Galaxy Clusters WG report

A. Beardmore, A. Read, M. Bonamente, Y. Chen, Y.P. Chen, L. David, K. Forster, K. Kettula, X. Matumoto, E. Miller, J. de Plaa, G. Schellenberger, S. Snowden,N.-J. Westergaard, M. Stuhlinger,S. Suchy, C, Tenzer

IACHEC meeting 2013, Theddingworth

1) HIFLUGCS extension
2) Multi-Mission Study
3) SZ, Grav lensing
4) NuSTAR
5) Suzaku paper

1) HIFLUGCS extension

G. Shellenberger et al.

IACHEC meeting 2013, Theddingworth

- To account for different sizes of the extraction regions due to CCD gaps, we scale the spectra with the BACKSCAL value:

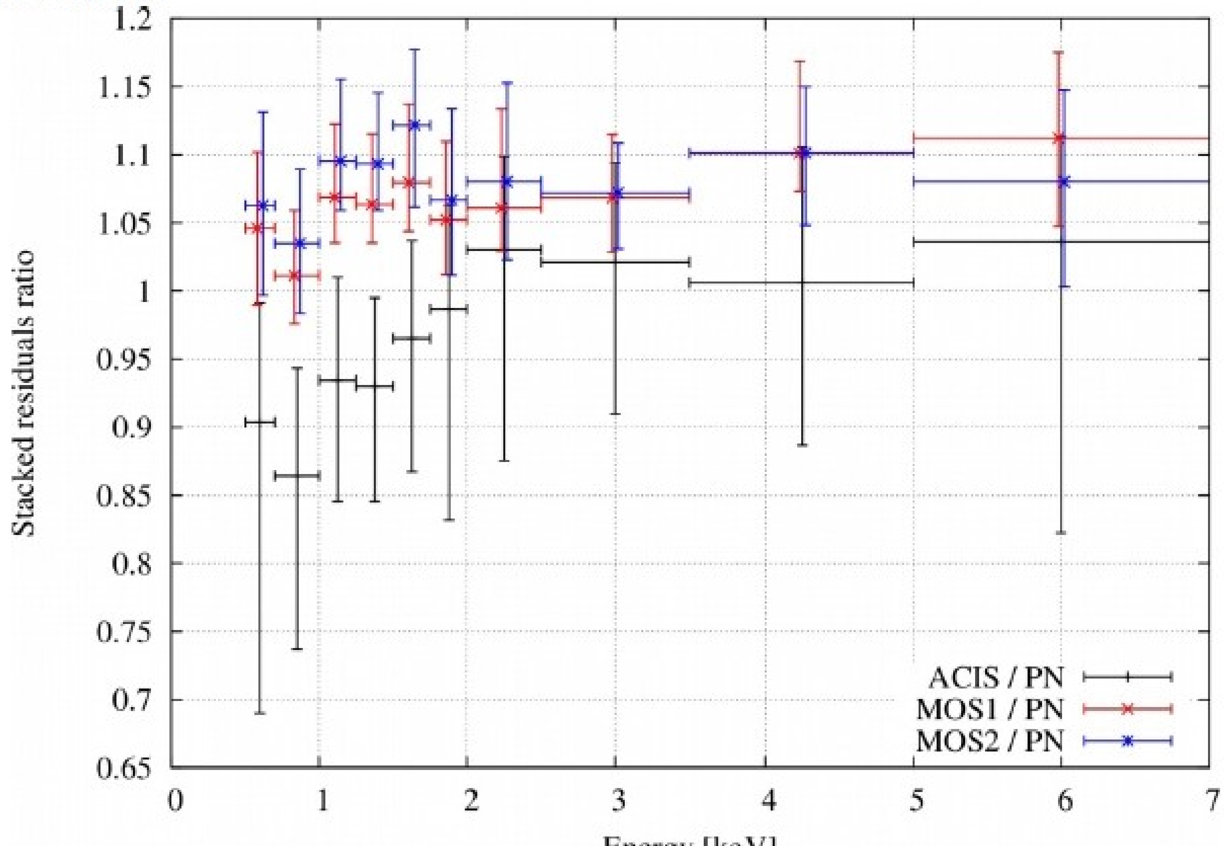
$$R_{I \text{ over } pn} = \frac{data_I}{model_{pn} \otimes resp_I} \times \frac{model_{pn} \otimes resp_{pn}}{data_{pn}} =$$

$$\frac{BACKSCAL_{pn}}{BACKSCAL_I} \times \frac{data_I}{model_{pn} \otimes resp_I} \times \frac{model_{pn} \otimes resp_{pn}}{data_{pn}}$$

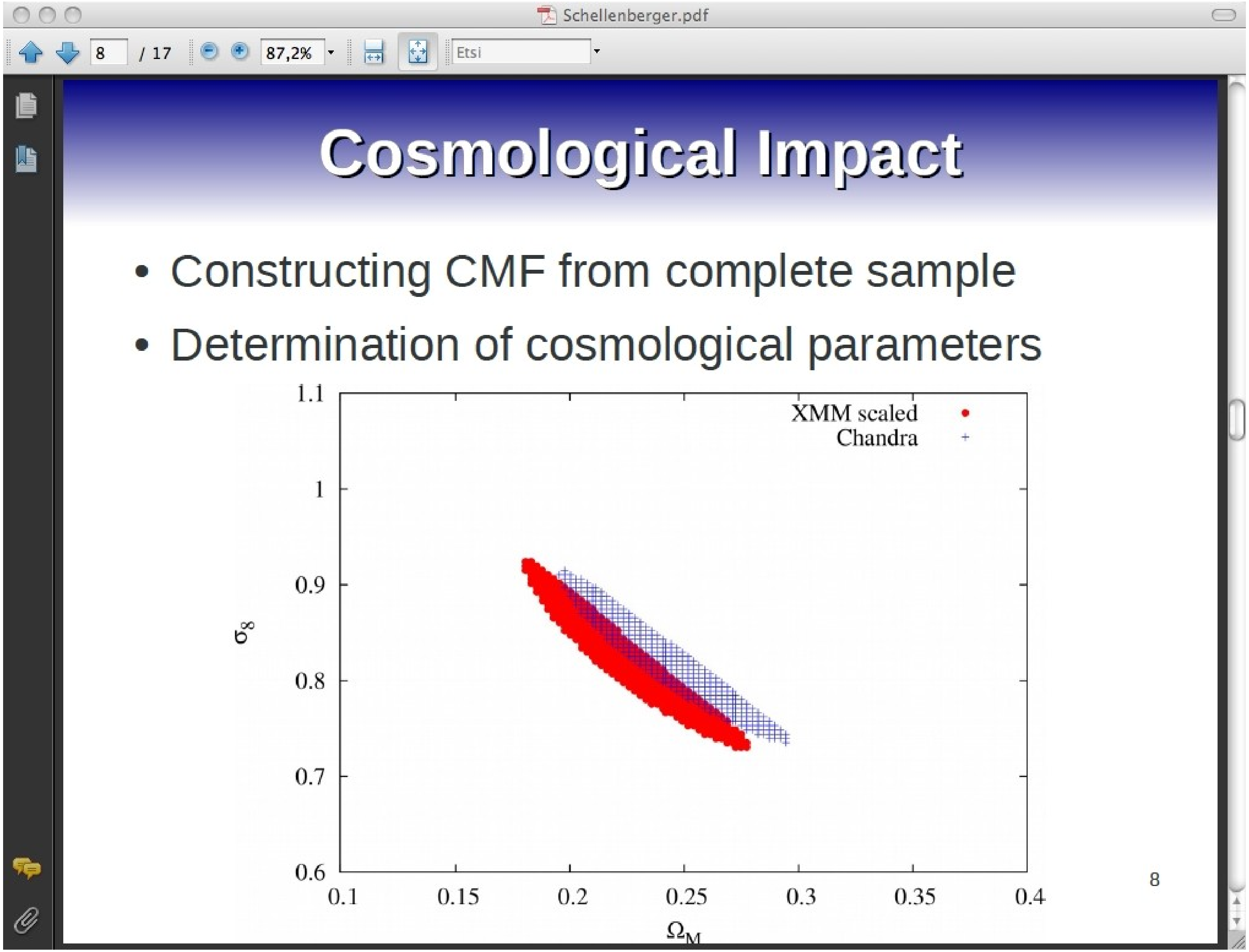
- Linear scaling not exact, because brightness drops with radius
- BACKSCAL not correctly calculated for ACIS-I? CCD gaps and bad pixels not excluded from BACKSCAL?
- Larry has a tool for it. Gerritt should learn this. **TASK1**

Stacked residuals ratio

- Following Kettula et al. (2013) and Longinotti et al. (2008)
- 10 energy bands, $R_{Chan,PN} = \frac{Data_{Chan}}{Model_{PN} \otimes Resp_{Chan}} \times \frac{Model_{PN} \otimes Resp_{PN}}{Data_{PN}}$
- build median

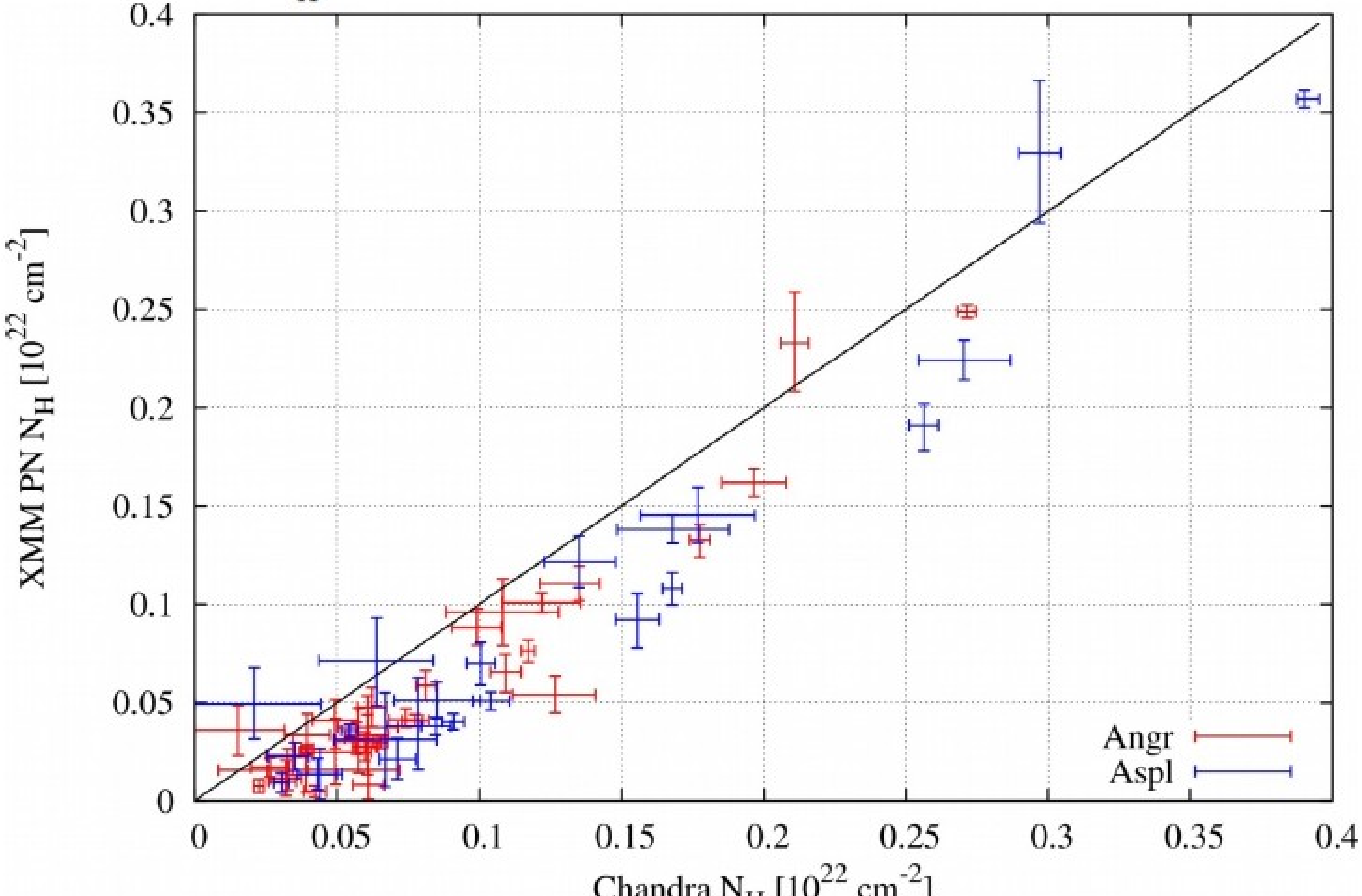


Why bother?


