The AGN Physics NuSTAR program

Giorgio Matt

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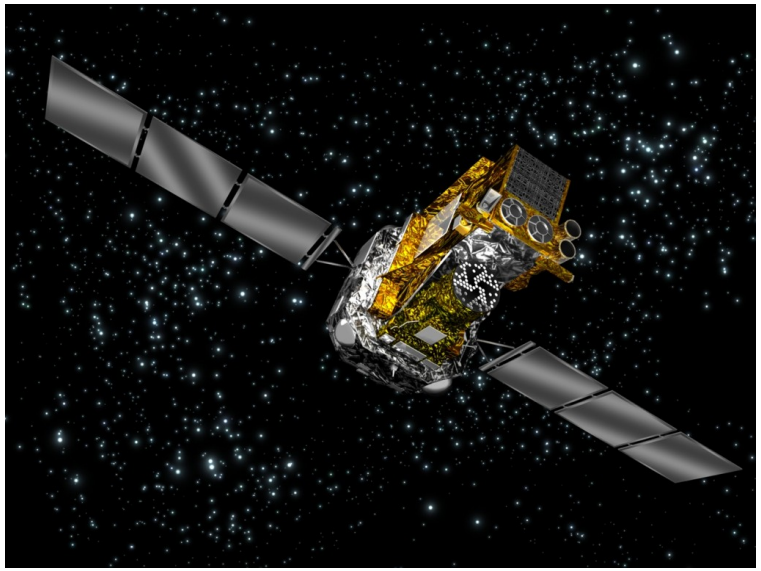
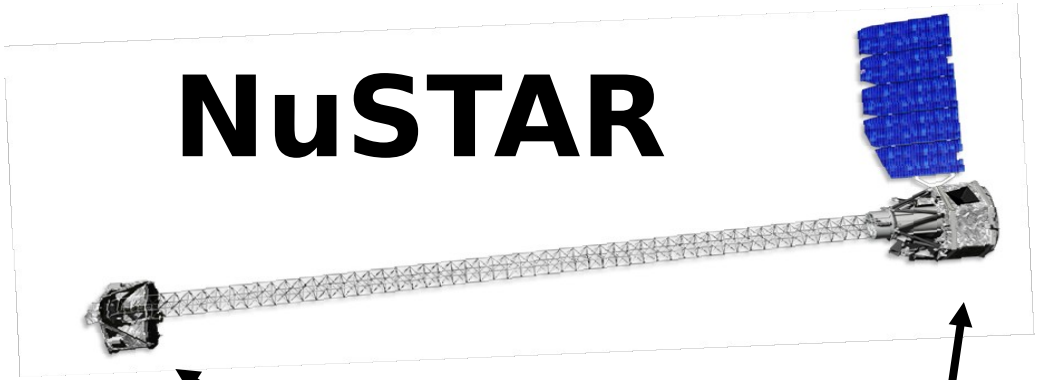
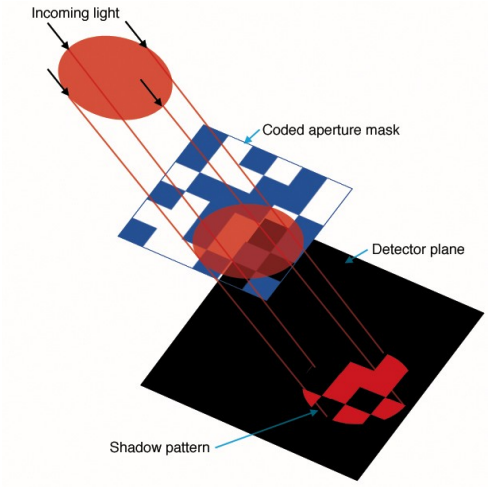
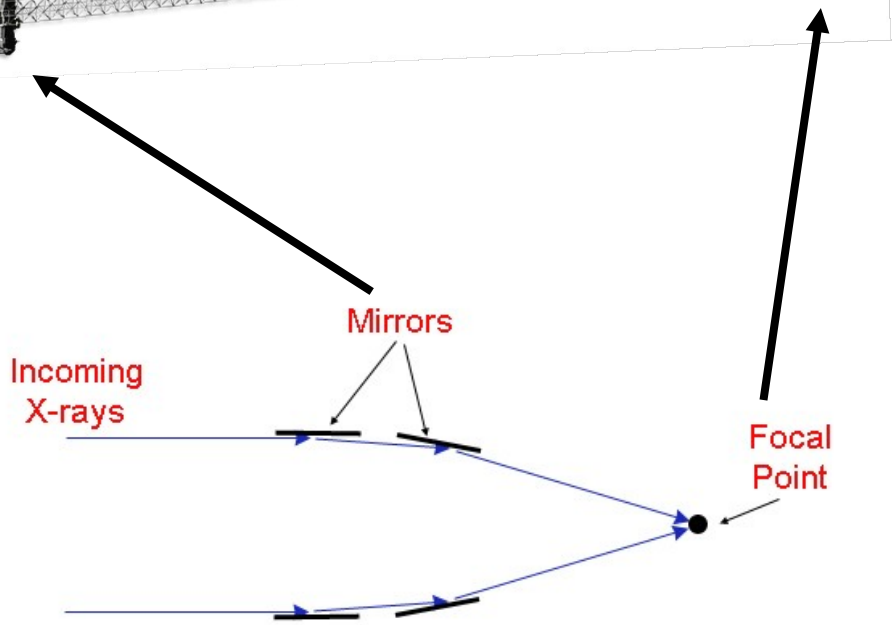
On behalf of the NuSTAR AGN Physics WG

NuSTAR is the **first** focusing hard X-ray satellite





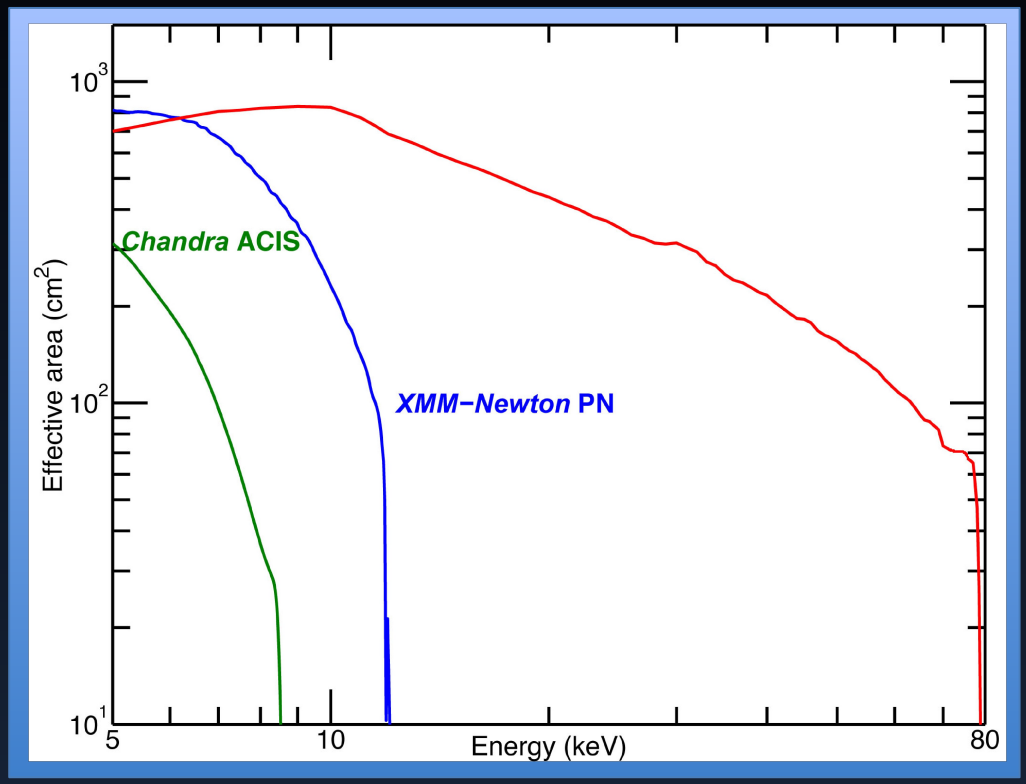




Coded Aperture Optics:
high background, large detector

Grazing Incidence Optics:
low background, compact detector

Collecting Area



NuSTAR two-telescope total collecting area

Sensitivity comparison

INTEGRAL (ISGRI)	***~0.5 mCrab (20-100 keV) with >Ms***
Swift (BAT)	***~0.8 mCrab (15-150 keV) with >Ms***
NuSTAR	***~0.8 μCrab (10-40 keV) In 1 Ms***

1 Ms Sensitivity

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

Imaging

HPD	58”
FWHM	18”
Localization	2” (1-σ)

