Hard X-ray Spectral Variability of the Brightest Seyfert AGN in the Swift/BAT Sample

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Swift/BAT

- The Burst Alert Telescope (BAT; Barthelmy et al.2005) is sensitive to X–ray photons in the 14-195 keV energy range. We studied *spectral variability in the 20-100 keV energy range*, thus avoiding effects due to absorption changes (for **sources with $N_H < 10^{24}$ cm^{-2}**).

- Baumgartner et al. (2011) recently released a catalog of sources detected in the first 58 months of BAT observations. It consists of 1092 sources, detected at a significance level of at least 5 σ. The majority of the sources in this catalogue are AGN (with 519 objects classified as Seyferts).

- We chose to study the 5 (hard X-ray variable) Seyferts which have the highest flux in this *Swift BAT 58-Month Hard X-ray Survey* catalogue, among all radio-quiet AGN:

NGC 4151, NGC 4945, NGC 2110, IC 4329 and NGC 4388

Previous findings

NGC 4151

E_c might anti-correlate with source flux, from 50 keV (bright) to 100 keV (dim) (Lubinski et al. 2010). Γ=1.4-1.6 (Zdziarski et al. 1996, Petrucci et al. 2001, Winter et al. 2009). R=0.01,1. Possible Γ and/or R variations.

NGC 4945

Possible presence of material with NH=10^{24} cm^{-2} (Iwasawa et al. 1993). Γ=1.4-1.8 (Iwasawa et al. 1993...Winter 2009). E_c=100-300 keV. R=0.06 (Done et al. 2003).

NGC 2110

R=0.17-0.5 and Γ=1.9-2.0 (Malagutti et al. 1999, Beckmann et al. 2009) or Γ=1.54 (Winter et al. 2009).

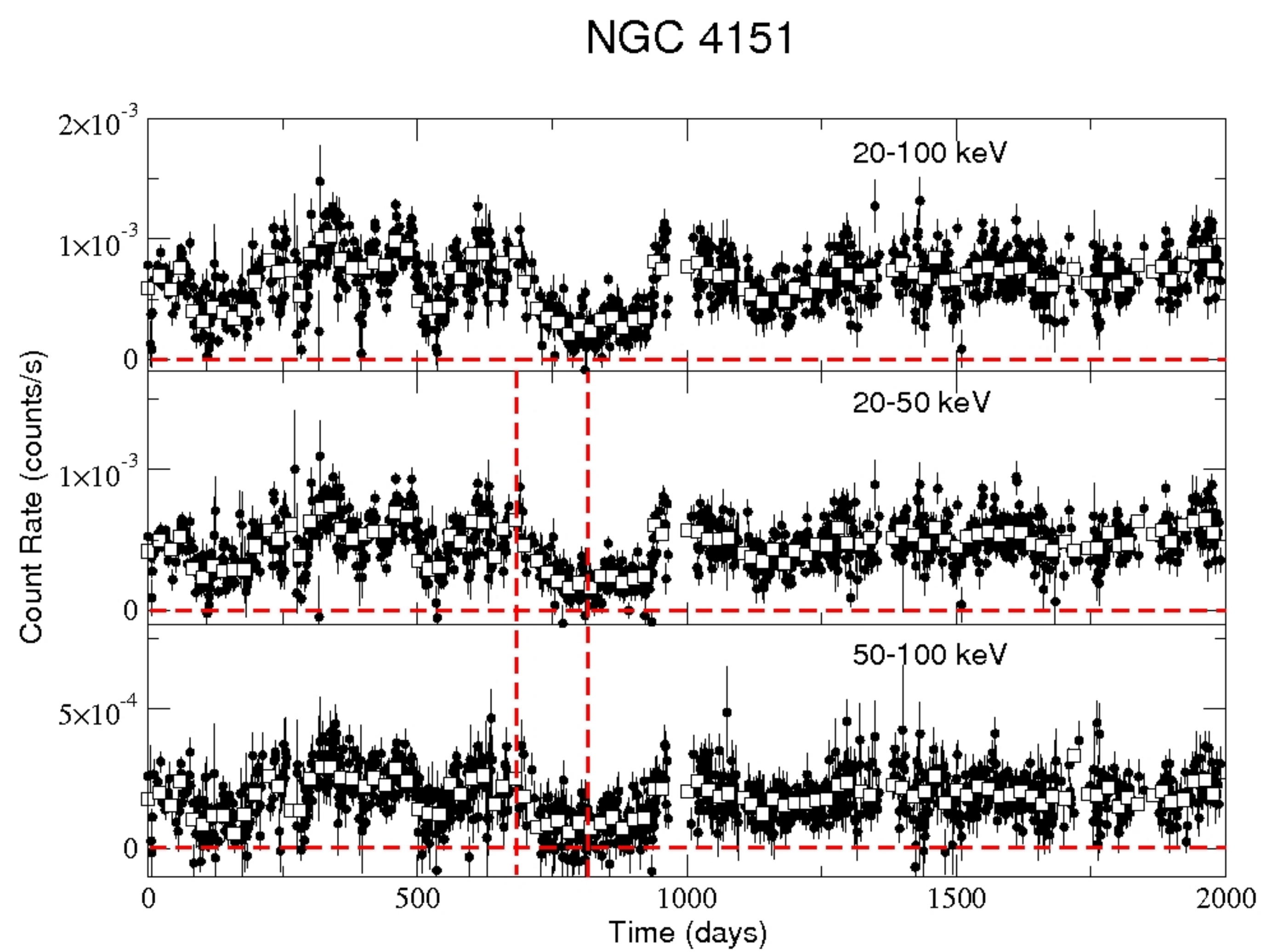
IC 4329

Flux variations in the 0.1-100 keV were not associated with significant spectral variations (Perola 1999). E_c=250 keV-1700 keV (Madejski et al. 1995) or E_c=80 keV (Beckmann et al. 2009). Γ=1.4-1.8 (Beckmann et al. 2009, Winter et al. 2009). R=0.4-1.2 (Miyoshi et al. 1998, Done & Madejski et al. 2000).

NGC 4388

13 years of BeppoSAX data showed no significant spectral variations. INTEGRAL and Suzaku revealed flux variations by factors of 1.4-1.5. Γ=1.3-1.8 (Beckmann et al. 2009, Winter et al. 2009).R=1.3-1.5 (Shirai et al. 2008). Barely detected spectral variations with the most important one being a change of the normalization of the power-law continuum.

Hard X-rays: Spectral Variability



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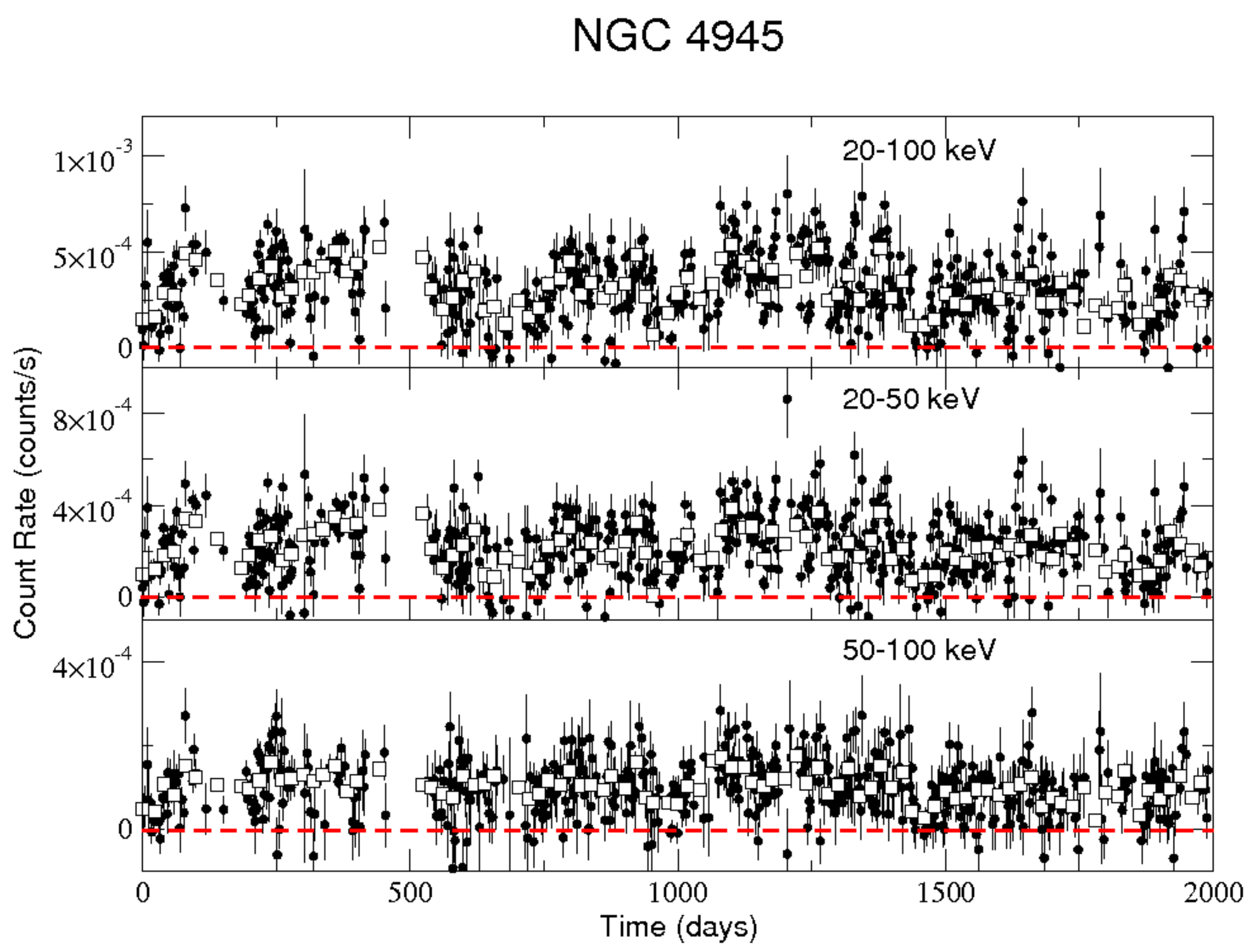

