Clusters of galaxies WG session

12th IACHEC meeting, 2017, Lake Arrowhead

Program

1) Multi Mission Study

2) Multi-Mission Study

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

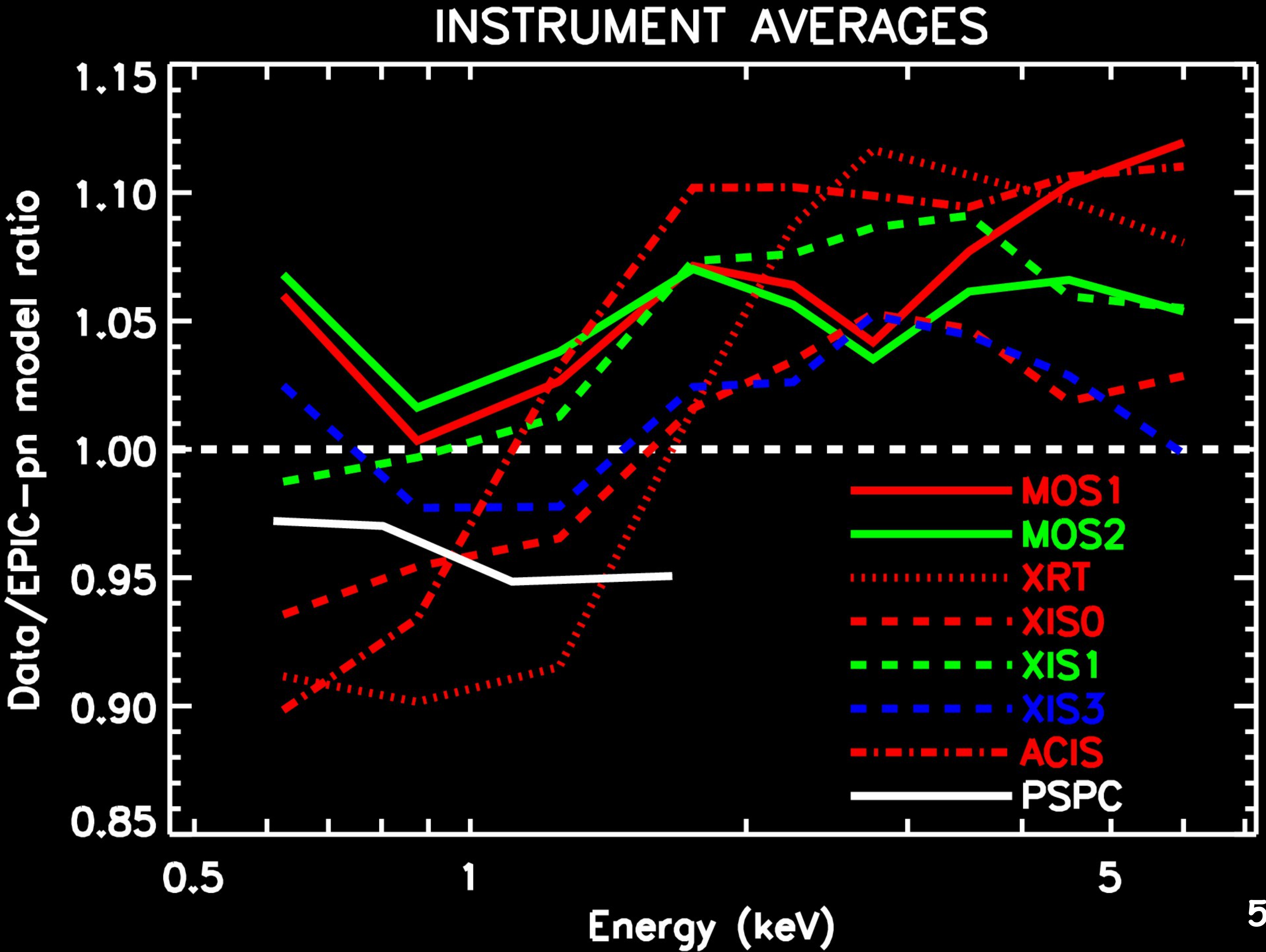
Contents

1) Method for evaluating cross-cal uncertainties

2) Reference model accuracy does not matter

3) More clusters

4) A preliminary extension


INSTRUMENT AVERAGES
Data/EPIC-pn model ratio
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.5
1
5
Energy (keV)
MOS1
MOS2
XRT
XIS0
XIS1
XIS3
ACIS
PSPC

