Clusters of galaxies WG session

11th IACHEC meeting, 2016, IUCAA, India

IACHEC Clusters of Galaxies WG Action items from April 2015

1) HIFLUGCS Fe and S emission line ratio spectroscopy ***(Gerrit, JN)***
2) HIFLUGS data to WIKI ***(Gerrit, JN)***
3) Multi Mission Study ***(JN...)***
4) Residual ratios for simultaneous XMM/Chandra blazar observations ***(JN, M. Smith, H. Marshall)***
5) Astro-H AO ***(JN)***
6) AstroSat calibration time / AO ***(JN, K. Mukerjee)***
7) NuSTAR AO ***(JN, Karl Forster)***
8) eROSITA

1) Multi-Mission Study

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

11th IACHEC meeting 2016, Pune, India

1.1) Method for evaluating cross-cal uncertainties

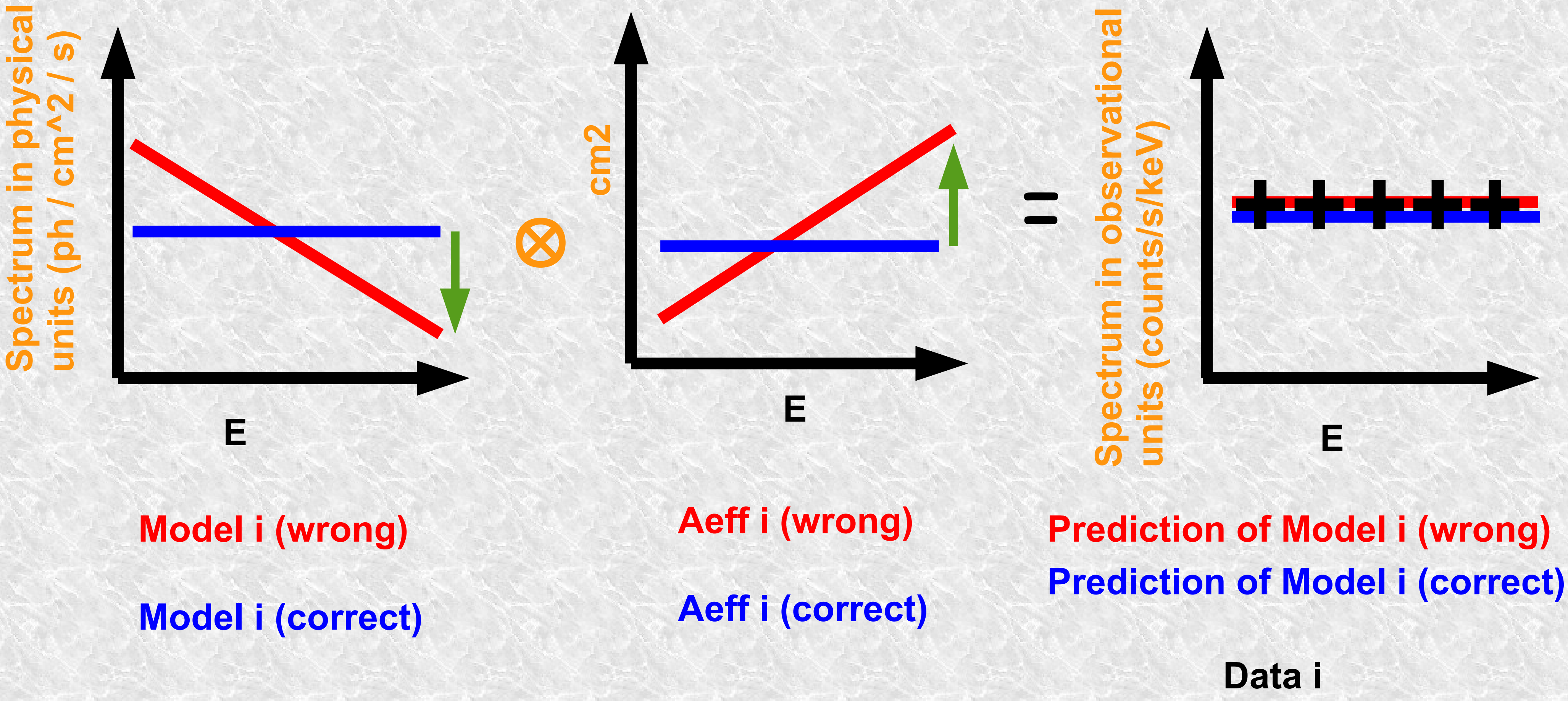
- Comparison of cluster spectra measured with XMM-Newton/EPIC, Chandra/ACIS, Swift/XRT, Suzaku/XIS, ROSAT/PSPC
i.e. 5 missions, 10 instruments

- Residual ratios to evaluate the effective area cross-calibration:
  - At the moment we use EPIC-pn as a reference instument **ref**
  - For instrument **i** we calculate the mean of the ratio

$$R_{i/ref} = \frac{data_i}{model_{ref} \otimes resp_i} \times \frac{model_{ref} \otimes resp_{ref}}{data_{ref}}$$

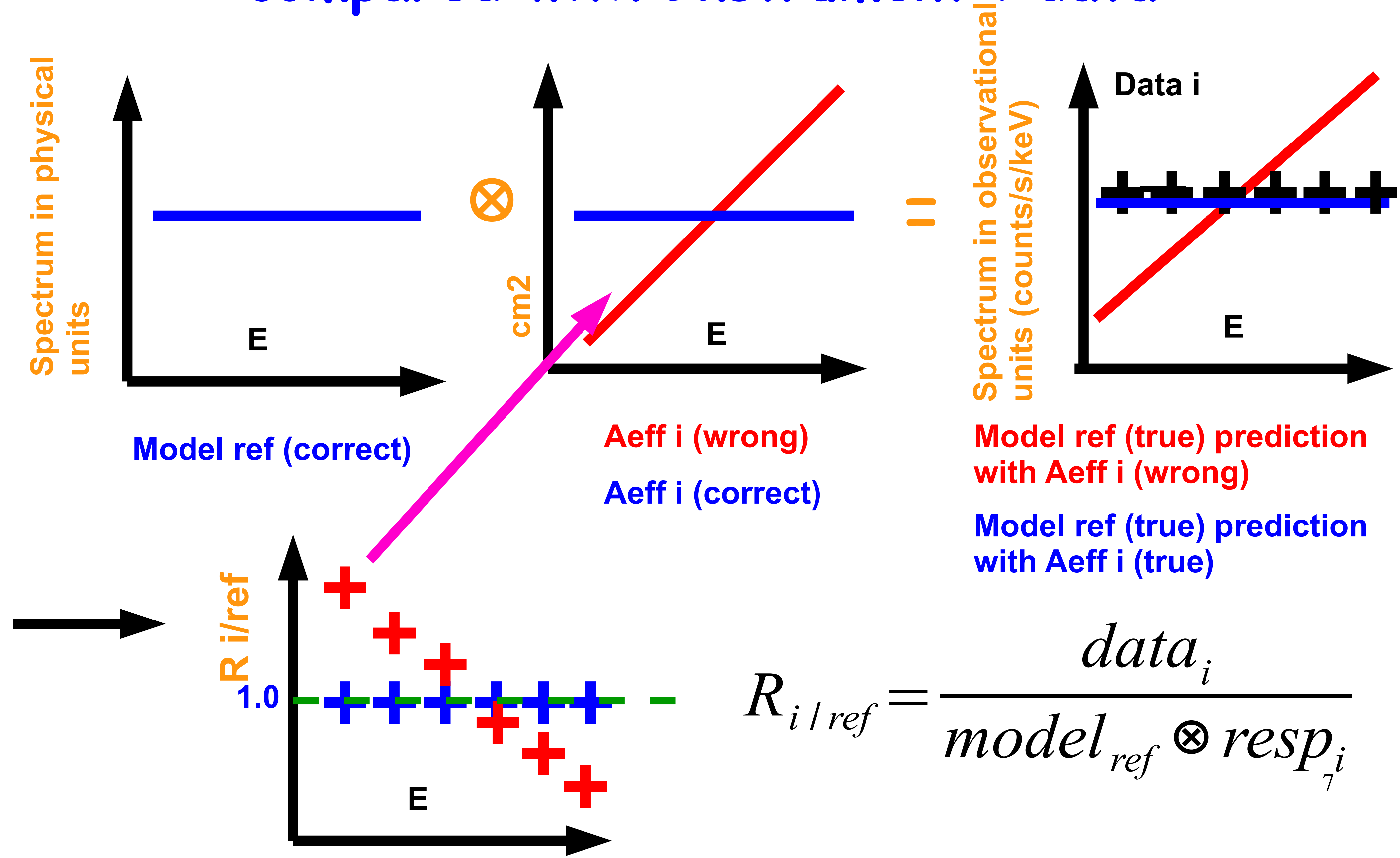
- The latter term corrects for deviations btw. pn model and pn data which cannot be produced by the model (no point in comparing reference instrument with another using a model which does not fit the reference instrument data)