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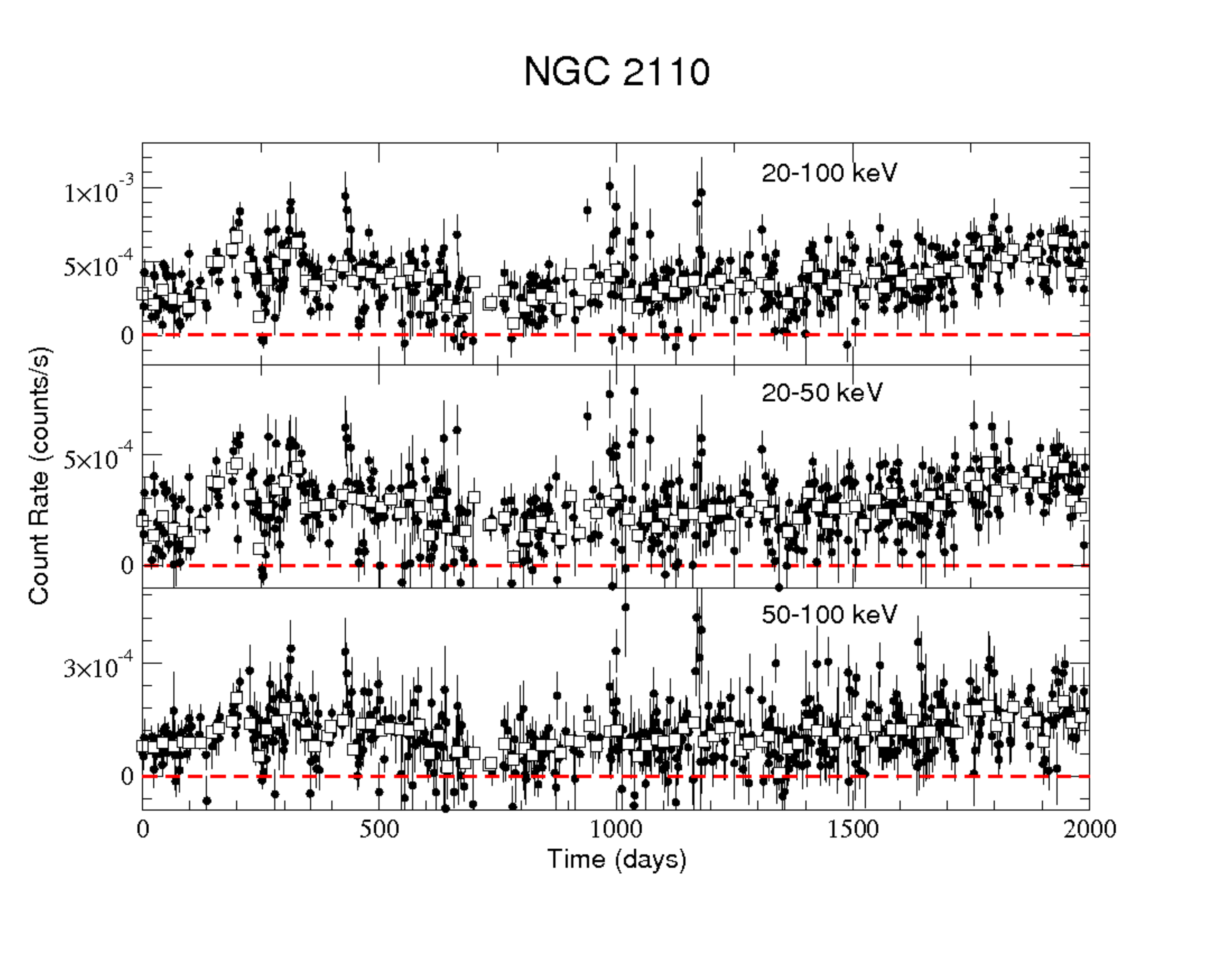

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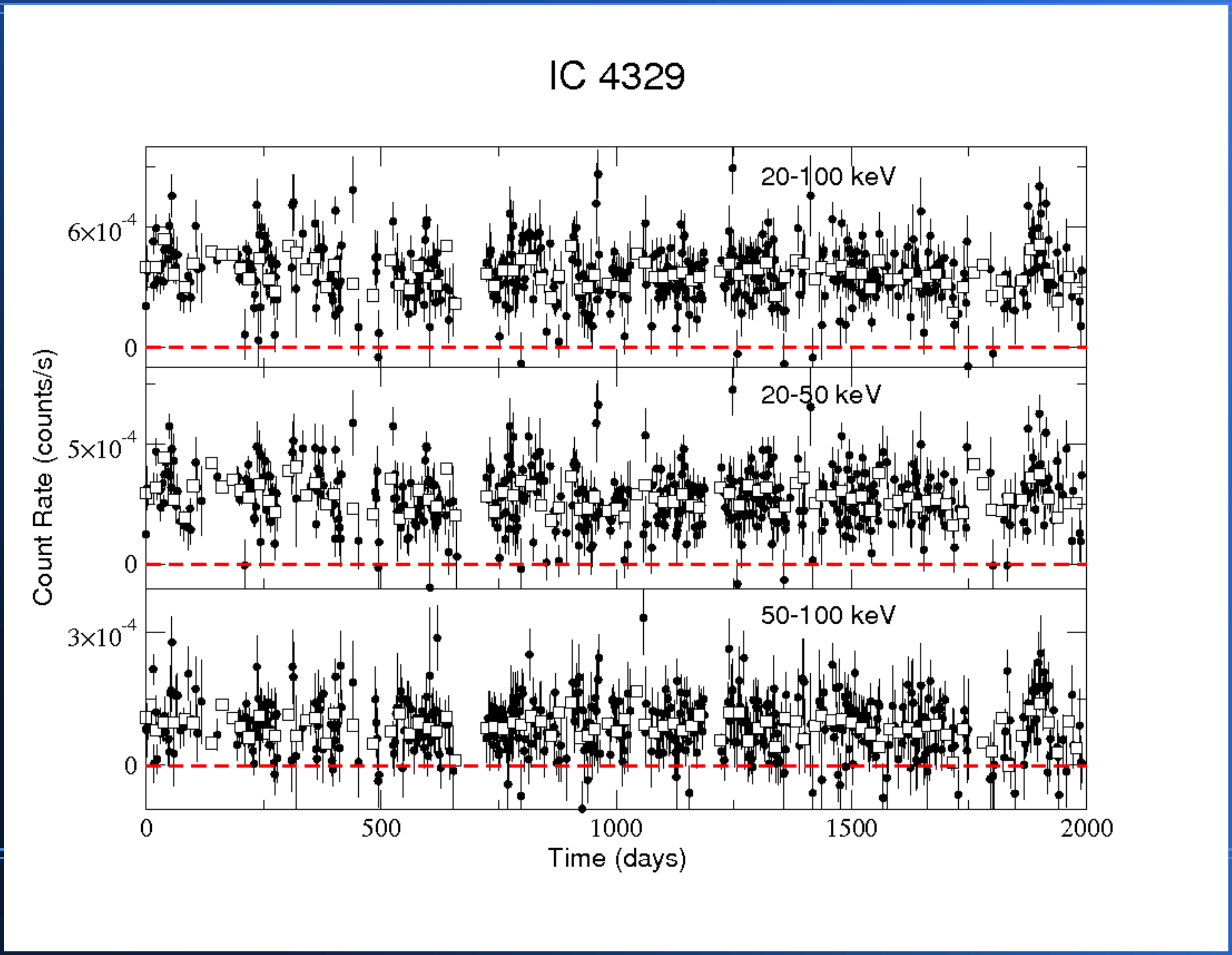

