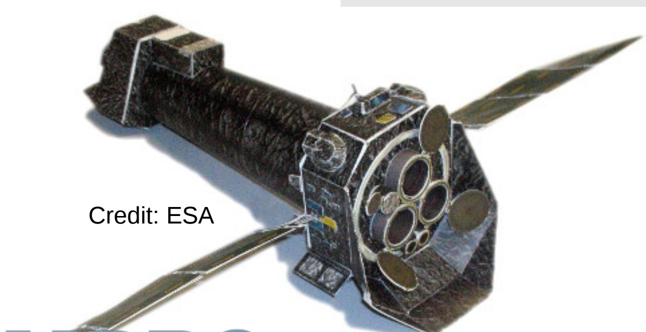
Credit: NASA/CXC/M.Weiss

Effective Area Cross Calibration of Chandra and XMM-Newton with HIFLUGCS

Gerrit Schellenberger

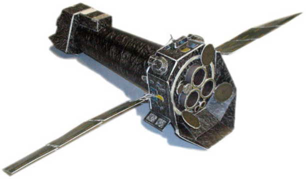


Credit: ESA

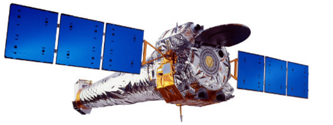
IMPRS astronomy & astrophysics Bonn and Cologne

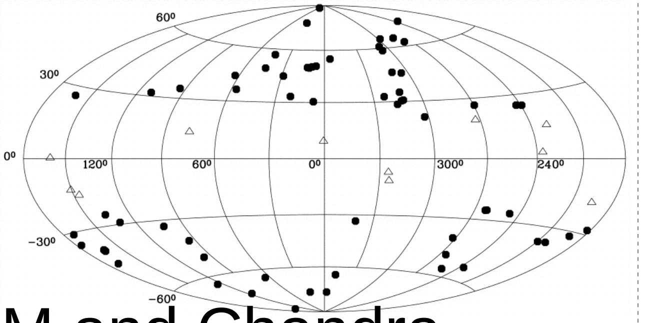
Bonn-Cologne Graduate School of Physics and Astronomy

Argelander-Institut für Astronomie



Data Reduction/Analysis



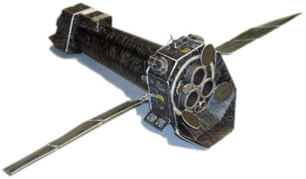


- Cluster selection: HIFLUGCS sample
  - Complete
  - Many objects (64)
  - X-ray brightest clusters
  - Long exposure time available for XMM and Chandra
  - Wider range of temperatures

- Region selection:
  - Center: X-ray peak
  - Outer border: 3.5 arcmin (Chandra ACIS-S, Background)
  - NCC: Circle with radius 3.5 arcmin
  - CC: Annulus up to 3.5 arcmin excluding the cool core

    → see Hudson et al. (2010)

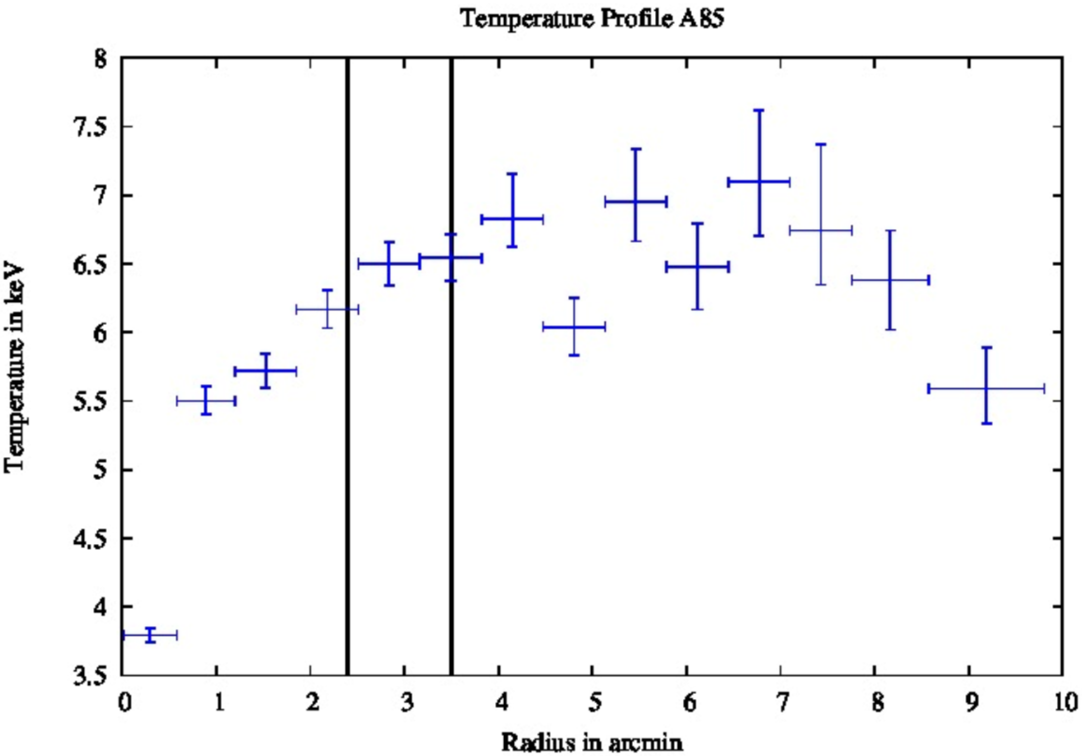
- Excluded objects:
  - A2244 not observed with XMM-Newton
  - Cool core radius larger than 3.5 arcmin for 7 clusters
  - 56 Objects