Instrument i, calibration incorrectly implemented



Biased best-fit model obtained

Instrument ref model (correct) prediction compared with Instrument_i data

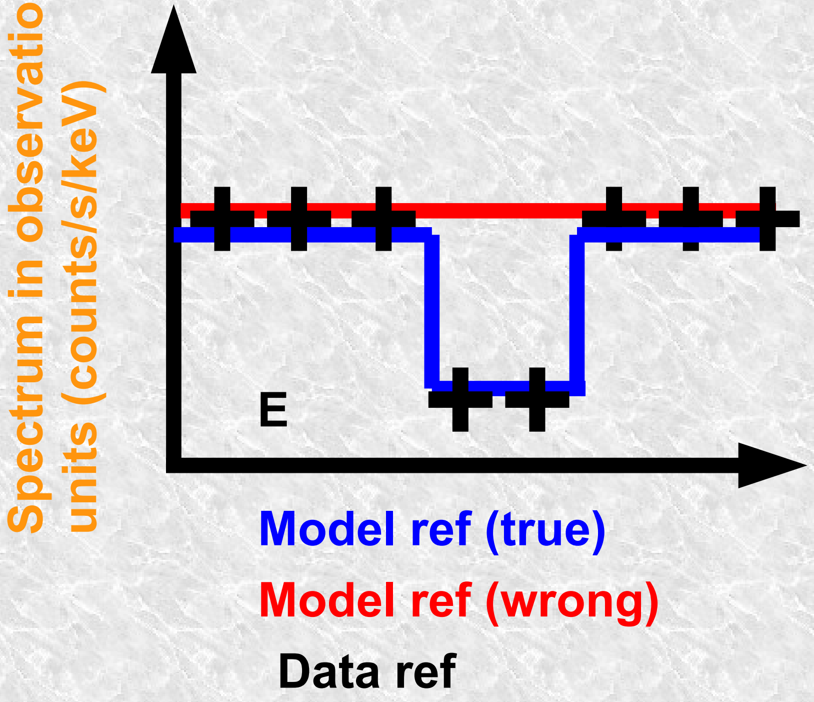


$$R_{i/ref} = \frac{data_i}{model_{ref} \otimes resp_i}$$

- Deviation from unity tells that there is a mismatch between the model prediction of Instrument ref and the data of Instrument i
- Because we “know” that Instrument i is wrong, the residuals tell by how much at each energy
- In practise we do not know which, if any, instrument is accurately calibrated
- Residuals tell that the combined effect of the calibration inaccuracies of the two instruments is at the level indicated by the residuals
- The cross-calibration uncertainties evaluated

A complication

- Above we assumed that the (true) Model ref describes the data ref accurately
- If the reference instrument model does not describe accurately the reference data, its prediction with **a correct Aeff i** is problematic to interpret
- Usually it is also problematic to fit the data accurately

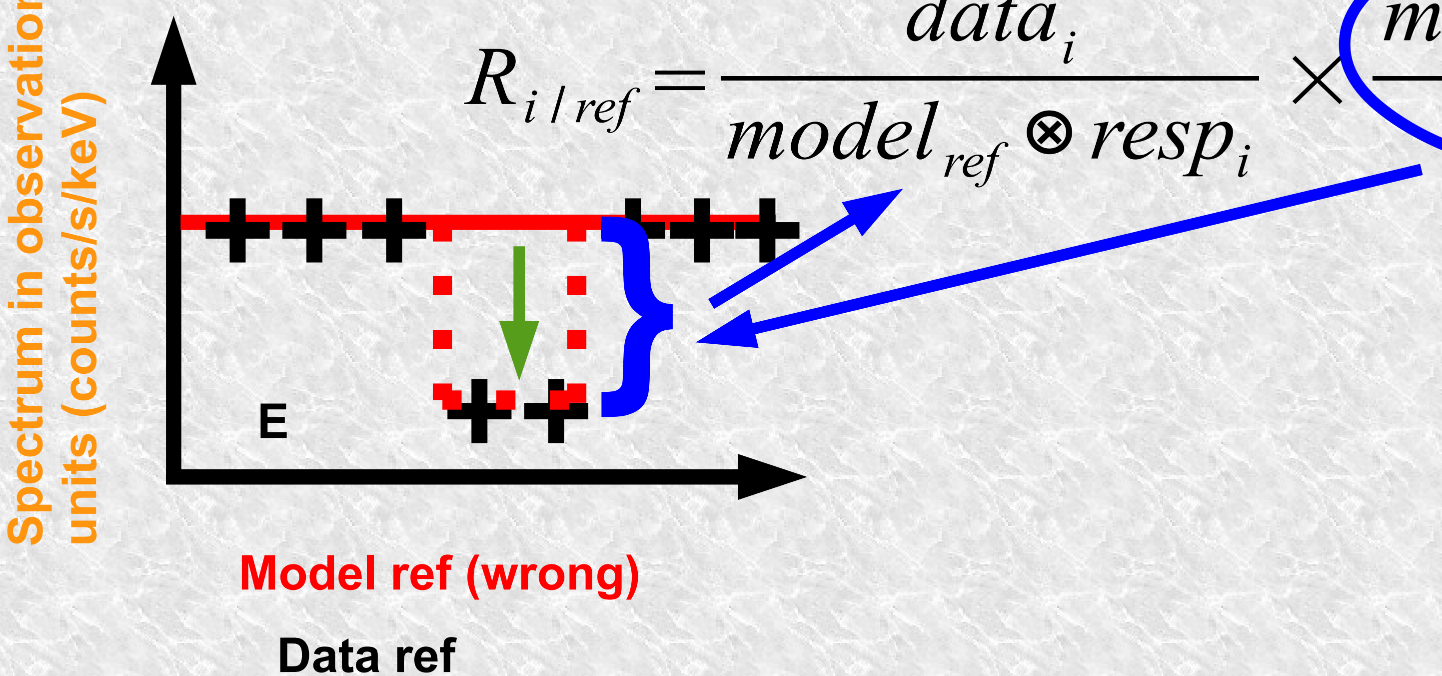


$$R_{i/ref} = \frac{data_i}{model_{ref} \otimes resp_i}$$

Solution

- A phenomenological mathematical model that fits the data is OK for cross-cal
  - Since we know the relative difference between the data ref and model ref, we can use this info to correct the model prediction to match the data (fudge factor kind of thing)
  - A second term on the R formula does exactly that

$$R_{i/ref} = \frac{data_i}{model_{ref} \otimes resp_i} \times \frac{model_{ref} \otimes resp_{ref}}{data_{ref}}$$

