Energy dependence of variability in low mass X-ray binaries

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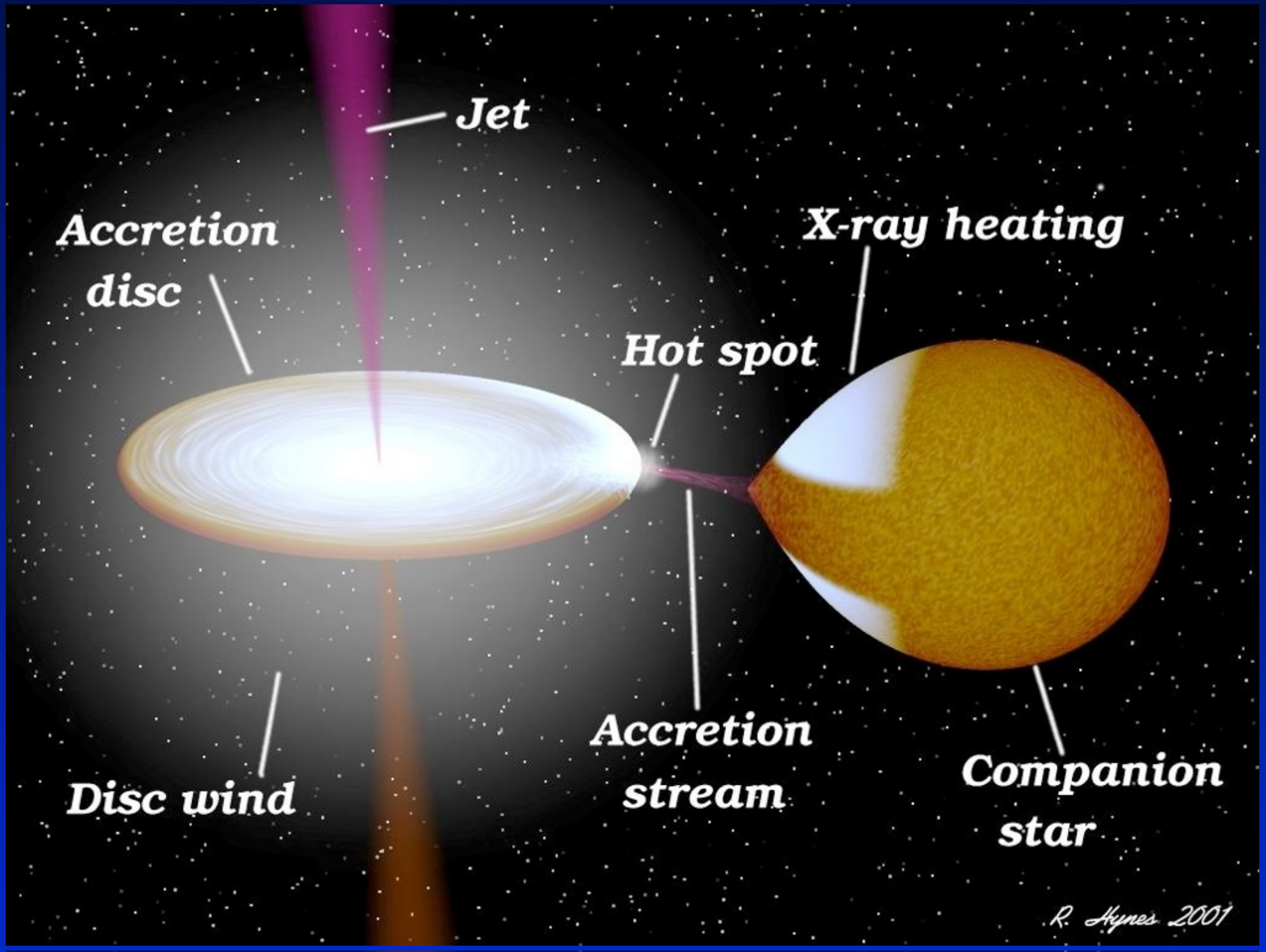
- The observed power spectral shape depends on the energy band, and hence spectral component, we are looking at.

Low mass black hole X-ray binary

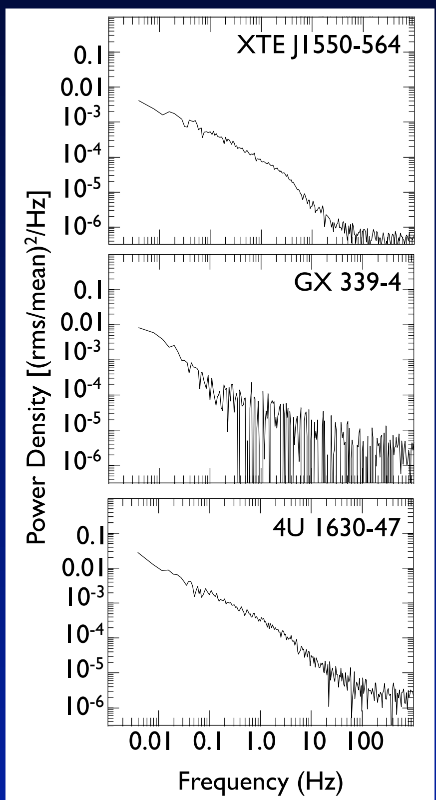
- central object is a stellar mass (3-20 $M_\odot$) black hole
- accretes matter from its low mass companion star ($M_s \lesssim 1\ M_\odot$, type A,F,G,K,M) through a disc (Roche-lobe overflow)
- X-ray emitting region close to event horizon R_S



State of the art

Timing properties of BH XRBs as seen with RXTE

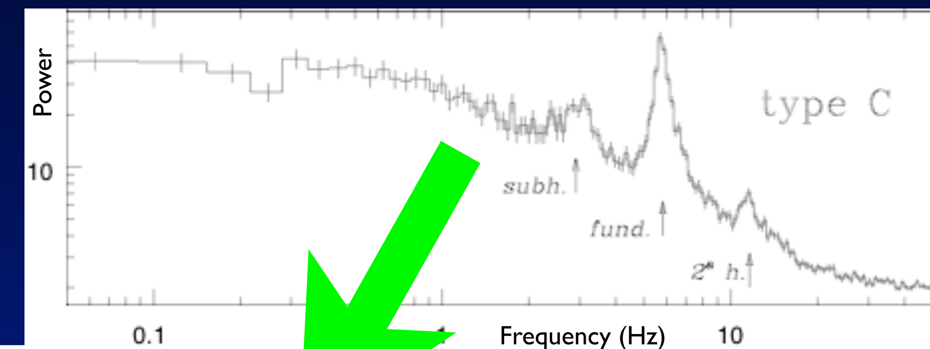
(3 - 20 keV)



