Modelling the Full X-ray Spectrum of MCG-6-30-15

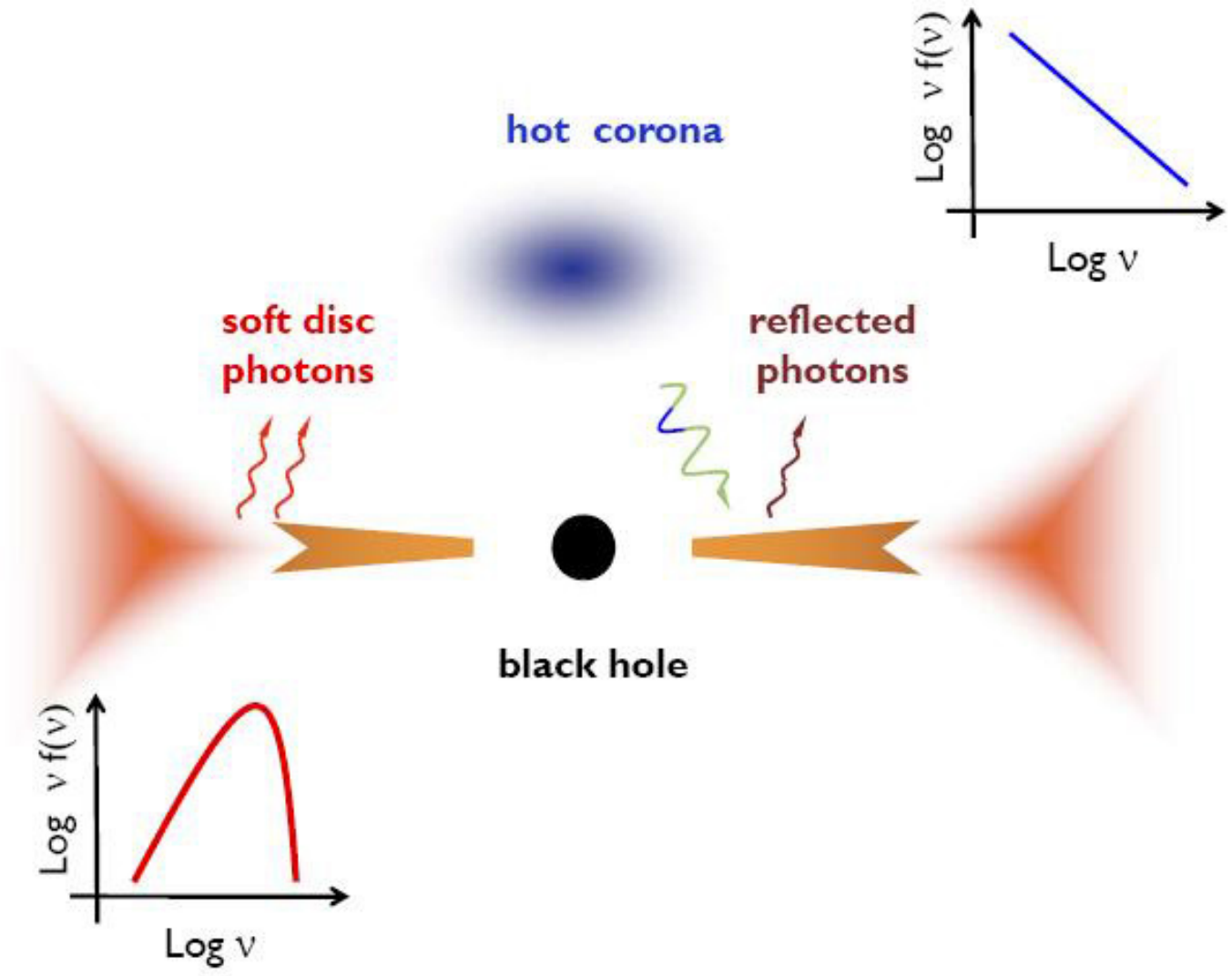
Chia-Ying Chiang, Dominic Walton, and Andy Fabian