Field of View

FWZI	12.5’ x 12.5’
FWHI	10’ @ 10 keV
	8’ @ 40 keV
	6’ @ 68 keV

Timing

relative	100 microsec
absolute	3 msec

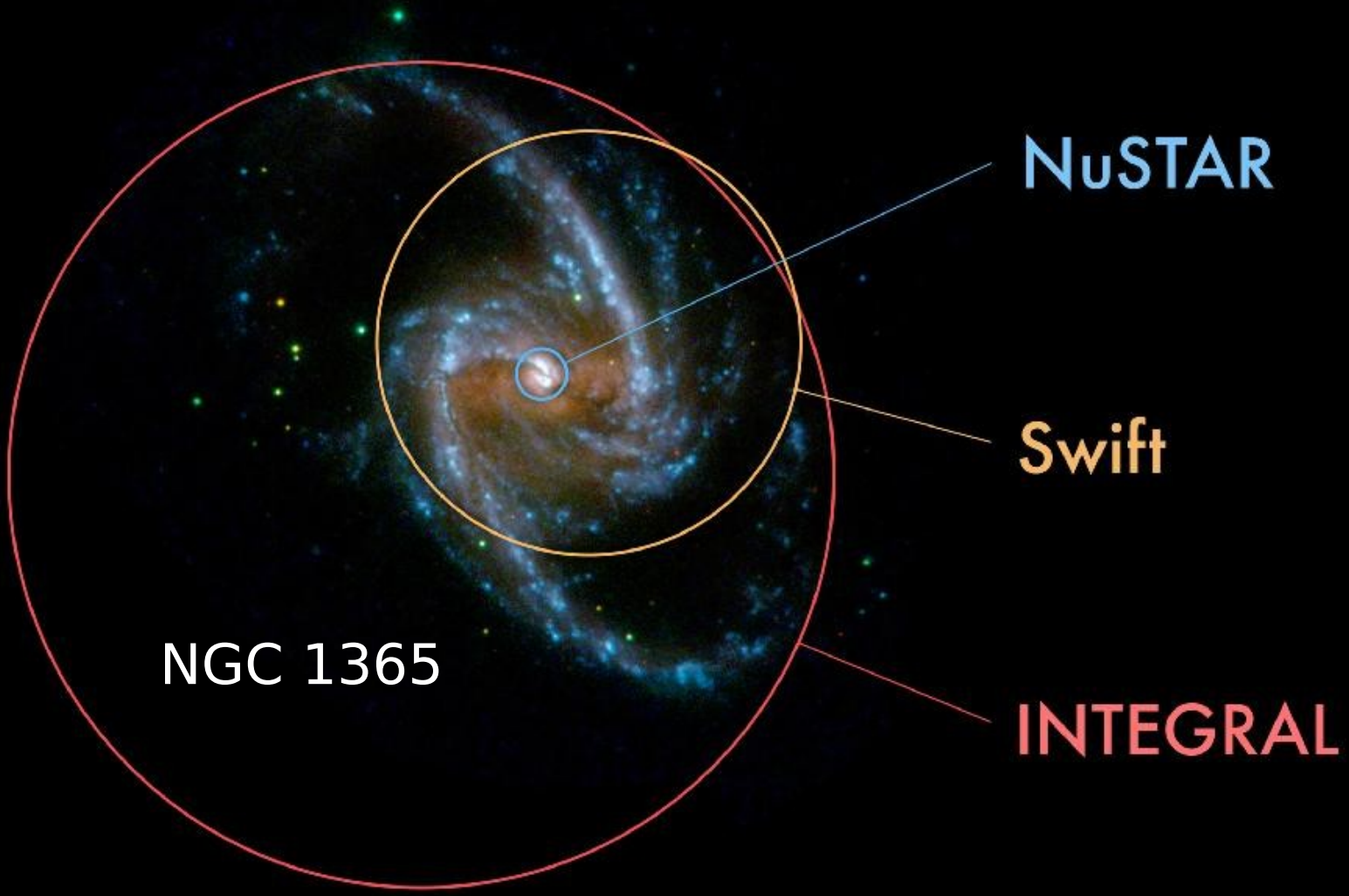
Spectral response

energy range	3-79 keV
threshold	2.0 keV
ΔE @ 6 keV	0.4 keV FWHM
ΔE @ 60 keV	1.0 keV FWHM

Target of Opportunity

response <24 hr (reqmt)
typical 6-8 hours
80% sky accessibility

High-Energy Missions in Orbit:
comparison of pixel scales

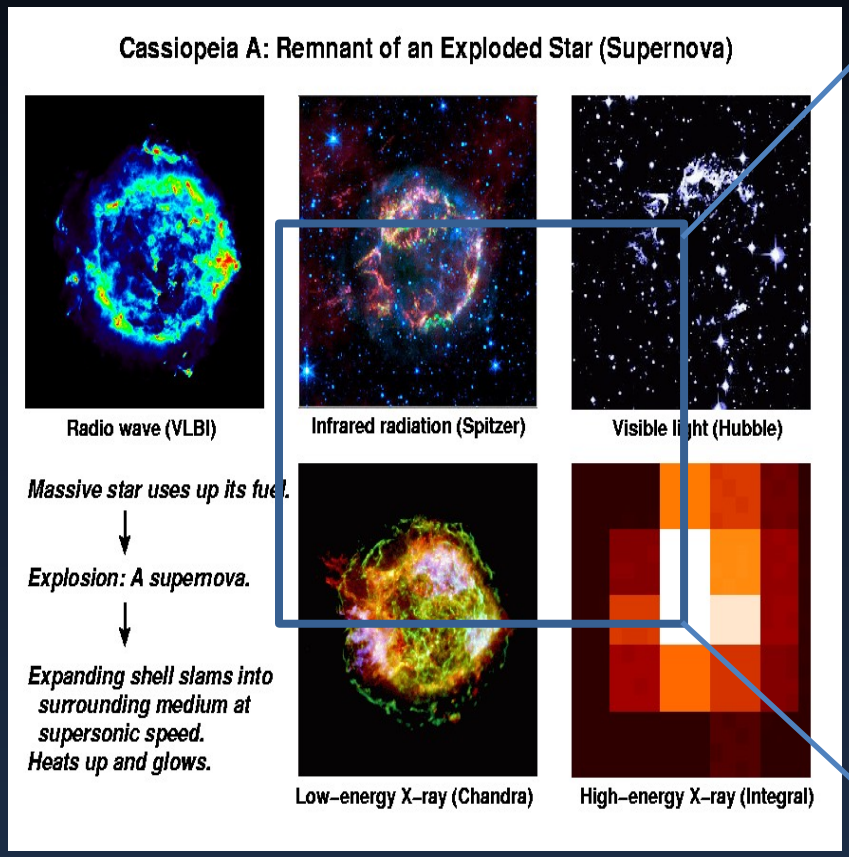


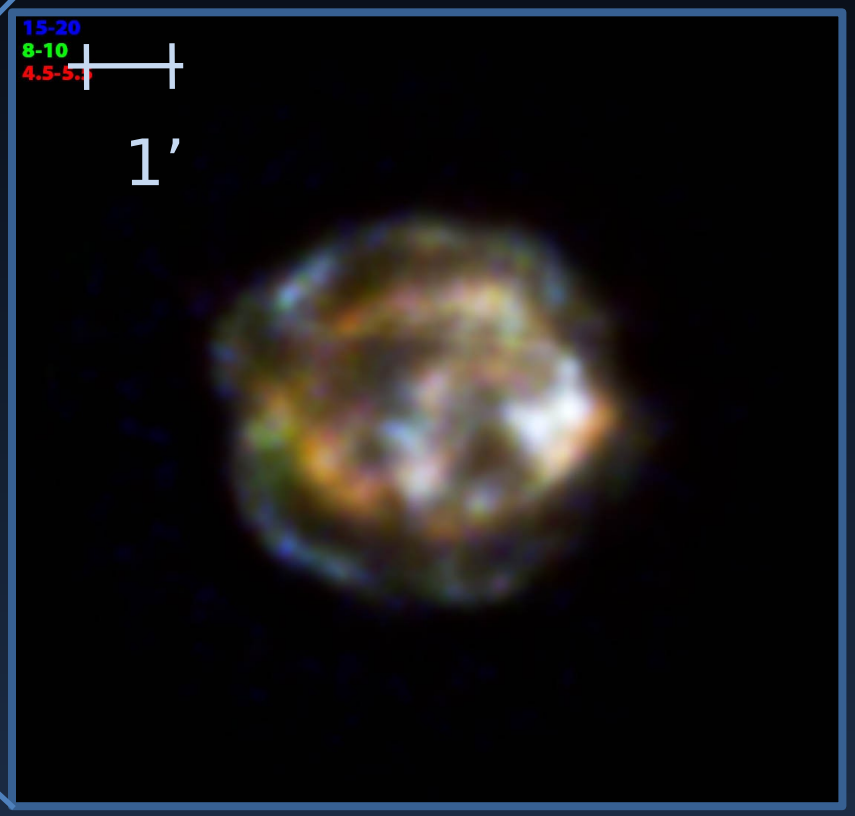
Imaging

Cas A supernova remnant

INTEGRAL ISGRI
E>15 keV

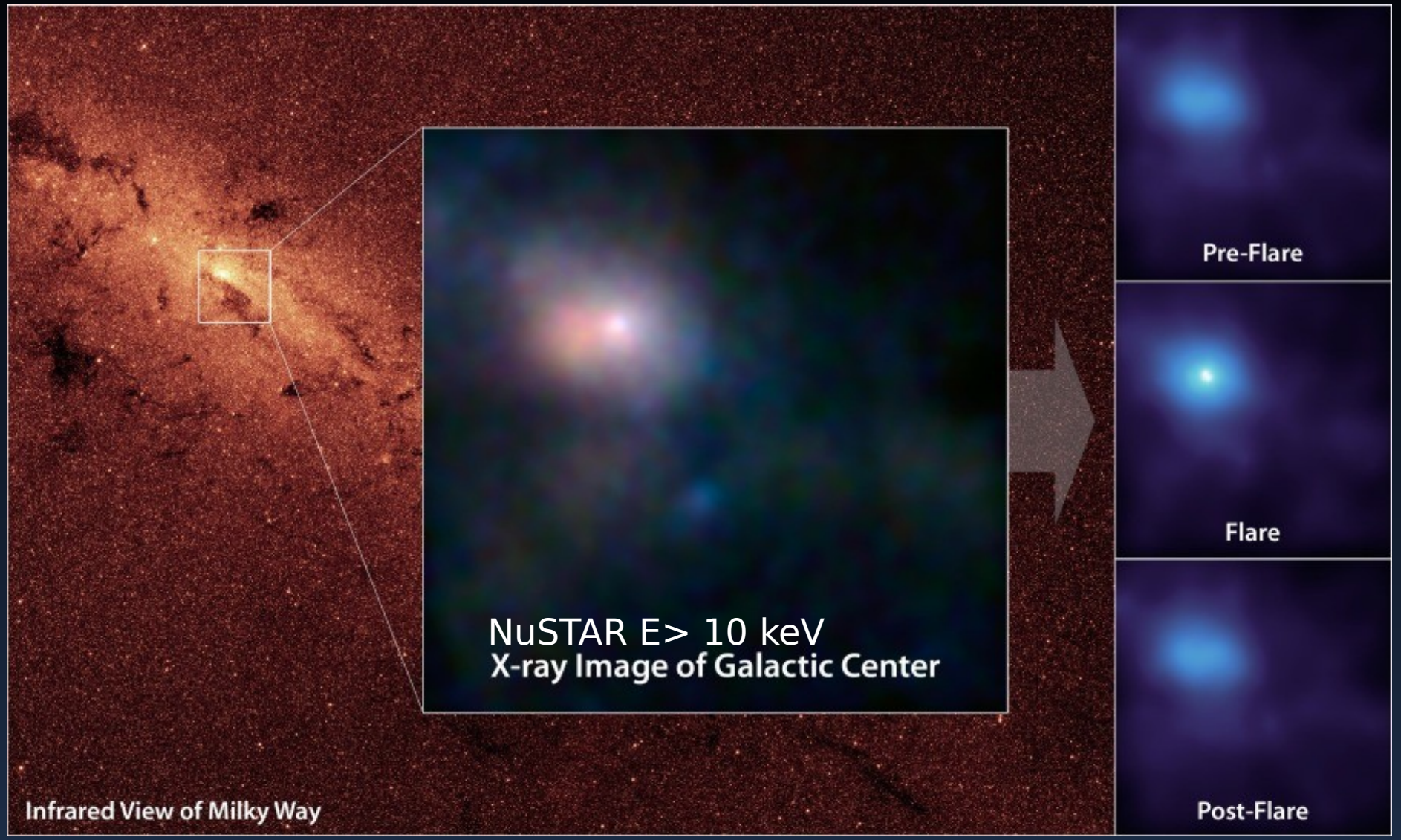
NuSTAR Image
Red : 4.5 – 5.5 keV
Green: 8 – 10 keV
Blue: 10 – 25 keV