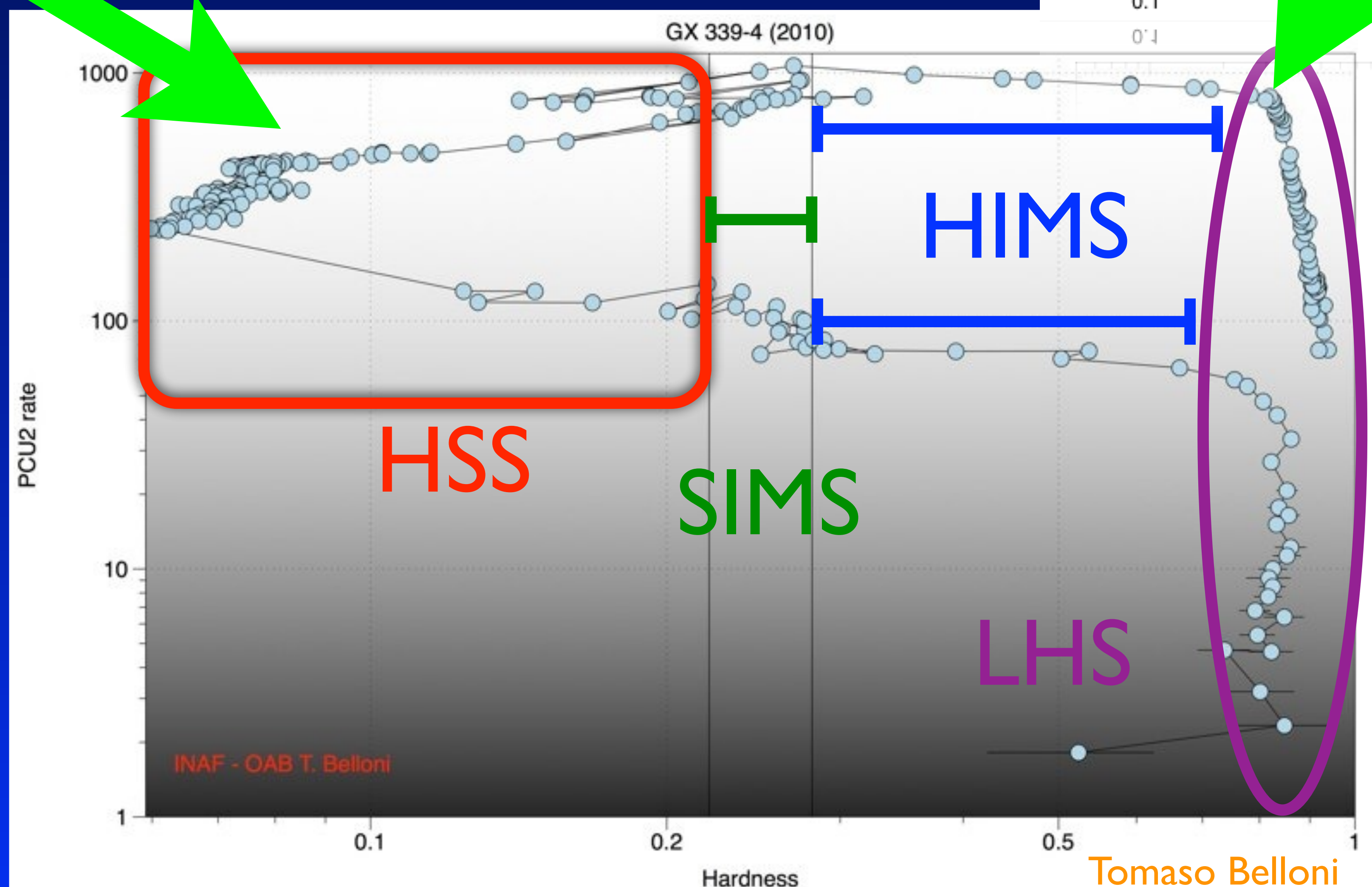
McClintock & Remillard 2006 Black Hole binaries

power law noise

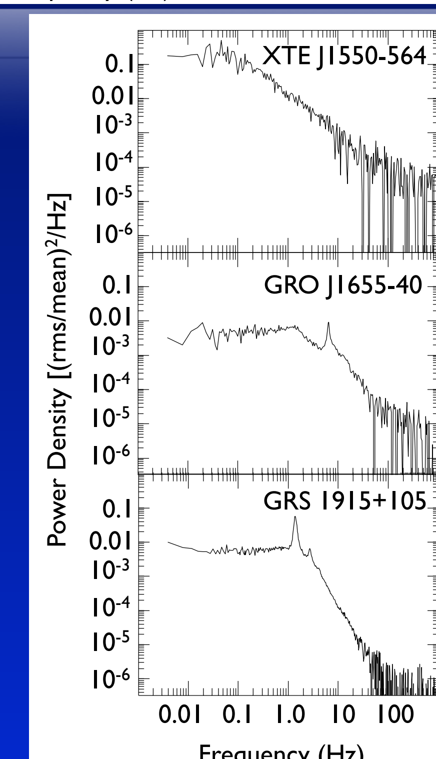
Casella et al. 2004, A&A, 426, 587



hardness - intensity diagram



Tomaso Belloni



McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

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PDS of GRS 1915+105

- requires its own classification scheme ➜ shows 12 variability classes

Belloni et al. 2000, A&A, 355, 271

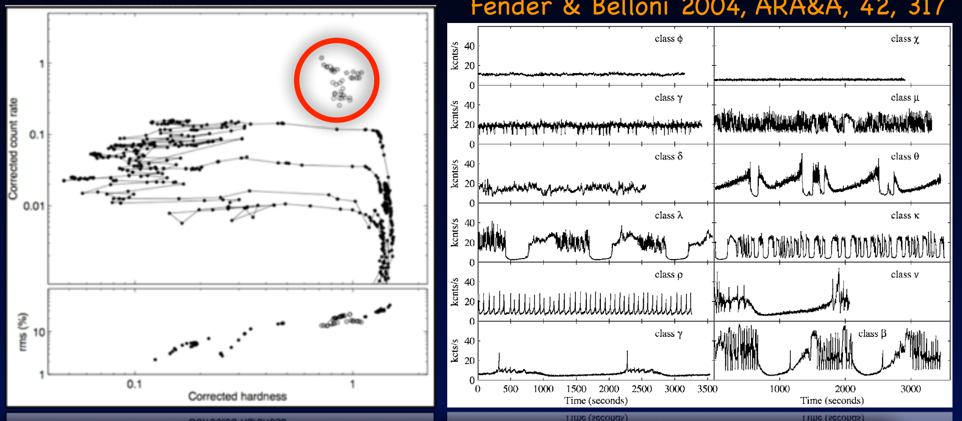
- XMM-Newton observations (2003 & 2004) during χ variability class ≈ conventional "hard" state