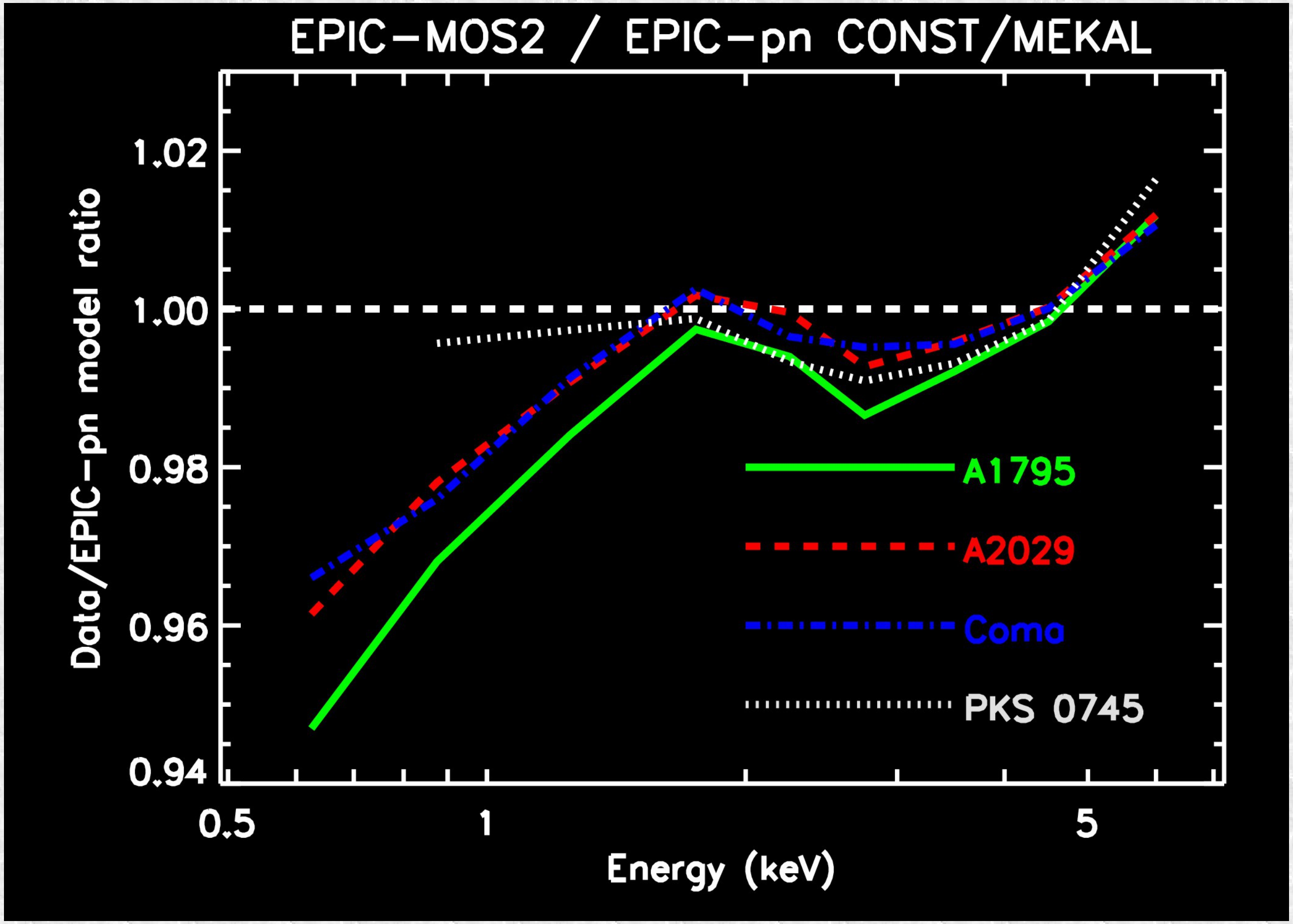


- Caveat: due to statistical uncertainties you will never reach the absolutely correct model, whatever method you use
- Keep statistical uncertainties small compared to the calibration effects
- In other words given the statistical uncertainty level, one can only study systematic effects bigger than this
- In cluster sample we aim to keep statistical uncertainties at 1% level.

1.2) Reference model accuracy does not matter

Model accuracy does not matter

- For the **relative** effective area comparison the accuracy of the reference model does not matter much
- Proof: MOS2/pn residuals ratios for the sample using phabs x mekal or **a constant** model for fitting pn spectra: above 1 keV differences at the level of statistical error of 2%.



1.3) Extraction regions

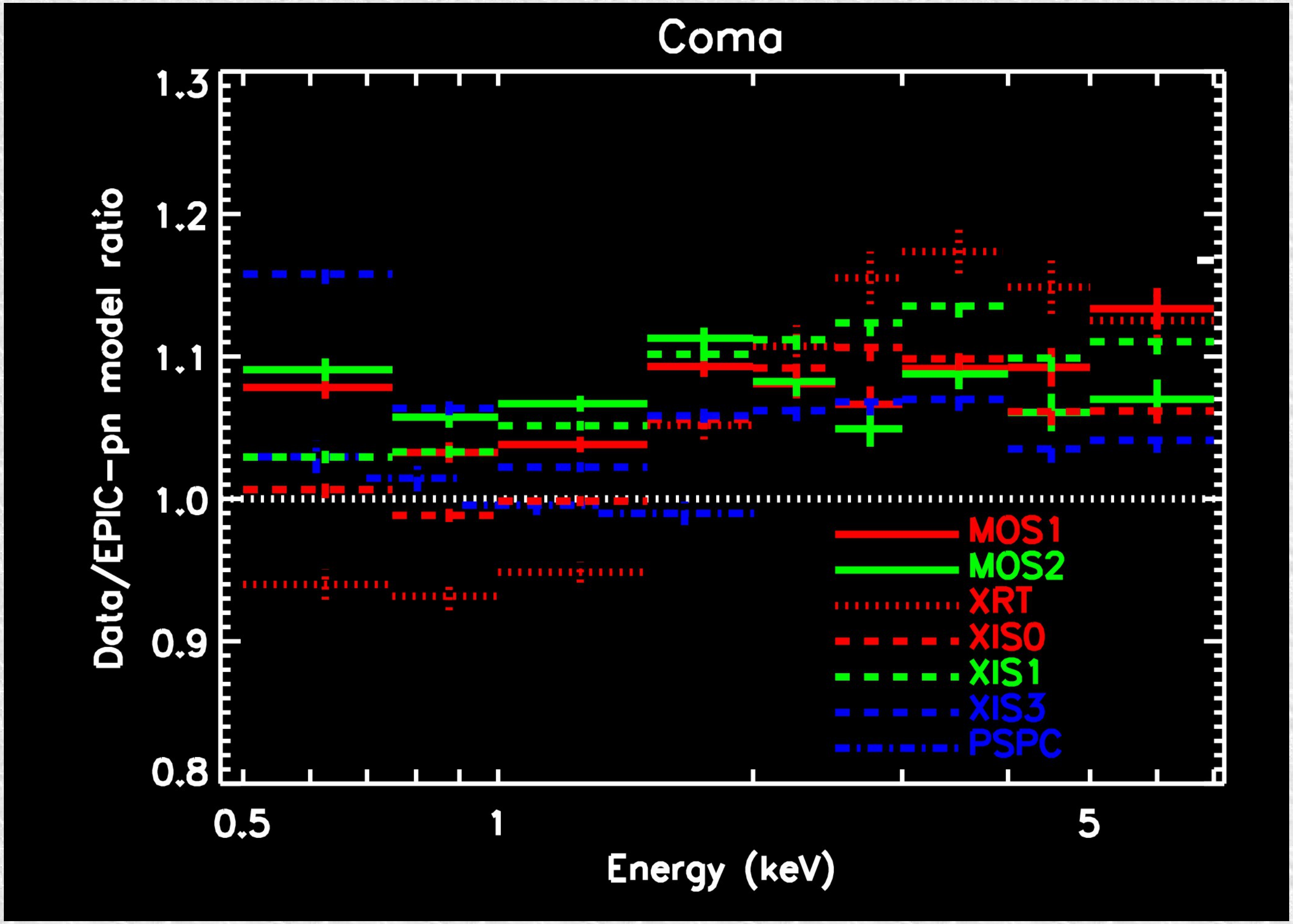
Define extraction region

- So it is OK to use mergers and cool cores and fit them with whatever model ➔ extract spectra from clustercentric circle with extraction radius r_{ext}
- Lower limit of r_{ext} affected by requirements of
  - a few% statistical precision in small enough energy bins **DEFINE**
- Upper limit of r_{ext} affected by requirements of
  - Bkg below 10% **DEFINE** of signal in the 0.5-7 keV range
- At the moment we use r_{ext} = 6 arcmin