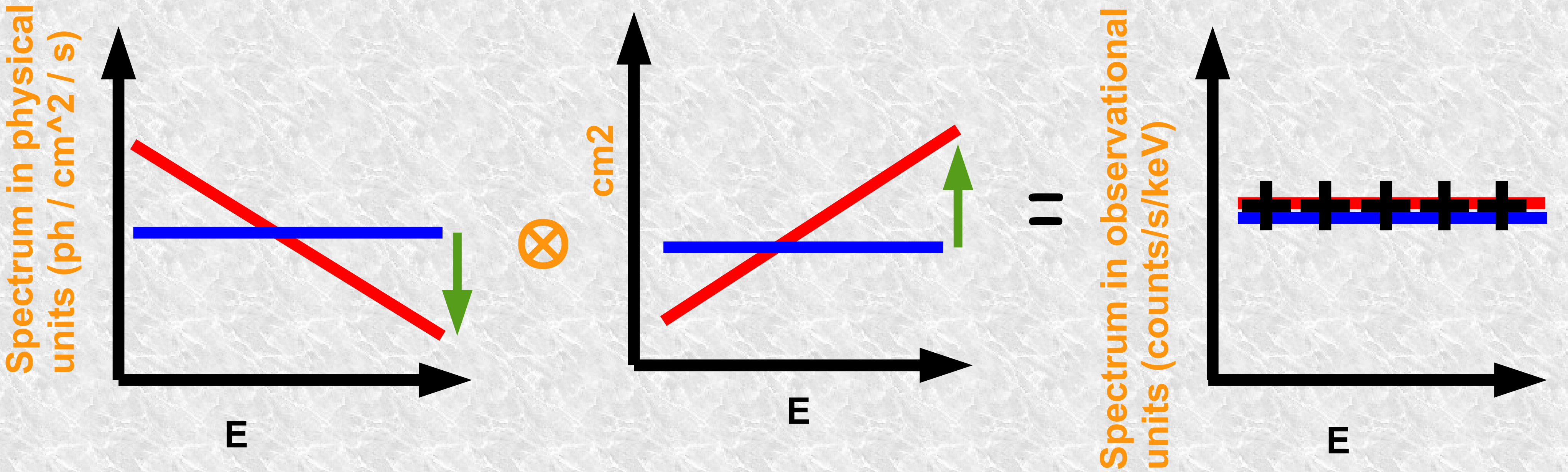
1) Method for evaluating cross-cal uncertainties

- 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



Model i (wrong)

Model i (correct)

Aeff i (wrong)

Aeff i (correct)