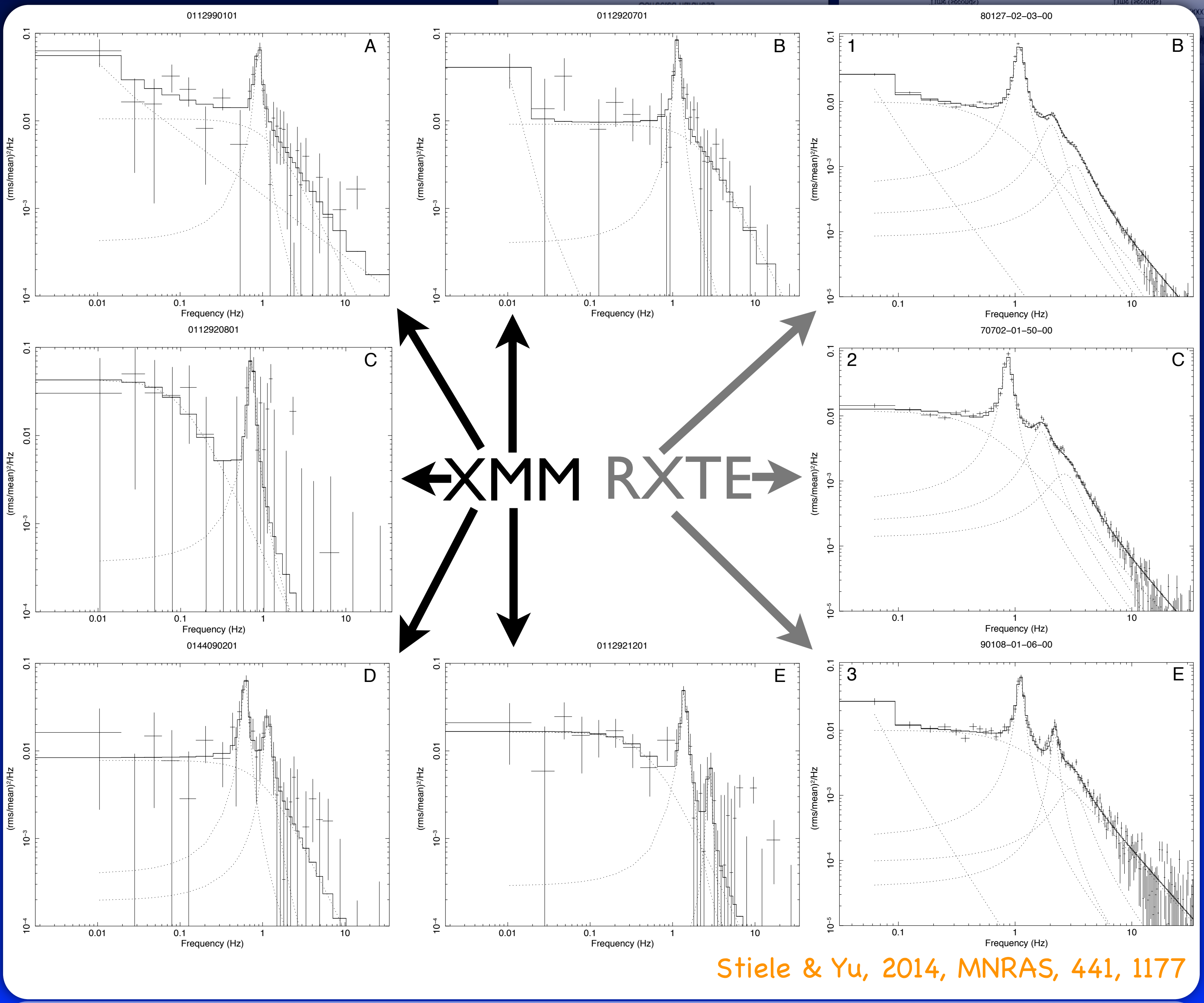
Reig et al. 2003, A&A, 412, 229; van Oers et al. 2010, MNRAS, 409, 763

- band limited noise and quasi-periodic oscillation (+ upper harmonics)
- overall shape agrees between XMM and RXTE
- source highly absorbed below 1.5 keV Martocchia et al. (2006, A&A, 448, 677)

- 4.5 - 8 keV
- (4.9 - 14.8 keV)

