

# *The NuSTAR view of Radio-quiet AGN*

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on behalf of the  
NuSTAR AGN Physics WG

Active Galactic Nuclei 11  
Where Black Holes and Galaxies meet  
Trieste, 23-26 September 2014

# Outline

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- Brief introduction about scientific goals
  - Radio-quiet AGN seen by NuSTAR
    - Results
  - Conclusions

# Outline

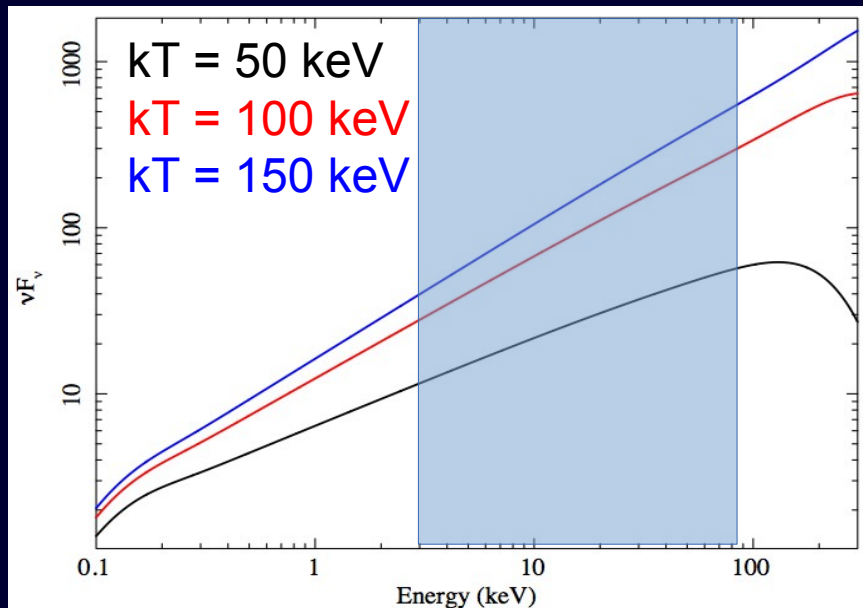
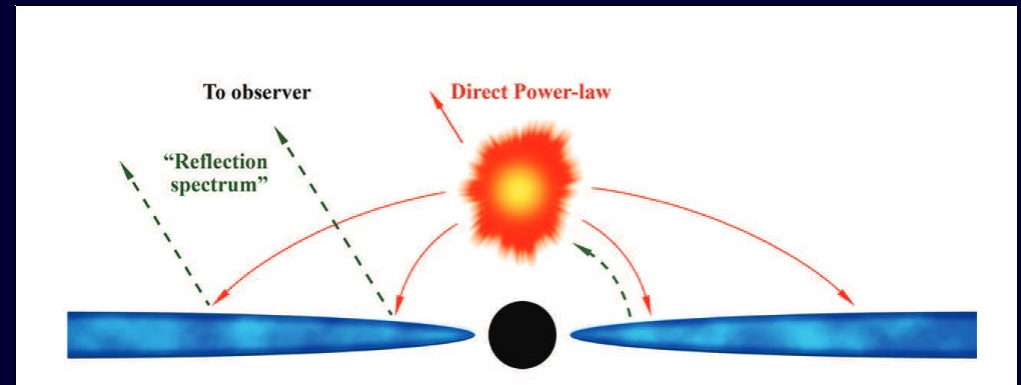
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# Introduction – Primary emission

One of the main open problem for AGN is the nature of the primary X-ray emission.

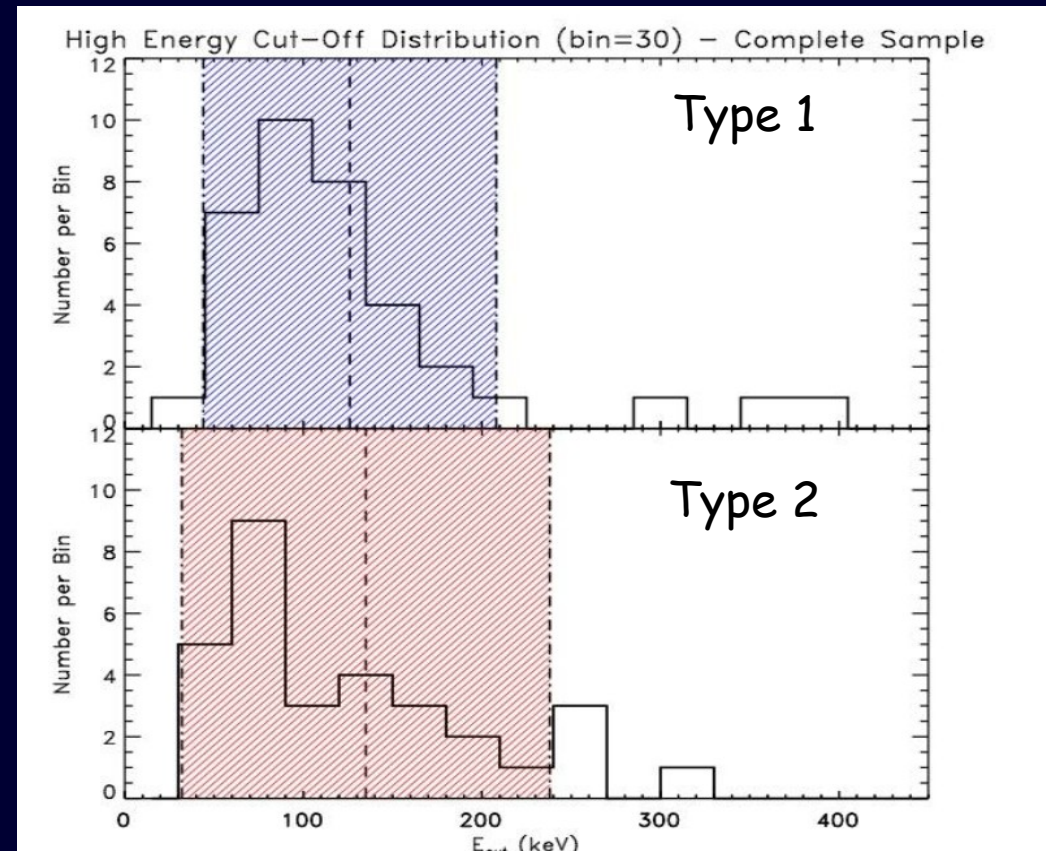
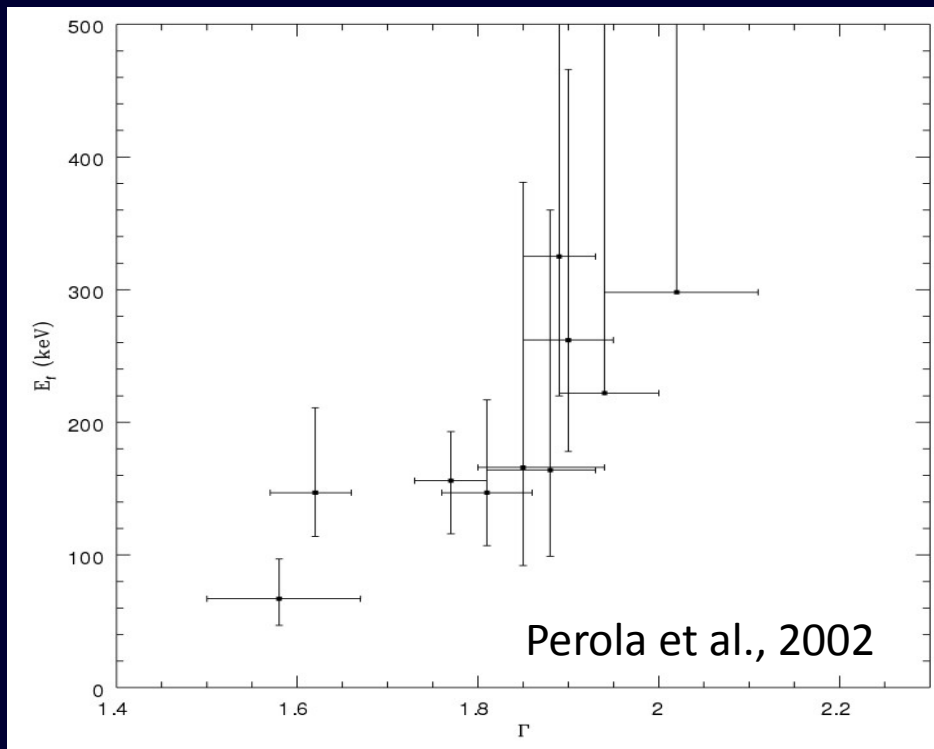
It is due to Comptonization of soft photons, but the geometry, optical depth and temperature of the emitting corona are largely unknown.



Most popular models imply  $E_{\text{cut}} = 2-3 kT$ , so measuring  $E_{\text{cut}}$  helps constraining Comptonization models.

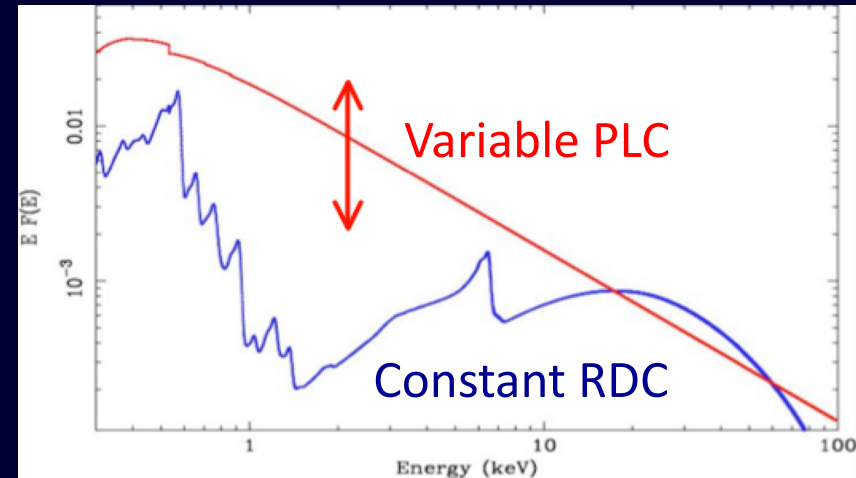
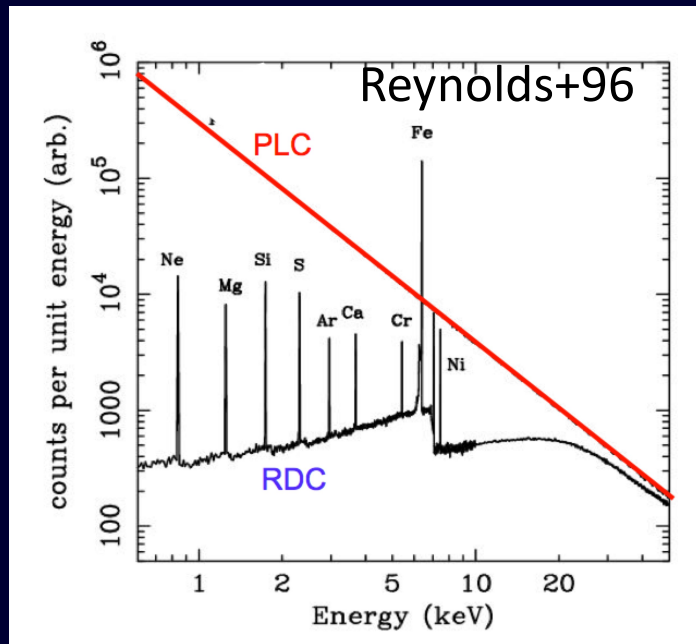
# Introduction – Primary emission