Institute of Astronomy, University of Cambridge

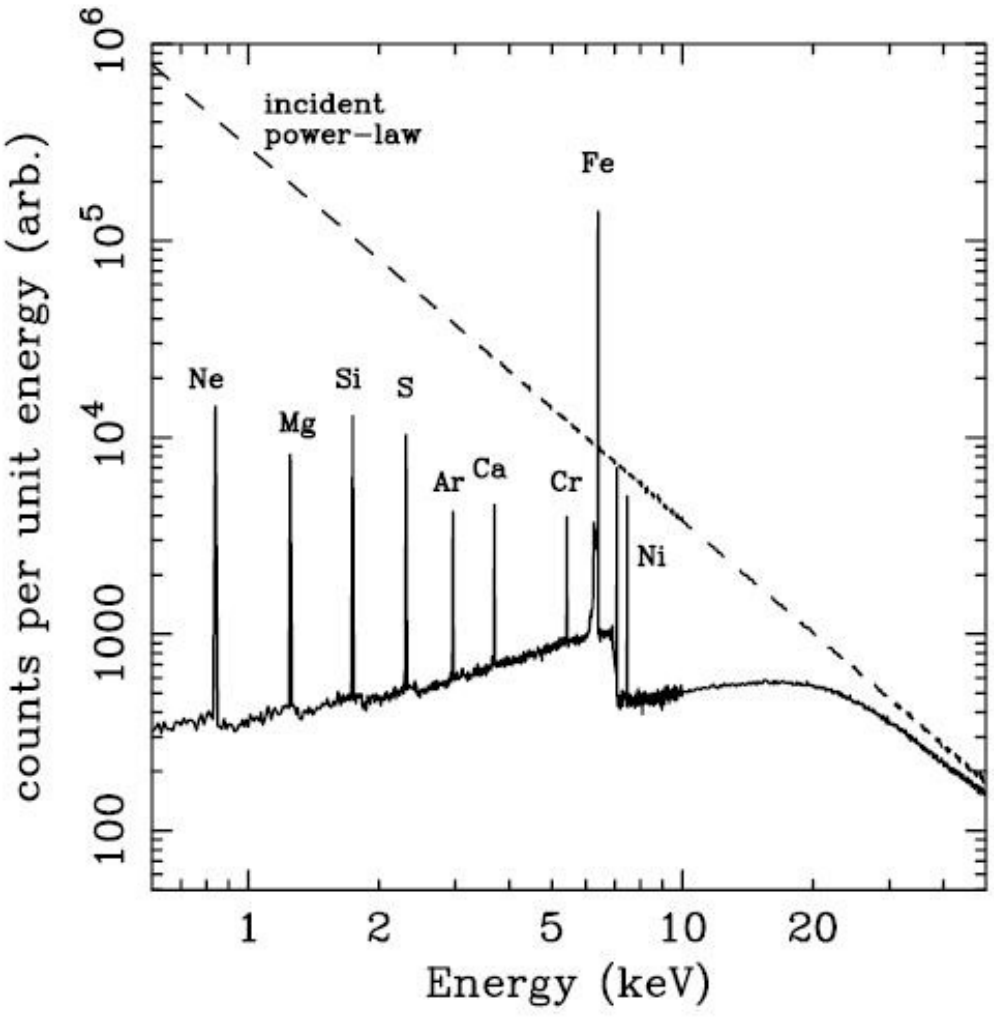
Winchester,18 July 2011

Outline

Geometry & Spectrum

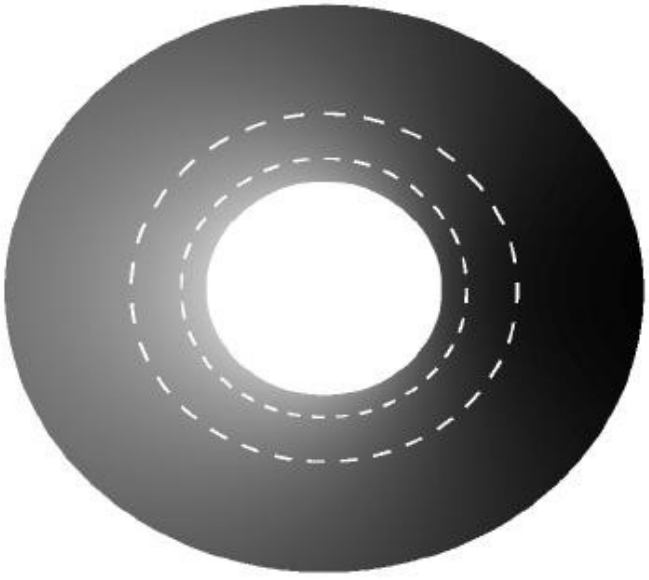


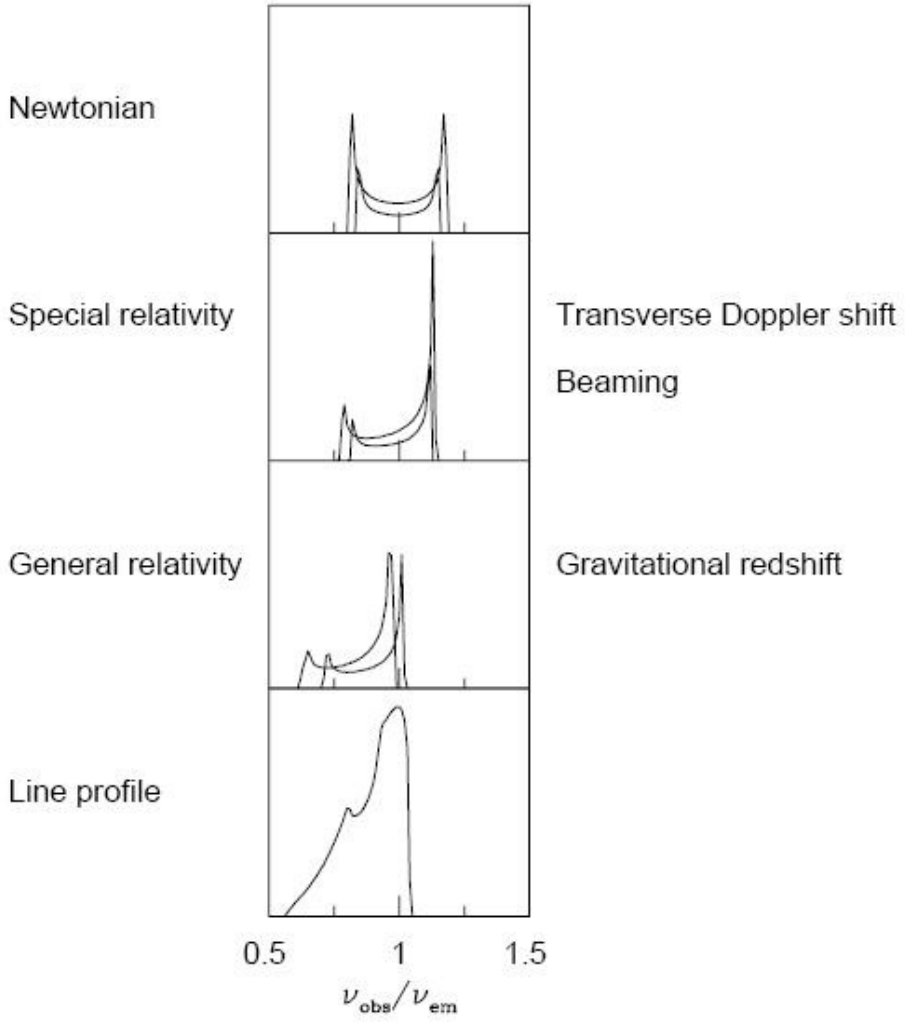
Reflected Spectrum



(Reynolds, PhD thesis, 1996)

Relativistic Effects

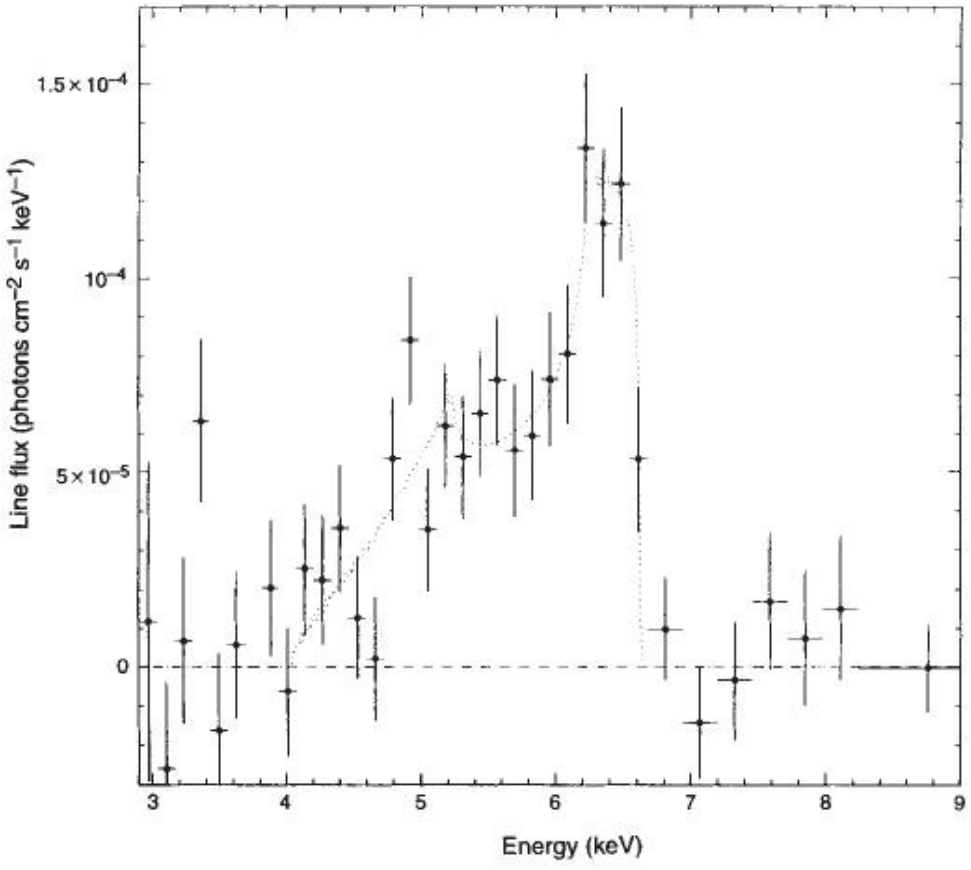




(Fabian et al. 2000)

