Timing studies of the soft emission in the low-hard state of black hole X-ray binaries with XMM-Newton

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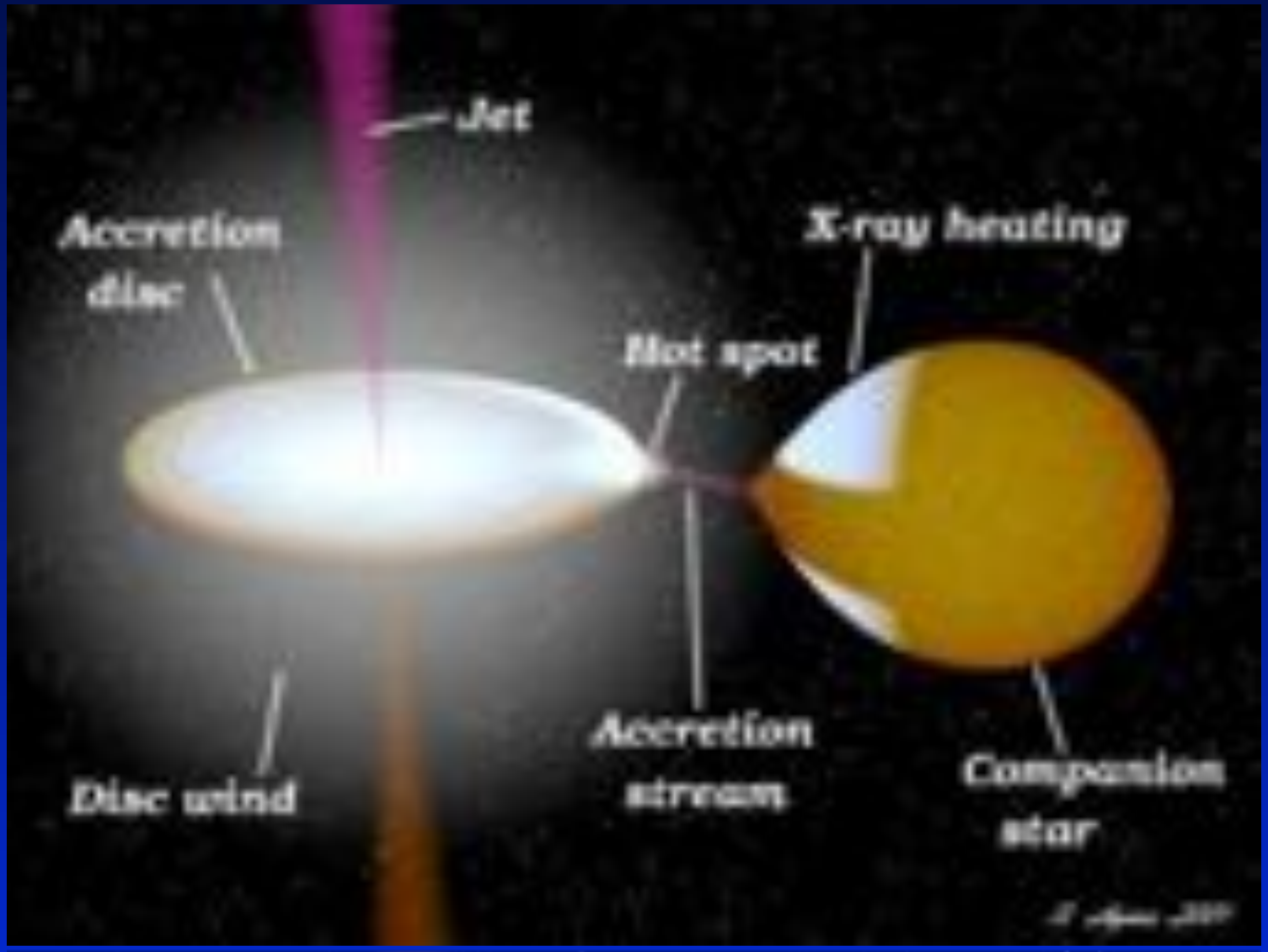
Low mass black hole X-ray binary

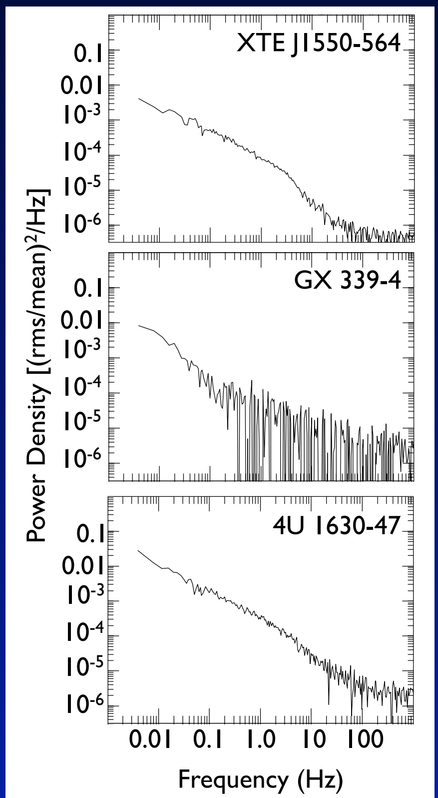
- Central object is a stellar mass (3-20 $M_\odot$) black hole
- Accretes matter from its low mass companion star ($M_s \lesssim 1\ M_\odot$, type A,F,G,K,M) through a disc (Roche-lobe overflow)
- X-ray emitting region close to event horizon R_S



State of the art

Timing properties of BH XRBs as seen with RXTE

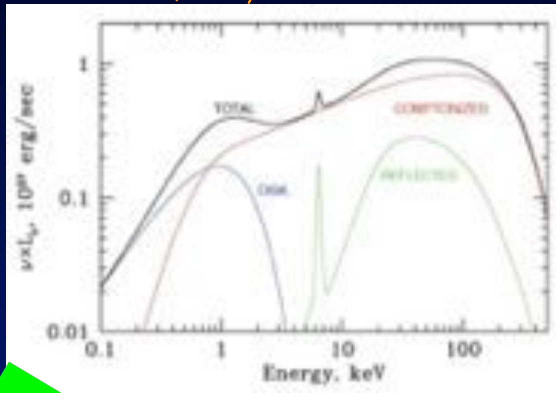
(3 - 20 keV)



