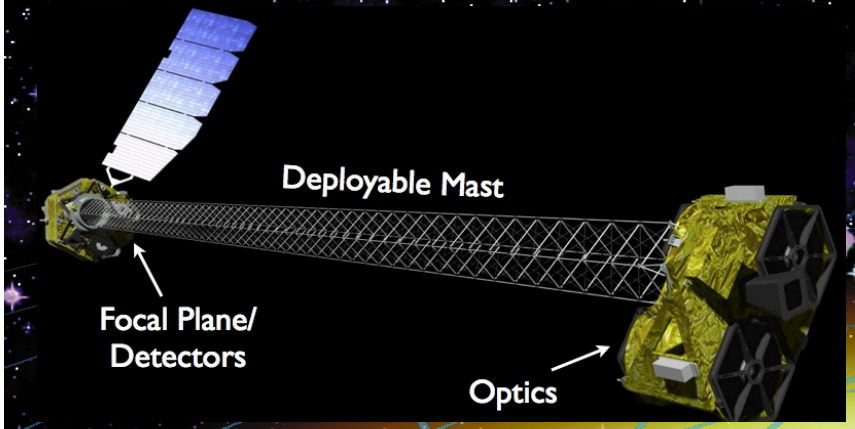
NuSTAR's View of AGN



Laura Brenneman (Harvard-Smithsonian CfA)
on behalf of the *NuSTAR* AGN Physics Team

X-ray Astronomy: Towards the Next 50 Years

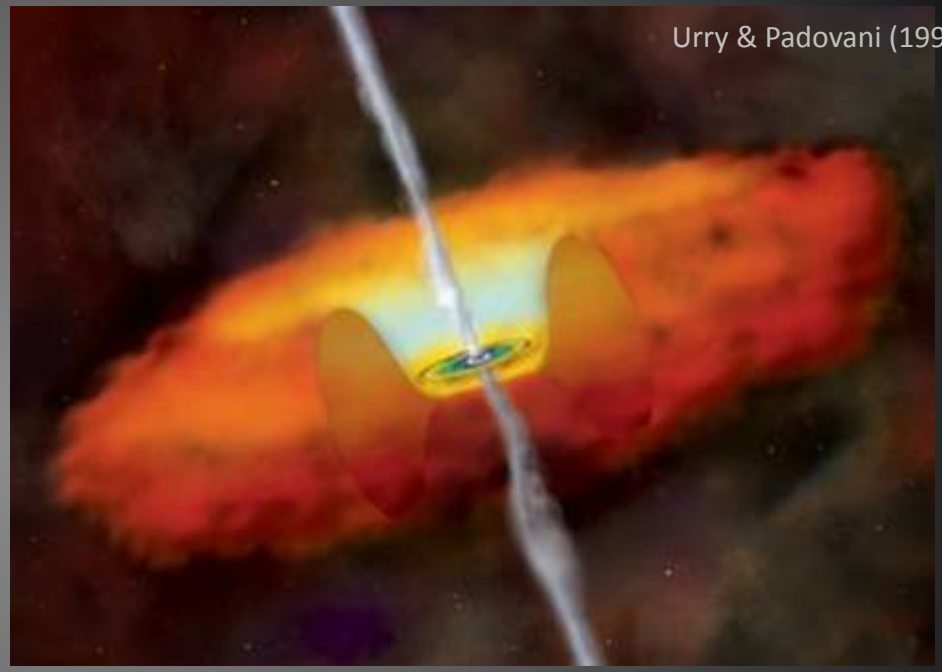
October 2, 2012

Outline

- Outstanding questions in AGN research
- *NuSTAR's* AGN Physics program
- Simultaneous observing campaigns: *XMM* & *Suzaku*
- Early results for IC 4329A
- Conclusions and future prospects

Outstanding Questions in AGN Research

- What are the physical properties of the so-called **corona**?
- What is the distribution of **SMBH spins**?
- What is the nature of the **soft X-ray excess**?
- How are **jets** triggered? What is their role in feedback?


Urry & Padovani (1995)

- What physical processes create the **absorbing structures** in AGN?
- What are the true physical properties of **obscured AGN** and what is their role in the CXB?

How *NuSTAR* Can Provide Answers

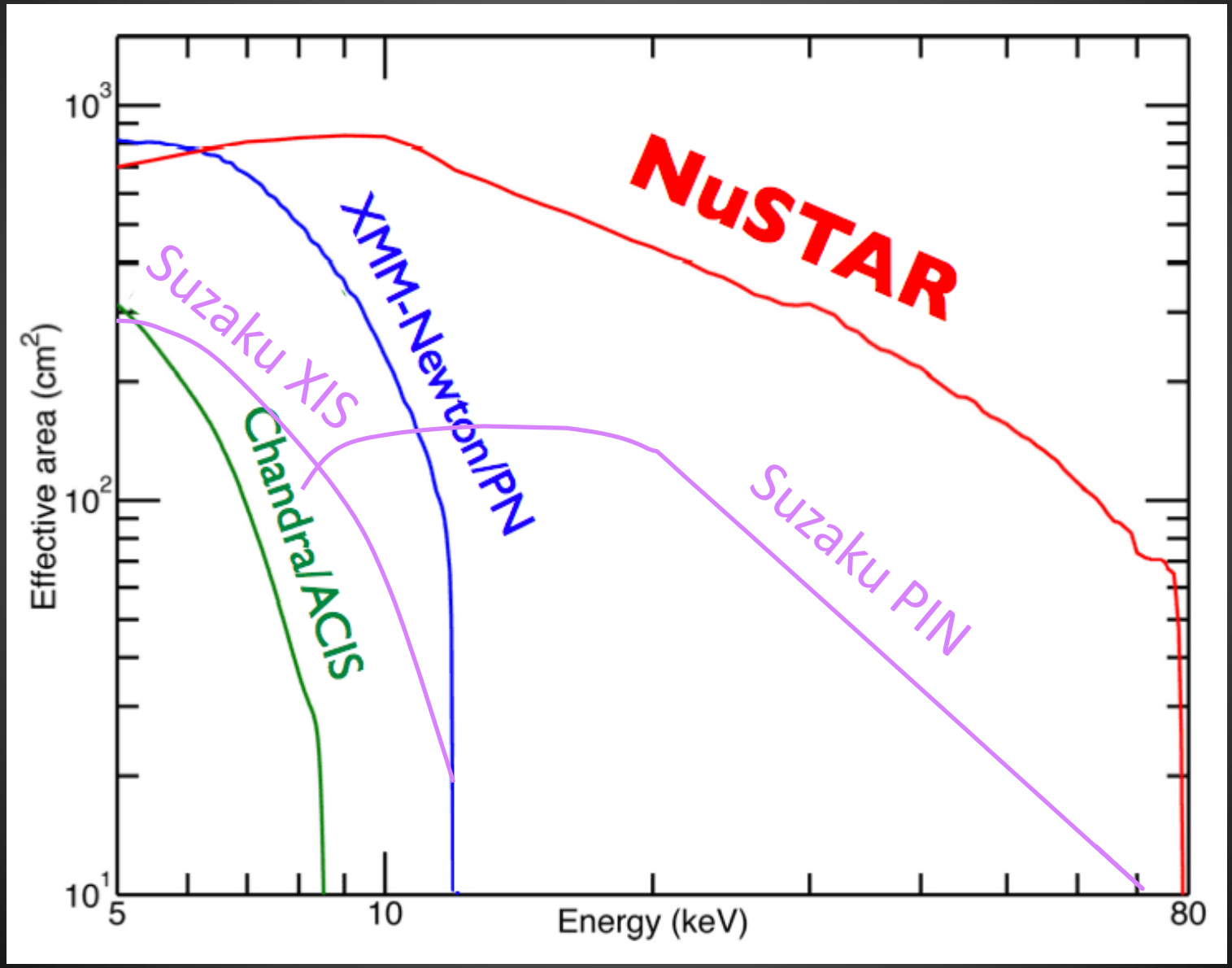
- Low background + high effective area = **unprecedented sensitivity from 5-80 keV.**

    1. Focusing optics vs. coded apertures
    2. Extendable mast for long focal length
    3. Low-earth, near-equatorial orbit
    4. 2 focal planes, 4 32 x 32 pixel CZT detectors each

- Ideal for **precision imaging, spectroscopy, timing** studies across a broad energy range.

- Enables searching for obscured AGN, breaking model degeneracies >10 keV, among many other science goals.

How *NuSTAR* Can Provide Answers



The AGN Physics Working Group

• **Chair: Giorgio Matt**; other members (present at the conference) include Laura Brenneman, Andy Fabian, Massimo Cappi, Fiona Harrison.

• Principle science goals: coronal properties, SMBH spins, separating reflection signatures from absorption, soft excess.