Fender & Belloni 2004, ARA&A, 42, 317

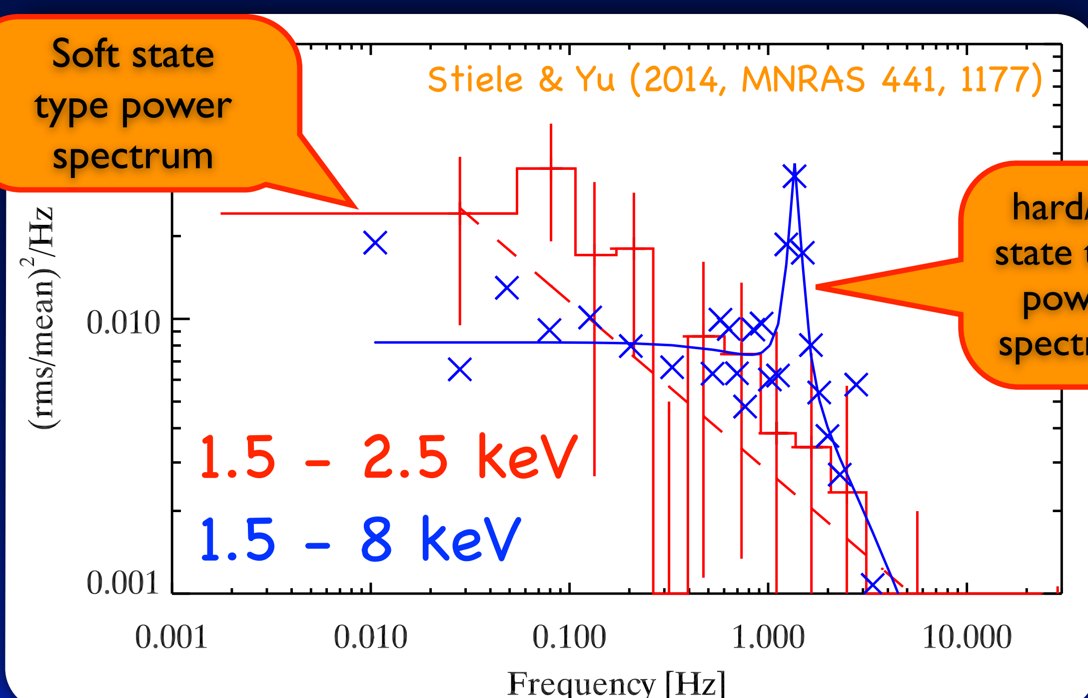




Stiele & Yu, 2014, MNRAS, 441, 1177

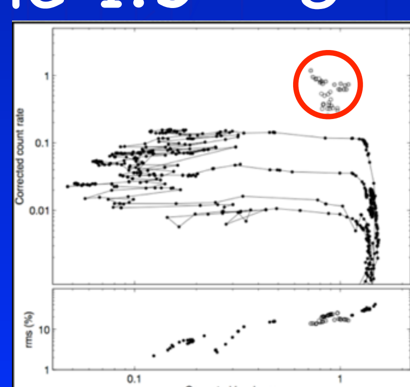
PDS: Zoom in Low Energies

- 1.5 – 2.5 keV
- decent fit with power law

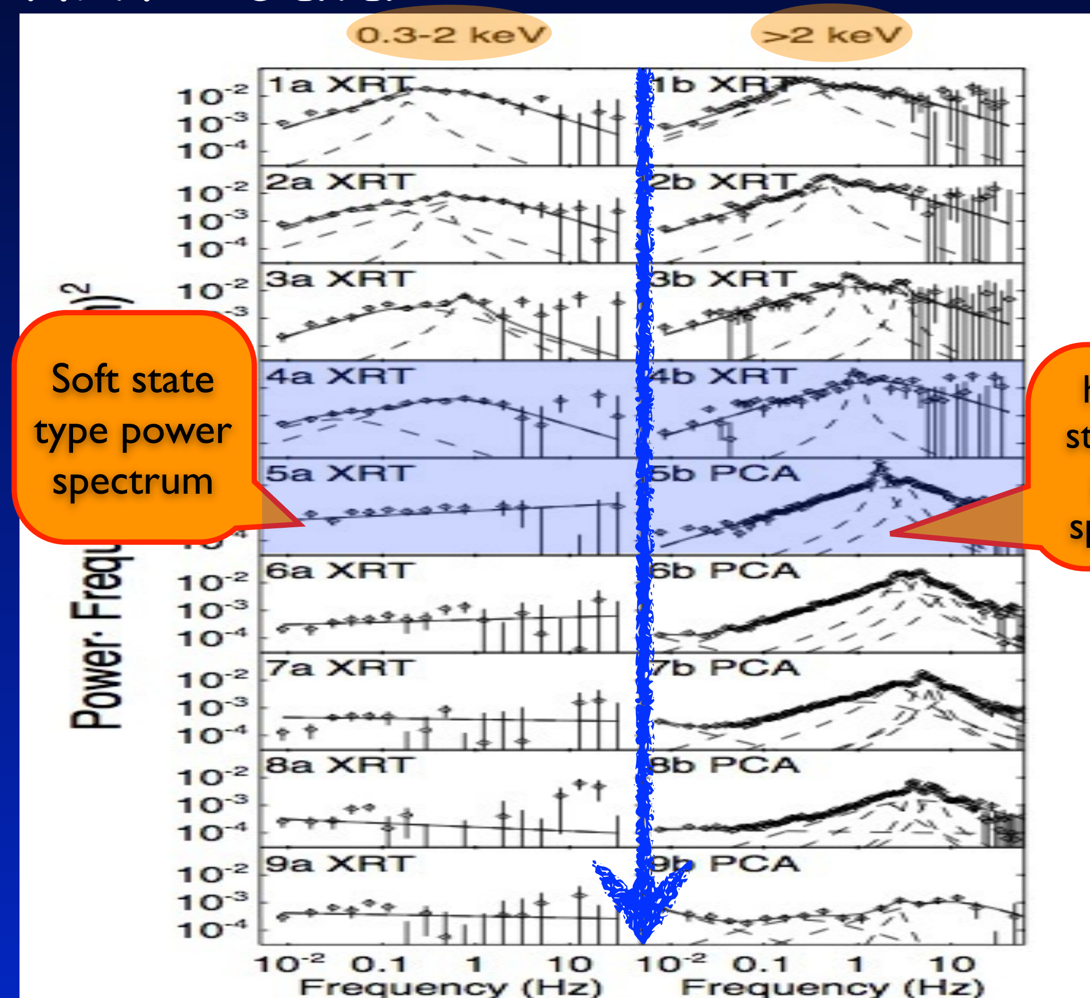


- using a ZC-Lorentzian break frequency at ~0.45 Hz, while at ~3.35 Hz in the 1.5 – 8 keV band

same observations; same state



- similar result found for MAXI J 1659-152 based on Swift and RXTE data Yu & Zhang 2013, ApJ, 770, 135



- **fits into the picture of a relation between State C and the hard intermediate state**

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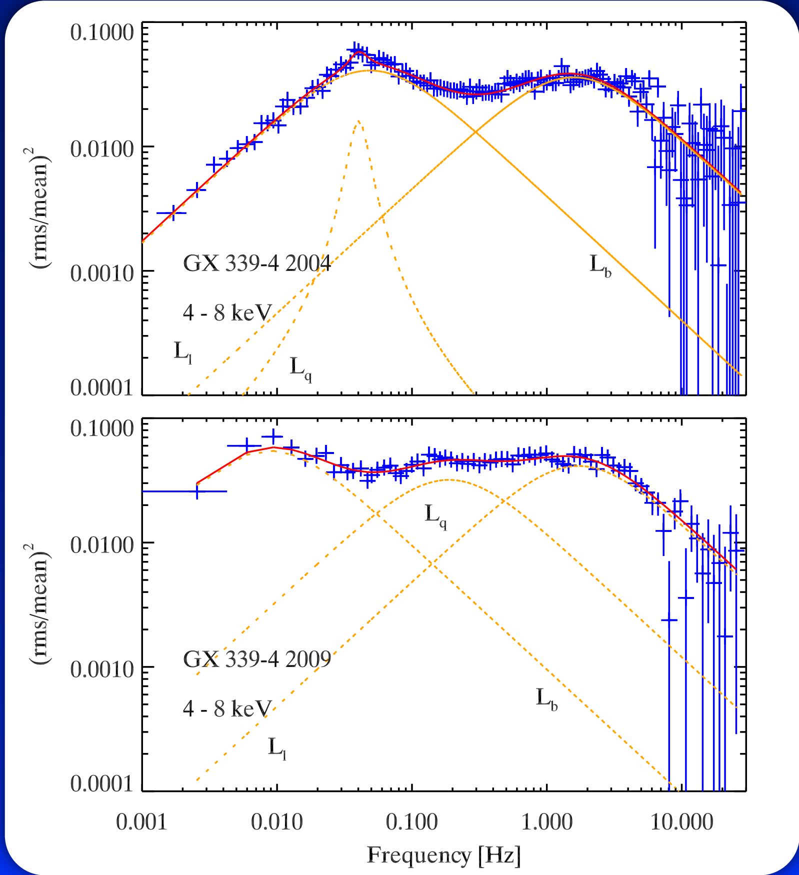
- The observed power spectral shape depends on the energy band, and hence spectral component, we are looking at. Stiele & Yu 2014, MNRAS 441, 1177