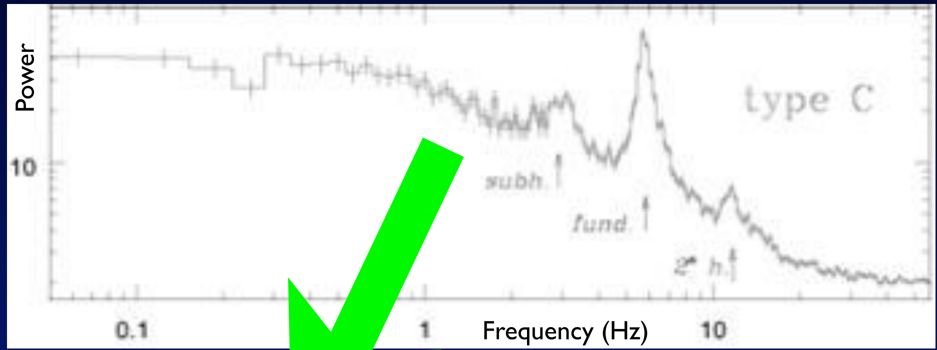
McClintock & Remillard 2006 Black Hole binaries

power law noise

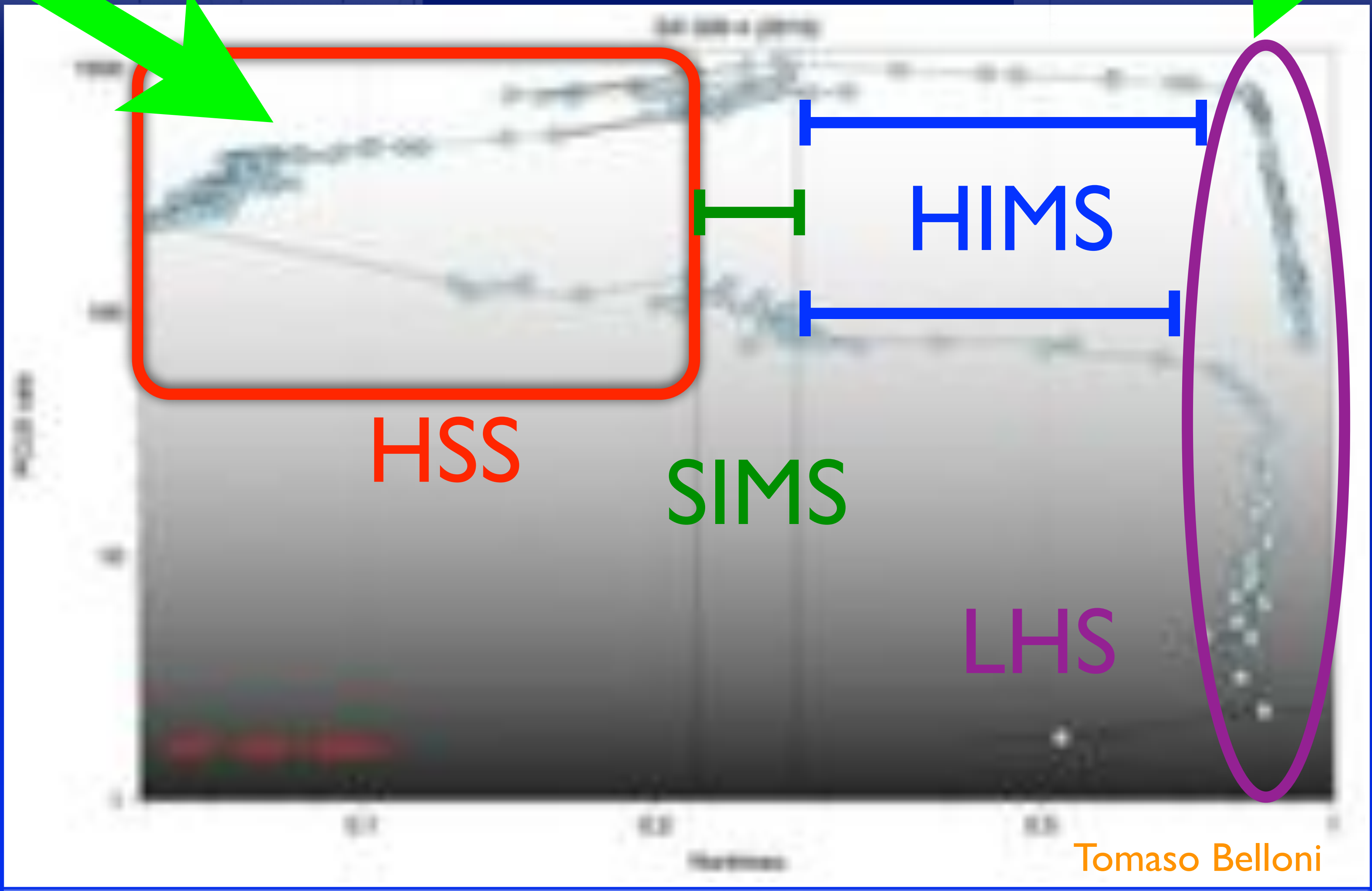
Gilfanov 2010, X-ray emission from BH binaries

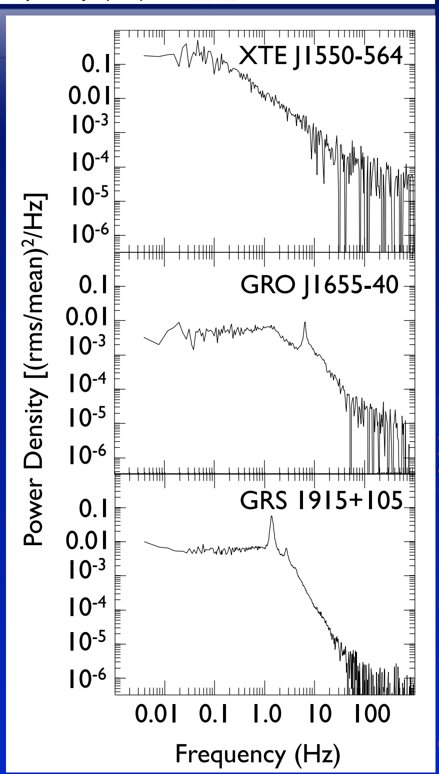


Casella et al. 2004, A&A, 426, 587



hardness - intensity diagram





McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

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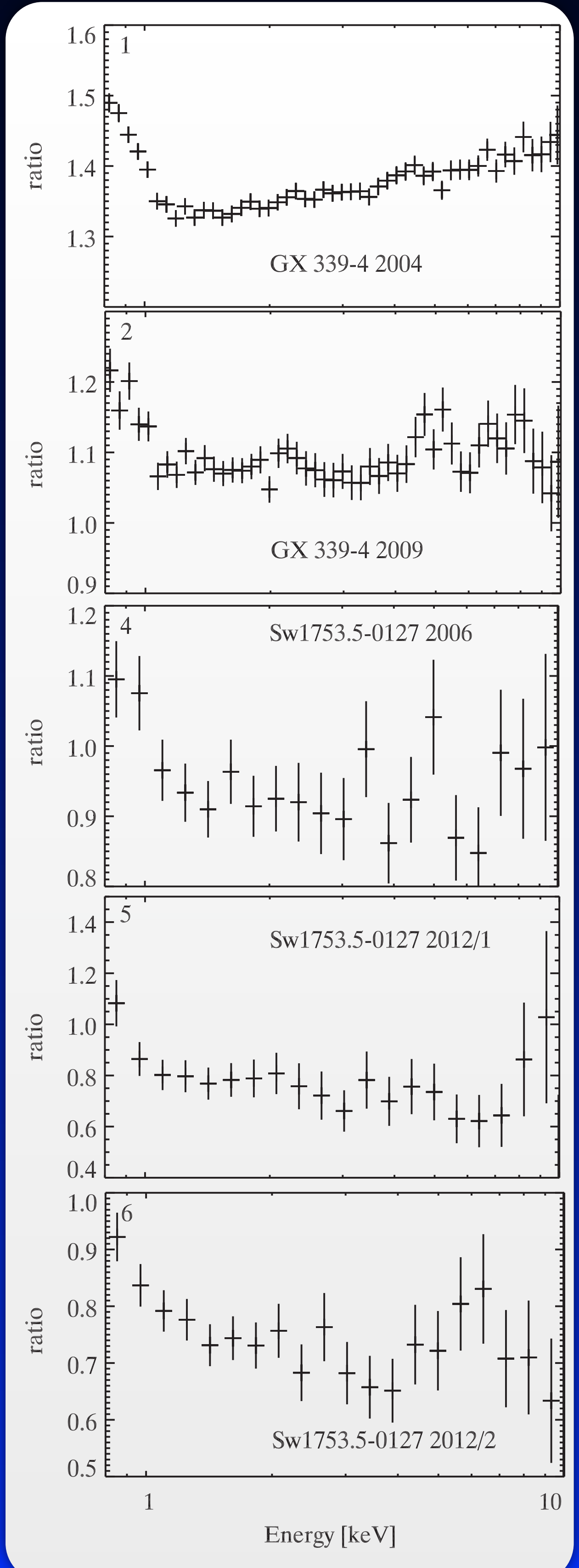
Covariance ratios