• SOC web site, including schedule of observations:
http://www.srl.caltech.edu/NuSTAR_Public/NuSTAROperationSite/Home.php

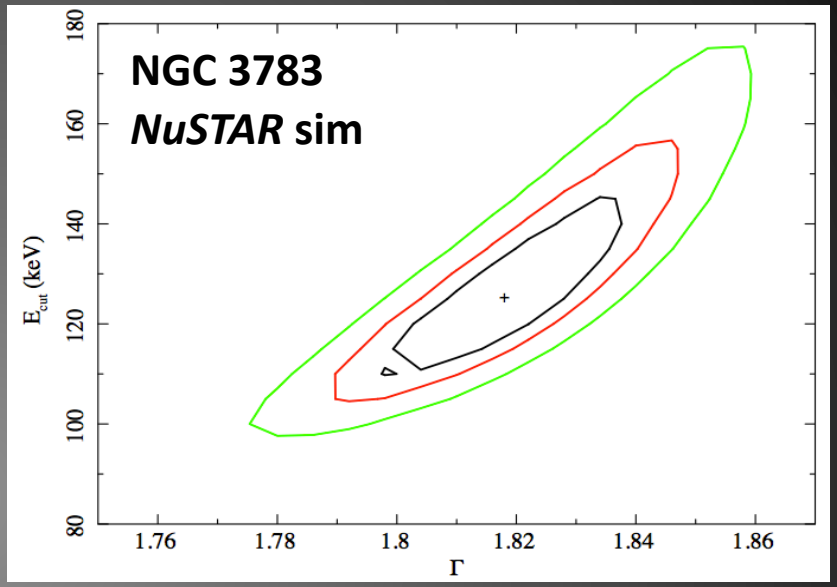
• Total of 9 targeted sources for observing in cycle 1, 0.6 Ms/10 Ms:

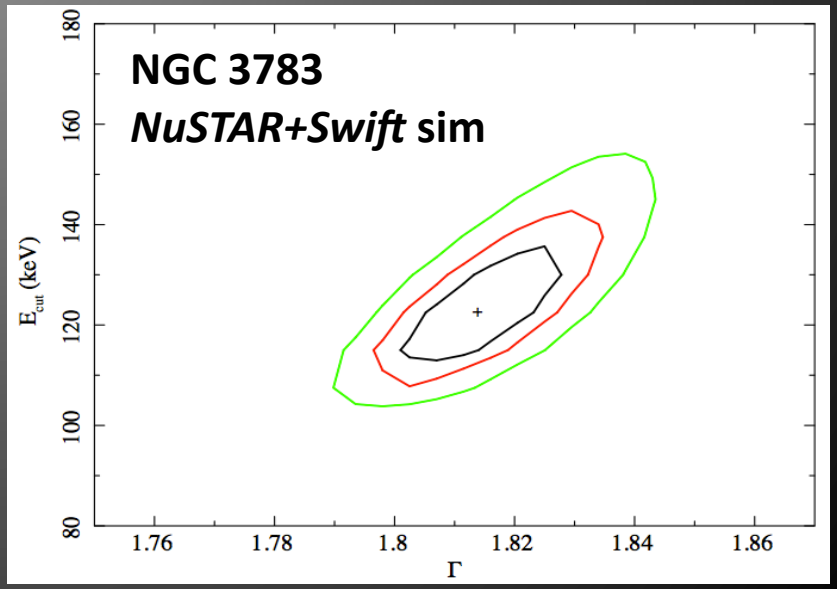
• **3C 273**	**300 ks**
• **Ark 120**	**90 ks**
• **MCG—6-30-15**	**180 ks**
• **3C 120**	**180 ks**
• **Swift J2127.4+5654**	**180 ks**
• **NGC 4151**	**150 ks**
• **IC 4329A**	**120 ks**
• **NGC 3783**	**300 ks**
• **MCG—5-23-16**	**300 ks**

Simultaneous *XMM* & *Suzaku* Campaigns

- Science goals: SMBH spin, coronal properties
- ***Suzaku* AO-7: 3 sources, ~310 ks, focus on corona**
  - 3C 273*
  - NGC 4151
  - IC 4329A
- ***XMM* AO-11: 5 sources, ~1.1 Ms, focus on spin**
  - 3C 273*
  - MCG—6-30-15
  - Ark 120
  - 3C 120 (also *Swift* to check for inner disk disruption)
  - SWIFT J2127.4+5654
- Bonus science: **soft excess** (MCG—6, Ark 120, IC 4329A), **absorption vs. reflection** (MCG—6, NGC 4151, IC 4329A)

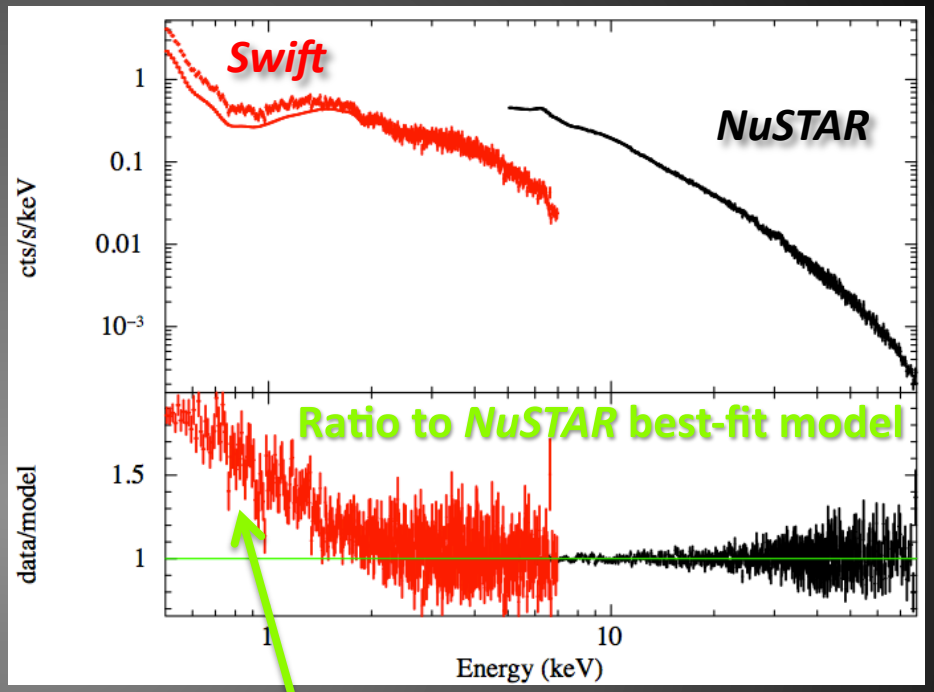
The Nature of the Corona





- Compact electron plasma close to BH, responsible for power-law in X-rays.
- Geometry? Sphere, slab, etc.
- Size? Active regions?
- Origin? Magnetic, thermal or not?
- Temperature? Correlation with Γ ?
- Optical Depth? Measure apart from kT?

The Nature of the Corona



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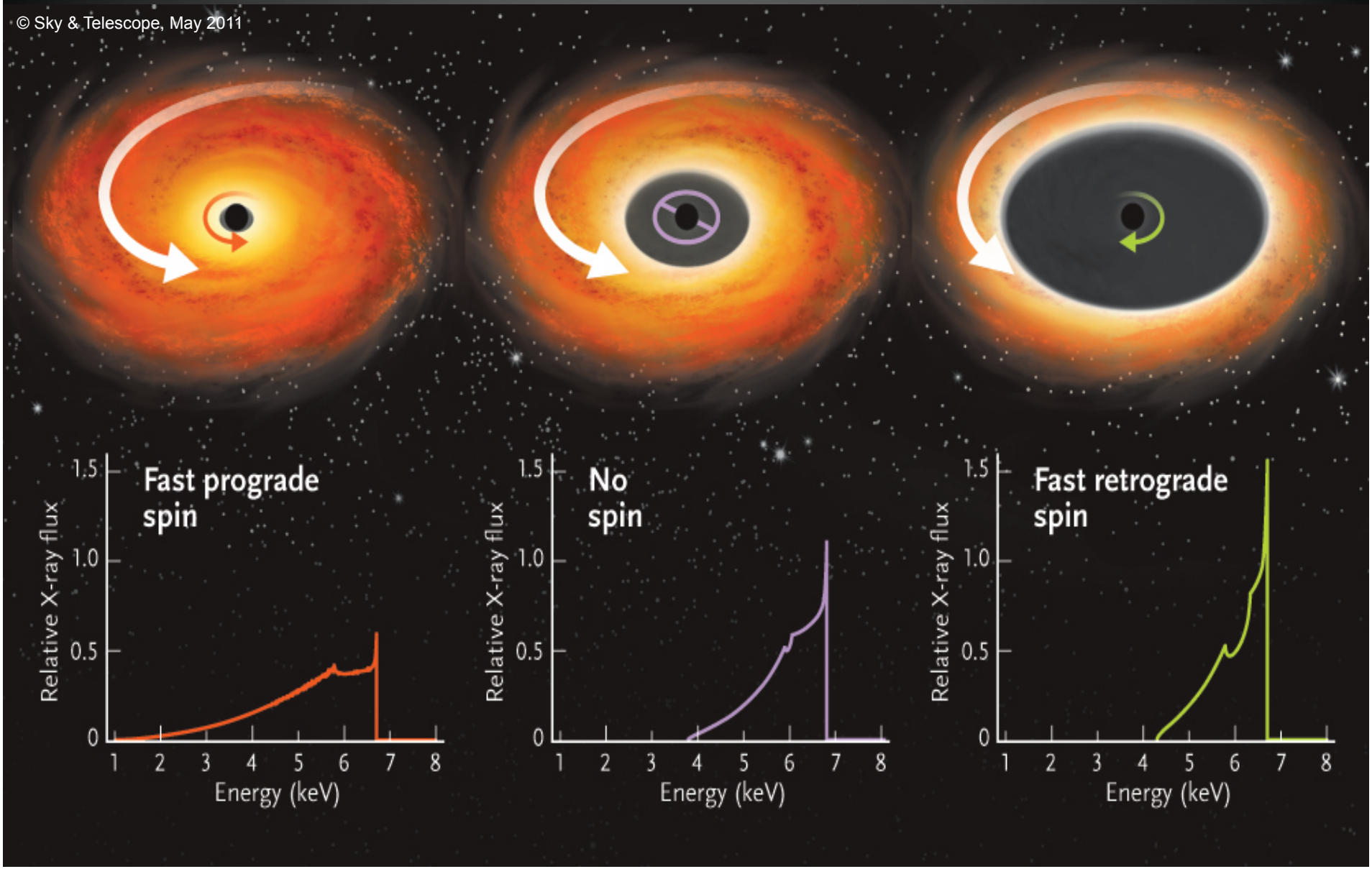
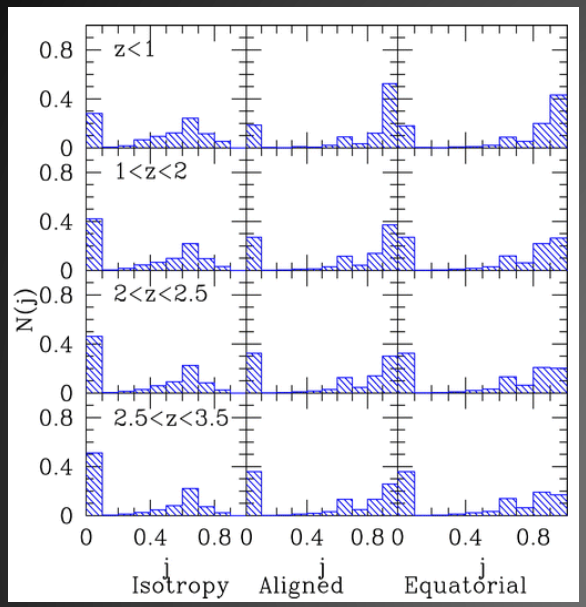
Importance of having data across broad energy range, especially in AGN with complex absorption, soft excess.