So far, we have only a handful of results based on non focusing, and therefore strongly background-dominated, satellites (BeppoSAX-PDS, Suzaku HXD-PIN, INTEGRAL, Swift-BAT)

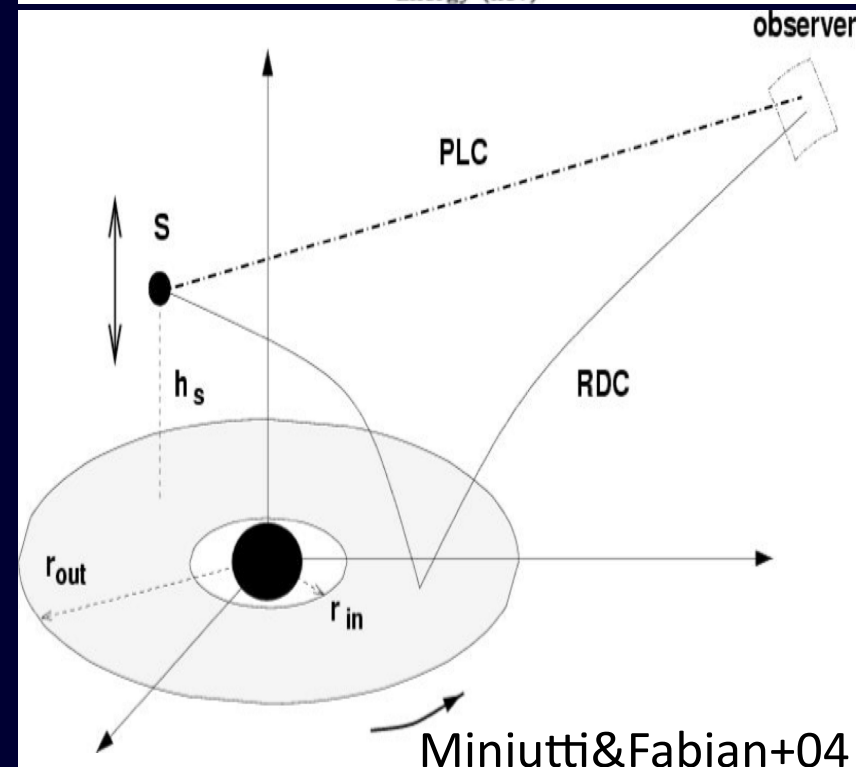


De Rosa et al. 2012, Molina et al. 2013

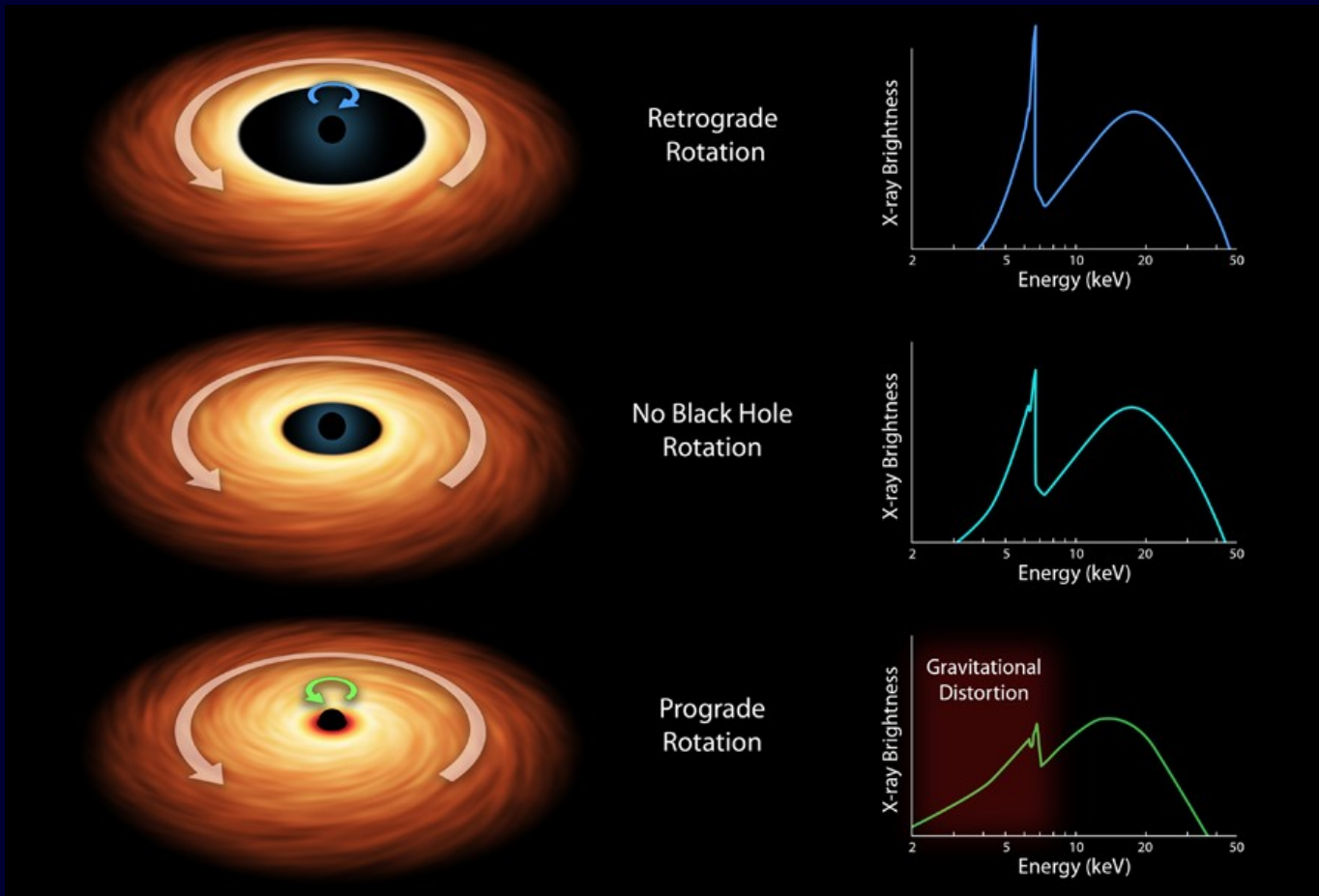
# Introduction – Relativistic reflection



Light bending model:  
much of the flux is bent onto the disk  
giving a constant, strong RDC



# Introduction – Relativistic reflection



Spin alters shape of Fe  $K\alpha$  line and Compton hump in predictable, measurable ways.

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# The NuSTAR satellite

## Nuclear Spectroscopic Telescope Array

### 1 Ms Sensitivity

$3.2 \times 10^{-15}$  erg/cm<sup>2</sup>/s ( 6 – 10 keV)

$1.4 \times 10^{-14}$  erg/cm<sup>2</sup>/s (10 – 30 keV)

### Imaging

HPD 58"

FWHM 18"

Localization 2" (1-sigma)

Harrison et al., 2013

### Spectral response

energy range: 3-79 keV

$\Delta E$  @ 6 keV 0.4 keV FWHM

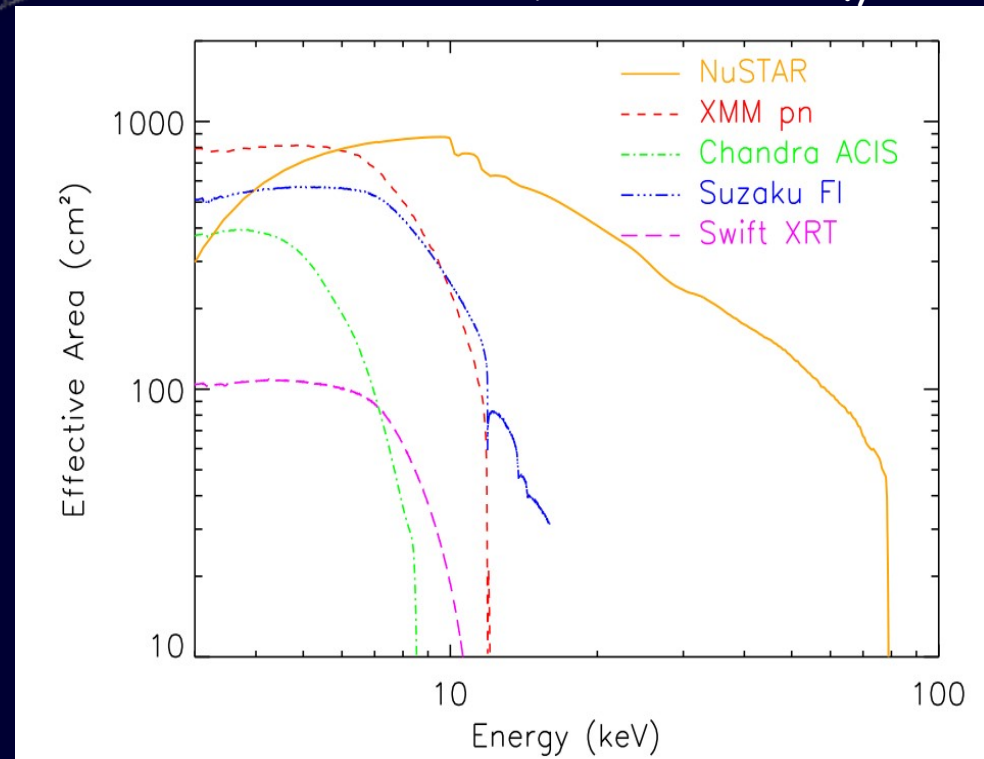
$\Delta E$  @ 60 keV 1.0 keV FWHM

### Target of Opportunity

response <24 hr

typical 6-8 hours

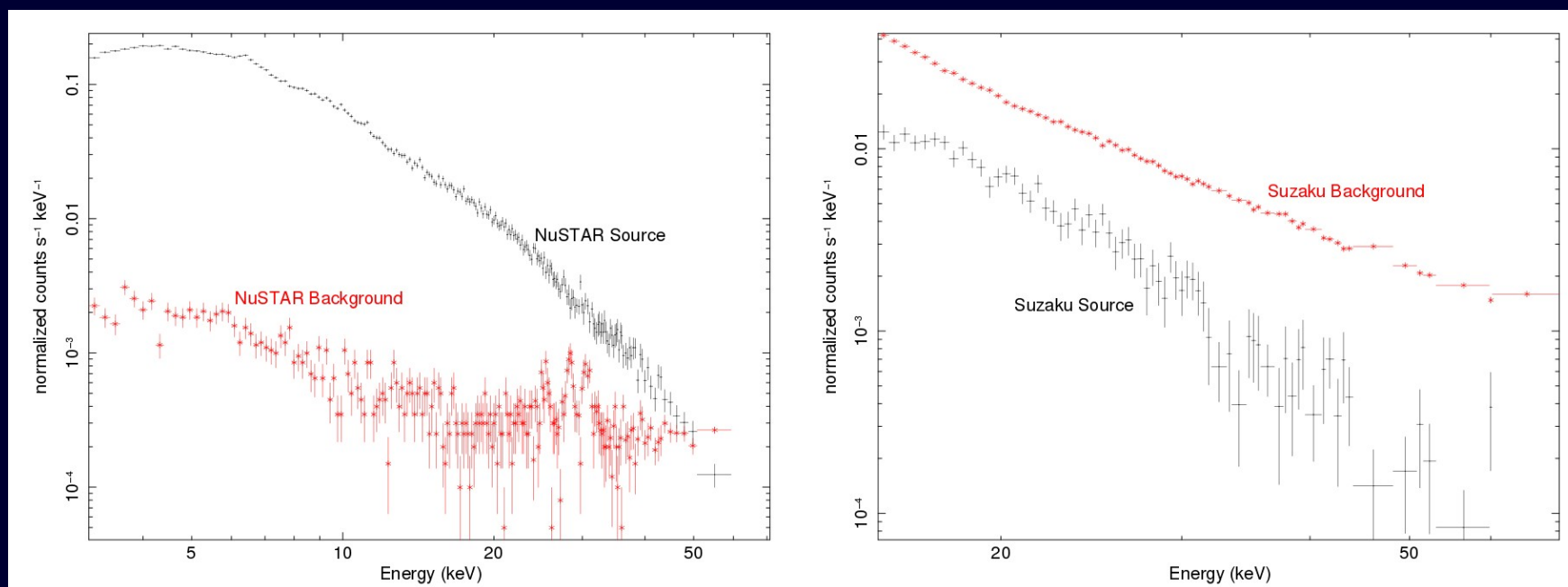
80% sky accessibility



# The NuSTAR satellite

The combination of NuSTAR high effective area and low background yields  
~100x better S/N versus Suzaku HXD-PIN