- Covariance spectrum: rms spectrum between a narrow energy band (X) and a broad reference band (Y; 1–4 keV; Wilkinson & Uttley 2009, MNRAS 397, 666)

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

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

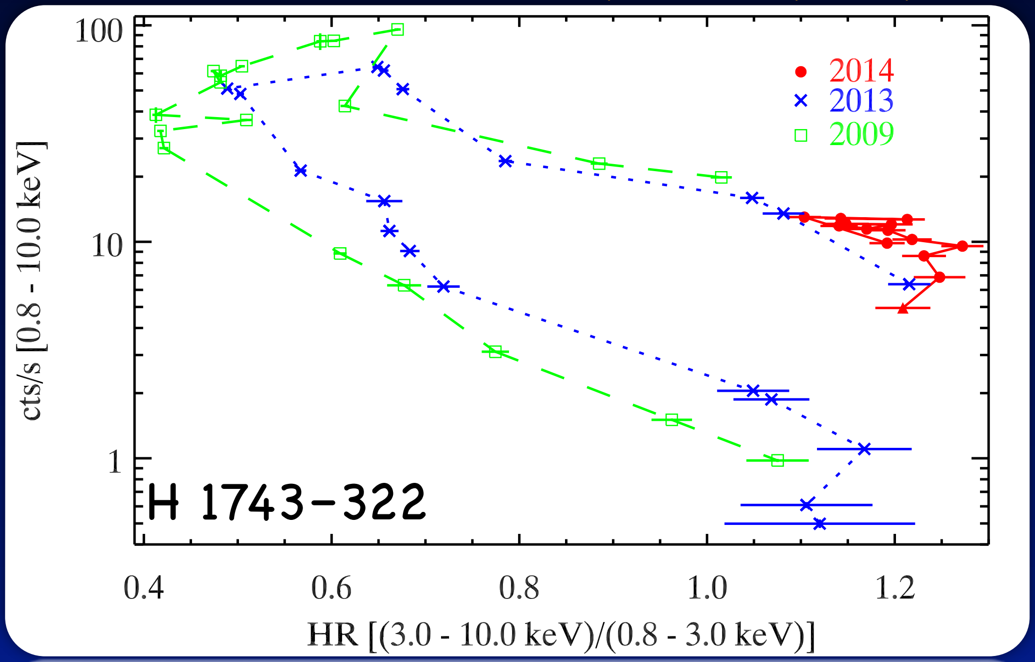


Stiele & Yu 2015, MNRAS 452, 3666

Some remain hard

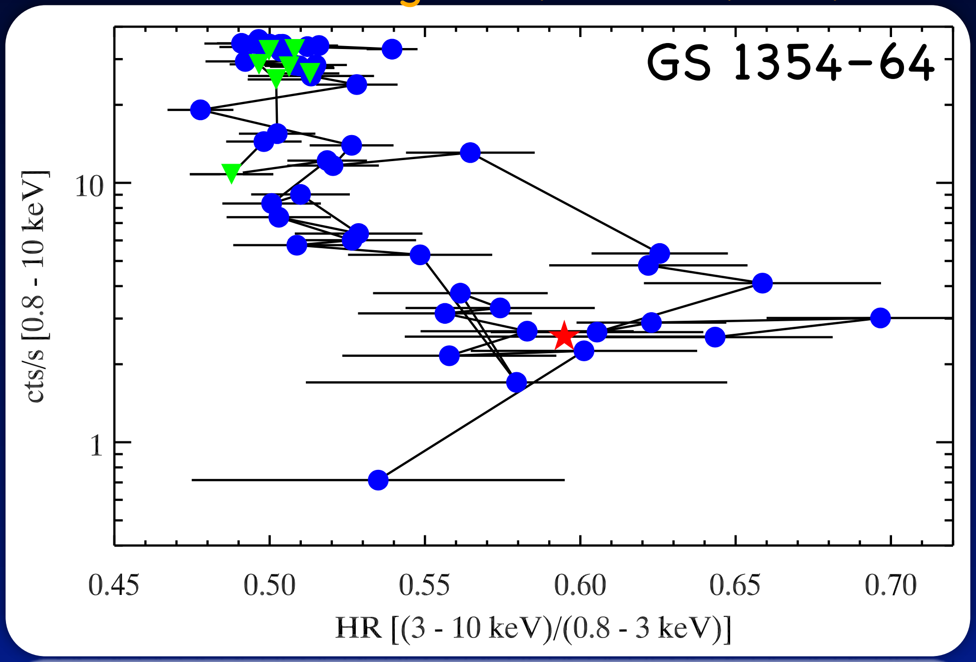
Some outbursts do not make it to the soft state