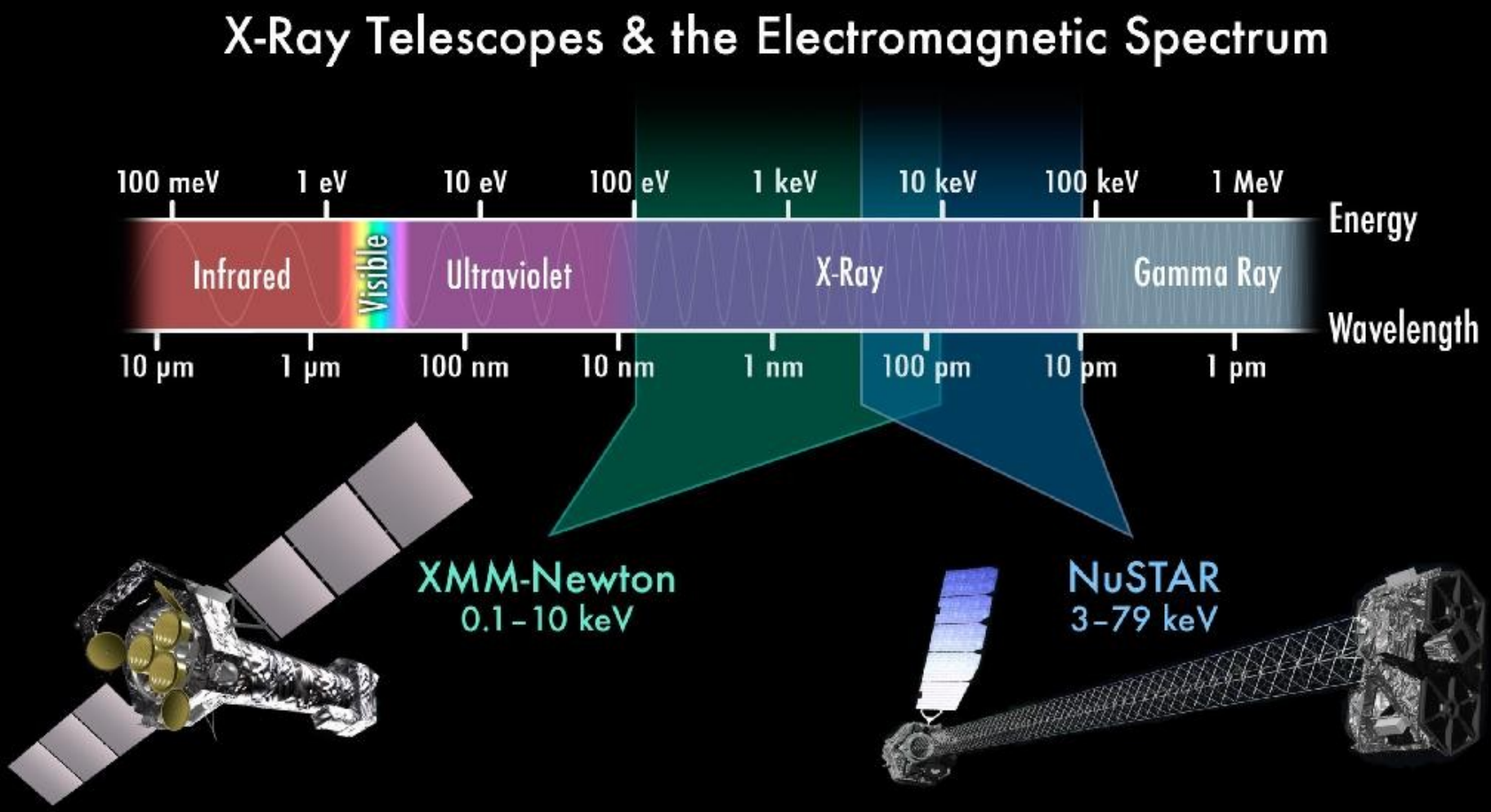




Grefenstette et al. (2014)

Imaging


NuSTAR E> 10 keV
X-ray Image of Galactic Center
Infrared View of Milky Way
Pre-Flare
Flare
Post-Flare



low-energy X-rays
“soft” X-rays

high-energy X-rays
“hard” X-rays

Baseline Science Mission

- SMall Explorer Mission (SMEX), launched in June 2012
- As typical for an Explorer, all baseline observations led by the science team
- After the current initial calibration period has been completed, observations became public through HEASARC two months after a data set is completed
- 1.5 Ms of NuSTAR made available for coordinated observations with XMM in AO13 (with a factor 6 oversubscription)
- Mission extended to 2015-16 with allocated budget for two more years
- GO program will start in April 2015 (deadline for proposals: November 25, 2014)

- ~140-person international science team broken into 13 science working groups:

Science Working Groups

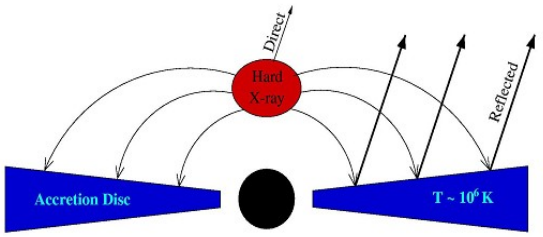
Science Group	Working Group Chair
Galactic Survey	Chuck Hailey
Supernovae and ToOs	Steve Boggs
Supernova Remnants and PWN	Fiona Harrison
Magnetars and RPP	Vicky Kaspi
Galactic Binaries	John Tomsick
Ultraluminous X-ray sources	Fiona Harrison
Extragalactic Surveys	Daniel Stern
Blazars	Greg Madejski/Paolo Giommi
Obscured AGN	Daniel Stern
AGN Physics	Giorgio Matt
Galaxy Clusters	Allan Hornstrup/Silvano Molendi
Starburst Galaxies	Ann Hornschemeier
Solar Physics	David Smith

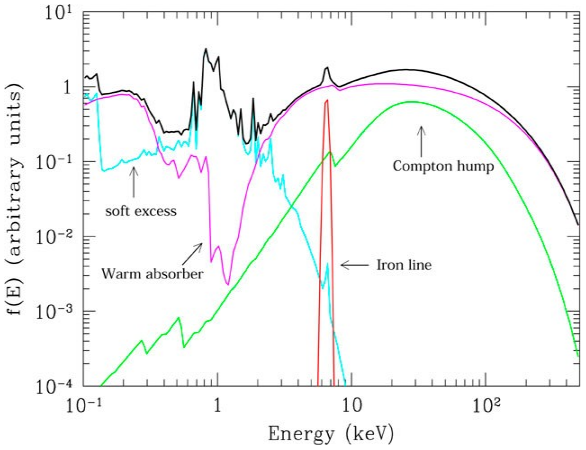
AGN Physics: Scientific rationale

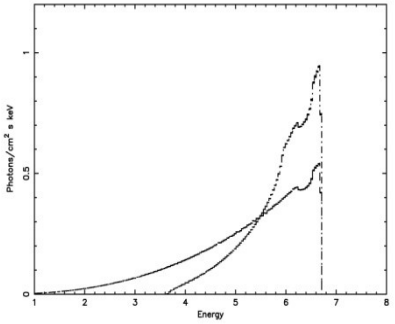
- **Determine the physical parameters of the hot corona (temperature, optical depth)**

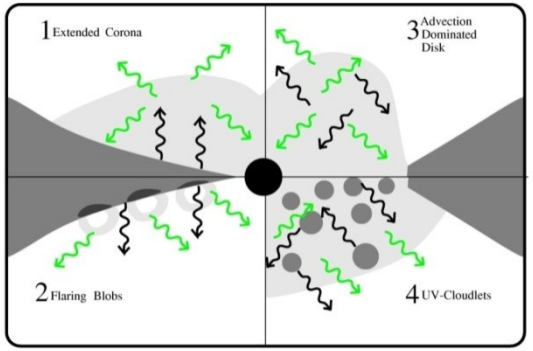
- **Measure the spin of the Black Hole**

- **Search for similarities and differences between radio quiet and radio loud AGN**









RQ objects in the AGN Physics NuSTAR Program

- **4 sources observed simultaneously with XMM [Swift J2127.4+5654, MCG-6-30-15, 3C120, Ark 120] for BH spin and corona T. Ark 120 re-observed recently in coordination with XMM and Chandra.**
- **2 sources observed simultaneously with Suzaku [IC4329A, NGC4151] for BH spin and corona T**
- **MCG-5-23-16 observed twice, the second time simultaneously with Suzaku**
- **Mrk 335 observed, in coordination with Suzaku, during an extended low state**
- **A monitoring campaign studied the spectral variability of NGC4051**
- **NuSTAR joined the XMM-led monitoring campaign on NGC5548 and on PDS 456**
- **1H0707+495 and Fairall 9 observed recently (the latter simultaneously with XMM)**

Content of this talk

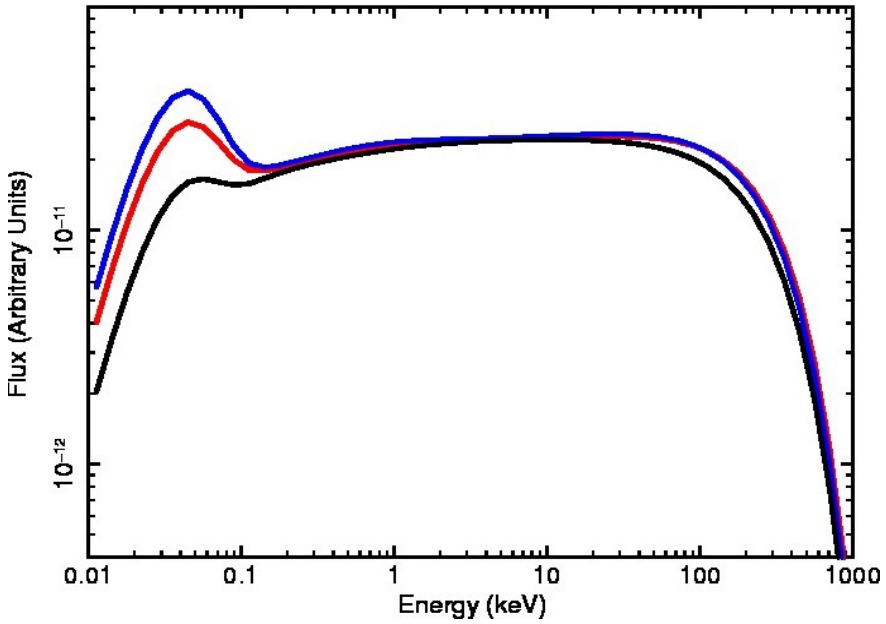
- **The coronal parameters in IC4329A, MCG-5-23-16 and SwiftJ2127.4+5654**
- **The relativistic reflection in NGC1365 *(Risaliti et al., 2013, Walton et al. 2014)* and the BH spin of SwiftJ2127.4+5654 and MCG-6-30-15 *(Marinucci et al., 2014a,b)***
- **The hard X-rays time lags of MCG-5-23-16 *(Zoghbi et al., 2014)***
- **The extreme relativistic reflection in Mrk 335 (Parker et al. 2014)**
- **The soft excess of Ark 120 *(Matt et al., 2014)***