MCG-6-30-15: 125 ks net exposure time and  
same 15-70 keV flux ( $6.5 \times 10^{-11}$  erg/cm<sup>2</sup>/s)



Marinucci et al., 2014a

# Radio-quiet AGN observed by NuSTAR

Target	Exposure Time	Simultaneous	Reference
Ark 120	130 ks	XMM-Newton	Matt et al., 2014
IC 4329A	180 ks	Suzaku	Brenneman et al., 2014a,b
MCG—6-30-15	3x130ks	XMM-Newton	Marinucci et al., 2014a
Mrk 335	300 ks	Swift	Parker et al., 2014
NGC 1365	4x130 ks	XMM-Newton	Risaliti et al., 2013 Walton et al., 2014
SWIFT J2127.4	3x130ks	XMM-Newton	Marinucci et al., 2014b

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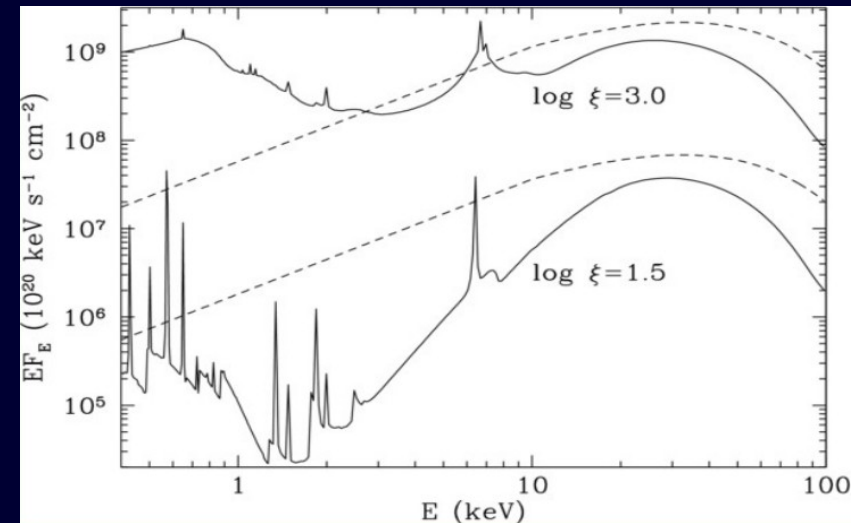
# The soft excess in Ark 120

Most AGN show soft X-ray emission in excess of the extrapolation of the hard primary emission

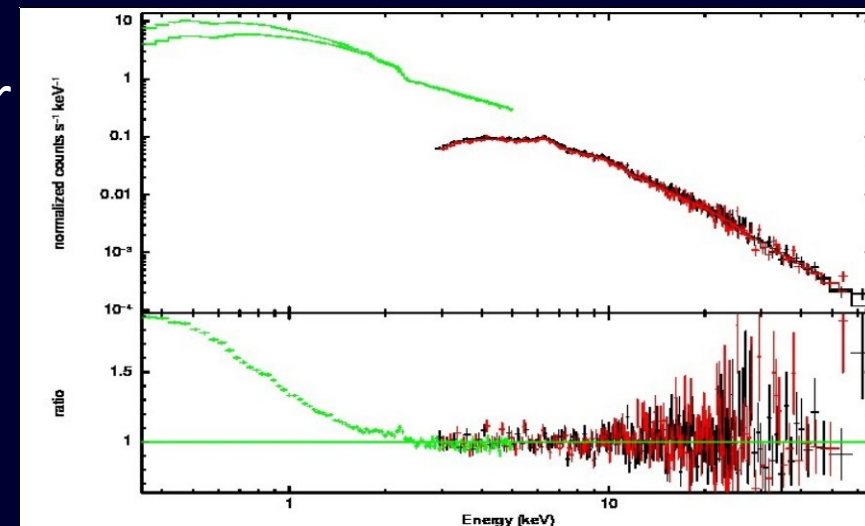
In many sources the soft excess is well explained by ionized reflection from the accretion disk (e.g. Walton et al. 2013)

However, there are sources in which another component is required (Patrick et al. 2012, Lohfink et al. 2012, Petrucci et al. 2013)

Ark 120 is one of them (Matt et al. 2014)

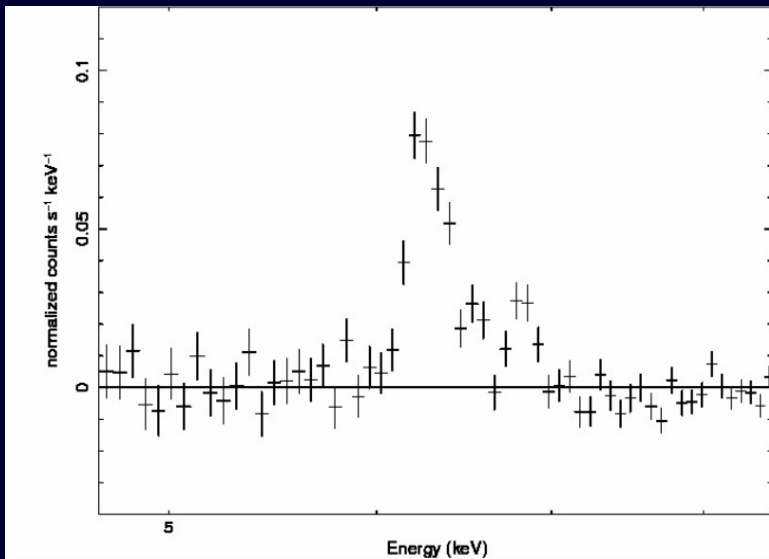


Ross & Fabian 2005

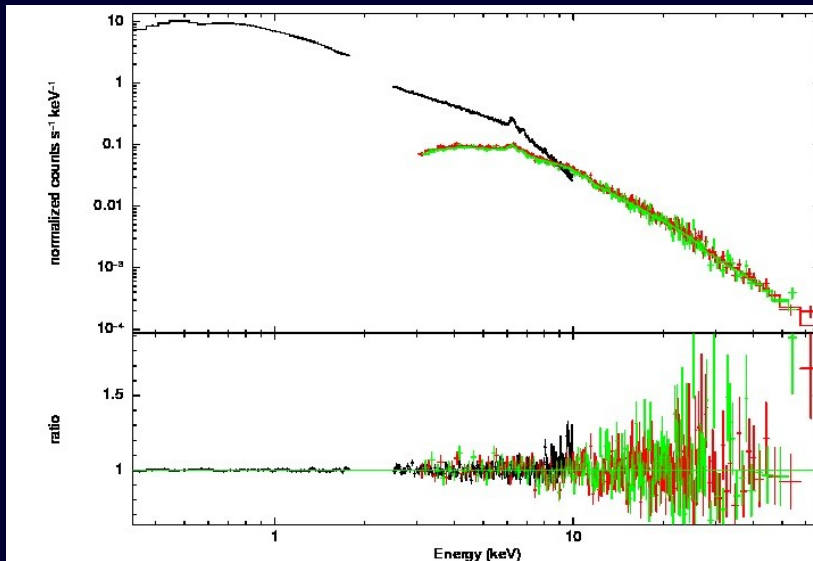


Matt et al. 2014

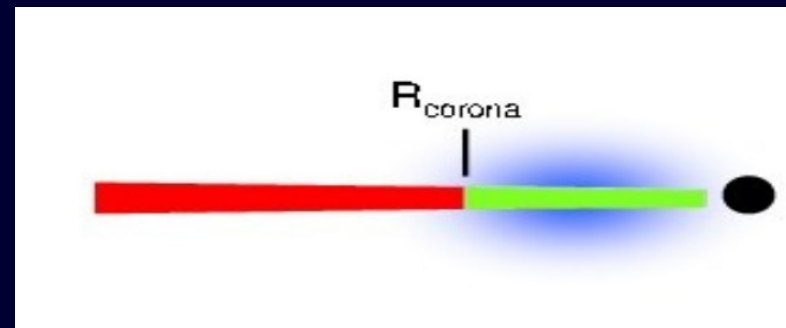
# The soft excess in Ark 120



Matt et al. 2014



No obvious evidence for a relativistic Iron line (differently from a previous Suzaku observation, Nardini et al. 2011)



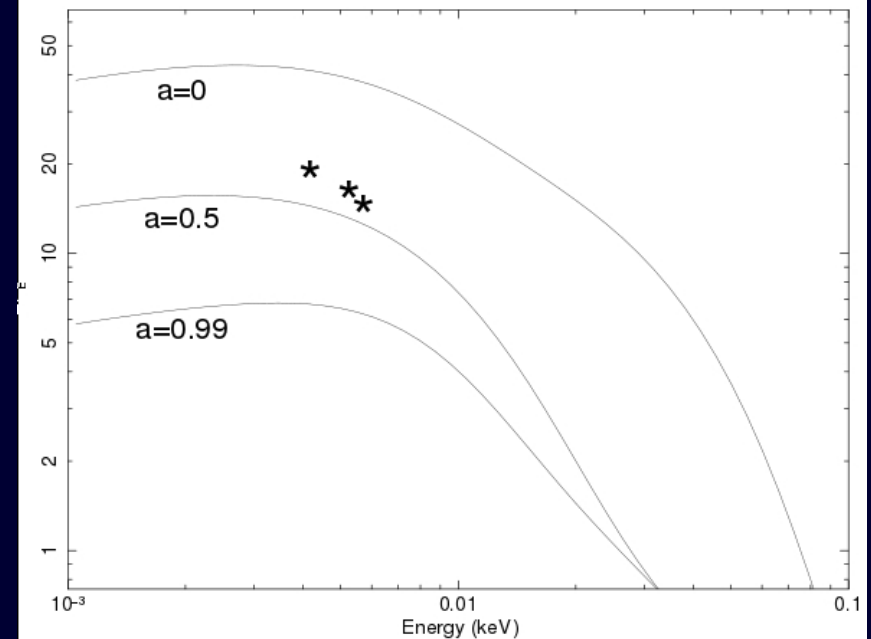
The broad-band best fit is with a Comptonization model for the soft excess. Optxagnf (Done et al. 2012) is a disk/corona emission model which assumes a thermal disk emission outside the coronal radius, and soft and hard Comptonization inside.

