Revealing the coronal properties of Seyfert galaxies with NuSTAR

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on behalf of the
NuSTAR AGN Physics WG

Arcetri
High Energy processes around compact objects
June 12, 2014

Overview

- Brief introduction on high-energy cutoff measurements
- Nearby AGN seen by NuSTAR
- Results
- Conclusions and future perspectives

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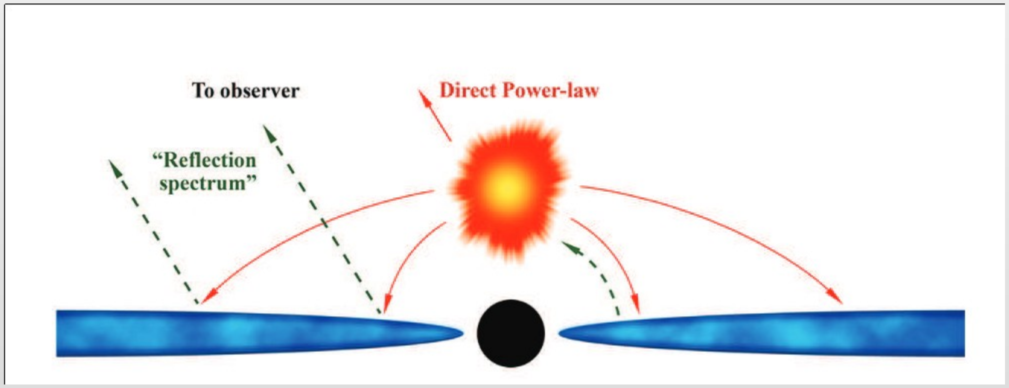
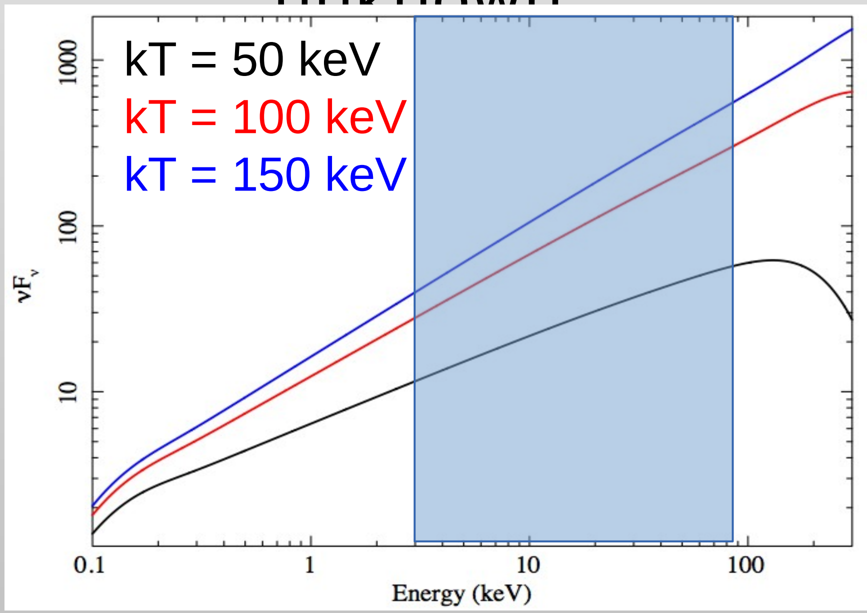
Introduction