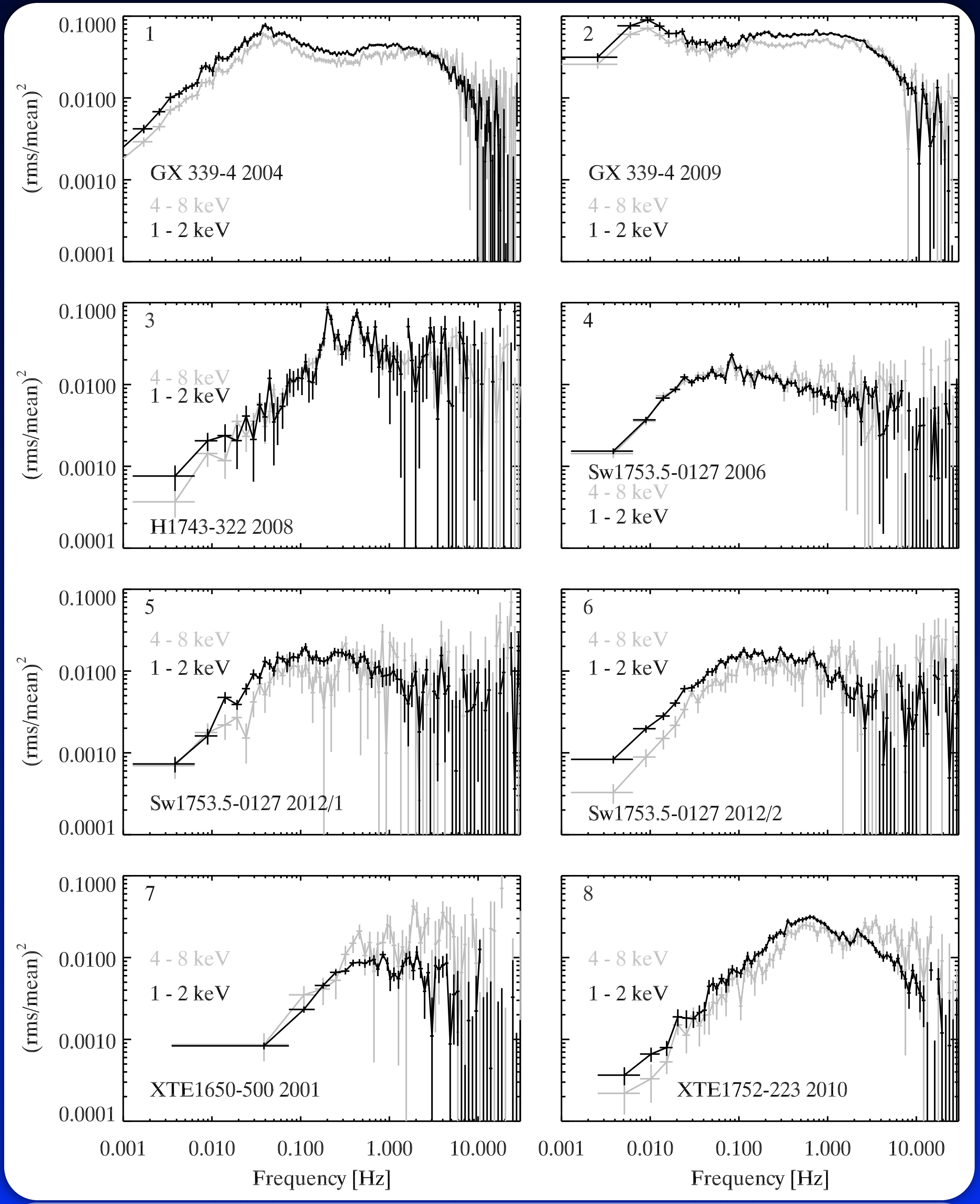
PDS in low hard state

- sample of eight observations of 5 different BH XRBs
- two energy bands 1-2 keV and 4-8 keV

Stiele & Yu 2015, MNRAS 452, 3666



Stiele & Yu 2015, MNRAS 452, 3666



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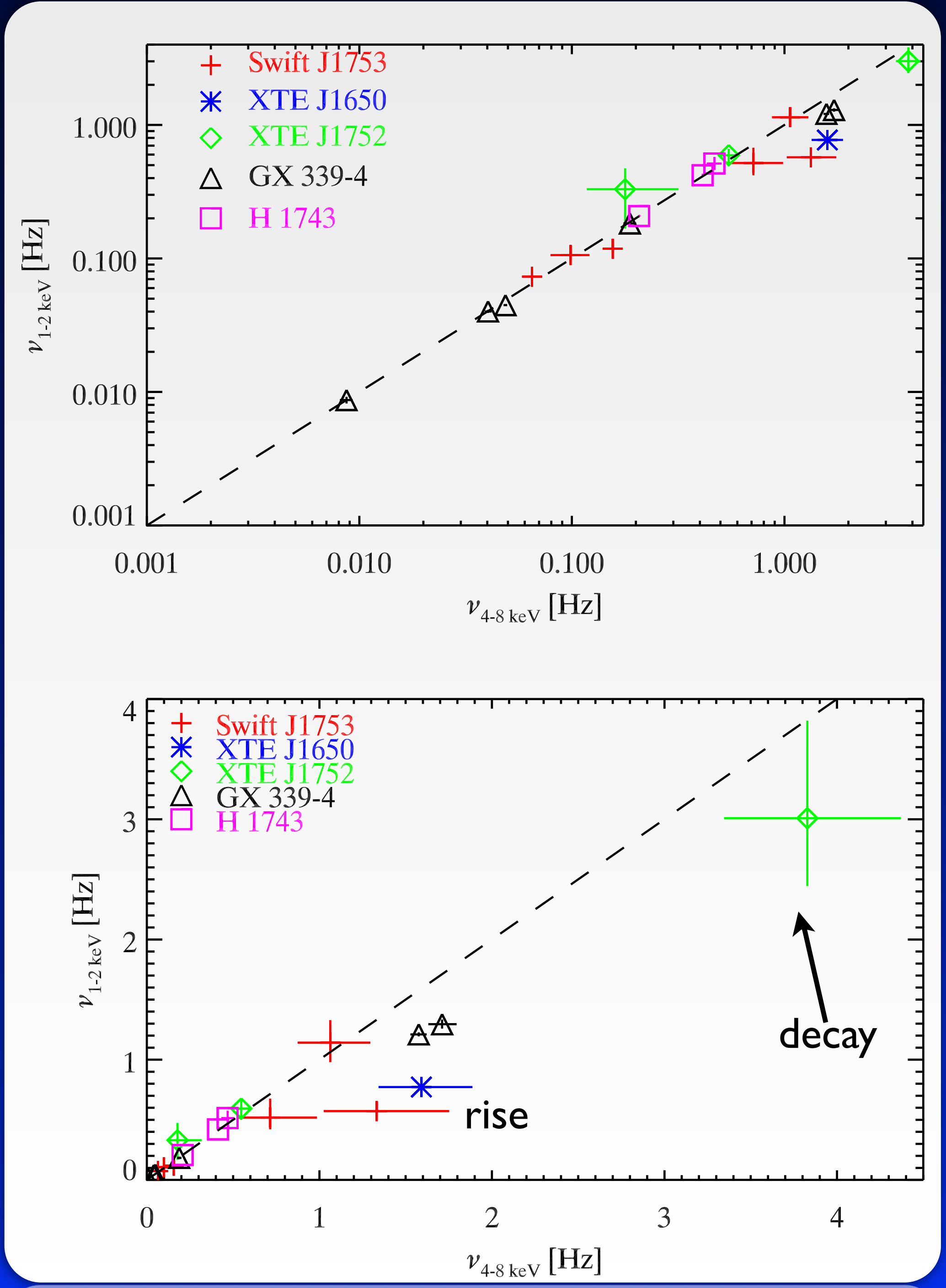
Characteristic frequency of the BLN

