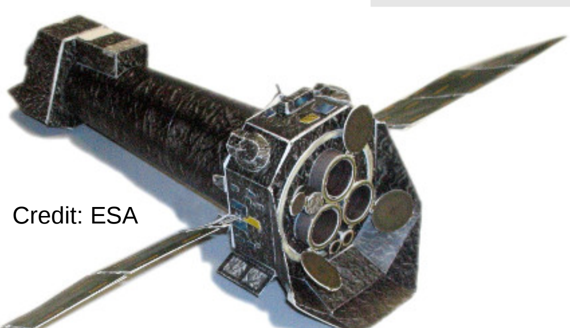
Credit: NASA/CXC/M.Weiss

Cross Calibration using HIFLUGCS Galaxy Clusters



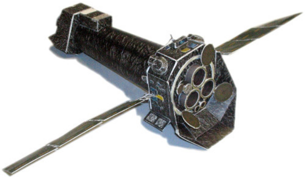
Credit: ESA

Gerrit Schellenberger

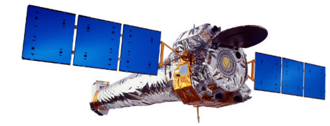
IMPRS astronomy & astrophysics Bonn and Cologne

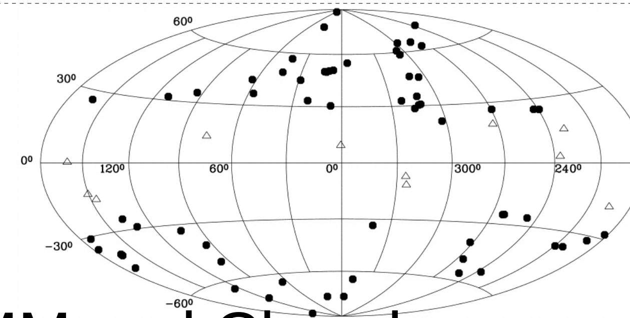
bcgs Bonn-Cologne Graduate School of Physics and Astronomy

Argelander-Institut für Astronomie



Data Reduction/Analysis



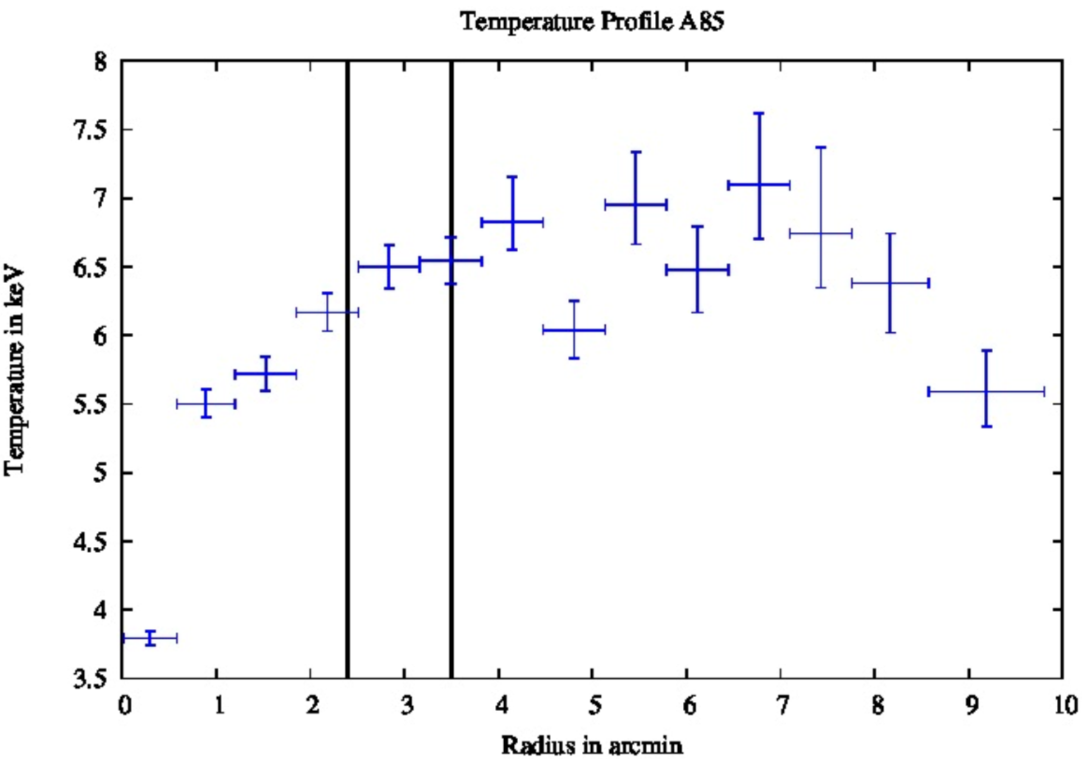


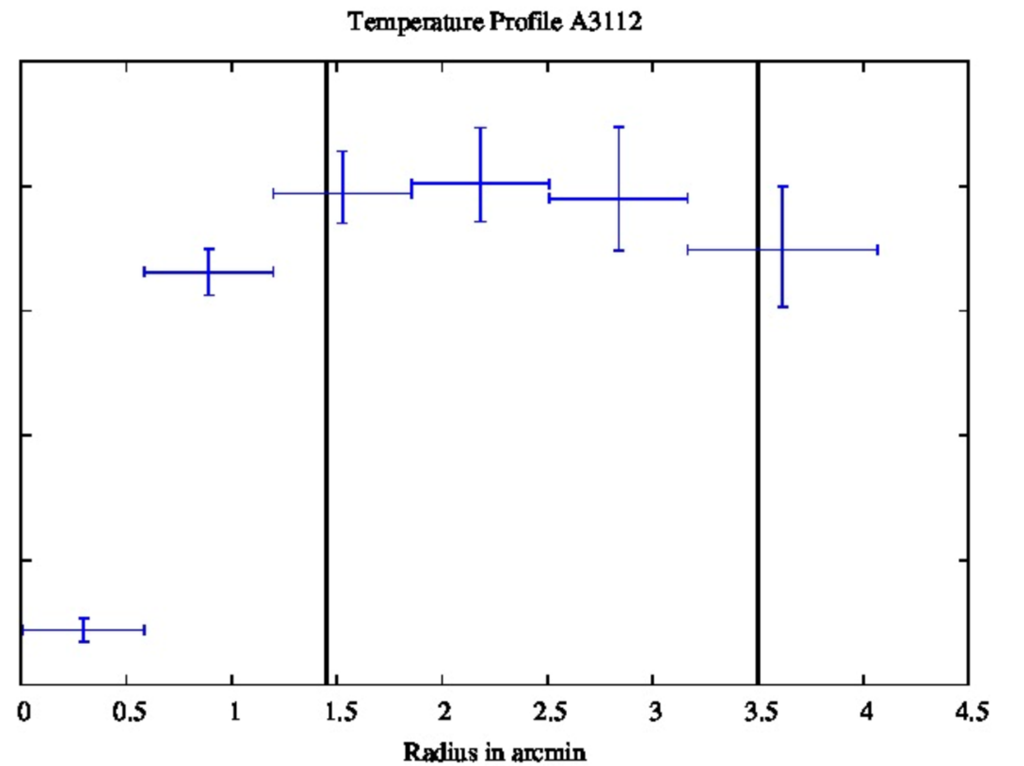
- Cluster selection: HIFLUGCS sample
  - Complete
  - Many objects (64)
  - X-ray brightest clusters
  - Long exposure time available for XMM and Chandra
  - Wider range of temperatures