SMBH Spins from Reflection

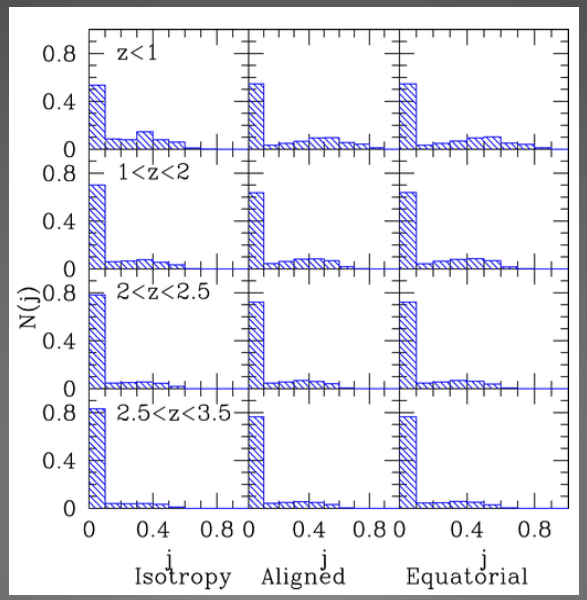


Black Hole Spin and Galaxy Evolution

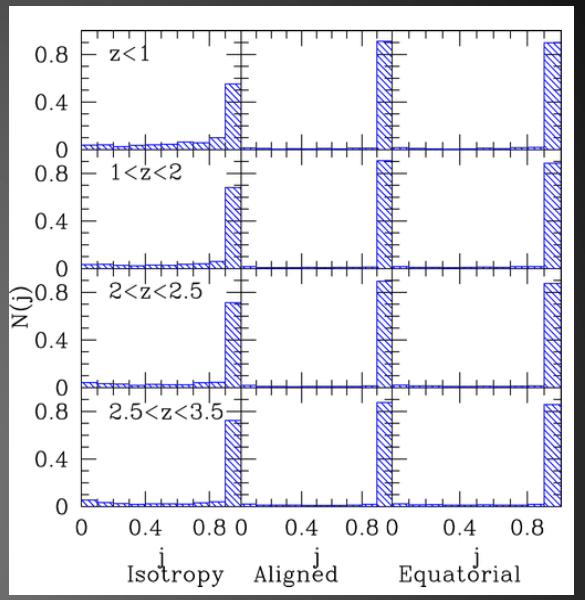


Mergers only

Berti & Volonteri (2008)



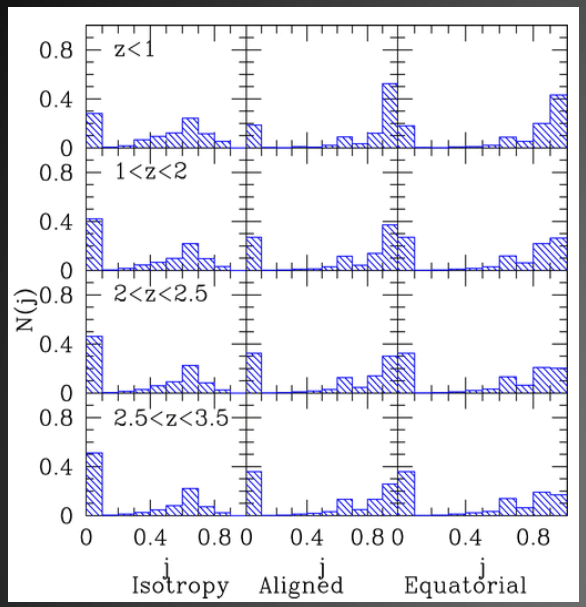
Mergers + chaotic accretion



Mergers + prolonged accretion

- Mergers of galaxies (and, eventually, their SMBHs) result in a wide spread of spins of the resulting SMBHs.
- Mergers and chaotic accretion (i.e., random angles) result in low BH spins.
- Mergers and prolonged, prograde accretion result in high BH spins.

Black Hole Spin and Galaxy Evolution



Mergers only

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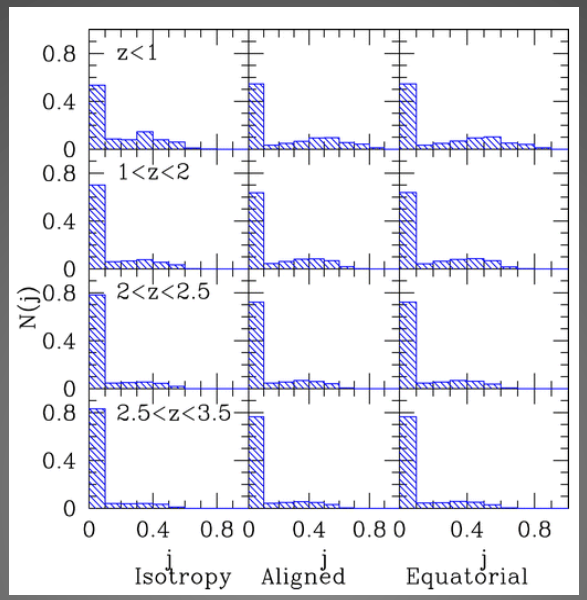
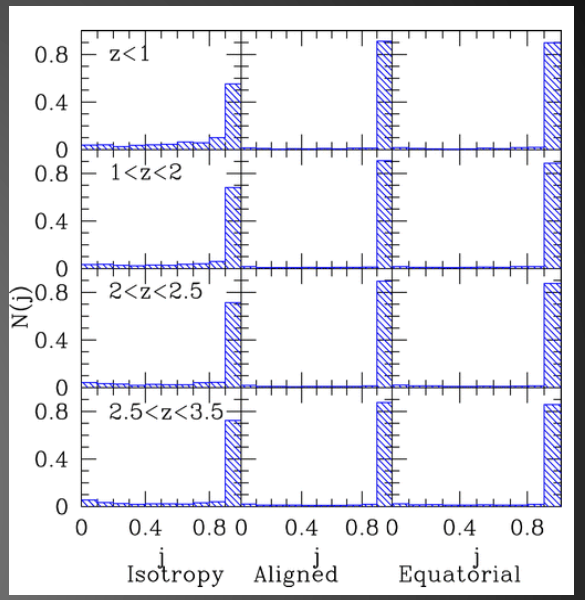