Schellenberger.pdf
8
/ 17
87,2%
Etsi
Cosmological Impact
• Constructing CMF from complete sample
• Determination of cosmological parameters
XMM scaled
Chandra
1.1
1
0.9
0.8
0.7
0.6
σ_8
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Ω_M
8

NH as calibration uncertainty measure

- Comparing best-fit N_H values of the different detectors shows a systematically higher column density for ACIS but relative difference is constant with N_H



2) Multi-Mission Study

J. Nevalainen, A. Beardmore, L. David, K. Kettula, E. Miller, S. Snowden,

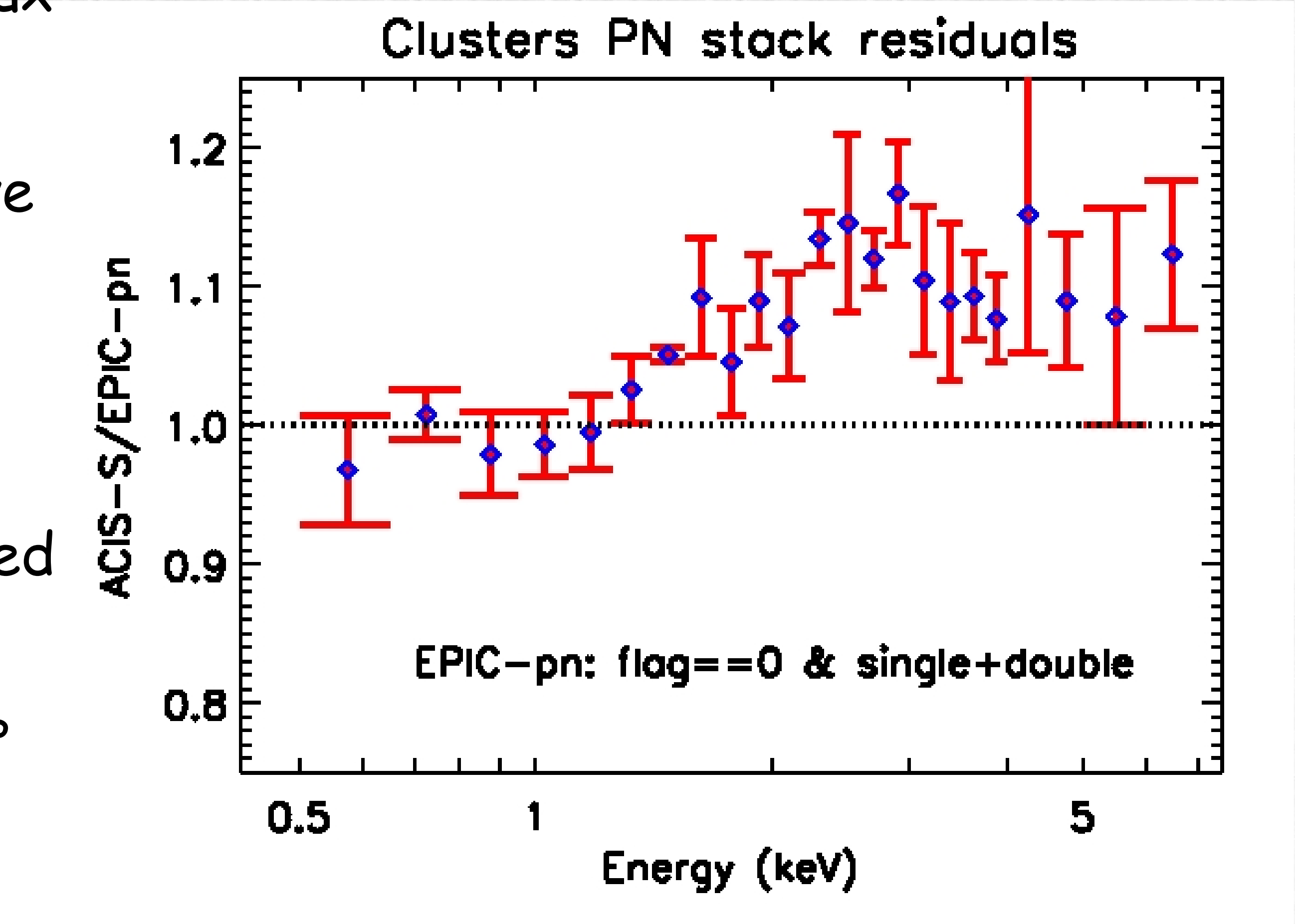
IACHEC meeting 2013, Theddingworth

Chandra/XMM

- There are cross-correlation problems between XMM-Newton/EPIC and Chandra/ACIS (Nevalainen et al., 2010):

  - ACIS 2-7 keV band flux ~10% higher
  - 2-7 keV band effective area shape calibration OK
  - At 2.0- 1.0 keV pn effarea underestimated or ACIS effarea overestimated by 20%

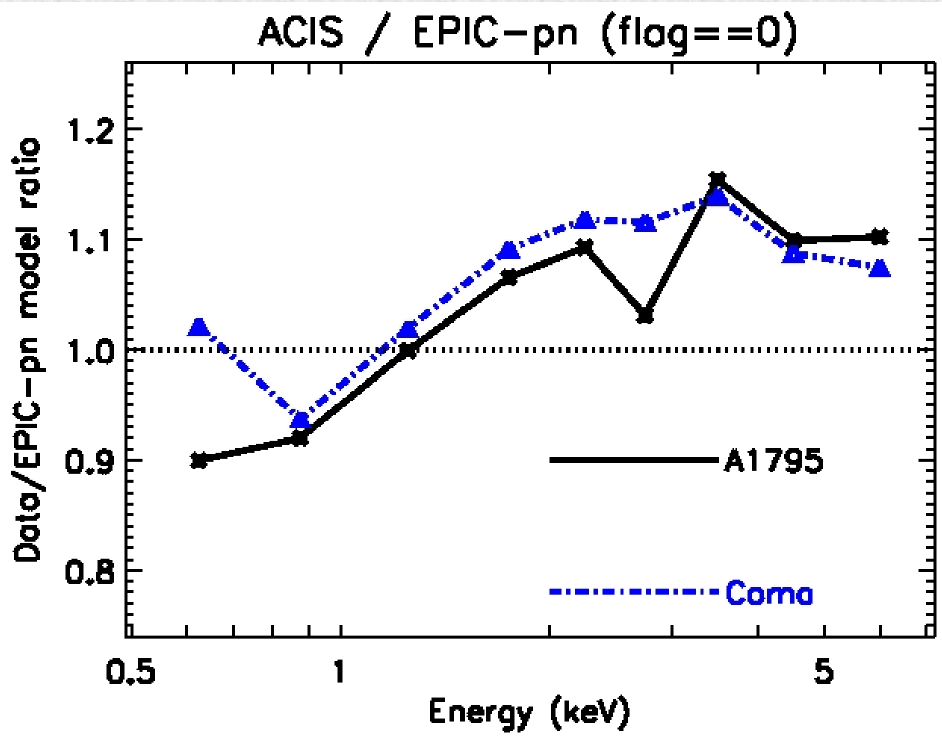
ACIS-S subsample

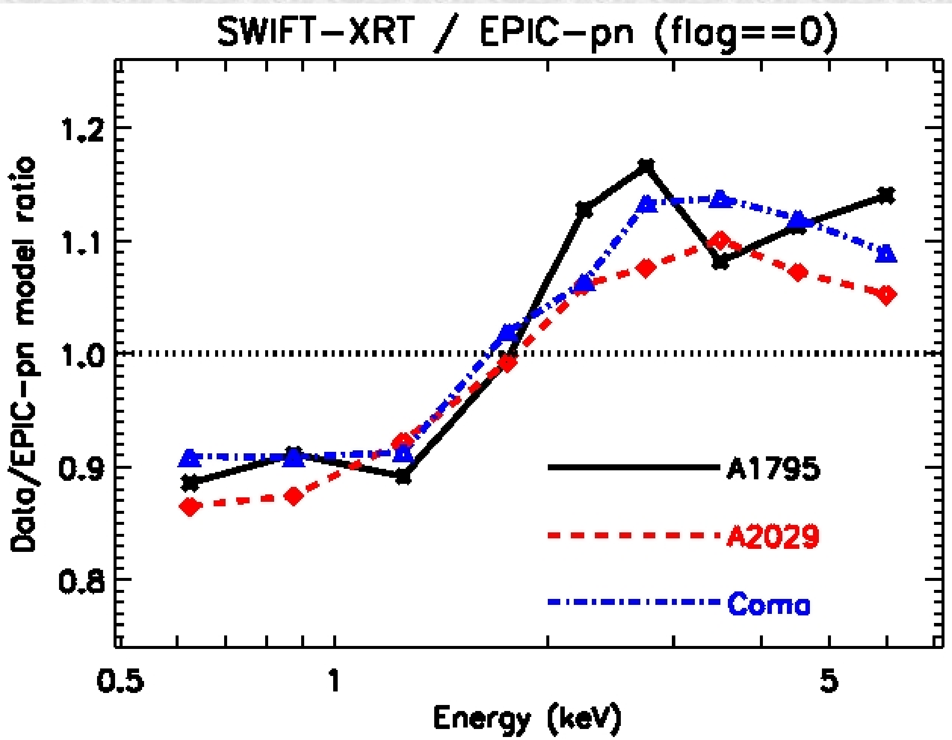


New cans of worms

- We included now Swift/XRT, Suzaku/XIS and ROSAT/PSPC into the comparison work
- We use 3-6 arcmin annulus for the extraction of the spectra, so that
  - we minimise the scatter from the cool core (we are wasting data, but this enables the comparison with Suzaku which has a larger PSF). **Perhaps OK to use center?**
  - we minimise the PSF scatter from and to our extraction region (again, dictated by Suzaku)
  - we stay in the bright part of the clusters and thus minimise background systematics (background a few% of the cluster emission)

Is pn a freak?