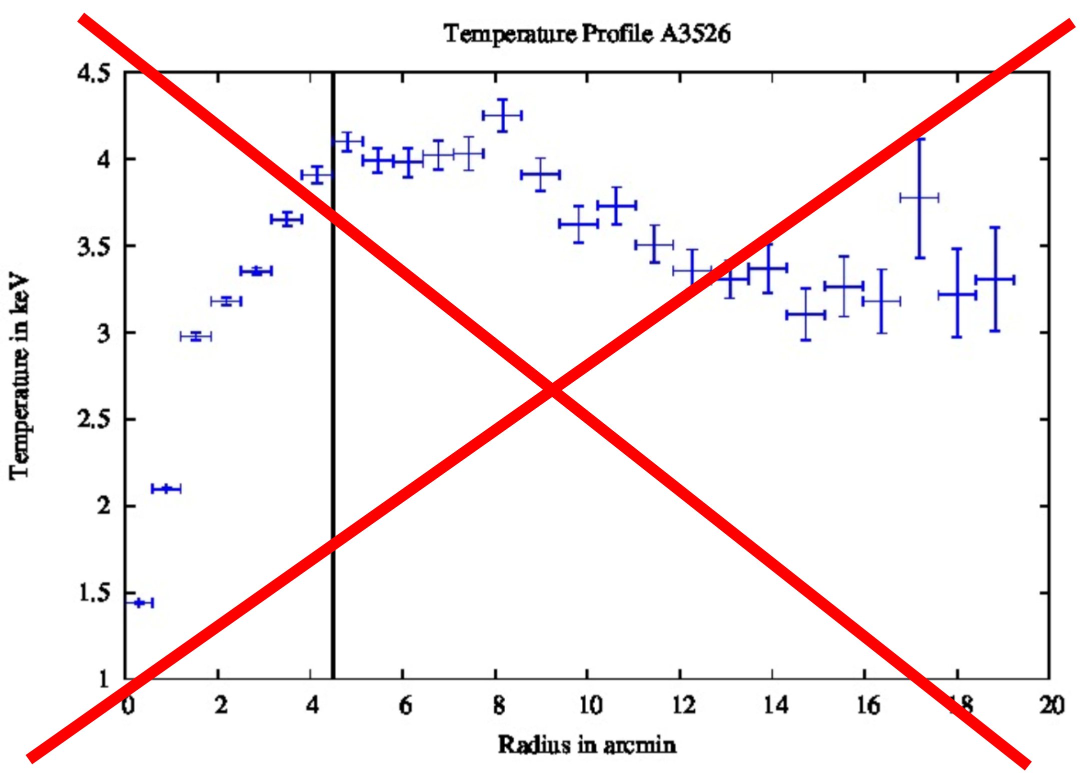
- Region selection:
  - Center: X-ray peak
  - Outer border: 3.5 arcmin (Chandra ACIS-S, Background)
  - NCC: Circle with radius 3.5 arcmin
  - CC: Annulus up to 3.5 arcmin excluding the cool core

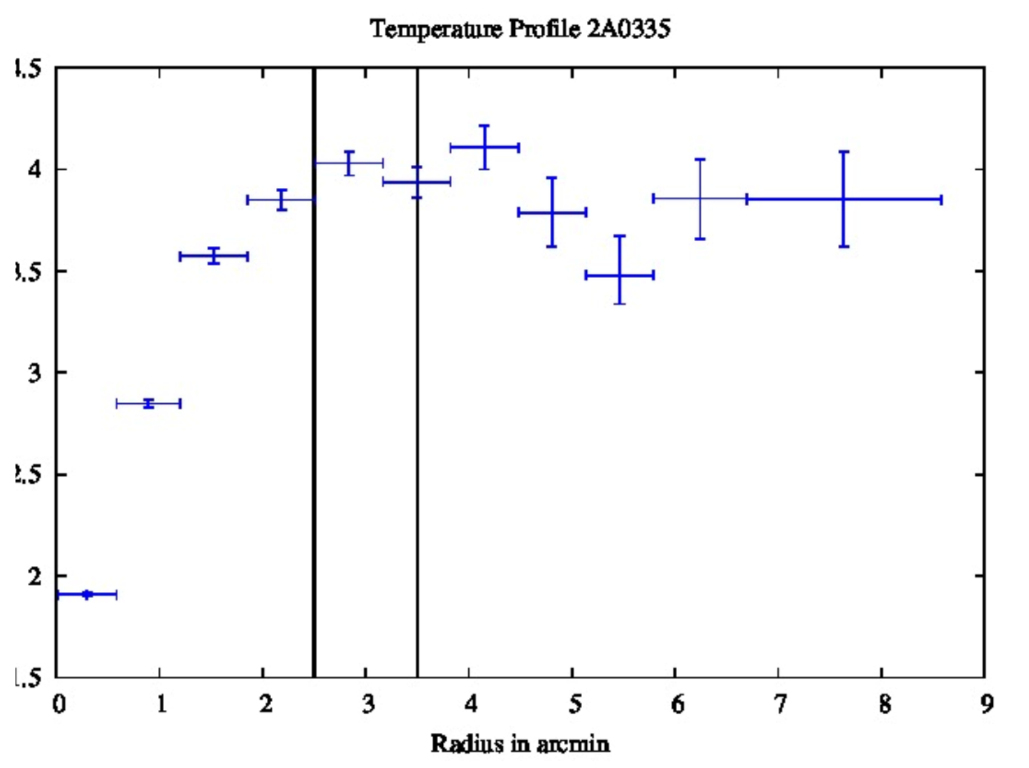
    → see Hudson et al. (2010)

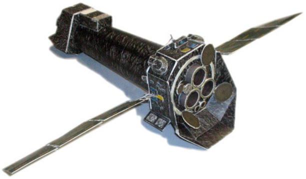
- Excluded objects:
  - A2244 not observed with XMM-Newton
  - Cool core radius larger than 3.5 arcmin for 7 clusters
  - 56 Objects


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

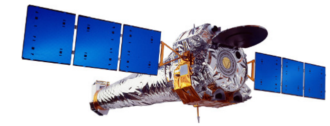

Temperature Profile A3112
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Radius in arcmin


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

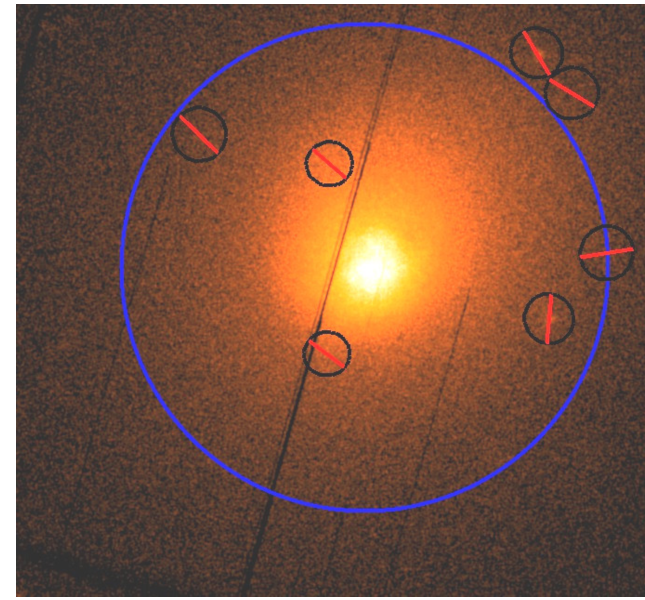

Temperature Profile 2A0335
4
3
2
0
1
2
3
4
5
6
7
8
9
Radius in arcmin



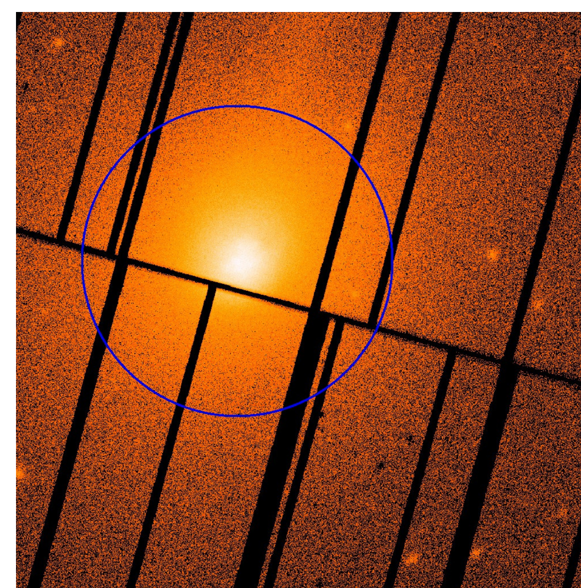
Data Reduction/Analysis

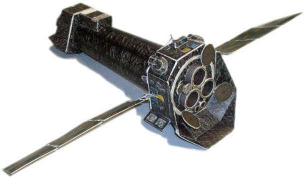


- Point sources:
  - Detected in Chandra data using wavedetect
  - 15 arcsec added on detected point source radius (PSF)
  - Same point source regions in XMM and Chandra data excluded