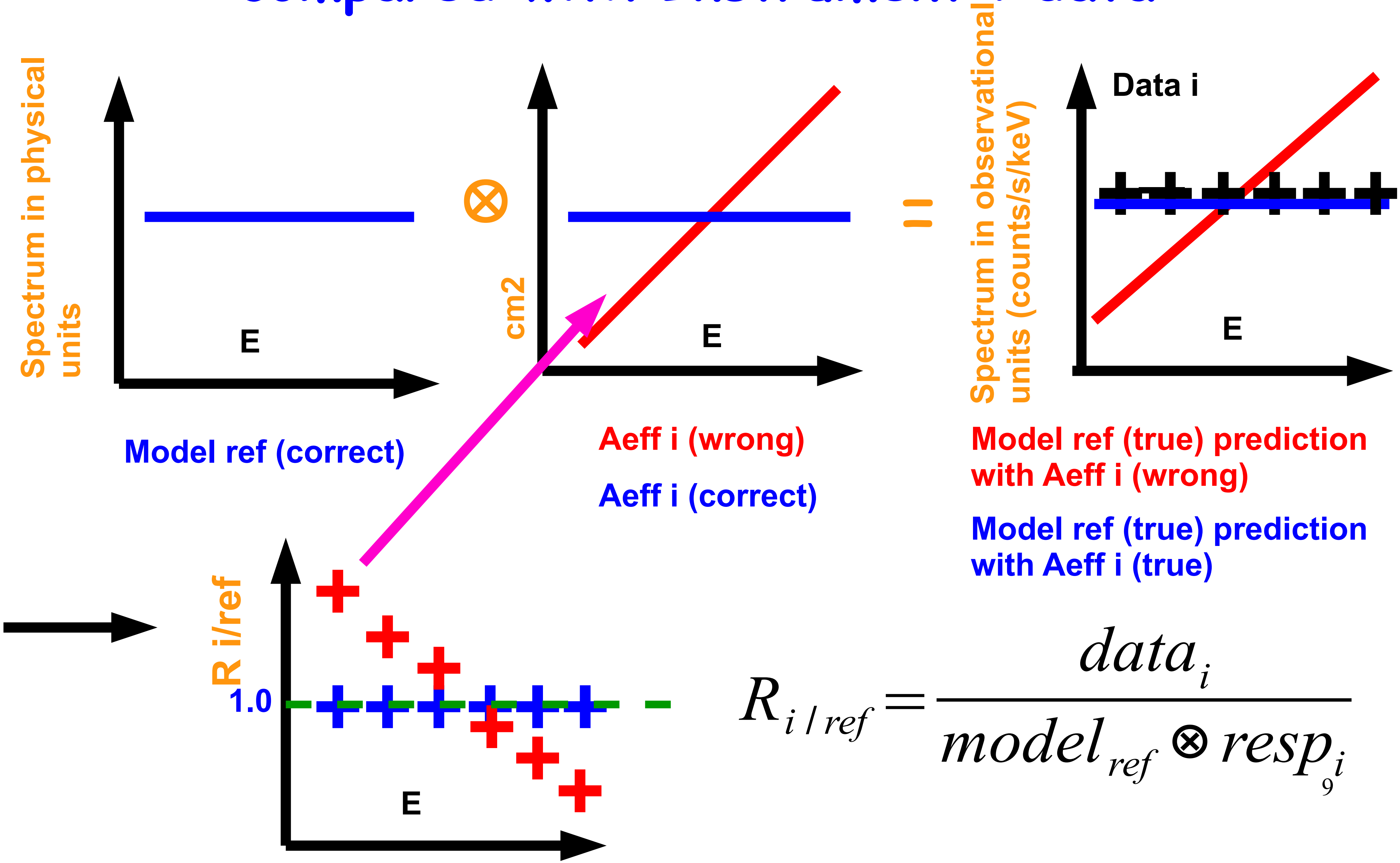
Prediction of Model i (wrong)

Prediction of Model i (correct)