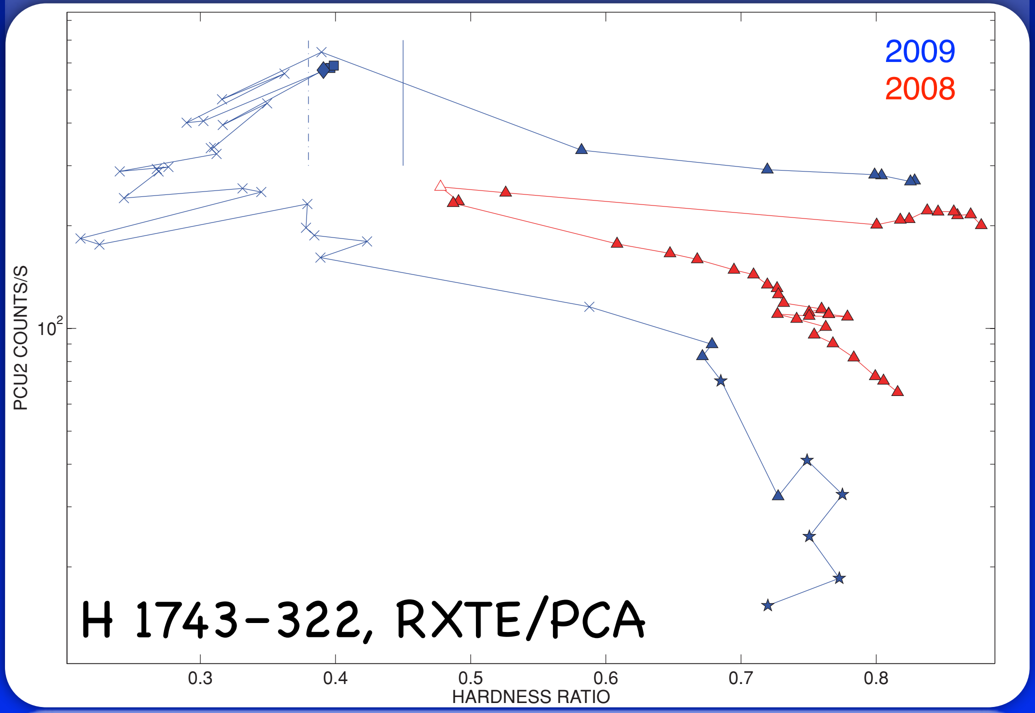
Stiele & Yu 2016, MNRAS, 460, 1946



Swift/XRT

Stiele & Kong 2016, MNRAS, 459, 4038



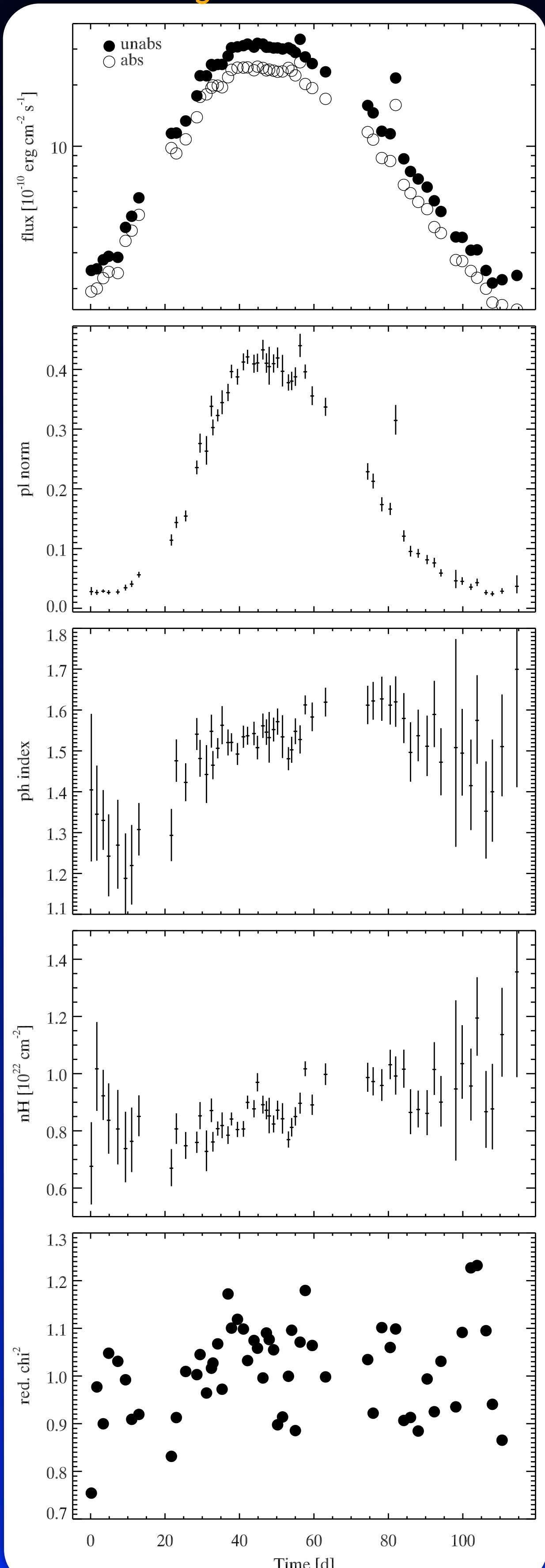


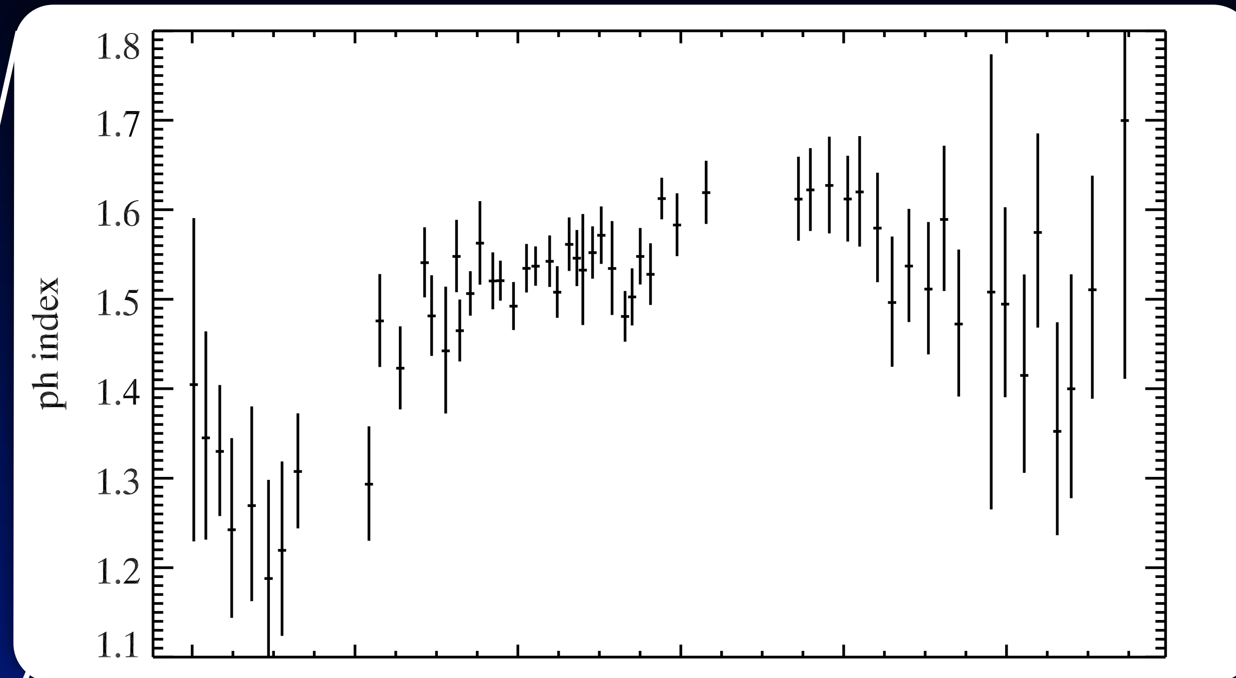
Motta et al. 2010, MNRAS 408, 1796

- H 1743-322 showed a so-called "failed" outburst in 2008 and 2014
- XMM-Newton observed H 1743-322 during these two "failed" outbursts
- GS 1354-64 showed a hard-state only outburst in 2015