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

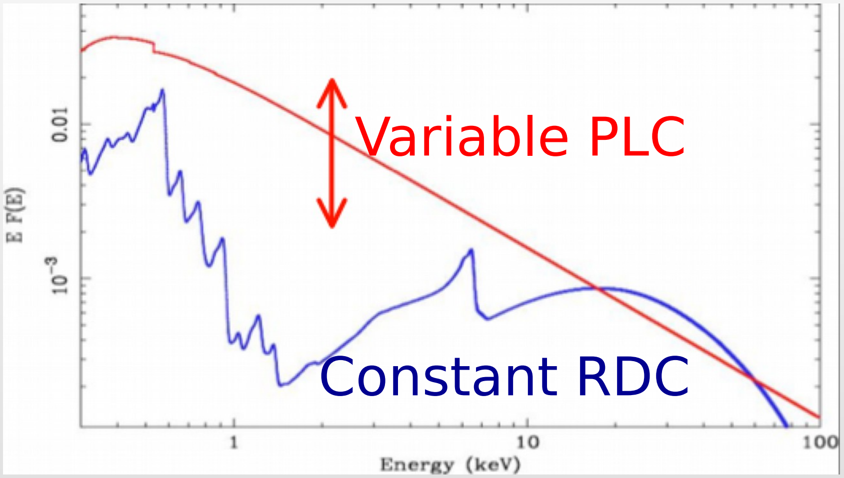


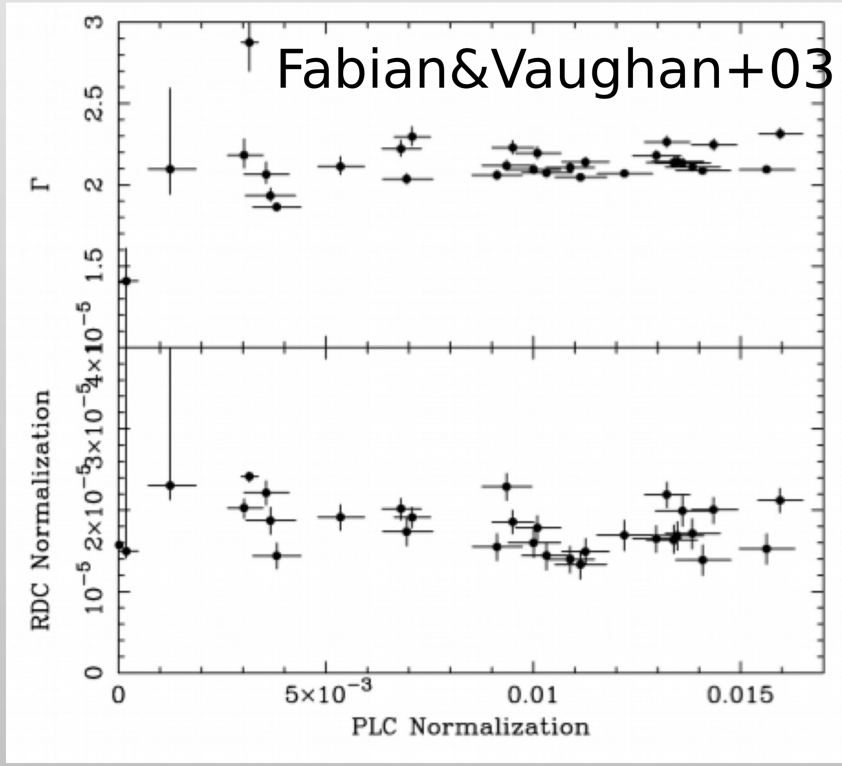


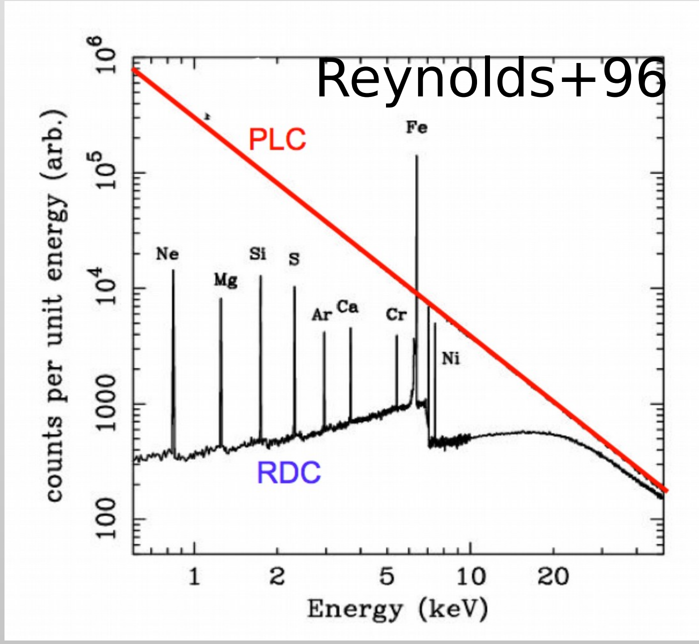
Most popular models imply E_{cut}=2-3x kT_e, so measuring E_{cut} helps constraining Comptonization models.

Introduction

Since the primary X-ray radiation illuminates the disc and is partly reflected towards the observer's line of sight it is fundamental to properly take it into account.