Data i

Biased best-fit model obtained

Instrument ref model (correct) prediction compared with Instrument i data

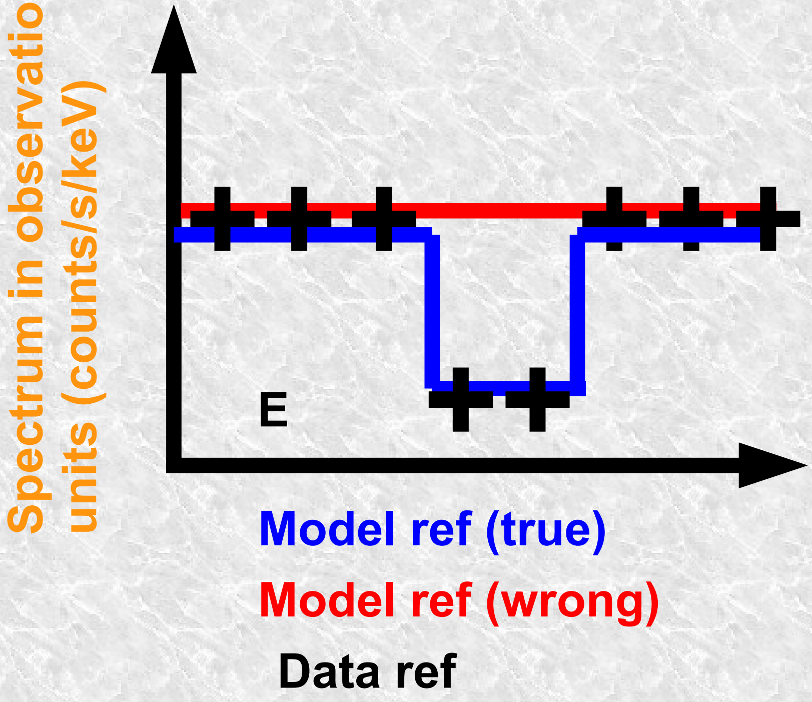


$$R_{i\,/\,ref} = \frac{data_i}{model_{ref} \otimes resp_i}$$

- 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

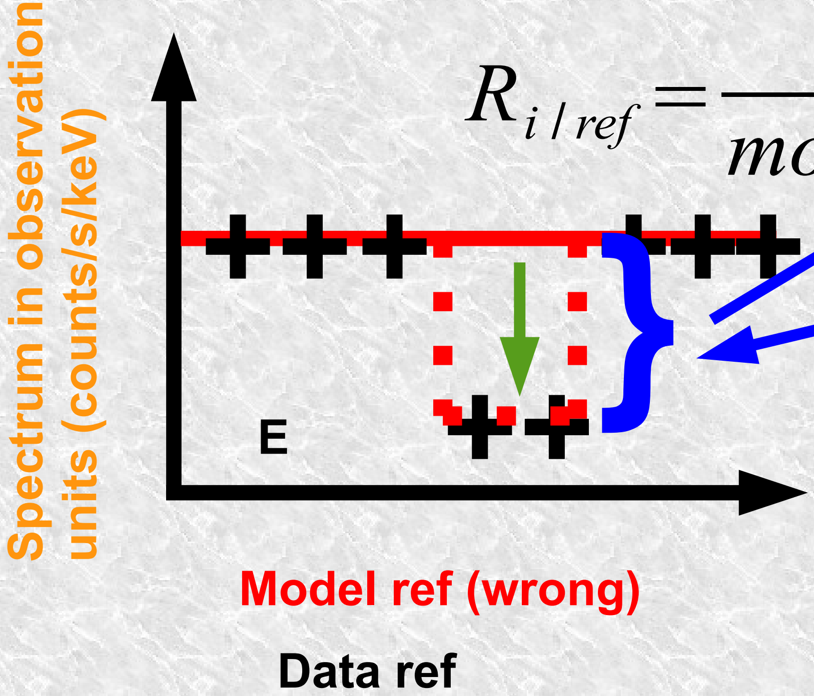


$$R_{i/ref} = \frac{data_i}{model_{ref} \otimes resp_i}$$

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

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

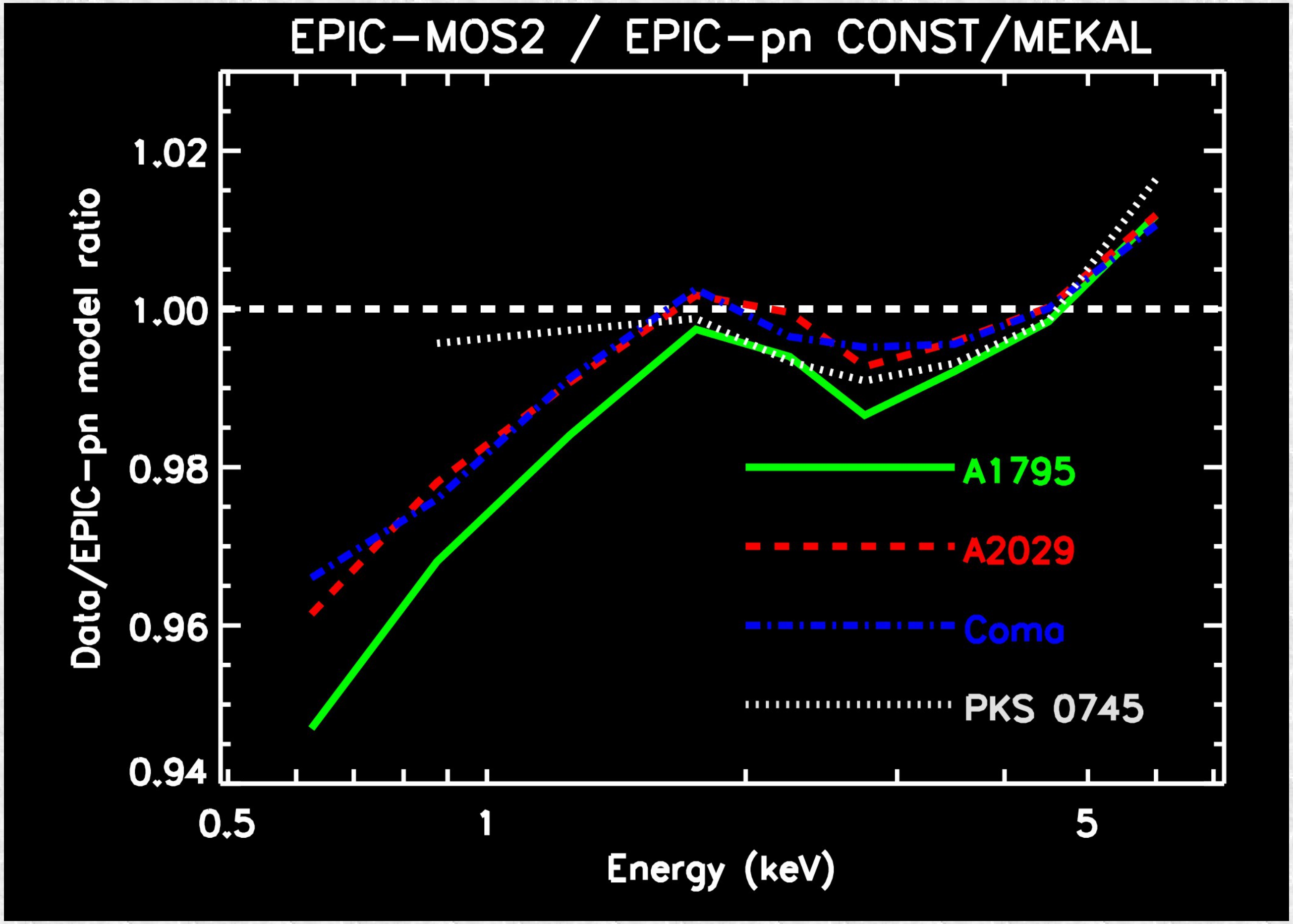


- Caveat: due to statistical uncertainties you will never reach the absolutely correct model, whatever method you use
- Keep statistical uncertainties small compared to the calibration effects
- In other words given the statistical uncertainty level, one can only study systematic effects bigger than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

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%.



3) More clusters

More clusters

- Lots of cluster data in the archive
- Let's make a large data base to improve statistics
- Useful for ATHENA too
- Need to define the criteria for selecting data/observations in order to maintain pre-defined quality requirements

Requirements

1) Statistical precision of 1 % in the 9 energy bins (4 for ROSAT)