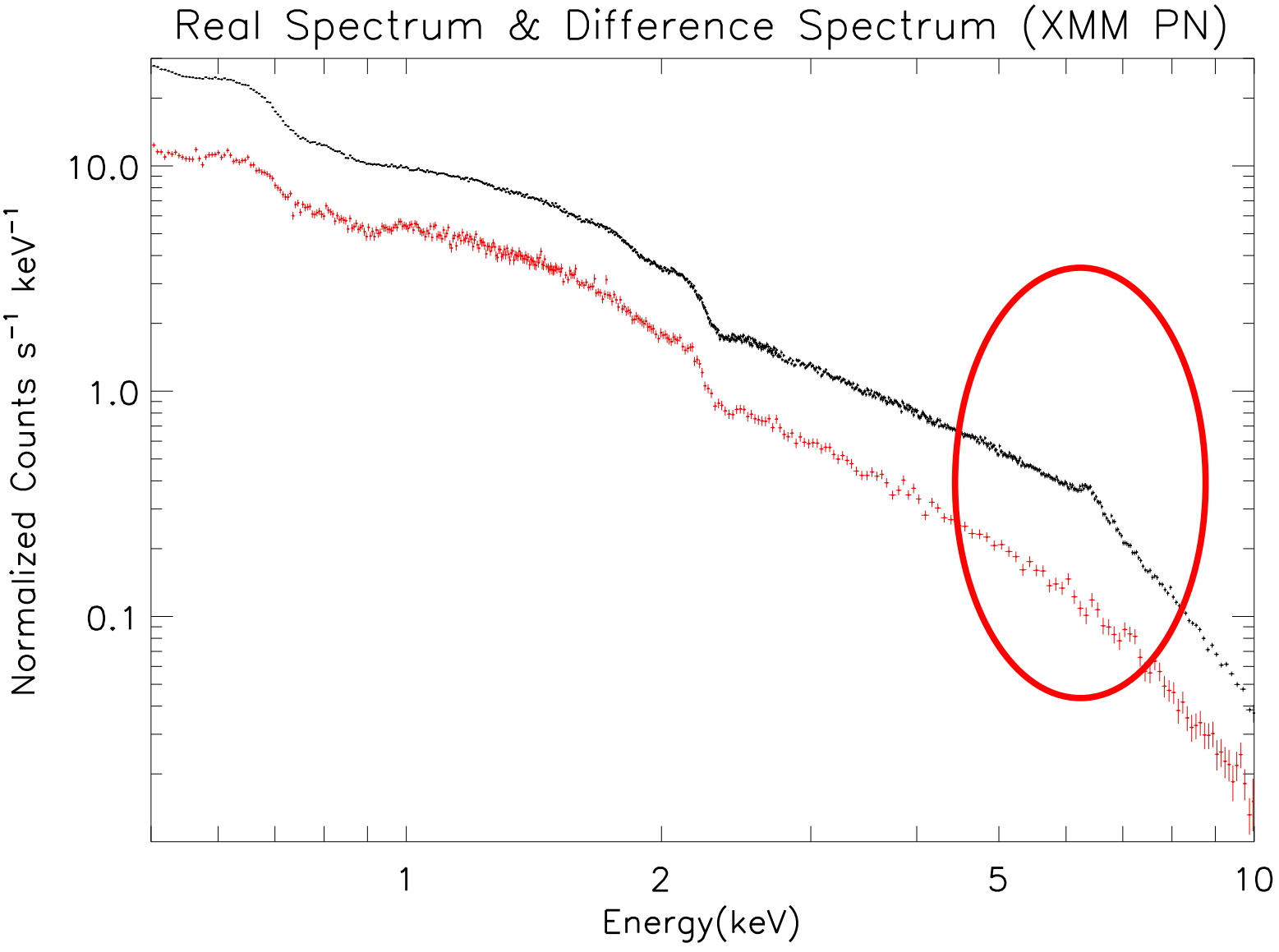
MCG-6-30-15

- Seyfert 1 Galaxy, AGN
- z = 0.00775
- Broad iron line first confirmed by *ASCA* observation
- Spin parameter a ∼ 0.989 (Reynolds et al. 2005)
- One of the most studied AGN

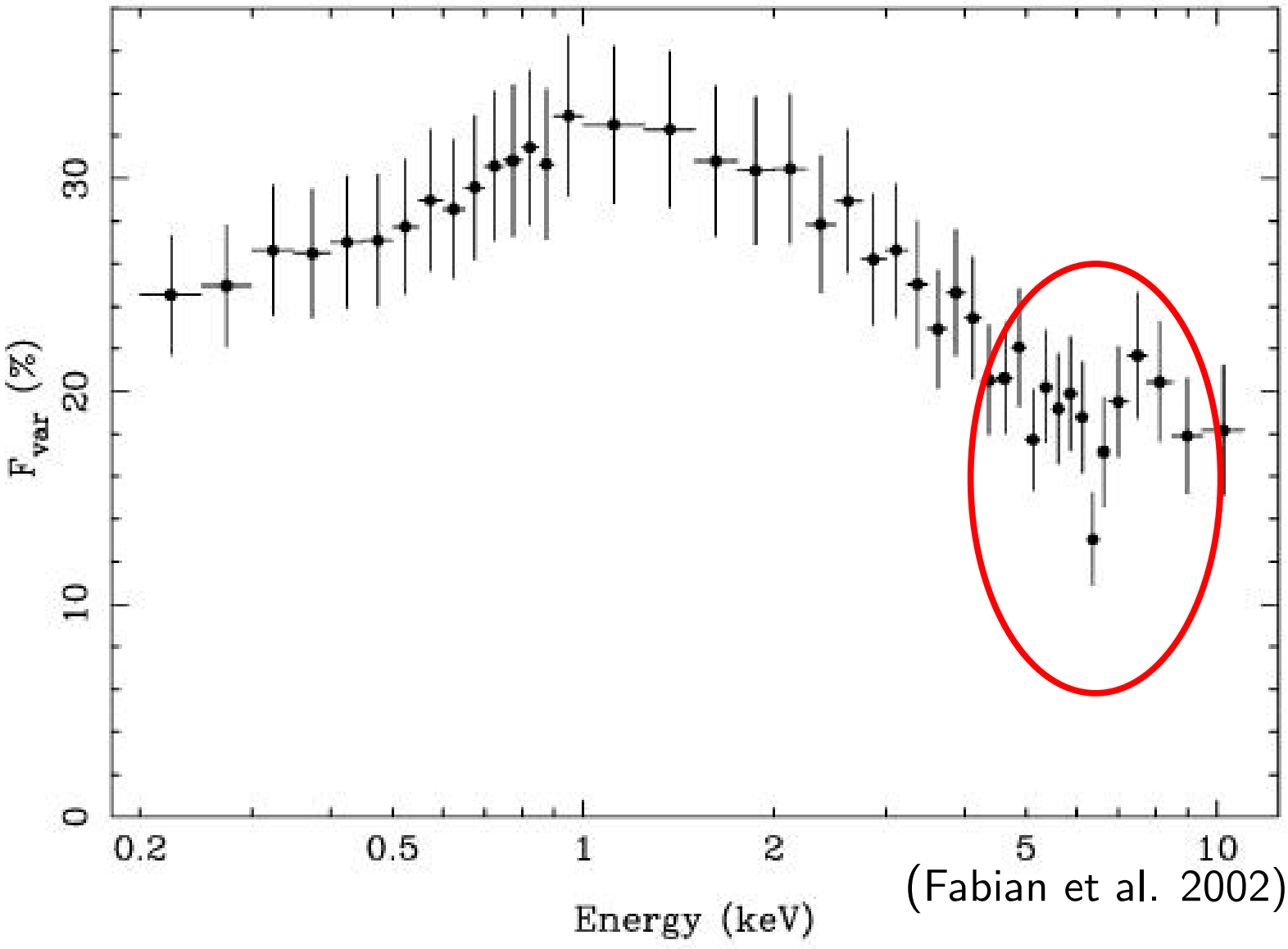


(Tanaka et al. 1995)