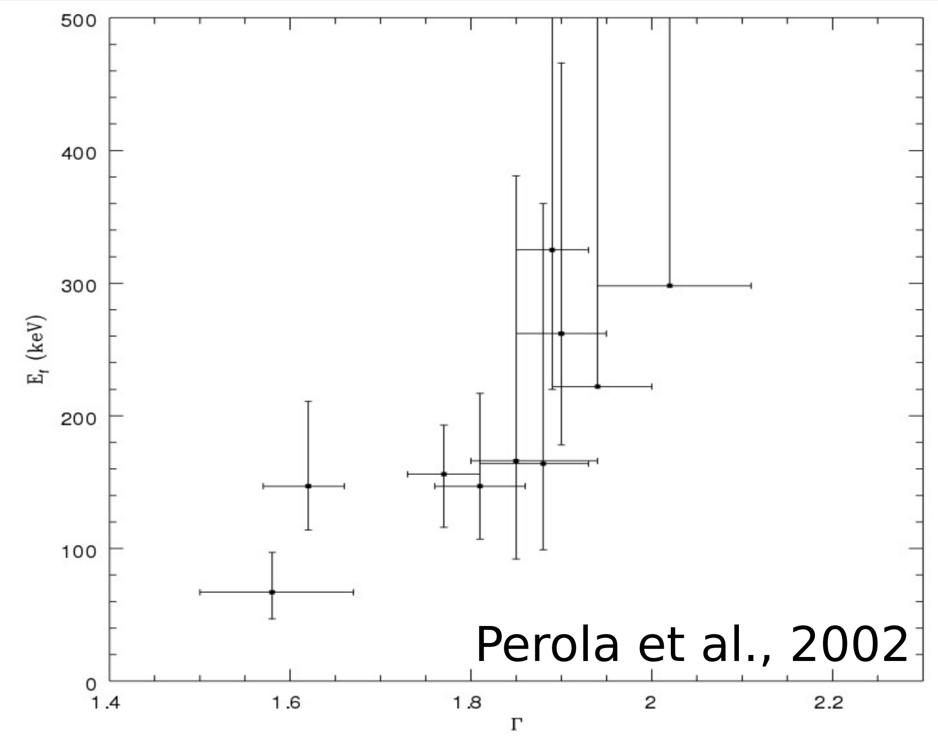


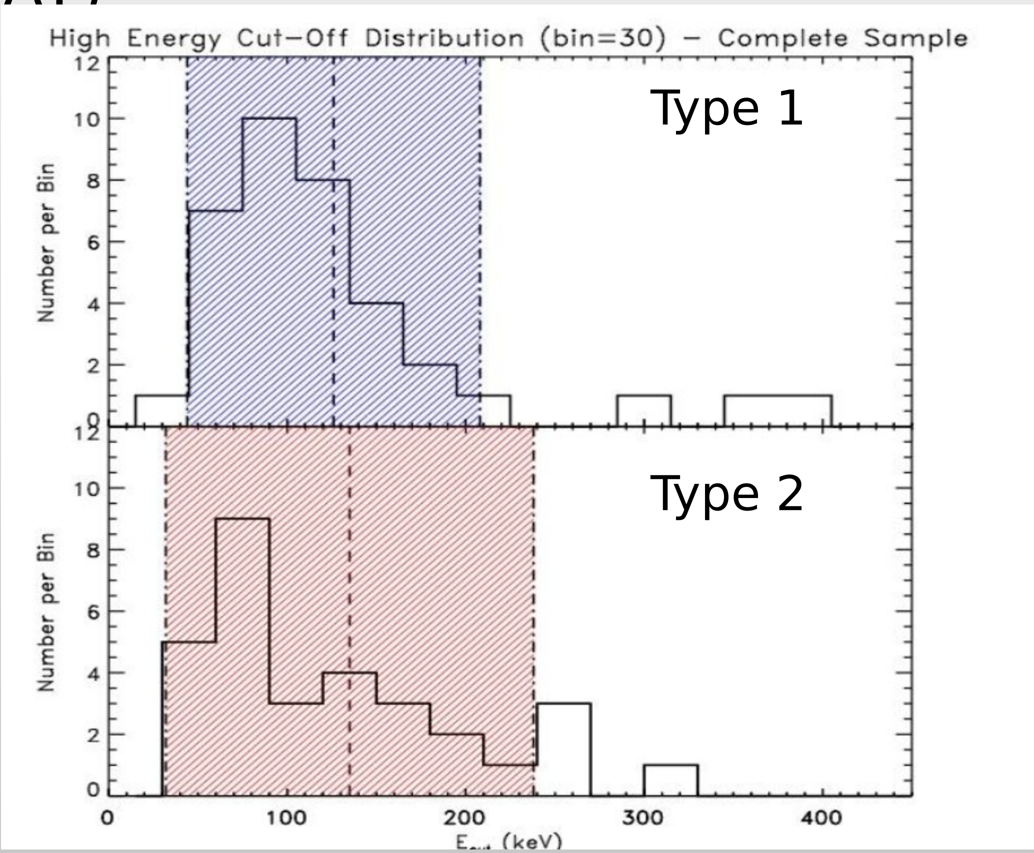




Introduction

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

Overview

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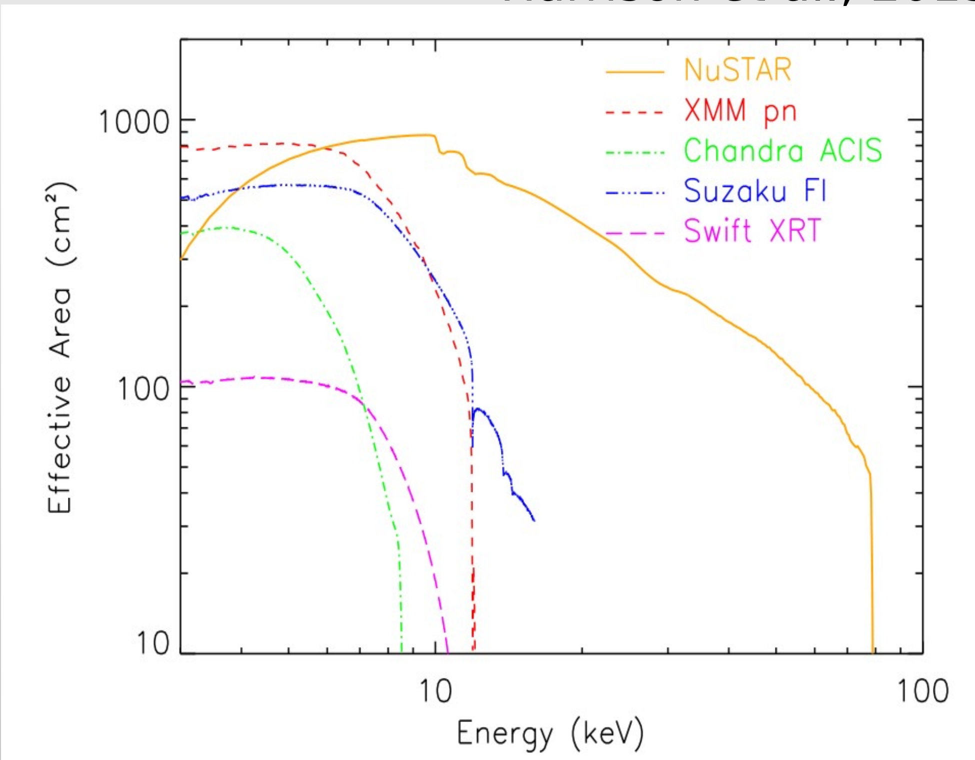
The NuSTAR satellite

1 Ms Sensitivity
  3.2×10^{-15} erg/cm²/s (6 – 10 keV)
  1.4×10^{-14} erg/cm²/s (10 – 30 keV)

Imaging
  HPD 58”
  FWHM 18”
  Localization 2” (1-sigm

Harrison et al., 2013

Spectral response
  energy range: 3-79 keV
  ΔE @ 6 keV 0.4 keV FWHM
  ΔE @ 60 keV 1.0 keV FWHM

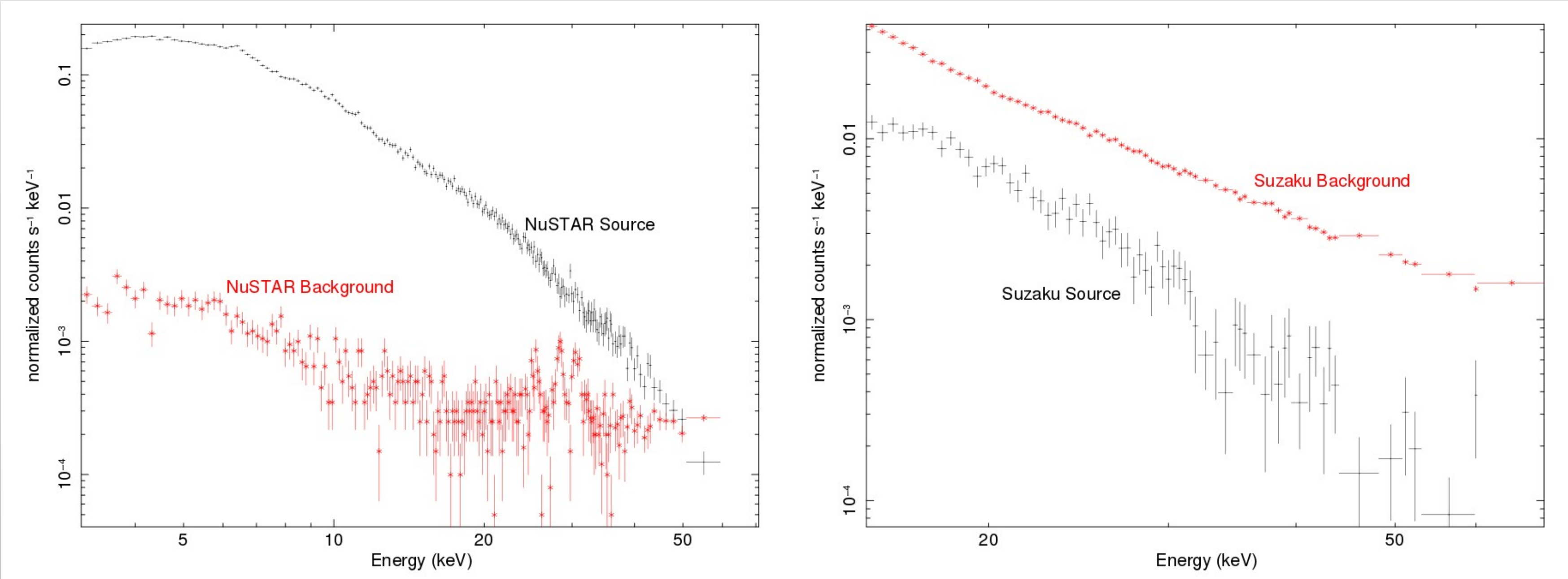


Target of Opportunity
  response <24 hr
  typical 6-8 hours
  80% sky accessibility

The NuSTAR satellite

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

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



Marinucci et al., 2014a