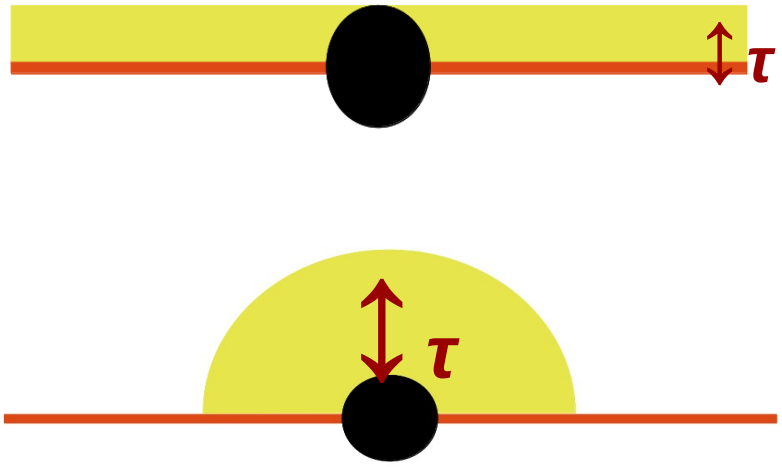
Coronal parameters

Primary hard X-ray emission likely due to Comptonization in a hot corona → quasi-exponential high energy cutoffs expected

Evidence for high energy cutoffs in BeppoSAX and XMM - INTEGRAL samples

NuSTAR is providing for the first time source-dominated obs above 10 keV → coronal parameters



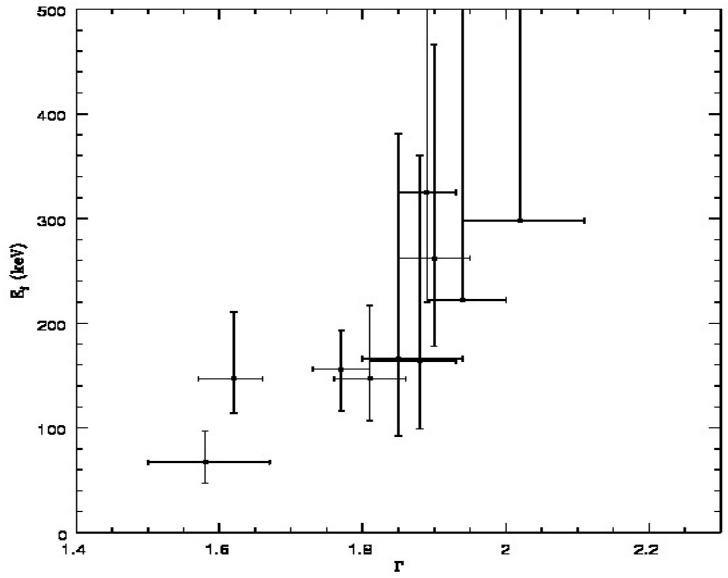


Coronal parameters

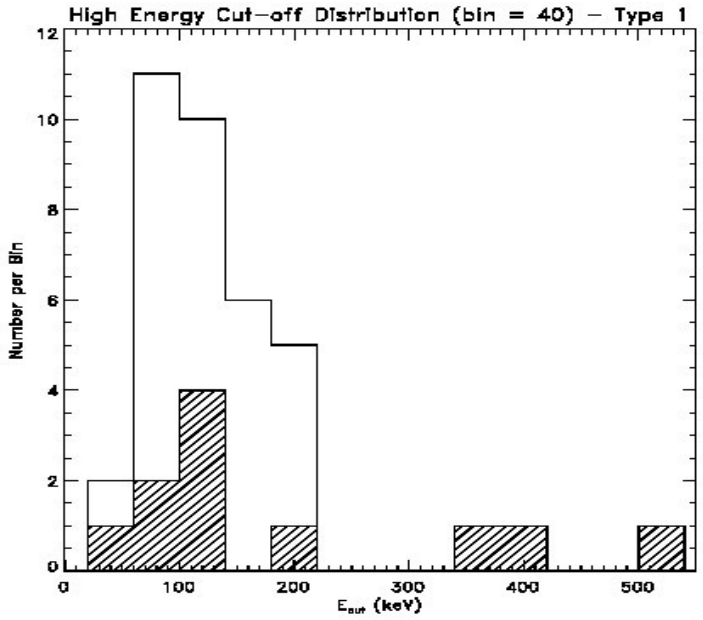
Primary hard X-ray emission due to Comptonization in a hot corona → high energy cutoffs expected

Evidence for high energy cutoffs in BeppoSAX and XMM - INTEGRAL samples

NuSTAR is providing for the first time source-dominated obs above 10 keV → coronal parameters



(Perola et al. 2002)



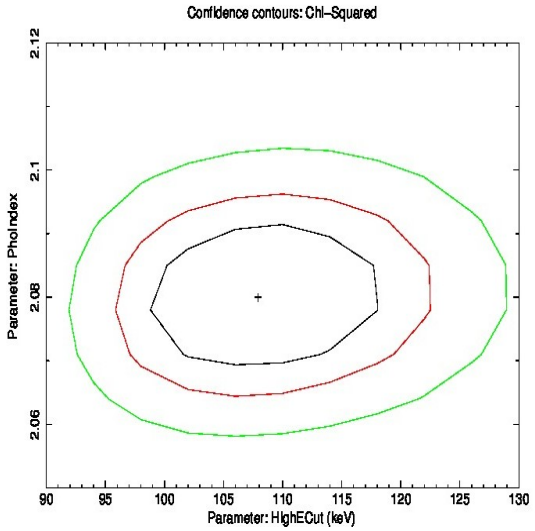
(Malizia et al. 2014)

Coronal parameters

Primary hard X-ray emission due to Comptonization in a hot corona → high energy cutoffs expected

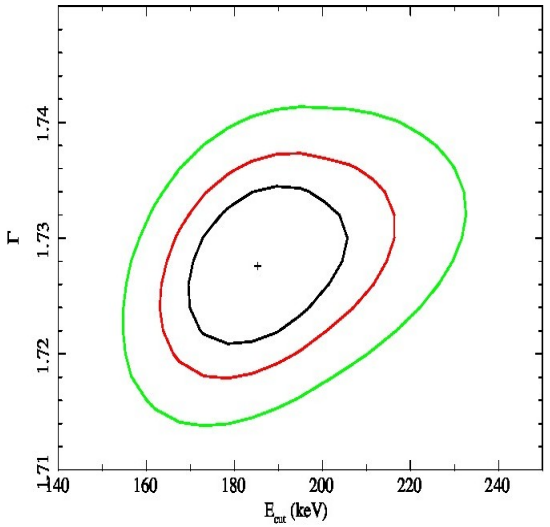
Evidence for high energy cutoffs in BeppoSAX and XMM - INTEGRAL samples

NuSTAR is providing for the first time source-dominated obs above 10 keV → coronal parameters



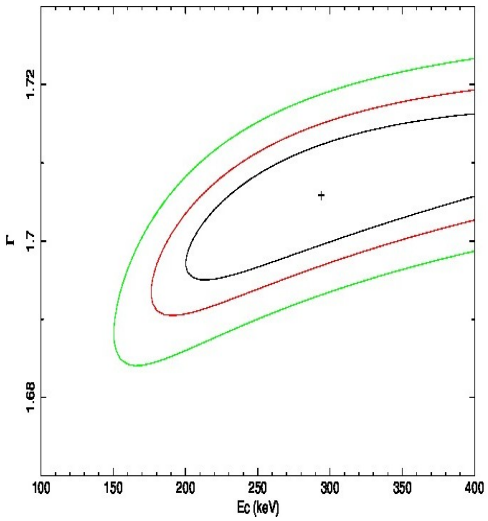
Swift J2127.4+5654 (Marinucci et al. 2014)

kT~68/53 keV τ~0.35/1.35 (slab/sphere)



IC4329A (Brenneman et al. 2014)

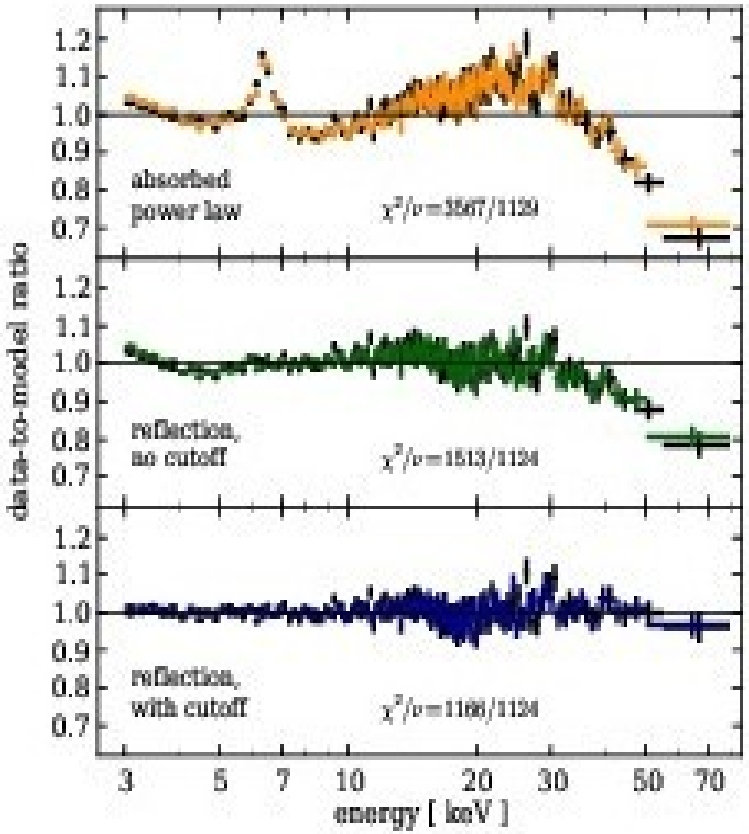
kT~61/50 keV τ~0.7/2.35 (slab/sphere)

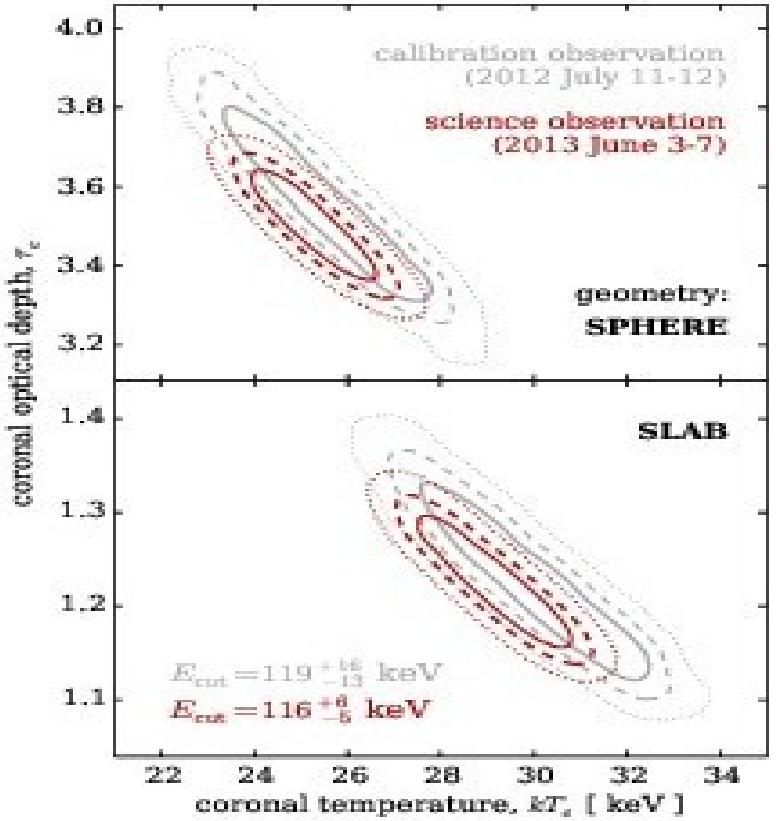


Ark 120 (Matt et al. 2014)