Disconnection of Variability

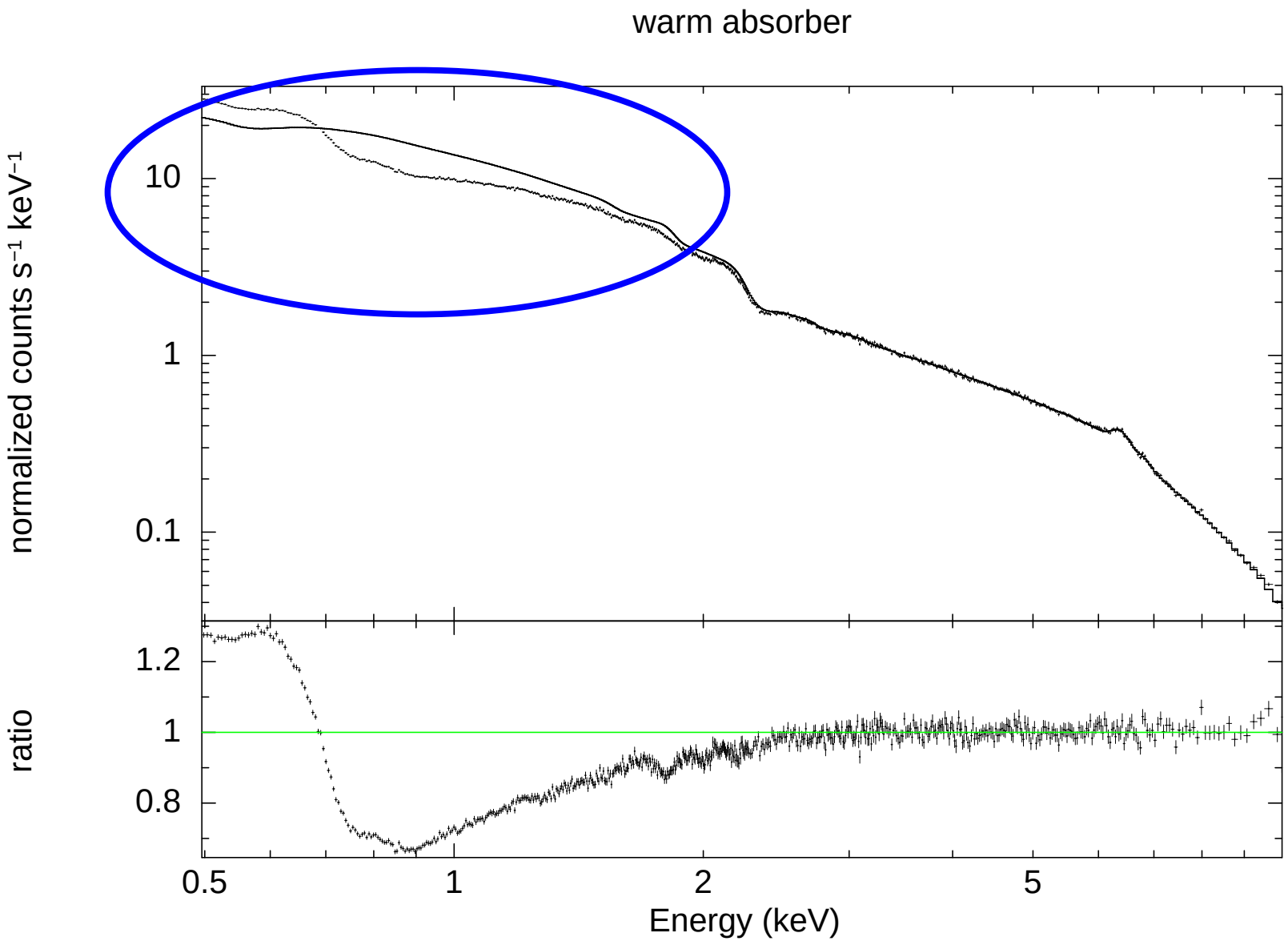


Disconnection of Variability



(Fabian et al. 2002)

Warm Absorbers



The Models

Reflection Model

- Extremely broad iron line
- Variability from the powerlaw component
- Gravitational light bending model to explain the invariability of the iron line
- using only full covering absorbers

Absorption Model

- Narrow iron line
- Variability from the warm absorbers due to changing covering factors
- Partial covering clumpy absorbers to mimic the broad iron line profile and explain the hard excess
- "3+2" model

Papers Over Last Few Years

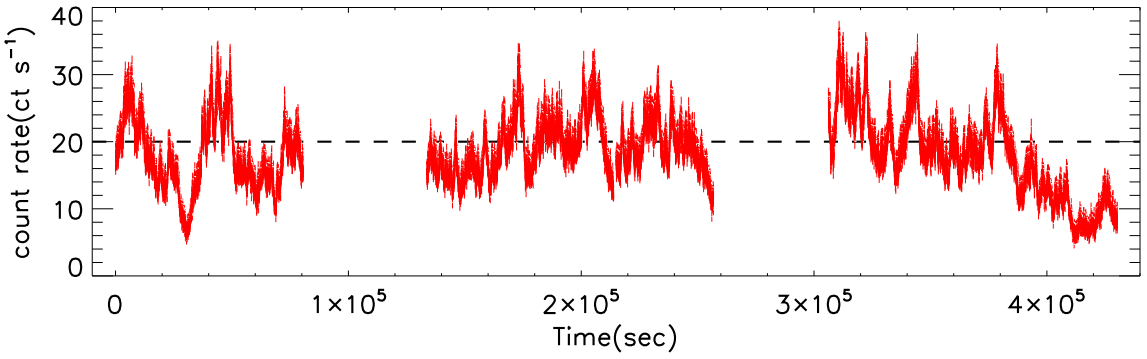
- *Suzaku Observations of the Hard X-Ray Variability of MCG -6-30-15: the Effects of Strong Gravity around a Kerr Black Hole* , Miniutti et al., PASJ, 2007
- *An absorption origin for the X-ray spectral variability of MCG-6-30-15*, Miller et al., A&A, 2008
- *The absorption-dominated model for the X-ray spectra of typeI active galaxies: MCG-6-30-15*, Miller et al., MNRAS, 2009
- *Spectral Variation of the Seyfert 1 Galaxy MCG -6-30-15 Observed with Suzaku*, Miyakawa et al., PASJ, 2009
- *Negative X-ray reverberation time delays from MCG-6-30-15 and Mrk 766*, Emmanoulopoulos et al., MNRAS, 2011
- *Modelling the broad-band spectra of MCG-6-30-15 with a relativistic reflection model*, Chiang et al., MNRAS, 2011

Datasets

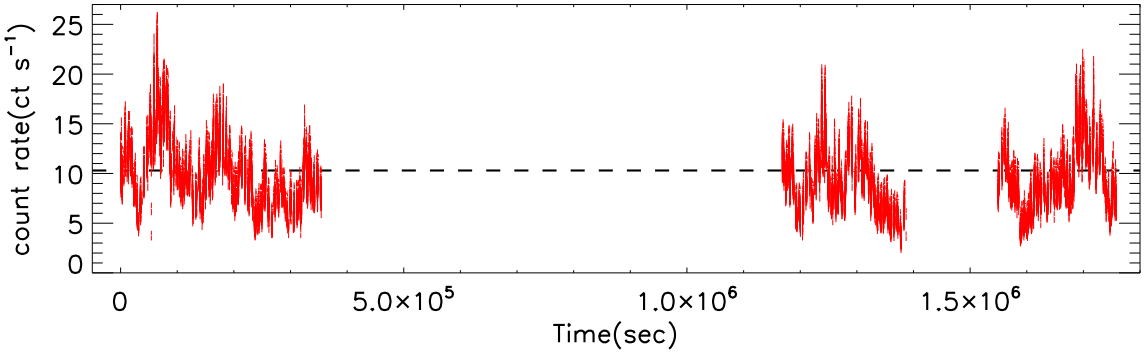
Table: The table lists the summary of all datasets used in this work. *XMM-Newton* Epic PN: 2.2-10 keV; *XMM-Newton* RGS: 0.4-1.7 keV; *BeppoSAX*: 13-200 keV; *Suzaku* XIS: 0.5-12 keV; *Suzaku* PIN: 14-45 keV; *Chandra* MEG: 0.5-5 keV; *Chandra* HEG: 0.8-7.5 keV