AGN observed by NuSTAR

AGN Physics WG:

Target	R.A.	Dec.	T_observd	ObsDate
3C273	187.277917	2.052500	371.5 ks	2012 Jul
MCG-5-23-16	146.917319	-30.948734	243.5 ks	2012 Jul+
IC4329A	207.330000	-30.309444	185.2 ks	2012 Aug
SwiftJ2127d4p5654	321.937083	56.944444	212.4 ks	2012 Nov
NGC4151	182.635833	39.405833	151.2 ks	2012 Nov
MCG-6-30-15	203.974167	-34.295556	209.3 ks	2013 Jan+
Cyg_A	299.868153	40.733916	67.1 ks	2013 Feb+
Ark120	79.047500	-0.149722	93.2 ks	2013 Feb
3C120	68.296250	5.354444	181.4 ks	2013 Feb
3C390.3	280.537458	79.771424	104.7 ks	2013 May
Mkn335	1.581339	20.202914	146.9 ks	2013 Jun
NGC4051	180.790060	44.531334	185.4 ks	2013 Jun
NGC5548	214.497958	25.136806	219.0 ks	2013 Jul+
Cen A	201.365063	-43.019112	58.6 ks	2013 Aug
PDS 456	262.082483	-14.265519	376.0 ks	2013 Aug
NGC3783	174.757339	0.000000	...... ks	....