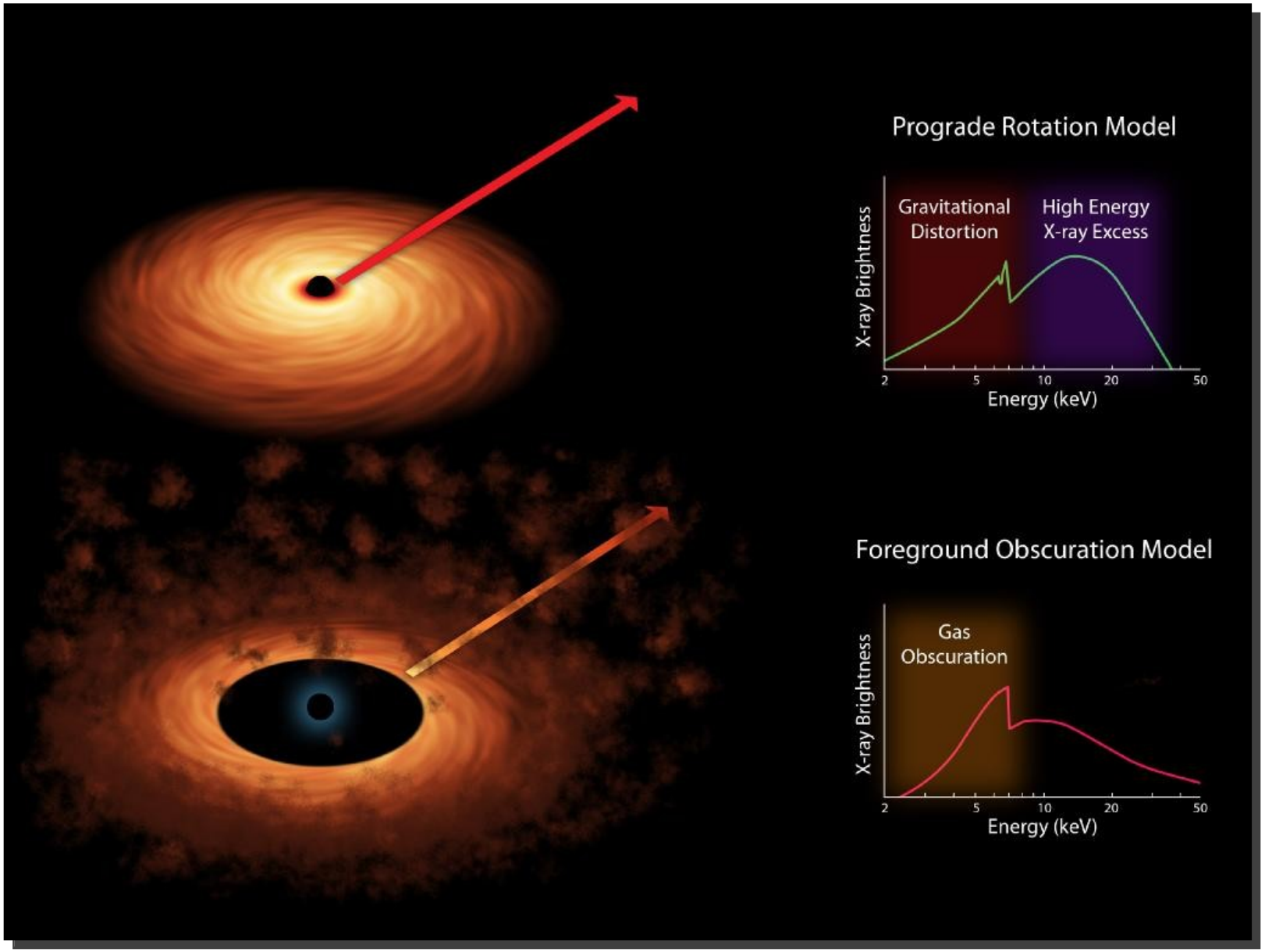
Coronal parameters

The best case so far: MCG-5-23-16 (Balokovic et al., submitted)





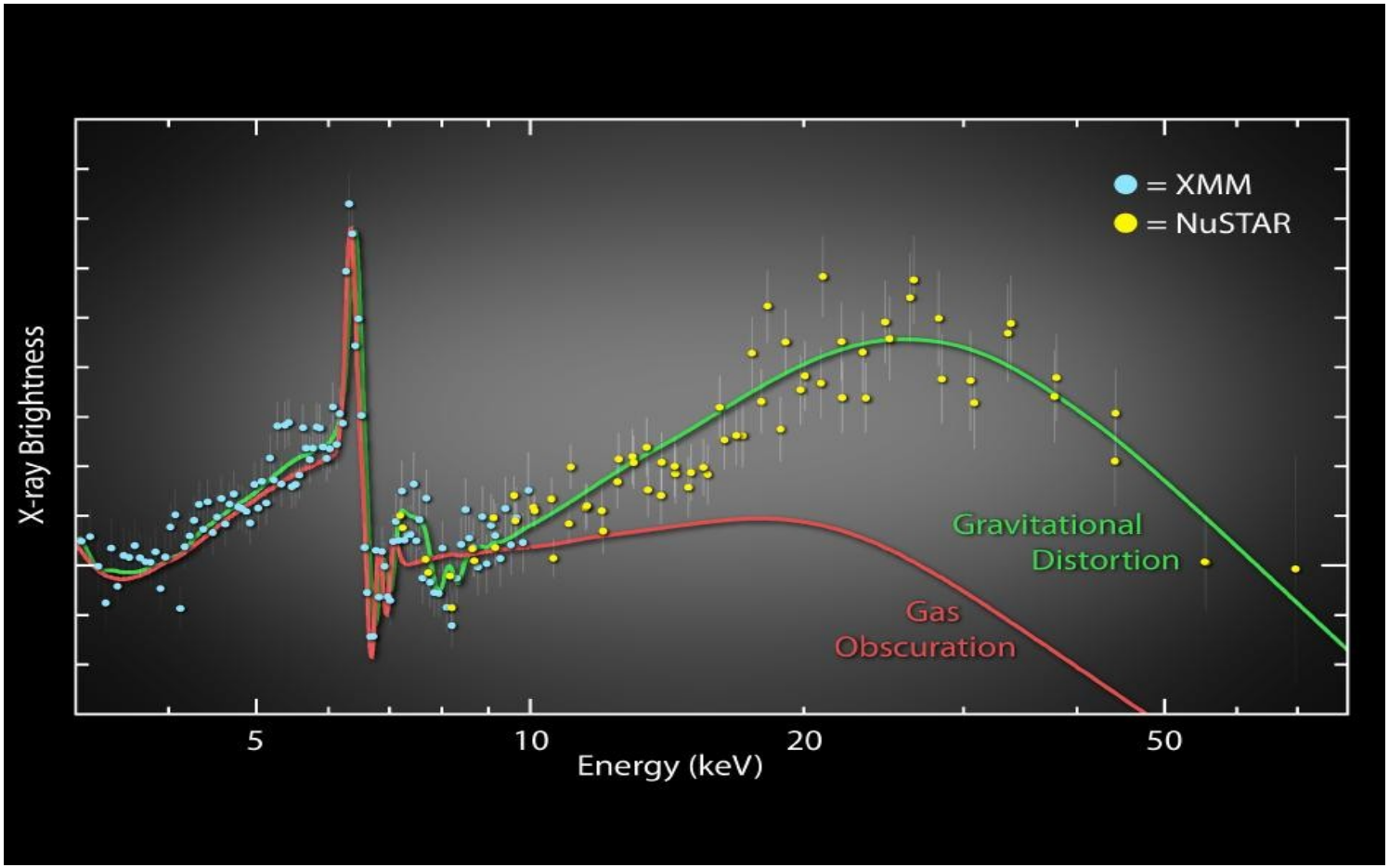
The relativistic reflection in NGC1365



The relativistic reflection in NGC1365

Observed simultaneously by XMM and NuSTAR.

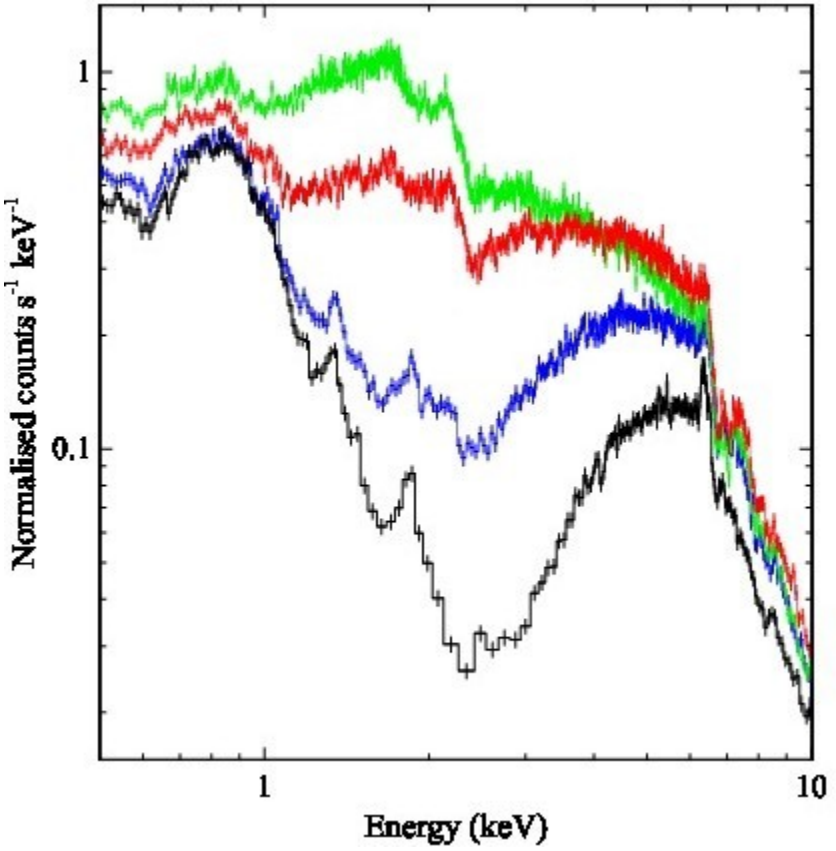
Both absorption and reflection models fit well the XMM data, but only reflaction also the NuSTAR data (Risaliti et al. 2013)