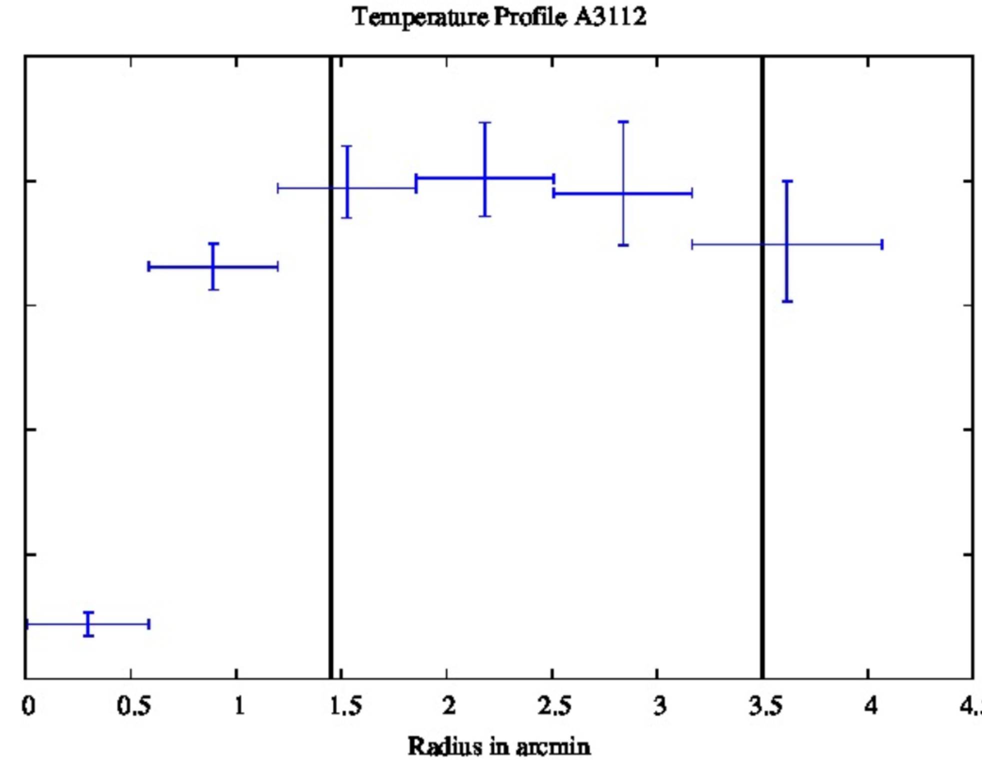


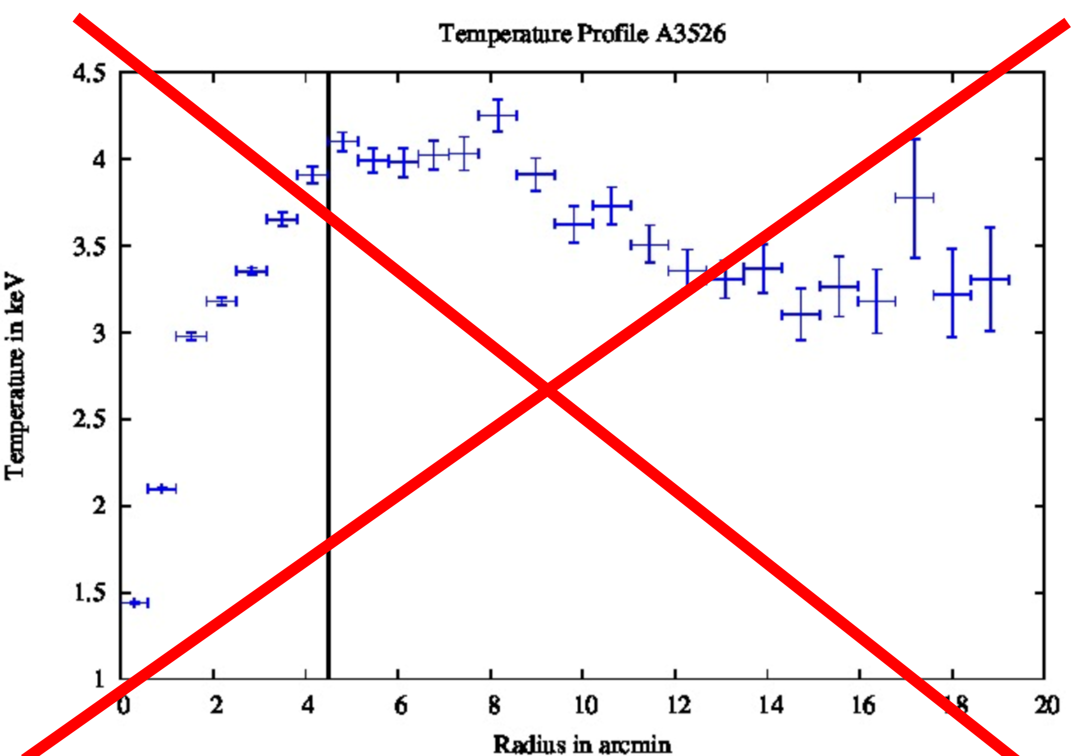
Data Reduction/Analysis

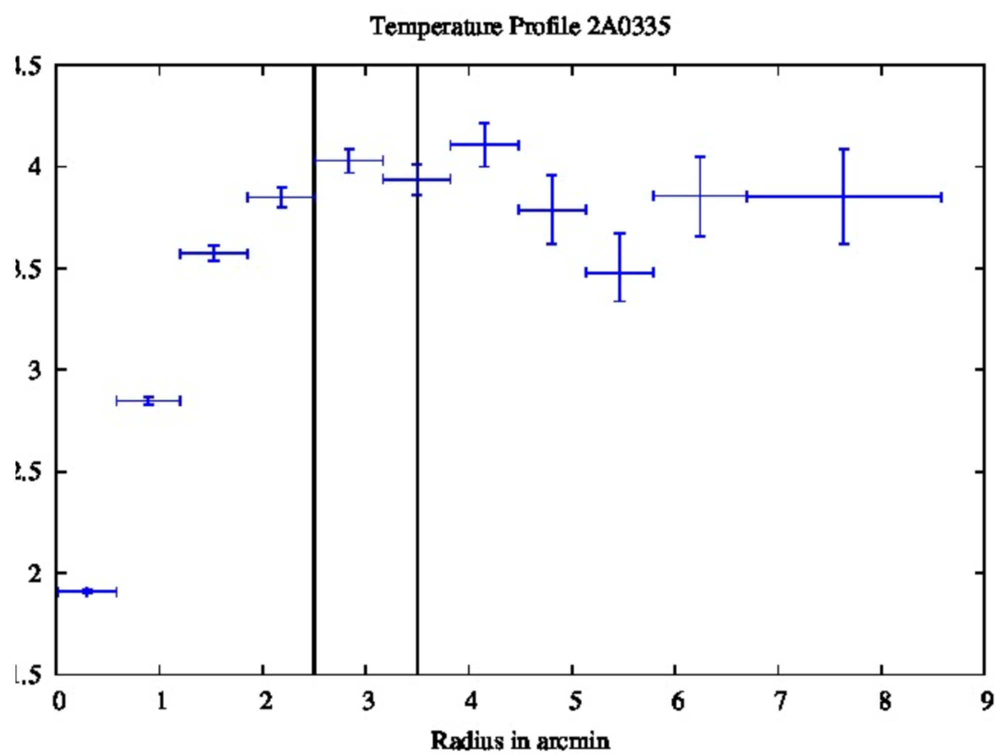
- SAS 12; CCF from Dec 2012
- CIAO 4.5; CALDB 4.5.5.1