Stiele & Yu 2015, MNRAS 452, 3666

- determine characteristic frequency in a soft (1–2 keV) and hard (4–8 keV) band, where $\nu_{\max} = \sqrt{\nu^2 + \Delta^2}$ is the centroid frequency and Δ is the half width at half maximum (Belloni et al. 2002, ApJ, 572, 392), for each component present in the power density spectra
- for most observations we find that at least for the component with the highest characteristic frequency

$$\nu_{\max,\,1-2\,\mathrm{keV}} < \nu_{\max,\,4-8\,\mathrm{keV}}$$



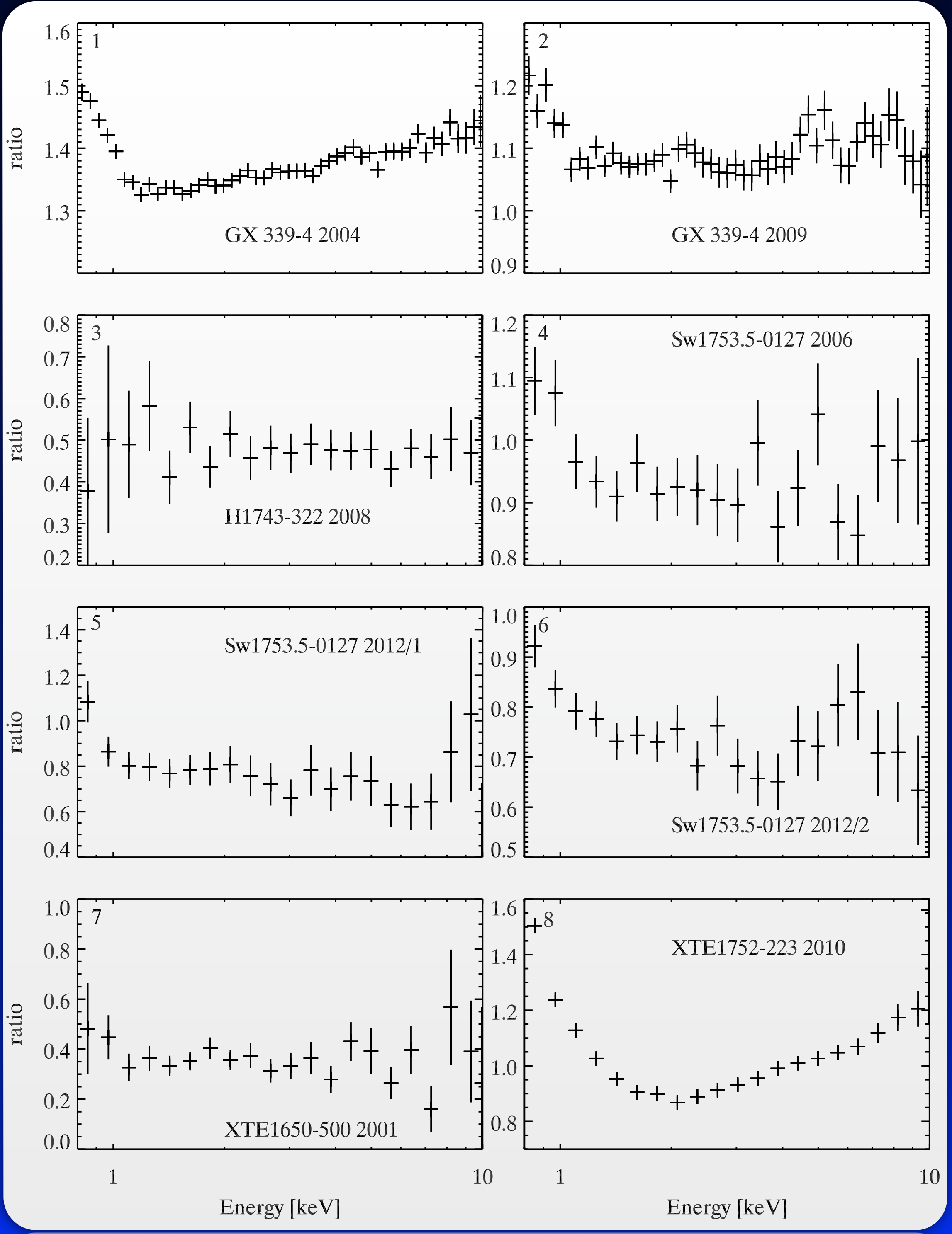
Covariance ratios

- covariance spectrum: rms spectrum between a narrow energy band and a broad reference band (Wilkinson & Uttley 2009, MNRAS 397, 666)

$$\sigma^2_{\rm cov} = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})(Y_i - \bar{Y}), \quad \sigma_{\rm cov,norm} = \frac{\sigma^2_{\rm cov}}{\sqrt{\sigma^2_{\rm xs,y}}},$$

- error bars are smaller compared to normal rms spectrum
- model independent way to compare variability on different time scales
- ratio of rms spectra on short (segments of 4s with 0.1s time bins) and long time scales (segments of 270s with 2.7s time bins)
- increase of covariance ratio at lower energies has been interpreted as sign of additional disc variability (Wilkinson & Uttley 2009, MNRAS 397, 666)

Stiele & Yu 2015, MNRAS 452, 3666



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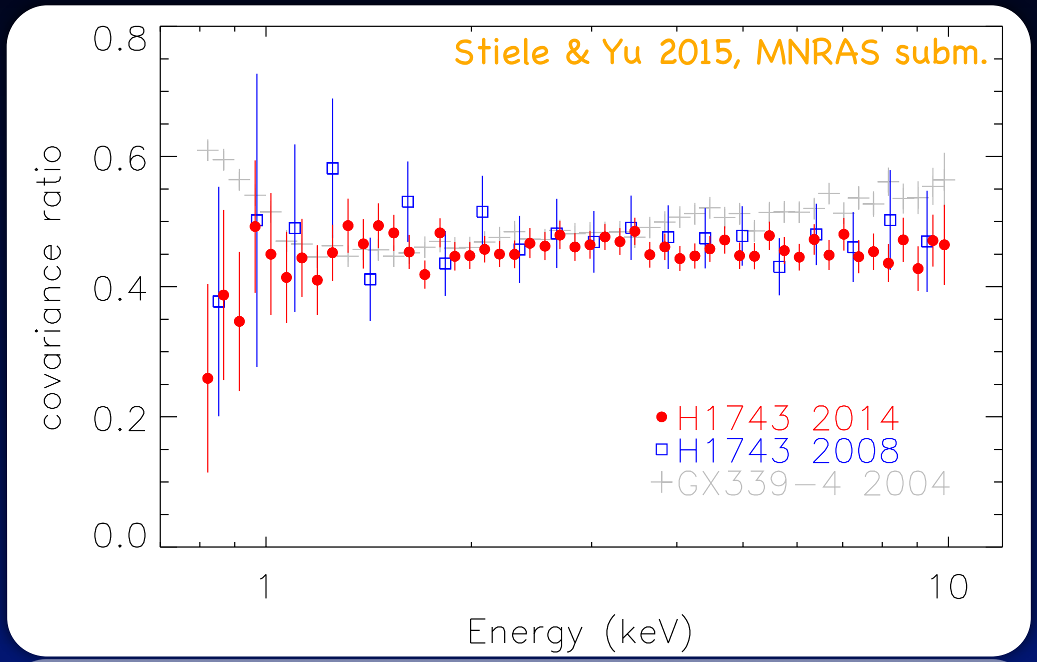
Covariance ratio of H 1743

- XMM observed H 1743 in 2008 and 2014 during a so-called "failed" outburst
- flat cov. ratio are observed
- in contrast to increase seen in e.g. GX 339-4, Swift J1753.5-0127, which has been interpreted as additional disc variability on long scales (Wilkinson & Uttley 2009, MNRAS 397, 666)