Statistical precision

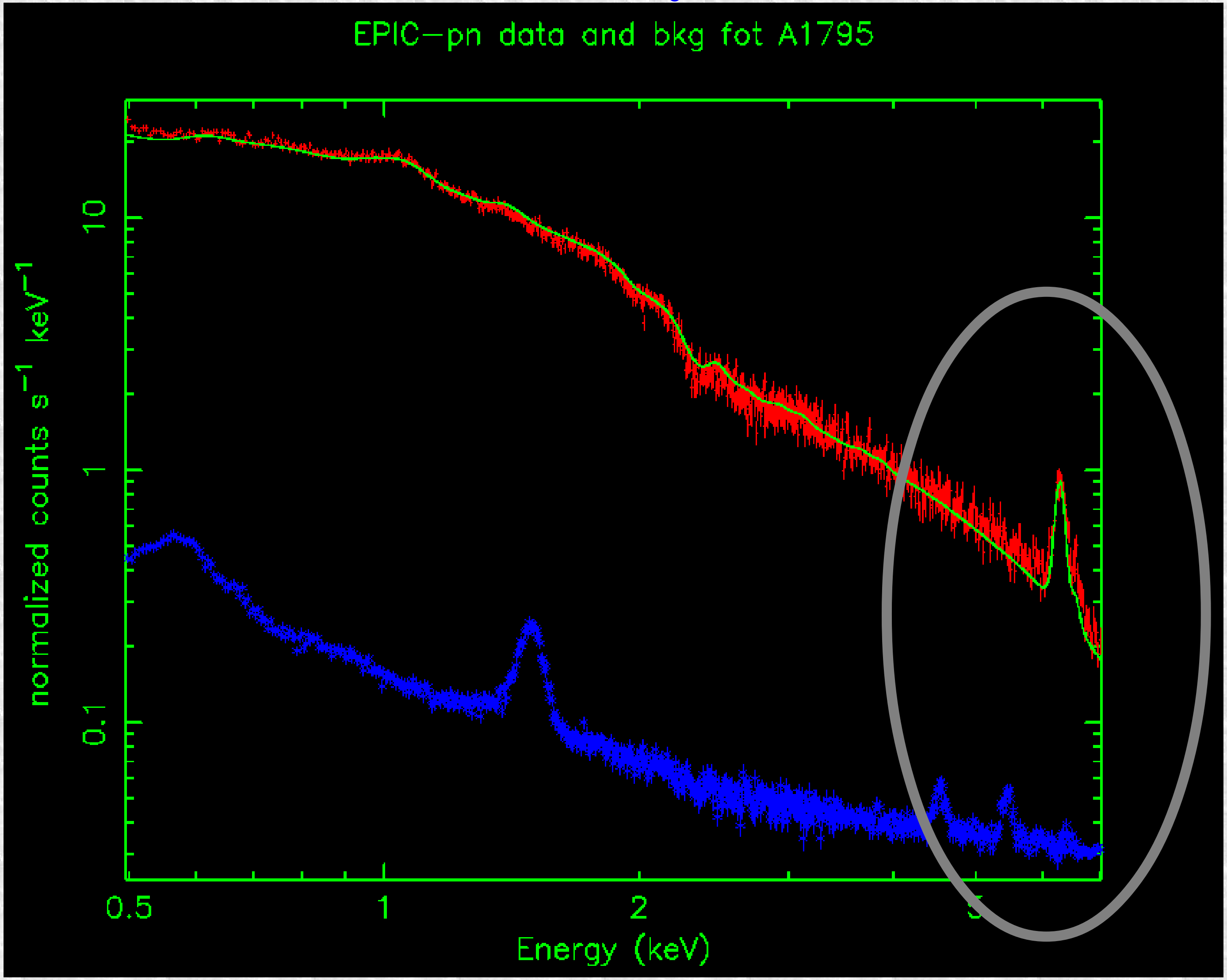
- At the moment we use 9 spectral bins (ROSAT 4 bins)
- 3% statistical precision in each bin→ 100000 c (40000 c ROSAT)

Coma r_{ext} = 6' : 17 ks EPIC exposure



Bkg/source signal for A1795 with XMM-Newton pn

- r_{ext} > 6' makes things worse at E = 7 keV
- KT < 6 keV makes things worse at E = 7 keV



Define extraction region

- Choice of the extraction radius determines what region of the instrument we calibrate
- Nearest hottest clusters limited to $r_{ext} \leq 6$ arcmin by bkg
- Our scope in this project is the ≈ on-axis effective area

1.3) Cluster selection

Cluster selection criteria

- Hot enough so that we
  - have enough counts at the highest energies *(Perseus is an exception, perhaps a few more* ***TBD****)*
  - minimise the 1 keV line emission (we are studying the effective area, not RMF nor energy scale calibration), i.e kT > ≈ 6 keV **DEFINE**
- Not too distant so that the cluster is not too faint i.e. **z < X DEFINE**
- Observed with XMM-Newton, Chandra, Suzaku, Swift and ROSAT

1.4) Observation selection

Observation criteria

- For selecting the observations with the above 5 missions, we require
  - The total exposure time must be at least X ks to obtain good enough statistics (in our 4 cluster sample, at least 10 ks required for $\mathbf{r}_{ext}$ = 6') **DEFINE**
  - The center of the cluster must not be too much offset (< ≈ 3 arcmin **DEFINE**) from the center of the FOV of the pointing so that we don't fold in instrument effects which are different between the central and outer regions of the FOV (e.g. vignetting). **Check this in detail. Perhaps we can relax this**
  - Merging of multiple observations **DEFINE** (close in time?)