2) Bkg/src below 10% at all energies in the 0.5-7.0 keV band

3) PSF scatter minimised

4) Extract the same emission with all instruments

5) Do not mix redistribution calibration with the effarea calibration

6) Do not mix vignetting calibration with the effarea calibration

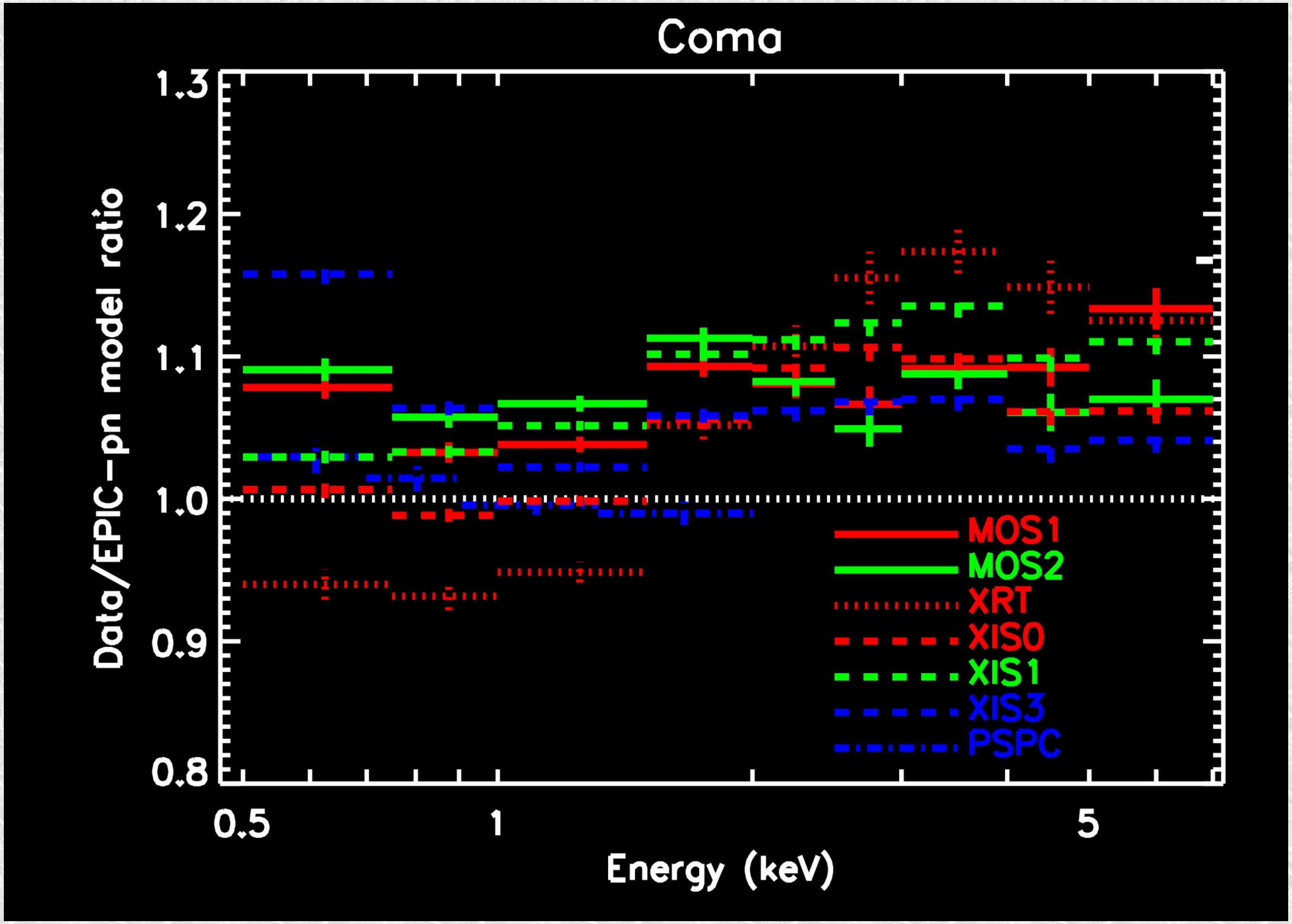
1) Statistical precision

- Due to the stack residuals method, it is OK to use mergers and cool cores and fit them with whatever model ➔ extract spectra from cluster-centric circle with extraction radius r_{ext}
- r_{ext} cannot be too small so that we satisfy the photon statistics criterion
  - 1% statistical precision in small enough energy bins
- Cluster cannot be too distant so that we get enough photons