- 2 possible explanations:
  - higher inclination of H 1743-322 (around 80°; Homan et al. 2005; Miller et al. 2006) compared to other BH LMXRBs (< 70°; Motta et al. 2015) ➜ see H1743 more edge-on ➜ additional disc contribution on longer time scales does not show up
  - presence/absence of add. disc variability ➜ normal/"hard state only" outburst

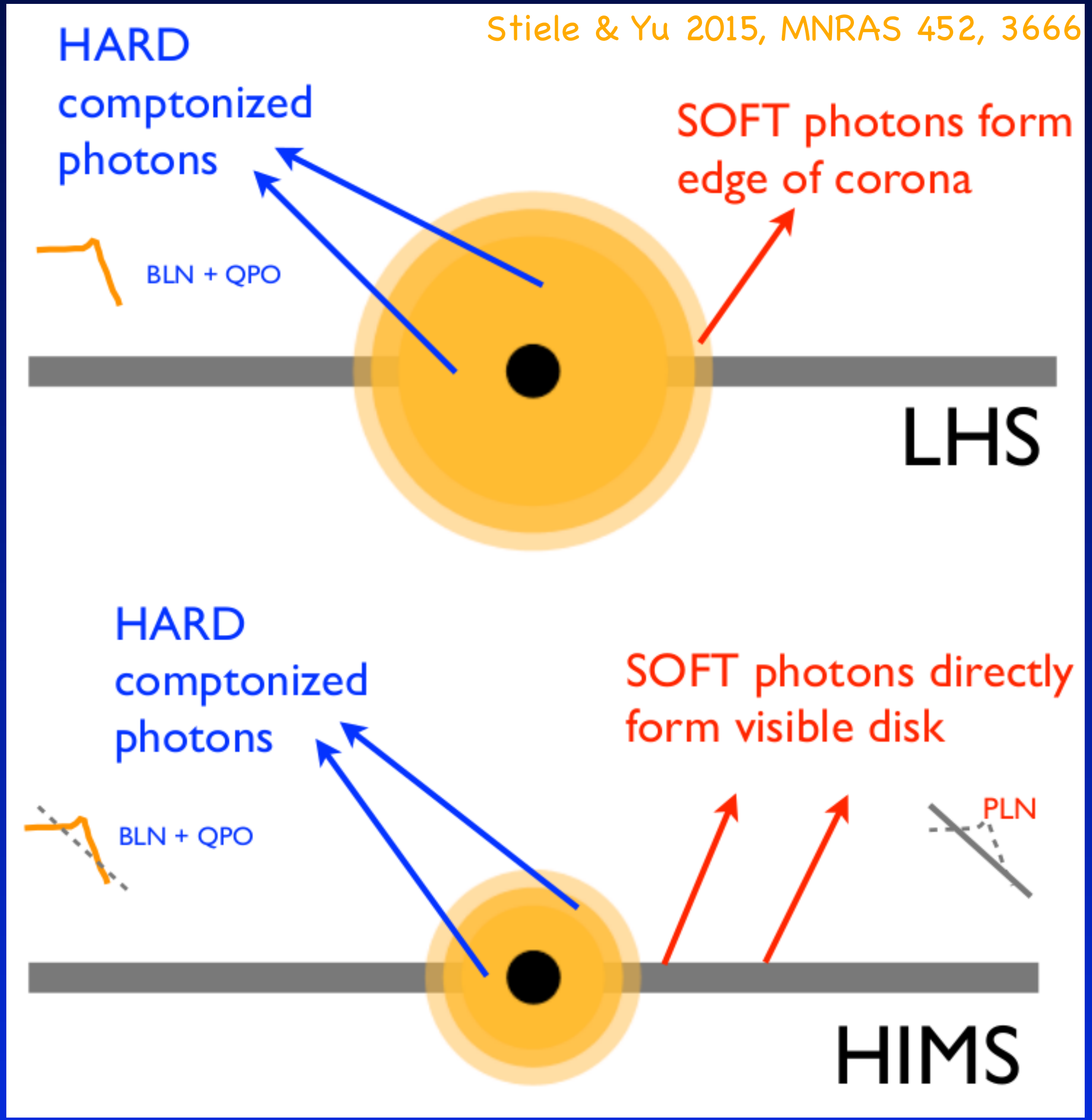
Schematic picture of the possible accretion geometry

Power spectral state depends on which spectral component we are looking at !

- from energy spectra: ratio of disc blackbody flux to flux of the Comptonized component > 10 % in observations where

$$\nu_{\mathrm{max},\,1-2\,\mathrm{keV}} < \nu_{\mathrm{max},\,4-8\,\mathrm{keV}}$$

- energy dependence of ν_{max} ➜ seed photon input for Comptonized photons varies between different energy bands (Gierlinski & Zdziarski 2005; MNRAS 363, 1349)
- energy dependence of ν_{max} mainly observed at $\nu > 1$ Hz ➜ inner disc radius moves inward during outburst evolution (Ingram & Done 2011, MNRAS 415, 2323)