Observation	Date	ObsID	Exposure (ks)
XMM-Newton	31/07 - 01/08, 2001	0029740101	55.2
	02/08 - 03/08, 2001	0029740701	85.5
	04/08 - 05/08, 2001	0029740801	86.8
Beppo-SAX	31/07 - 05/08, 2001	51346001	49.6
Suzaku	09/01 - 14/01, 2006	700007010	143.3
	23/01 - 26/01, 2006	700007020	98.5
	27/01 - 30/01, 2006	700007030	96.7
Chandra	19/05 - 27/05, 2004	4759-4762	497.1

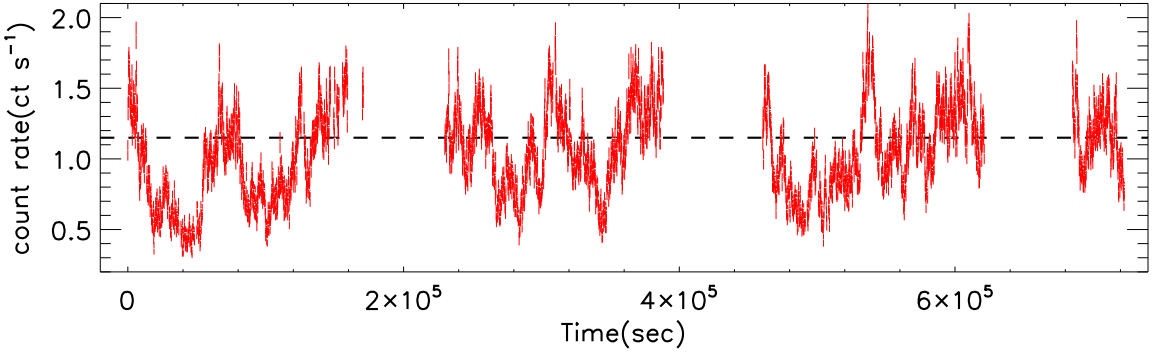
Light Curves



XMM-Newton

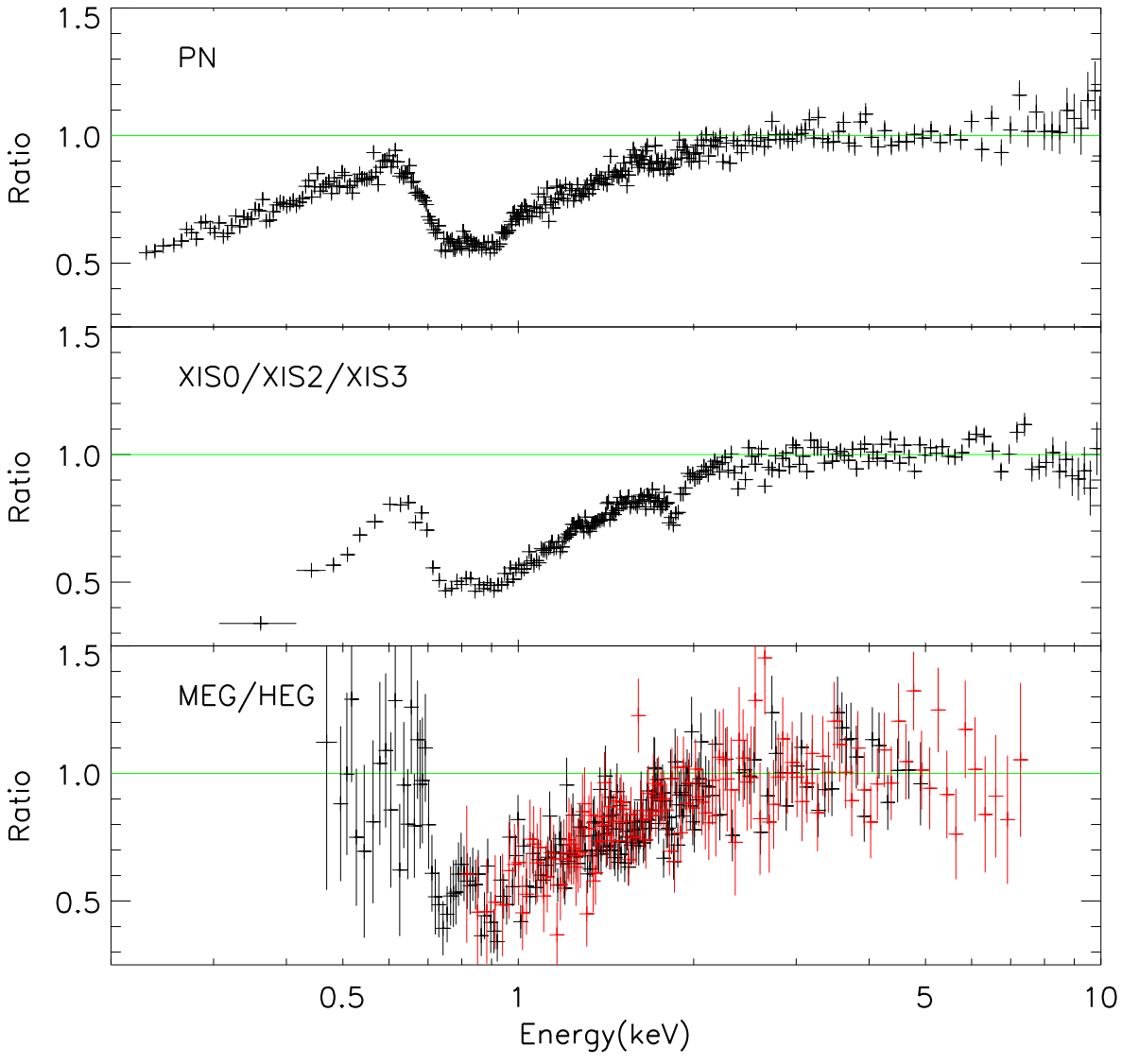


Suzaku



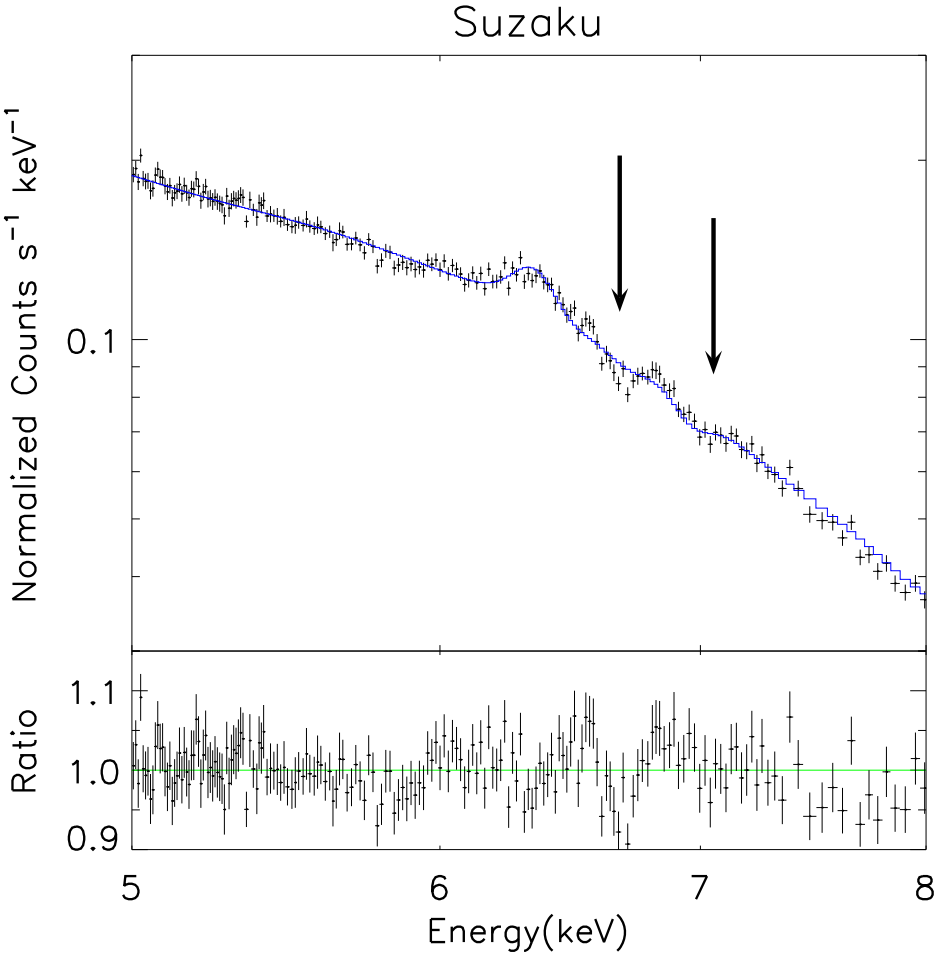
Chandra

Difference Spectra