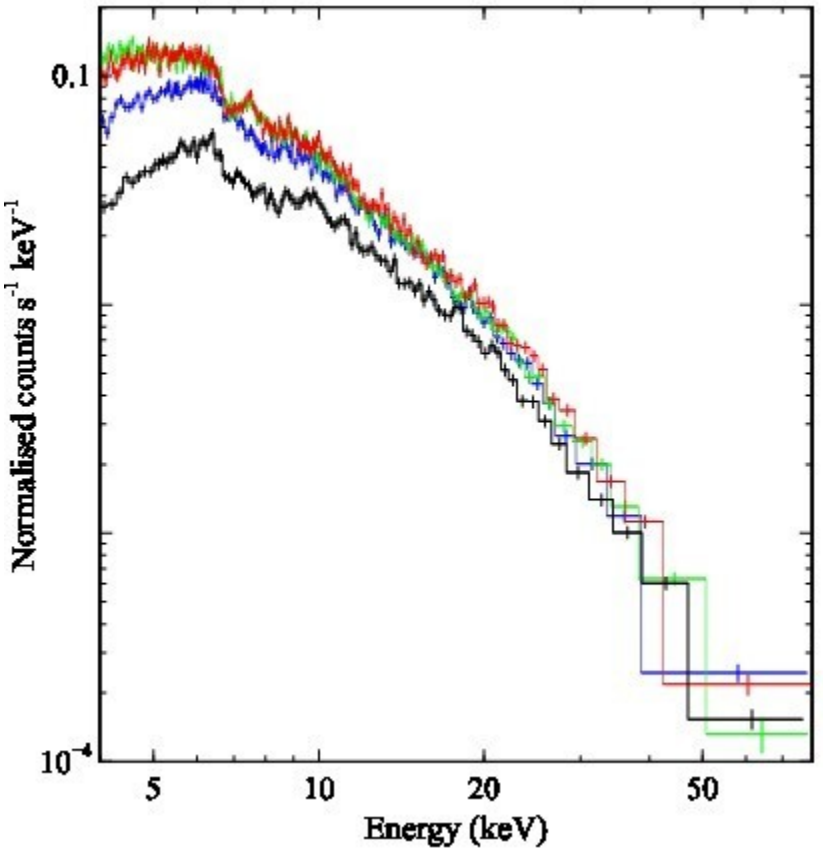


The relativistic reflection in NGC1365

Observed simultaneously by XMM and NuSTAR.

Consistent results are found in all observations, despite huge differences in the absorption parameters (Walton et al. 2014)





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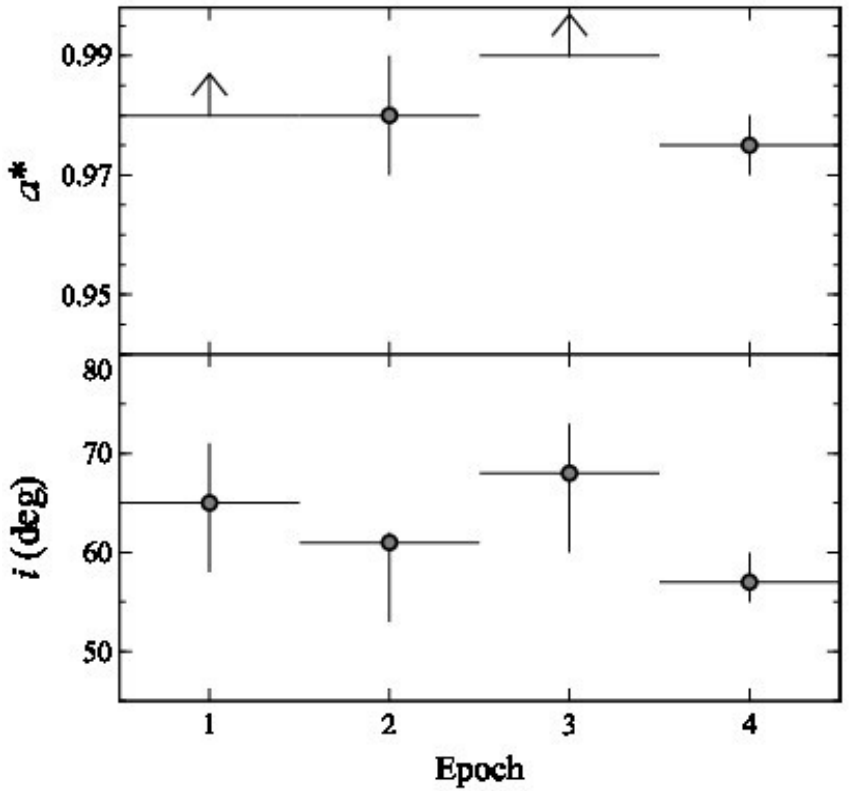
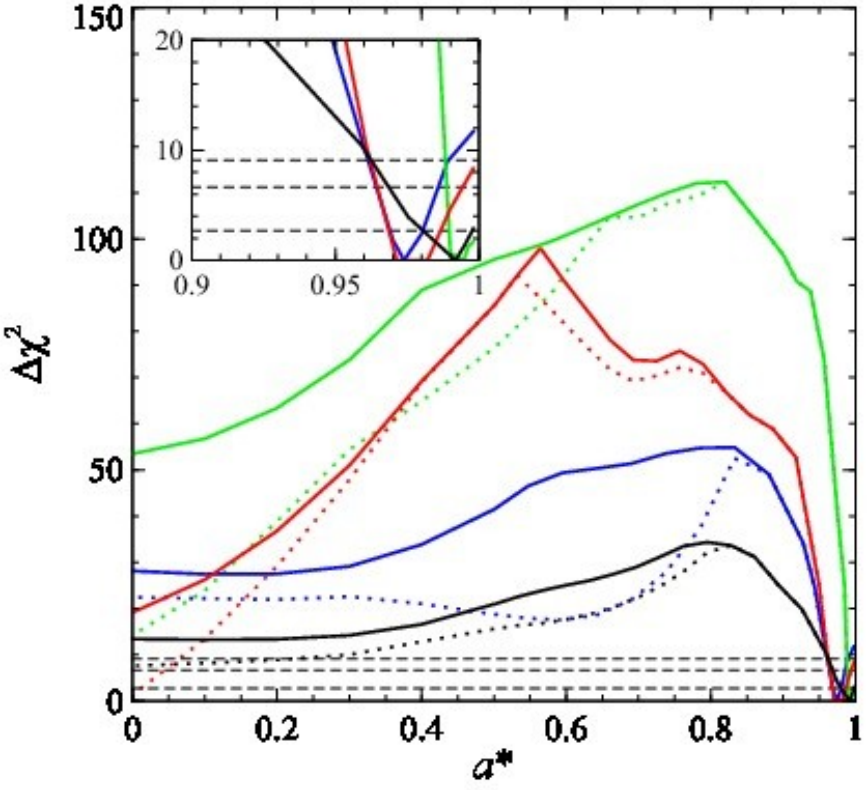
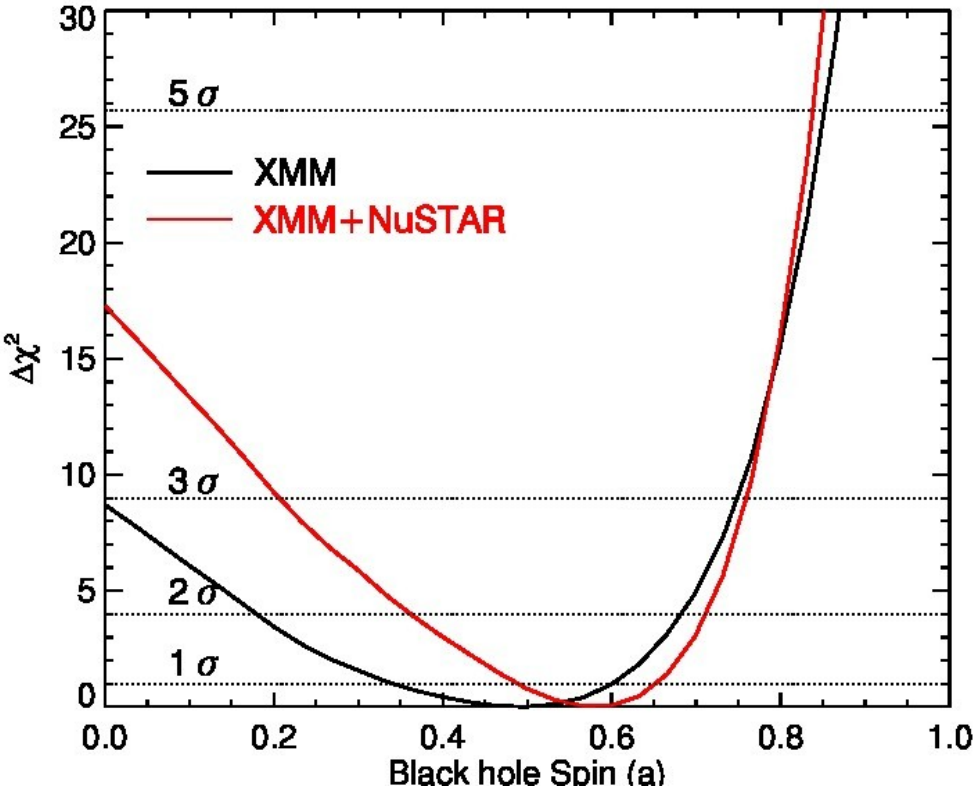




BH spin measurements

The broad band provided by NuSTAR + XMM (or Suzaku) allows a good estimated of the continuum spectrum, and so a robust measurements of the BH spin via relativistic effects on the iron line and the reflection component



Spin ~1 confirmed in MCG-6-30-15 (Marinucci et al. 2014b)

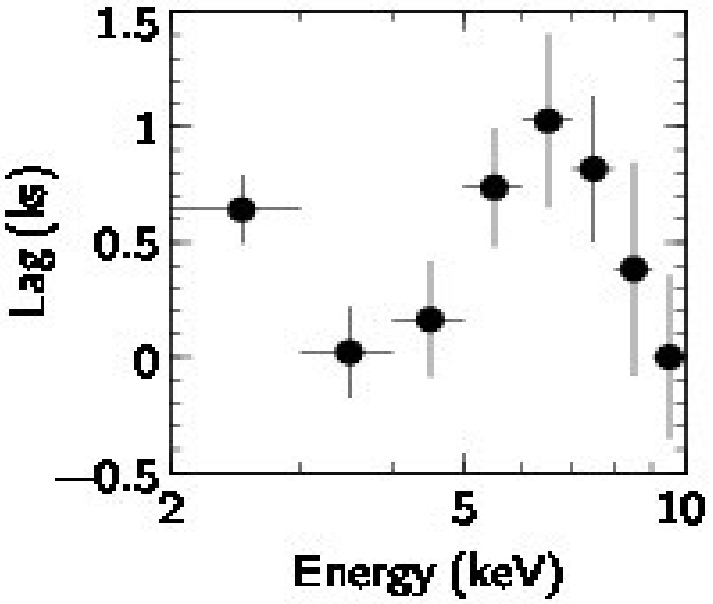
SwiftJ2127.4+5654 (Marinucci et al. 2014a)