1.5) Current sample

Sample

- Currently the sample consists of

  A1795, A2029, Coma and PKS 0745-19

Calibration versions studied

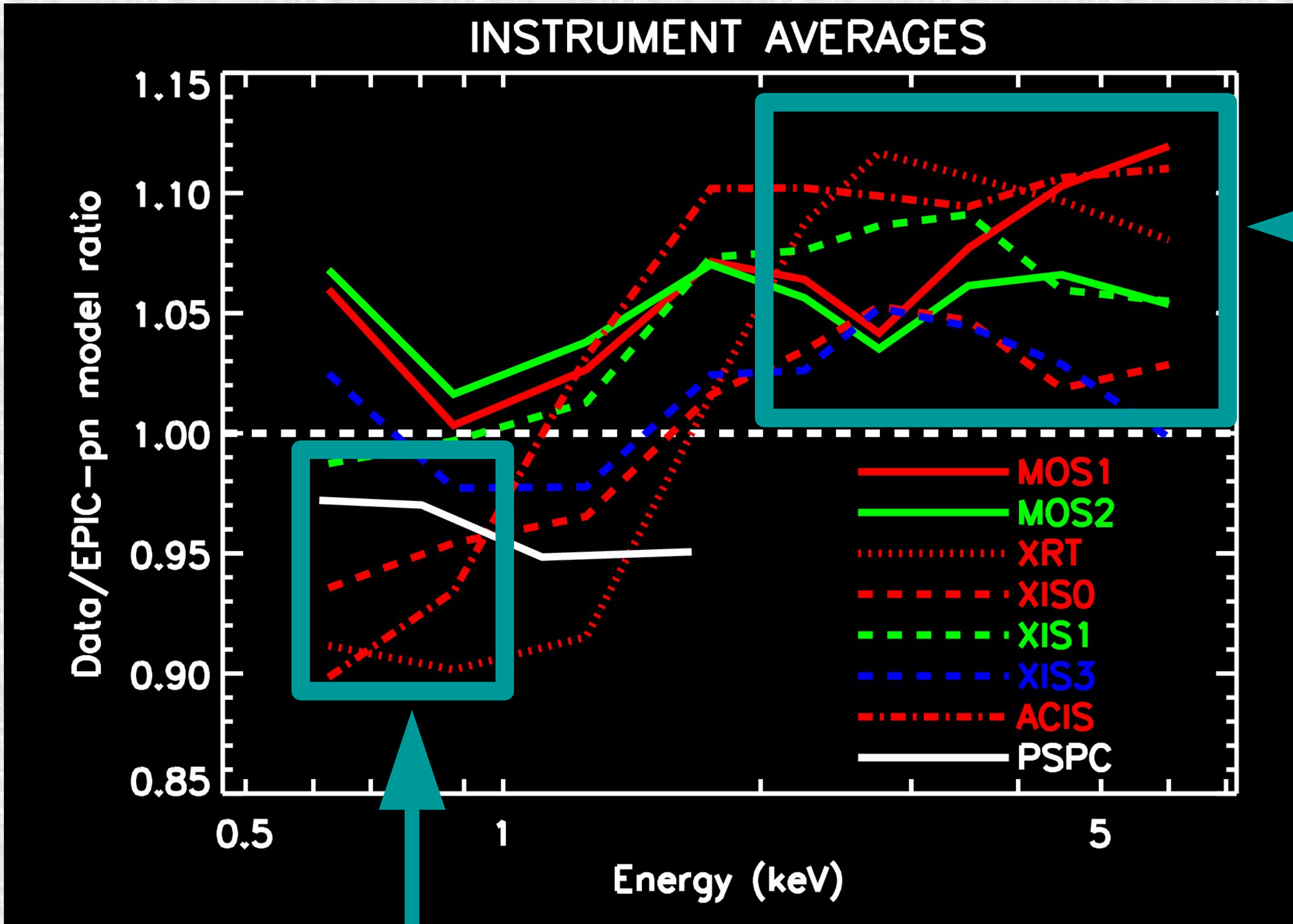
Satellite/instrument	Date of processing	Software/CALDB
XMM-Newton/EPIC	April 2014	xmmsas_20131209_1901-13.5.0
Chandra/ACIS	May 2014	ciao-4.6
Swift/XRT	April 2014	
Suzaku/XIS	May 2014	xissimarfgen 2010-11-05 ae_xi0_contami_20130813.fits
ROSAT/PSPC-B	May 2013	

At the moment the results apply to calibration status on May 2014

1.6) Preliminary results from the 4 clusters sample

Residuals ratios

The average instr/pn residual ratio of each pair



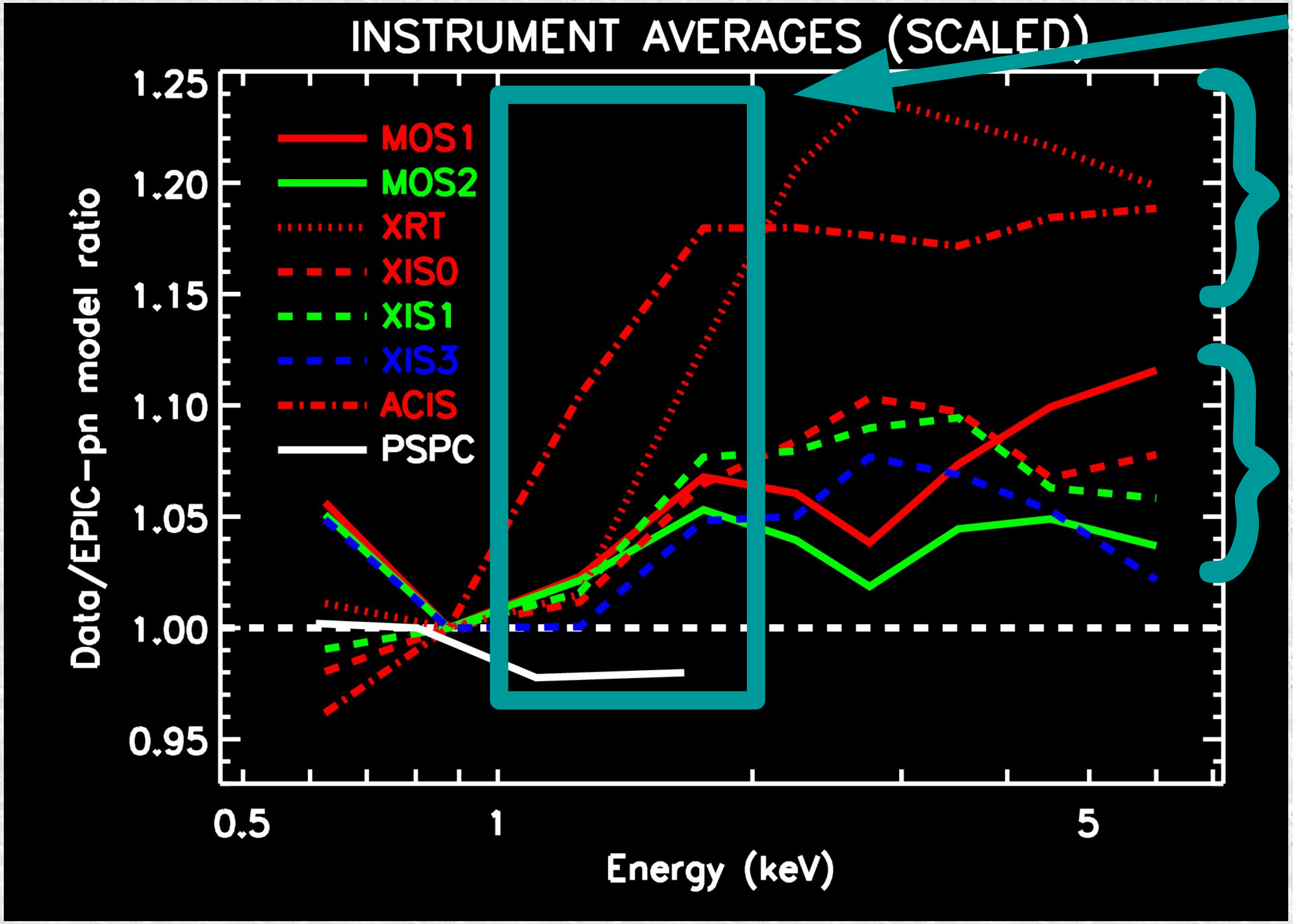
All instruments show higher flux than pn at > 2 keV, but with a varying degree (0-15%)

Most instruments show lower flux than pn at < 1 keV, but with a varying degree (0-10%)

Request 1 to IACHEC community: Are the evidence convincing enough to make conclusions about EPIC-pn calibration?

Scaled residuals ratios

The average instr/pn residual ratio of each pair, scaled to unity at 0.75-1.0 keV



The 1-2 keV gradient:

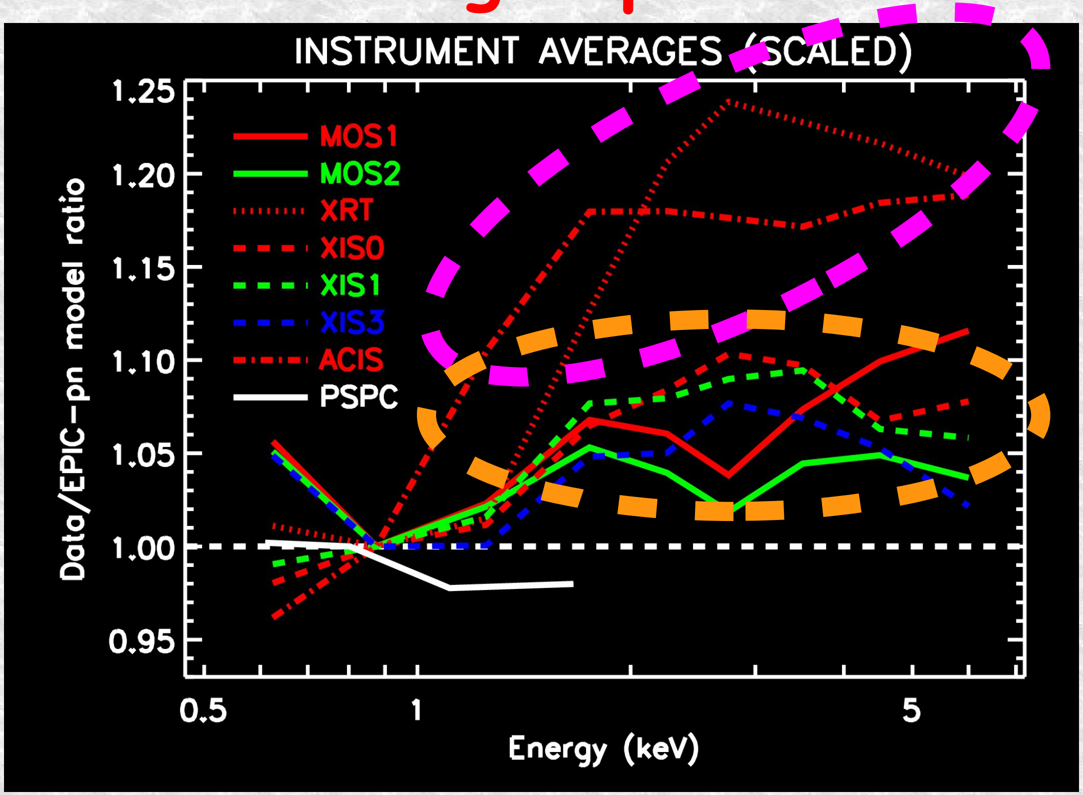
1) Swift/XRT and Chandra/ACIS similar: 20% increase

2) XMM/MOS and Suzaku/XIS similar: 5% increase

➔ Not a single instrument is guilty

Scaled residuals ratios

Request 2 to IACHEC community: explain why there are the two groups



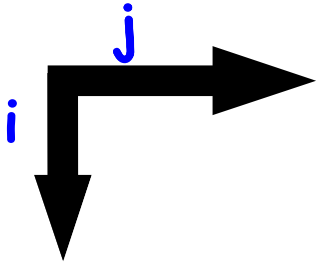
A) Chandra/ACIS & Swift/XRT

B) EPIC/MOS & Suzaku/XIS

The average instr/pn residual ratio of each pair, scaled to unity at 0.75-1.0 keV

I.e. is (are) there some element(s) of the effective area instrumentation or calibration that is (are) common within a given group, but different btw. the two groups?

1.6) More satellites/instruments



Current data base

	A1795	A2029	Coma	PKS 0745-19
XMM	☺	☺	☺	☺
Chandra	☺	☺	☺	☺
Suzaku	☺	☺	☺	☺
Swift	☺	☺	☺	☺
Rosat	☺	☺	☺	☺
NuSTAR	😐	😐	☹	😐
eRosita	😐	😐	😐	😐
AstroSat	☺	😐	😐	too short
Astro-H	☹	☹	☹	☹

Astrosat

- Currently **A1795, PKS 0745-19**, A496, Perseus and A2256 observed

Astro-H

- Clusters do not contribute much in the HXD
- Clusters not good for internal AstroH calibration
- Blazars good for both internal and cross-mission calibration, and thus are preferred
- Have to do through science AO

eRosita

- All sky observed, including MMS list, but only shortly ($\approx$ 1ks)
- Michael Freyberg from eRosita team tries to cover our clusters with pointed observations

2) Increase the current cluster sample

More clusters

- Need more clusters to be able to derive statistically robust conclusions (e.g. when applying Prof. Meng's method, Concordance Calibration)
- Following list consists hot nearby clusters from HIFLUGCS sample, following these criteria:
  - kt > 6 keV, except for Perseus
  - Offset btw. the cluster center and pointing FOV center < 3 arcmin
  - Exposure > 10 ks in the available data

X: XMM/EPIC

C: Chandra/ACIS

R: ROSAT/PSPC

SW: Swift/XRT

SU: Suzaku/XIS

AS: Astrosat/SXT

A1835?

cluster	X	C	R	SW	SU	AS
A85	☺	☺	☺	☹	☹	☹
A119	☺	☺	☺	☹	☹	☹
A399	☺	☺	☺	☹	☹	☹
A401	☺	☺	☺	☺	☹	☹
A478	☺	☺	☺	☹	☹	☹
A754	?	☺	☹	☹	☹	☹
A644	☺	☺	☺	☹	☹	☹
A1413	☺	☺	☺	☹	☹	☹
A1650	☺	☺	☹	☹	☹	☹
A1651	☺	☺	☺	☺	☹	☹
Coma	☺	☺	☺	☺	☺	☹
A1689	☺	☺	☺	☹	☹	☹
A1795	☺	☺	☺	☺	☺	☺
A1914	☺	☺	☺	☹	☹	☹
A2029	☺	☺	☺	☺	☺	☹
A2065	☺	☺	☹	☹	☹	☹
A2142	☺	☺	☺	☹	☹	☹
A2163	?	?	☹	☹	☹	☹
A2204	☺	☺	☺	☹	☹	☹

cluster	X	C	R	SW	SU	AS
A2244	☺	☺	☺	☺	☺	☹
A2255	☺	☺	☺	☹	☹	☹
A2256	☺	☺	☺	☹	☺	☹
A2319	☺	☺	☹	☹	☹	☹
A3158	☺	☺	☹	☹	☹	☹
A3266	?	☺	☹	☹	☹	☹
A3391	☺	☺	☺	☹	☹	☹
A3558	☺	☺	☹	☹	☹	☹
A3571	☺	☺	☺	☹	☺	☹
A3627	?	?	☺	☹	☺	☹
A3667	?	☺	☺	☹	☺	☹
A3827	☺	☺	☹	☹	☹	☹
A3888	☺	☺	☺	☹	☹	☹
Ophiu	☺	☺	☺	4ks	☺	☹
Perse	☺	☺	☺	☺	☺	☺
PKS0745	☺	☺	☺	☺	☺	☹
RXCJ1504	?	?	?	☹	?	☹
Triang	☺	☺	☺	☹	☺	☹
ZwCl1215	☺	☺	☹	☹	☹	☹

All 5 instruments

- 6 (or 7) clusters observed with all with good enough data
  - Sample too small **(is it?)** for proper statistics (Prof Meng's method) ☹
  - Common wisdom not true: "Your clusters will eventually be observed, don't worry" ☹
  - Need to promote the cluster sample to the instrument calibration teams to be able to proceed. This is hard even with the 4 clusters. ☹
    - Try pushing the 10-20 keV band of the hottest clusters **(TBD)**
  - Calibration via science AO: contrived. Hard to make a competitive proposal by justifying scientifically the most studied bright nearby clusters ☹

    ➔ Need to pick the data if/when observed, as before ☹
  - Fortunately **ATHENA** team has cross-mission calibration early in the mission planning ☺

Subsamples of instruments

- XMM + Chandra + Swift ≈ 9 clusters
- XMM + Chandra + Suzaku ≈ 10 clusters
  - ➔Numbers remain small