1) Statistical precision

- At the moment we use 9 spectral bins (ROSAT 4 bins). **Is this OK? Yes!**
- 1% statistical precision in each bin→ 100000 c (40000 c ROSAT). **Is this OK? Yes!**

Coma r_{ext} = 6' : 17 ks EPIC exposure, z=0.023

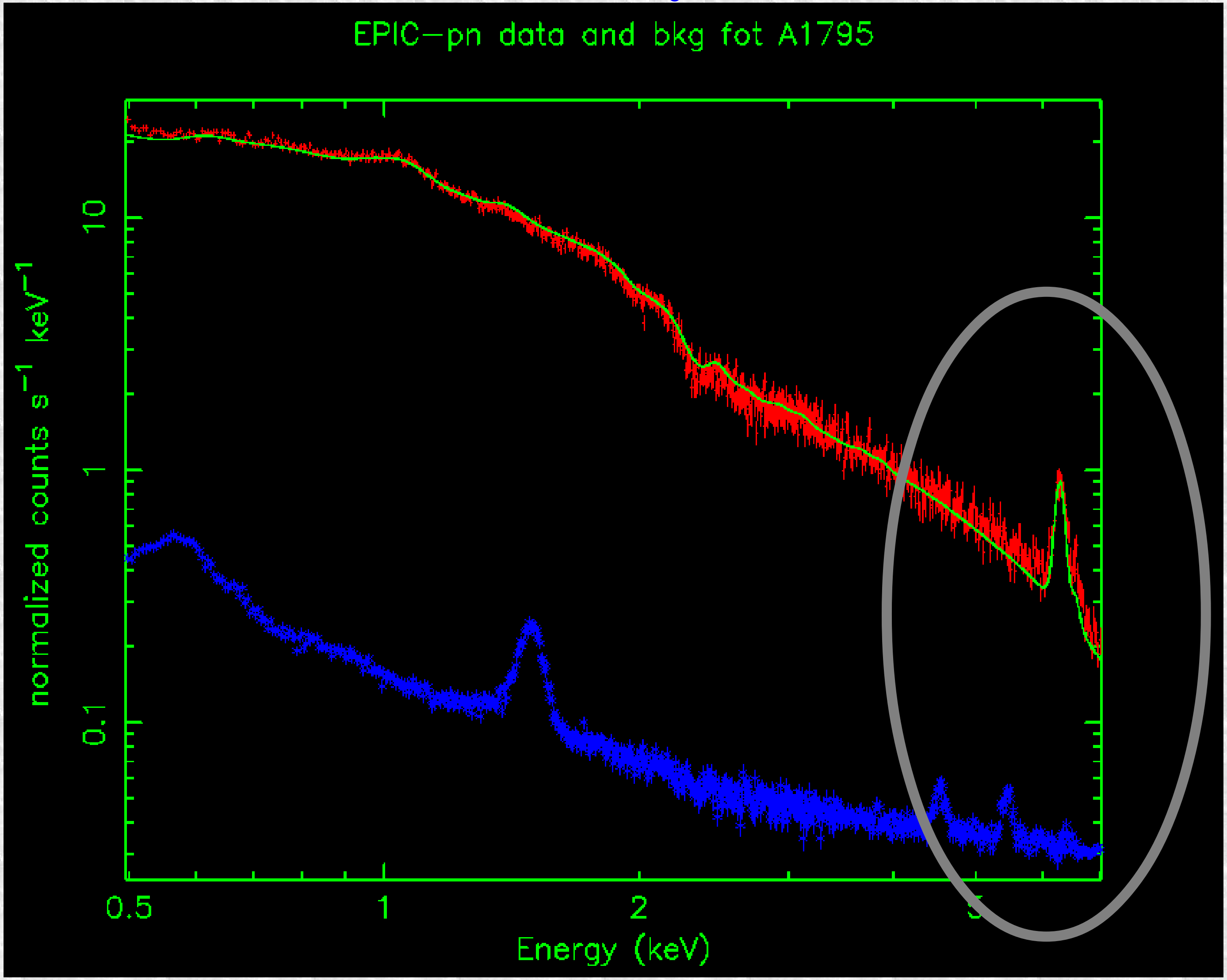


2) Background minimisation

- **r_{ext}** cannot be too large so that we satisfy the background minimisation criterium
  - Bkg below 10% of signal in the 0.5-7 keV range. **Is this OK? Yes, at the moment. May have to relax if this is too constraining.**