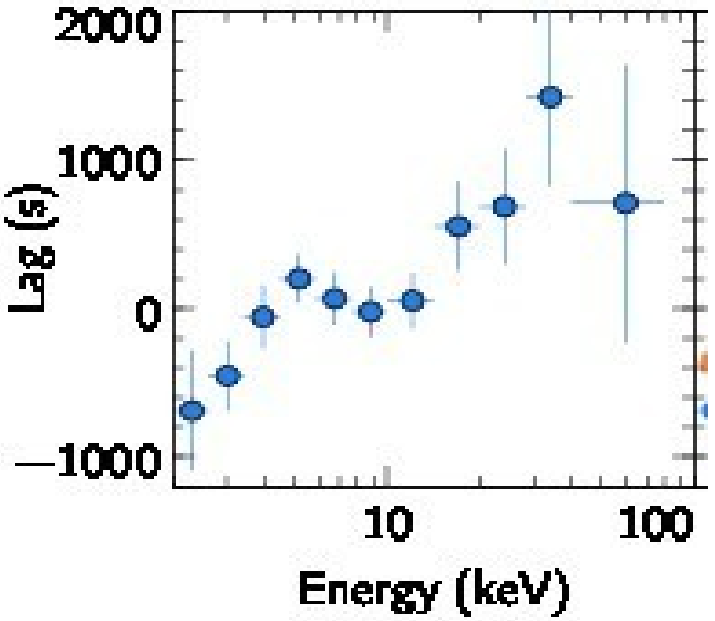
The hard X-ray time lag in MCG-5-23-16

Soft time lags observed in many AGN (e.g. Fabian et al. 2009, De Marco et al. 2013, Uttley et al. 2014) --> Reflection from inner disc

More recently, reverberation of iron lines have also been observed (e.g. Zoghbi et al. 2012, Kara et al. 2014)

Compton hump reverberation expected !!

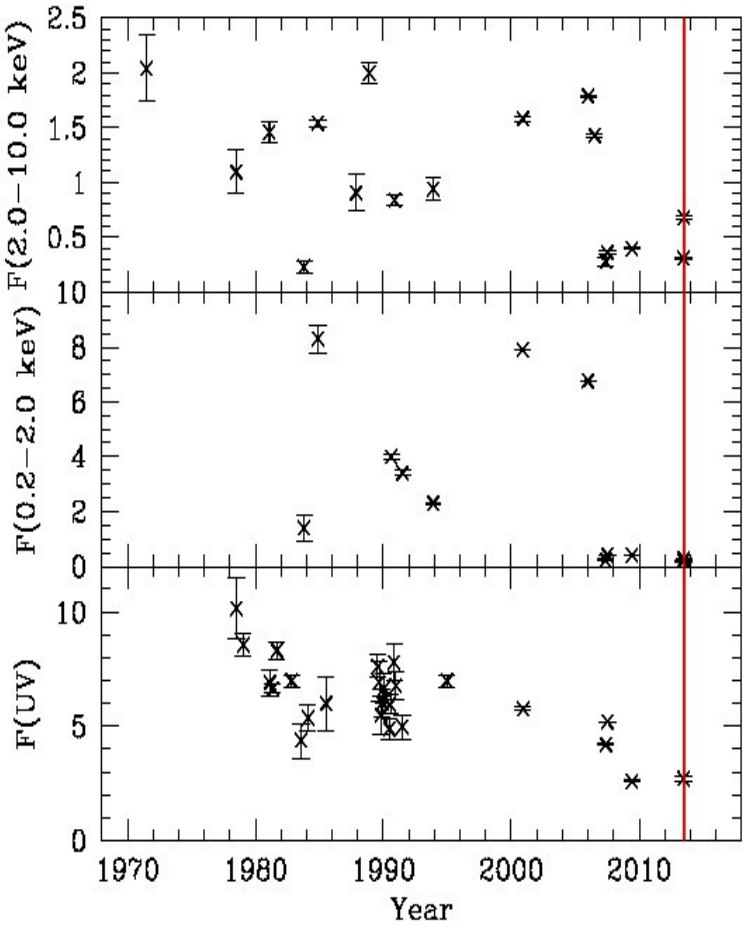


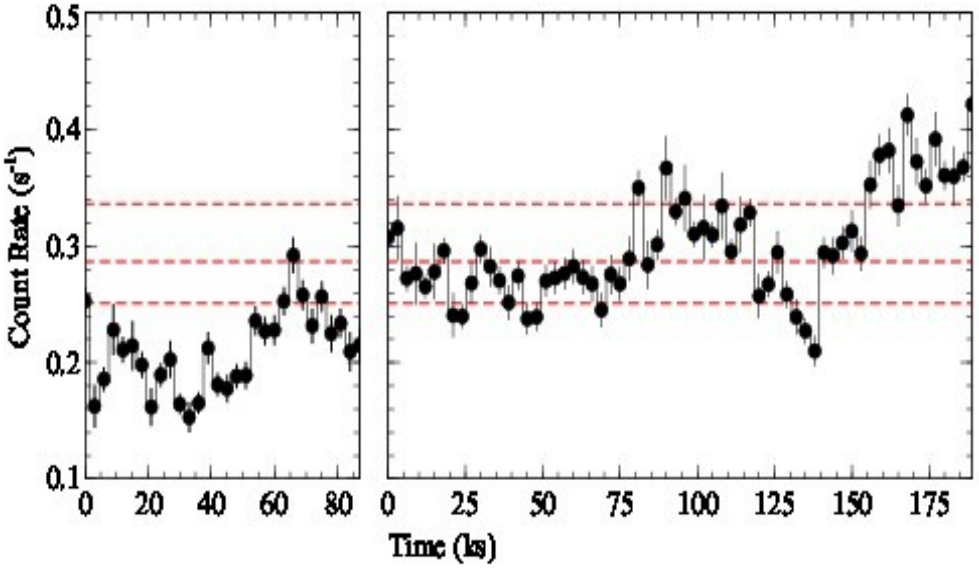


XMM (*Zoghbi et al. 2013*)

NuSTAR (*Zoghbi et al. 2014*)

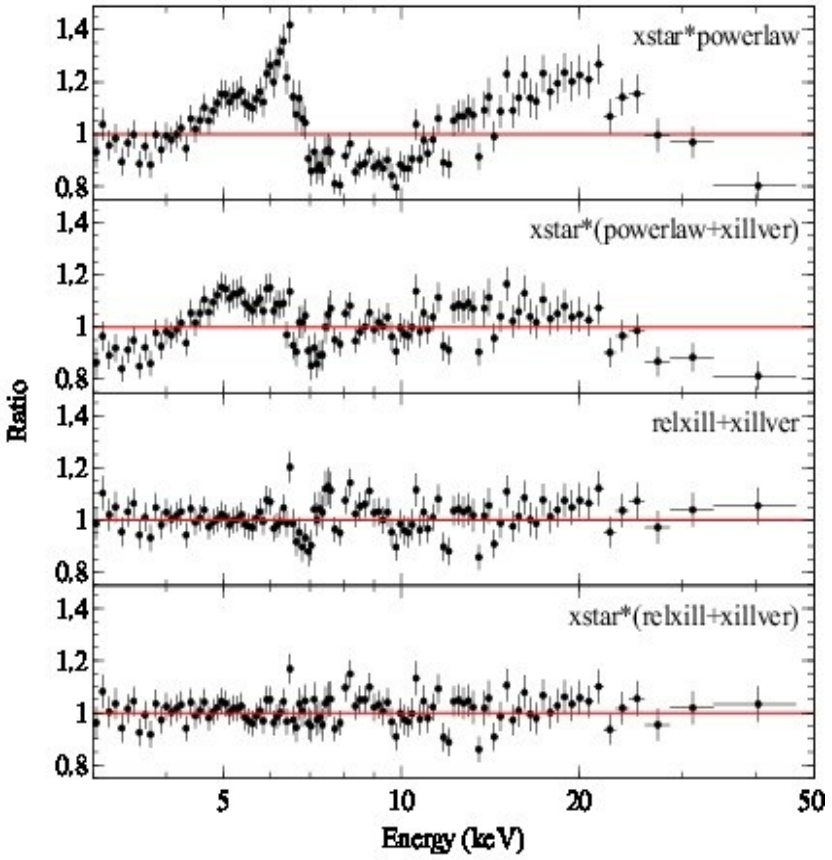
Mrk 335: Relativistic effects within 2 Rg from the event horizon?

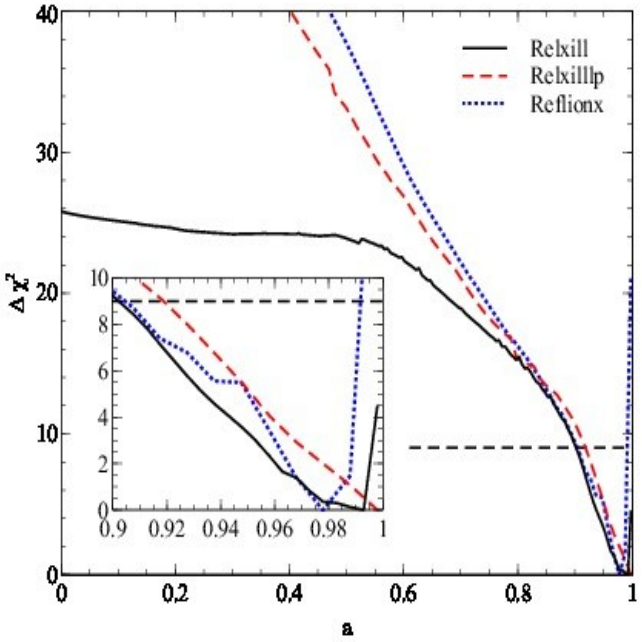




The source was found in a very low flux state (Parker et al. 2014).

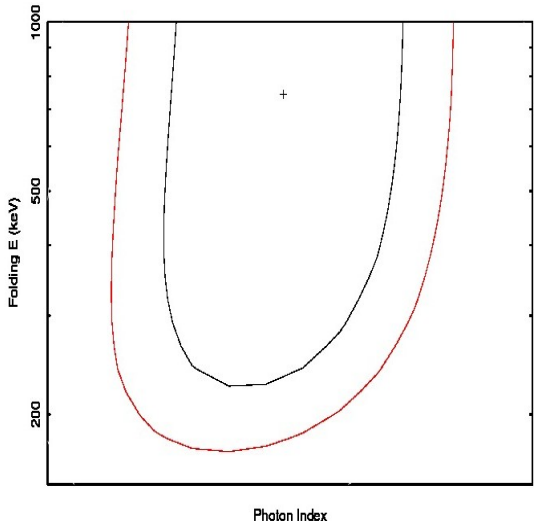
Mrk 335: Relativistic effects within 2 Rg from the event horizon?