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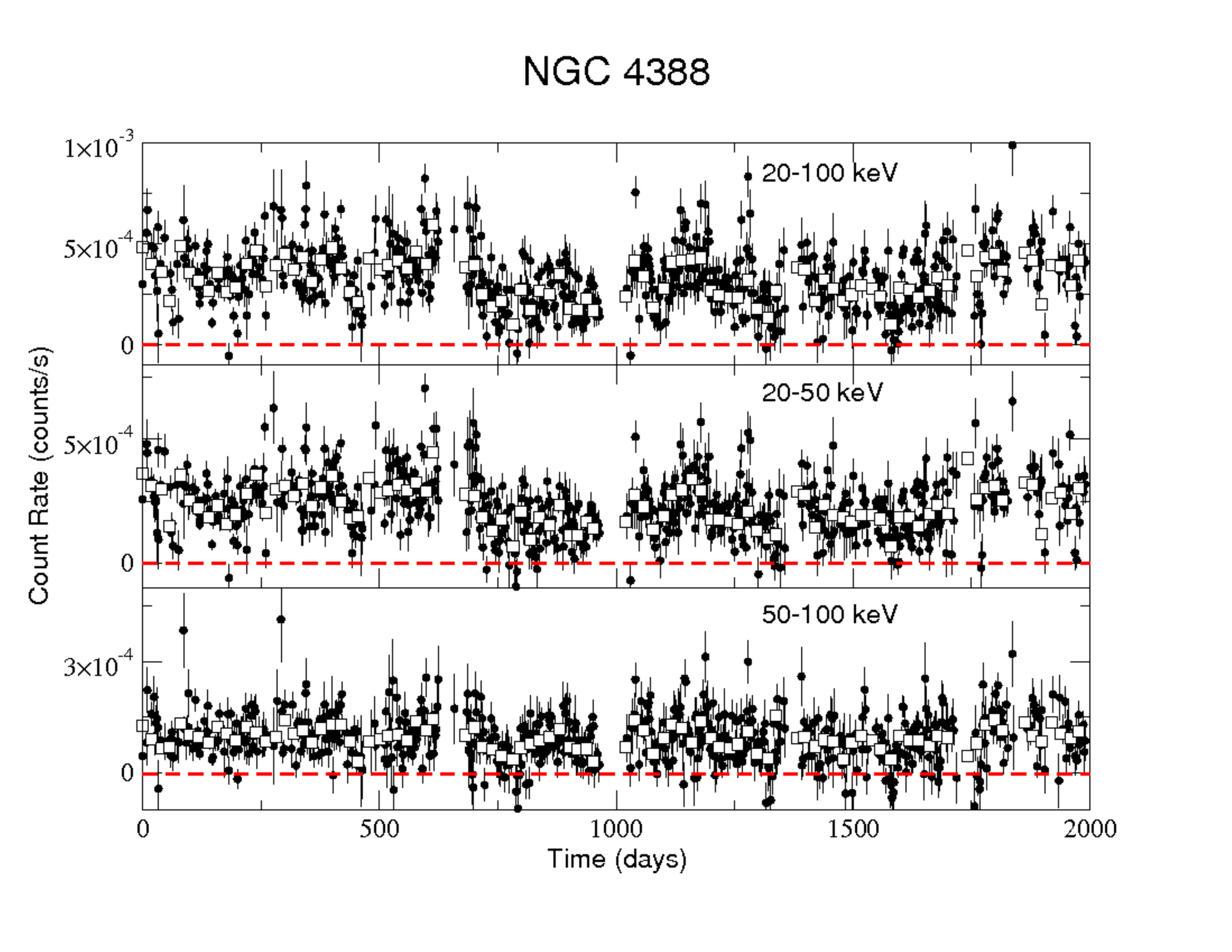
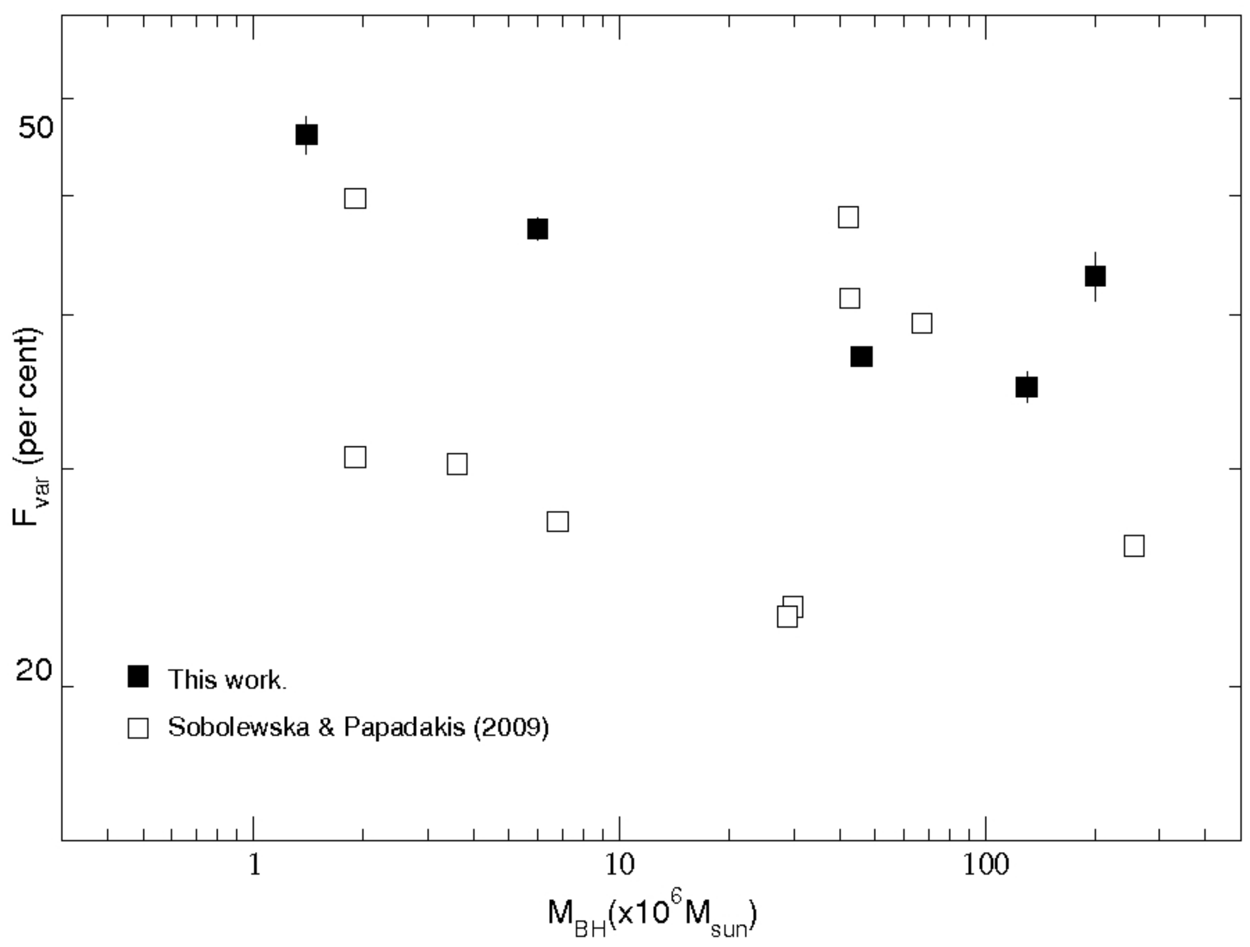