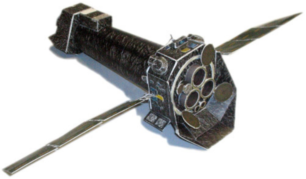
- MOS: Flag = 0 + pattern <= 12
- PN: Flag = 0 + patter = 0 (no doubles!)


Temperature Profile A85
Temperature in keV
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
0 1 2 3 4 5 6 7 8 9 10
Radius in arcmin


Temperature Profile A3112
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Radius in arcmin

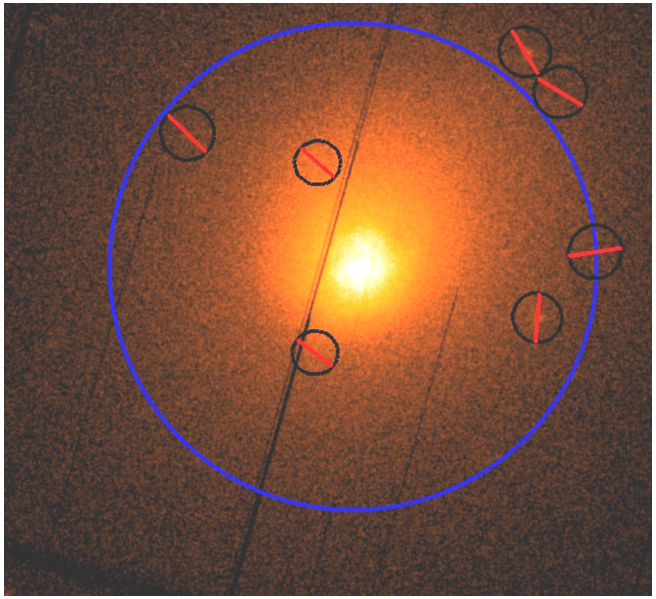

Temperature Profile A3526
Temperature in keV
4.5
4
3.5
3
2.5
2
1.5
1
0 2 4 6 8 10 12 14 16 18 20
Radius in arcmin


Temperature Profile 2A0335
4
3
2
0 1 2 3 4 5 6 7 8 9
Radius in arcmin

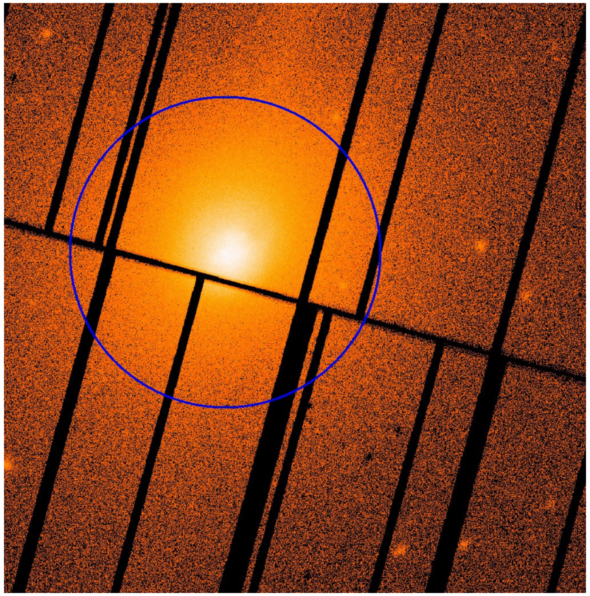


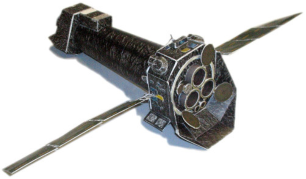
Data Reduction/Analysis

- Point sources:
  - Detected in Chandra data using wavedetect
  - 15 arcsec added on detected point source radius (PSF)
  - Same point source regions in XMM and Chandra data excluded



- Chip gaps and bad columns in XMM observations (MOS1/2 and PN) marked by hand and excluded from all instruments
- Chandra wobble avoids real chip gaps in ACIS-I observations



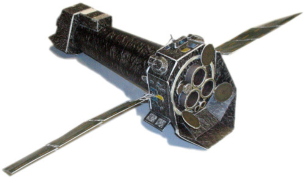


Background

- Background components:
  - Particle (continuum and fluorescent lines)
  - Soft protons
  - Cosmic X-ray background
  - SWCX

- Blank sky background subtraction
  - Particle background level determined in high energy band
  - Rescaling of blank sky spectra to match observation

- Tests:
  - BG changed up to 2 keV by 10%
    → for 90% clusters: Temperature change < 1%
  - BG spectra simulated with high NH
    → all clusters less then 3% change (90% less than 1%)



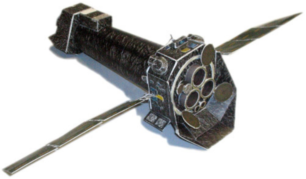
Results – Stacked residuals

- Quantify uncertainties of the effective area calibration as a function of energy

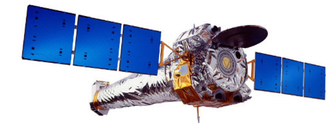
$$R_{ij} = \frac{\mathrm{data}_i}{\mathrm{model}_j \otimes \mathrm{response}_i} \times \frac{\mathrm{model}_j \otimes \mathrm{response}_j}{\mathrm{data}_j}$$