Brenneman et al. 2014a

Brenneman et al. 2014b

Marinucci et al. 2014b

Matt et al. 2014

AGN observed by NuSTAR

Extragalactic Surveys WG:

Target	R.A.	Dec.	T_observd	ObsDate
ECDFS	52.932500	-27.970000	1605.8 ks	2012 Sep+
COSMOS	149.762440	2.489683	3372.4 ks	2012 Dec+
EGS	214.503830	52.577075	440.1 ks	2013 Nov+
0 - 2MASXJ04440903p28130	214.503830	52.577075	0.0 ks	2013 Nov
0 - 2MASXJ04234080p04080	65.920000	4.134000	20.1 ks	2012 Jul
0 - 2MASXJ05081967p17214	77.082100	17.363300	16.9 ks	2012 Jul
1 - NGC7582	349.597870	-42.370583	33.0 ks	2012 Aug+
2 - NGC612	23.490379	-36.493031	17.0 ks	2012 Sep
3 - 3C382	278.764130	32.696350	106.8 ks	2012 Sep+
4 - PBCJ1630d5p3924	247.636250	39.384111	17.0 ks	2012 Sep
5 - NGC2110	88.047417	-7.456222	33.7 ks	2012 Oct+
6 - Mrk1210	121.024208	5.113750	16.9 ks	2012 Oct
7 - NGC1320	51.202961	-3.042420	44.2 ks	2012 Oct+
8 - IC751	179.719803	42.570110	100.2 ks	2012 Oct+
9 - M51	202.469750	47.195194	18.5 ks	2012 Oct
10 - CXOUJ194719d3p444942	296.830750	44.828468	19.1 ks	2012 Nov
11 - 2MASXJ06302561p63404	97.607903	63.676701	18.4 ks	2012 Nov
12 - NGC7319	339.014916	33.975858	15.7 ks	2012 Nov
13 - MCG-01-05-047	28.204166	-3.446833	14.9 ks	2012 Nov
14 - IRAS09104p4109	138.439583	40.941111	18.0 ks	2012 Dec
15 - RBS0770	140.929184	22.909065	20.6 ks	2012 Dec

→ Marinucci et al., in prep.

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NuSTAR cutoff measurements

So far, NuSTAR has provided a number of cutoff measurements in AGN with different spectral characteristics:

Relativistic reflection

SWIFT J2127.4+5654 (E_c=108±10 keV), $L_{2\text{-}10\ keV}=1.5\times10^{43}$ erg/s

Cold, distant reflection

IC 4329A (E_c=186±14 keV), $L_{2\text{-}10\ keV}=6.3\times10^{43}$ erg/s

Ark 120 (E_c>190 keV), $L_{2\text{-}10\ keV}=5.6\times10^{43}$ erg/s

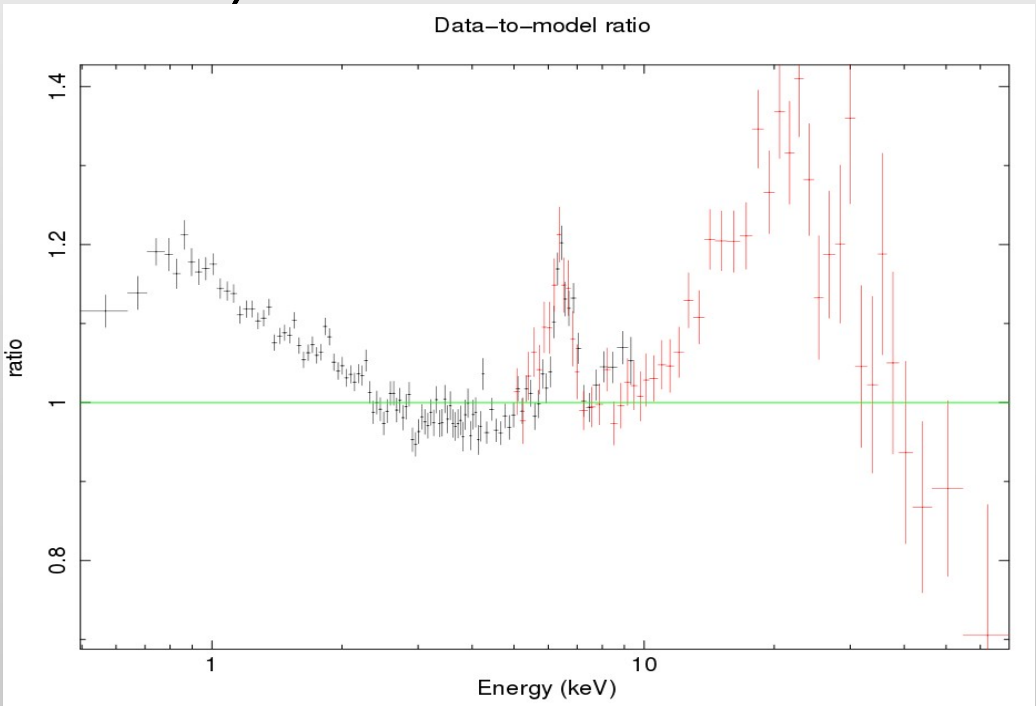
No reflection

NGC 2110 (E_c>210 keV), $L_{2\text{-}10\ keV}=0.4\text{-}3.5\times10^{43}$ erg/s

Swift J2127.4+5654

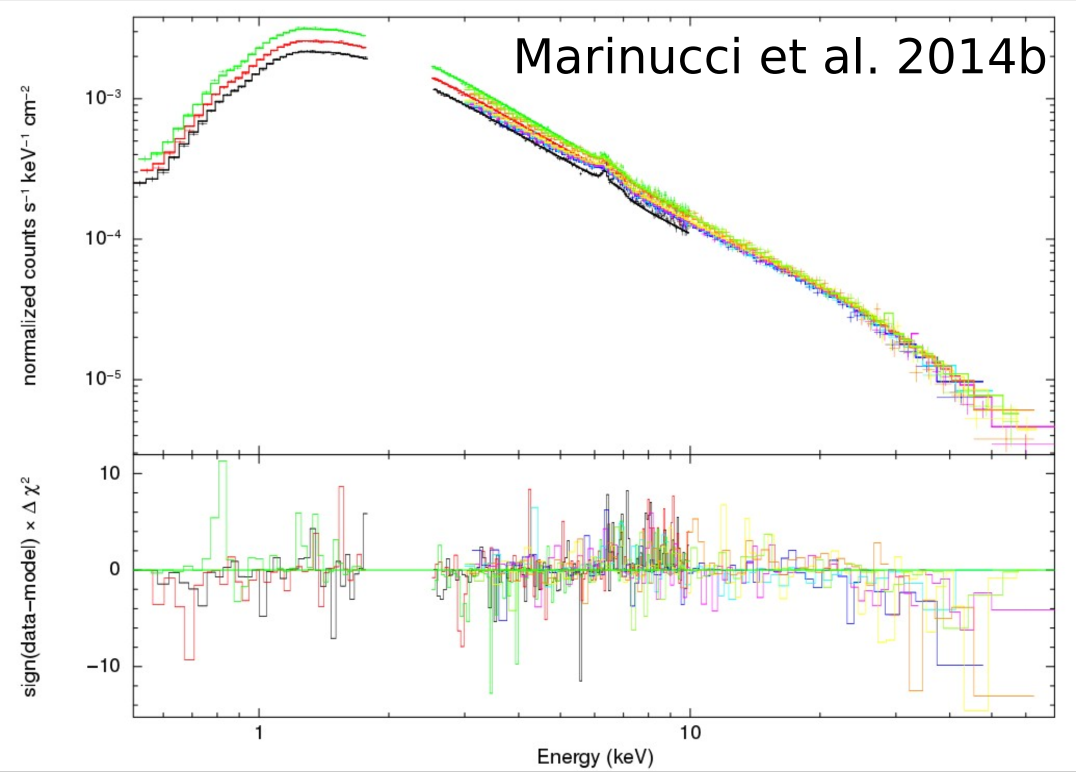
NLS1 with a relativistically broadened Fe Kα emission line (a=0.6±0.2), a steep continuum (Γ=2-2.4), E_c=30-90 keV, L_{bol}/L_{Edd}~0.18 (Miniutti+09, Malizia+08, Panessa+11, Sanfrutos+13)