- 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



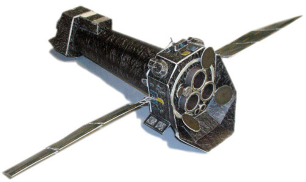


Results – Stacked residuals

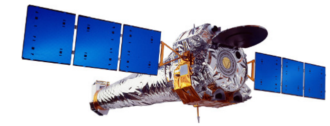
- Quantify uncertainties of the effective area calibration as a function of energy

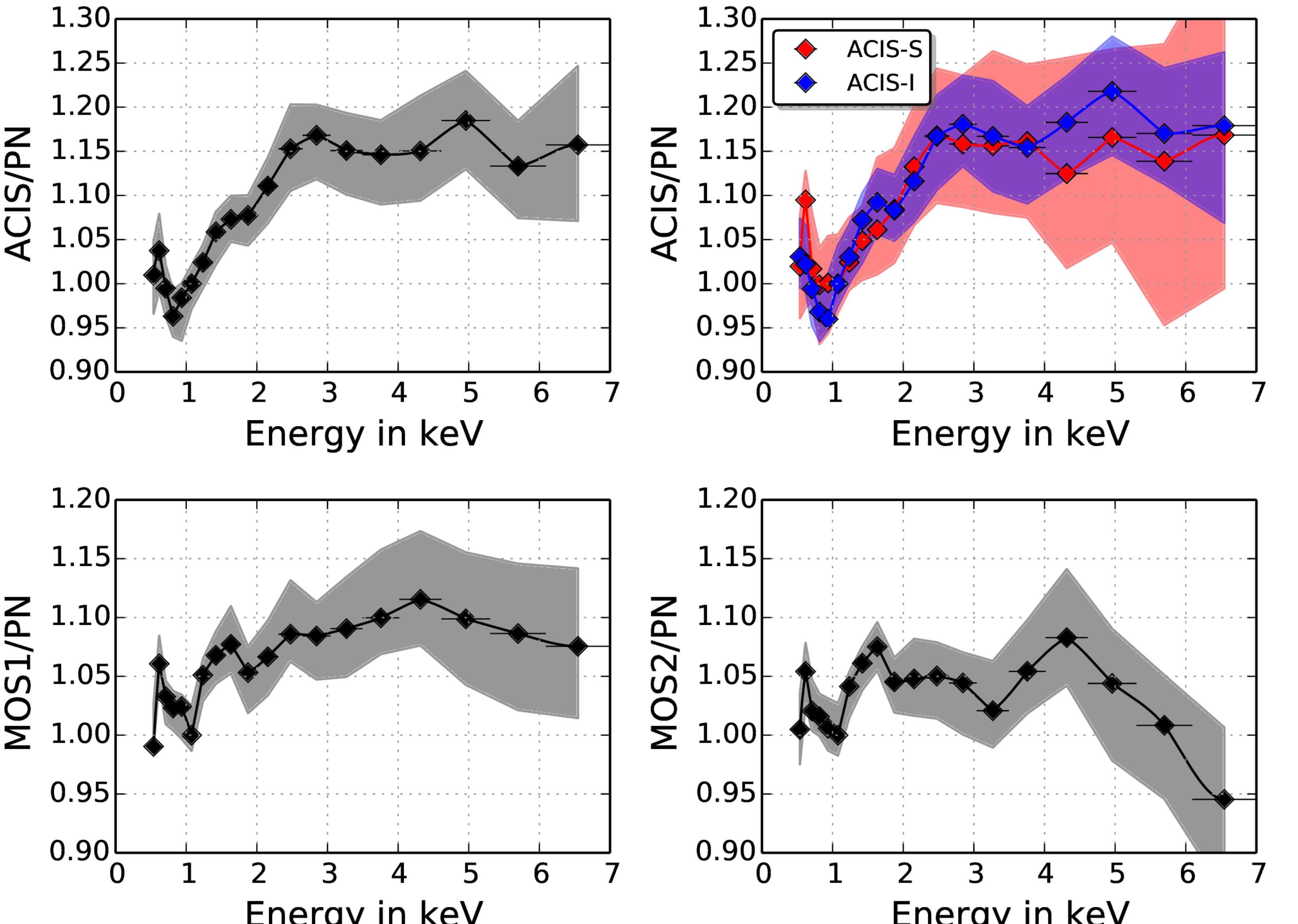
$$R_{ij} = \frac{\mathrm{data}_i}{\mathrm{model}_j \otimes \mathrm{response}_i} \times \frac{\mathrm{model}_j \otimes \mathrm{response}_j}{\mathrm{data}_j}$$

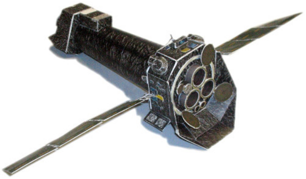
- Reference instrument (EPIC-PN)
- Calculate model prediction of reference instrument
- Divide data by reference model folded with instrumental response
- Normalize by reference instrument residuals



Stacked residuals ratio

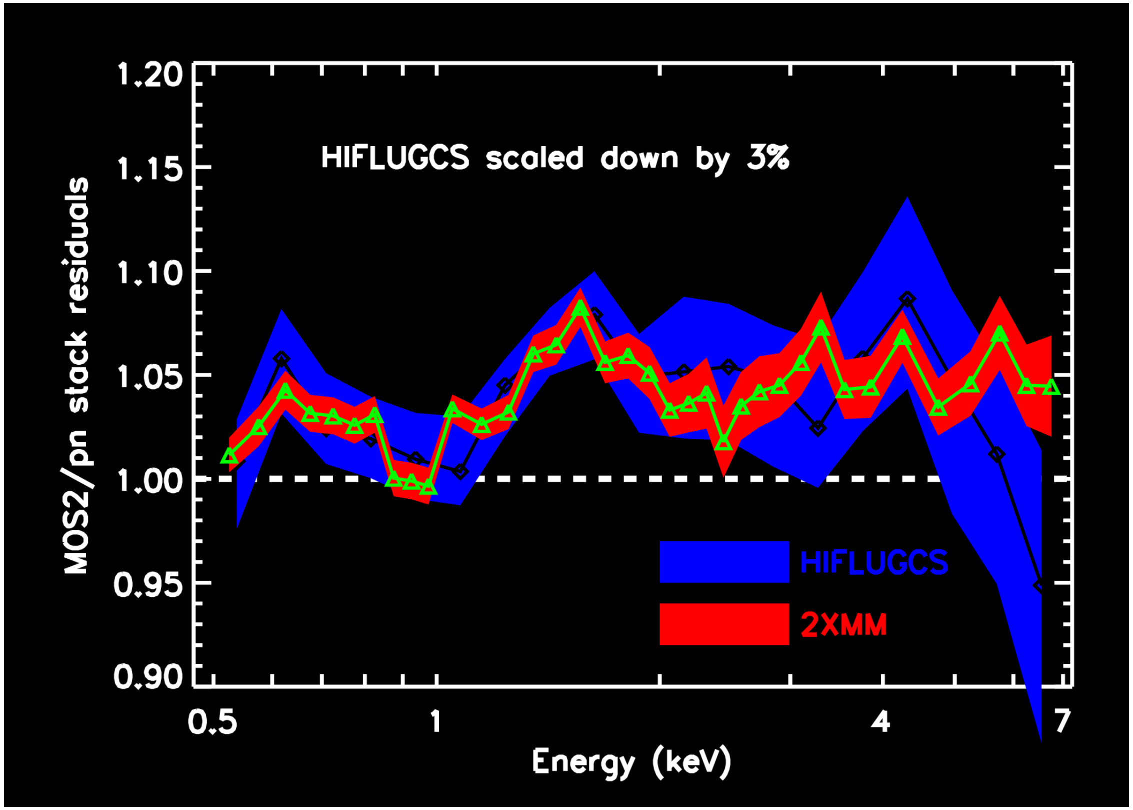






Stacked residuals ratio

MOS2/PN at high energies different to Read+14



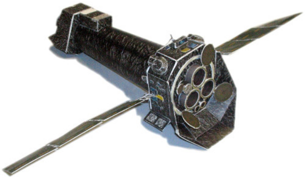
??Possible reasons??