Hard X-ray Variability vs BH Mass



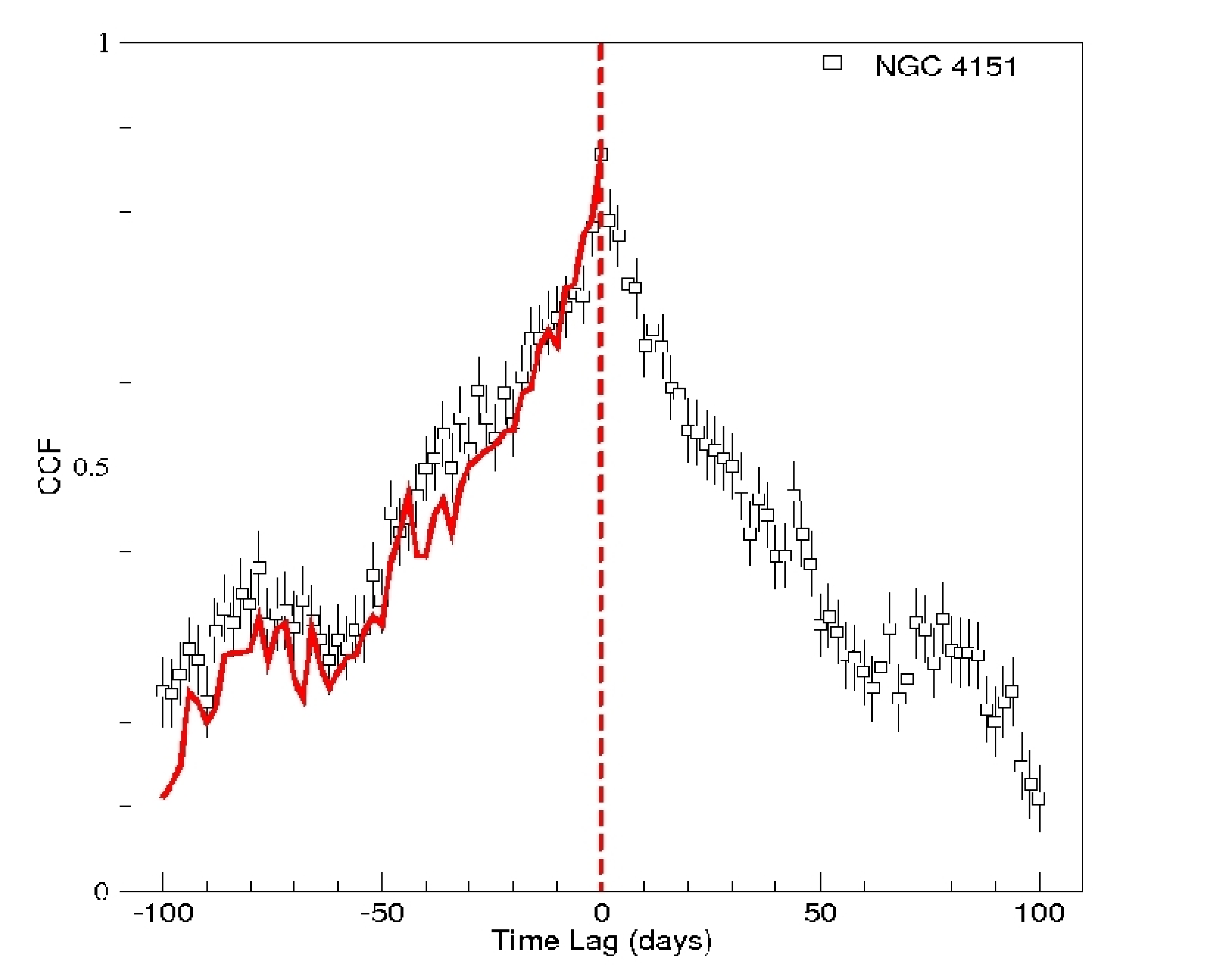
Hard X-ray Variability vs BH Mass

- The average *(20-50 keV) variability* amplitude of the AGN we studied is *comparable* to the average variability amplitude of the AGN long term, *2–10 keV light curves*.

- Thus the *variability must intrinsic to the sources* (i.e. neither changes in the ionization nor absorption) → *Flux variations (in the 2-10 keV energy range) due to* ***changes in the properties of the absorber must be small***.

- There appears to be an anti-correlation between variability amplitude and BH mass: *smaller BH mass objects appear to be “more” variable*.

Hard X-rays lead soft X-ray Variations



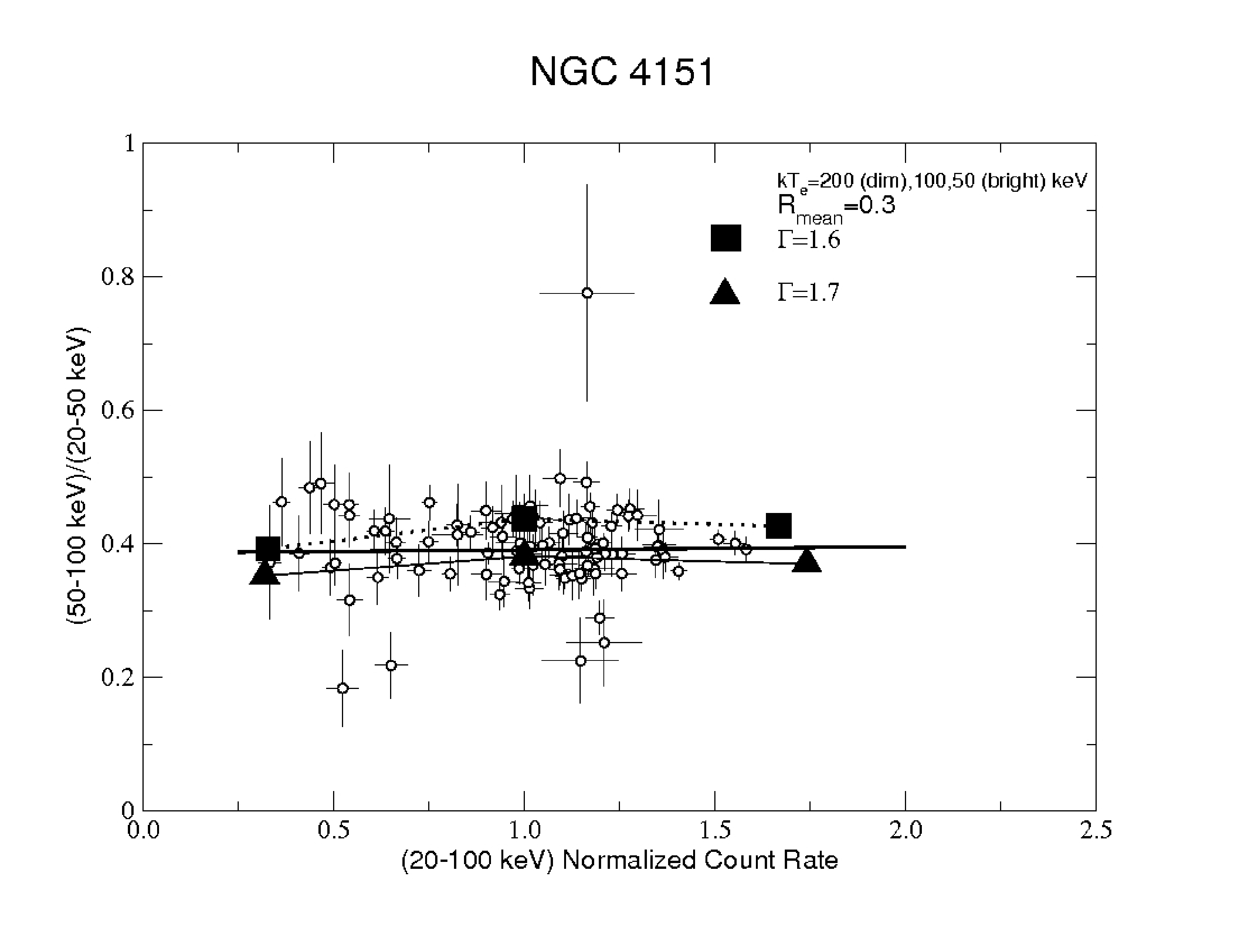
Hard X-rays lead soft X-ray Variations

The soft (20–50 keV) and hard band (50–100 keV) light curves, in all objects, are well correlated. We do not detect any delays down to 1 day.