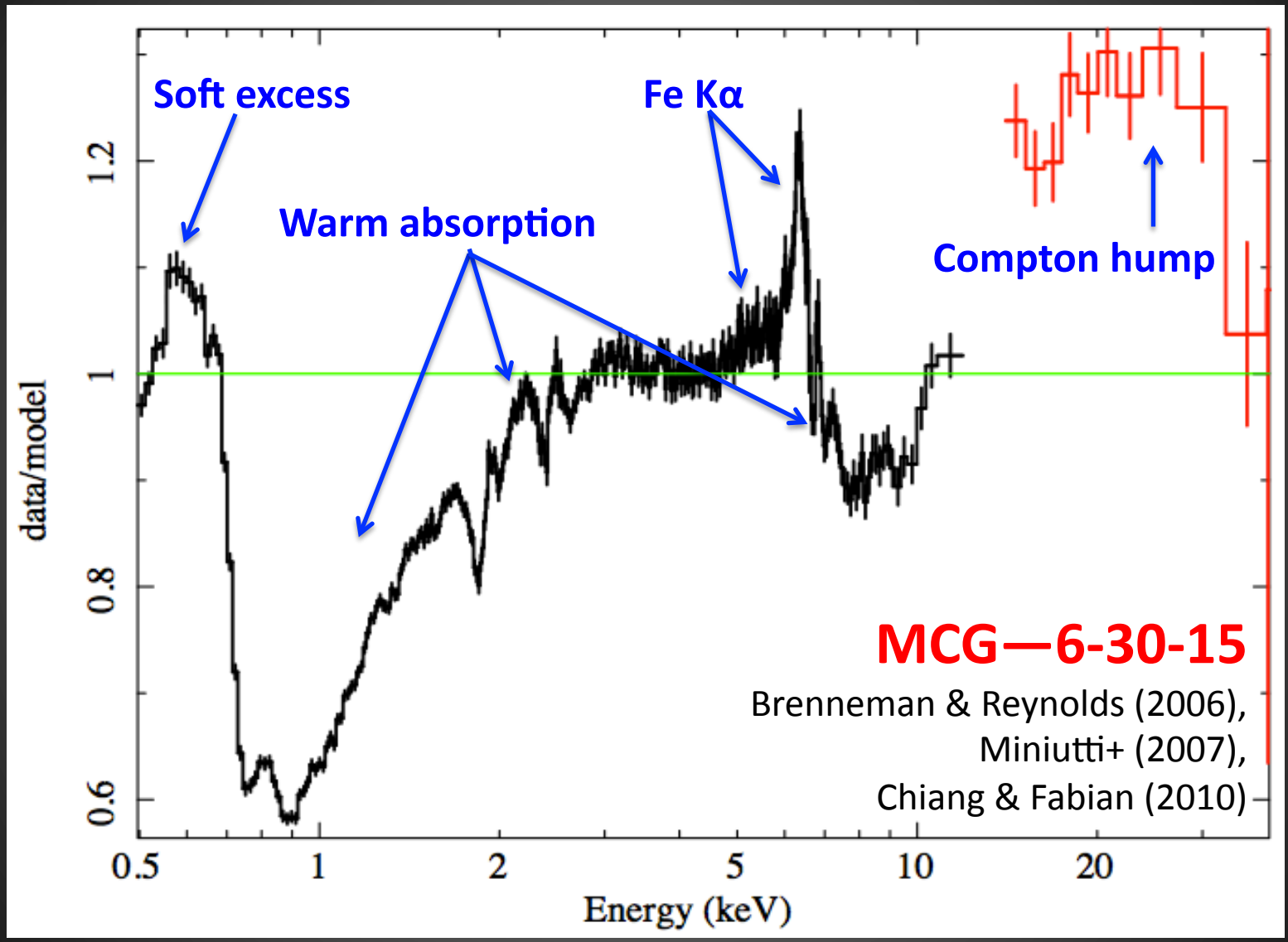
Mergers + chaotic accretion



Mergers + prolonged accretion

- *NuSTAR* won't increase sample size appreciably, but will improve precision and accuracy of spin measurements.
- Will help assess relative role of mergers vs. accretion for ~30-40 AGN in recent epochs.

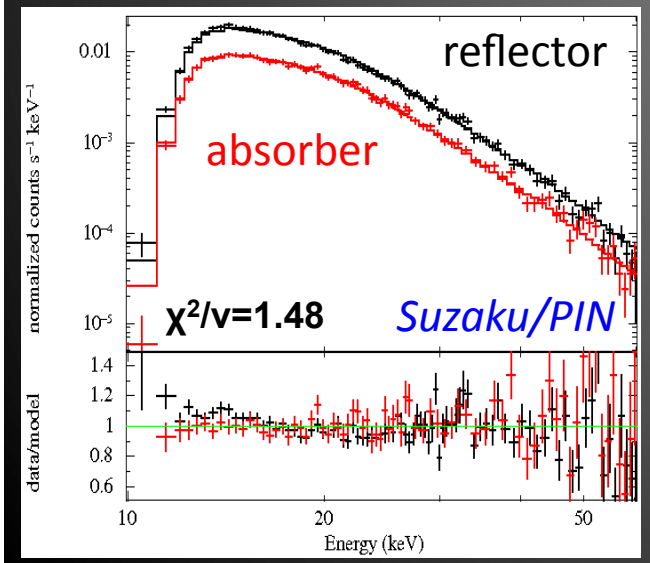
Caveat: Spectral Complexity

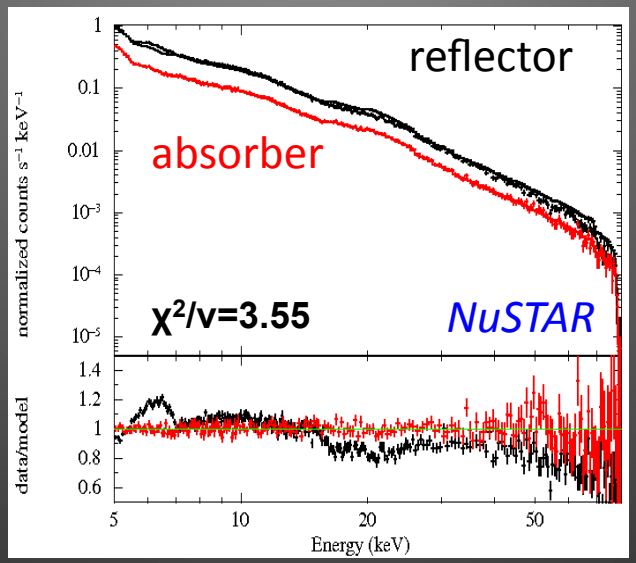


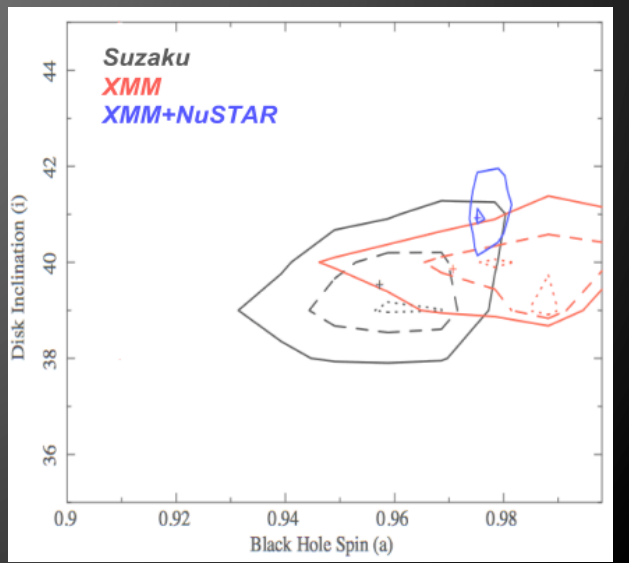
Major issues: how to model soft excess, separate absorption and reflection components?

Separating Reflection from Absorption

- **Multi-epoch & time-resolved spectral analysis** assess variability of three spectral components: continuum, reflection, absorption.
- A **physically consistent model** should be able to explain ALL the data: spin, disk inclination, abundances shouldn't change.
- ***NuSTAR*** has high enough collecting area, spectral resolution and low enough background >10 keV to differentiate between reflection and absorption (e.g., MCG—6: Miller, Turner & Reeves 2008 vs. Brenneman & Reynolds 2006).
- When used **simultaneously with *XMM* and/or *Suzaku***, will achieve best-ever constraints on BH spin (precision increased by factor ~10, more confident in measurement accuracy).







What about the Soft Excess (e.g., NGC 3783)?

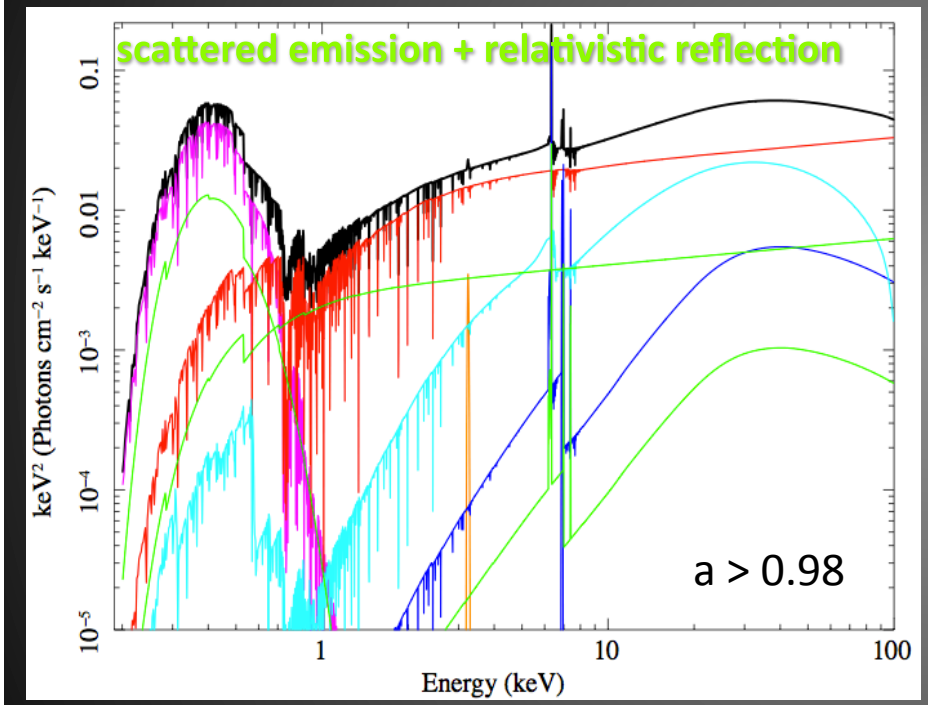
- **Present in majority of AGN** that are not totally absorbed <2 keV.

- 0.5-2 keV range **accounts for most of s/n in AGN observations** due to higher collecting area at these low energies, so parameterization of this region can highly influence spectral fitting!