HIFLUGCS

- Extended objects (chip gaps...)?
- Flares?
- Not enough counts a high energies?
- Fit-stack problem?

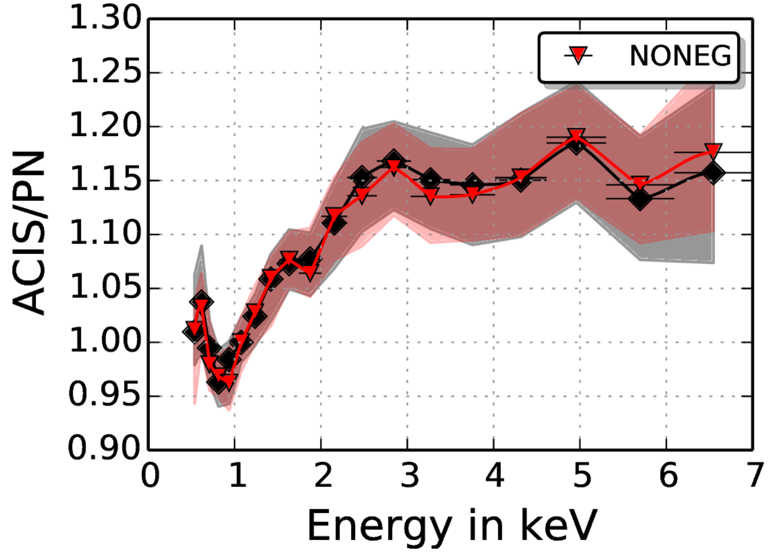
2XMM

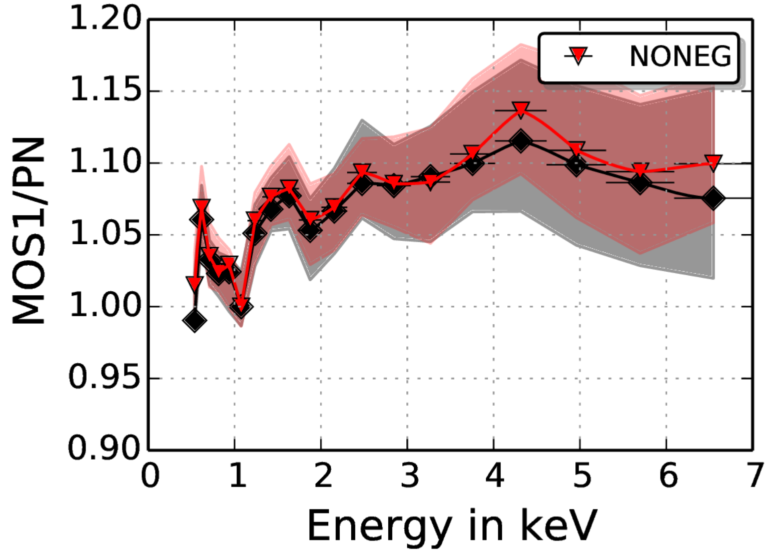
- Pile-up?
- Double PN events?
- Flares?
- Stack-fit problem?

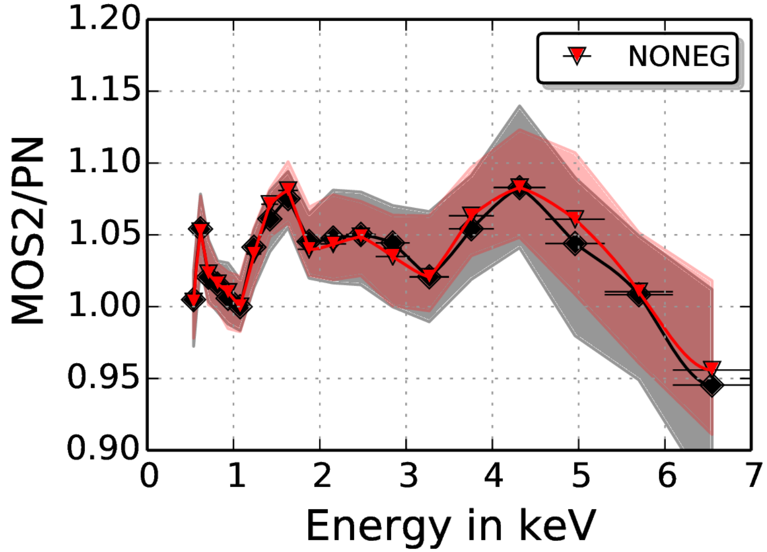


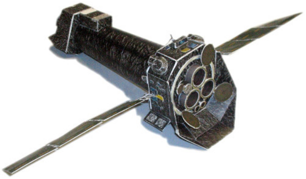
Stacked residuals ratio

Excluding clusters with negative spectral bins (red)