In the case of NGC 4151 (the object with the highest signal-to-noise ratio light curves) we detected a soft band delay, at **time scales > 10 days**. This is the **first time that such a delay within the X–ray band has been observed in AGN**.

The *physical mechanism* (perhaps a change in the temperature of the hot plasma in the corona?) *affects first the high energy part of the spectrum of the source, and then propagates to softer energies*.

Hard X-rays: Spectral Variability



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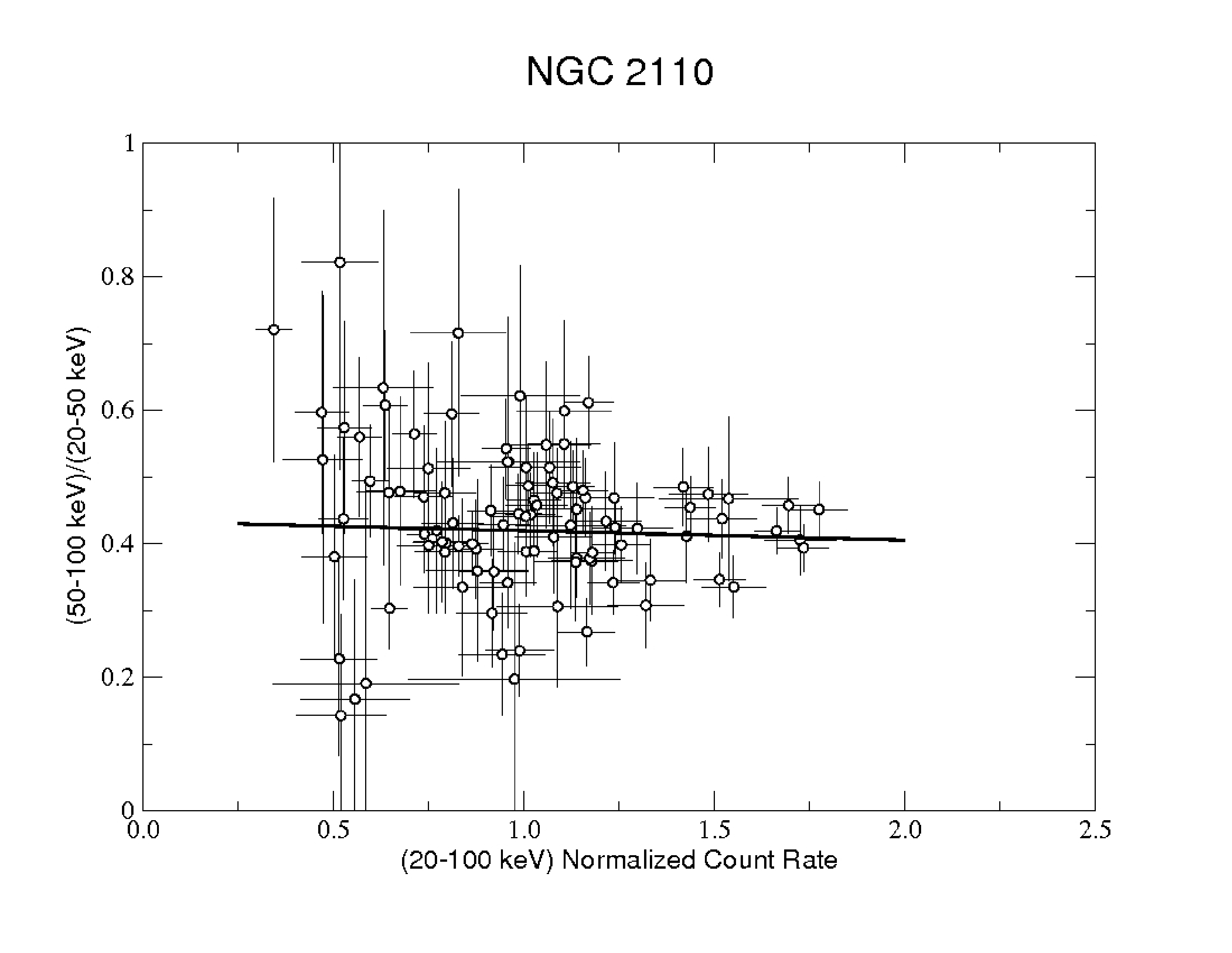

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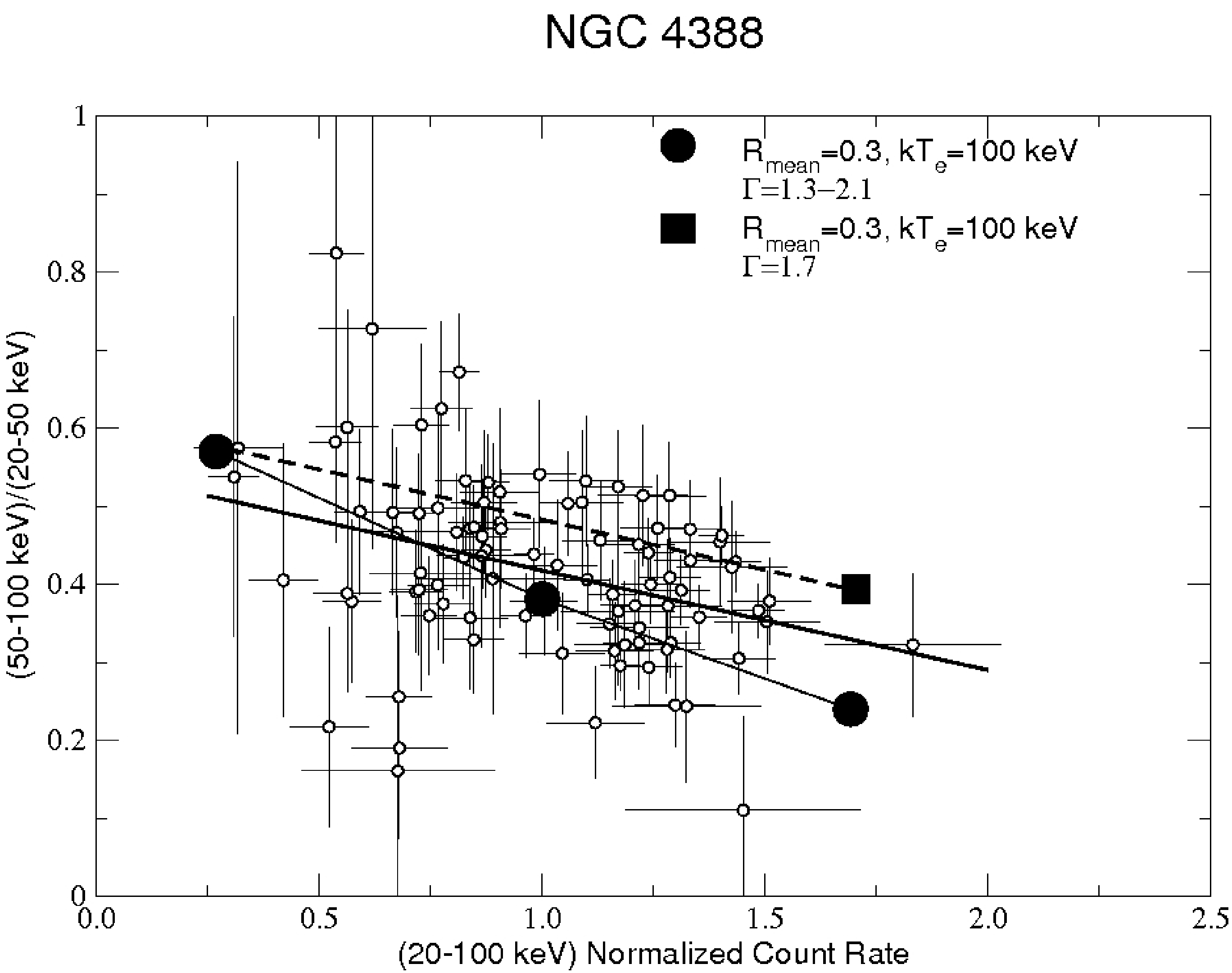