Fast Component

- Highly ionized ($\log\xi > 3.5$) fast component (Sako et al. 2003; Turner et al. 2004; Young et al. 2005; McKernan et al. 2007; Holczer et al. 2010)
- **Fe XXV** & **Fe XXVI** absorption lines
- $v \sim 2000$ km s^{-1}



Slow Component & Others

- Slow component with two different ionization states (Lee et al. 2001; Sako et al. 2003; Turner et al. 2004; McKernan et al. 2007; Holczer et al. 2010)
- Absorption features < 2 keV
- $v \sim 100$ km s^{-1}

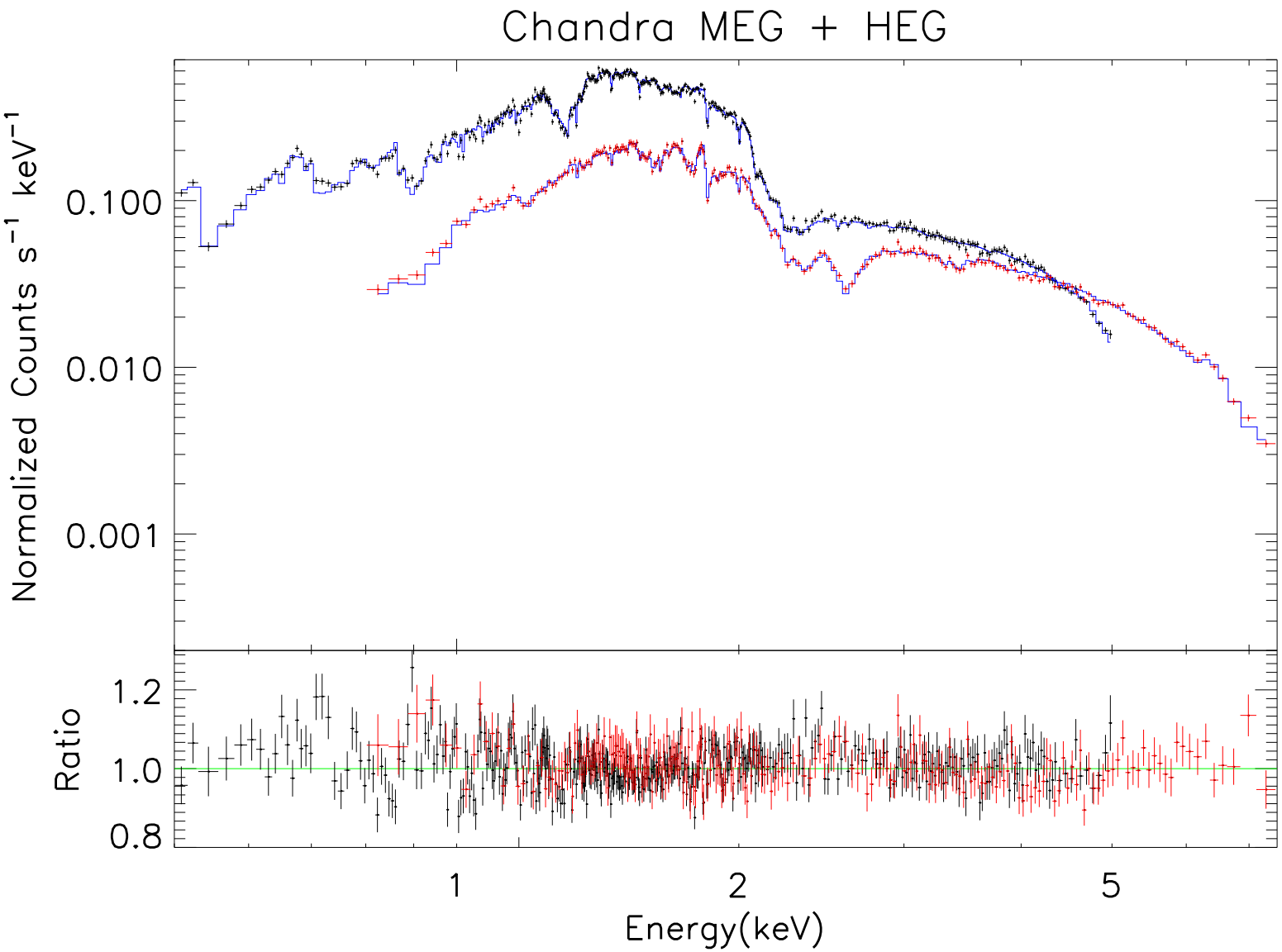
- Local component at $z = 0$ (Holczer et al. 2010)