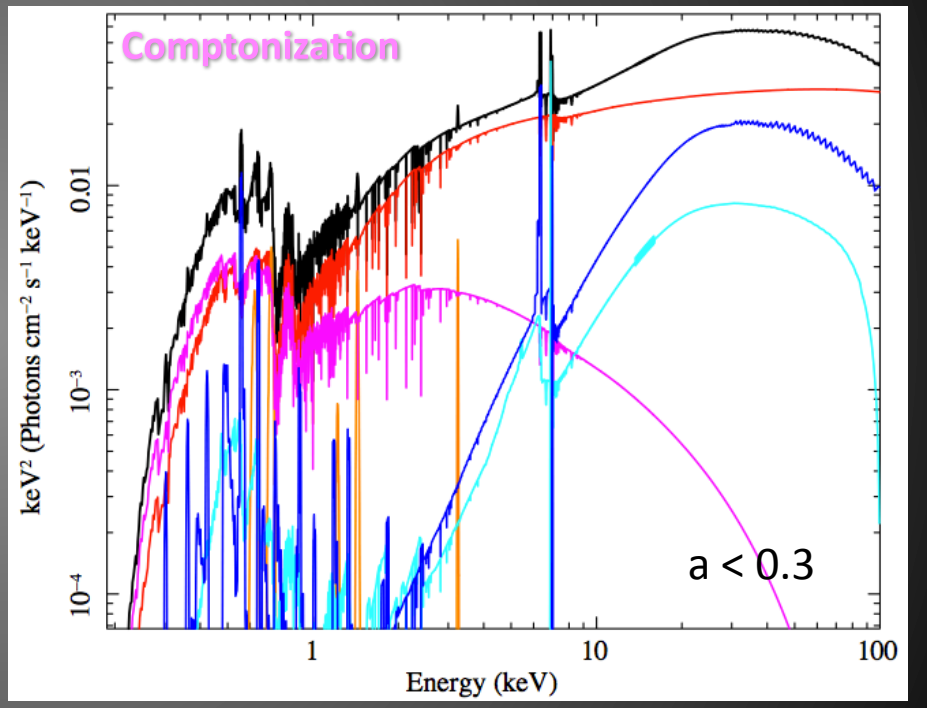
- **Physical origin of this emission is still a mystery**, may differ source-to-source (e.g., Crummy+ 2006):
    - Scattered emission?
    - Comptonization?
    - Photoionized lines?
    - Relativistic reflection?
    - *All of the above??*

What about the Soft Excess (e.g., NGC 3783)?

Brenneman+ (2011)

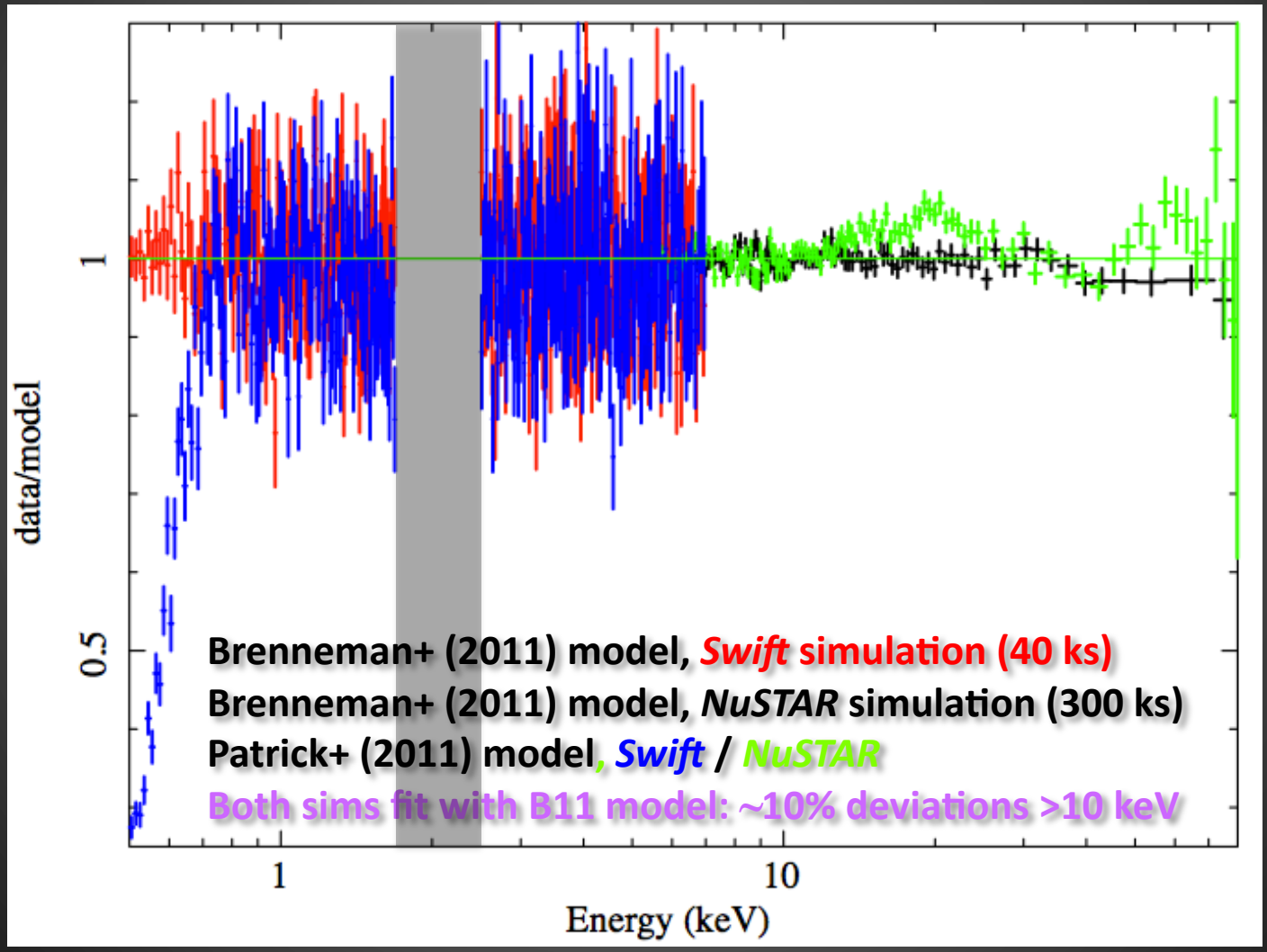


Patrick+ (2011)