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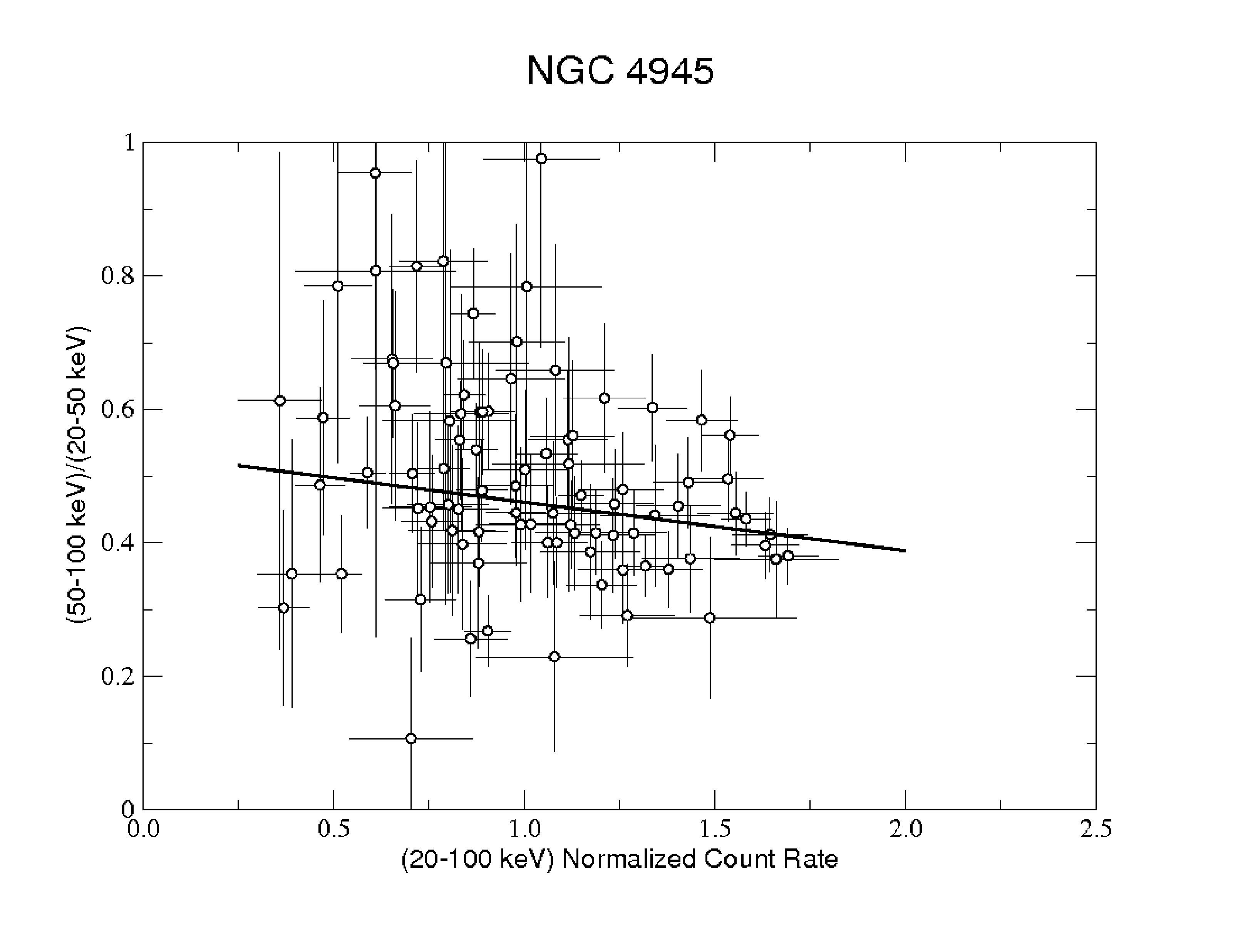
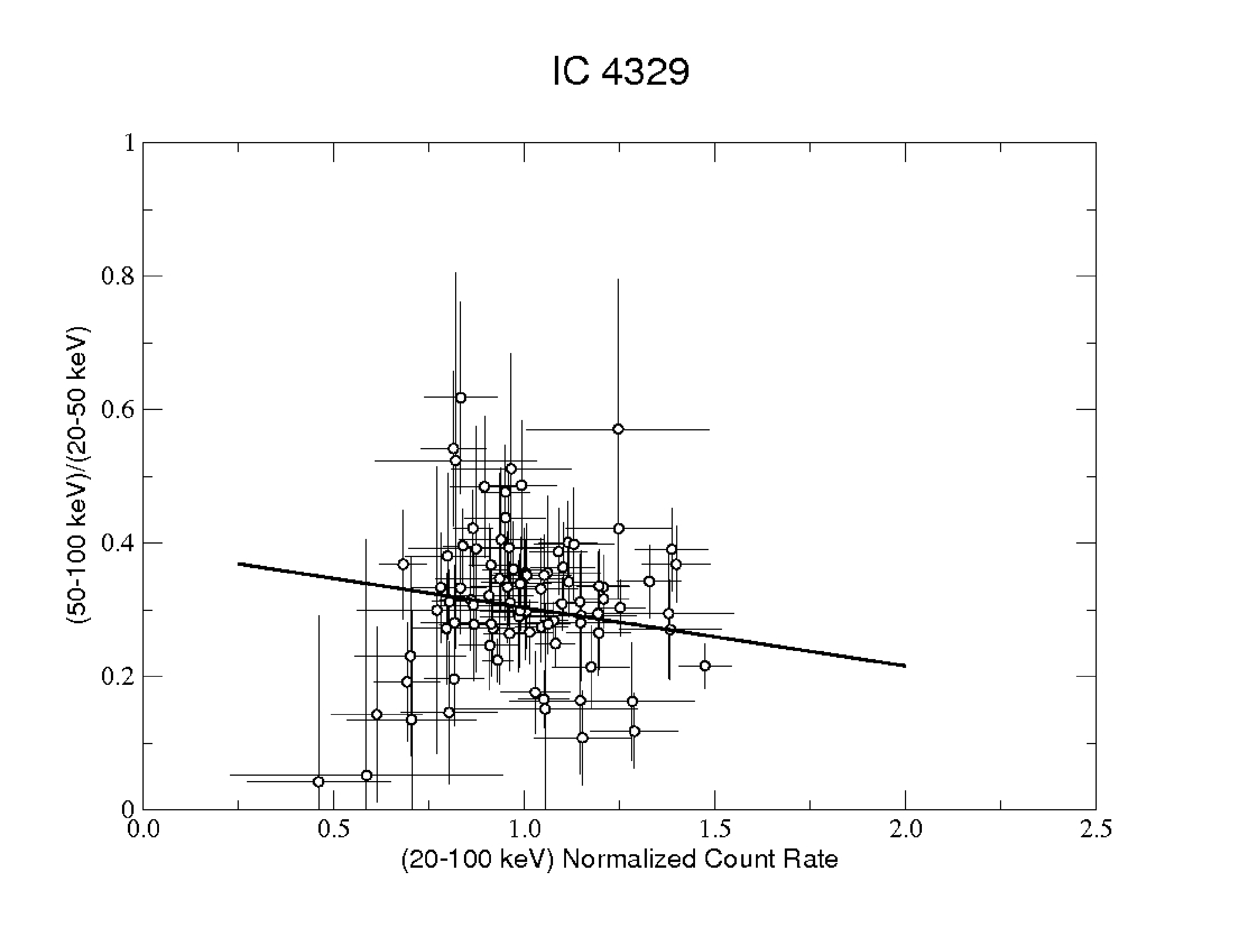


Hard X-rays: Spectral Variability



Hard X-rays: Spectral Variability

OBSERVATIONs

- Despite the significant flux variations, the shape of the 20–100 keV *spectrum remains constant* in NGC 4151 and NGC 2110.

- On the other hand, we detected *significant spectral variations in NGC 4388 and NGC 4945 (and IC 4329?): the hardness ratios decrease as the flux increases*. A similar trend has been observed previously in the 2-10 keV energy range (Sobolewska & Papadakis, 2009).