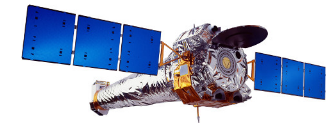




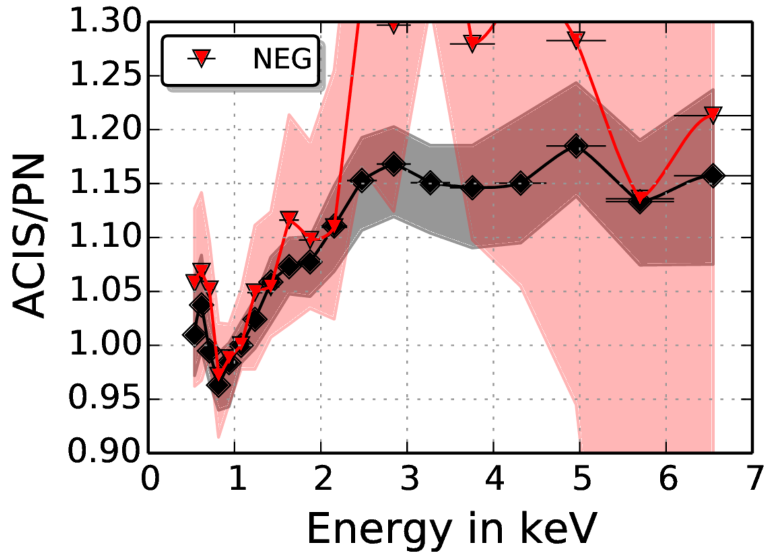


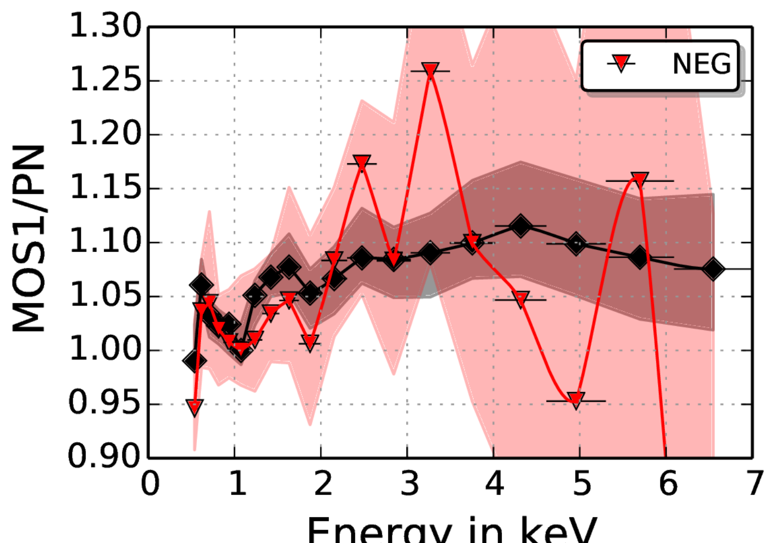


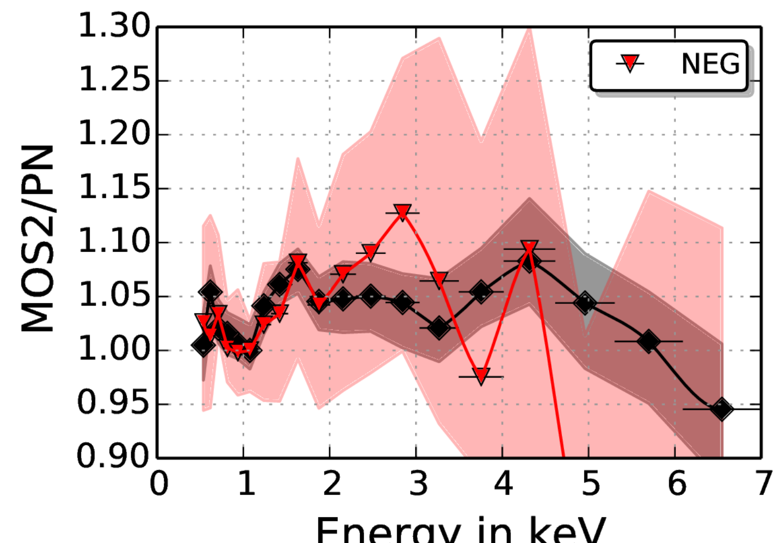
Stacked residuals ratio

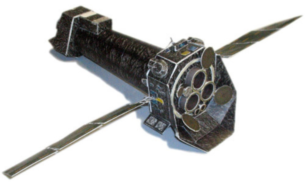


Only clusters with negative spectral bins (red)