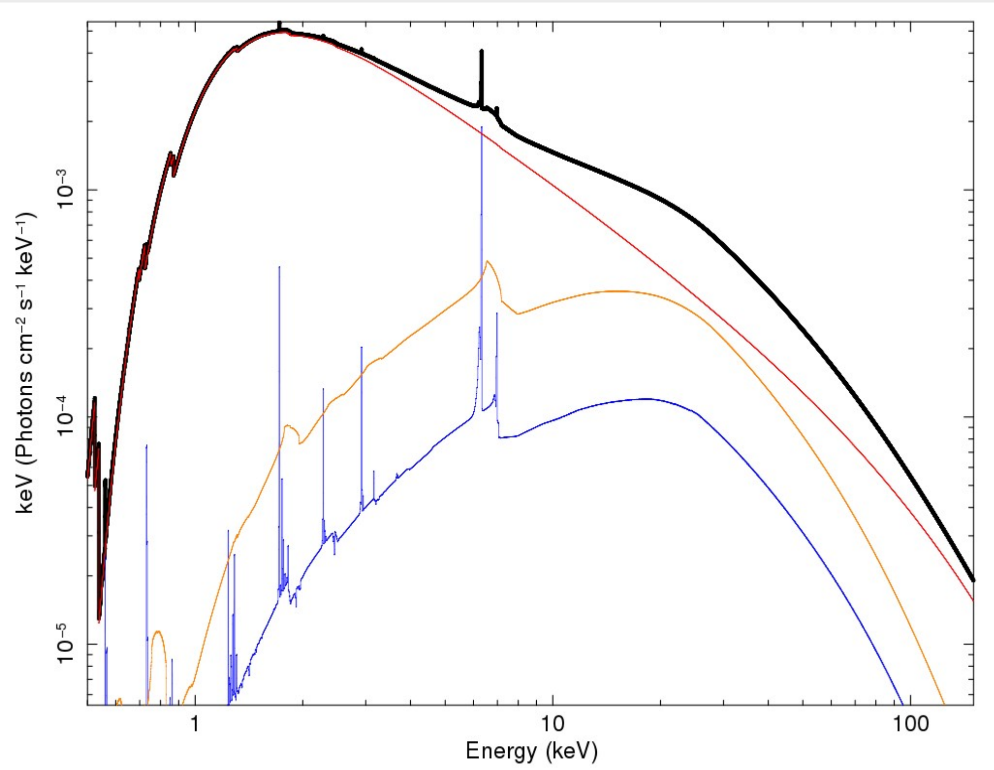
It was observed simultaneously with XMM-Newton for ~300 ks and both a strong Compton Hump and a broad Fe Kα line are present



Swift J2127.4+5654

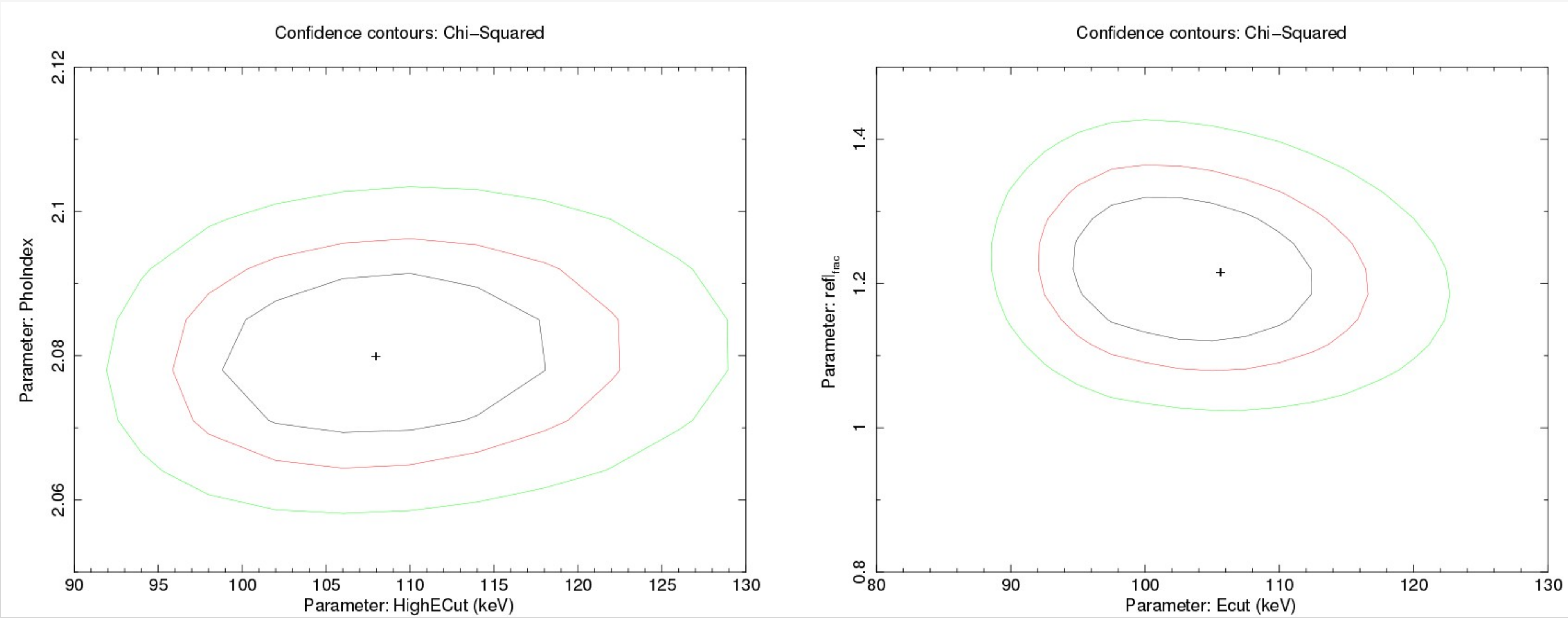
When a model composed of a primary continuum, relativistic and distant reflection components is applied to the data the only residuals are above ~25 keV