Hard X-rays: Spectral Variability

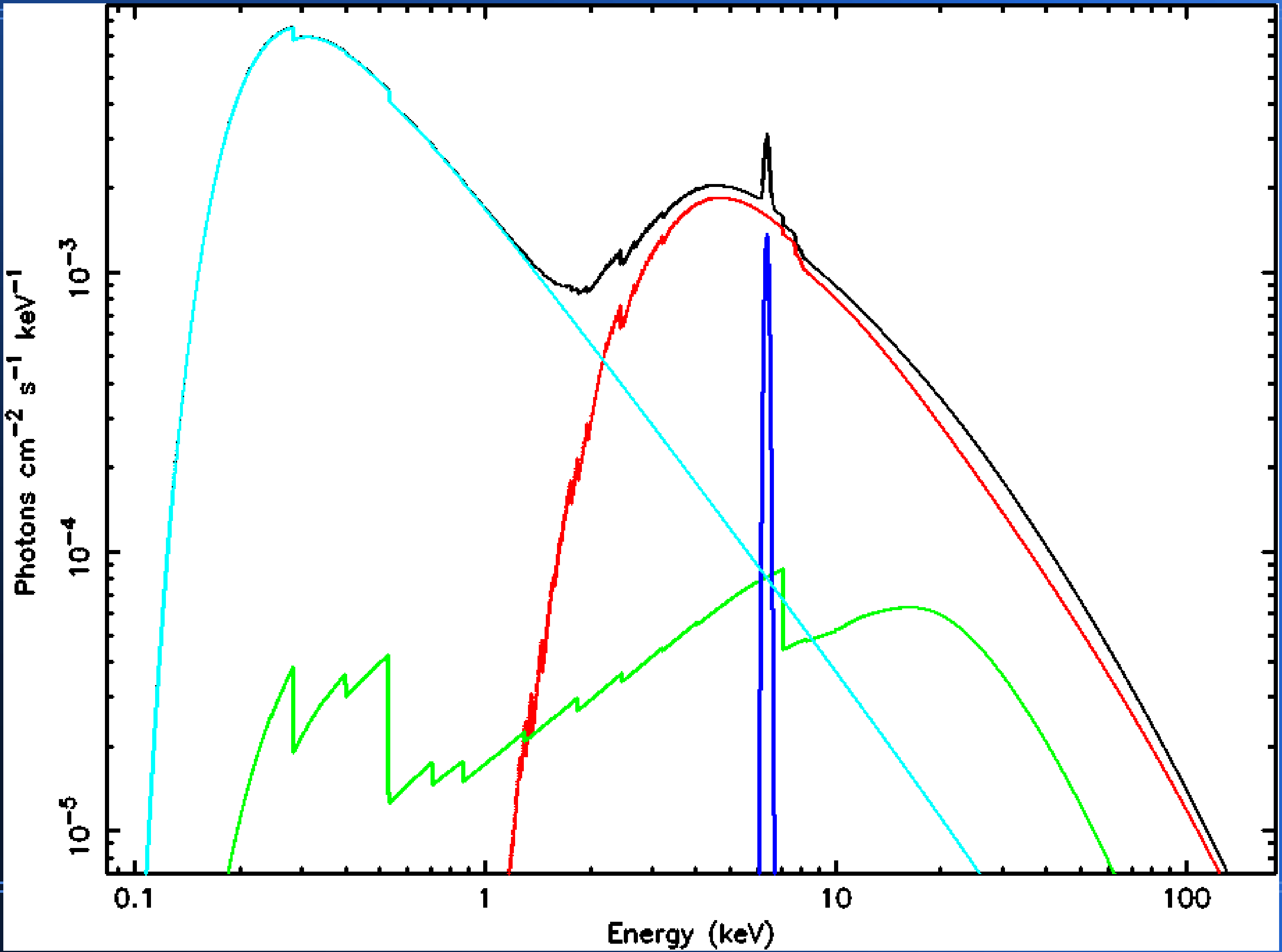
SIMULATIONs: ***MOTIVATION***

- There is not a clear understanding of **what parameter** drives the **spectral evolution** of BHs in general, and AGN in particular.

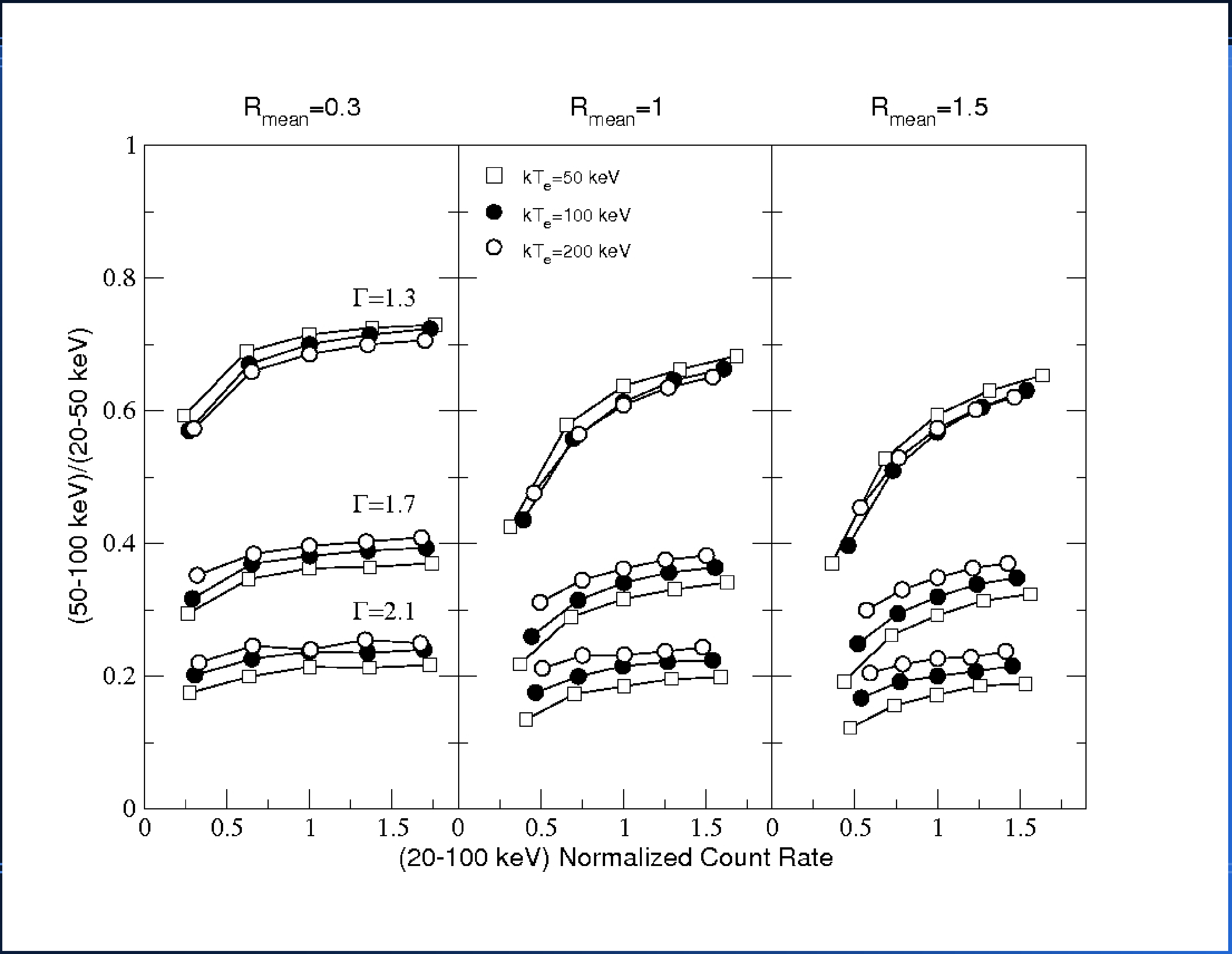
- Previous studies of AGN have claimed for hard X-ray spectral variations due to *changes either in the photon index (Γ), reflection covering factor (R) or kinetic temperature of the Comptonizing electrons (kT_e)*.

- In order to clarify the situation, we have simulated spectra and computed the hardness ratios corresponding to a simple spectral model of **Comptonization** plus a (constant) **reflection** component. We used this model, since it is the most commonly accepted model for the description of the hard X-ray emission from BHs, and AGN in particular.