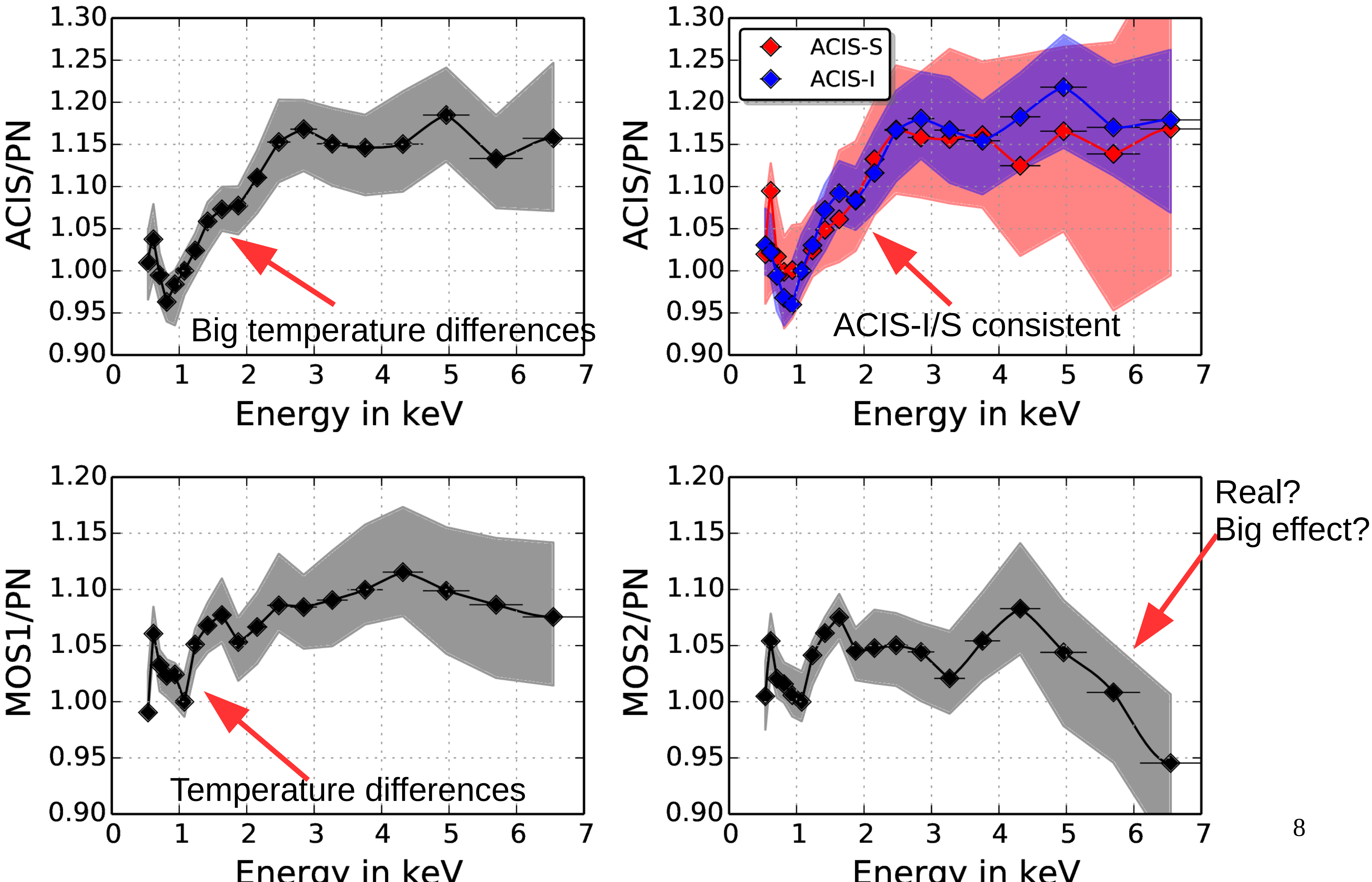
- Reference instrument (EPIC-PN)
- Calculate model prediction of reference instrument
- Divide data by reference model folded with instrumental response
- Normalize by reference instrument residuals
- Aim: find temperature differences -> normalization of SRR does not matter