# The soft excess in Ark 120

Matt et al. 2014

$a$	0	0.50	0.99
$L/L_{Edd}$	$0.16^{+0.16}_{-0.08}$	$0.05^{+0.01}_{-0.01}$	$0.04^{+0.03}_{-0.01}$
$R_c (R_G)$	$11.5^{+0.1}_{-3.4}$	$31.3^{+39.2}_{-16.6}$	$24.9^{+16.0}_{-15.2}$
$kT$ (keV)	$0.33^{+0.02}_{-0.02}$	$0.32^{+0.01}_{-0.01}$	$0.32^{+0.02}_{-0.01}$
$\tau$	$12.9^{+1.1}_{-0.9}$	$13.6^{+0.6}_{-0.2}$	$13.6^{+0.4}_{-0.7}$
$\Gamma$	$1.73^{+0.02}_{-0.02}$	$1.73^{+0.02}_{-0.02}$	$1.73^{+0.02}_{-0.02}$
$E_c$ (keV)	>190	>190	>190

Fluxes from the Optical Monitor on board on XMM-Newton support an intermediate value for the black hole spin.



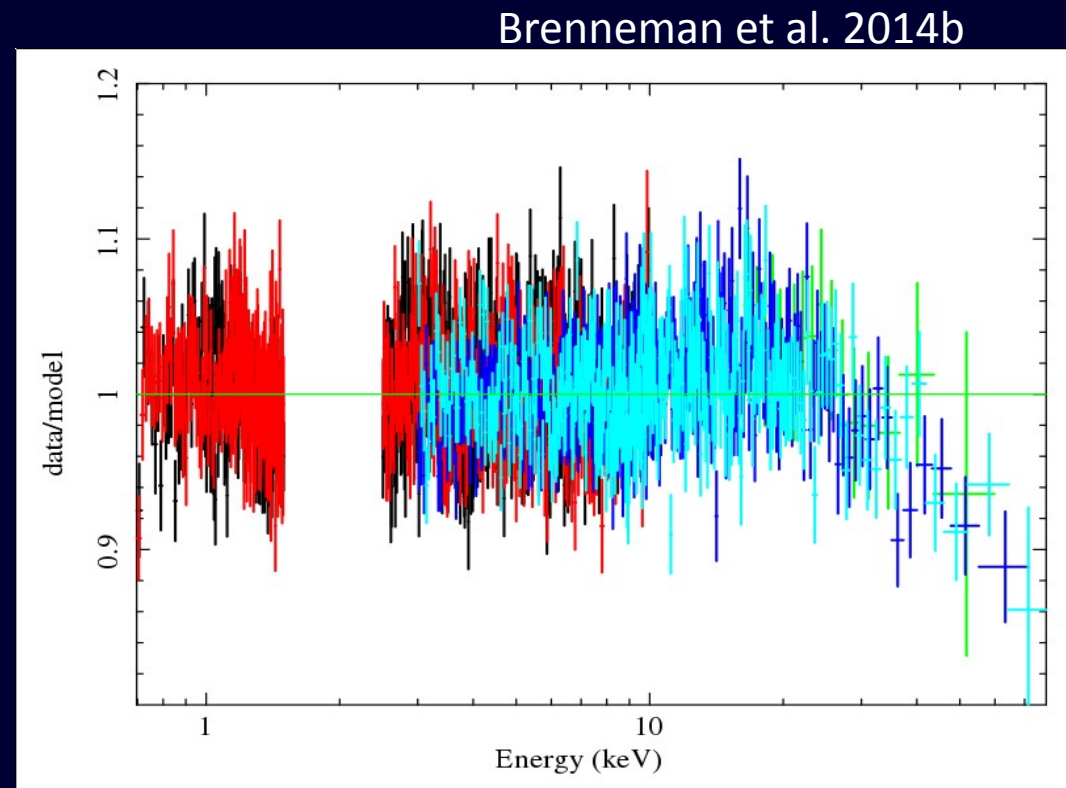
# Coronal parameters in IC 4329A

-Bright Sy1 galaxy,  $F_{2-10 \text{ keV}} \sim 0.1-1.8 \times 10^{-10} \text{ erg/cm}^2/\text{s}$

-  $E_c = 100^{+200}_{-40} \text{ keV}$  (INTEGRAL+XMM, Molina+13)

- Observed simultaneously by NuSTAR and Suzaku for  $\sim 120 \text{ ks}$  in 2012

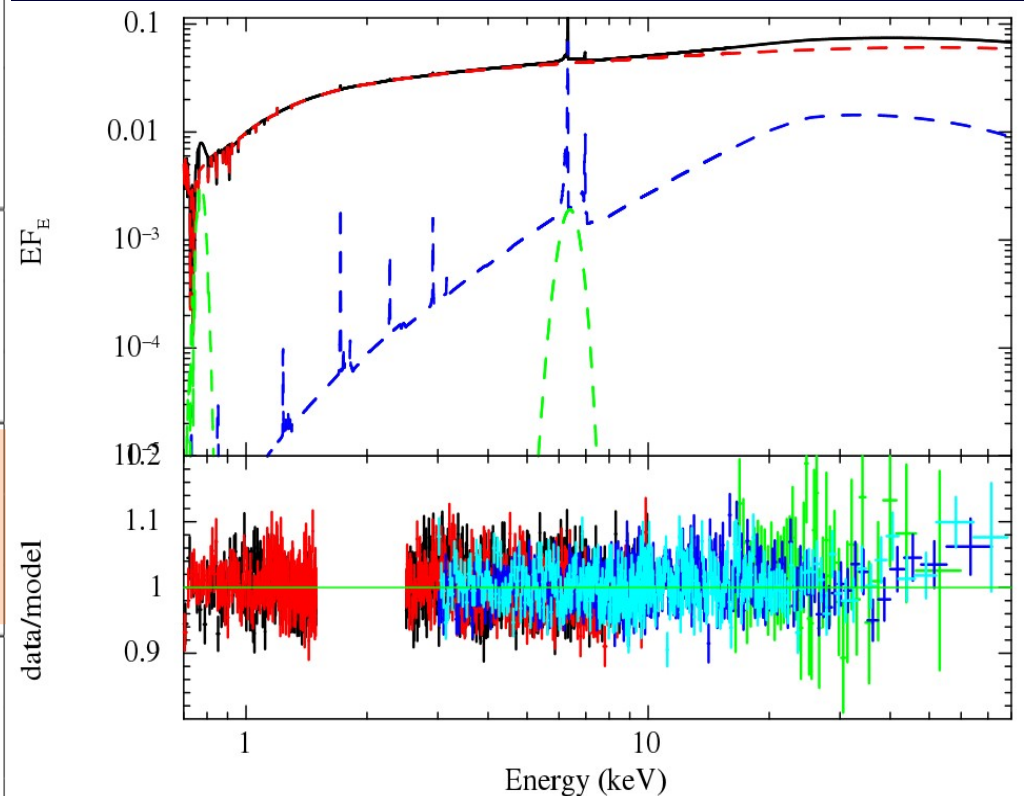
When a model composed of a primary continuum+reflection is applied to the data some residuals at high energies are found.





# Coronal parameters in IC 4329A

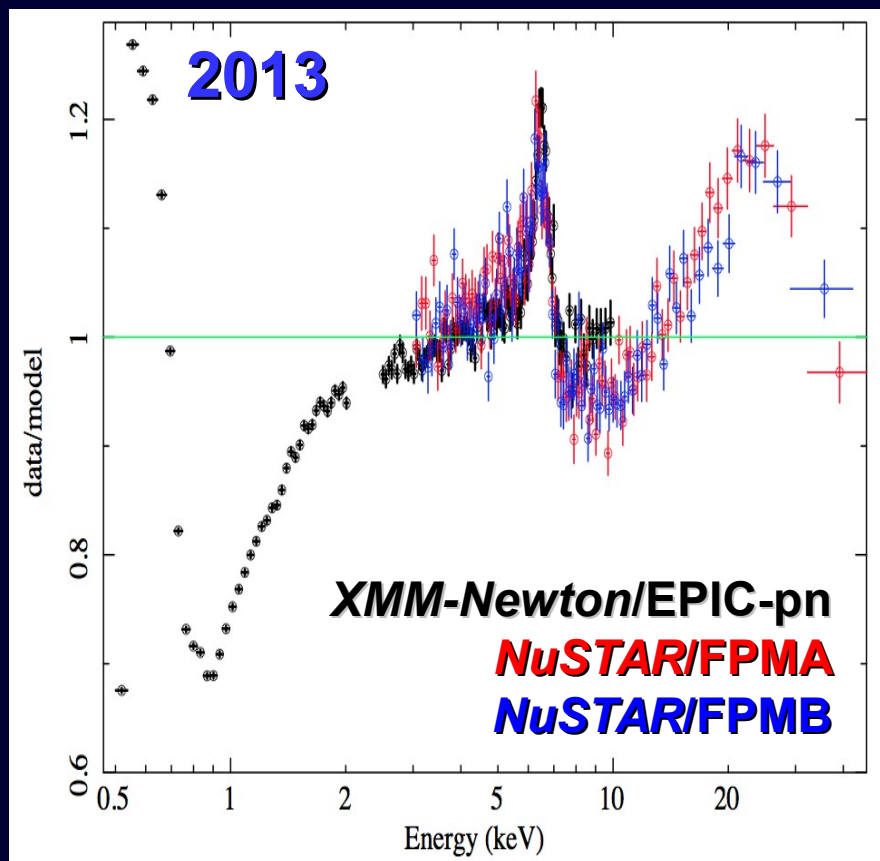
Component	Parameter (units)			
TBabs	$N_{\text{H}}$ ( $\text{cm}^{-2}$ )	$4.61 \times 10^{20}(f)$	$4.61 \times 10^{20}(f)$	$4.61 \times 10^{20}(f)$
XSTAR grid	$N_{\text{H}}$ ( $\text{cm}^{-2}$ )	$6.03 \pm 0.13 \times 10^{21}$	$6.02 \pm 0.13 \times 10^{21}$	$6.00^{+0.12}_{-0.13} \times 10^{21}$
	$\log \xi$ ( $\text{erg cm s}^{-1}$ )	$0.73 \pm 0.02$	$0.73 \pm 0.02$	$0.73 \pm 0.02$
zpo	$\Gamma$	$1.73 \pm 0.01$	$1.73(f)$	$1.73(f)$
	$E_{\text{cut}}$ (keV)	$186^{+14}_{-14}$	---	---
	$K_{\text{po}}$ ( $\text{ph cm}^{-2} \text{s}^{-1}$ )	$2.82 \pm 0.03 \times 10^{-2}$	---	---
comptT	$kT_e$ (keV)	---	$50^{+6}_{-3}$	$61 \pm 1$
	$\tau$	---	$2.34^{+0.16}_{-0.21}$	$0.68 \pm 0.02$
	$K_{\text{comptt}}$ ( $\text{ph cm}^{-2} \text{s}^{-1}$ )	---	$5.46^{+0.38}_{-0.54} \times 10^{-3}$	$4.46 \pm 0.11 \times 10^{-3}$
xillver	Fe/solar	$1.51^{+0.29}_{-0.28}$	$1.51^{+0.28}_{-0.27}$	$1.50^{+0.28}_{-0.27}$
	$\Gamma$	$1.73^*$	$1.73(f)$	$1.73(f)$
	$K_{\text{refl}}$ ( $\text{ph cm}^{-2} \text{s}^{-1}$ )	$2.79 \pm 0.20 \times 10^{-4}$	$2.74 \pm 0.18 \times 10^{-4}$	$2.89 \pm 0.18 \times 10^{-4}$



