SOFT AND HARD X-RAY EXCESS EMISSION IN ABELL 3112 OBSERVED WITH CHANDRA

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DATA AND DATA ANALYSIS METHODS

CHANDRA:

- Obs. 2516 (17.7 ks), 2216 (7 ks)
- *CIAO* 3.4 and *CALDB* 3.3 (same results also obtained with *CIAO* 3.3 and *CALDB* 3.2)
- Analyze only the 1-2.5' annulus
- Use blank-sky background
- Fit in 0.5-7 keV band

XMM-NEWTON:

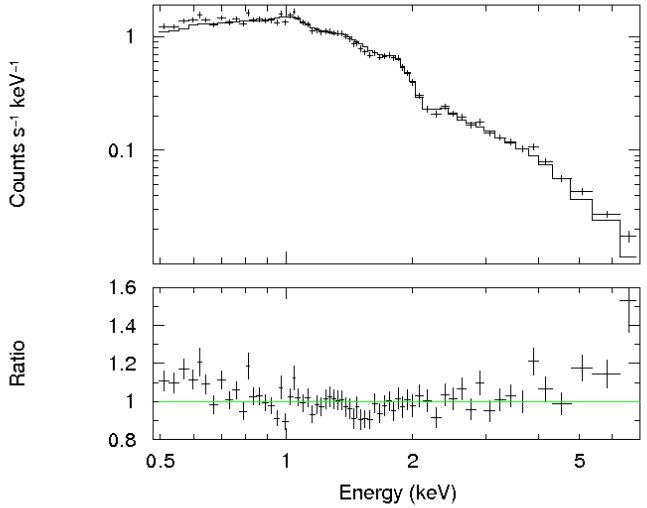
- Re-analyzed the Nevalainen et al. (2003) observation, 23 ks *MOS* data, 17 ks *PN* data
- *SAS* 7.0.0, calibration as of May 2007
- Use blank-sky from Nevalainen et al. (2005)
- Fit in 0.3-8 keV band

SPECTRAL FITS:

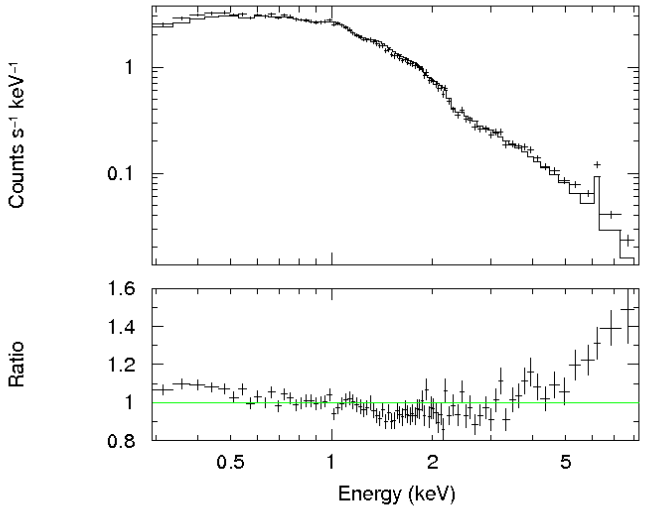
- Fit to a *wabs*mekal* model with Galactic N_H (fixed)
- Fit to *Chandra* data alone, and jointly to *Chandra+XMM-NEWTON*
- Fits to wide band (0.5-7/0.3-0.8 keV), soft band (0.5-4/0.3-4 keV) and hard band(2-7/2-8 keV)
- Addition of a power-law model and of a thermal model to explain residuals