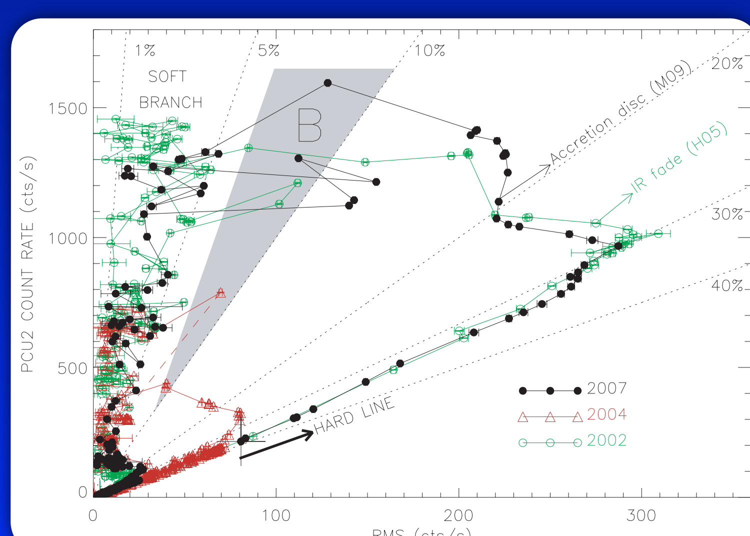
2015 outburst of GS 1354-64

Stiele & Kong 2016, MNRAS, 459, 4038





- Swift/XRT spectra
- Absorbed power law
- Photon index remains below ≃ 1.6
- rms variability > 10%
  → GS 1354 remains hard
- As it did in its 1997 outburst Revnivtsev et al. 2000, ApJ, 530, 955; Brocksopp et al. 2001, MNRAS, 323, 517



Muñoz-Darias et al. 2011, MNRAS 410, 679

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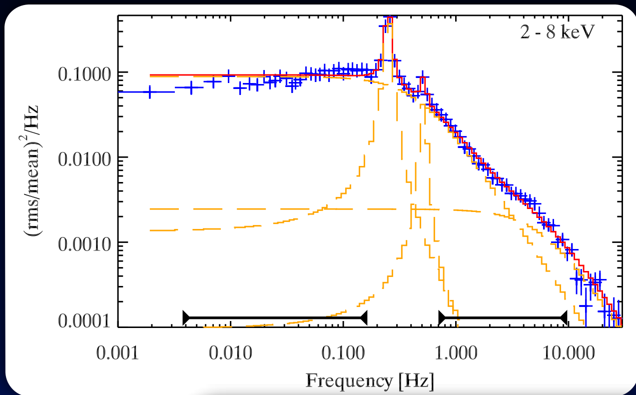
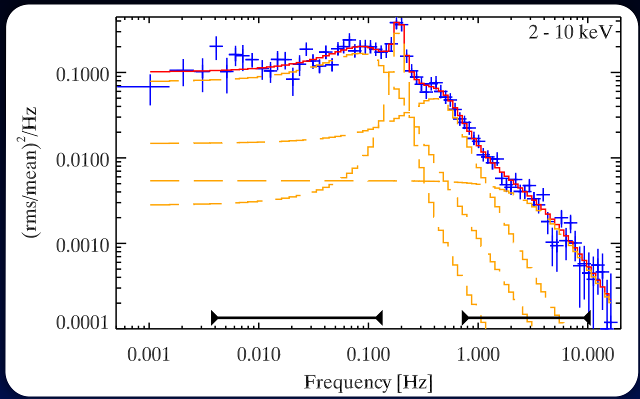
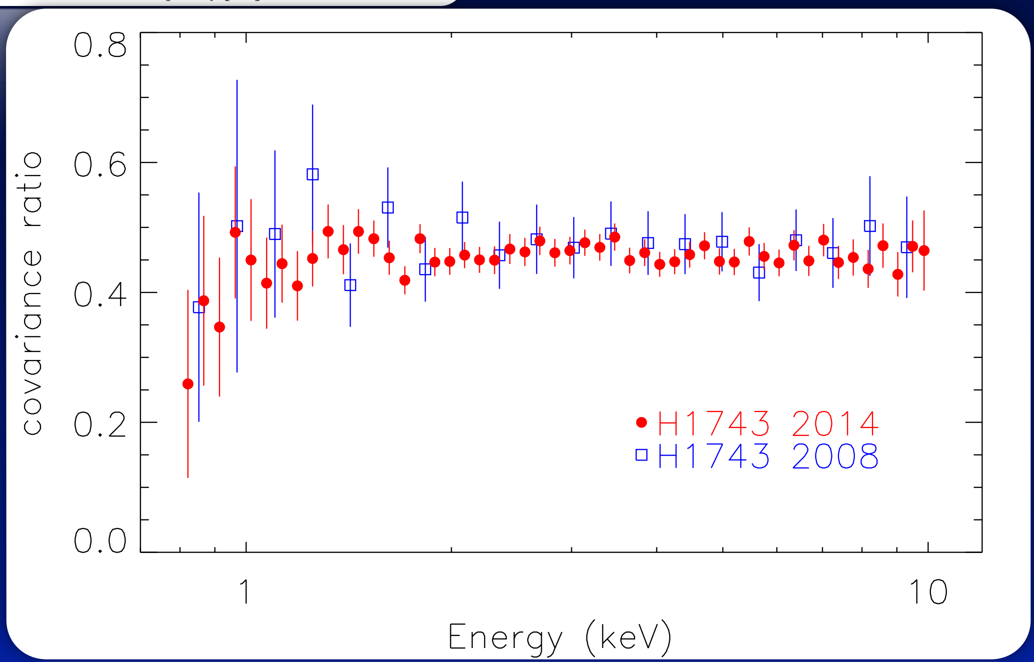
Covariance ratio