ACIS / EPIC-pn (flag==0)
Data/EPIC-pn model ratio
Energy (keV)
0.5
1
5
0.8
0.9
1.0
1.1
1.2
A1795
Coma


SWIFT-XRT / EPIC-pn (flag==0)
Data/EPIC-pn model ratio
Energy (keV)
0.5
1
5
0.8
0.9
1.0
1.1
1.2
A1795
A2029
Coma

Conclusions

- XMM-Newton-EPIC and Suzaku-XIS in rough agreement
- Chandra-ACIS and Swift-XRT in rough agreement
- The two pairs in clear disagreement ➔
- Grand Calibration Scheme (M. Guainazzi)

3) Cluster mass, temperature and pressure from X-rays, gravitational lensing and Sunyaev-Zeldovich effect as possible calibrators

J. Nevalainen, A. Mahdavi, D. Eckert

IACHEC meeting 2013, Theddingworth

New fields of worms

- Usually cross-calibration of effective area of an X-ray instrument means a comparison of spectral models derived using different instruments for the same source
- We explore here a new method: A comparison of
  - physical quantities: **1)** total mass and **2)** thermal pressure derived with an X-ray instrument

  with

  - the same physical quantities derived using different methods and wavelengths

+ A possible agreement yields confidence on the X-ray calibration accuracy

− A possible disgreement can be due to uncertainties of calibration and/or of the cluster physics

Total mass of a cluster of galaxies

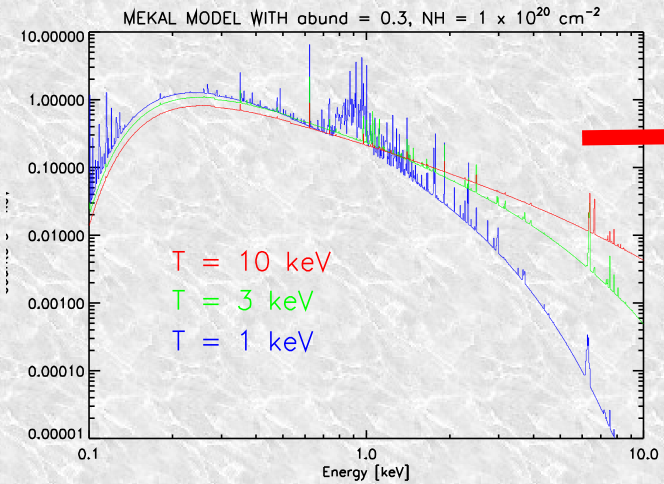
HYDROSTATIC X-RAY METHOD

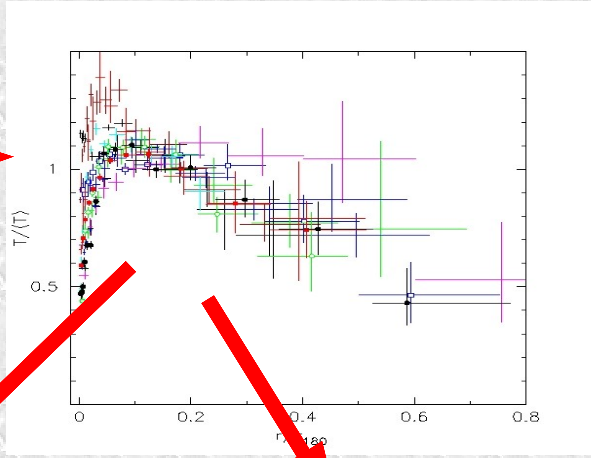
- The intracluster gas pressure gradient pulls gas particles away from the center
- The gravity pulls the gas particles towards the center
- In hydrostatic equilibrium the forces due to gas pressure gradient and gravity are in balance, matter is not moving

GRAVITY ← → GAS PRESSURE

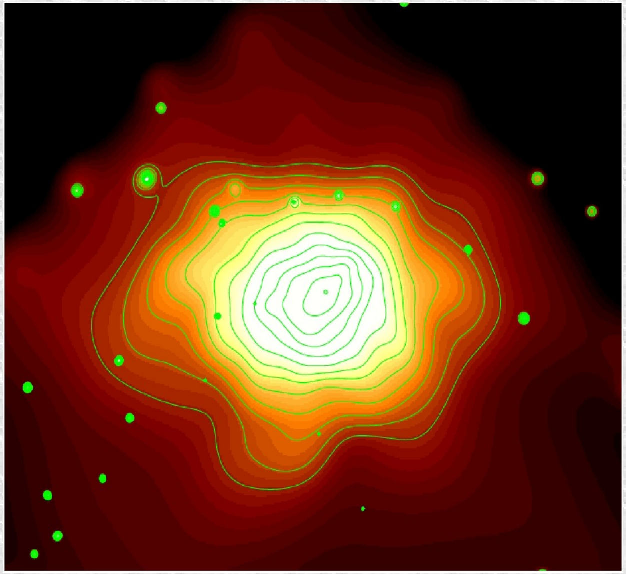
$$M_{tot}(<r) = -\frac{k}{\mu m_p G} T_g(r) r \left(\frac{d \ln \rho_g(r)}{d \ln r} + \frac{d \ln T_g(r)}{d \ln r} \right)$$

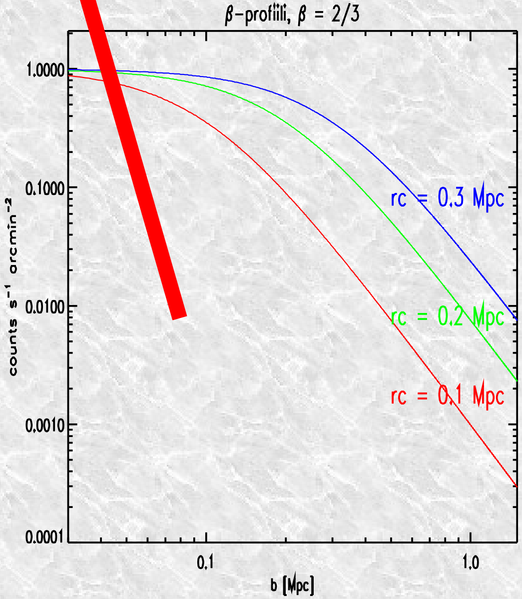
HYDROSTATIC X-RAY METHOD





$$M_{tot}(<r) = -\frac{k}{\mu m_p G} T_g(r) r \left(\frac{d \ln \rho_g(r)}{d \ln r} + \frac{d \ln T_g(r)}{d \ln r} \right)$$

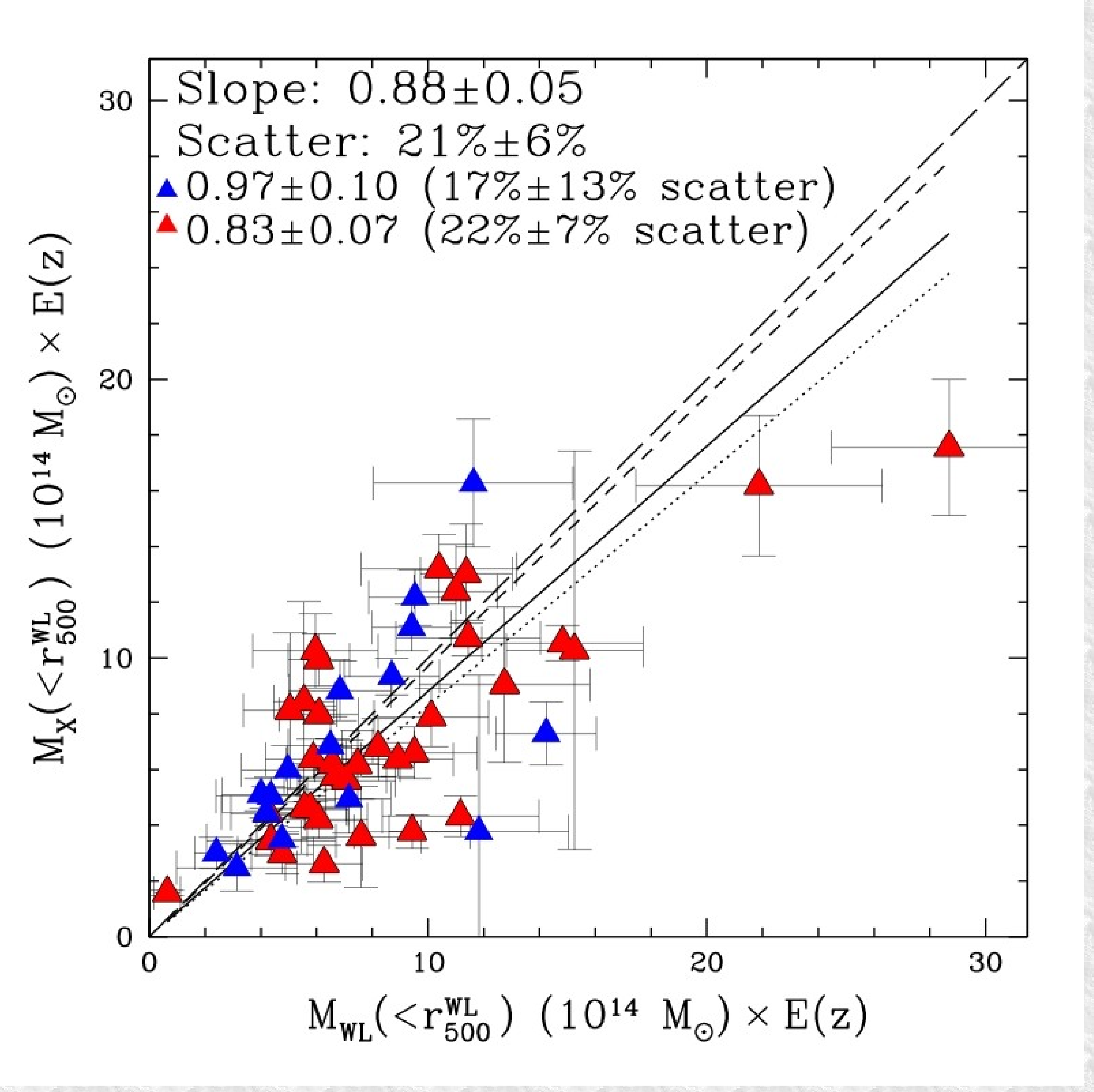




Gravitational lensing

- Gravitational lensing also yields the total mass M_{tot} for clusters of galaxies
- **Assuming that gravitational lensing is bias-free !!!**, comparison of X-ray total masses obtained using different instruments can be used to judge which gives T right, and thus has the effective area shape accurately calibrated
- Mahdavi et al: The Canadian Cluster Comparison Project (CCCP) , 50 clusters
- Gravitational lensing mass from Hoekstra et al. (2012), which contains a weak lensing analysis of CFH12k and Megacam data from the Canada-France-Hawaii Telescope
- Most observed with both XMM and Chandra

* Using XMM data **(pn or MOS?)** , CCF:s from Jan 2012, M_{grav} and $M_{X\text{-ray}}$ agree:

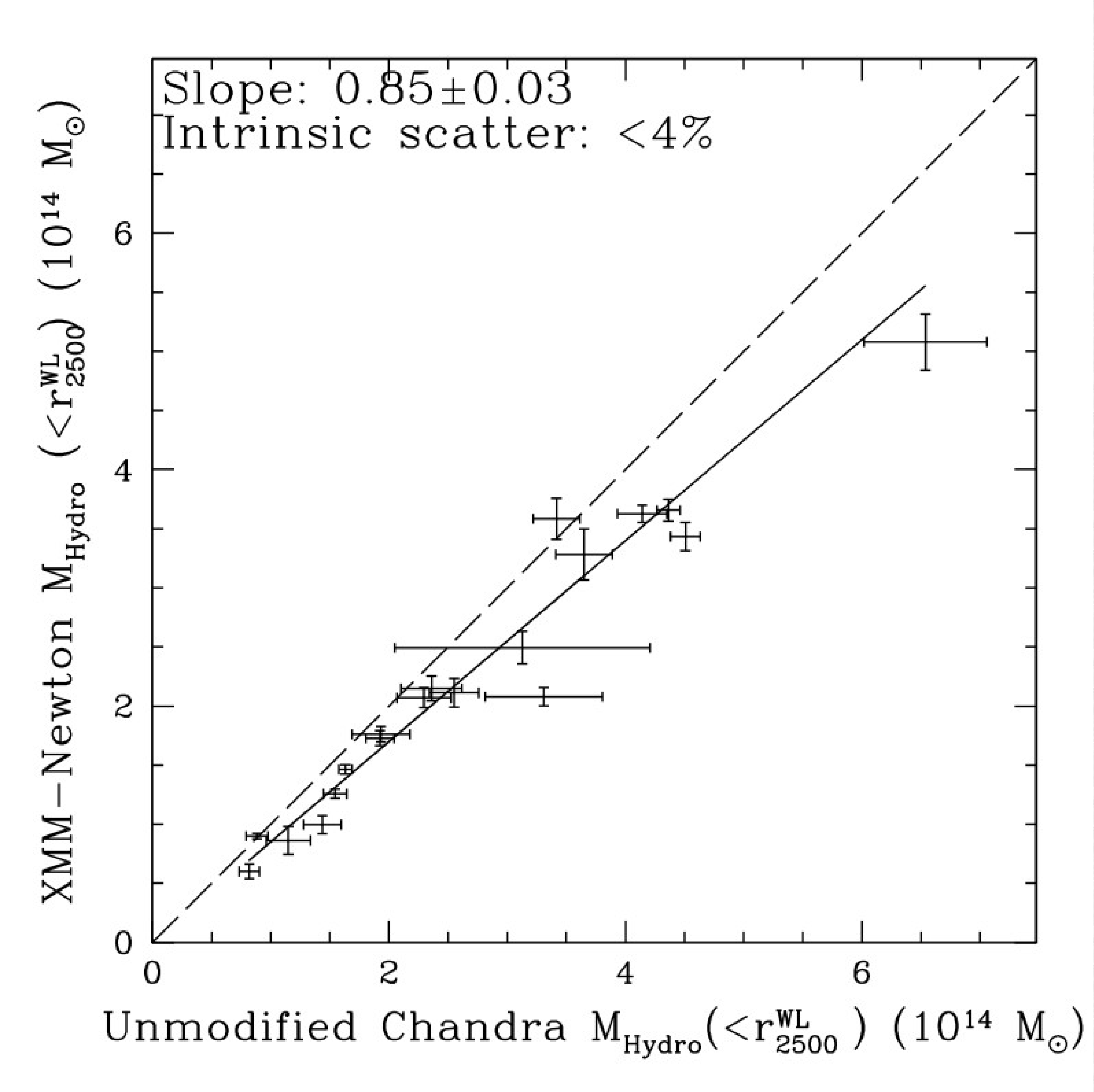


- Since Chandra gives higher temperatures, the hydrostatic X-ray masses derived from Chandra data are $\sim$15% bigger than XMM values

➔ Chandra X-ray mass 15% bigger than M_{grav}

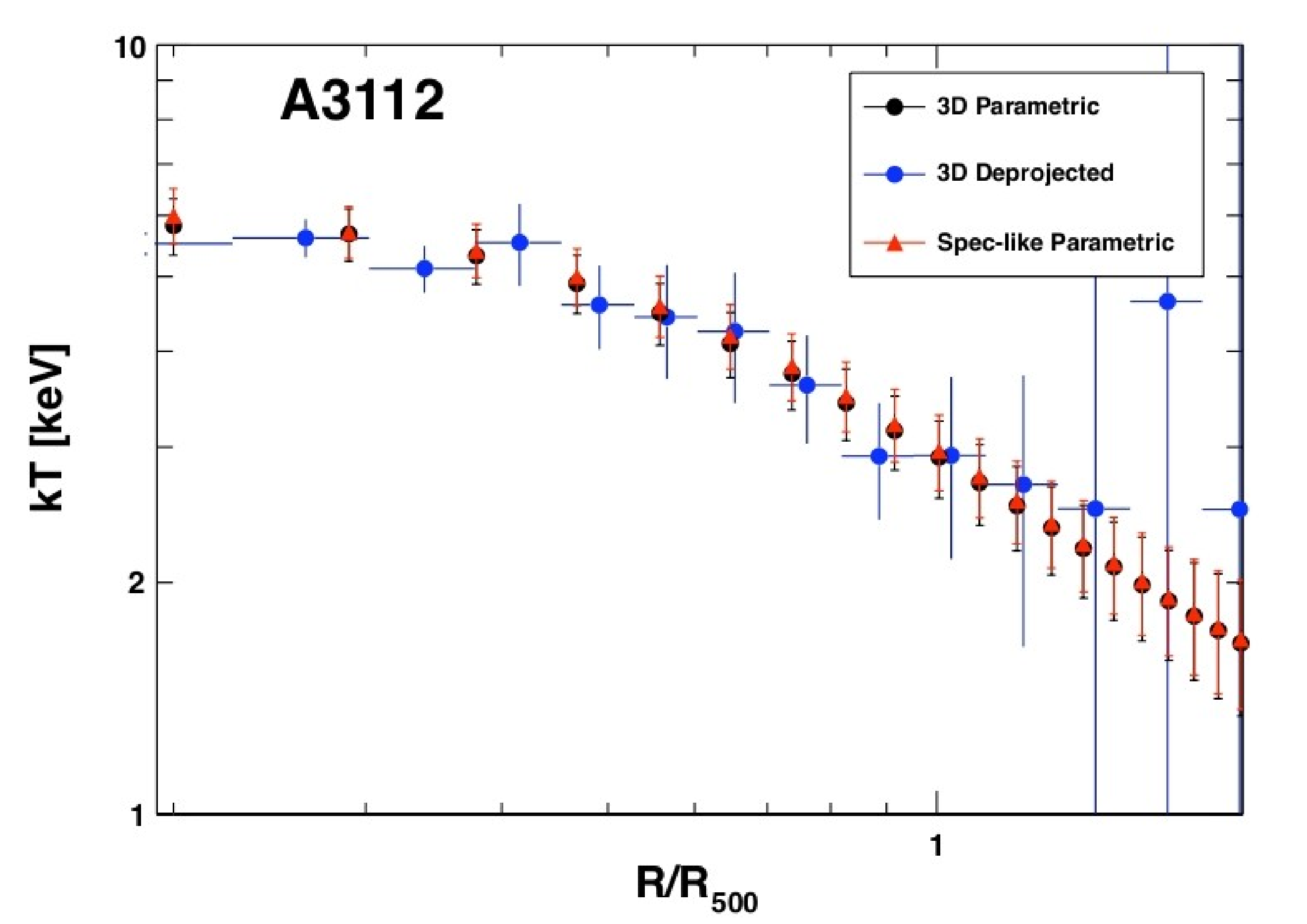
- ***This indictes that XMM is accurate***

- Collaboration with Mahdavi going on



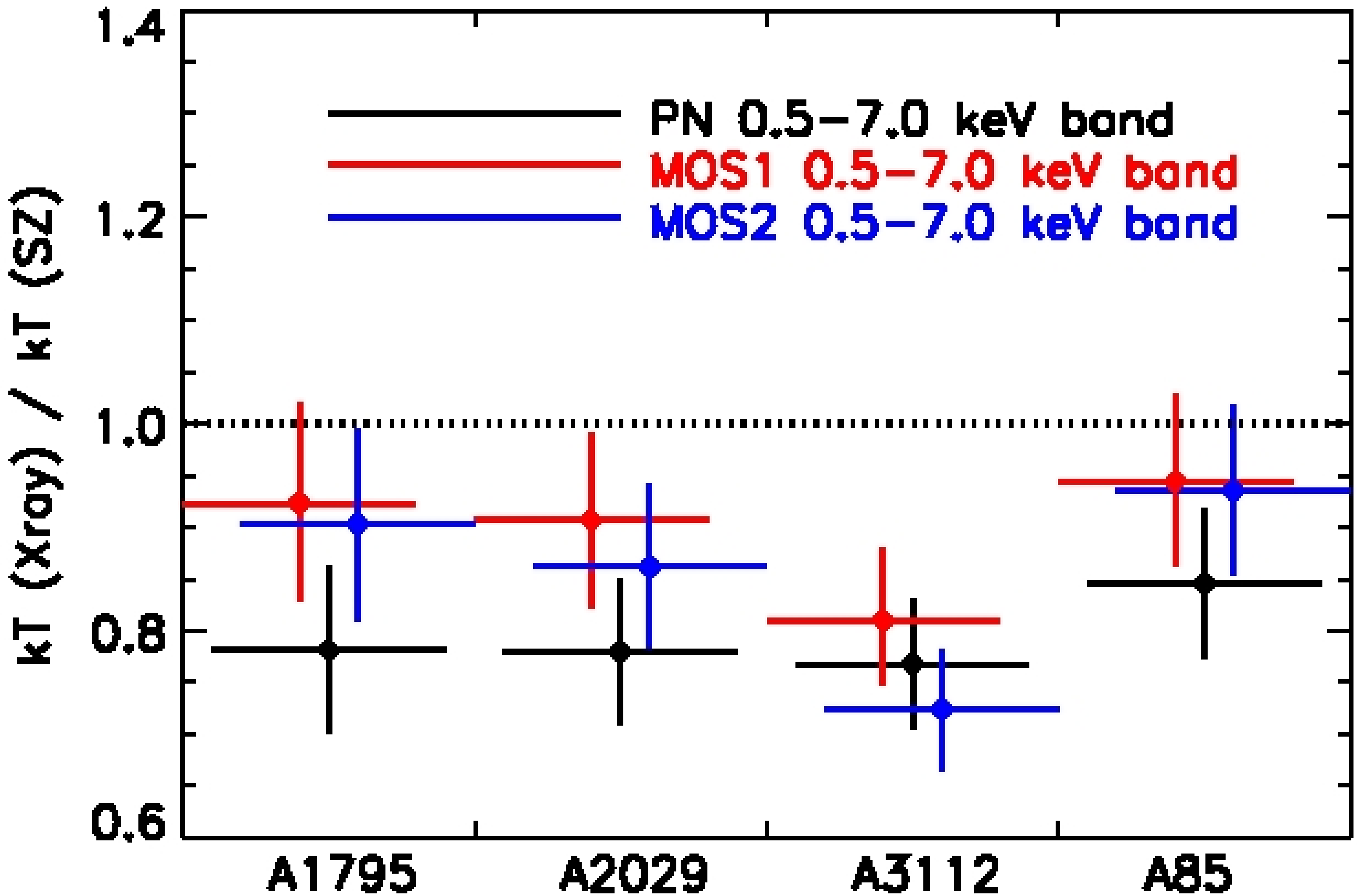
Sunyaev – Zeldovich effect

- Sunyaev-Zeldovich effect measured with Planck within r_{500} yields electron pressure $P(r_{500})$
- P(r) distribution modeled with universal profile (Arnaud et al. 2010) and scaled to $P(r_{500})$
- Electron density $n_e(r)$ derived using ROSAT PSPC
- Electron temperature profile derived using P(r) = k n(r) T(r)



- Electron temperature also derived via X-ray spectroscopy
- Collaboration with Eckert: XMM-Newton / Planck+ROSAT comparison of temperatures for A1795, A2029, A3112 and A85 (A2204 TBD) at 0.2-0.4 r500

- In 0.5-7.0 keV band XMM gives too small temperatures
- ACIS temperatures 10-20% higher → ACIS would match Planck+ROSAT well → ***This indictes that ACIS is accurate***



Conclusions

- XMM is better than Chandra based on X-ray / Grav lens masses
- Chandra is better than XMM based on SZ/X-ray thermal pressure

4) NuSTAR

- Discussion in IACHEC 2012 meeting with NuStar people (Kerstin, Karl, Fiona) about adding some clusters into calibration program
- Agreement that Coma, A1795 and A2029 will be observed
- These are the hottest clusters in the IACHEC sample, relaxed in the inner regions and well observed with many different X-ray missions.
- The brightest central regions covered within a few arcmin to minimise vignetting
- Fe XXV/XXVI EPIC measurement will help in the calibration