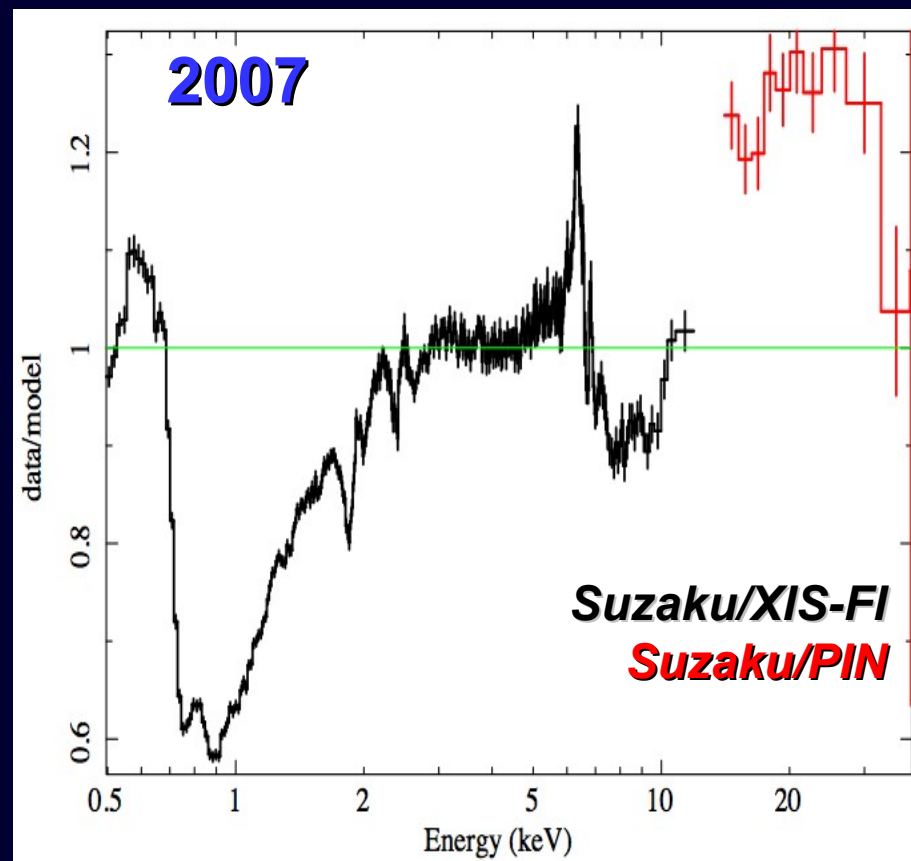
No evidence for relativistic lines.

Iron line and Compton reflection both originate from distant material.

# Relativistic reflection in MCG—6-30-15



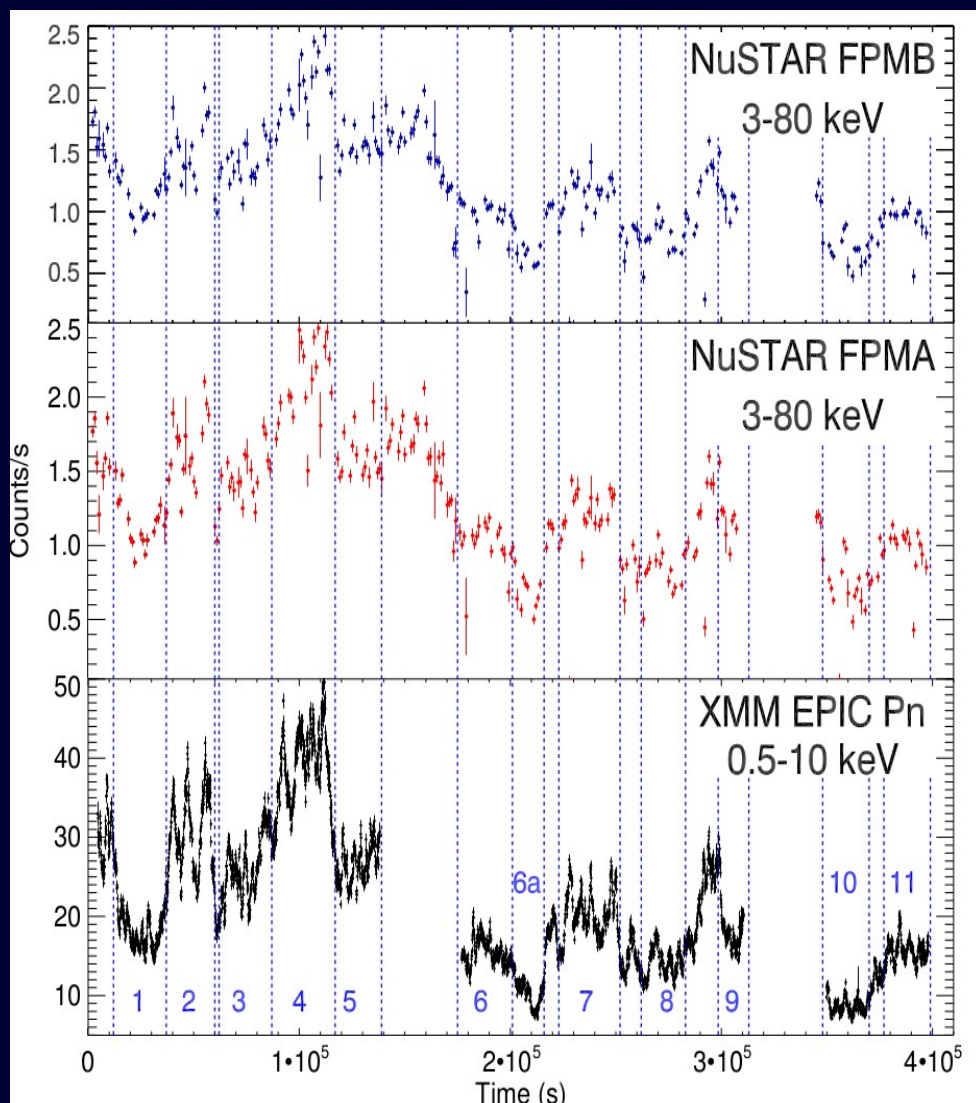
Brenneman et al., in prep.



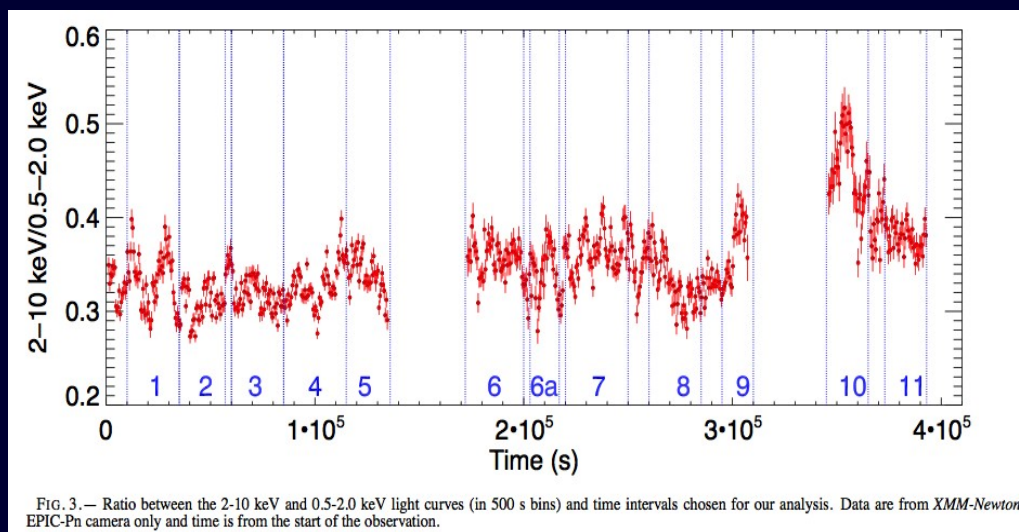
Miniutti et al., 2007

Residuals to a power-law are qualitatively similar to those seen in previous epochs, as is overall flux state.

# Relativistic reflection in MCG—6-30-15

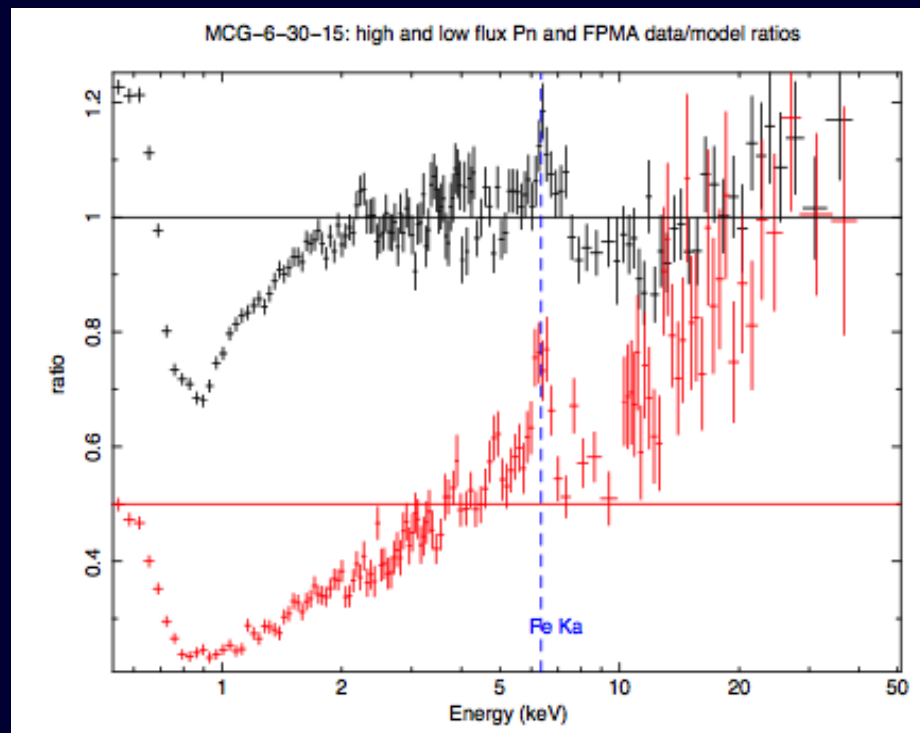


Marinucci et al. 2014a

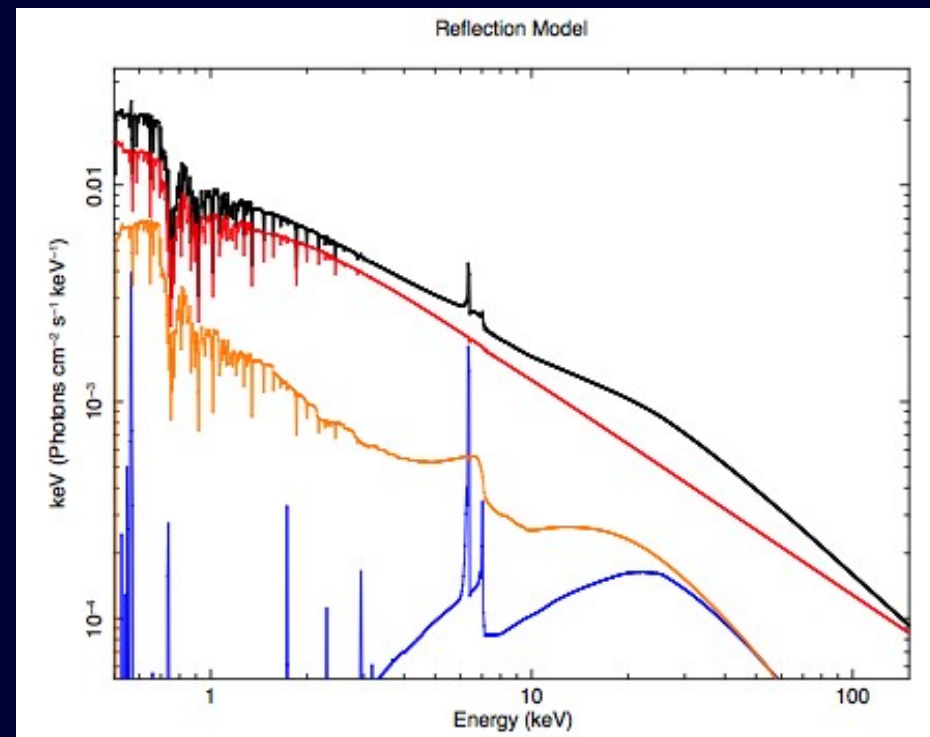


The source has been observed in a very bright and variable state in 2013 during the XMM+NuSTAR campaign (Marinucci et al. 2014a)