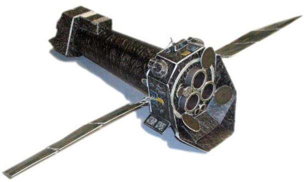
  -> Unity at 1.1keV



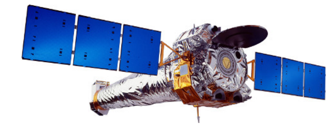
Stacked residuals ratio

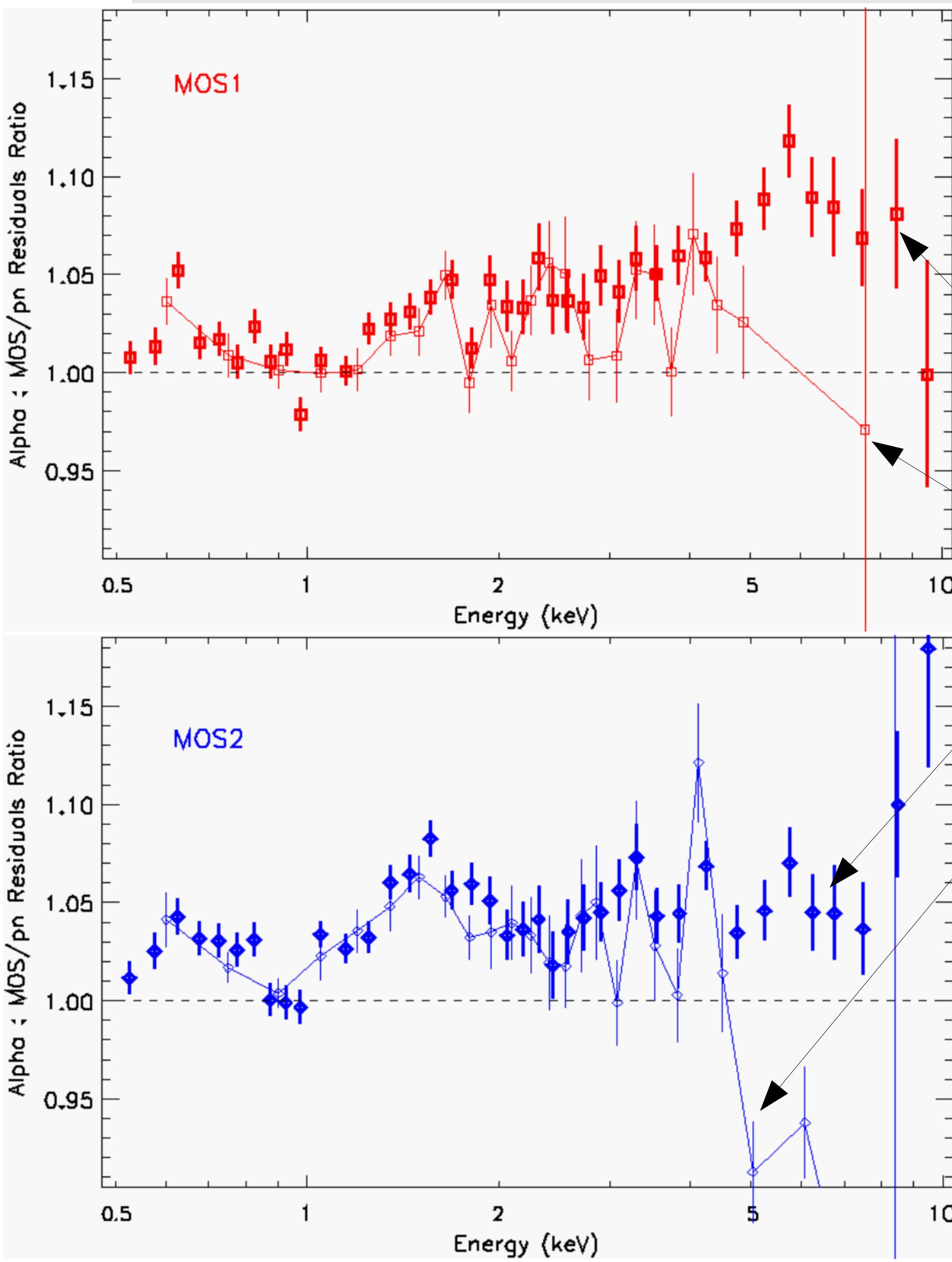






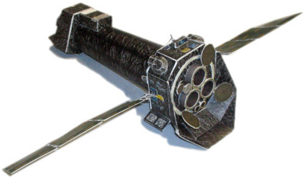
Stacked residuals ratio



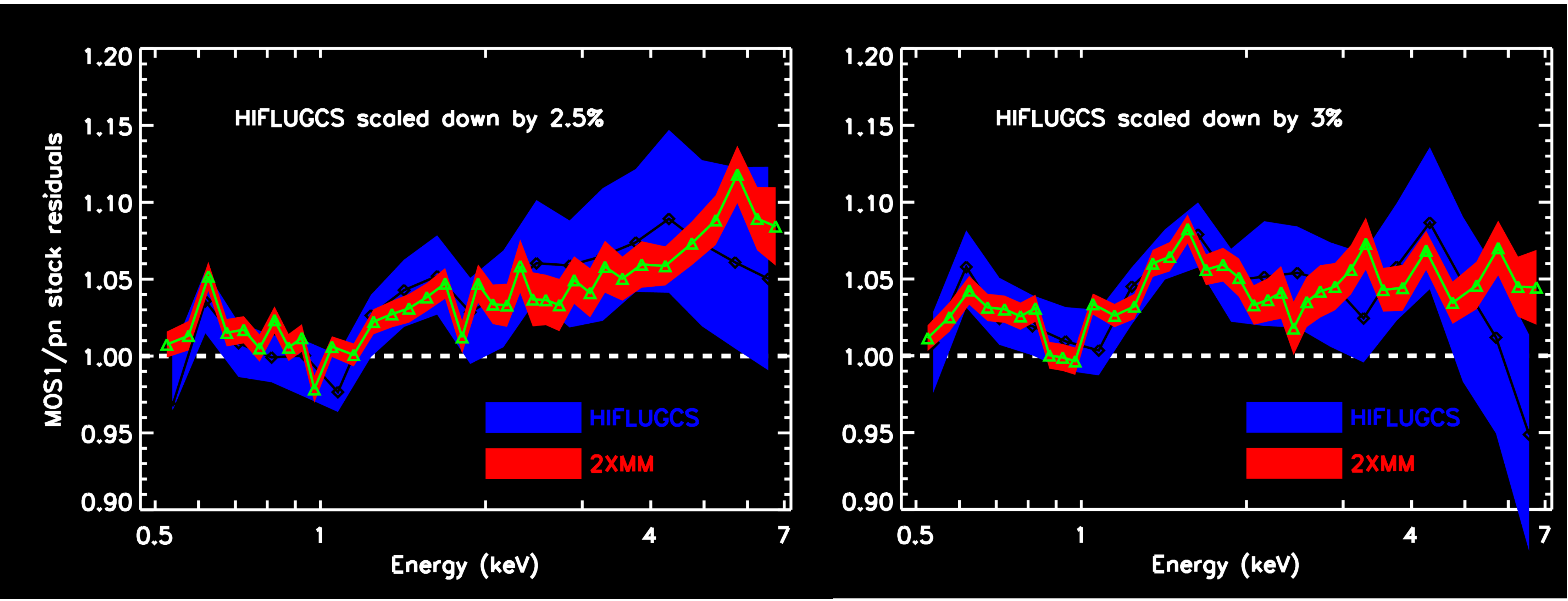