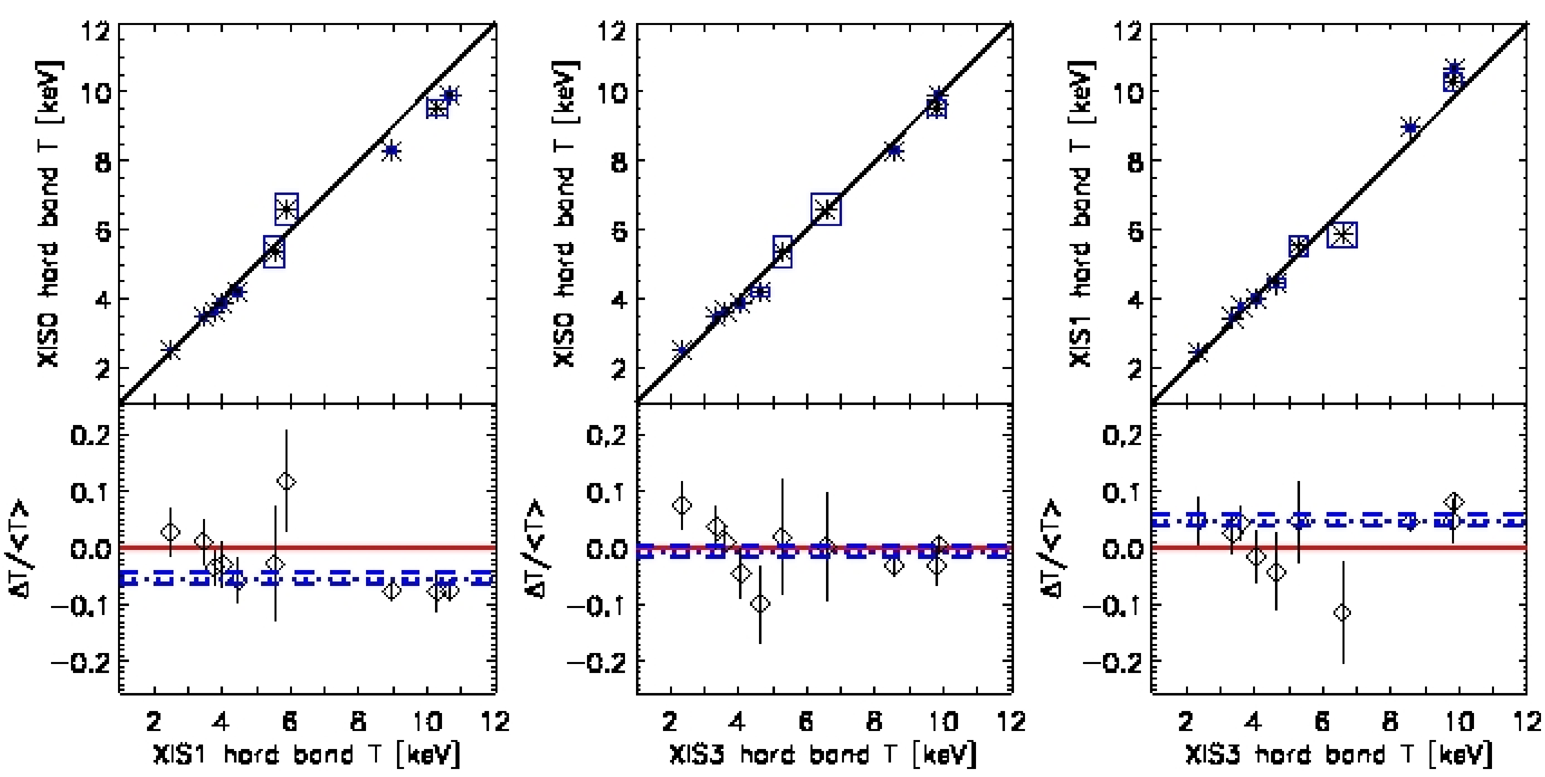
- **STRAY LIGHT!** Better use a bit more distant clusters, perhaps from REXCESS sample. Can be avoided by careful orientation. Maybe too constraining.
- Jukka and Niels-Jörgen will look at A1795. Simulate NuSTAR observation using a) optimal and b) worst case orientation.

5) Suzaku

- Spectroscopic analysis of clusters using two stages of calibration: CALDB 20080709 and CALDB 20110608
- Sample contains 11 ~ relaxed clusters observed with both Suzaku and XMM: A1060, A1795, A262, A3112, A496, AWM7, Centaurus, Coma, Ophiuchus, Triangulum
- Fit with 1-T MEKAL model in 0.5-2.0 and 2.0-7.0 keV bands
- Extraction regions 3-6 arcmin in order to
  - Minimise PSF scatter to and from the extraction region (area wider than PSF).
  - Minimise PSF scatter from the cool core.
  - Not too large region to minimize background effects (bkg a few % of cluster emission)
- Cluster center/FOV center offsets < 1', except A2199 4'

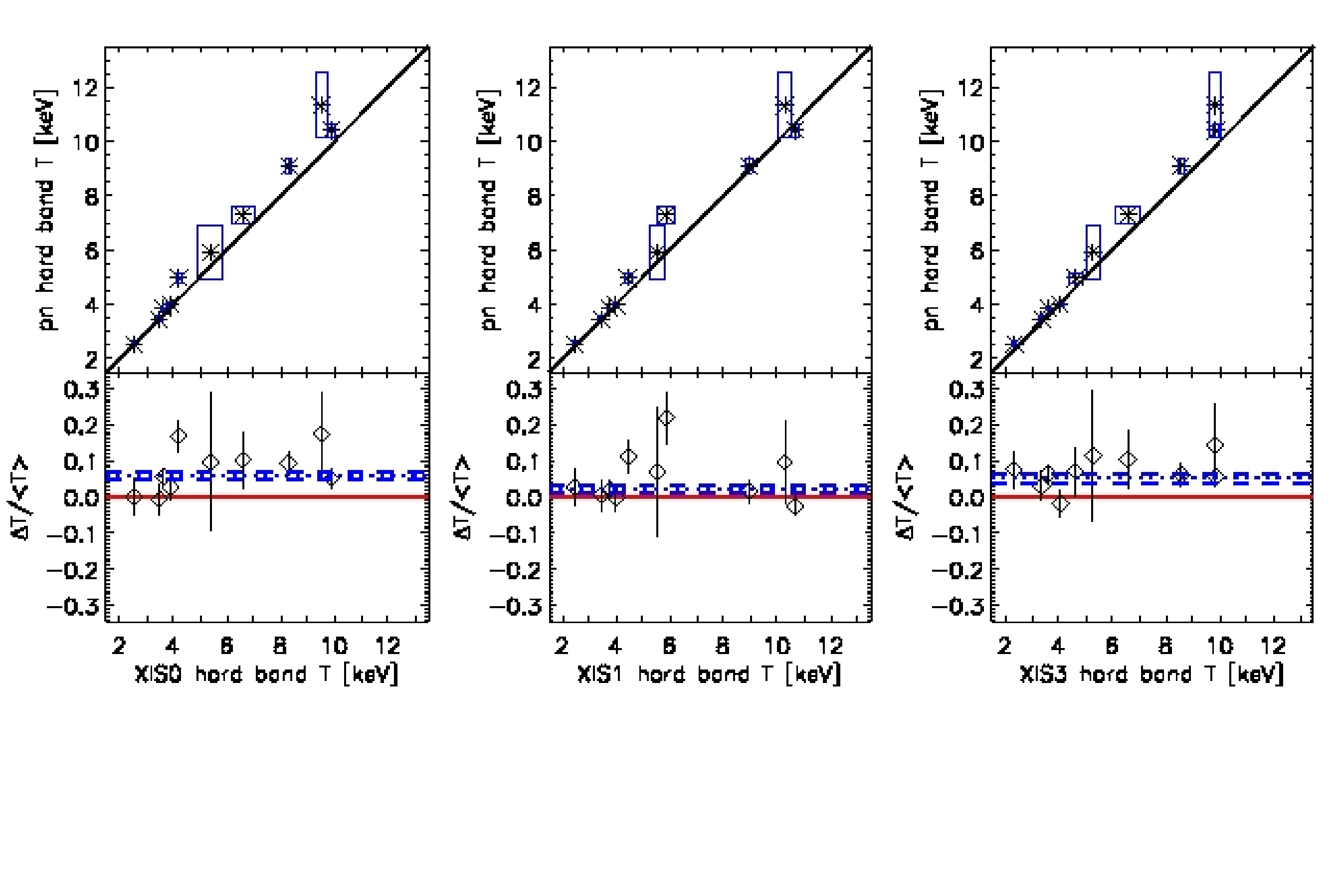
XIS hard band

- XIS0/XIS3 temperatures differ only by 1% (0.6σ)
- XIS1 temperatures 5% (5-6σ) higher



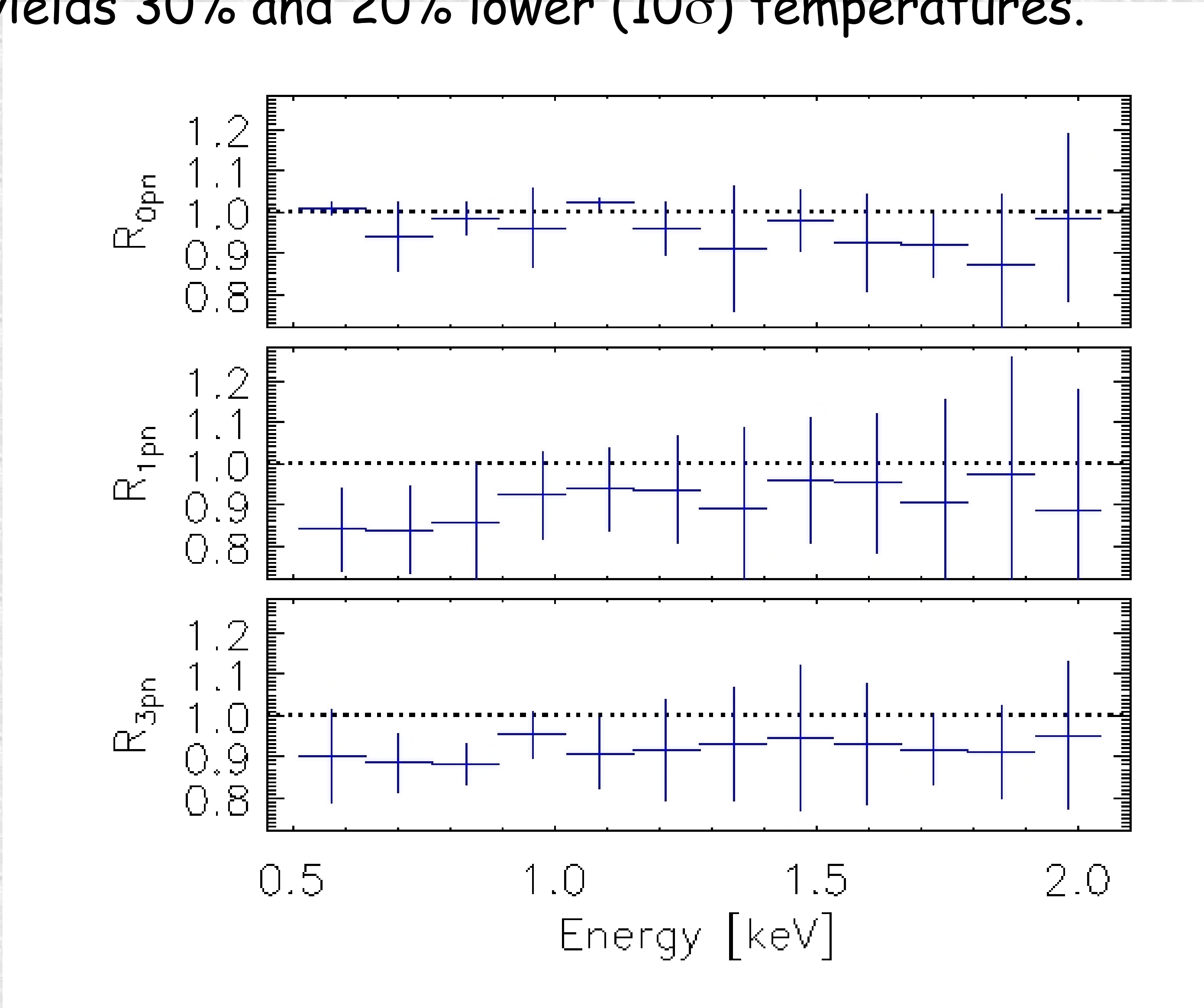
XIS/pn hard band

- XIS1/pn differ only by 2% (1σ). pn should be OK (Nevalainen et al., 2010) ➔ XIS1 should be OK
- XIS0 and XIS3 5% lower than pn. Suggested that XIS0 and XIS3 have a bit too hard effective area shape in 2-7 keV band.