# Relativistic reflection in MCG—6-30-15



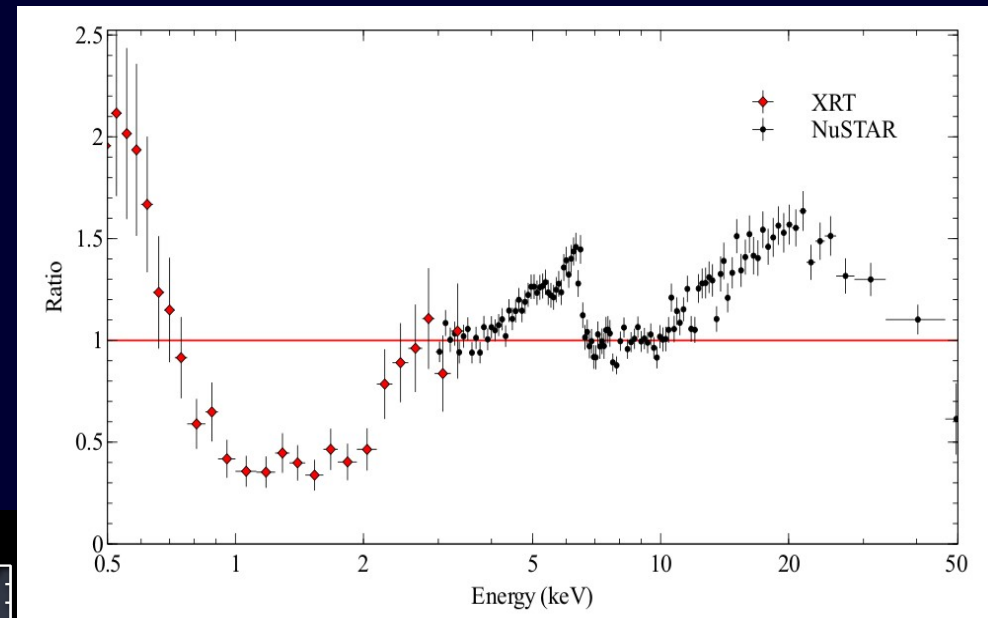
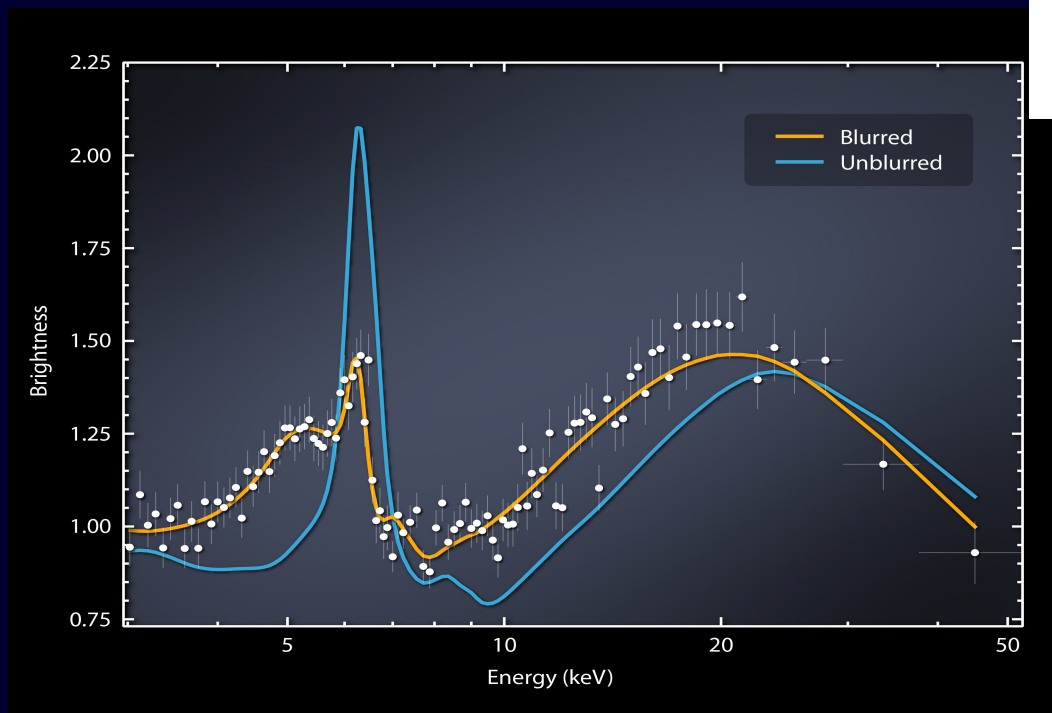
Marinucci et al. 2014a



The different spectral shape in the time intervals considered is explained in terms of the interaction between the primary continuum and the accretion disk.

# Relativistic reflection in Mrk 335

Mrk 335 was observed by NuSTAR and Swift in a very faint state, allowing us to study the reflection properties of the source.

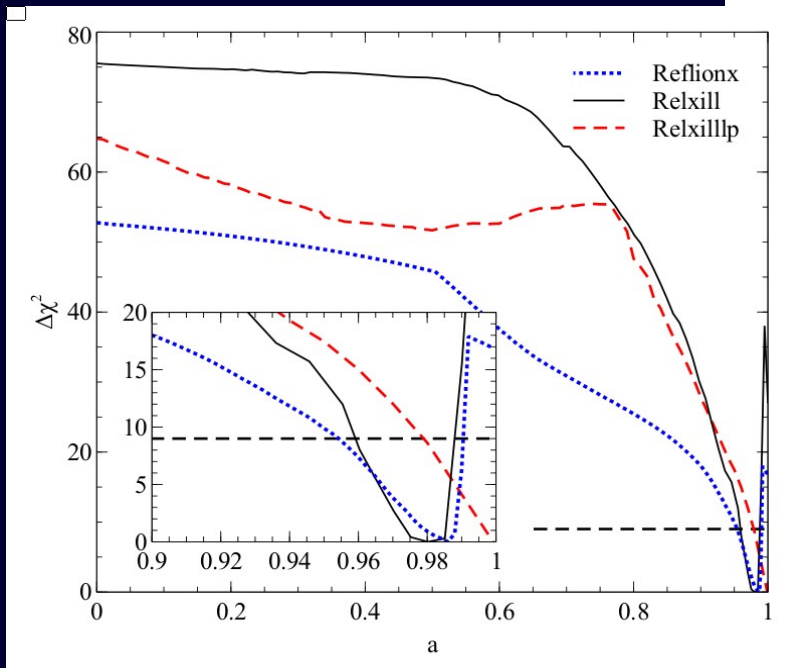
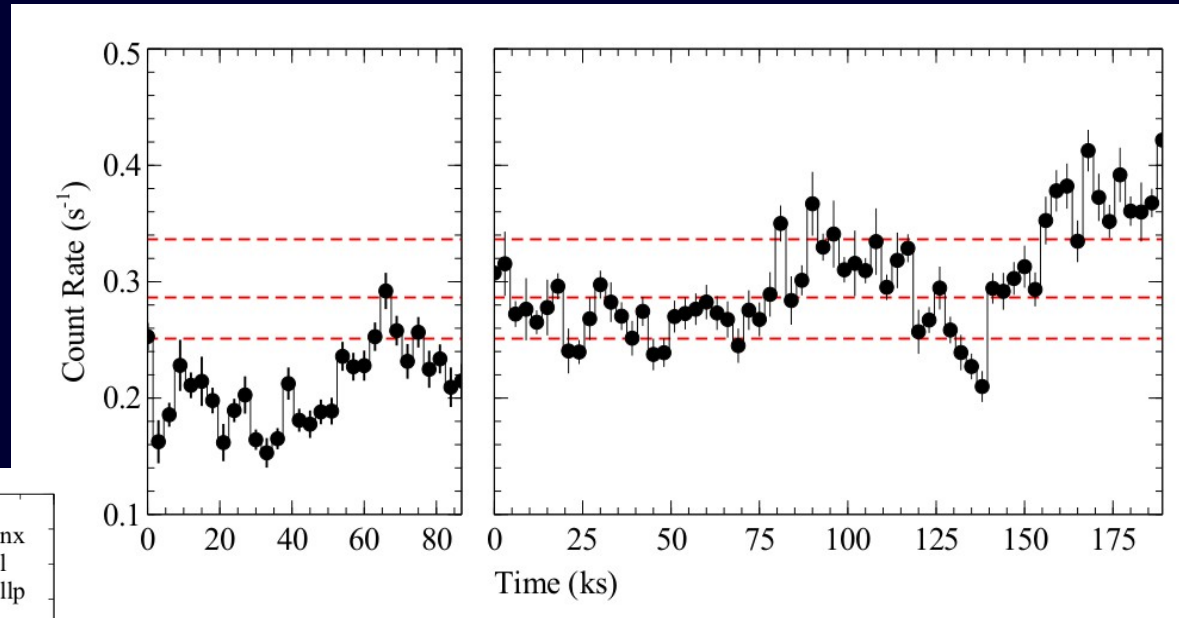


Parker et al. 2014

Once relativistic effects are taken into account, a black hole  $a > 0.97$  spin is measured.