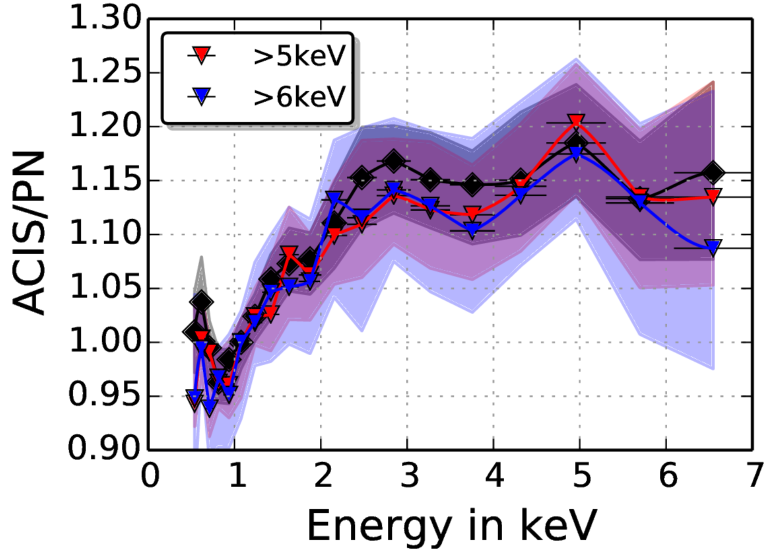


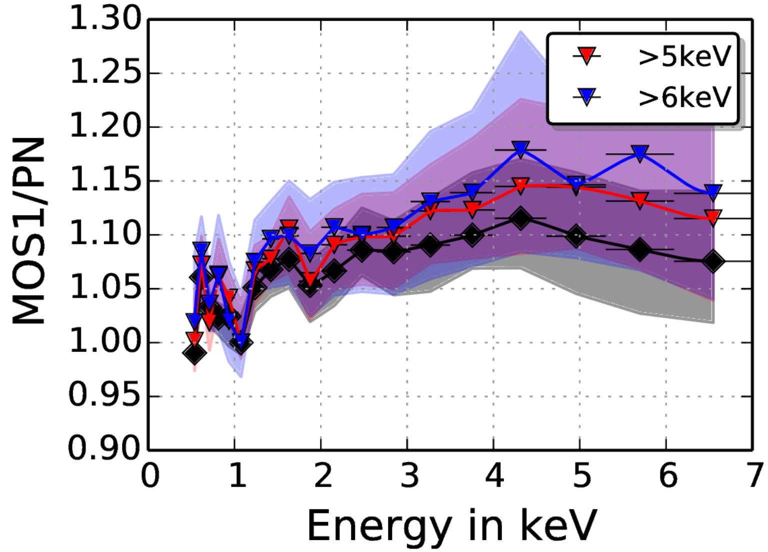


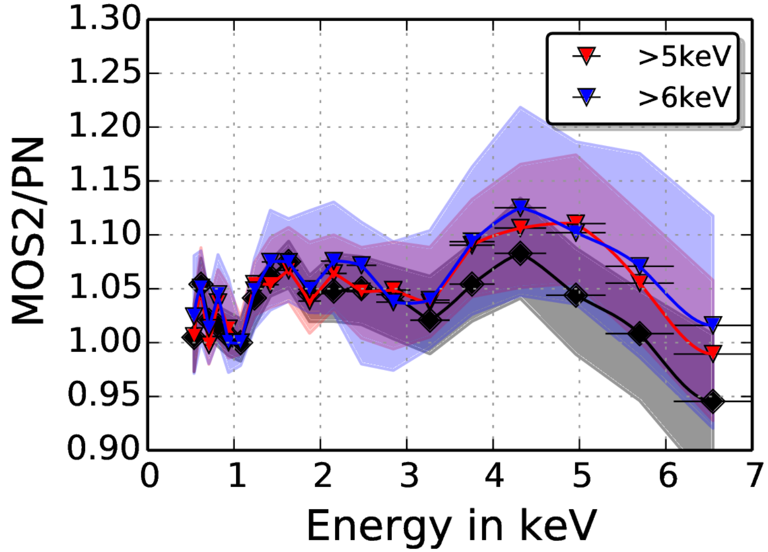


Stacked residuals ratio

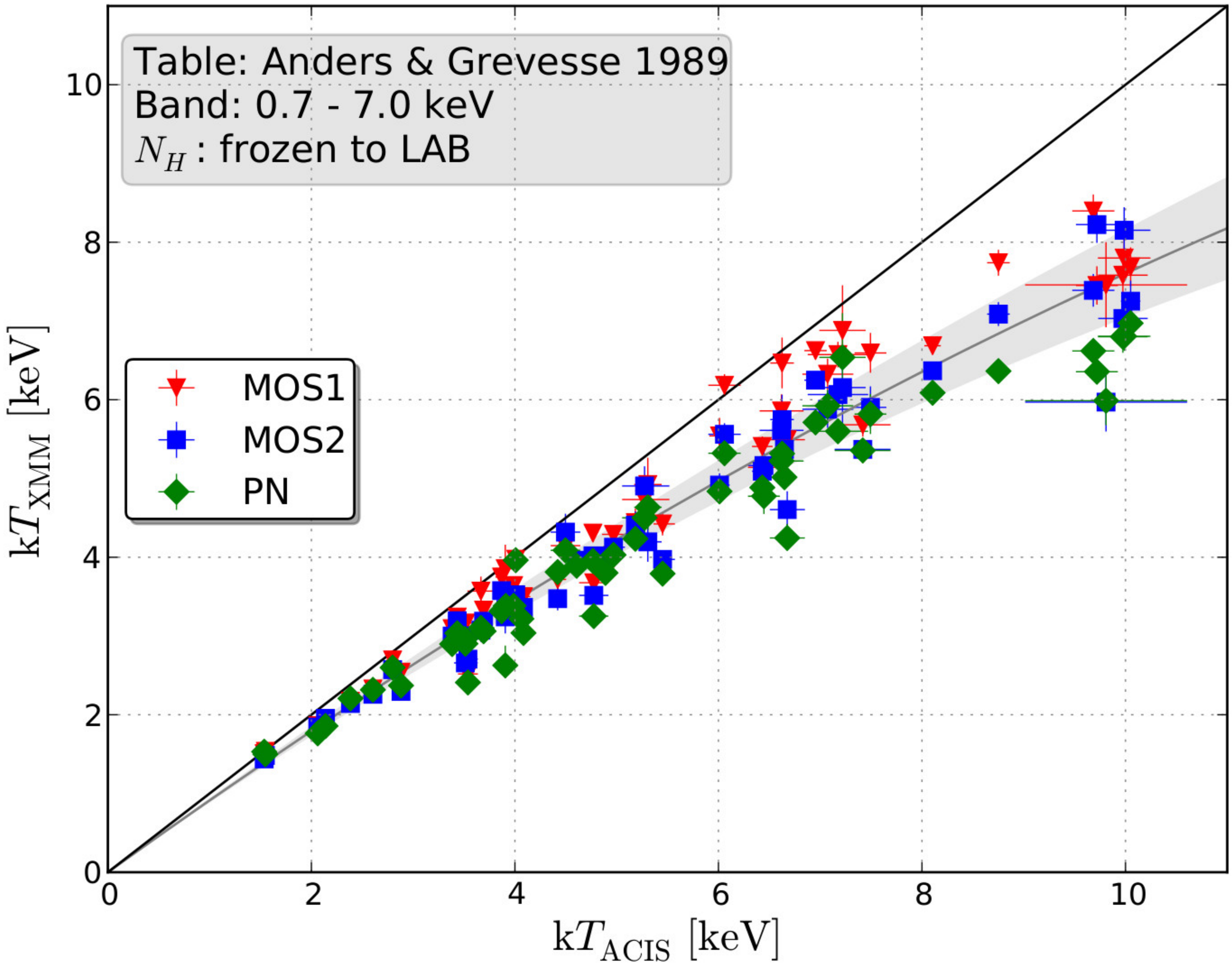
Only clusters with MOS1 temperature > 5keV (red) or 6 kev (blue)