FITS TO WIDE BAND

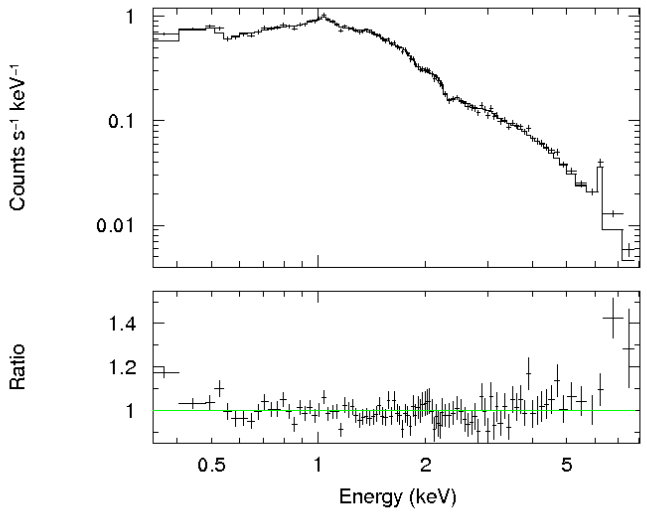
CHANDRA ACIS-S



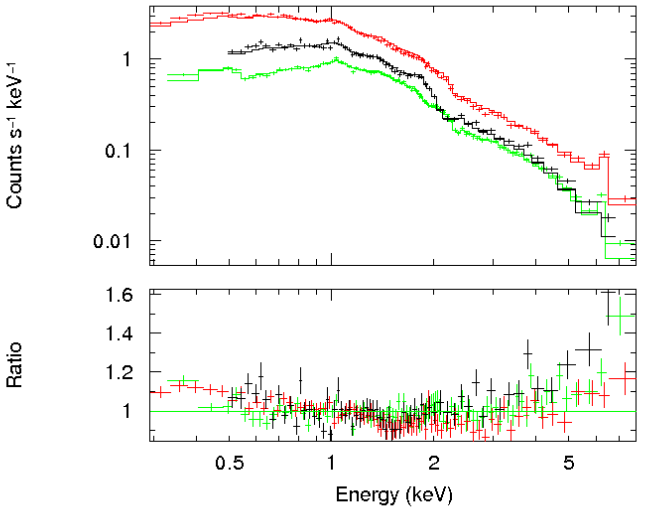
XMM PN



XMM MOS



ALL



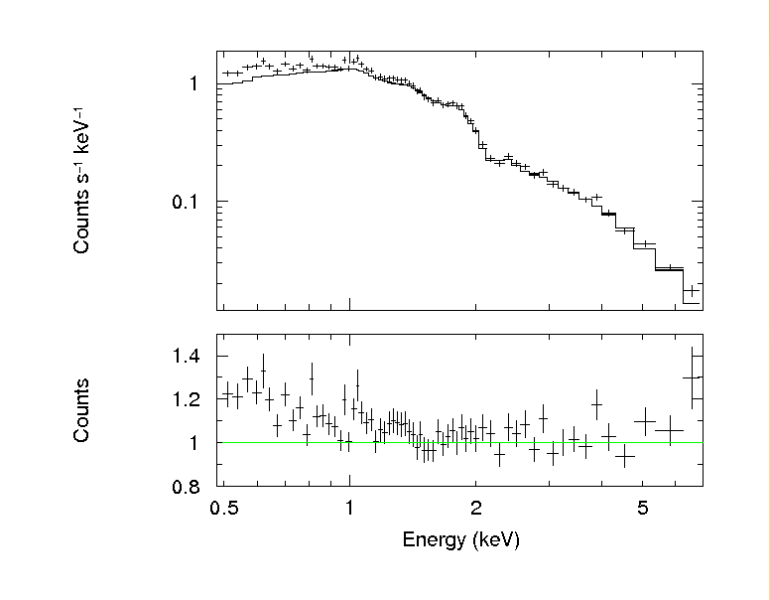
Bonamente, Nevalainen and Lieu (2007)

