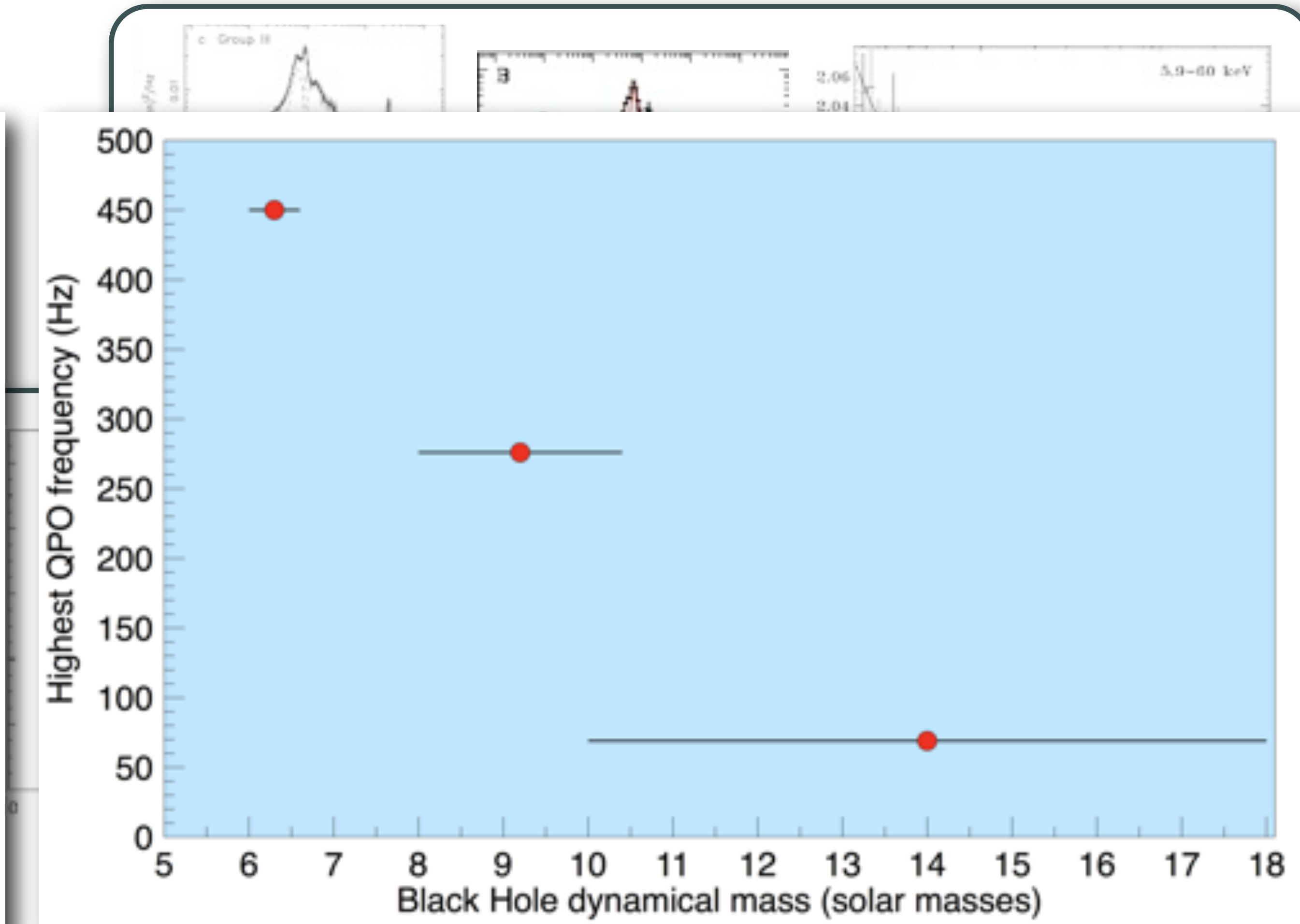
41/69 300/450 184/276 165/241



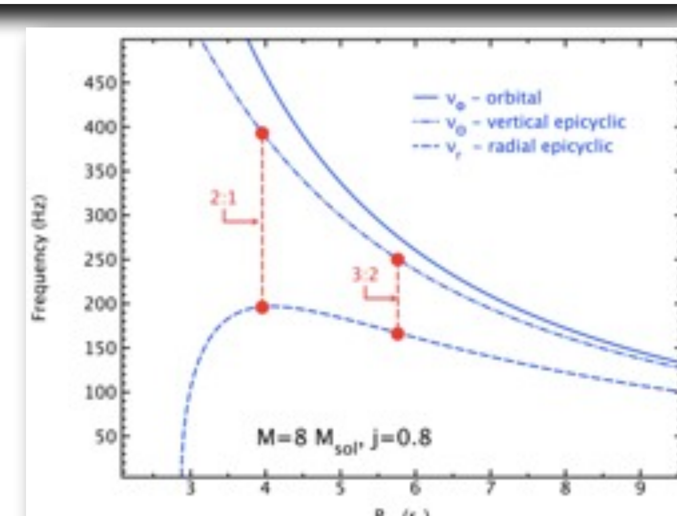
High-Frequency QPOs

- 30-450 Hz