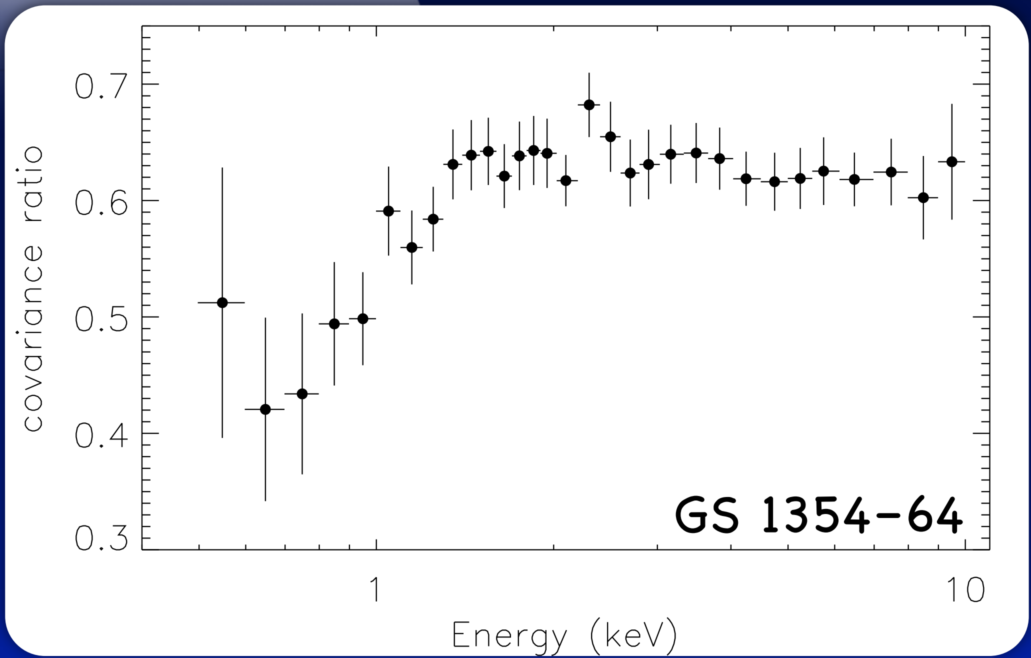




Stiele & Yu 2016, MNRAS, 460, 1946

Stiele & Kong 2016, MNRAS, 459, 4038





- H1743: flat covariance ratios are observed
- GS 1354: decrease towards lower energies

- 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)

Energy spectra

param.	GX 339/04	GX 339/09	Sw1753/06	Sw1753/12/1	Sw1753/12/2	GS1354
N_{dbb}	40922^{+15215}_{-13085}	10825^{+5996}_{-3448}	1526^{+676}_{-771}	3434^{+972}_{-1102}	5526^{+1511}_{-1630}	486^{+104}_{-63}
T_{in} [keV]	$0.202^{+0.013}_{-0.009}$	$0.223^{+0.014}_{-0.012}$	$0.213^{+0.033}_{-0.040}$	$0.270^{+0.010}_{-0.006}$	$0.257^{+0.014}_{-0.009}$	$0.50^{+0.01}_{-0.02}$
Γ	1.65 ± 0.01	$1.53^{+0.03}_{-0.05}$	1.73 ± 0.03	$1.57^{+0.03}_{-0.07}$	$1.60^{+0.01}_{-0.06}$	$1.51^{+0.05}_{-0.03}$
E_{cutoff} [keV]	7.6 ± 0.2	7.4 ± 0.2	> 9.3	7.2 ± 0.2	$7.3^{+0.1}_{-0.2}$	6.82 ± 0.08
E_{fold} [keV]	$17.8^{+6.5}_{-3.8}$	$19.8^{+5.6}_{-2.4}$	–	$15.1^{+3.9}_{-3.4}$	15.4 ± 2.2	9.4 ± 0.5

Stiele & Yu 2015, MNRAS 452, 3666 Stiele & Kong 2016, MNRAS, 459, 4038

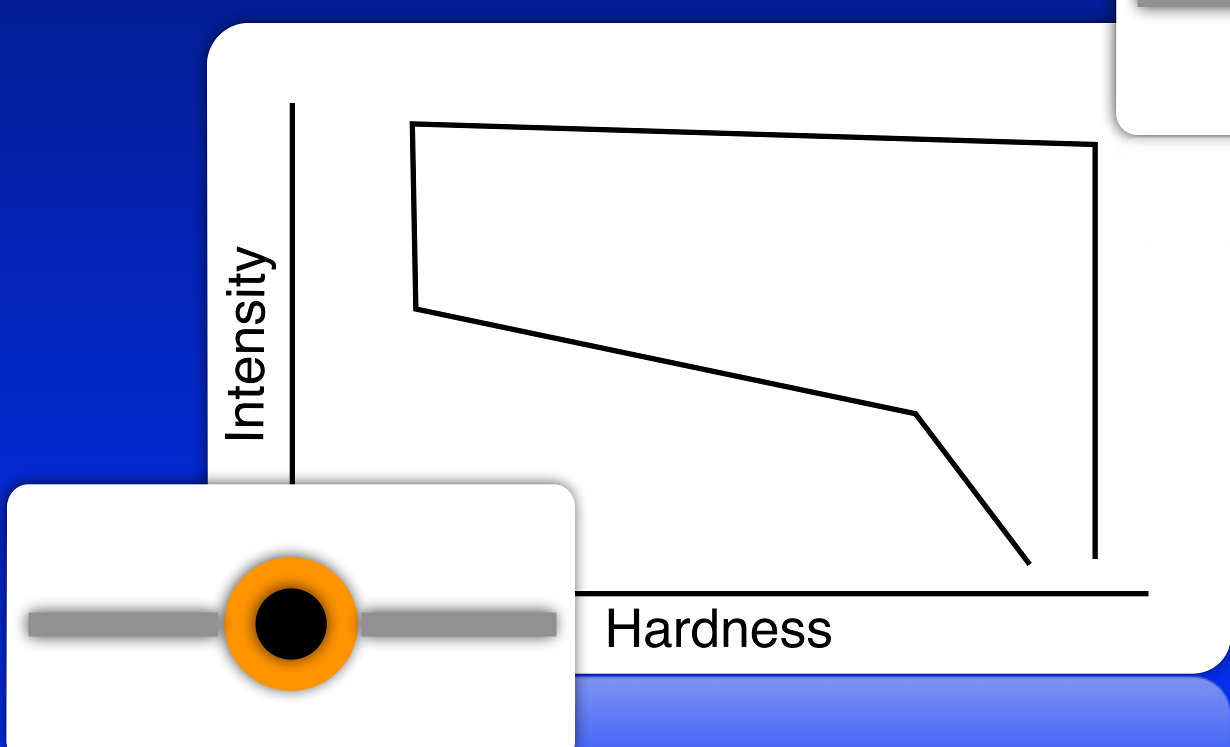
- TBabs × (diskbb + highecut × nthcomp)
- GS 1354-64: smaller inner disc radius; higher inner disc temperature