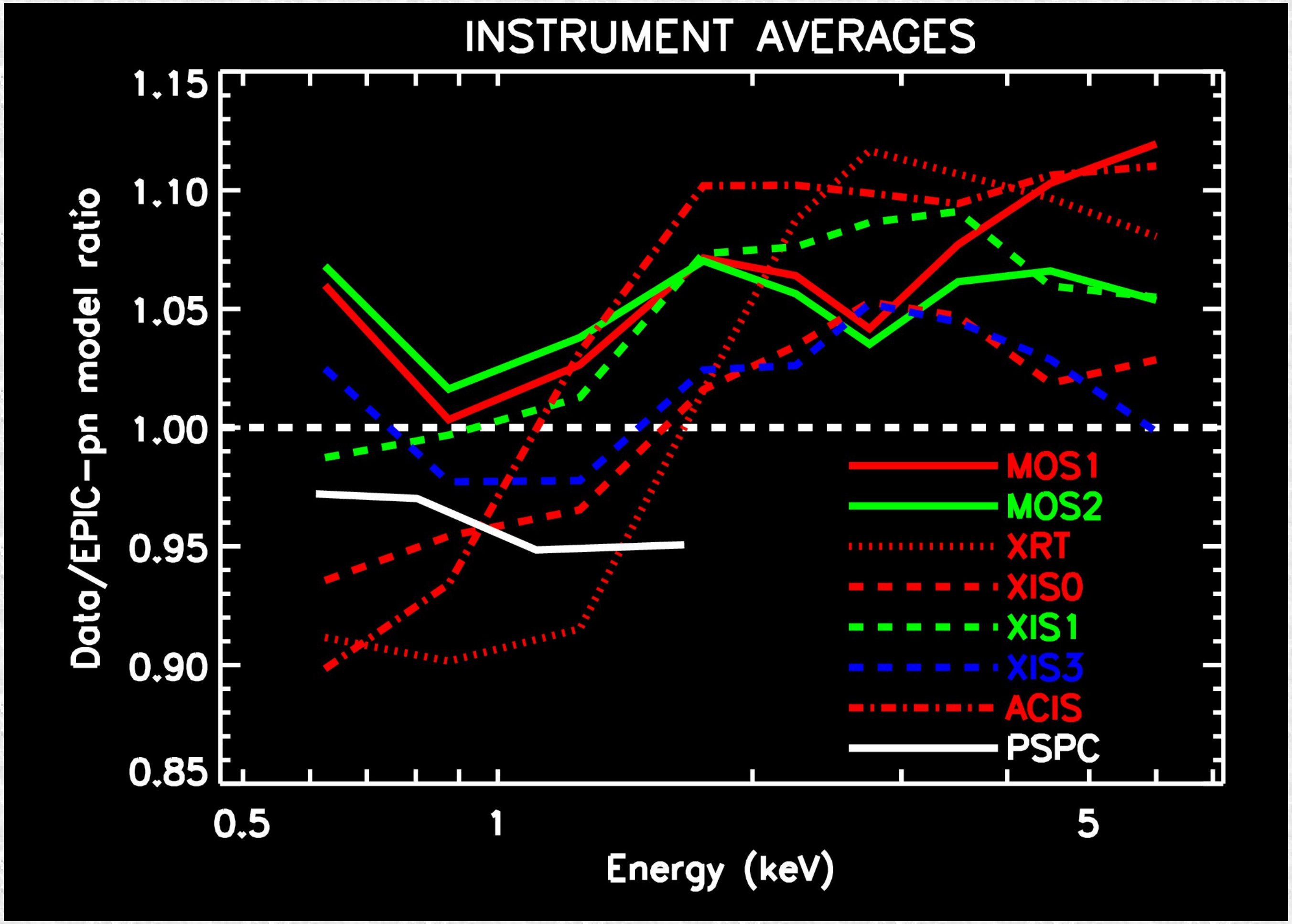
Subsamples of instruments

- XMM + Chandra + ROSAT : 25 clusters
  - This is currently the only statistically useful sample
  - Requires 250 ks of XMM time, i.e
  - Similar eROSITA time **(is this feasible?)**
  - Ms ASTROSAT time **(not feasible)**
  - Ms AstroH time **(not feasible)**
  - 25 ks of ATHENA time **(piece of cake, right?)**

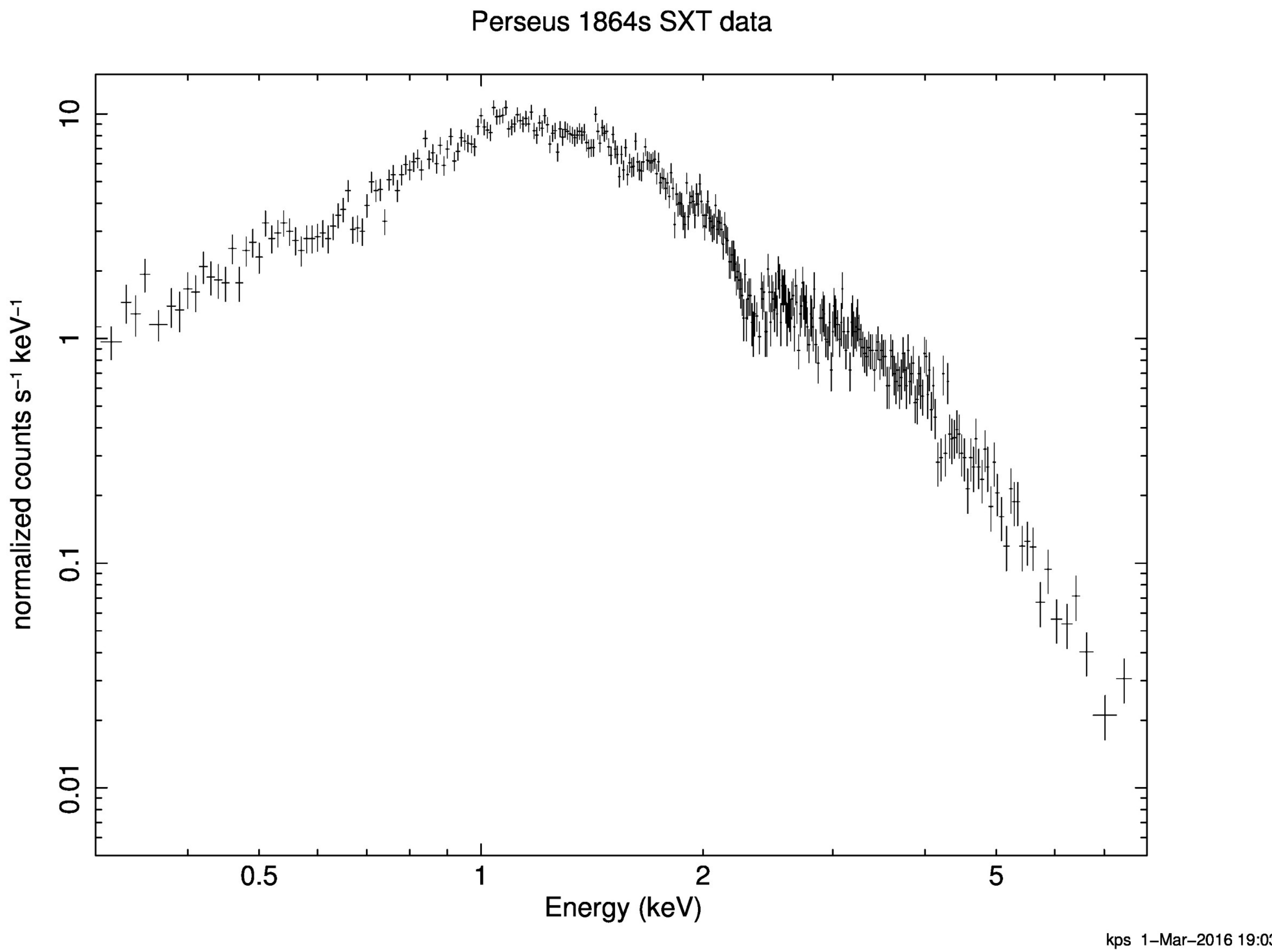
- Add cooler very nearby clusters, which might have enough counts up to E=7 keV (like Perseus)

So?

- Let's add the available data XMM, Chandra, ROSAT, Swift, Suzaku) into sample, try relaxing some of the criteria, and proceed for a publication



AstroSat SXT


Perseus 1864s SXT data
normalized counts s⁻¹ keV⁻¹
10
1
0.1
0.01
0.5
1
2
5
Energy (keV)
kps 1–Mar–2016 19:03

Count requirements

- Requirement of a few % statistical uncertainty level in 9 spectral bins very tough: total 100000 c (0.5-7 keV band) in the r=6 arcmin spectrum
- Perseus and A1795 OK
- Have to relax the criteria for Astrosat comparison?