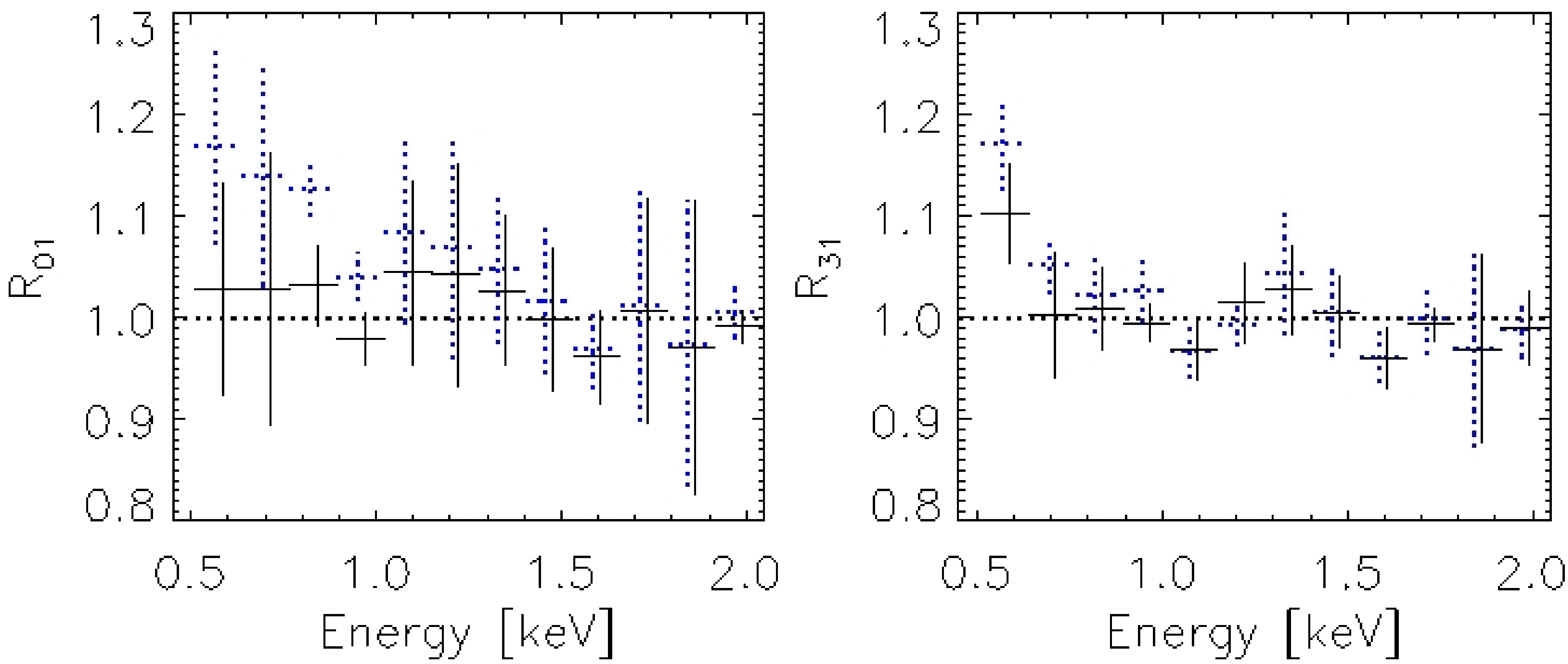


XIS pn soft band

- XIS1/XIS3 kT differ a bit (7%) but not very significantly (2.5σ)
- XIS0 yields 30% and 20% lower (10σ) temperatures.

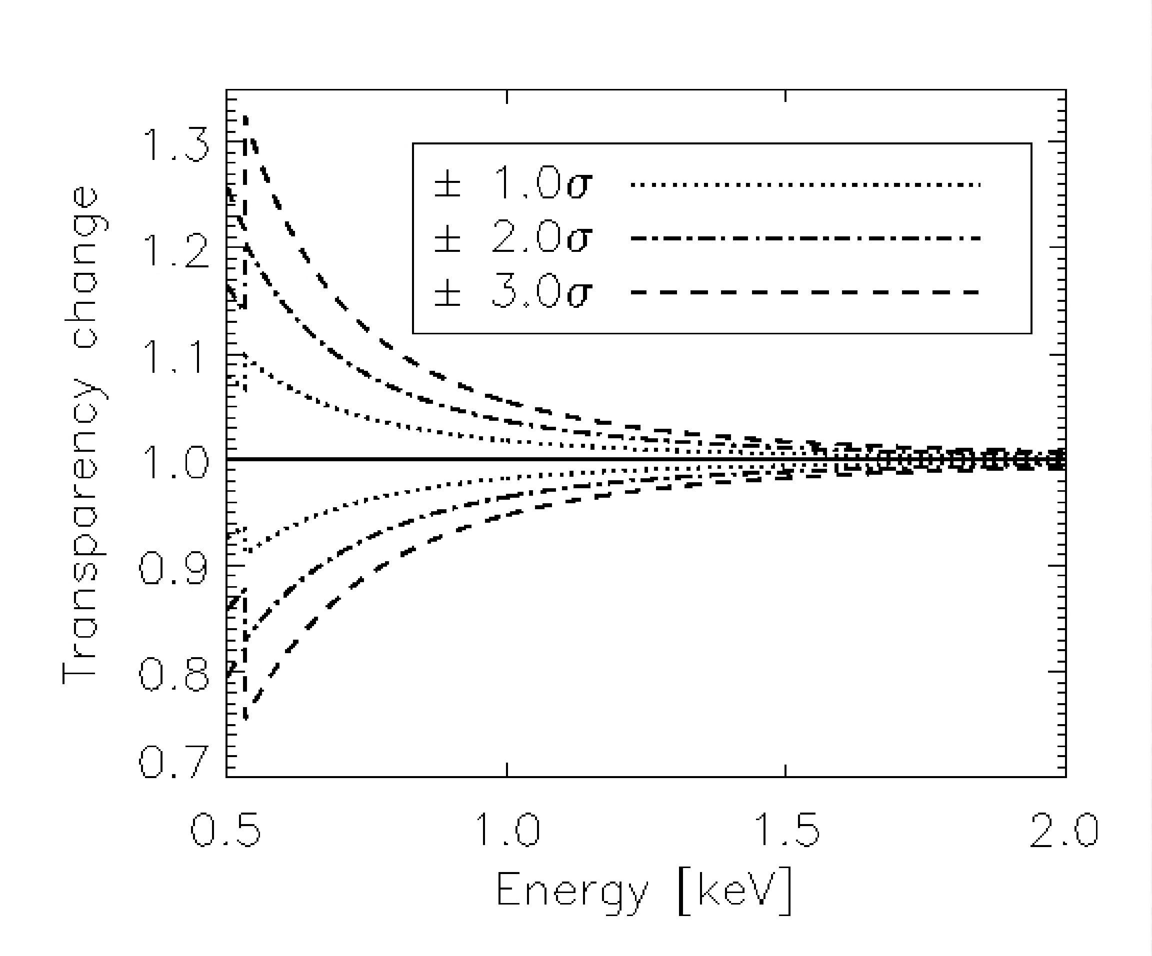


XIS soft stack residuals



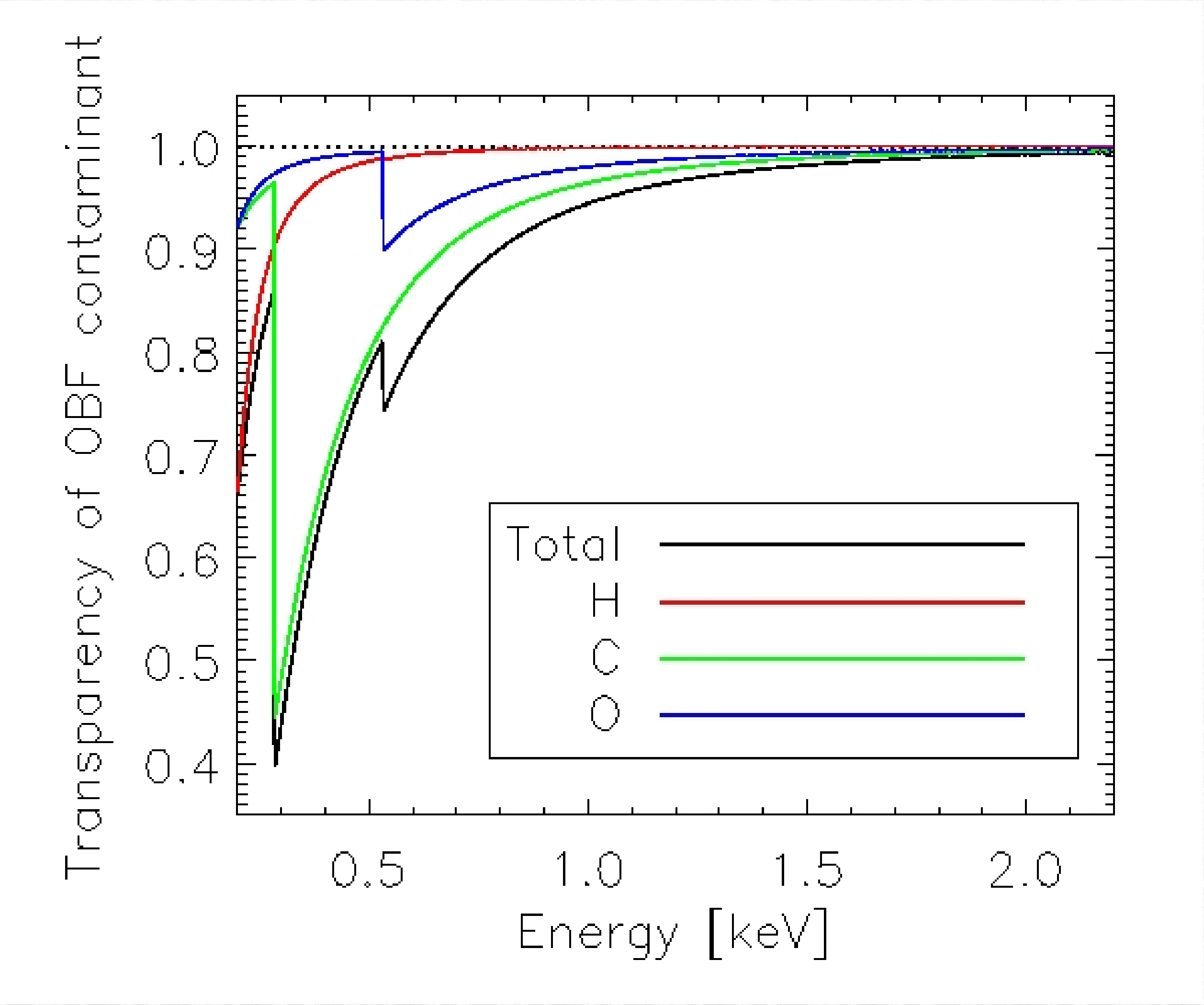
Is the contaminate to blame?