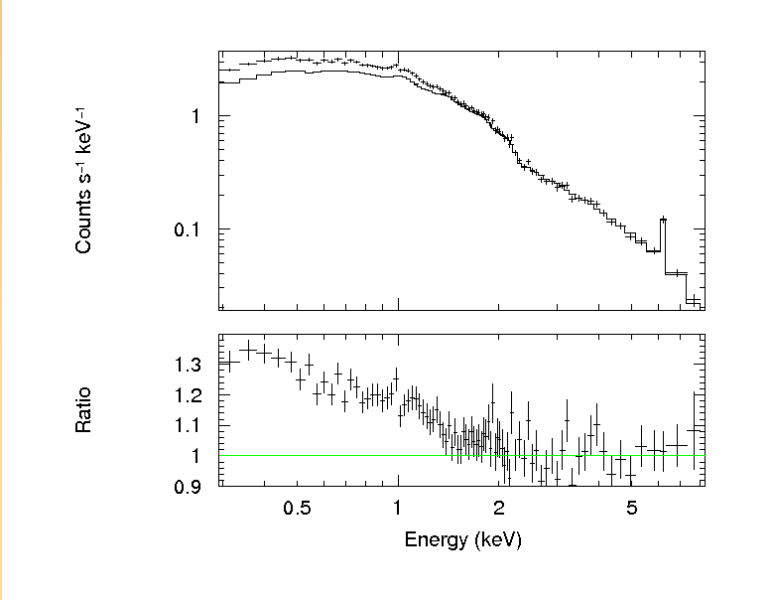
RESULTS OF SPECTRAL FIT

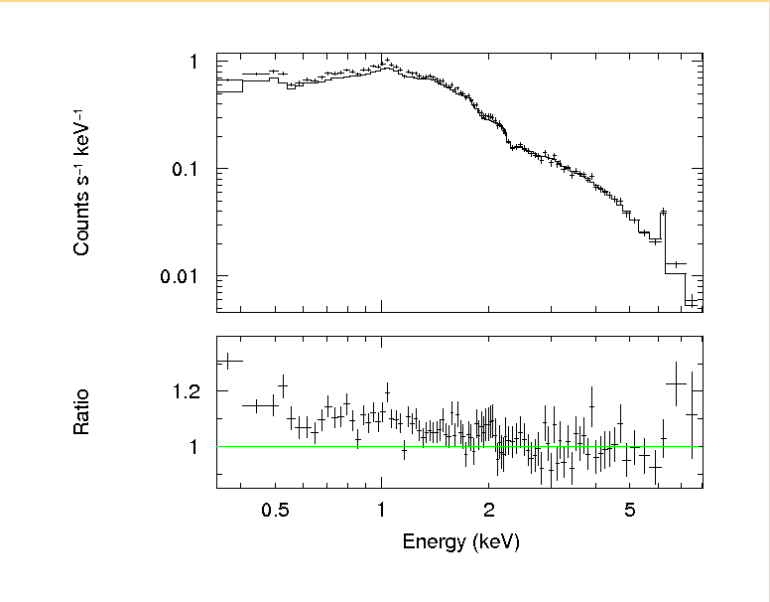
Table 1. SINGLE TEMPERATURE MODEL WITH FIXED AND VARIABLE N_H