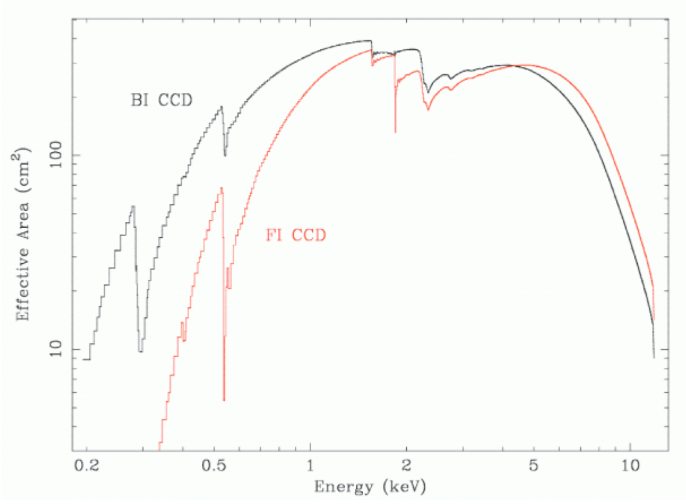
From the full FOV r=20'

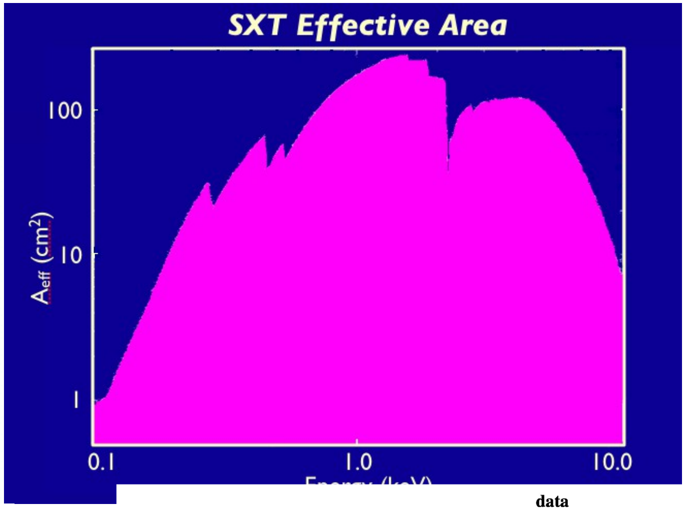
cluster	pn	pn	AS	AS
	exp. time ks	counts 0.5-7.0 keV	exp. time ks	counts 0.5-7.0 keV
A1795	14	370000	100	
A2256			80	
Perseus		470000	24	306000
PKS0745-15	10	160000	53	37000

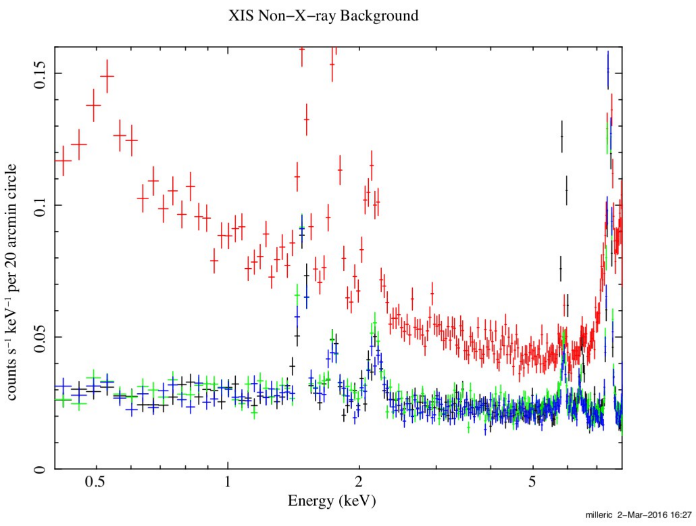
T measurement of A1795 at the virial radius?

Suzaku

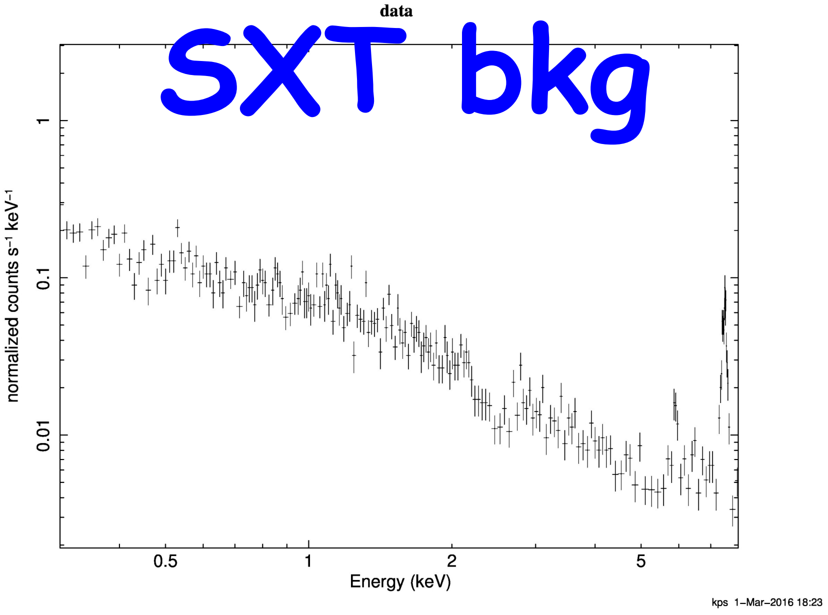
XIS A_{eff}





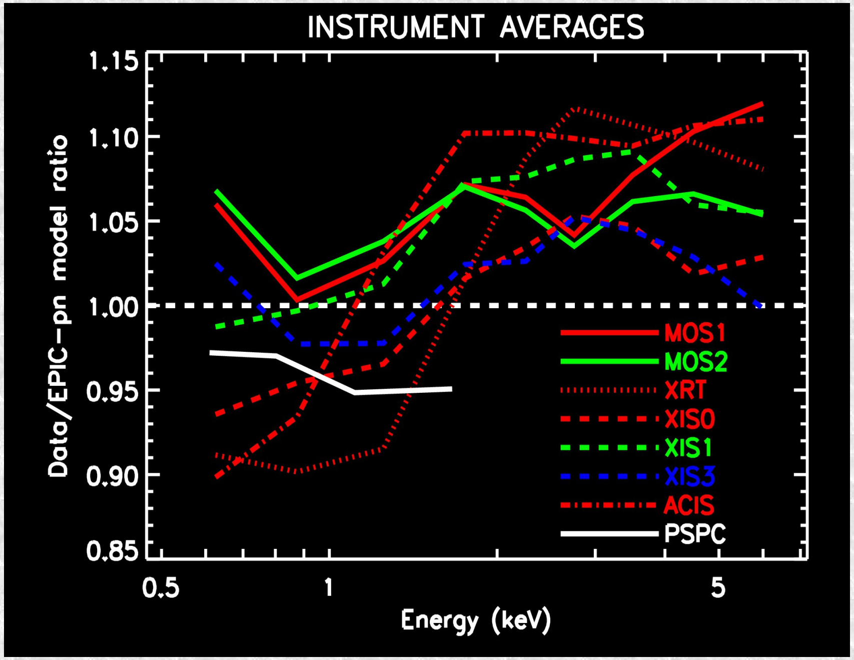


SXT bkg



Could we get τ values for Concordance Calibration from stack residuals?

$R_{i,ref}$ = XMM-Newton/pn



- Stack residuals ratio $R_{i,ref}$ can be used to rank the instruments by their accuracy of A_{eff} calibration and thus to get the τ values
- If one instrument has problem with A_{eff} calibration and all others are right, the set of $R_{i,wrong}$ curves should be similar, i.e. the deviation between the curves is minimised
- Compute a set of $R_{i,ref}$ curves for each instrument as ref in turn
- For each set of $R_{i,ref}$ calculate the "accuracy parameter" J_{ref}
- Seriously: let's calculate $R_{i,ref}$ for each instr. and see how it looks

$$J_{ref} = stdev\left(R_{(i,ref)}(E)\right)$$

$$\tau = \frac{(J_{ref})}{(max(J_{ref}))}$$

Problems

- Why low T cluster XMM/Chandra T agree better while hard band T agree...
- Why pn does not see the hot clusters predicted by the cosmology
- Donaghue paper
- Applegate paper
-