The spectrum is well fitted by an almost pure relativistic reflection component. Applying a lamp-post geometry, a very small height is found, as well as a high BH spin (Parker et al. 2014)

The soft excess of Ark 120



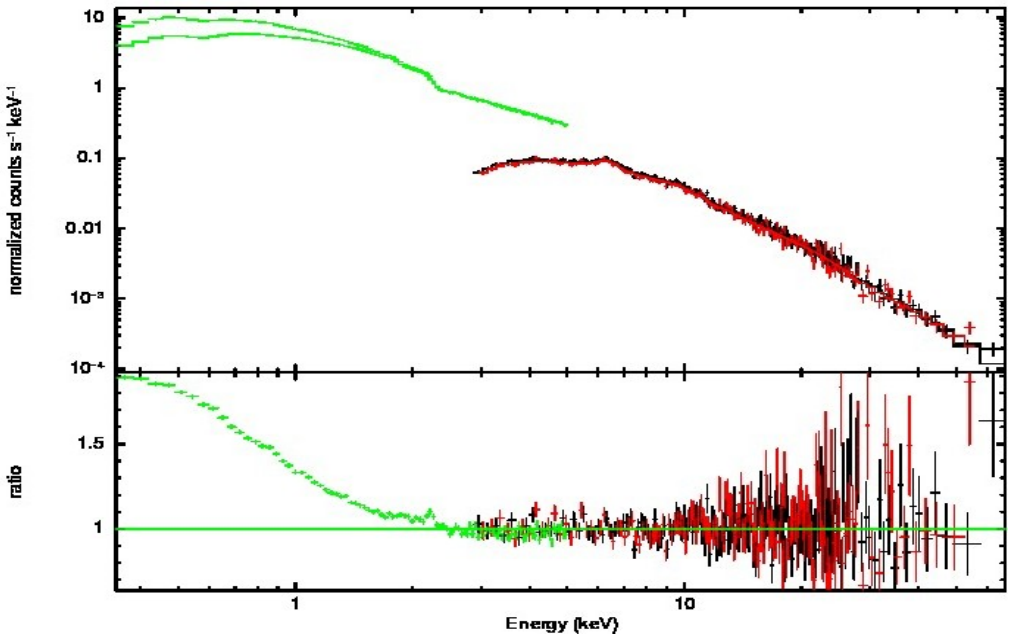
Bright, “bare” Seyfert 1 galaxy

Fit with NuSTAR data only (power law + reflection + iron line)

No High Energy Cutoff detected

Extrapolation to XMM shows strong excess

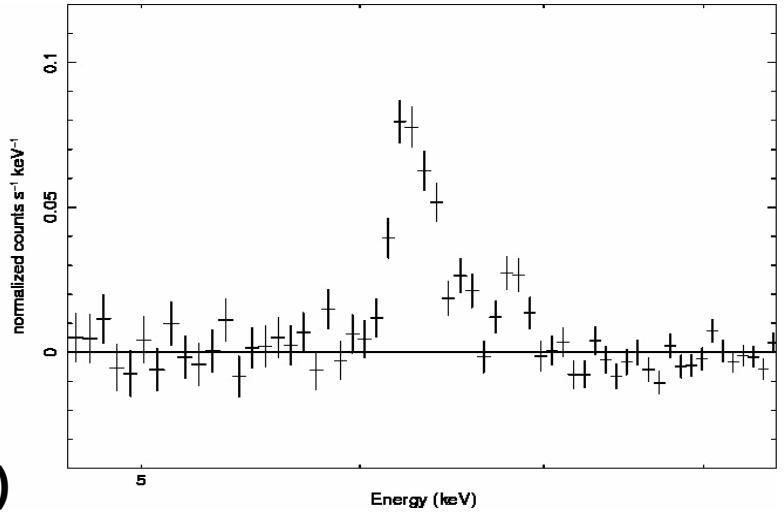
(Matt et al. 2014)

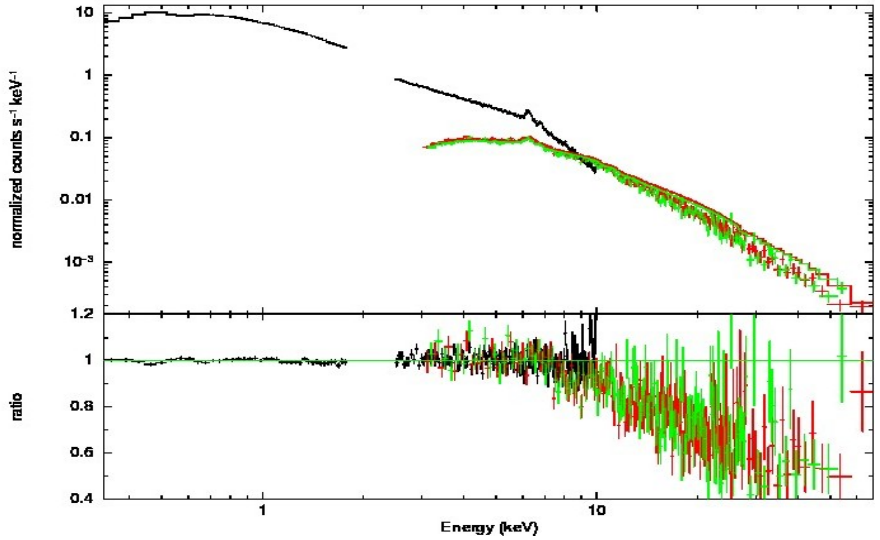


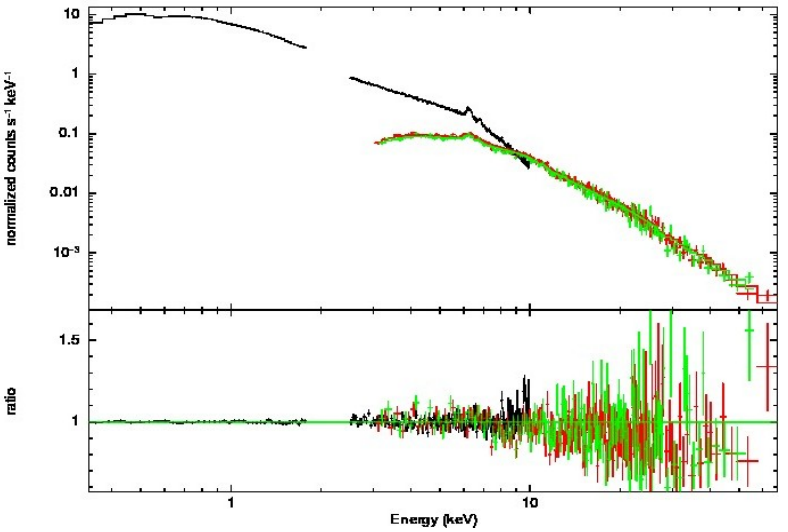
The soft excess of Ark 120

XMM: no obvious evidence for rel. Line (differently from a previous Suzaku obs, Nardini et al. 2011)

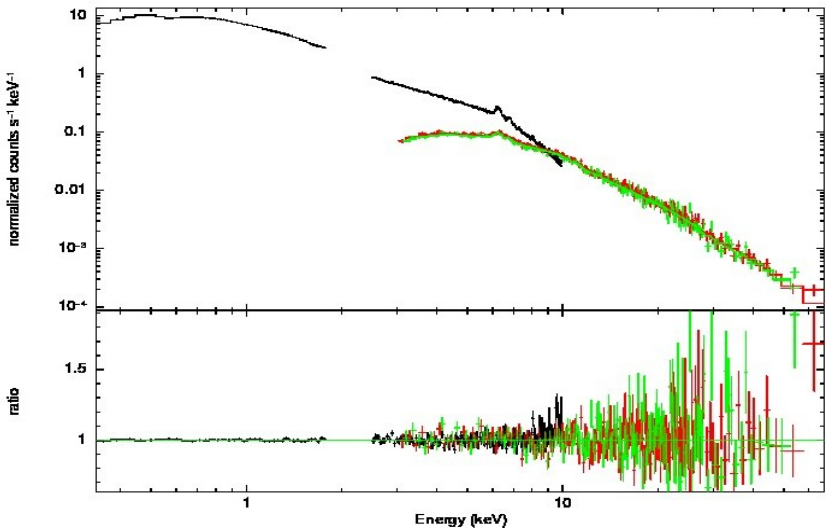
Soft excess with a simple power law or with a Comptonization model give comparable fits to the XMM spectrum, but very different extrapolation to NuSTAR (cold and ionized reflection included in the fit)



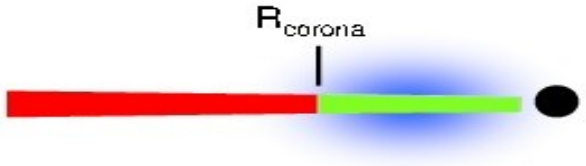


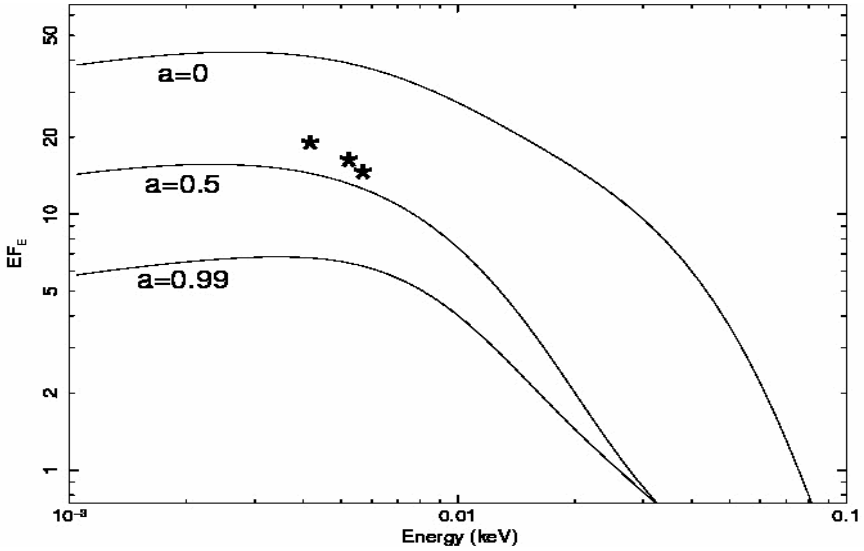


The soft excess of Ark 120



Indeed, the broad-band best fit is with a Comptonization model for the soft excess. A *cutoff p.l.*, *compTT, nthcomp* or *optxagnf* provide fits of comparable quality.





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.**

Extrapolating the best fit X-ray model to the OM UV data, an estimate of the black hole spin is possible

Summary and Outlook

NuSTAR is providing AGN spectra of unprecedented quality above 10 keV

A joint XMM-NuSTAR observing program also In AO14

A GO program will start in april 2015 (proposals due by November 25, 2014)