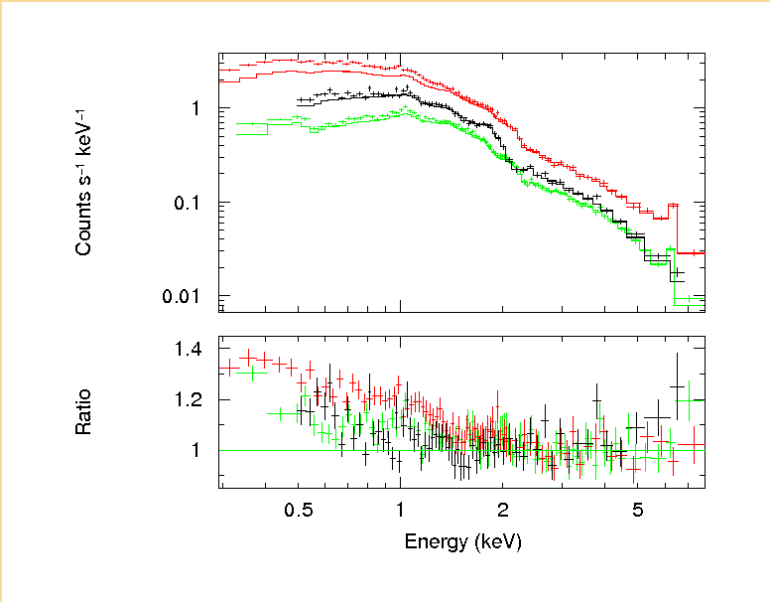
	Fixed Galactic $N_H = 2.6 \times 10^{20}$ (cm^{-2})				Free N_H				
Data	χ^2/dof (χ^2_r)	kT (keV)	A	Norm ($\times 10^{-2}$)	χ^2/dof (χ^2_r)	kT (keV)	A	Norm ($\times 10^{-2}$)	N_H (10^{20} cm^{-2})
ACIS	345.7/269(1.29)	4.94 ± 0.14	$0.40 \pm^{0.05}_{0.05}$	1.01 ± 0.01	294.9/268(1.10)	$5.70 \pm^{0.15}_{0.14}$	$0.50 \pm^{0.06}_{0.06}$	0.94 ± 0.01	≤ 0.35
PN	274.3/161(1.70)	$3.97 \pm^{0.10}_{0.05}$	$0.23 \pm^{0.02}_{0.02}$	0.97 ± 0.01	155.3/160(0.97)	$4.47 \pm^{0.06}_{0.07}$	$0.32 \pm^{0.02}_{0.02}$	0.91 ± 0.01	$1.10 \pm^{0.2}_{0.1}$
MOS	236.6/173(1.37)	$4.52 \pm^{0.05}_{0.07}$	$0.34 \pm^{0.03}_{0.03}$	1.05 ± 0.01	189.6/172(1.10)	$4.94 \pm^{0.07}_{0.14}$	$0.39 \pm^{0.04}_{0.02}$	1.00 ± 0.01	$1.34 \pm^{0.23}_{0.23}$
Joint[a]	918.3/606(1.52)	$4.37 \pm^{0.02}_{0.07}$	$0.29 \pm^{0.02}_{0.01}$	1.04 ± 0.01	685.7/605(1.13)	$4.83 \pm^{0.05}_{0.06}$	$0.38 \pm^{0.02}_{0.03}$	0.97 ± 0.01	$0.98 \pm^{0.13}_{0.13}$
				0.95 ± 0.01				0.99 ± 0.01	
				1.05 ± 0.01				0.87 ± 0.01	