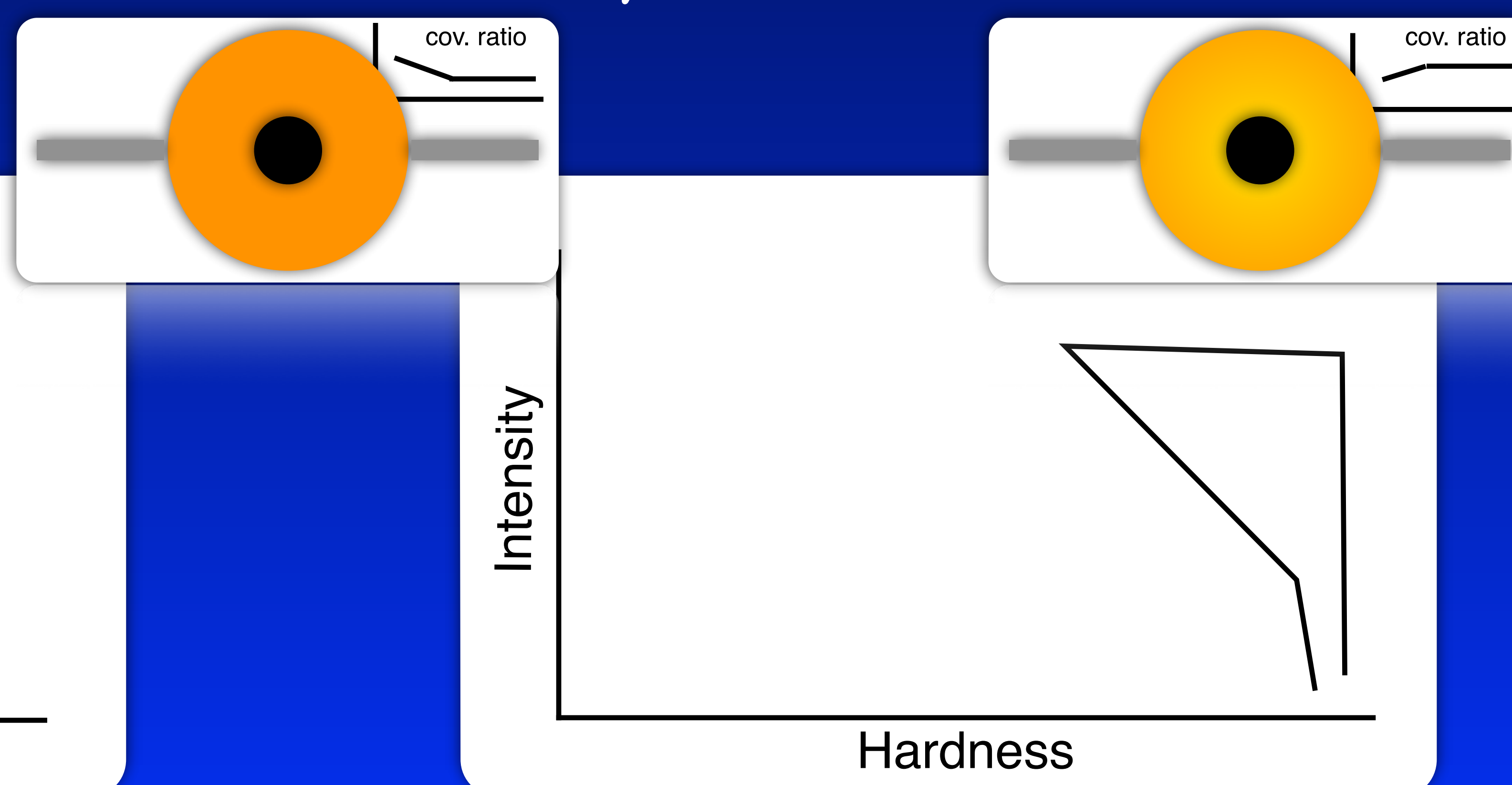
➜ Decrease in covariance ratio cannot be explained with faint disc component

- Intrinsic variability of disc?
- Driven by changes in the Comptonizing component?
- Indicate changes in the accretion geometry?

Covariance ratio

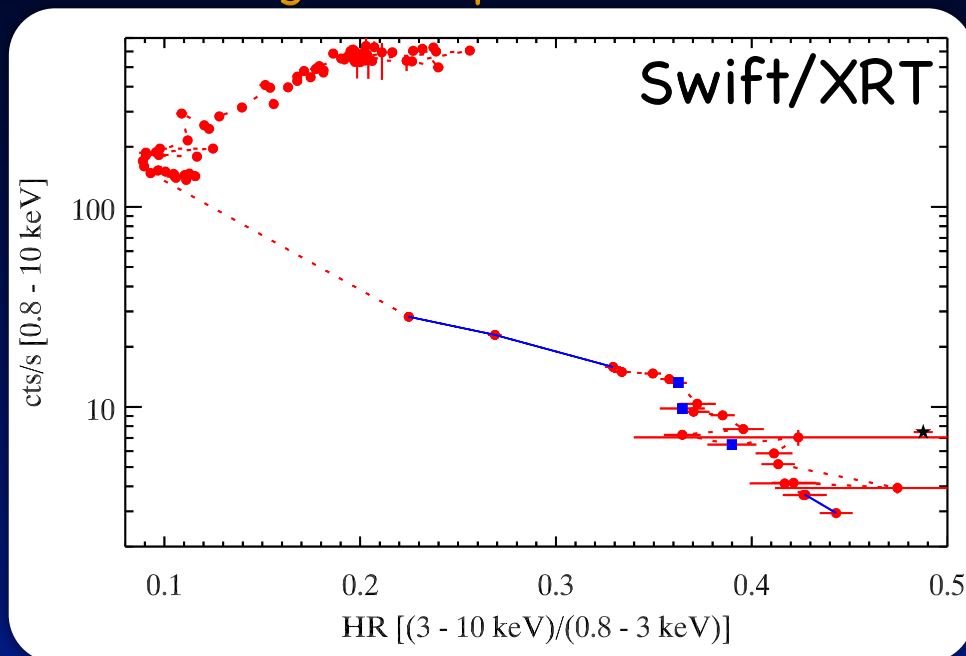
- 2 possible explanations:
  - Higher inclination of H 1743-322 (around 80°; Homan et al. 2005; Miller et al. 2006) compared to other BH LMXRBs (< 70°; Motta et al. 2015) ➜ see H1743 more edge-on ➜ additional disc contribution on longer time scales does not show up
  - Inclination of GS 1354-64 unknown
  - Presence/absence of add. disc variability ➜ normal/"hard state only" outburst