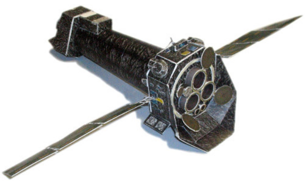
stack and fit
or
fit and stack

Read+14

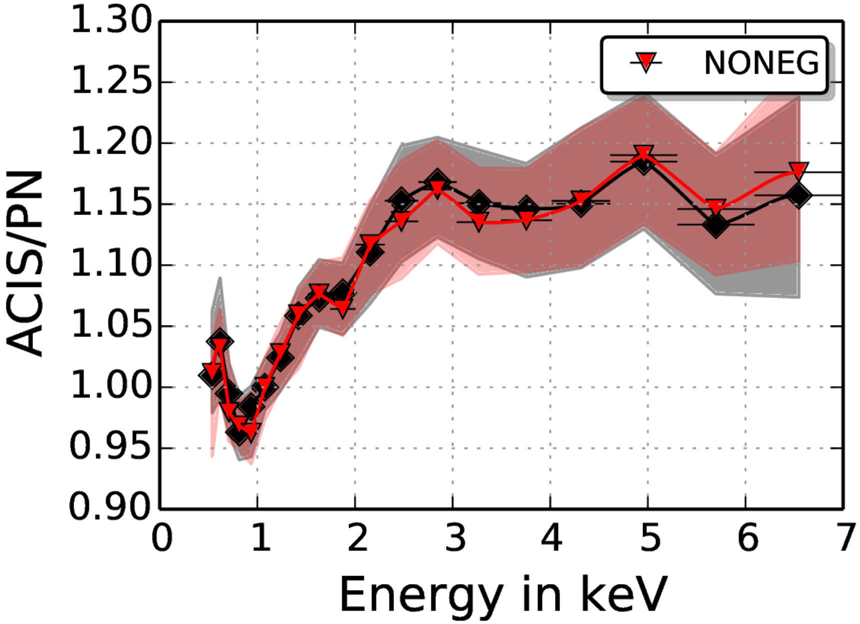


Stacked residuals ratio

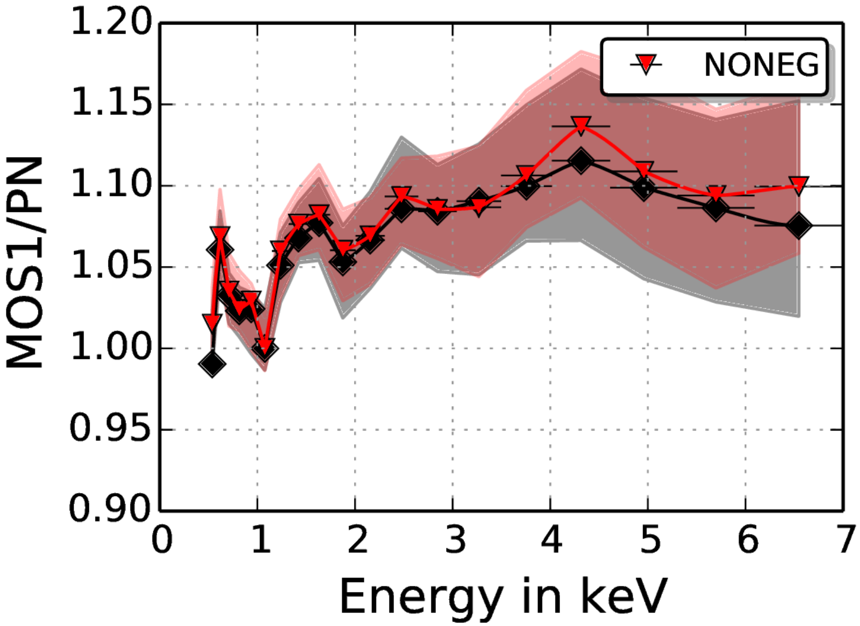


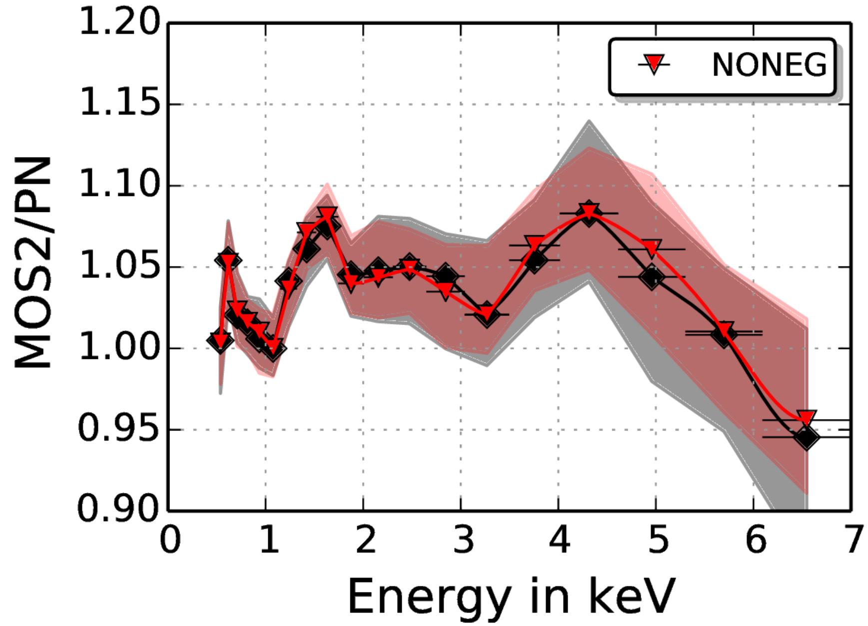


Stacked residuals ratio



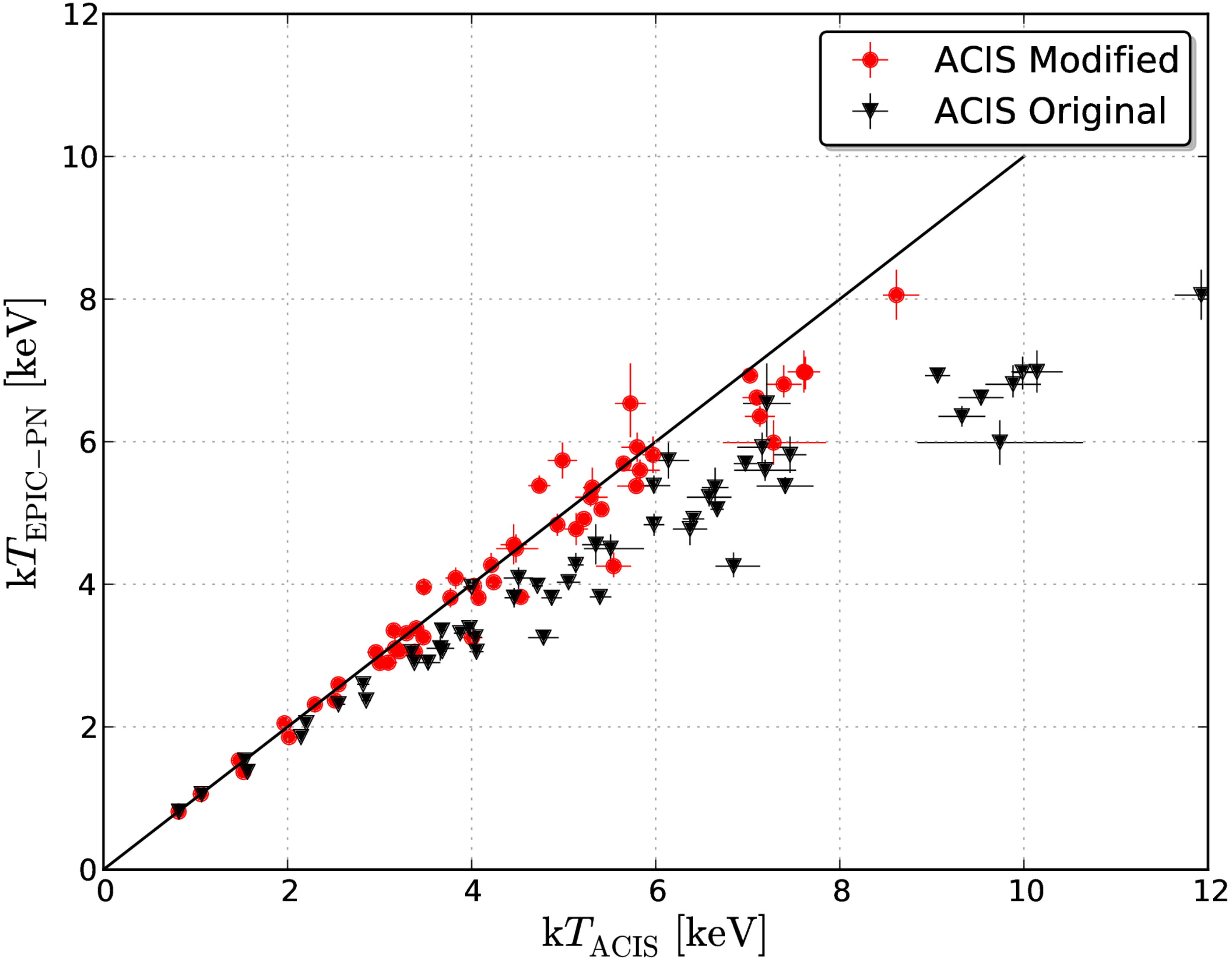
Excluding any clusters with negative spectral bins shown in red

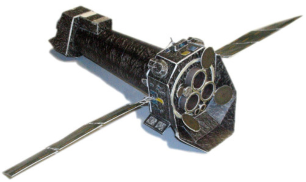




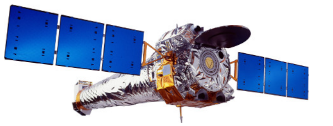
Modified ARF

Modification of, e.g., the ACIS effective area based on spline from the stacked residuals yields good agrement of temperatures