FITS TO HARD BAND

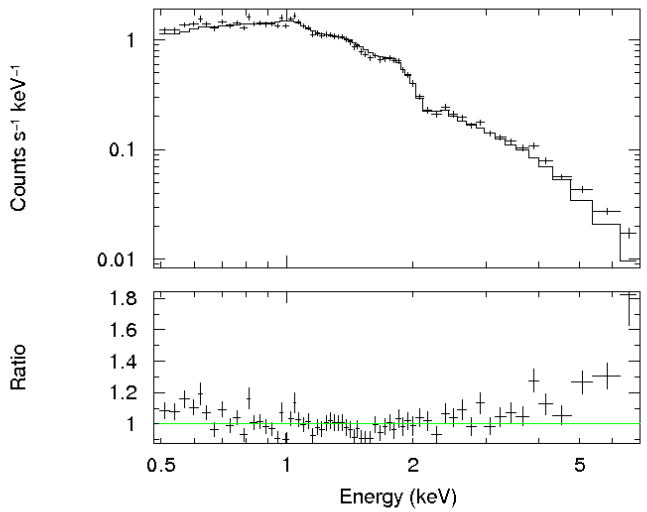


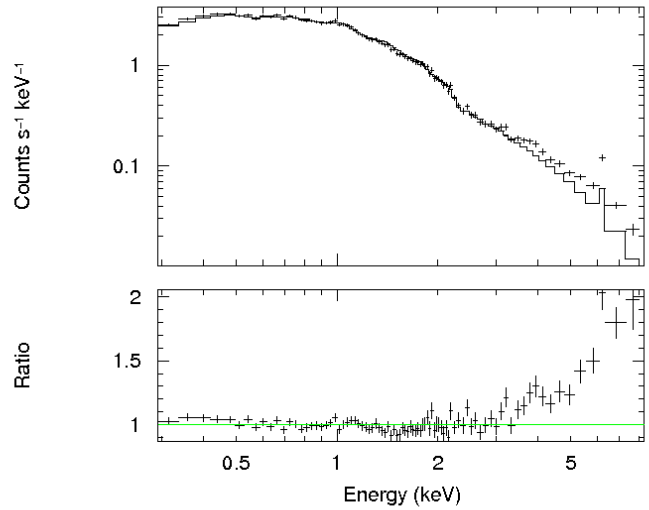


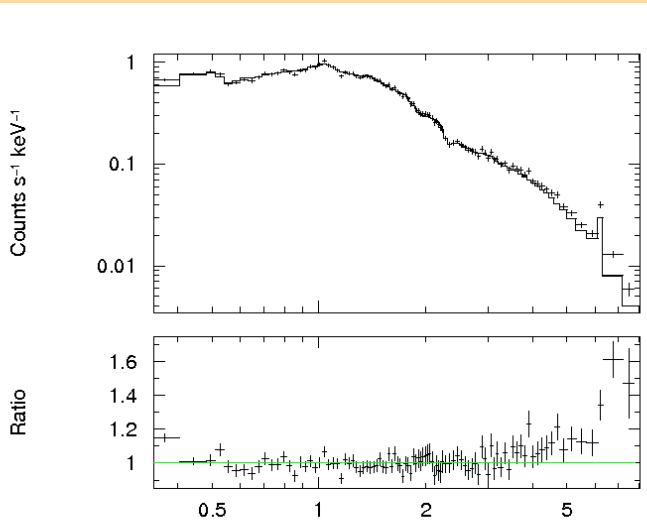




FITS TO SOFT BAND







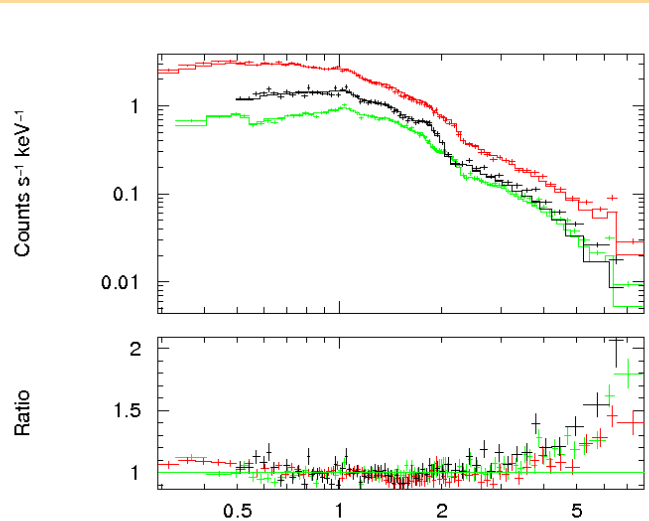


Table 2. NARROW-BAND SINGLE TEMPERATURE MODEL WITH FIXED N_H

Data	χ^2/dof (χ^2_r)	kT (keV)	A	Norm (10^{-2})
Fit to 2-7 keV band (2-8 keV for XMM-Newton data)				
ACIS	179.7/166 (1.08)	$5.88\pm^{0.57}_{0.36}$	0.45 ± 0.07	0.94 ± 0.03
PN	73.4/105 (0.70)	$5.28\pm^{0.23}_{0.21}$	$0.32\pm^{0.04}_{0.03}$	0.82 ± 0.02
MOS	115.4/105 (1.05)	$5.34\pm^{0.22}_{0.19}$	0.37 ± 0.04	0.97 ± 0.02
Joint[a]	365.6/394 (0.93)	$5.31\pm^{0.14}_{0.13}$	$0.36\pm^{0.03}_{0.02}$	$0.98\pm^{0.02}_{0.01}$
				0.81 ± 0.01
				0.97 ± 0.01
Fit to 0.5-4 keV band (0.3-4 keV for XMM-Newton data)				
ACIS	261.3/210 (1.24)	4.54 ± 0.014	0.29 ± 0.06	1.04 ± 0.02
PN	137.0/108 (1.29)	$3.46\pm^{0.07}_{0.06}$	0.13 ± 0.02	1.01 ± 0.01
MOS	165.6/116 (1.43)	4.24 ± 0.08	0.26 ± 0.03	1.08 ± 0.01
Joint[a]	638.6/437 (1.46)	$3.93\pm^{0.06}_{0.05}$	$0.20\pm^{0.01}_{0.03}$	1.07 ± 0.01
				0.97 ± 0.01
				1.10 ± 0.01

[a]For the joint fit, the three normalizations apply respectively to the ACIS, PN and MOS data.