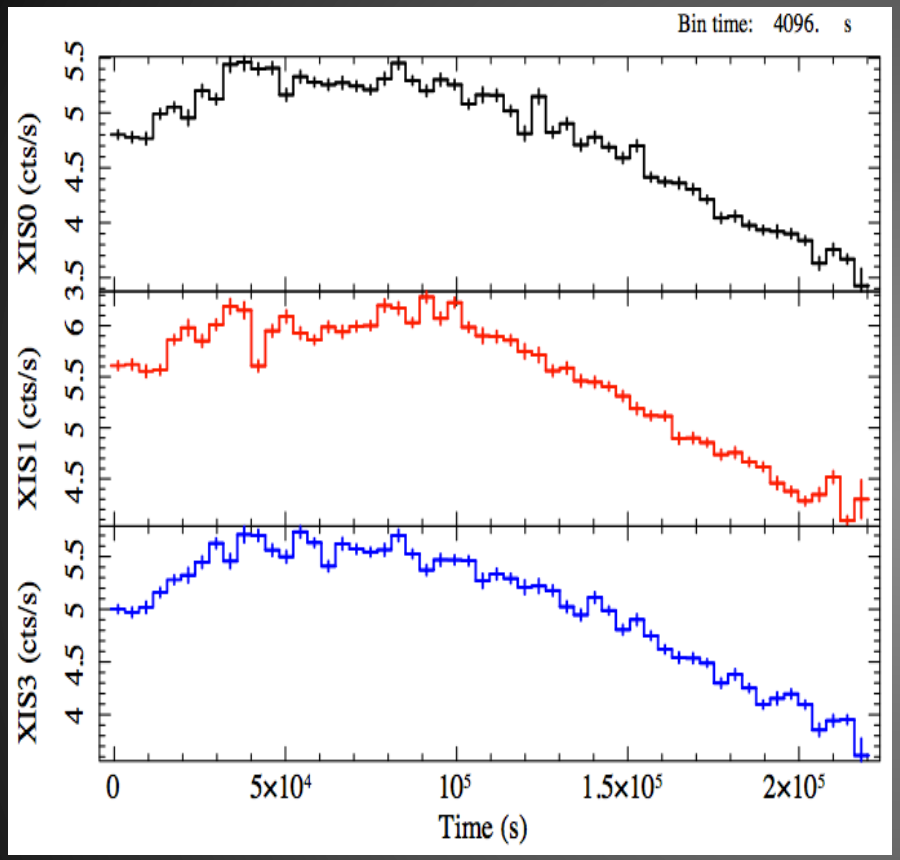


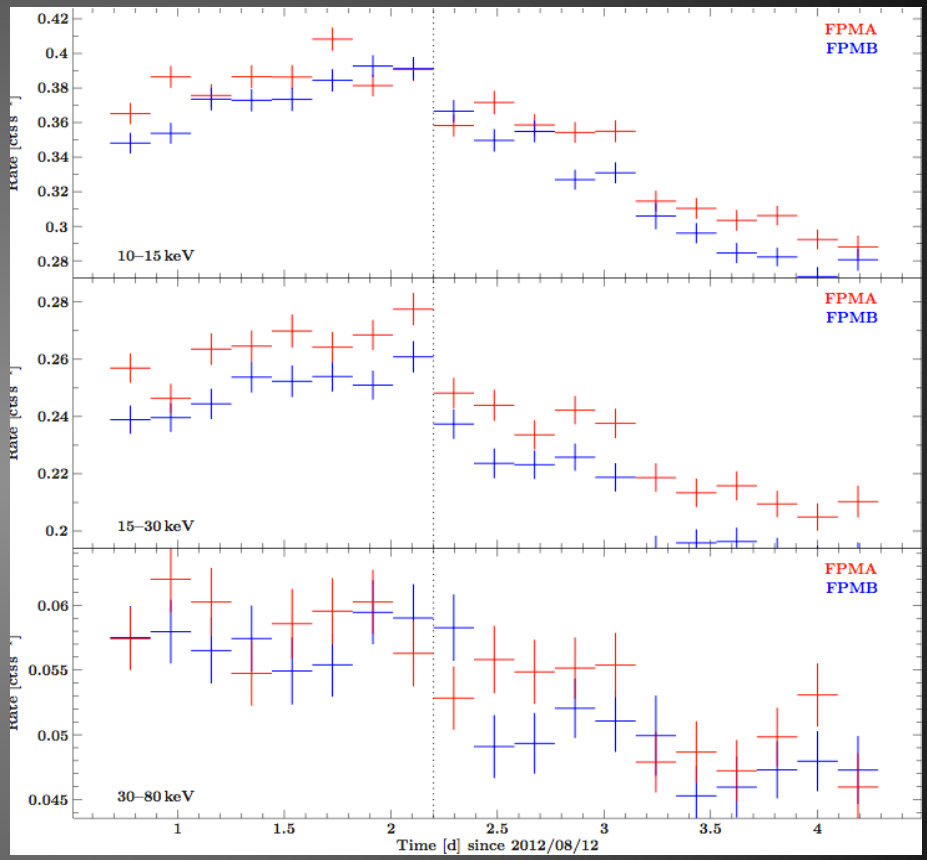
Similar statistical goodness-of-fit to *Suzaku* data, but measured spin depends critically on soft excess modeling, also iron abundance.

NuSTAR: Breaking Modeling Degeneracies



Preliminary Results on IC 4329A

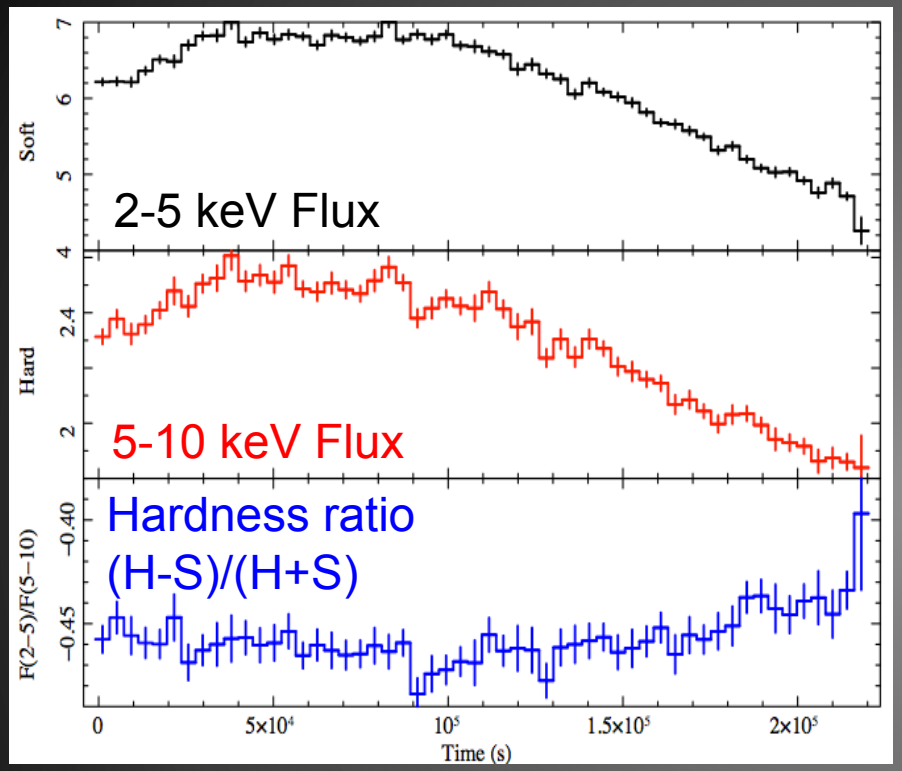




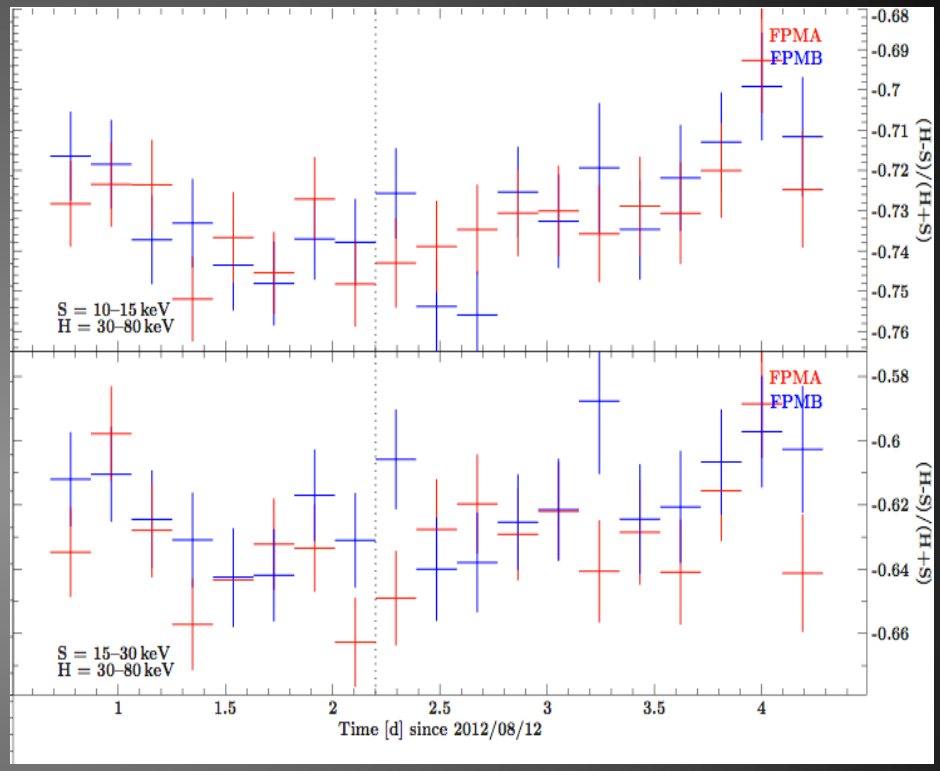
Suzaku *NuSTAR*

~34% flux decrease over observation after ~12% flux increase at start.