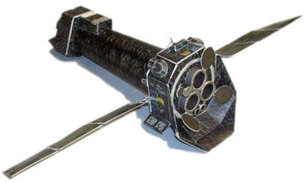




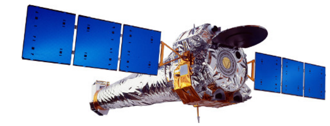


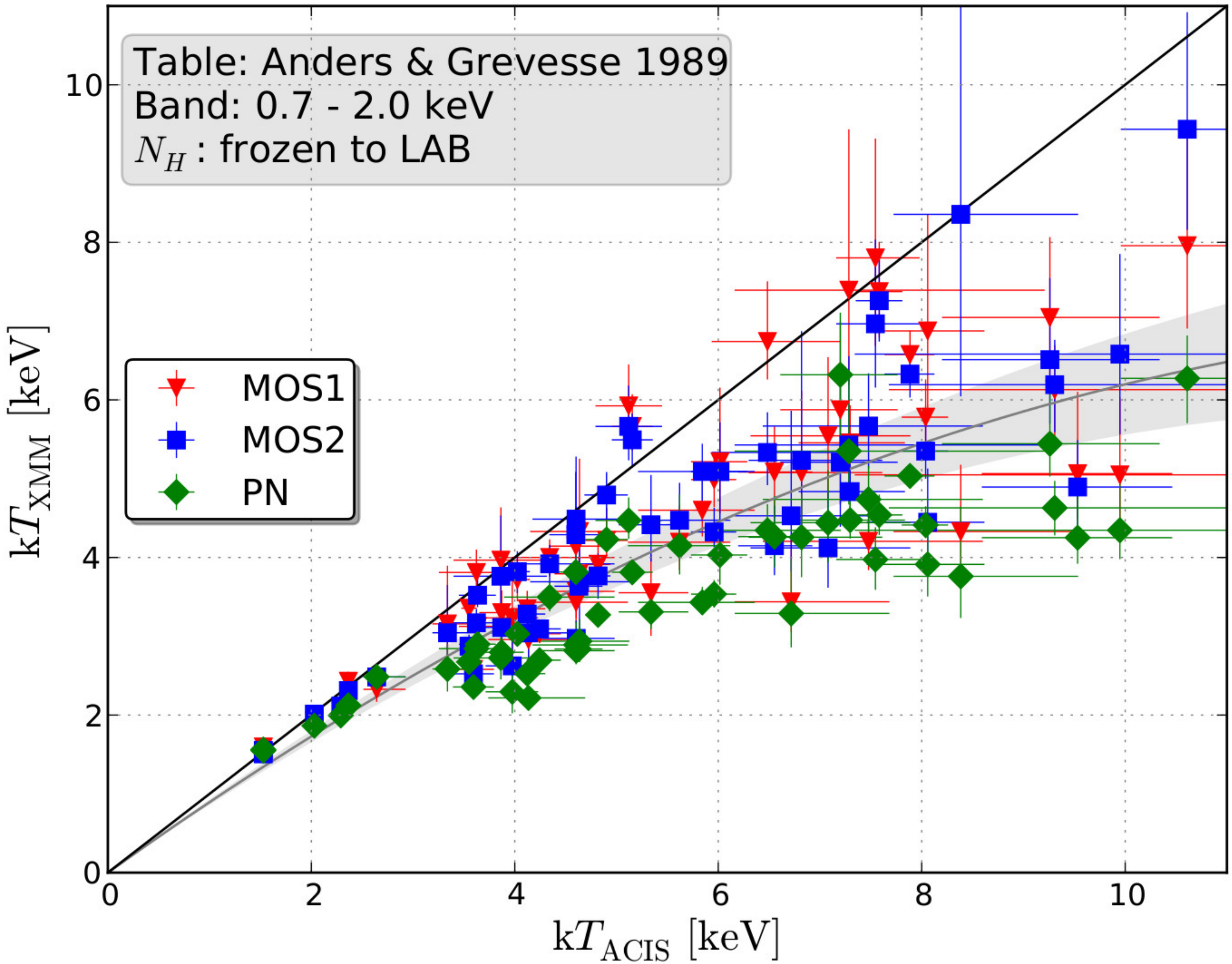
Results - Temperatures

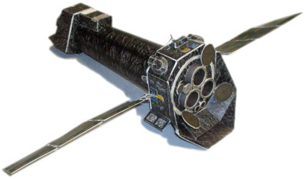




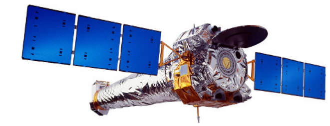
Results - Temperatures

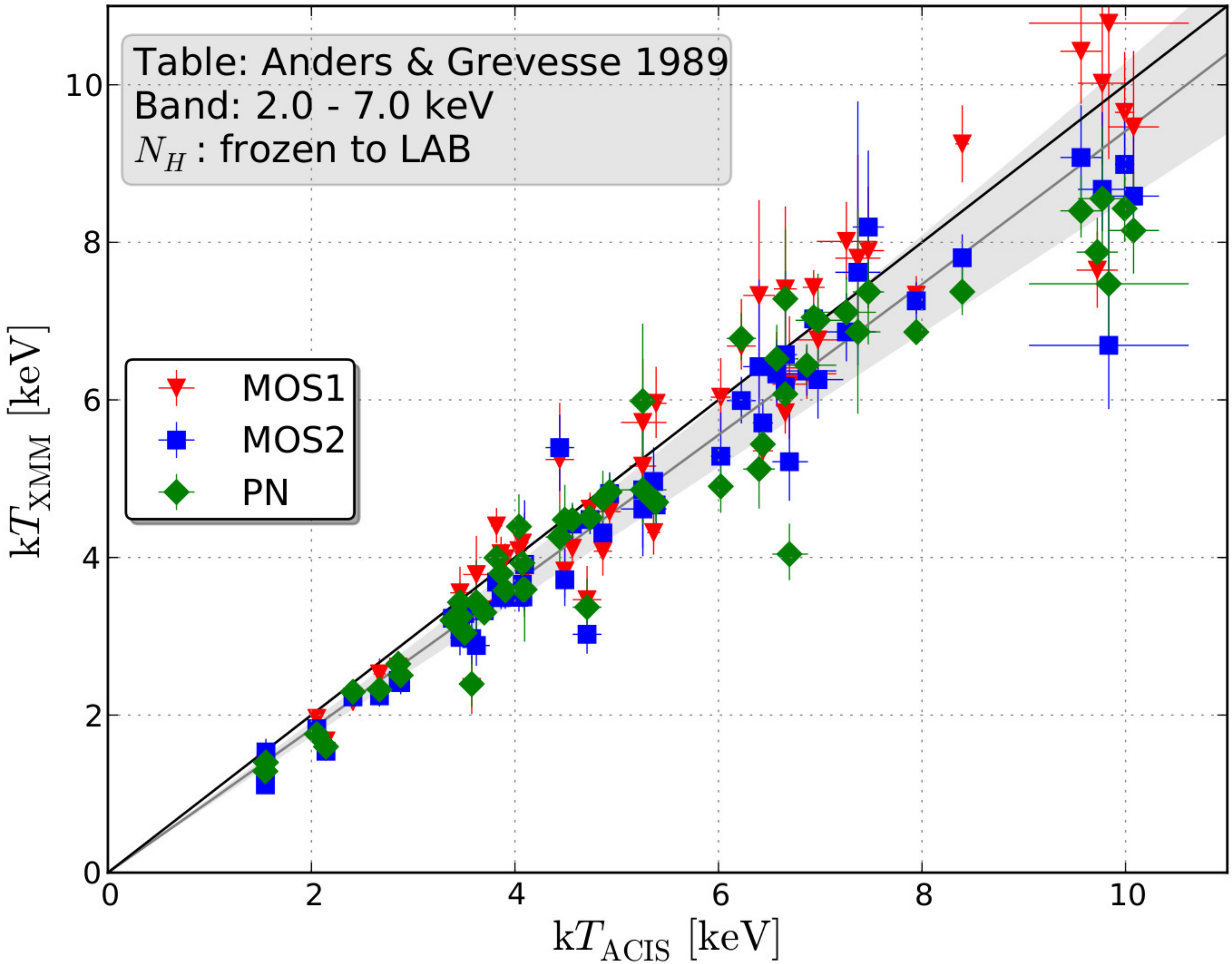


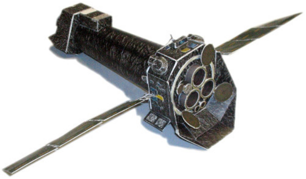




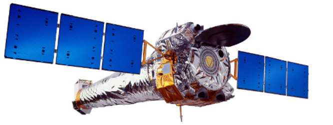
Results - Temperatures

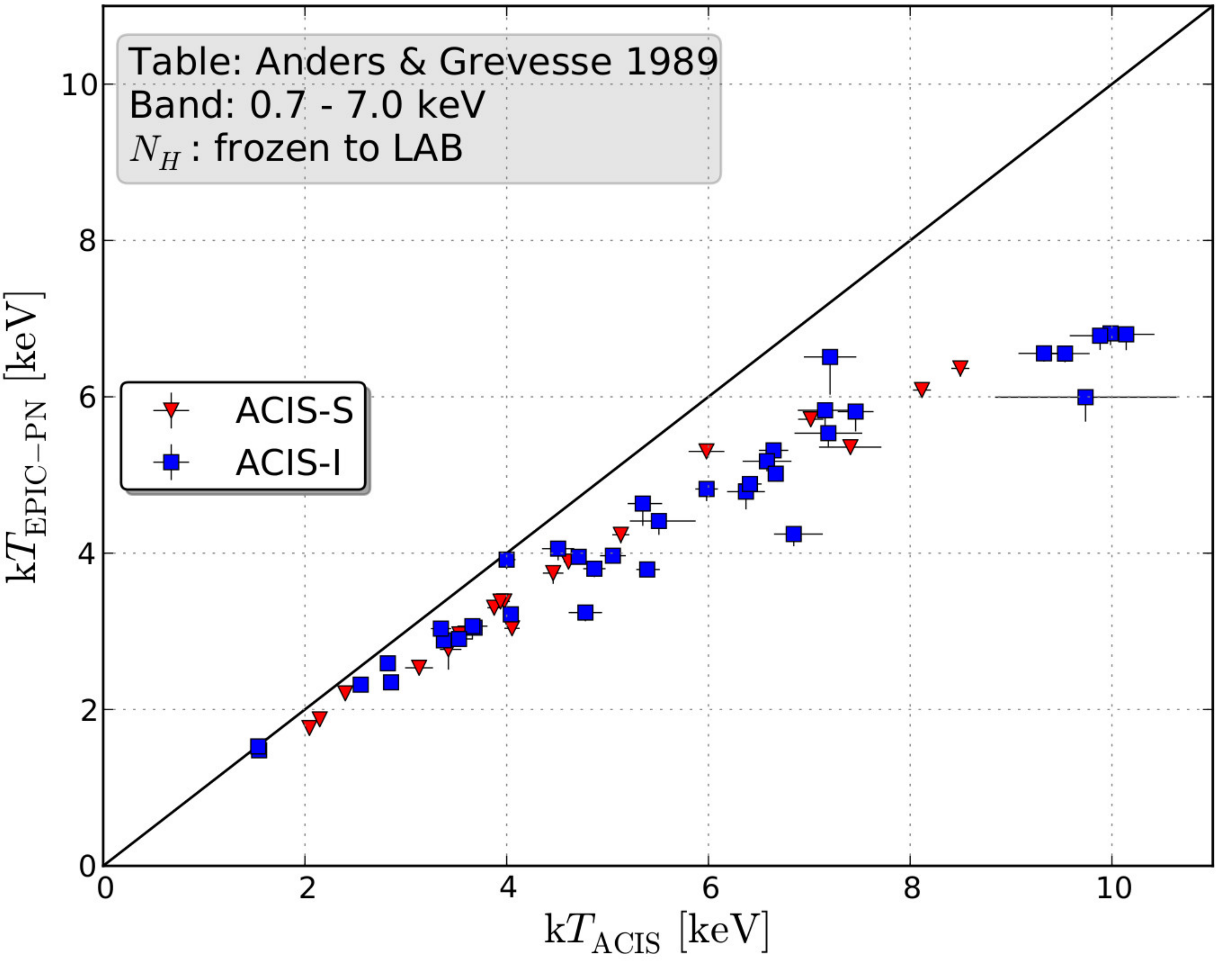