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



3) PSF minimisation

- r_{ext} cannot be too small so that the PSF scatter from the studied region to the studied region dominates
  - Dominated by Suzaku. 6 arcmin region should be OK. Needs to be verified, in particular if we go for a smaller region

4) Same emission studied with all instruments

- CCD gaps and dead areas different in different instruments
- Should use a common mask for all instruments
- Is this feasible? **No.**
- If not, let's do this independently and scale linearly to the full extraction region. This is quite consistent with the 2XMM point source analysis. **Or scale to unity at 1 keV and forget about the flux comparison.**
- **Point sources:** if their time-variability causes significant effect to the total extracted signal, they should be removed. Problem with Suzaku. **What is the case? Proceed with no point source removal.**
- **Center of the cluster:** **What should we use as a common definition? Chandra peak. Coma is special...**

5) Redistribution minimisation

- If the redistribution is not perfectly calibrated, the complex line emission at 1 keV may produce effects that mimick an effarea calibration problem
- Using only the hottest clusters minimises this problem. How hot? **Proceed with kT > 6 keV**
- Fe XXV and XXVI lines at 6-7 keV may be similarly problematic. Should we cut the spectra at 6 keV? **Examine the scatter first.**

6) Vignetting minimisation

- If the vignetting is not perfectly modelled, the extended nature of clusters may produce effects that mimick an effarea calibration problem
- Problem minimised by smaller region
- This is contrasted by the pressure of having a bigger region.
- Should estimate the effect of the allowed vignetting calibration uncertainties **TBD**
- We must have an upper limit for an offset btw. the FOV center and cluster center, in order not to confuse vignetting and effarea calibration. **3 arcmin? OK.**

7) On-axis effective area?

- Given the extended nature of clusters, we will not probe exactly the on-axis effective area calibration, but what?

Tasks for today

- **TASK 1:** Define the extraction radius
- **TASK 2:** Define a suitable cluster
- **TASK 3:** Define a suitable observation

TASK 1: Define the extraction radius

- Statistics requirement and PSF minimisation prefer bigger values
- bkg and vignetting minimisation prefer smaller values

Extraction radius = 6 arcmin

TASK 2: Define a suitable cluster

- Hot enough (minimise 1 keV line emission, better src/to bkg at 7 keV energies)
- Not too distant to yield enough photons
- Preferably low NH... if high, harder to get enough photons at the lowest energies. But we can cut the low energy band and use the rest. **No requirement for NH at the moment**

kT > 6 keV

z < 0.1

TASK 3: Define a suitable observation

- Long enough for statistics.
- Cluster center – FOV center offaxis minimised
- Proceed with single on-axis observations. If too constraining (not enough clusters with enough counts) we will discuss about merging several observations.

- **100000 c in central 6 arcmin (40000 for PSPC)**
- **Offaxis < 3 arcmin**

4) A preliminary extension of the data base

- Following **PRELIMINARY!** 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

A1835?

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

More clusters

- This needs to be done carefully with the definitions we agreed on today
- **Task 4:** Compile a list of available clusters and obs. ID:s fulfilling our criteria: Larry (Chandra), Eric (Suzaku), Andy B. (Swift), Steven Snowden (ROSAT), Jukka (XMM) ***Deadline end of April***
- **Task 5:** Extract and process data with May 2017 calibration information. ***Deadline end of June***
- **Task 6:** Jukka will do the stack residuals ratio analysis.