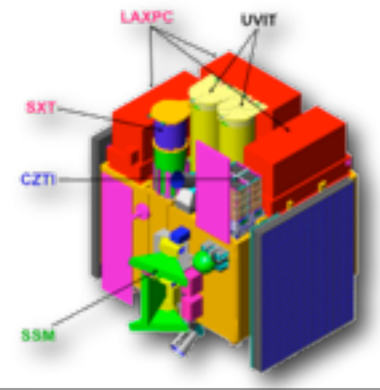


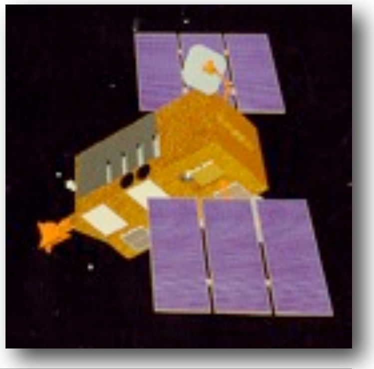
- Resonance model



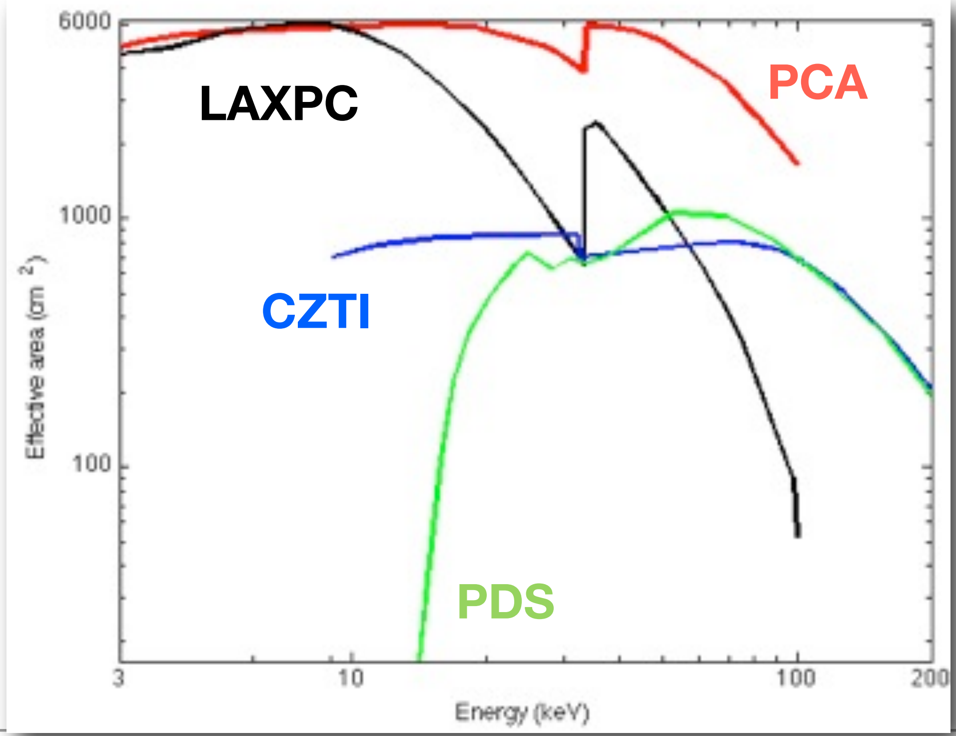
- Too few points... some of them not even real