- We used a local XSPEC model hcorat to investigate the contaminate absorption effect
- We used 0.8×10^{18} cm^{-2} as reference O column density for 2007 epoch

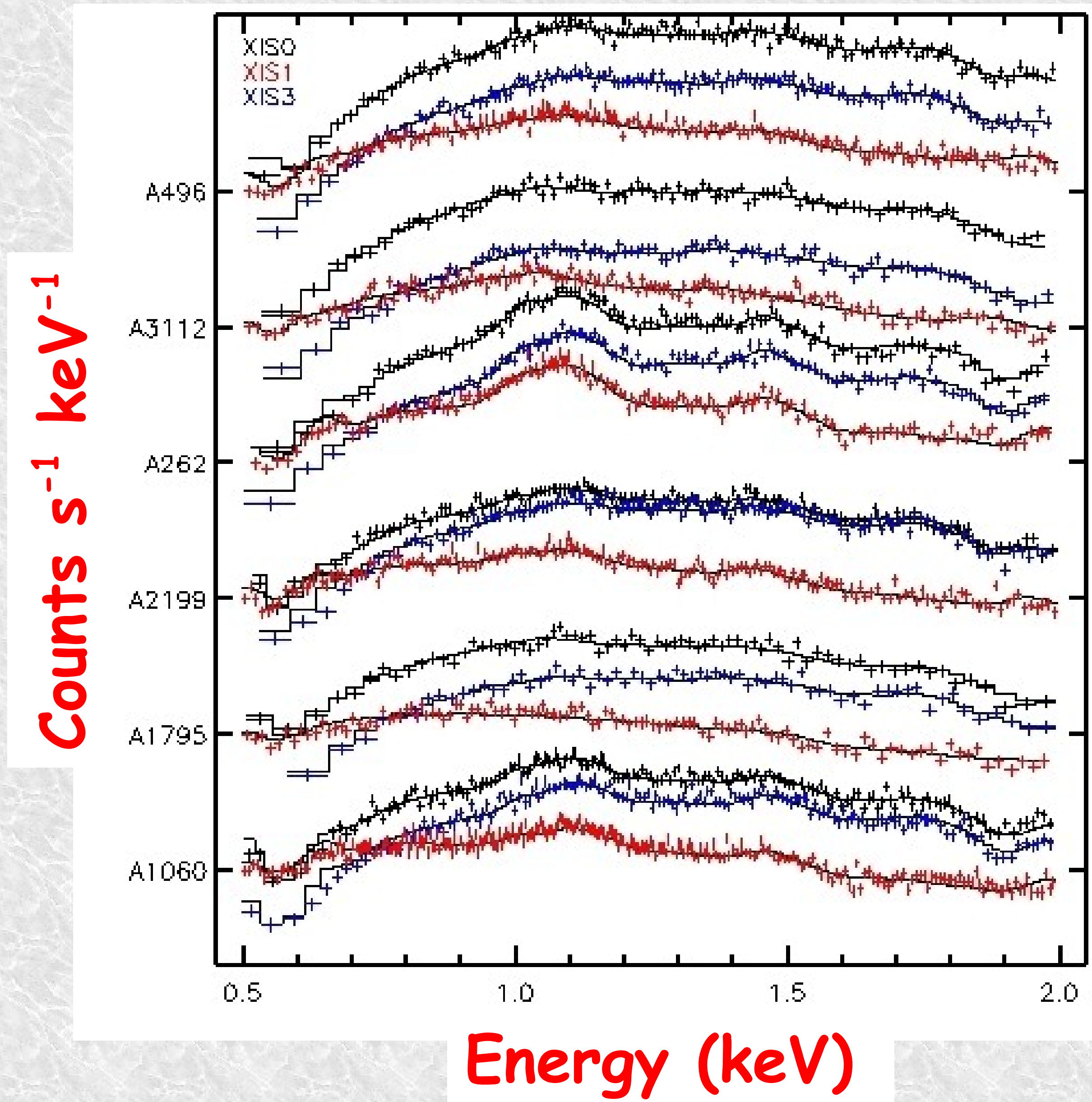


- Varying N_O, the effctive area energies due to O edge
- Varying O column by 3σ (the reported O measurement stat. + sys uncertainty is $\pm 5\times10^{16}$ cm^{-2}) yields 20% effect as required by the clusters by minimum.

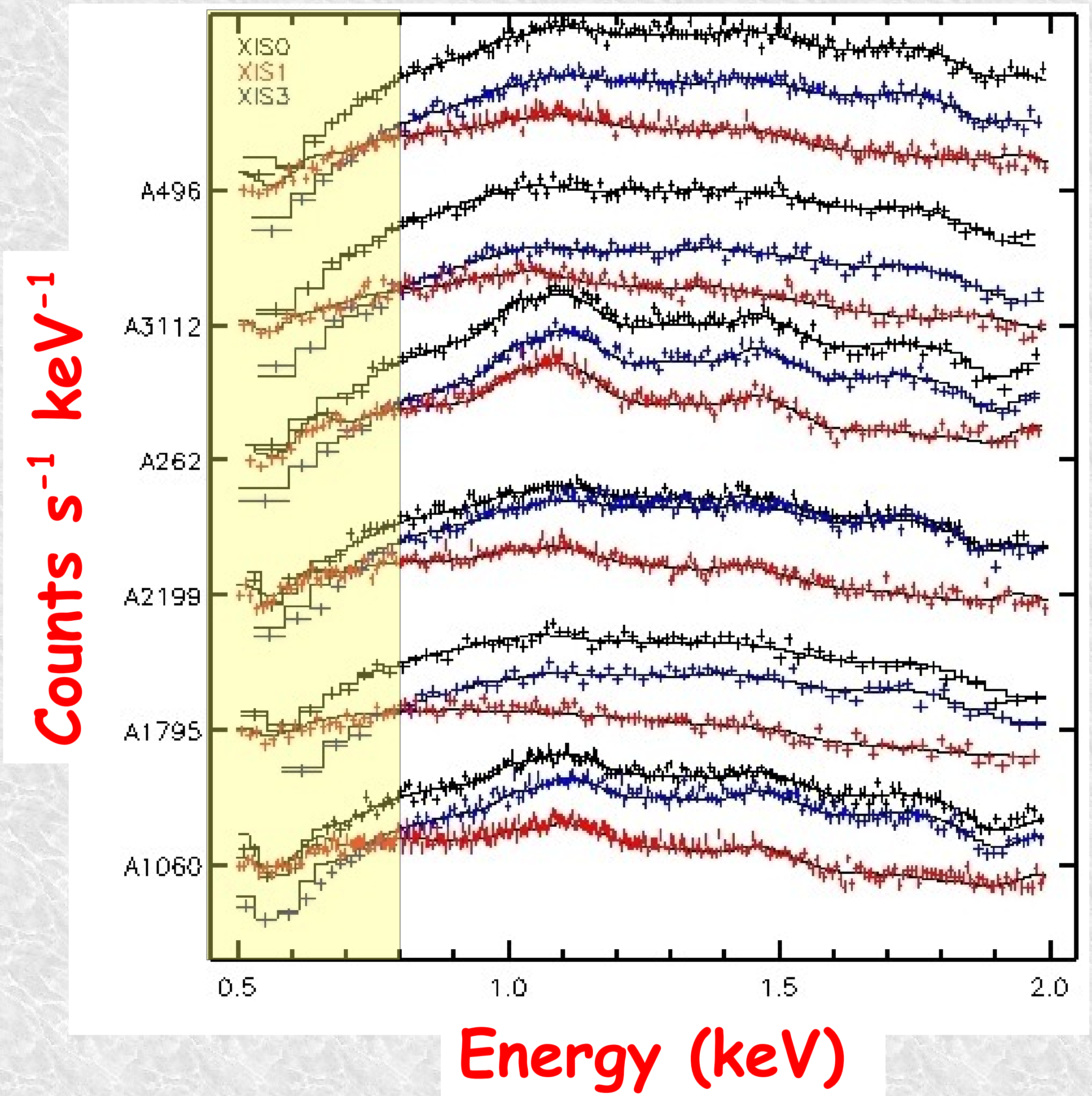
Transparency of the contaminant



We can measure the total O column with clusters



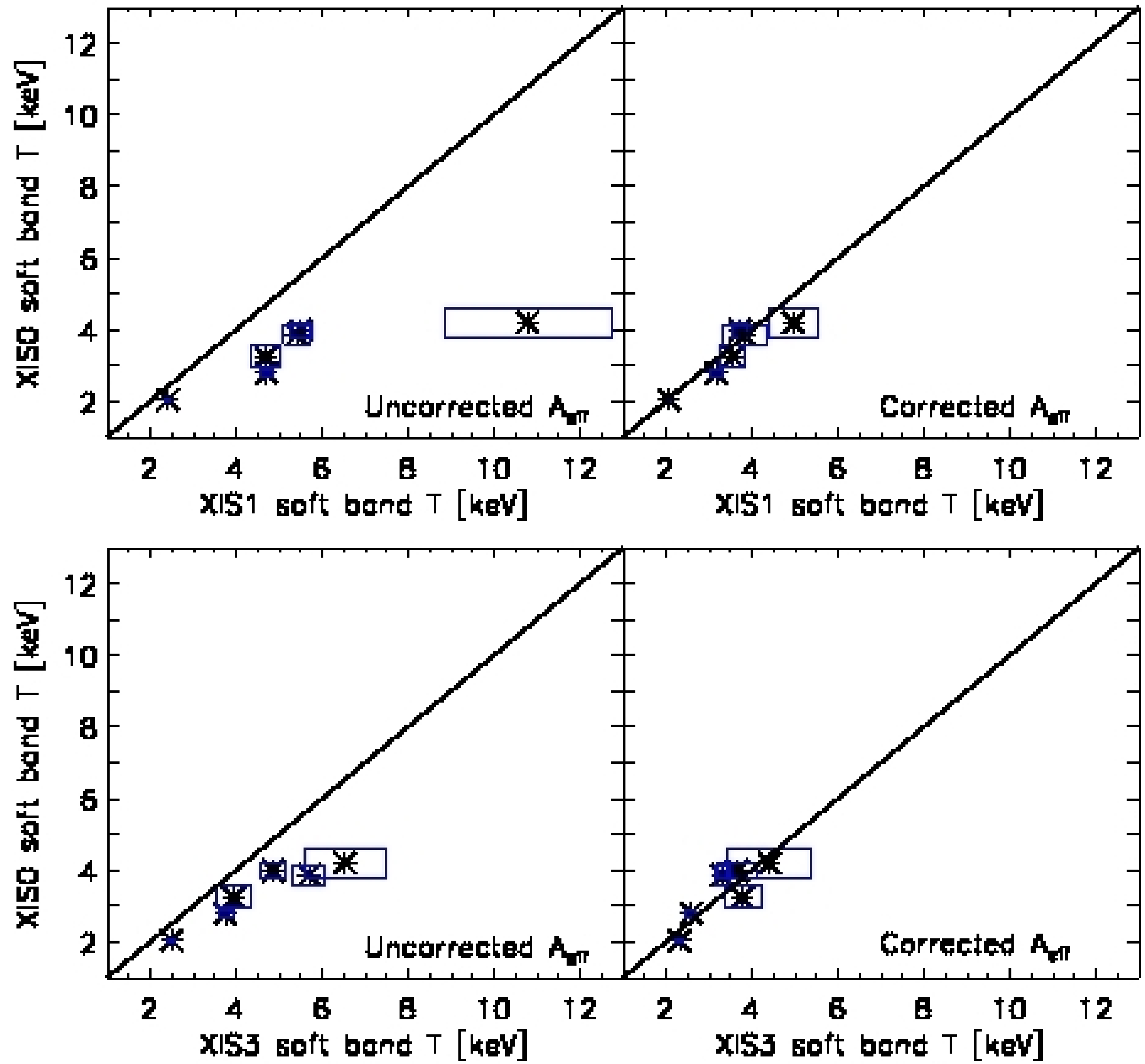
We can measure the total O column with clusters