<http://www.nustar.caltech.edu/news/nustar140812>

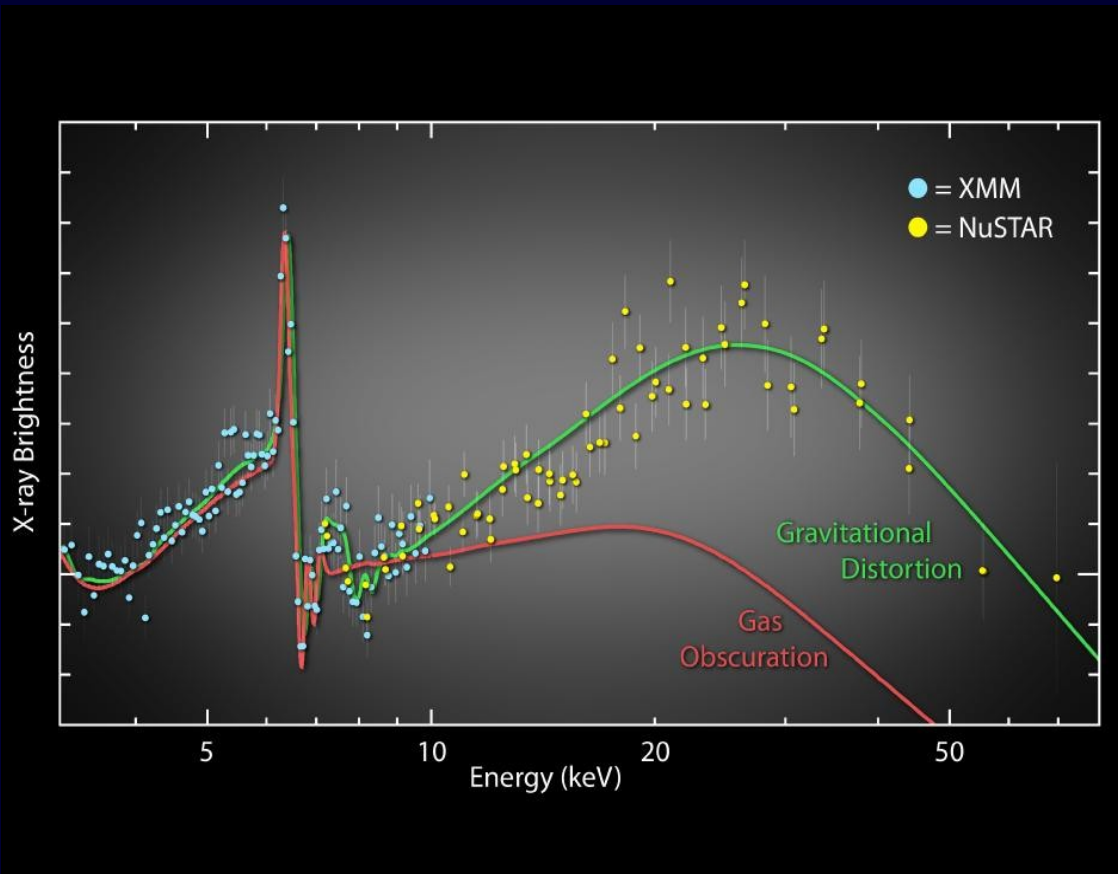
# Relativistic reflection in Mrk 335



Parker et al. 2014

When flux-resolved states are considered a maximally rotating black hole spin is measured.

# Black hole spin in NGC 1365

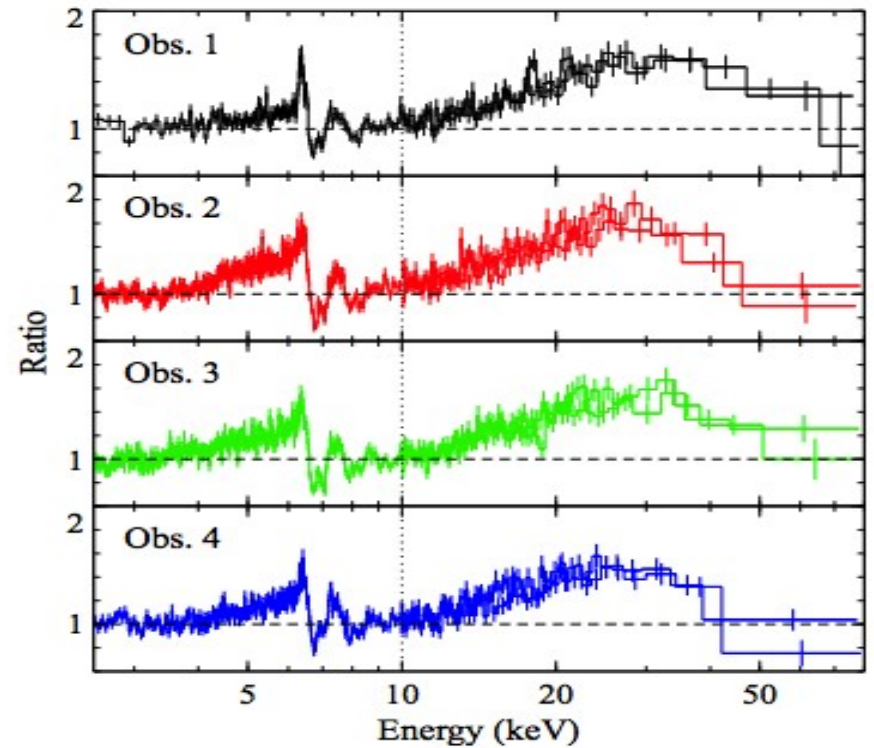
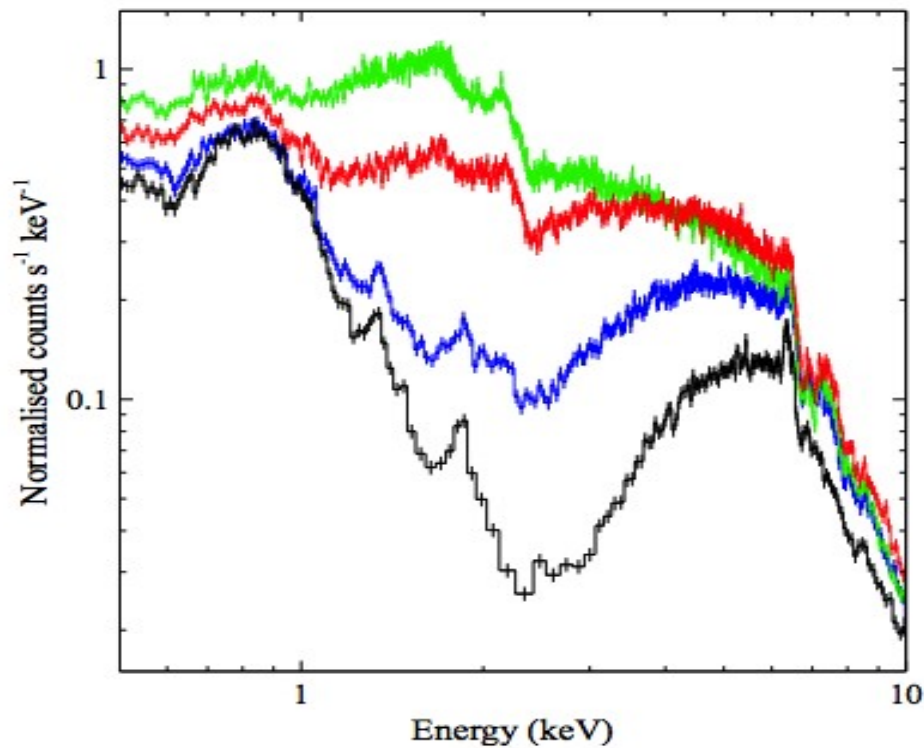


Risaliti et al. 2013, Nature

NGC 1365: a source in which both absorption and relativistic reflection play a major role in the X-rays

The first NuSTAR published paper is the spin measurement in NGC 1365

# Black hole spin in NGC 1365



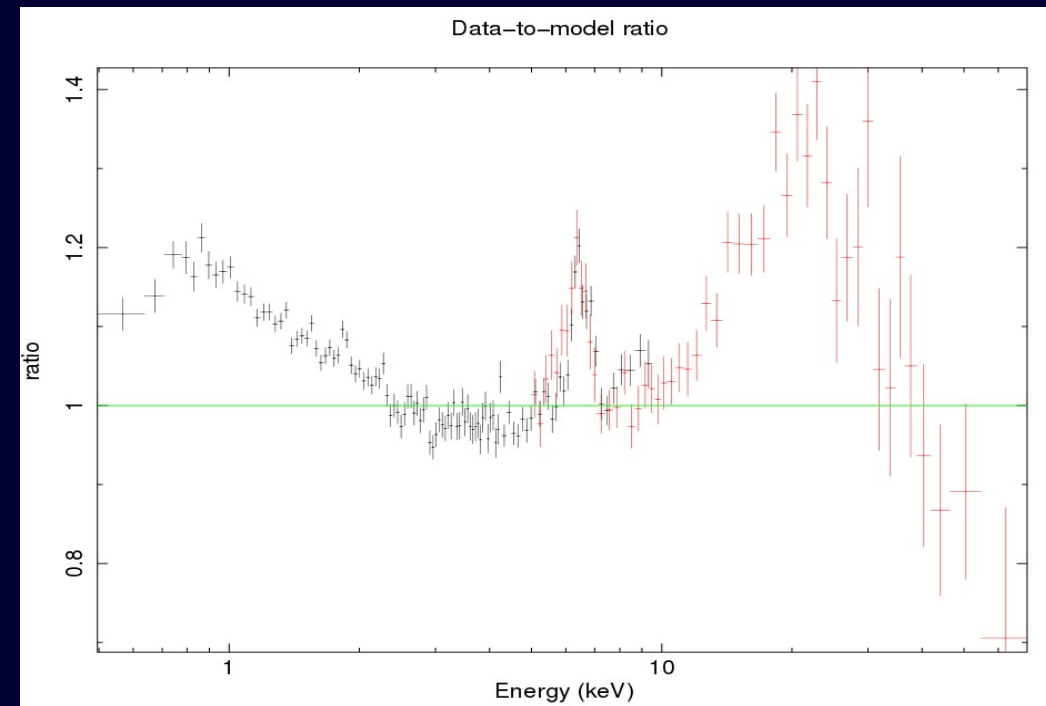
NGC 1365 was observed by XMM and NuSTAR four times. Despite large variations in the absorbers, no variations in the reflected components are found, demonstrating the robustness of the result.



# Relativistic reflection in SWIFT J2127.4

NLS1 with a relativistically broadened Fe K $\alpha$  emission line ( $a=0.6\pm 0.2$ ), a steep continuum ( $\Gamma=2-2.4$ ),  $E_c=30-90$  keV,  $L_{bol}/L_{Edd}\sim 0.18$  (Miniutti+09, Malizia+08, Panessa+11, Sanfrutos+13)

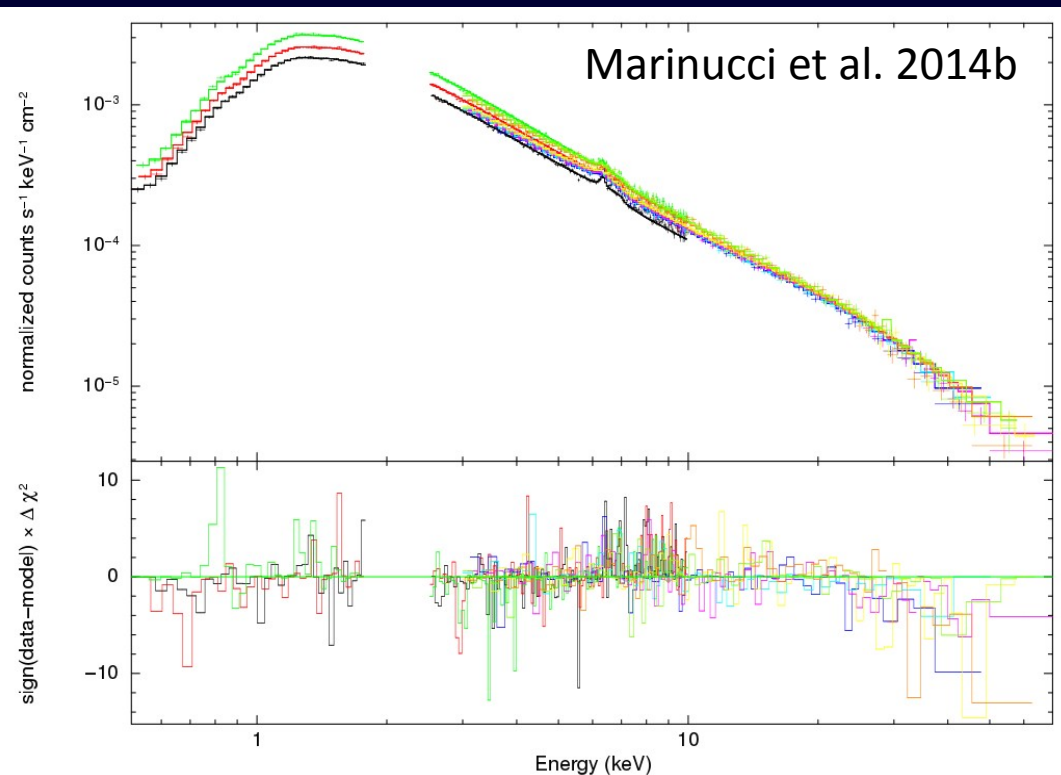
It was observed simultaneously with XMM-Newton for  $\sim 300$  ks and both a strong Compton Hump and a broad Fe K $\alpha$  line are present