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

Swift J2127.4+5654



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

SLAB

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

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

SPHERE

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

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

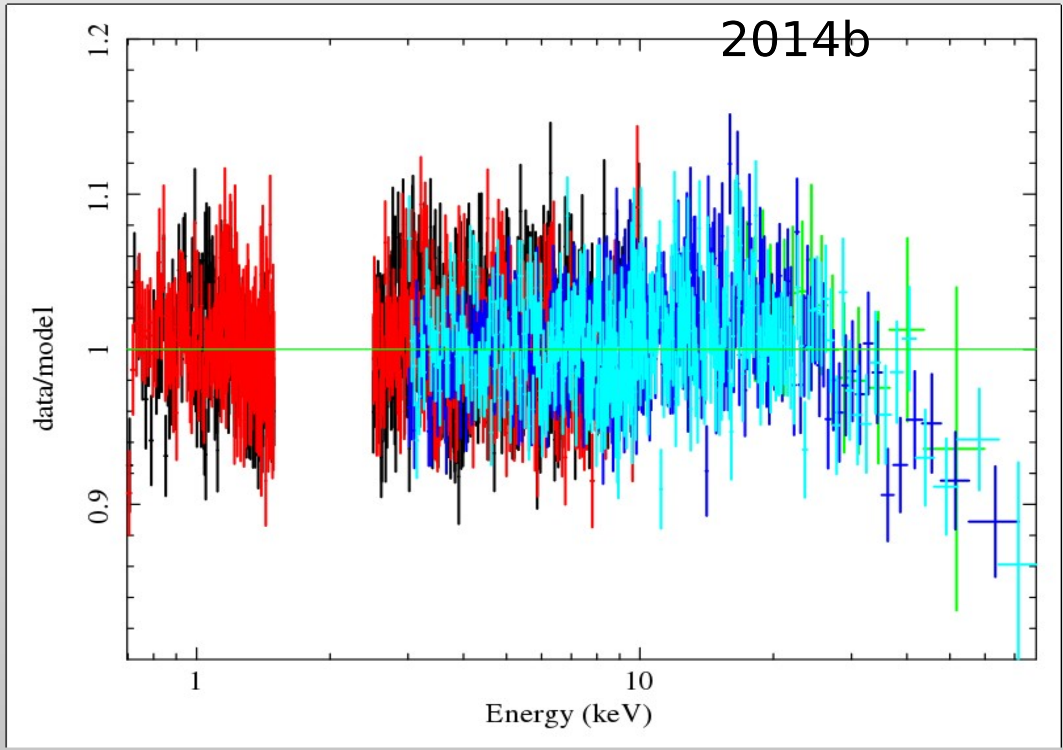
IC 4329A

-Bright Sy1 galaxy, $F_{2\text{-}10\ keV}$ ~ 0.1-1.8 $x10^{-10}$ erg/cm^2/s

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

- Observed simultaneously by NuSTAR and Suzaku for ~120 ks in 2012

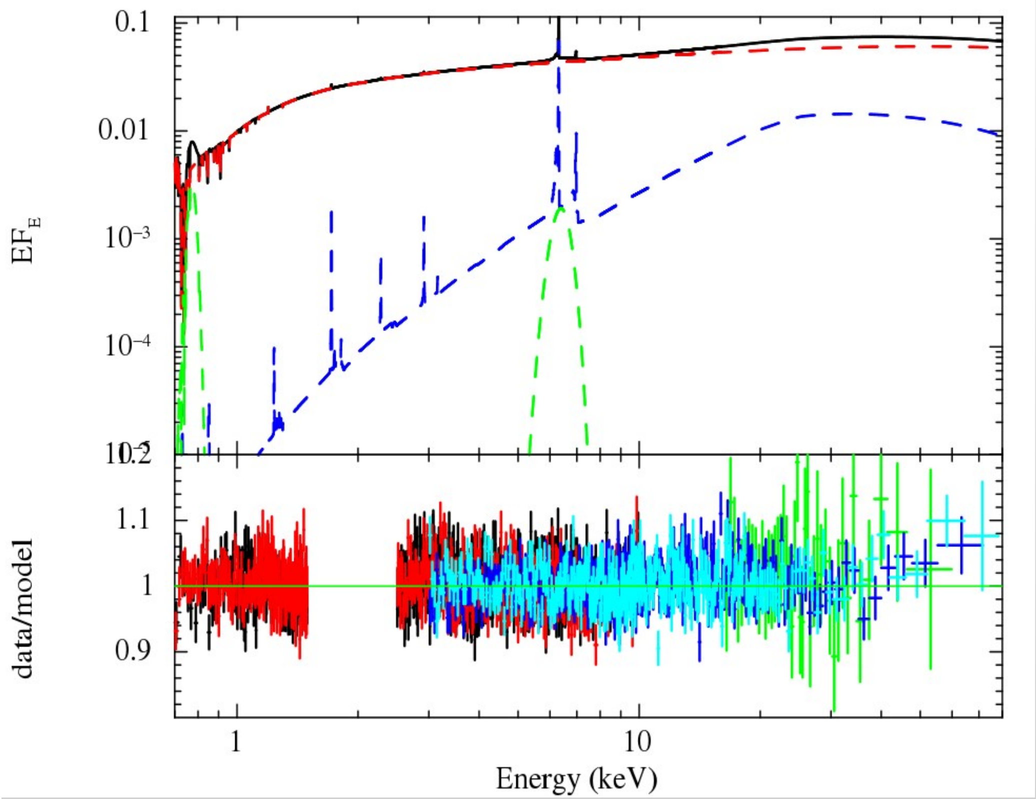
Brenneman et al. 2014b



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

IC 4329A

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

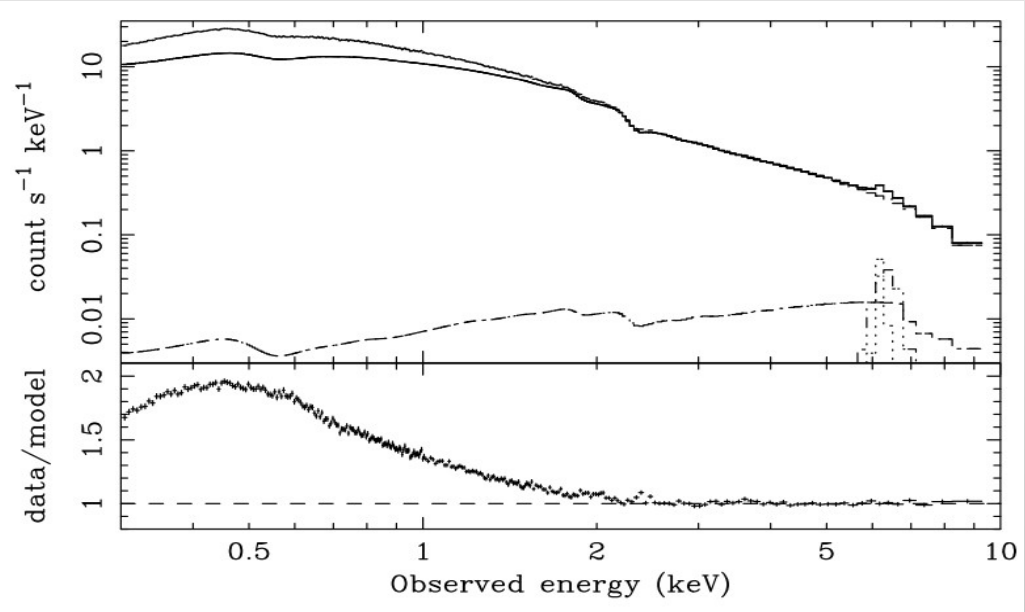


No evidence for relativistic lines.

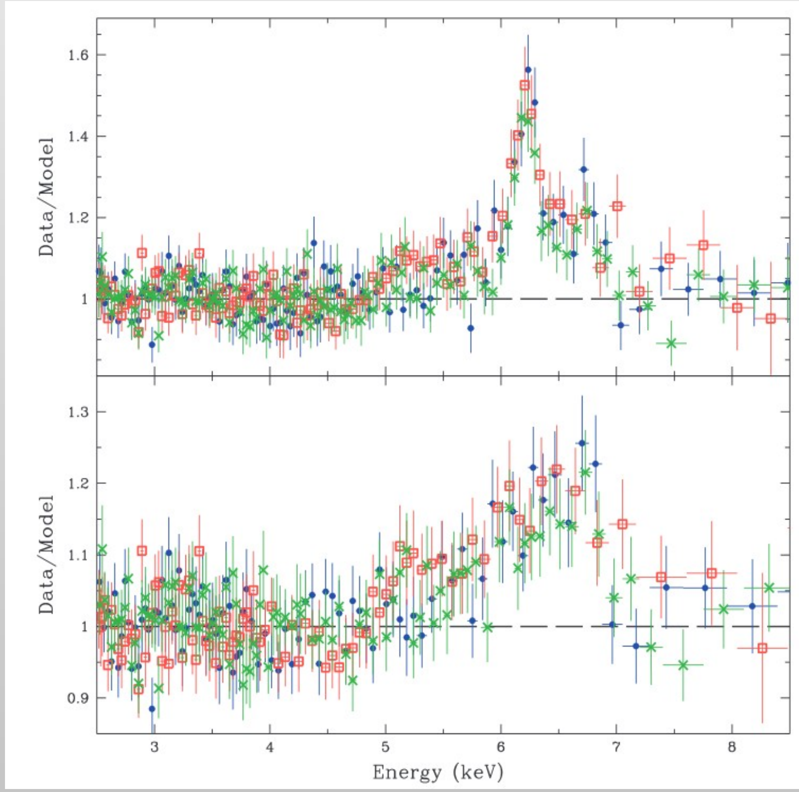
Iron line and Compton reflection originate from distant material.

Ark 120

- “Bare” Seyfert 1 galaxy, $F_{2\text{-}10\ keV} \sim 2\text{-}4\ x10^{-11}\ erg/cm^2/s$
- Prominent soft excess (XMM, Vaughan et al.+04)
- Relativistic Iron line (Suzaku, Nardini et al.+11)
- Observed simultaneously by NuSTAR and XMM for 90 ks in 2013