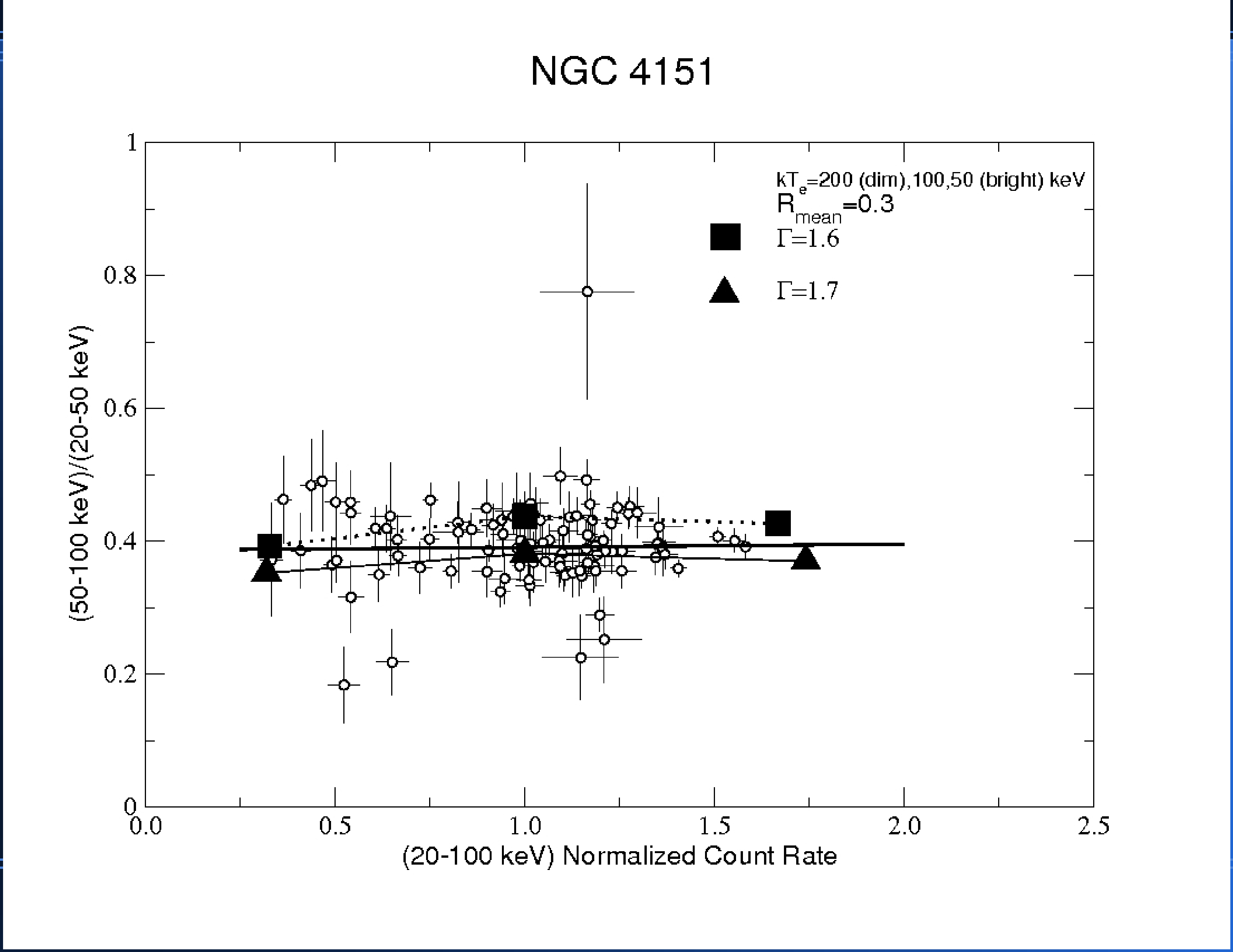
Soft X-rays: Spectral Variability



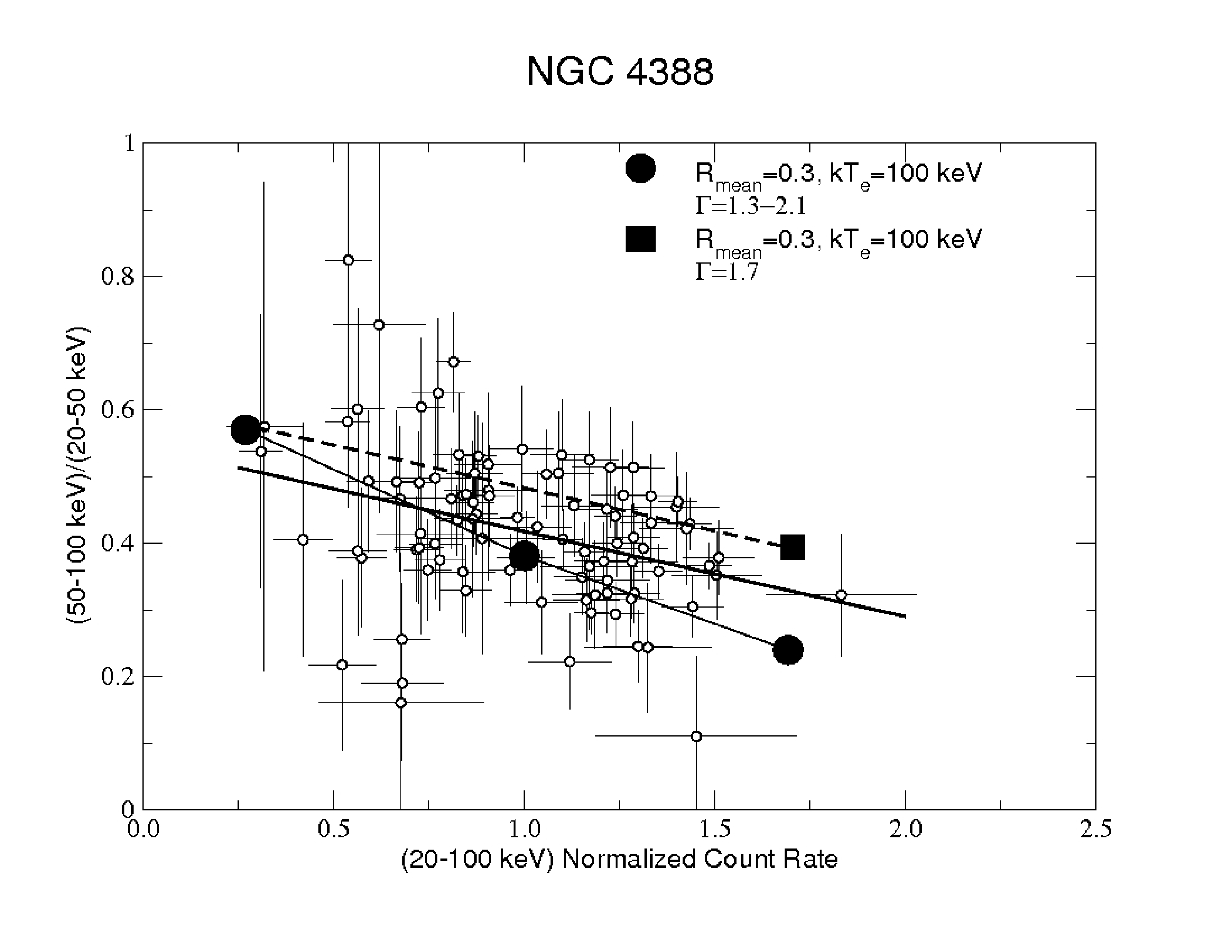
Hard X-rays: Spectral Variability



Hard X-rays: Spectral Variability



Hard X-rays: Spectral Variability



Hard X-rays: Spectral Variability

THE RESULTS

- In agreement by the previous studies for NGC 4151, *the **flatness** of the observed spectral changes are induced **mainly as a result of the change of*** kT_e (lower as the total flux increases). In agreement with previous results (Lubinski et al. 2010).

- *If the optical depth of the corona remains constant (or whether it is not the main parameter driving the spectral evolution): a decrease in the temperature of the corona results in a **steeper** continuum*. If kT_e decreases with increasing flux it is expected a positive correlation between Γ and flux → HR–flux diagrams similar to those of NGC 4388, NGC 4945 (and IC 4329?).

Hard X-rays: Spectral Variability

THE RESULTS

- One important difference between NGC 4151 and NGC 2110 with respect the other three sources is that *they accrete at < 1% of the Eddington limit*, as opposed to > 10% for the other sources. They both have a spectral slope flatter than 1.7

- This is similar to the "spectral slope–flux" evolution of two well studied GBHs, namely GRO J1655-40 and GX 339-4.

- There might be **different "spectral states" in AGN**, just **like in GBHs**, with *NGC 4151 and NGC 2110 being "hard-state" systems*.