Hardness Ratios



***Suzaku* XIS**

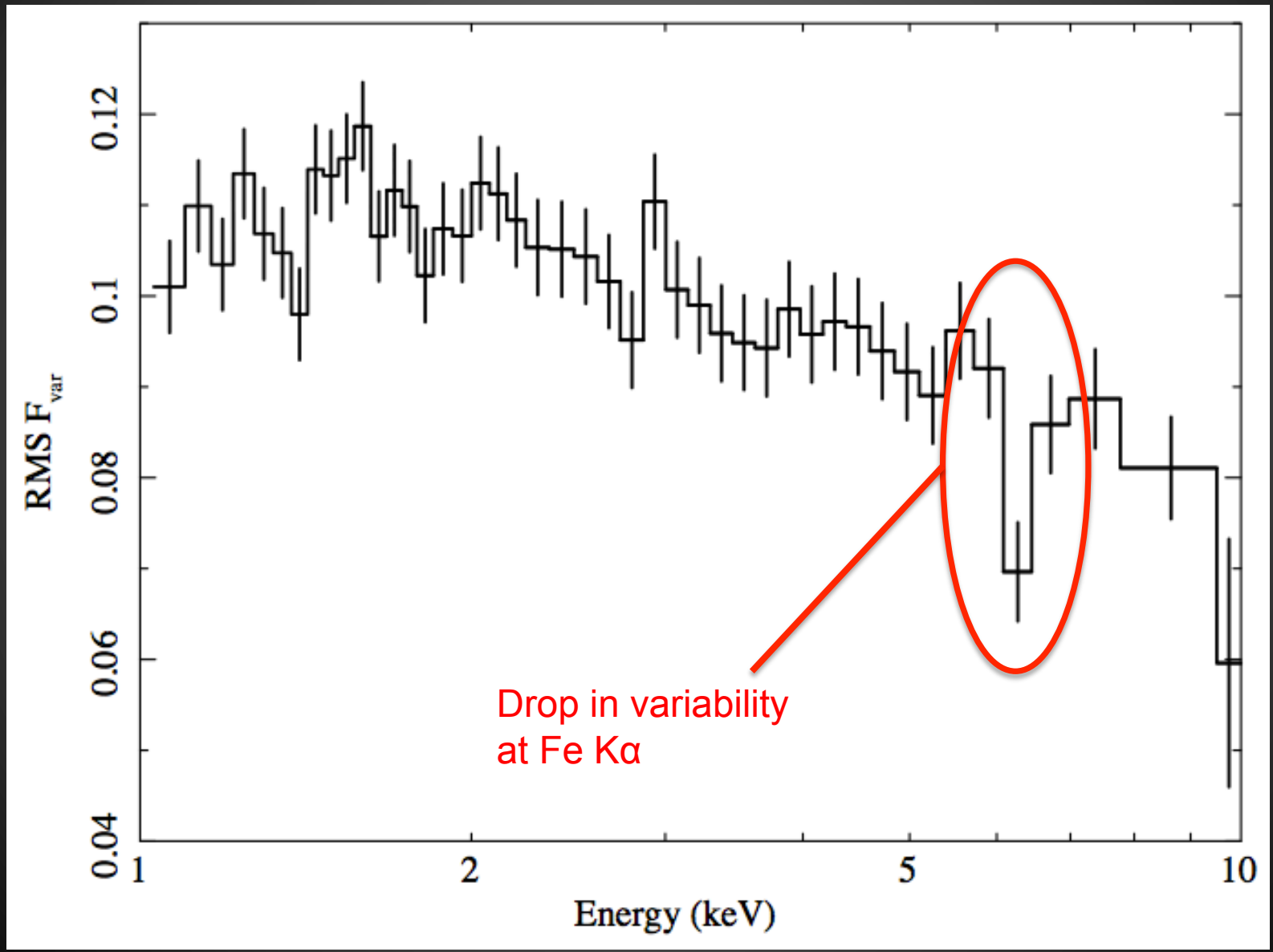


NuSTAR

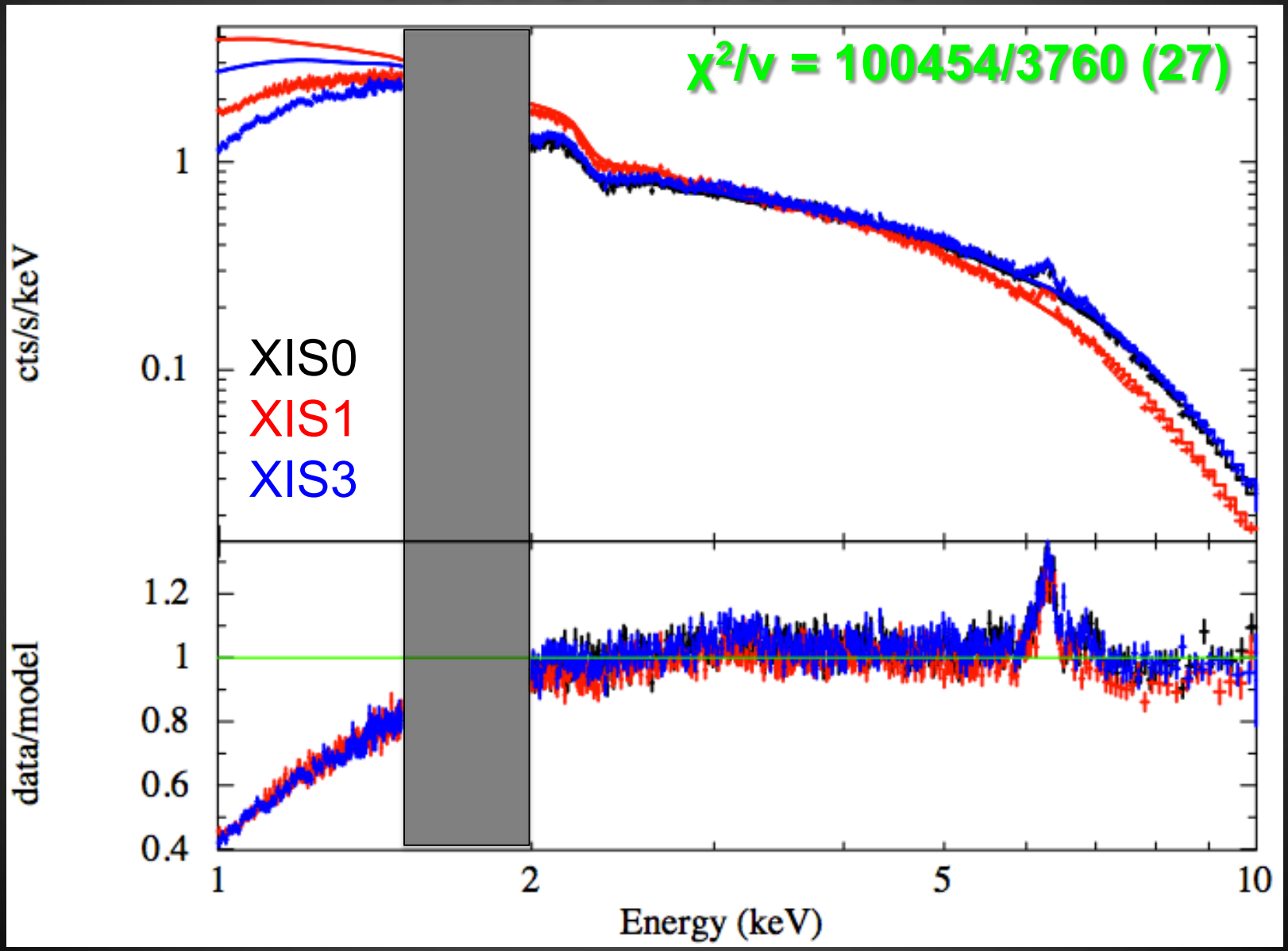
- Hardness ratio shows softer when brighter, harder when dimmer