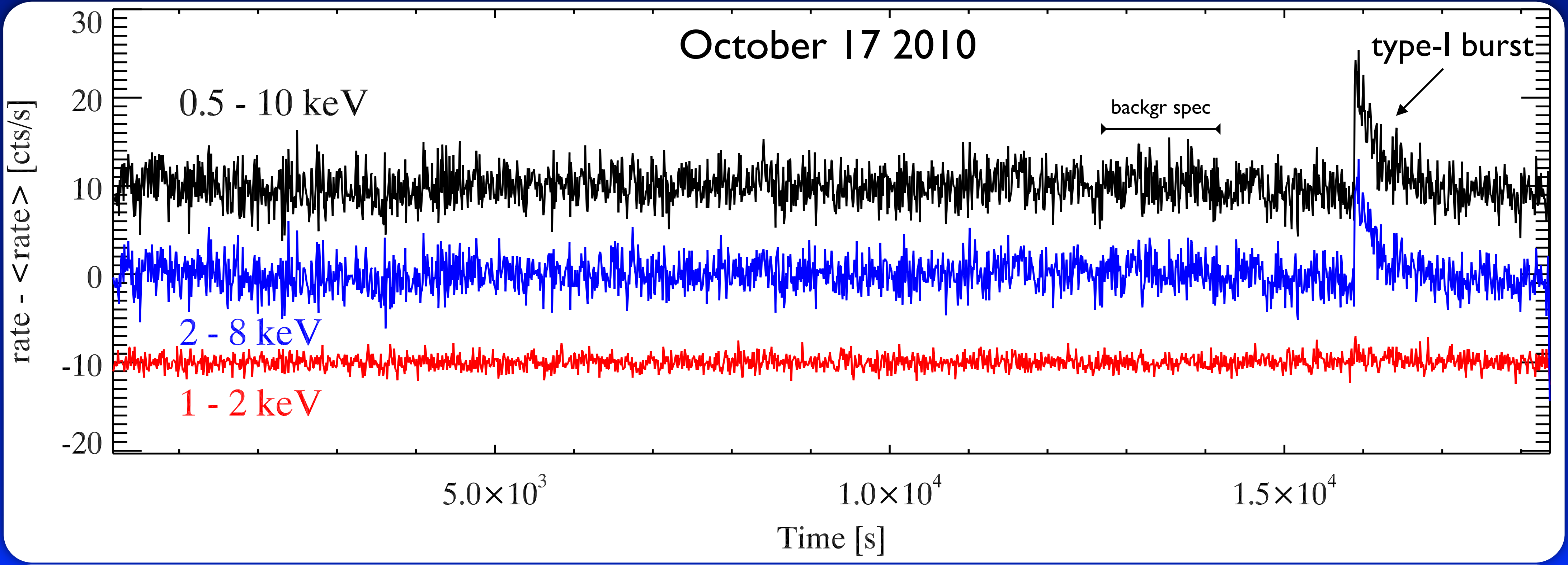
Summary

- energy dependence of power density spectra
- in low hard state:
- break frequency of band-limited noise evolves with energy (Stiele & Yu 2015, MNRAS 452, 3666)
- in (hard) intermediate state:
- two different PDS states coexist simultaneously in the hard and soft band (Stiele & Yu 2014, MNRAS 441, 1177)
- **observed PDS state depends on which spectral component we are looking at**

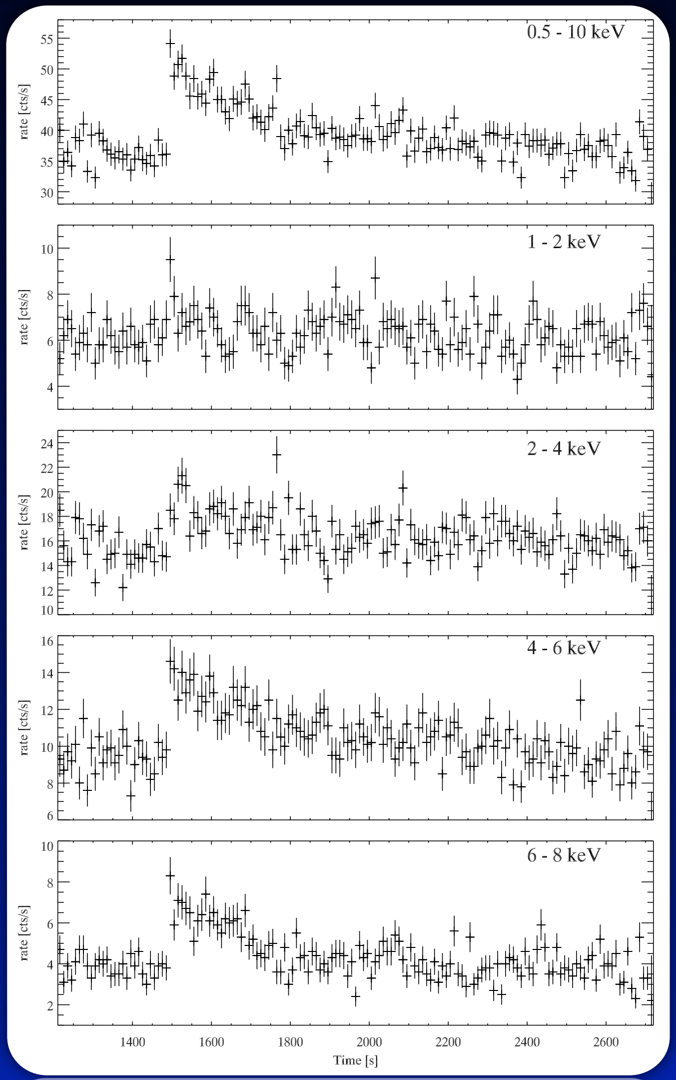
On the energy dependence of the persistent and bursting emission in GX 17+2

- GX 17+2 is a bursting, radio loud Z source
- low inclination (15º - 40º; Kuulkers et al. 1997, MNRAS, 287, 495)
- Distance: 8 kpc (Kuulkers et al. 2002)

XMM-Newton observations of GX 17+2



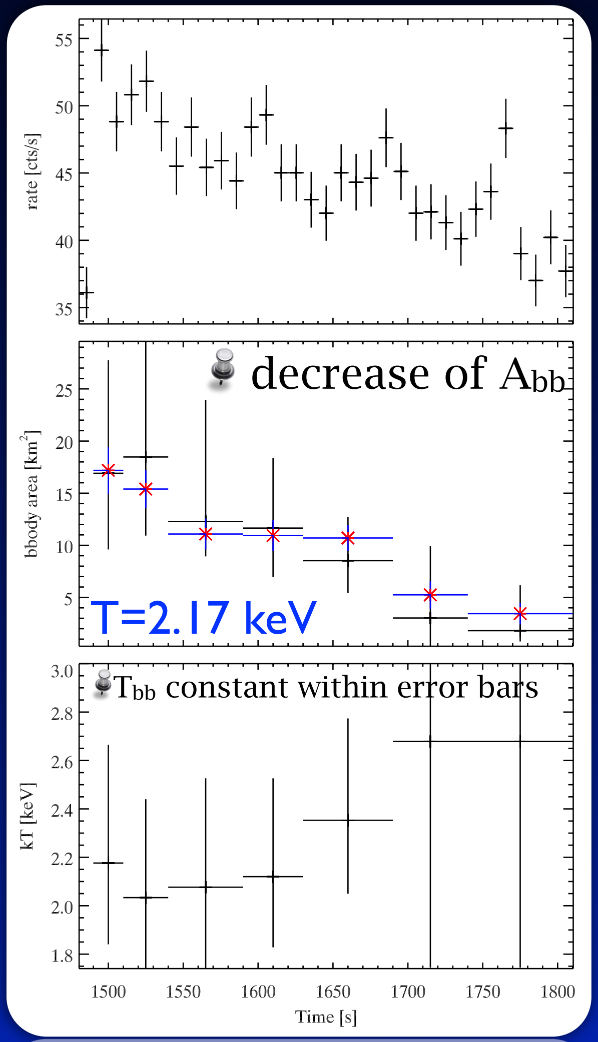
Light curves – energy dependence



- bin width: 9.997s
- different burst duration in different energy bands:
- 2 – 4 keV: light curve peaks about 20 – 30 s after peak in other energy bands
- 1 – 2 keV: burst not (really) visible

➡ **persistent soft emission**

Evolution of spectral parameters during burst



parameter	type-I
absorption [10^{22} cm^2]	1.33 ± 0.03
T_{bbody} [keV]	1.079 ± 0.003
A_{bbody} [km^2]	269 ± 4
nthcomp norm	0.113 ± 0.002
Γ	1.57 ± 0.05

- The background spectrum is modelled using an absorbed blackbody plus non-thermal Comptonisation model with the parameters given in the table
  - **A_{bbody}: background > burst**
  - **T_{bbody}: background < burst**

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Results

- light curves show that the persistent emission contains a soft component (below 2 – 3 keV) that is also present during the burst and that remains unchanged during the (type-I) burst
- spectral analysis of the persistent and of the bursting emission shows that the soft component of the persistent emission is emitted in a larger area and at lower temperature than the bursting emission

➜ the soft persistent emission origins in the boundary layer, while the bursting emission origins in unstable nuclear burning on the neutron star surface