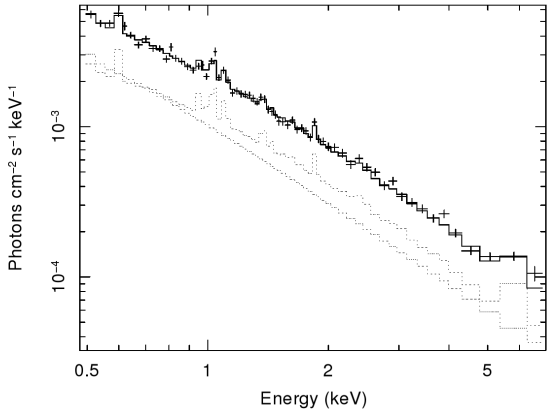
RESULTS OF NON-THERMAL FITS TO RESIDUALS

Table 3. NON-THERMAL MODEL

Data	χ^2/dof (χ^2_r)	kT (keV)	A	Norm. ($\times 10^{-2}$)	α	L_{42} [a] (10^{42} erg s^{-1})
ACIS	195.4/267 (1.10)	$5.36\pm^{0.43}_{0.56}$	$0.87\pm^{0.25}_{0.10}$	$0.50\pm^{0.14}_{0.11}$	$1.79\pm^{0.11}_{0.06}$	74.4
PN	118.6/159 (0.74)	$4.12\pm^{0.24}_{0.23}$	$0.47\pm^{0.05}_{0.04}$	$0.57\pm^{0.03}_{0.05}$	$1.83\pm^{0.07}_{0.04}$	61.0
MOS	185.1/172 (1.08)	$4.44\pm^{0.19}_{0.25}$	0.48 ± 0.05	0.74 ± 0.06	$1.74\pm^{0.07}_{0.06}$	49.8
Joint [b]	643.7/604 (1.07)	$4.59\pm^{0.09}_{0.08}$	$0.50\pm^{0.03}_{0.02}$	0.69 ± 0.10	$1.85\pm^{0.02}_{0.04}$	46.0
				$0.59\pm^{0.03}_{0.01}$		56.0
				0.71 ± 0.01		56.0

[a] L_{42} is the unabsorbed luminosity of the non-thermal model in the 0.5-7 keV band.

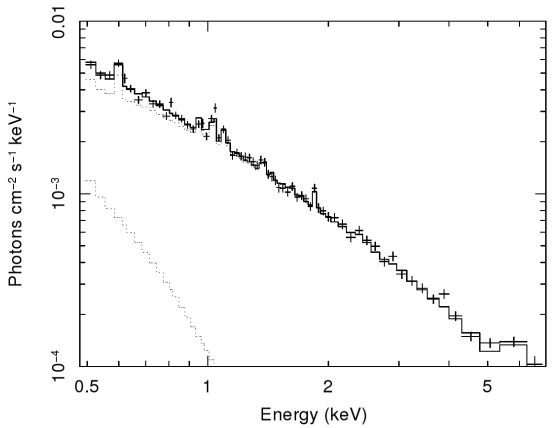
[b] For the joint fit, the three normalizations apply respectively to the ACIS, PN and MOS data.