XSTAR Grids

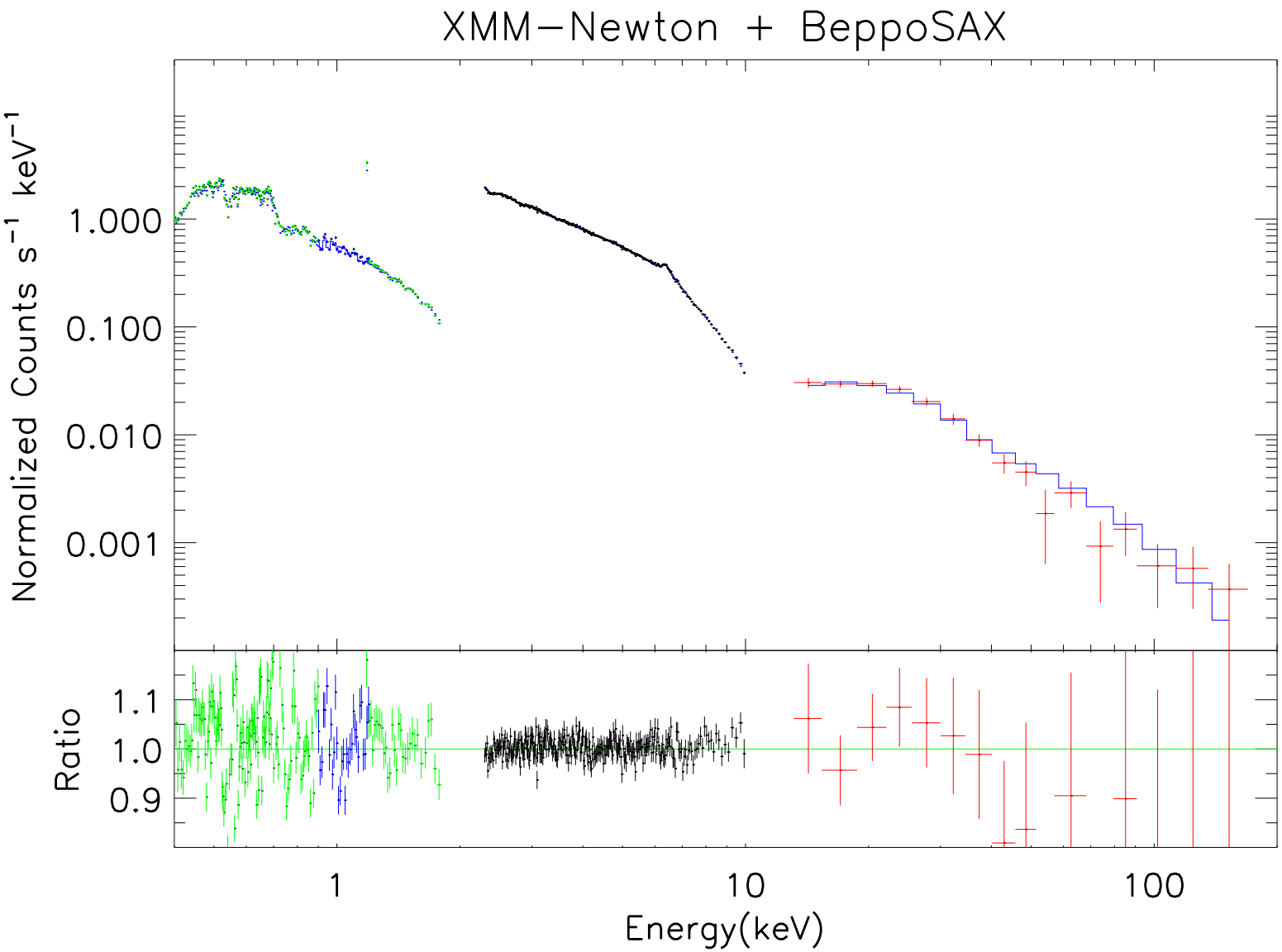
- $L = 2 \times 10^{43}$ erg s^{-1} (Young et al. 2005)
- Powerlaw spectrum shape
- Gas density $= 10^{12}$ cm^{-3}
- $C_v = 1.0$
- $v_{\rm turb} = 100$, 500, 1000 km s^{-1}
- $T = 10^4$, 3×10^4, 10^5 K
- Variable iron and oxygen abundances
- Use dust in Tbnew to model the Fe-L edge

Model: Tbnew*Tbnew*(4 xstar grids)*(powerlaw + kdblur*reflionx + reflionx + Gaussian), using Wilms, Allen & McCray (2000) abundance

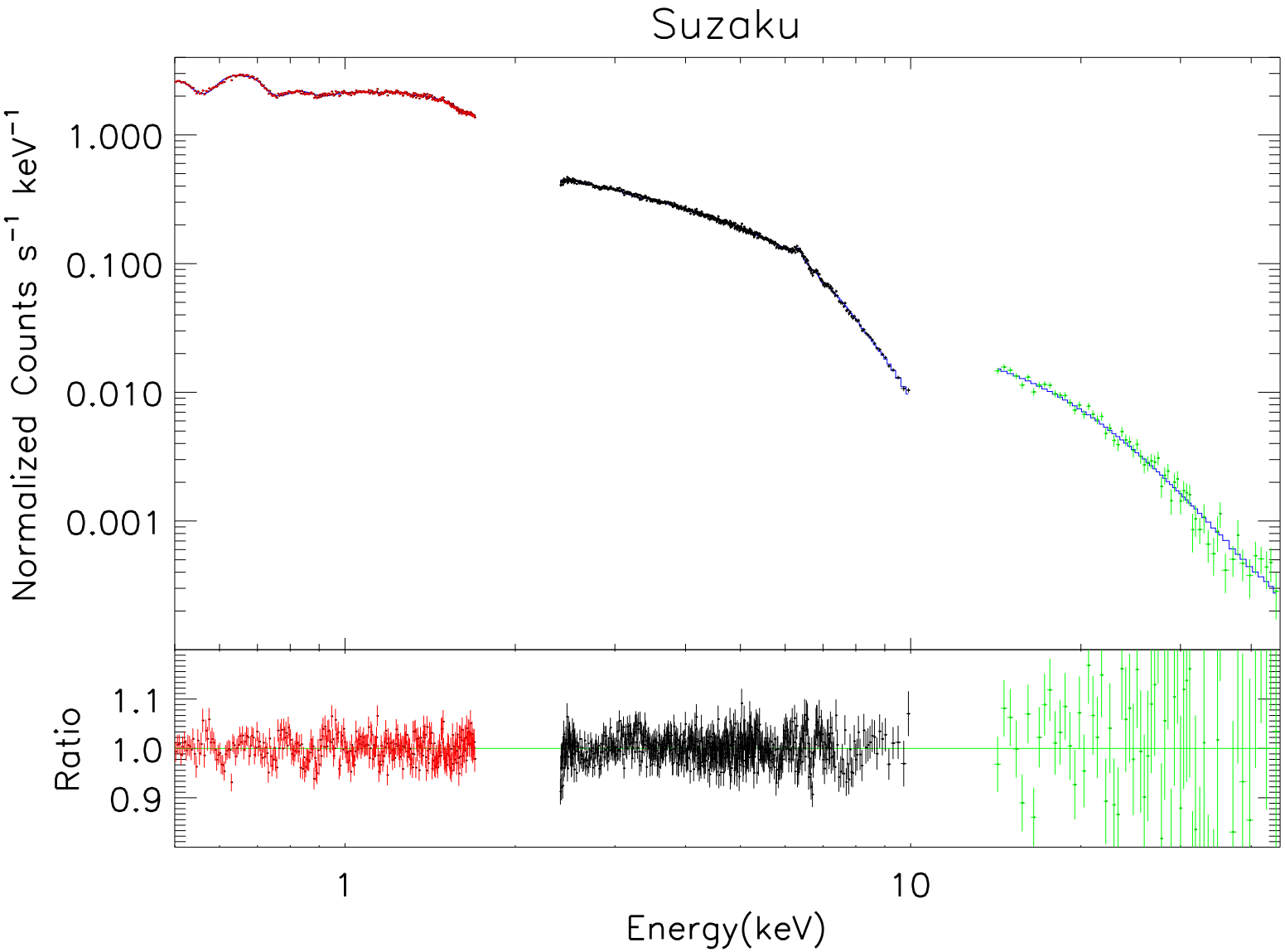
Chandra


Chandra MEG + HEG
Normalized Counts s^{-1} keV^{-1}
0.100
0.010
0.001
Ratio
1.2
1.0
0.8
1
2
5
Energy(keV)