- Hardness ratios mirror behavior seen at lower energies

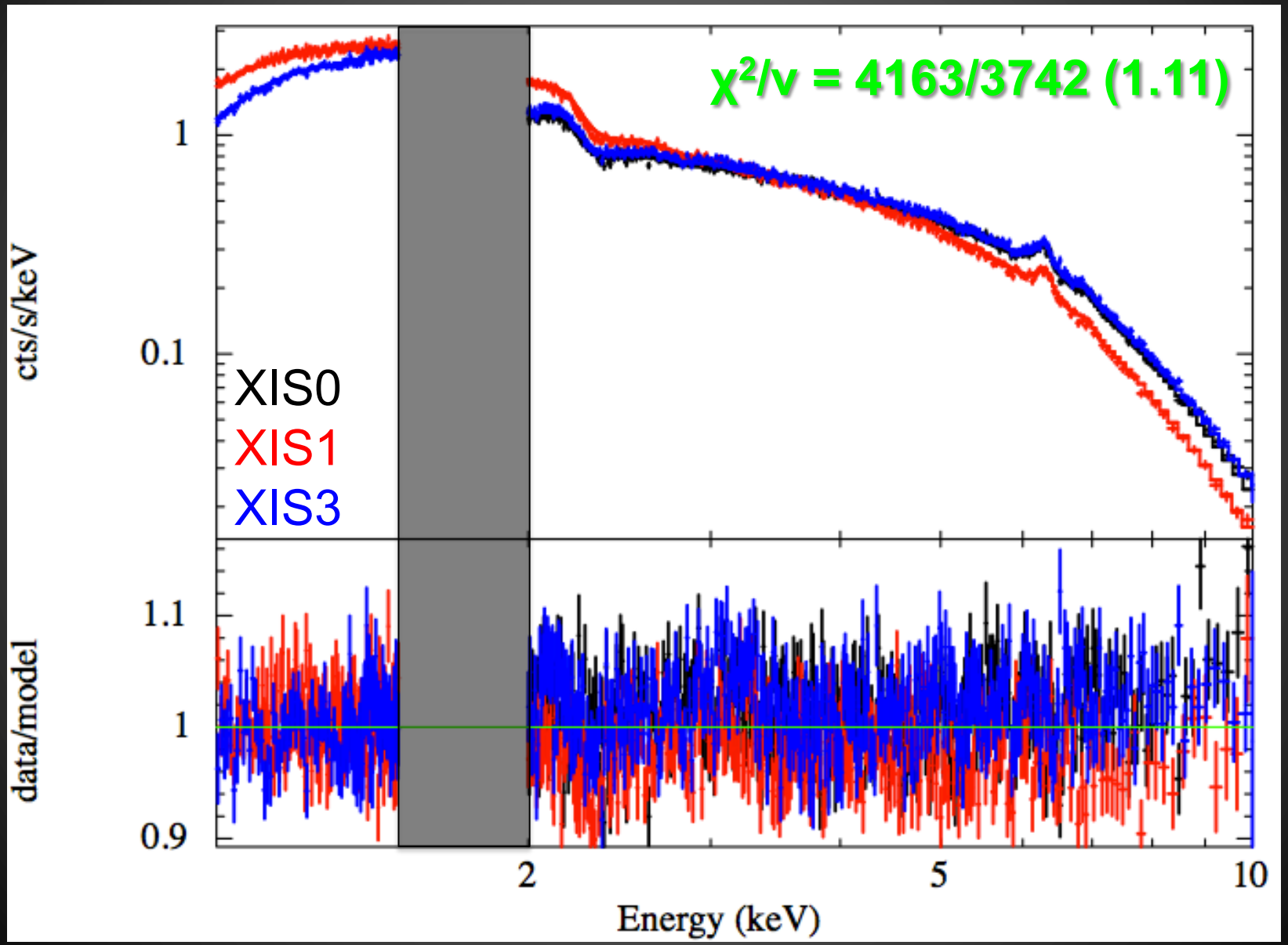
Suzaku: Model-independent Variability



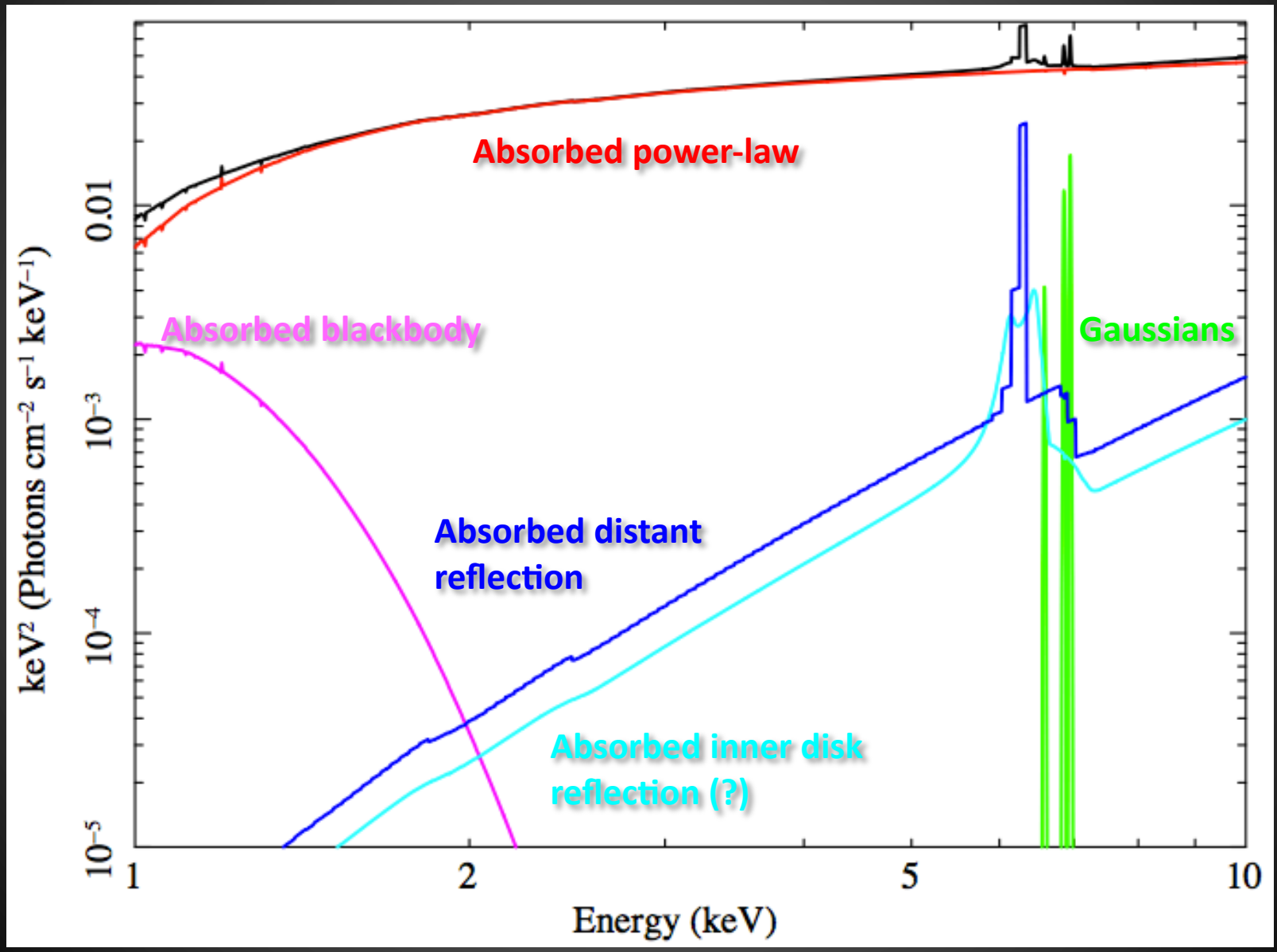
Time-averaged *Suzaku* Spectra: Power-Law Fit



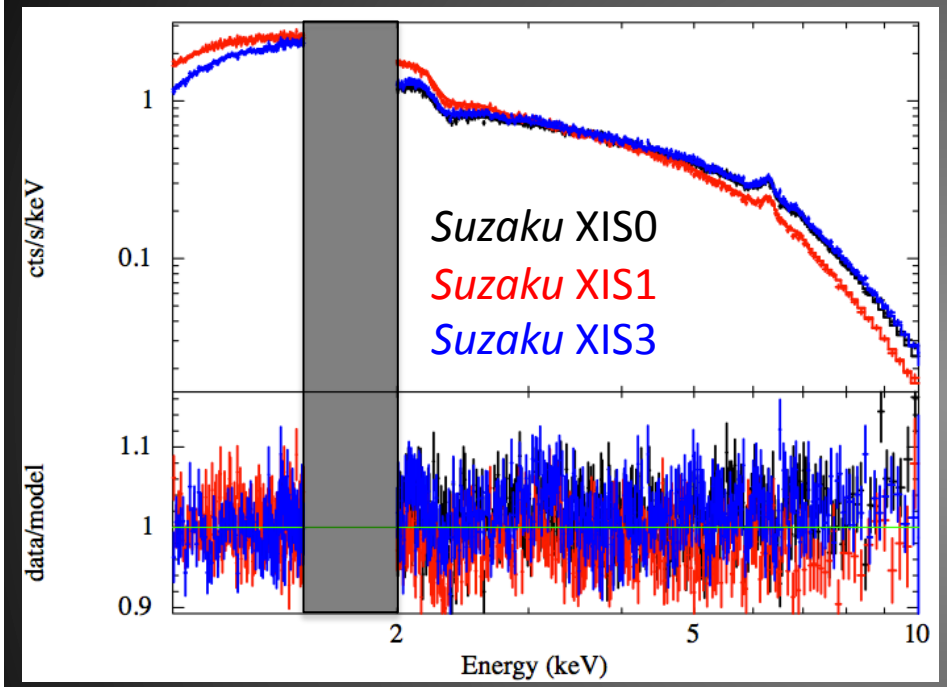
Time-averaged *Suzaku* Spectra: Best Fit

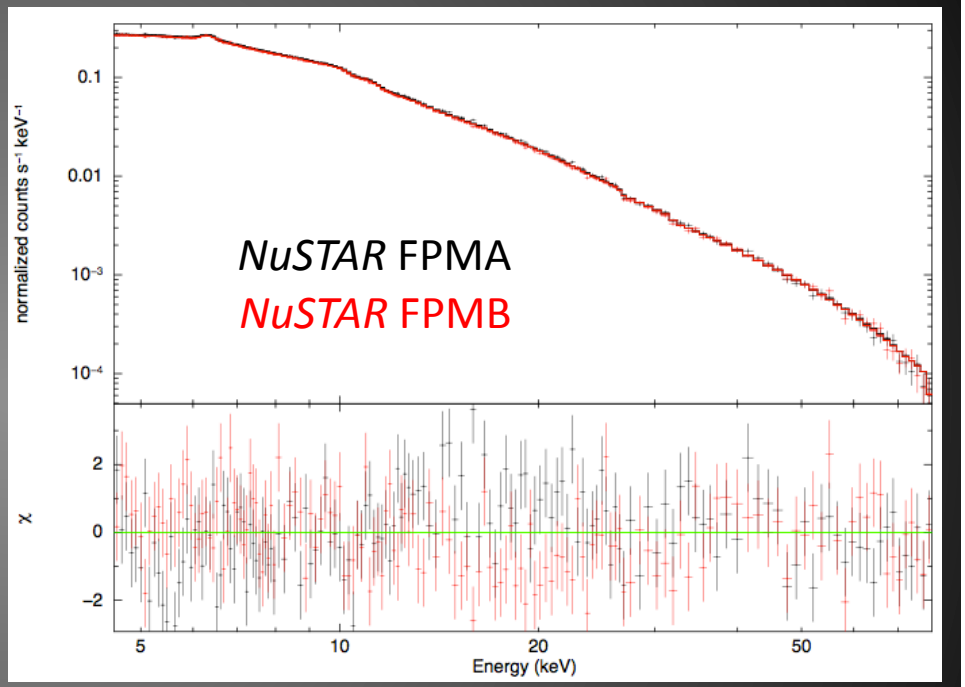


Best-fit Spectral Model for *Suzaku*



Suzaku + *NuSTAR* Time-averaged Spectra





- power-law: Γ = 1.79… not yet combined for E_{cut} constraints → kT, τ
- WAs: 2 zones, ~10^{21} cm^{-2}, log ξ_1 = 0.61, log ξ_2 = 4.0, $\Delta\chi^2/\Delta\nu$ = 27854/4
- bbody: kT = 0.12 keV, $\Delta\chi^2/\Delta\nu$ = 92/2
- distant reflionx: Fe/solar = 2, $\Delta\chi^2/\Delta\nu$ = 943/2
- **inner relconv(reflionx): ξ < 30, i = 30°, q = 1.25, a = ???, $\Delta\chi^2/\Delta\nu$ = 0/4**

Summary

- *NuSTAR* will address several open questions in AGN research:
  - **Coronal physics**
  - **SMBH spin**
  - **Reflection vs. absorption**
  - **Demographics of obscured AGN**
  - **Jet production**
- **Simultaneous observations with *XMM, Suzaku, Swift*** will provide highest sensitivity ever achieved from 0.5-80 keV.
- **Improved accuracy and precision** on SMBH spin, coronal temperature and optical depth measurements.
- Early results on **IC 4329A** show excellent cross-calibration between *NuSTAR* and *Suzaku*, will independently constrain kT, τ, but likely not BH spin.

Synergies and Future Directions

- *Astro-H* (2014): larger area, better spectral resolution than *Suzaku*
  - separate absorption from emission in Fe K band
  - break degeneracy between truncated disk and lower spin(?)

- ~~*GEMS* (2014): Most sensitive X-ray polarimeter flown~~
  - ~~independent check on spin, but likely only for XRBs~~

- *ASTROSAT* (2014): Simultaneous UV & X-ray spectroscopy
  - tighter constraints on disk thermal emission, warm absorption

- *IXO/ATHENA/EPE* (??): Further large increase in area over these missions
  - probe accretion/coronal physics on orbital timescales
  - increase sample size by ~10x
  - polarimeter?