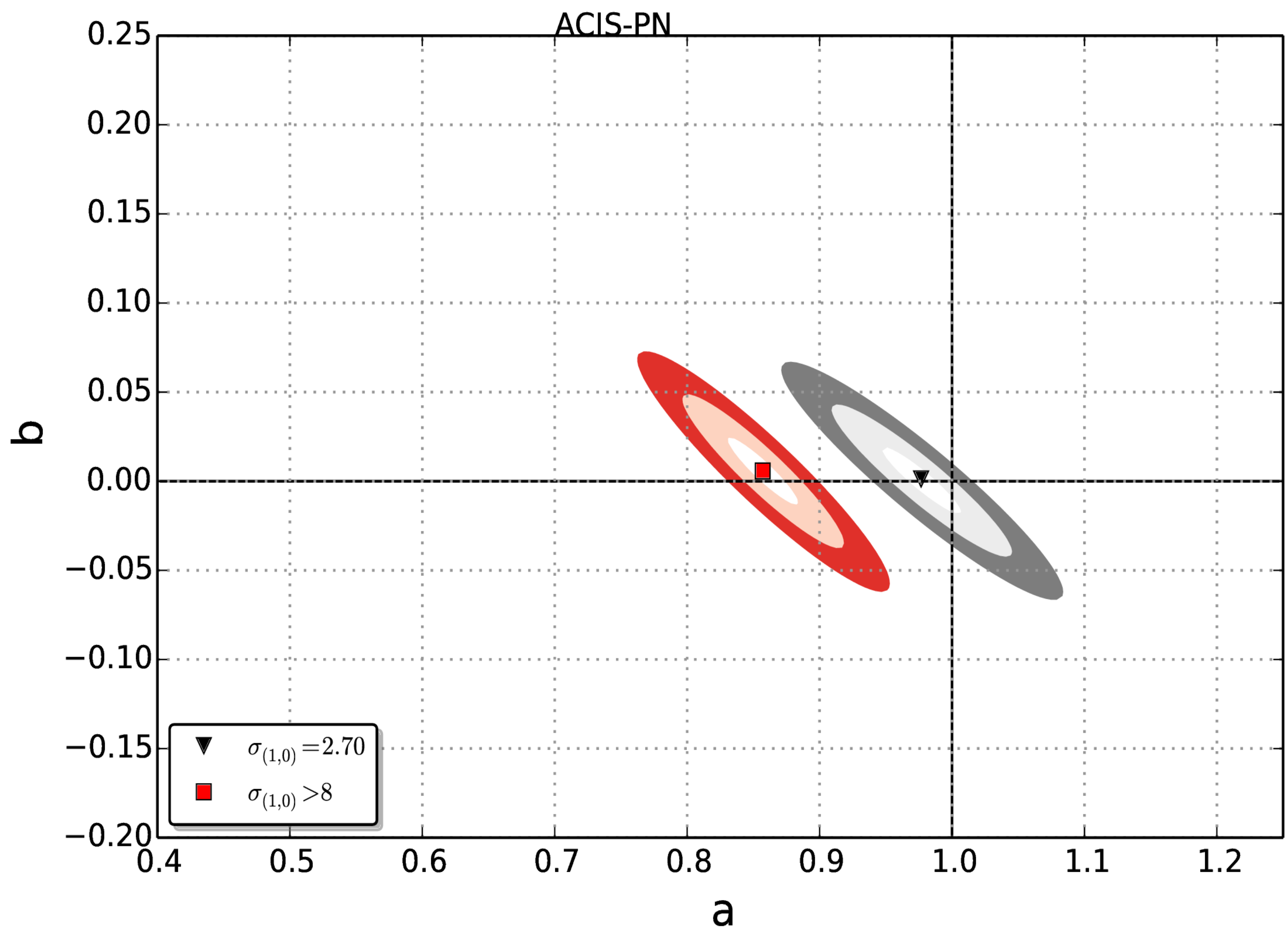


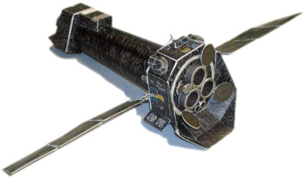
Modified ARF



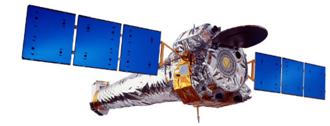
$$\log_{10}\frac{kT_{\mathrm{I_Y,band}}}{1\,\mathrm{keV}} = a \times \log_{10}\frac{kT_{\mathrm{I_X,band}}}{1\,\mathrm{keV}} + b$$

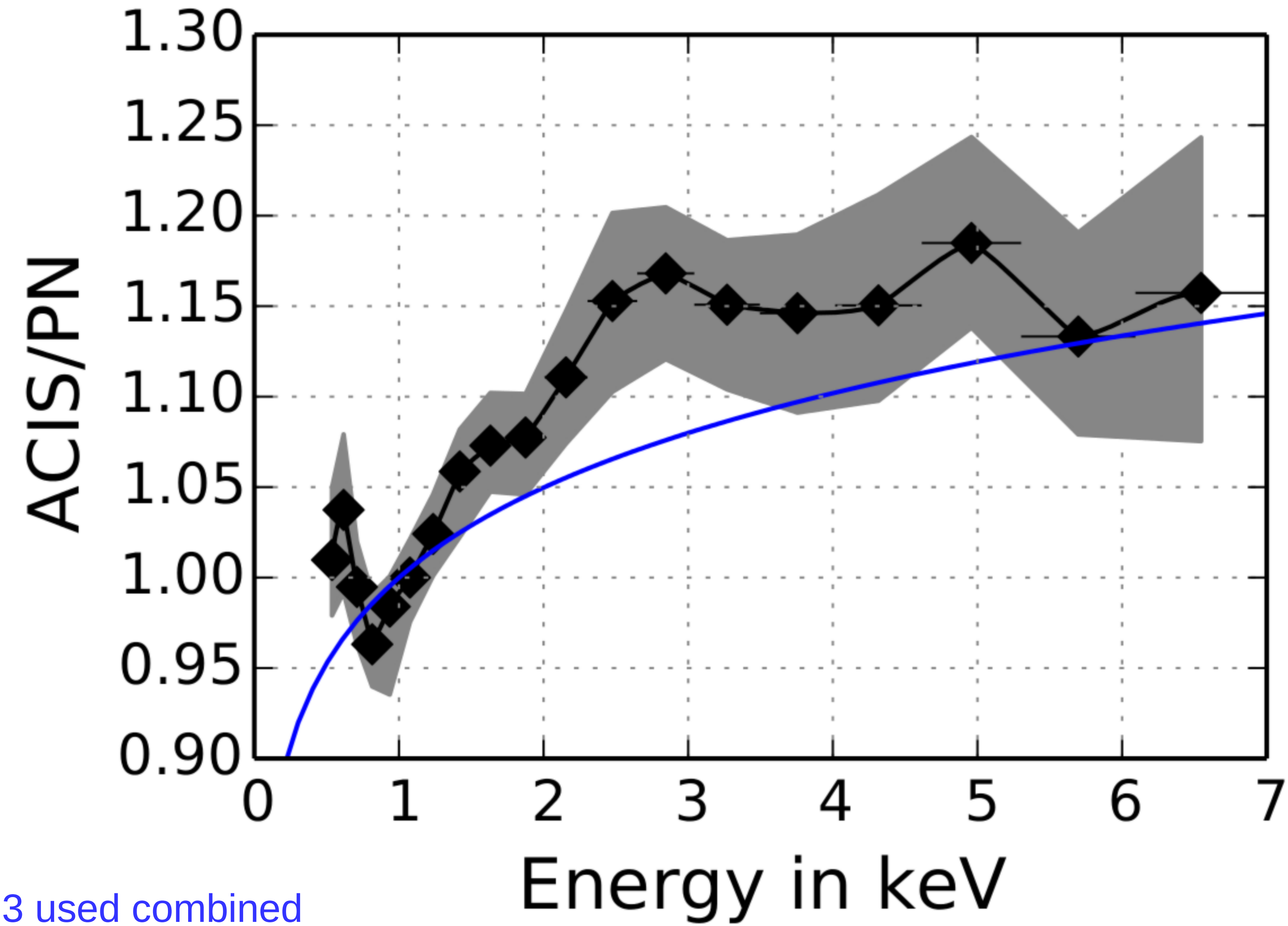
Fitting ACIS-PN temperatures of the whole sample with powerlaw
- before (red) and after (black) the arf modification of ACIS





Mahdavi+13

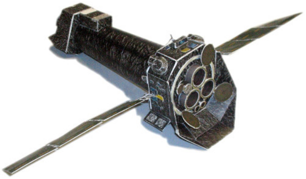




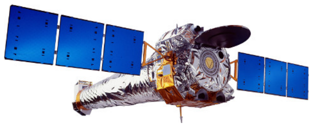
Mahdavi+13 used combined XMM-EPIC fits to get eff. area correction

$$A_{\rm CXO}^{\rm corrected}(E) = A_{\rm CXO}(E)\left(\frac{E}{\rm keV}\right)^{\zeta}$$

$$\zeta = 0.07$$



Summary



- Galaxy cluster sample used to quantify effective area calibration uncertainties
- Steep gradiant found in ACIS/PN
- Smaller gradiant found in MOS1/PN and MOS2/PN
- MOS1/PN and MOS2/PN same behaviour at low energies
- MOS2/PN drop at high energies -> not seen in Read+14