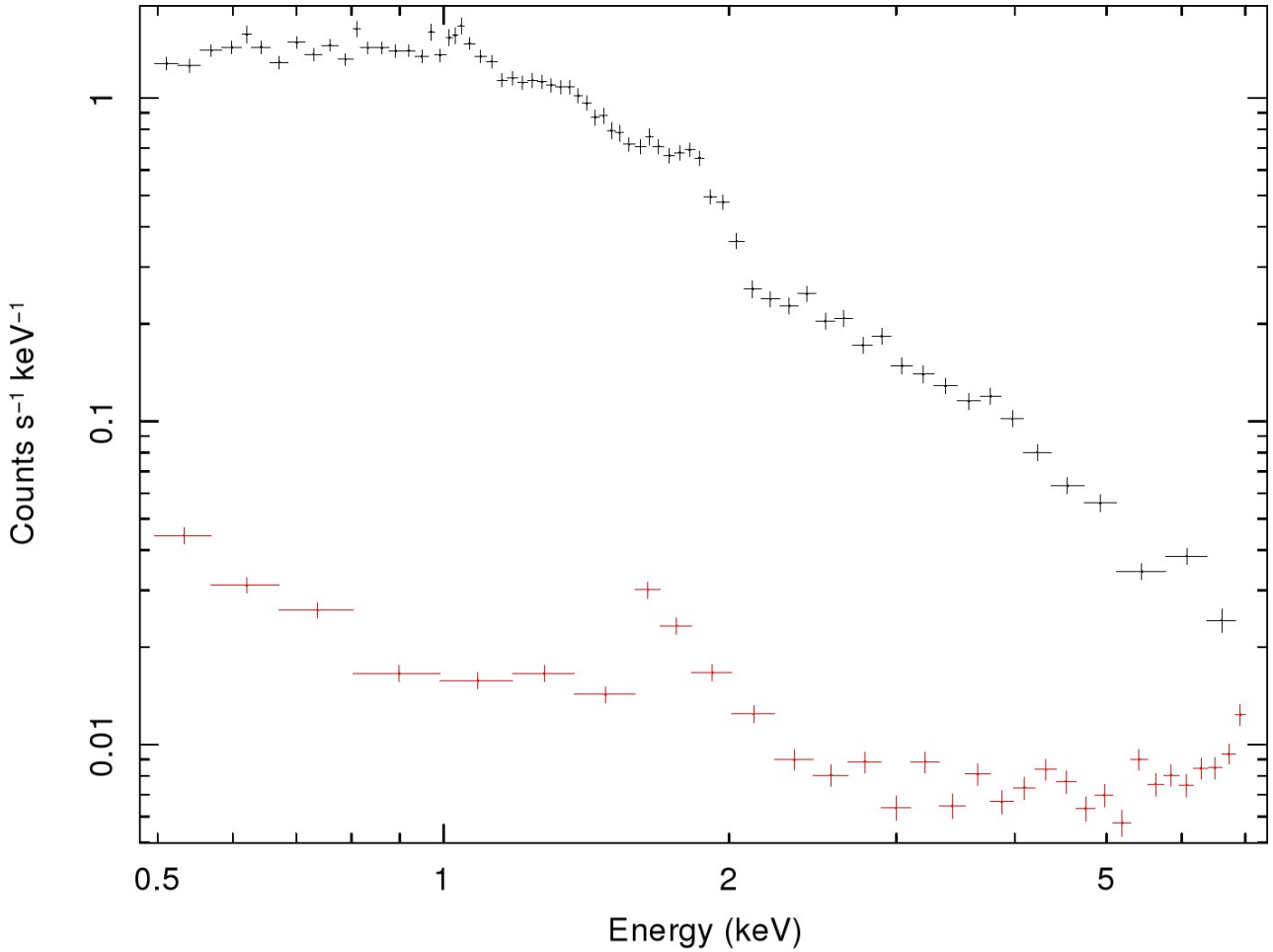
RESULTS OF THERMAL FITS TO RESIDUALS

Table 4. TWO-TEMPERATURE MODEL

Data	χ^2/dof (χ^2_r)	$kT_{\rm hot}$ (keV)	A	Norm. ($\times 10^{-2}$)	$kT_{\rm warm}$ (keV)	A	Norm. ($\times 10^{-3}$)
ACIS	296.6/266 (1.11)	$5.61\pm^{0.27}_{0.33}$	$0.51\pm^{0.07}_{0.05}$	0.94 ± 0.03	$0.34\pm^{0.32}_{0.12}$	≤ 2.5	$0.14\pm^{0.17}_{0.03}$
PN	117.8/158 (0.74)	$5.34\pm^{0.23}_{0.30}$	$0.38\pm^{0.03}_{0.04}$	0.78 ± 0.04	$0.89\pm^{0.20}_{0.16}$	≤ 0.17	$0.9\pm^{0.04}_{0.03}$
MOS	178.8/170 (1.05)	$4.68\pm^{0.10}_{0.07}$	0.39 ± 0.03	1.03 ± 0.01	≤ 0.10	≤ 0.04	$3.39\pm^{1.59}_{1.02}$
Joint	654.5/603 (1.09)	$5.12\pm^{0.09}_{0.05}$	$0.39\pm^{0.03}_{0.02}$	0.94 ± 0.01	$0.62\pm^{0.04}_{0.10}$	≤ 0.01	$0.24\pm^{0.02}_{0.01}$
				0.59 ± 0.01			
				0.71 ± 0.01			

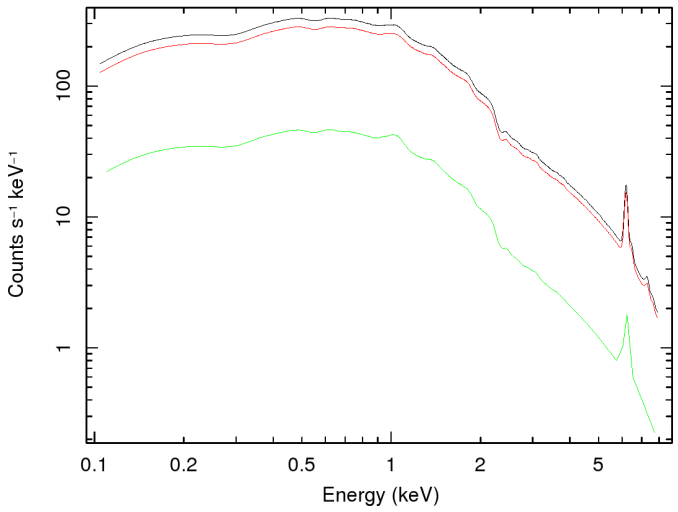


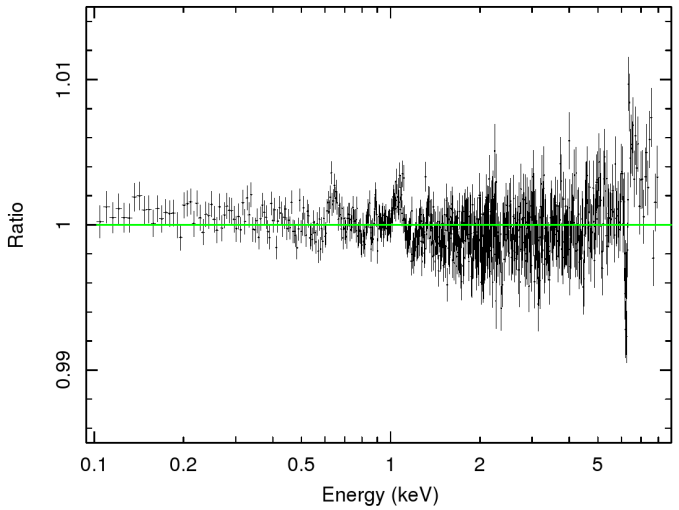
CHANDRA BACKGROUND



EFFECT OF PROJECTION FROM OUTER ANNULI

- Simulations based on Vikhlinin (2006) temperature profile, nearly flat in 0.1-0.3 r_{500}
- full 1-2.5' cylinder (black)
- only isothermal region (0.1-0.3 r_{500}) in red
- only outer region (>0.3 r_{500}) in green





- Virtually no residuals to fit to an isothermal spectrum

CONCLUSIONS

- Presence of low and/or high energy X-ray residuals in Chandra spectrum of A3112
- Confirmation of earlier detection with XMM-Newton
- Differences in the amount of residuals between instruments remain
- Residuals *not* due to background subtraction, or to projection effect
- Possible effects of these residual is to indicate cooler gas in clusters,
  and/or non-thermal pressure

- Another cluster with outstanding XMM-NEWTON excess is AS1101, which has only 10 ks Chandra obs.
  worthwhile to obtain deeper data for both A3112 and AS1101 for further investigations