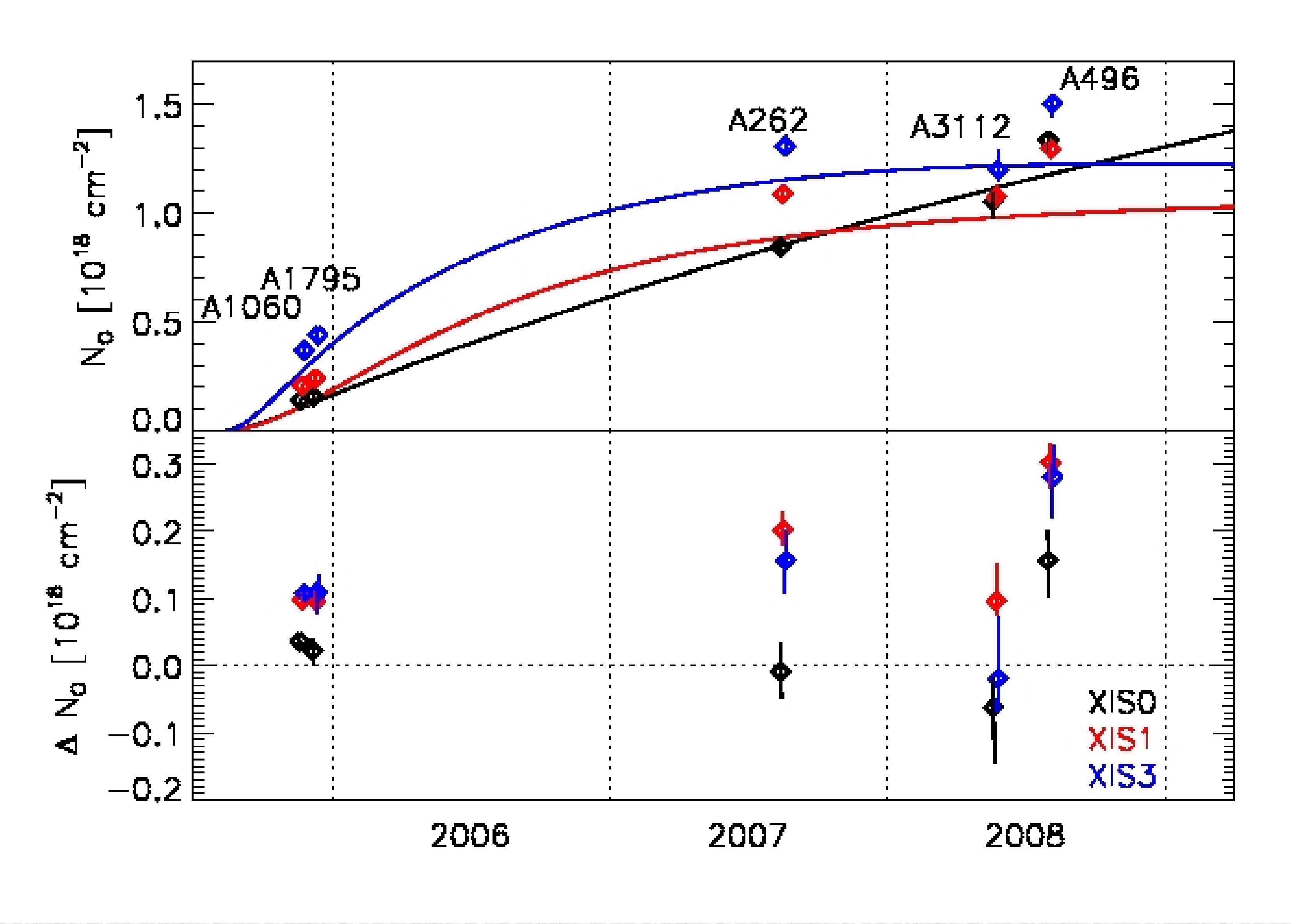
Fitting the arf

- We fit the XIS0,1,3 cluster spectra simultaneously with a model where temperatures are forced equal and the models multiplied by a local XSPEC contaminate model **hcorat**
- H/C fixed to CALBD value
- O/C fixed to time dependent CALDB value
- We allow only the O column density to vary, in order to find the best effective area when keeping the emission model fixed
- The best-fit yields the required change in O column density ΔN_O

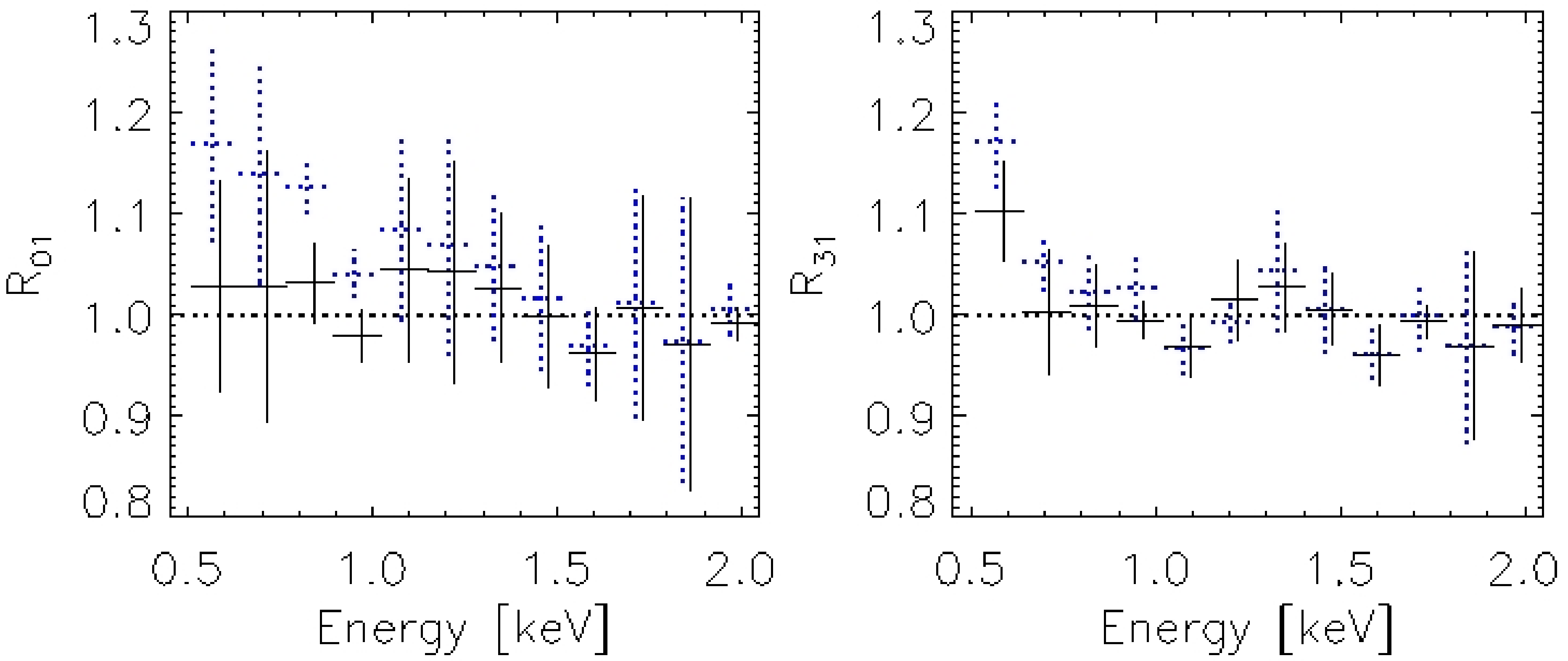
Temperatures using modified response



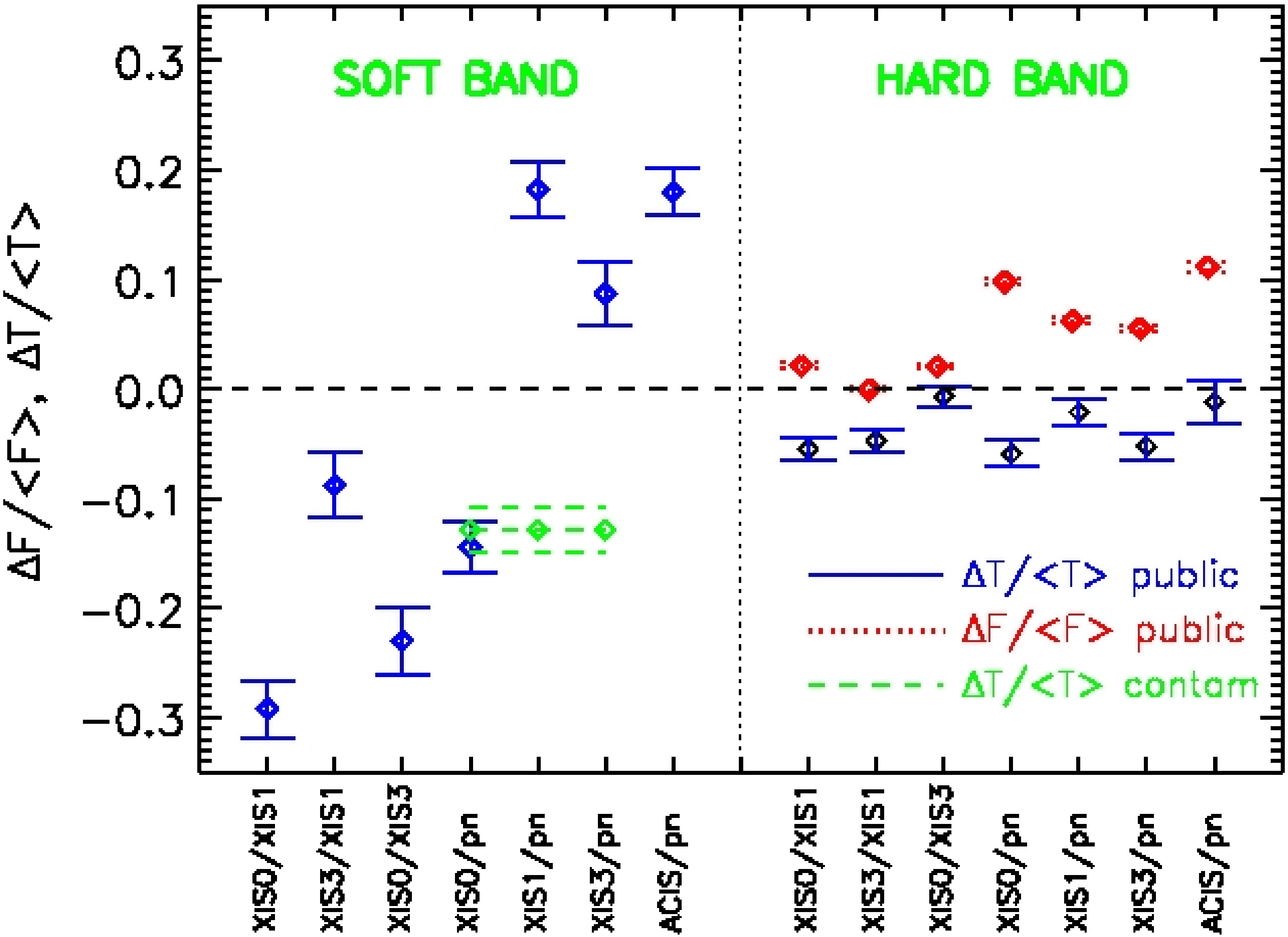
Required column densities



Soft band stack residuals



Summary of temperatures



Data in wiki page

- WIKI