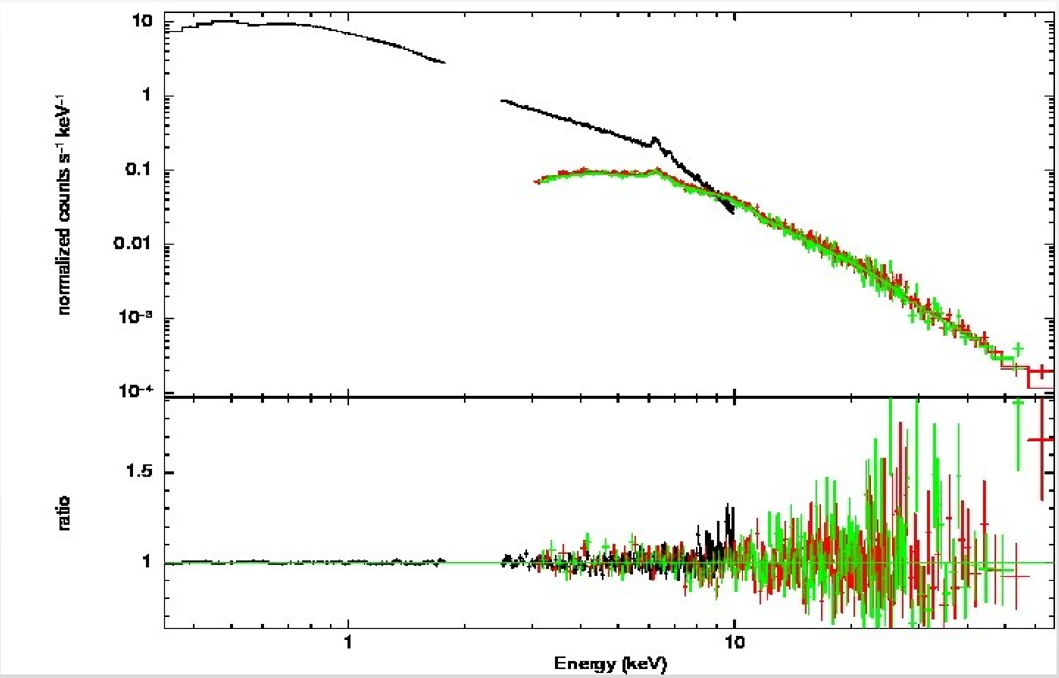


Vaughan et al. 2004

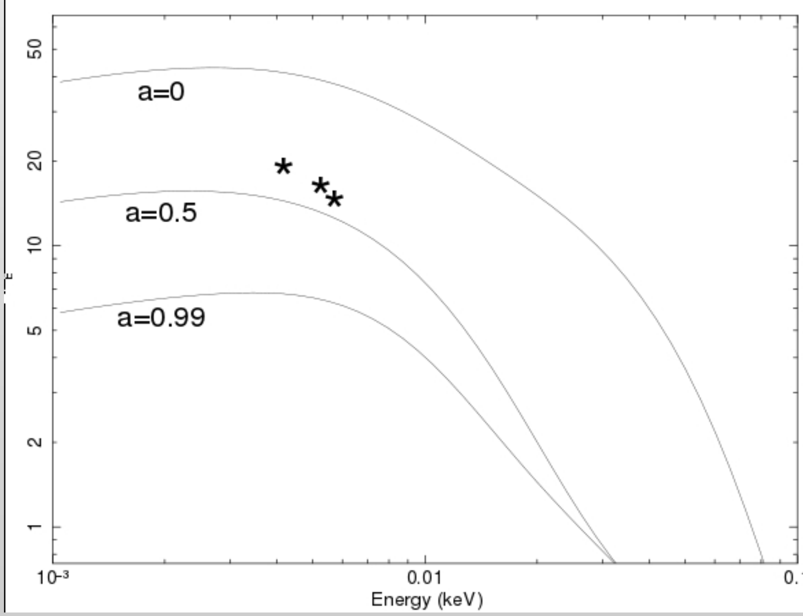


Nardini et al. 2011

Ark 120



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)	$0.33^{+0.02}_{-0.02}$	$0.32^{+0.01}_{-0.01}$	$0.32^{+0.02}_{-0.01}$
τ	$12.9^{+1.1}_{-0.9}$	$13.6^{+0.6}_{-0.2}$	$13.6^{+0.4}_{-0.7}$
Γ	$1.73^{+0.02}_{-0.02}$	$1.73^{+0.02}_{-0.02}$	$1.73^{+0.02}_{-0.02}$
E_c (keV)	>190	>190	>190



When 0.5-80 keV data are considered the coronal parameters can be derived, testing the optxagnf model (Done et al., 2012).

The OM fluxes support an intermediate value for the black hole spin.

NGC 2110

-Bright Sy2 galaxy, $F_{2\text{-}10\ keV}$ ~ 0.3-2.3 x10^{-10} erg/cm^2/s with a rather flat spectrum (Γ=1.65-1.7)

- Strong flux variations

- Narrow and variable iron line

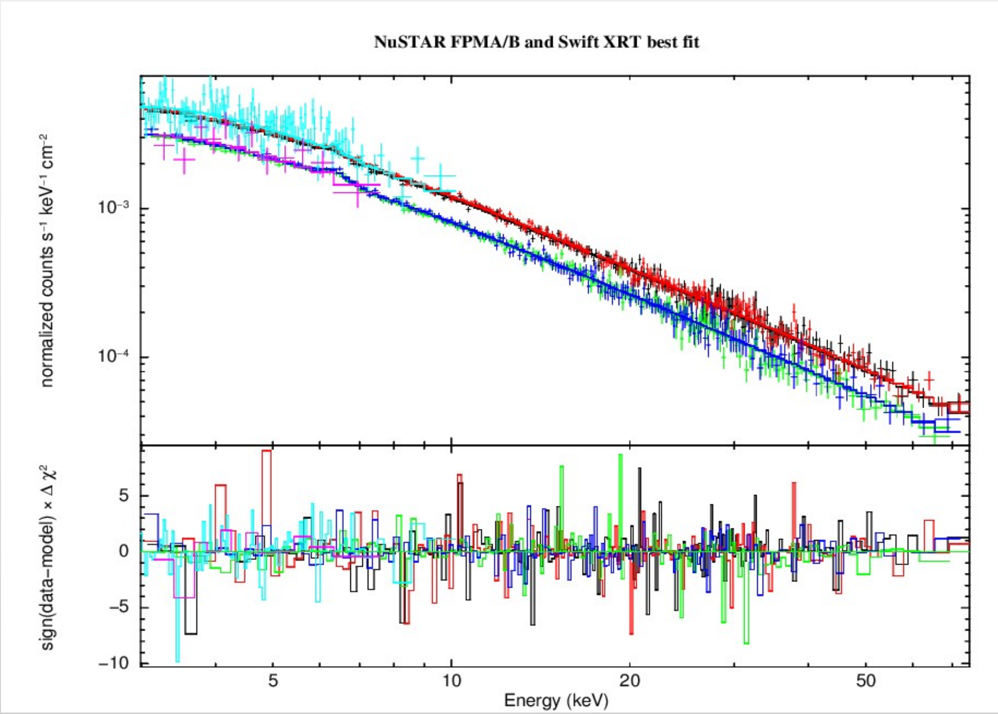
- Reflection from cold material can be neglected (i.e. perfect candidate for a cutoff energy measurement)

Marinucci et al., in prep

Instrument	Date	N_H	Γ	Fe Kα En.	σ	EW	$F_{K\alpha}$	$F_{K\beta}$	$F_{3-10\ keV}$
BeppoSAX	1997-10-12	4.3 ± 0.9	1.74 ± 0.09	$6.43^{+0.06}_{-0.09}$	< 280	194^{+69}_{-50}	$8.3^{+3.0}_{-2.3}$	< 1.3	2.77 ± 0.05
Chandra	2001-12-19	4.0 ± 1.8	$1.67^{+0.30}_{-0.25}$	6.400 ± 0.008	16^{+14}_{-10}	90^{+30}_{-25}	$5.4^{+1.8}_{-1.5}$	< 2.8	3.84 ± 0.07
Chandra	2003-03-05	< 4.5	$1.25^{+0.48}_{-0.33}$	6.391 ± 0.016	30^{+31}_{-16}	135^{+60}_{-45}	$5.5^{+2.5}_{-2.0}$	< 2.0	2.80 ± 0.07
XMM	2003-03-05	3.9 ± 0.4	1.57 ± 0.05	6.42 ± 0.01	62 ± 14	145 ± 15	5.0 ± 0.5	0.8 ± 0.3	2.26 ± 0.03
Suzaku	2005-09-16	3.8 ± 0.2	1.63 ± 0.02	6.40 ± 0.01	50 ± 15	55 ± 5	8.4 ± 0.8	0.6 ± 0.5	9.90 ± 0.03
Suzaku	2012-08-31	4.5 ± 0.2	1.63 ± 0.02	6.39 ± 0.01	< 55	50 ± 7	9.7 ± 0.9	< 1.0	11.8 ± 0.1
NuSTAR	2012-10-05	4.0 ± 0.4	1.64 ± 0.03	6.33 ± 0.07	< 192	35 ± 10	9.5 ± 3.0	< 2.3	17.1 ± 0.2
NuSTAR	2013-02-14	4.0 ± 0.7	1.64 ± 0.05	6.45 ± 0.07	175^{+200}_{-140}	90^{+42}_{-25}	$16.0^{+8.0}_{-4.0}$	< 3.4	11.7 ± 0.2

NGC 2110

When we analyze the NuSTAR+Swift high and low flux states no Compton reflection is detected and E_c>210 keV.



$L_{2\text{-}10\ keV}$=0.4-3.5x10^{43} erg/s

↓

L_{bol}/L_{Edd}=2x10^{-3} - 3x10^{-2}

The lack of high energy cutoff could be linked to the low accretion rate of the source?

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Conclusions

- High energy cut-off have been measured in a number of AGN with NuSTAR (more are yet to come!)

- The hard X-ray band (3-80 keV) is fundamental for testing and discriminating between different Comptonization models

- Further observations will help us in understanding the nature of the primary continuum, such as the relation between the accretion rate and the cutoff energy and the link between the disc reflection and the extension of the hot corona.