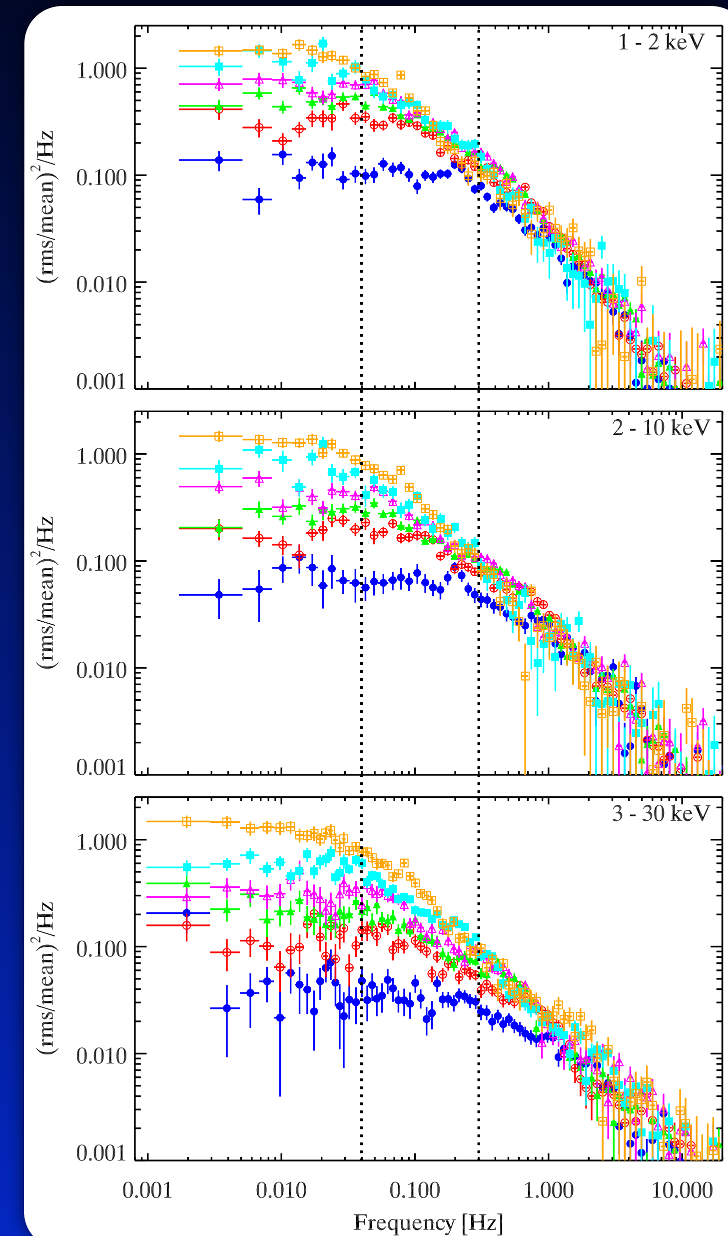


Soft-to-Hard transition

Stiele & Kong 2017, ApJ, arXiv:1706.08980



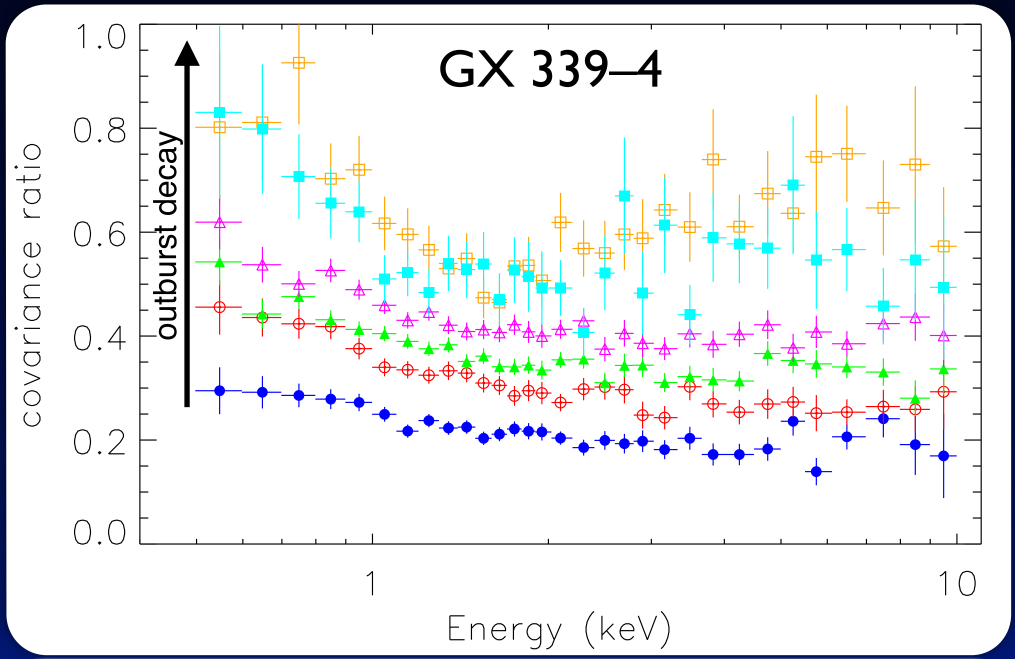
Stiele & Kong 2017, ApJ, arXiv:1706.08980



- GX 339-4
- Swift/XRT monitoring of the 2014/15 outburst
- XMM-Newton & NuSTAR observed source during soft-to-hard state transition

Covariance ratio

Stiele & Kong 2017, ApJ, arXiv:1706.08980



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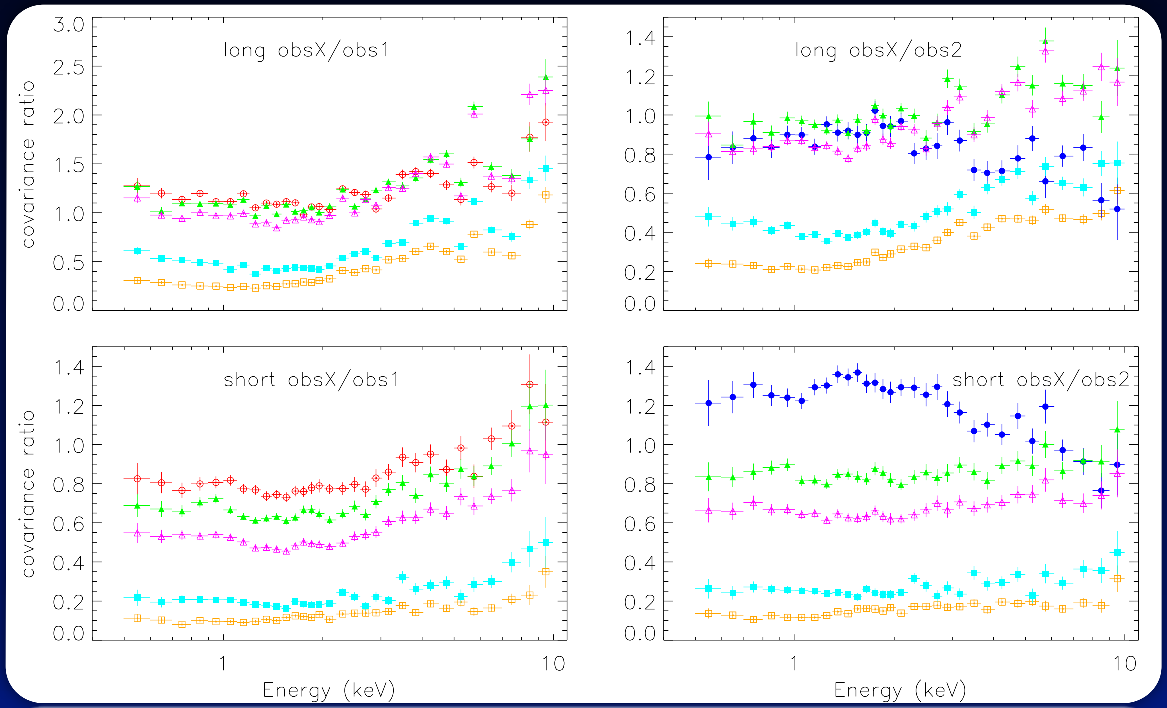

- Averaged covariance ratio increases during outburst decay
- Long time scale variability contributes more to overall variability than short time scale one
- Increase towards lower energies steepens ➜ long time scale variability at soft energies becomes more and more important as source hardens

➜ Accretion disc instabilities (invoked by damped mass accretion rate variations or oscillations in the disc truncation radius (Lyubarskii 1997; Meyer-Hofmeister & Meyer 2003)) get stronger when source hardens

Summary

- Covariance ratio
- GX 339-4, Swift J1753.5-0127 LHS outburst rise: ratio increases towards lower energies ➜ additional disc variability
- H 1743-322, GS 1354−64: ratio remains flat or decreases

➜ Observed during "failed" outburst; disc variability ↔ type of outburst?

➜ Inclination?

- Soft-to-hard transition: ratio increases; increase steepens

➜ Accretion disc instabilities get stronger when source hardens