Marinucci et al. 2014b

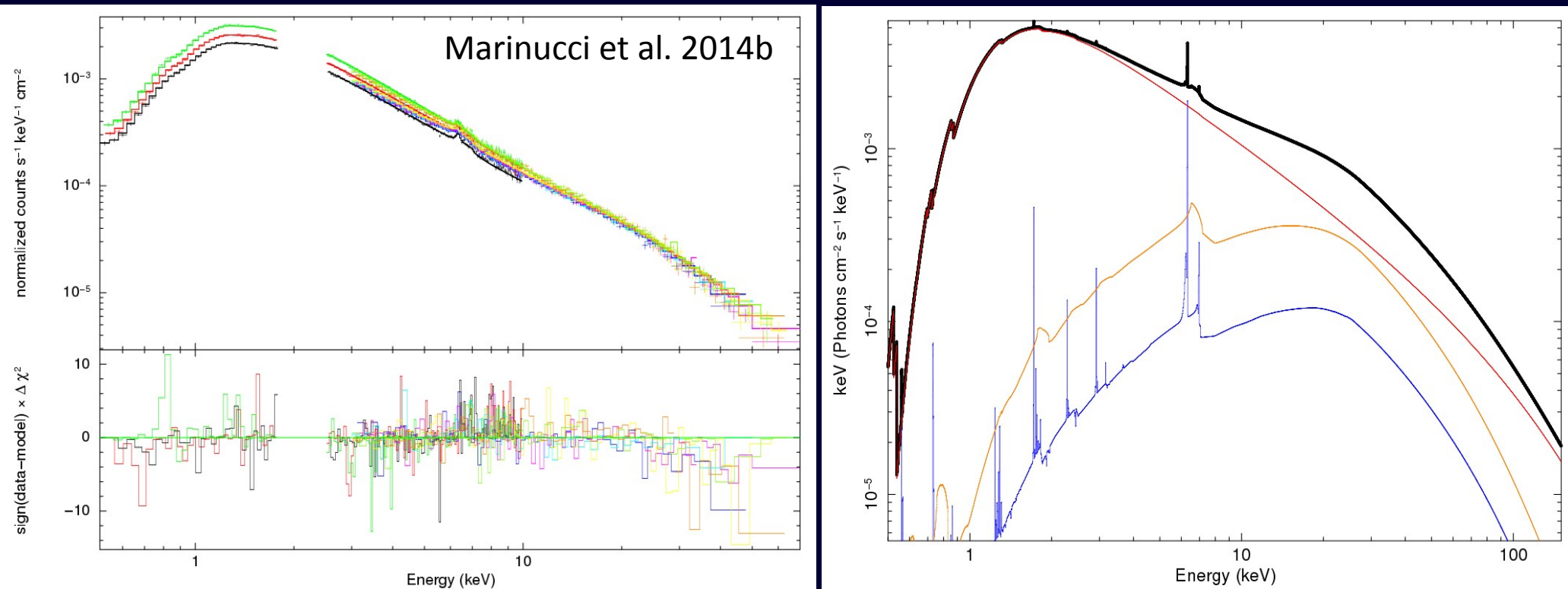
# Relativistic reflection in SWIFT J2127.4

When a model composed of a primary continuum, relativistic and distant reflection components is applied to the data the only residuals are above  $\sim 25$  keV



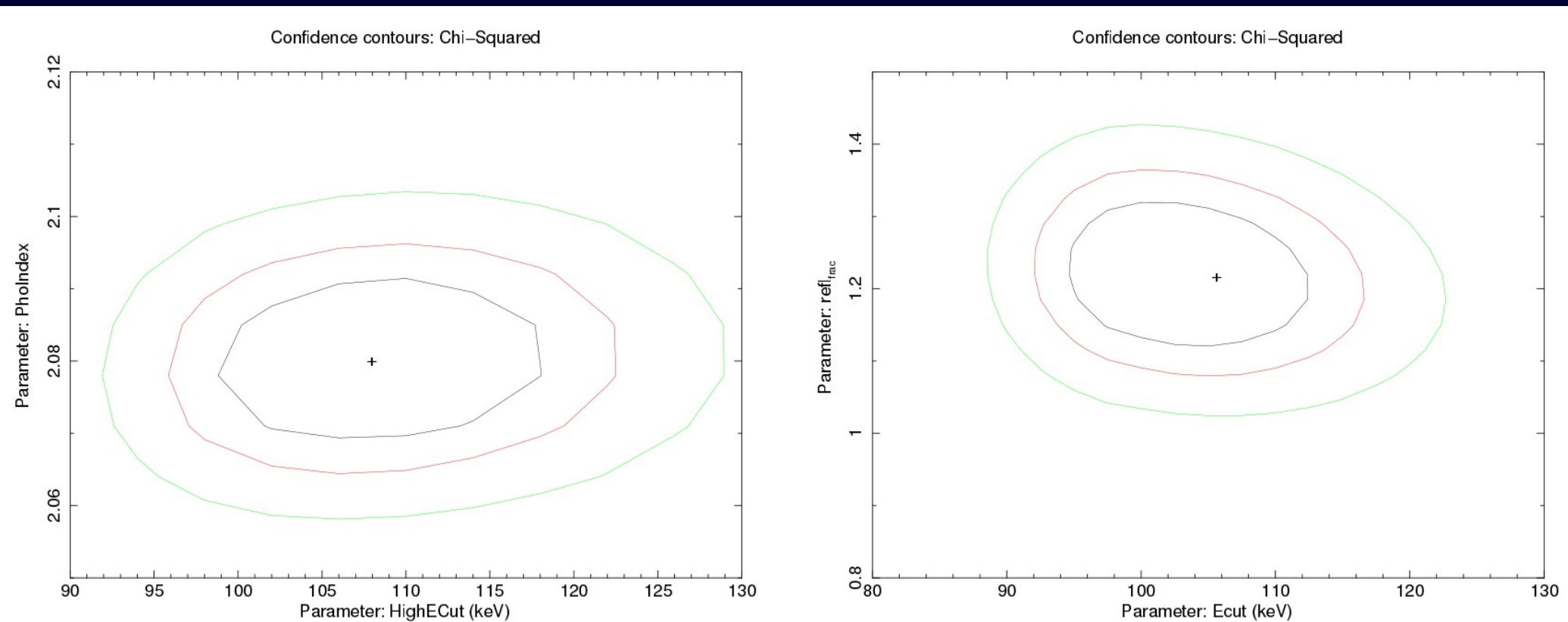
# Relativistic reflection in SWIFT J2127.4

When a model composed of a primary continuum, relativistic and distant reflection components is applied to the data the only residuals are above  $\sim 25$  keV



The inclusion of relxill model (Garcia & Dauser +14) allows us to measure a cutoff energy  $E_c = 108 \pm 10$  keV and to infer the contribution of the disk to the Compton hump.

# Relativistic reflection in SWIFT J2127.4



Using compTT (Titarchuk+94) with two different geometries we get:

SLAB

$$kT_e = 68^{+37}_{-32} \text{ keV}$$

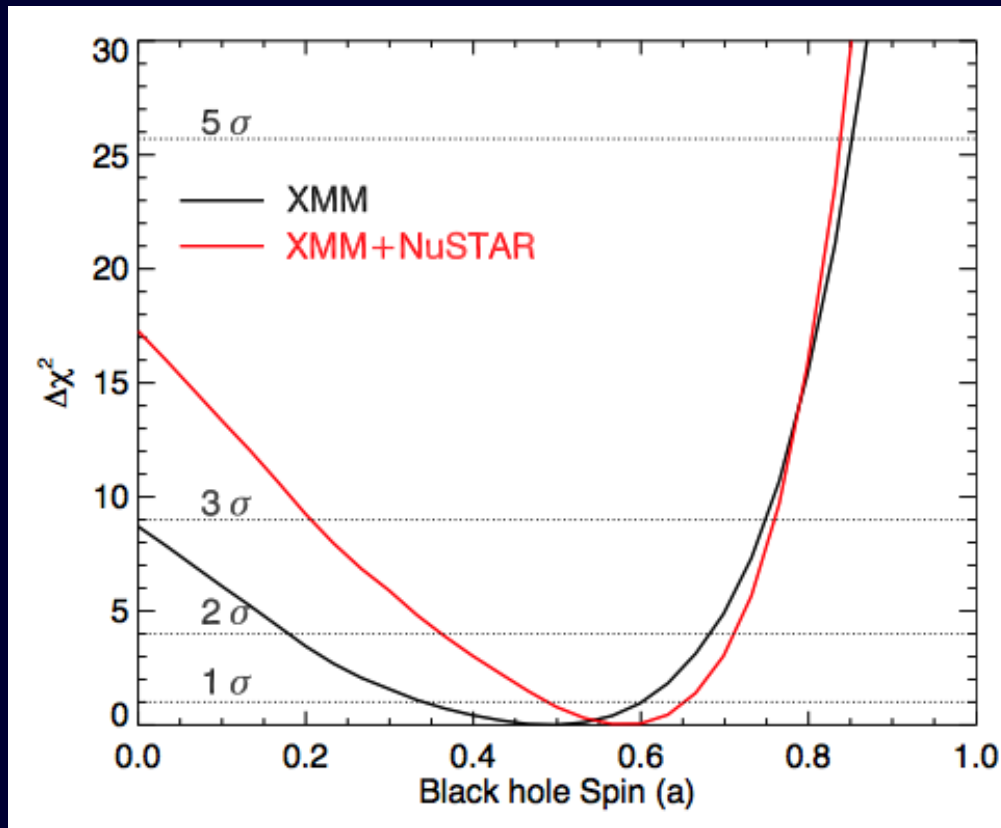
$$\tau = 0.35^{+0.35}_{-0.19}$$

SPHERE

$$kT_e = 53^{+28}_{-26} \text{ keV}$$

$$\tau = 1.35^{+1.03}_{-0.67}$$

# Relativistic reflection in SWIFT J2127.4



Marinucci et al. 2014b

Thanks to the broad (0.5-80 keV) spectral coverage, we confirmed the intermediate spin value in this source, discarding non-spinning solutions with a significance  $>3\sigma$

$$a=0.58^{+0.11}_{-0.17}$$

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# Conclusions

- The recent NuSTAR observational campaign of Radio-quiet AGN allowed us to study:

PRIMARY  
EMISSION

First measurements of the coronal parameters  
 $T$  and  $\tau$  in IC 4329A and SWIFT J 2127.4

Warm Comptonization in Ark 120  
(in addition to reflection?)

REPROCESSED  
EMISSION

Robust detection and clear discrimination  
between relativistic and cold reflection

Black hole spin measurements in a number of  
sources: Ark 120, MCG—6-30-15, NGC 1365,  
Mrk335 and SWIFT J2127.4

- Bringing the two pieces of information together we have an unprecedented powerful tool to investigate the innermost environment (corona and accretion disk) of the nucleus