RXTE and THE FUTURE



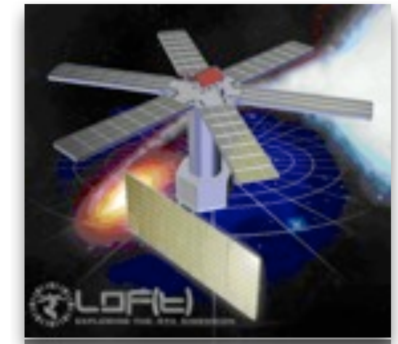


- All this thanks to 15 years of RXTE
- Timing is important!
- The near future: ASTROSAT (2011)
- Better than RXTE above > 20 keV

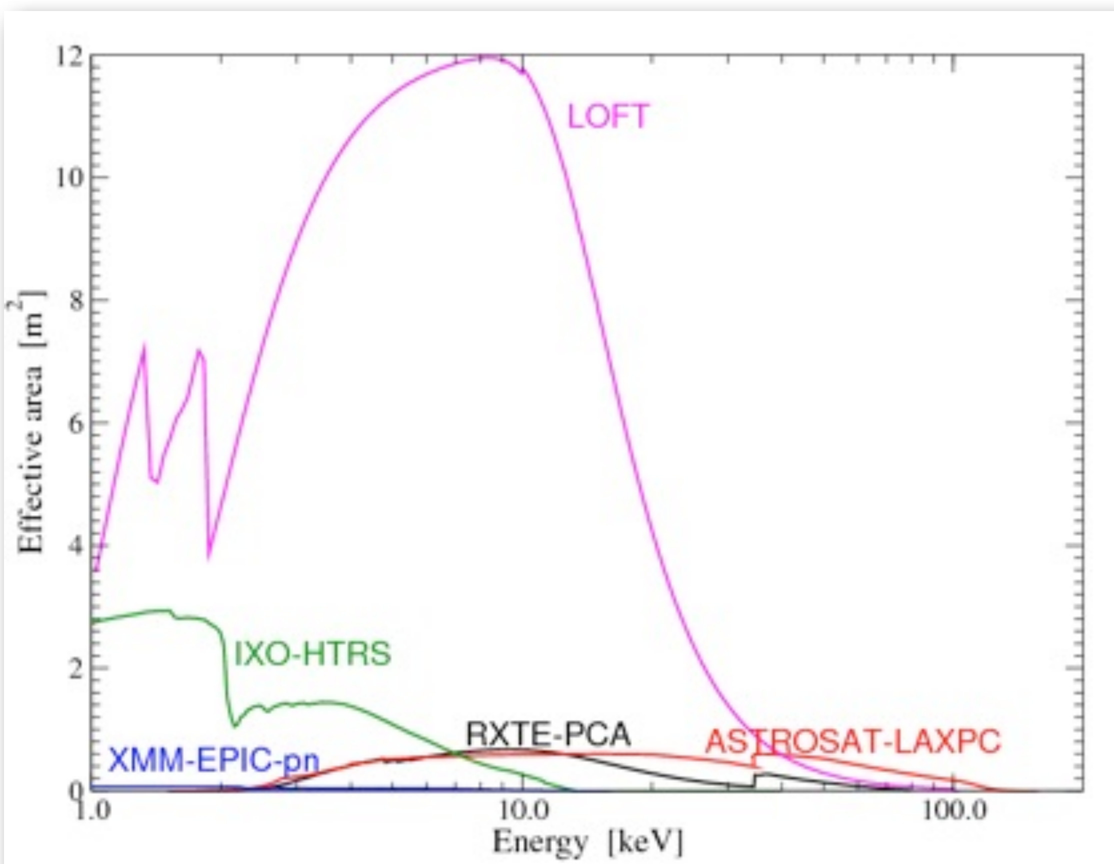


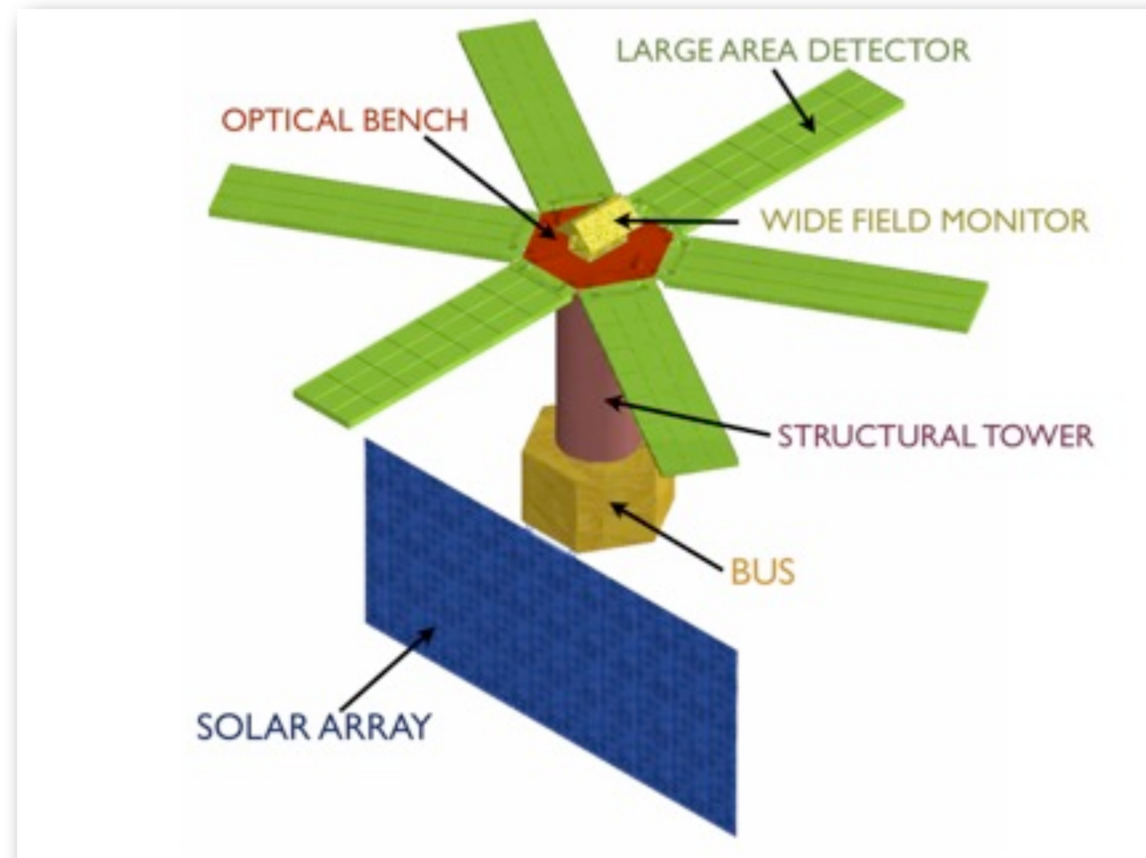
	UVIT/OPT	SXT	LAXPC	CZTI	SSM
Detector	UV: photon counting CCD Opt: CCD photometer	X-ray CCD (at the focal plane)	Proportional Counter	CdZnTe detector array	Position-sensitive proportional counter
Imaging property	imaging	imaging	non-imaging	imaging (< 100 keV)	imaging
Optics	Twin Ritchey-Chretien 2 mirror system	Conical foil (~Wolter-I) mirrors	Collimator	2-D coded mask	1-D coded mask
Bandwidth	130-320 nm	0.3-8 keV	3-100 keV	10-150 keV	2-10 keV
Geometric Area (cm^2)	1250	250	10800	1000	180
Effective Area (cm^2)	60 (depends on filter)	125@0.5 keV 200@1-2 keV 25@6 keV	6000@5-30 keV	500 (<100 keV) 1000 (>100 keV)	~40@2 keV 90@5 keV (Xe gas)
Field of View	0.50° dia	0.35° (FWHM)	1° x 1°	6° x 6° (< 100 keV) 17° x 17° (> 100 keV)	
Energy Resolution	<100 nm (depends on filter)	2%@6 keV	9%@22 keV	5%@10 keV	19%@6 keV
Angular Resolution	1.8 arcsec	3-4 arcmin (HPD)	1-5 arcmin in scan mode only	8 arcmin	~10 arcmin
Time resolution	10 ms	2.6s, 0.3s, 1ms	10 microsec	1 ms	1 ms
Typical obs. time per target	30 min	0.5 - 1 day	1 - 2 days	2 days	5 min
Sensitivity (Obs. Time)	21^{st} magnitude (5σ) (1800s)	10 microCrab (5σ) (10000s)	0.1 milliCrab (3σ) (1000s)	0.5 milliCrab (3σ) (1000s)	~30 milliCrab (3σ) (300s)

LOFT



- Selected for assessment by ESA
- Launched in 2020
- 12 m^2 effective area





LOFT: BH QPOs

- Pinning of GR frequencies
- Identification of ν_K and ISCO
- Additional peaks?
- BH spin measurement from radius
- Feedback on accretion studies