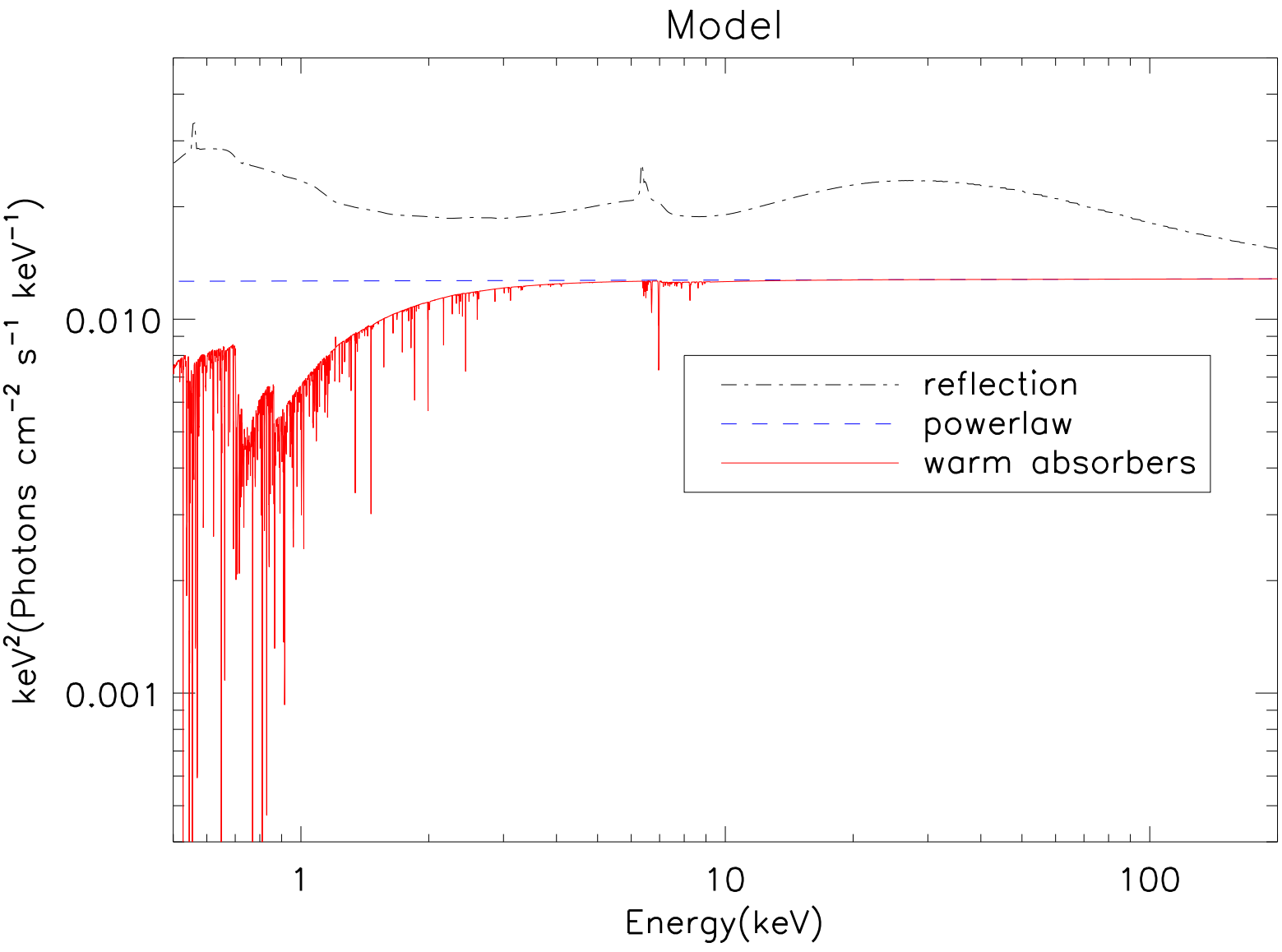
XMM-Newton


XMM−Newton + BeppoSAX
Normalized Counts s^{-1} keV^{-1}
1.000
0.100
0.010
0.001
Ratio
1.1
1.0
0.9
1
10
100
Energy(keV)

Suzaku


Suzaku
Normalized Counts s^{-1} keV^{-1}
1.000
0.100
0.010
0.001
Ratio
1.1
1.0
0.9
1
10
Energy(keV)

Model


Model
0.010
0.001
keV²(Photons cm⁻² s⁻¹ keV⁻¹)
1
10
100
Energy(keV)
reflection
powerlaw
warm absorbers

Fitting Parameters

Table: N_H is given in 10^{21} cm^{-2}, temperature in Kelvin, and ξ in erg cm s^{-1}.

Absorber	fast	slow (1)	slow (2)	local
T (K)	3×10^4	10^4	3×10^4	10^4
		Chandra		
N_H	$209.4^{+36.9}_{-33.8}$	$3.43^{+0.31}_{-0.42}$	$0.27^{+0.20}_{-0.13}$	(0.406)
$\log \xi$	(3.82)	1.71 ± 0.03	$2.47^{+0.03}_{-0.16}$	$-1.62^{+0.05}_{-0.02}$
		XMM + BeppoSAX		
N_H	$27.4^{+9.5}_{-14.0}$	$2.72^{+0.63}_{-0.28}$	$0.99^{+0.46}_{-5.30}$	(0.406)
$\log \xi$	(3.82)	$1.68^{+0.05}_{-0.03}$	$2.49^{+0.01}_{-0.10}$	-0.57 ± 0.03
		Suzaku		
N_H	$38.9^{+10.4}_{-8.1}$	$8.99^{+0.87}_{-0.91}$	$0.14^{+0.12}_{-0.14}$	(0.406)
$\log \xi$	(3.82)	$1.61^{+0.03}_{-0.04}$	$1.73^{+0.11}_{-0.13}$	$2.00^{+0.00}_{-0.13}$

Fitting Parameters

parameter	*Chandra* HETGS	*XMM* + *BeppoSAX*	*Suzaku*
Γ	1.97 ± 0.00	$2.00^{+0.00}_{-0.01}$	1.98 ± 0.01
index	$8.00^{+0.00}_{-0.16}$	$3.78^{+0.05}_{-0.08}$	3.09
$R_{\rm in}(R_{\rm g})$	$1.31^{+0.08}_{-0.00}$	$1.57^{+0.13}_{-1.57}$	2.50
$A_{\rm Fe}$	$1.79^{+0.10}_{-0.29}$	$1.73^{+0.19}_{-0.12}$	$4.00^{+0.00}_{-0.10}$
$E_{\rm Fe}$	$6.53^{+0.06}_{-0.09}$	6.52 ± 0.03	$6.38^{+0.01}_{-0.02}$
ϕ	$35.0^{+0.6}_{-35.0}{}^{\circ}$	$37.7^{+3.4}_{-2.2}{}^{\circ}$	44.0°
$\chi^2/d.o.f.$	2417.7/2139	5059.3/3809	1684.7/1576

Comparison

work		Holczer et al.	Miller et al.	present work
		full covering zones		
fast	N_H	81 ± 7	(80.0)	$209.4^{+36.9}_{-33.8}$
	log ξ	3.82 ± 0.03	(3.95)	(3.82)
slow(1)	N_H	2.3 ± 0.3	0.27 ± 0.03	$3.43^{+0.31}_{-0.42}$
	log ξ	-1.5-0.5	0.88 ± 0.16	1.71 ± 0.03
slow(2)	N_H	3.0 ± 0.4	11.8 ± 0.5	$0.27^{+0.20}_{-0.13}$
	log ξ	1.5-3.5	2.39 ± 0.01	$2.47^{+0.03}_{-0.16}$
local	N_H	0.40	-	(0.406)
	log ξ	-	-	$-1.62^{+0.05}_{-0.02}$
		partial covering zones		
zone 1	N_H	-	1910 ± 300	-
	log ξ	-	-	-
zone 2	N_H	-	29 ± 1	-
	log ξ	-	1.38 ± 0.03	-

Summary

- The relativistic reflection model has no trouble modelling both the hard excess and the soft excess.
- Most energies are generated within a few gravitational radii; signatures from inner radius are expected.
- The reflection model can robustly interpret the spectra of MCG-6-30-15 in the range 0.4-200 keV without any partial-covering absorbers.

THANK YOU VERY MUCH FOR YOUR ATTENTION!!