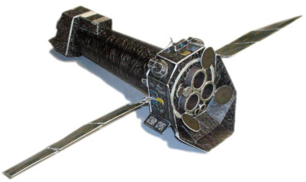




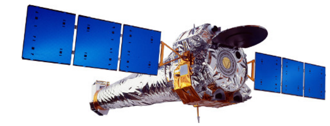
Results - Temperatures

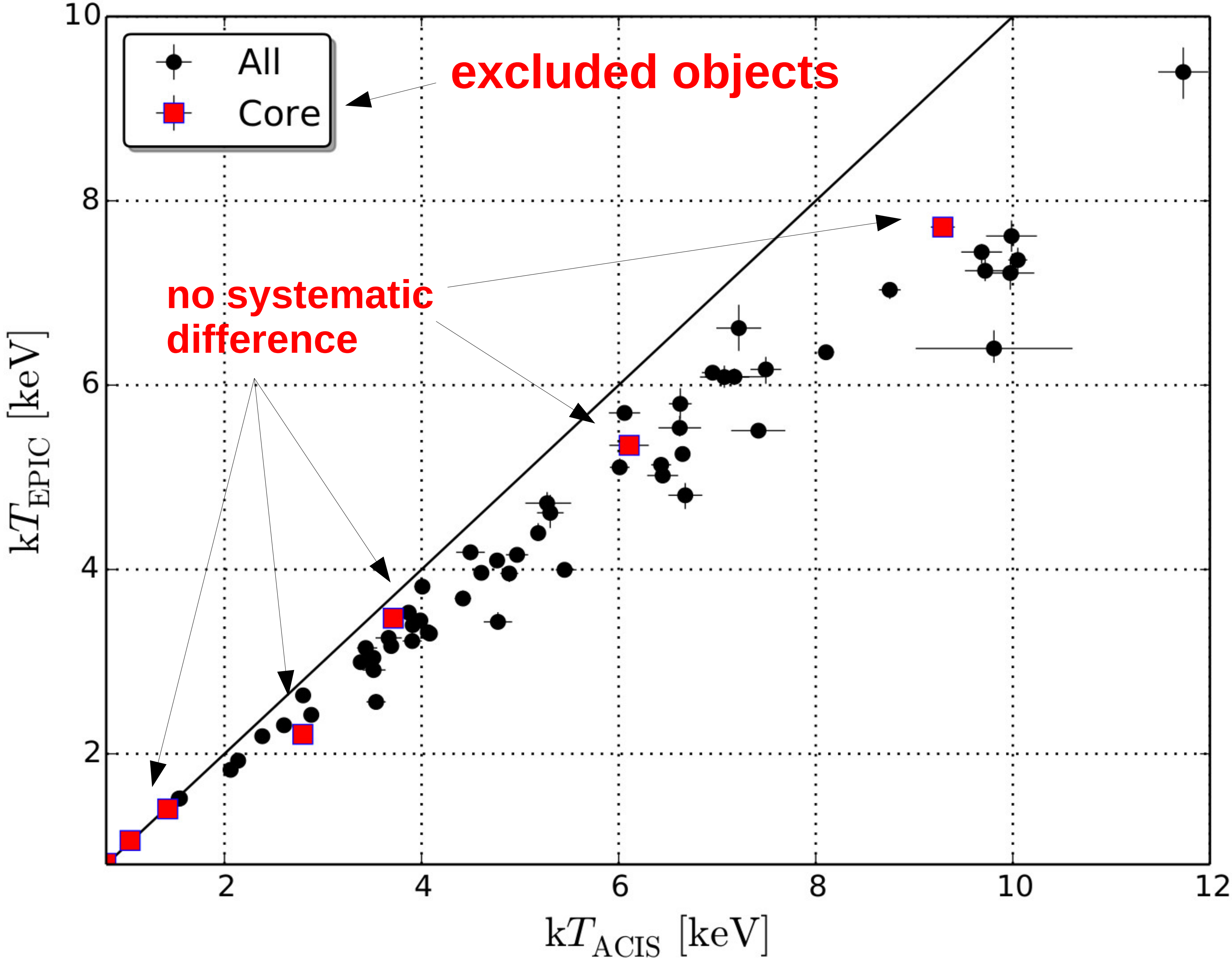


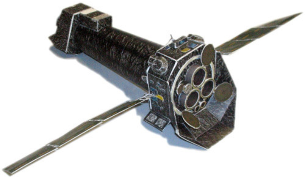




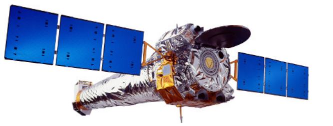
Results - Temperatures



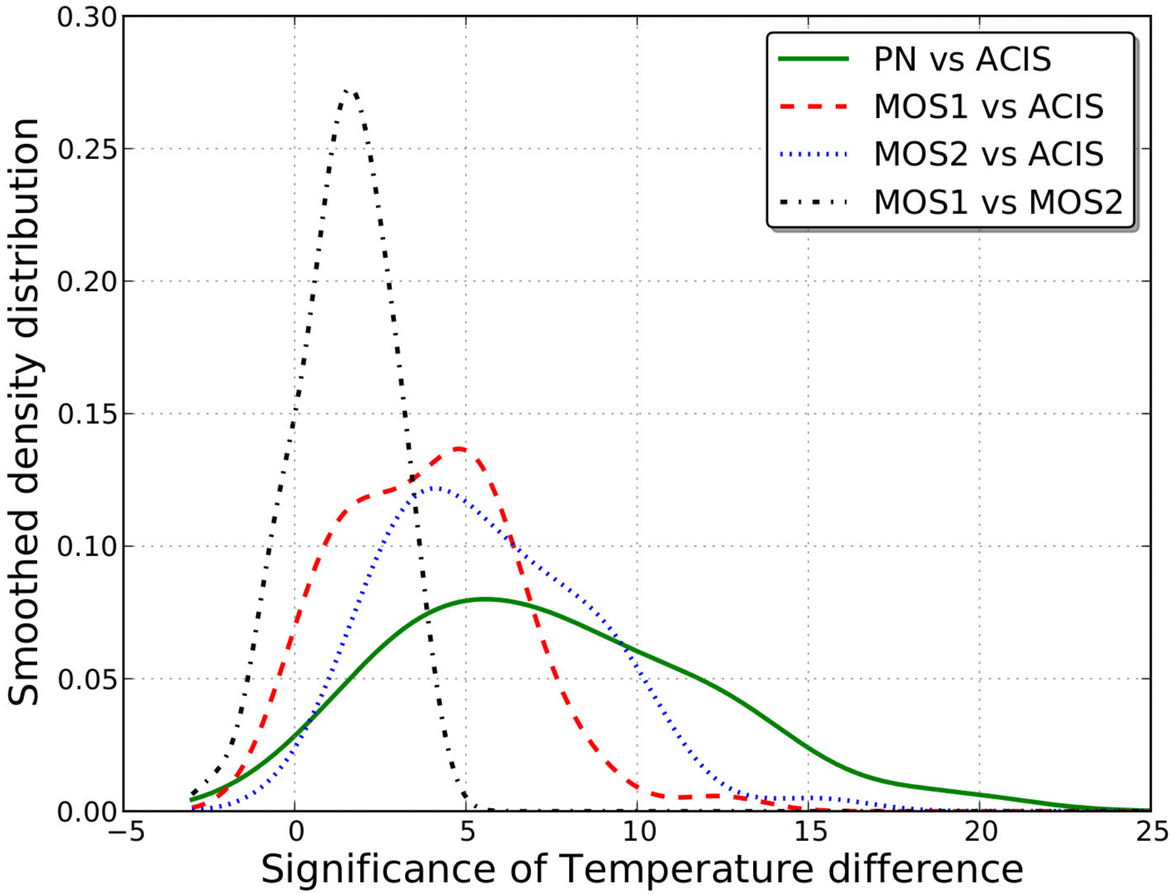




Results - Significance



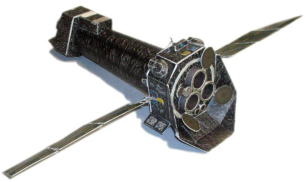
Significance of temperature difference of HIFLUGCS clusters



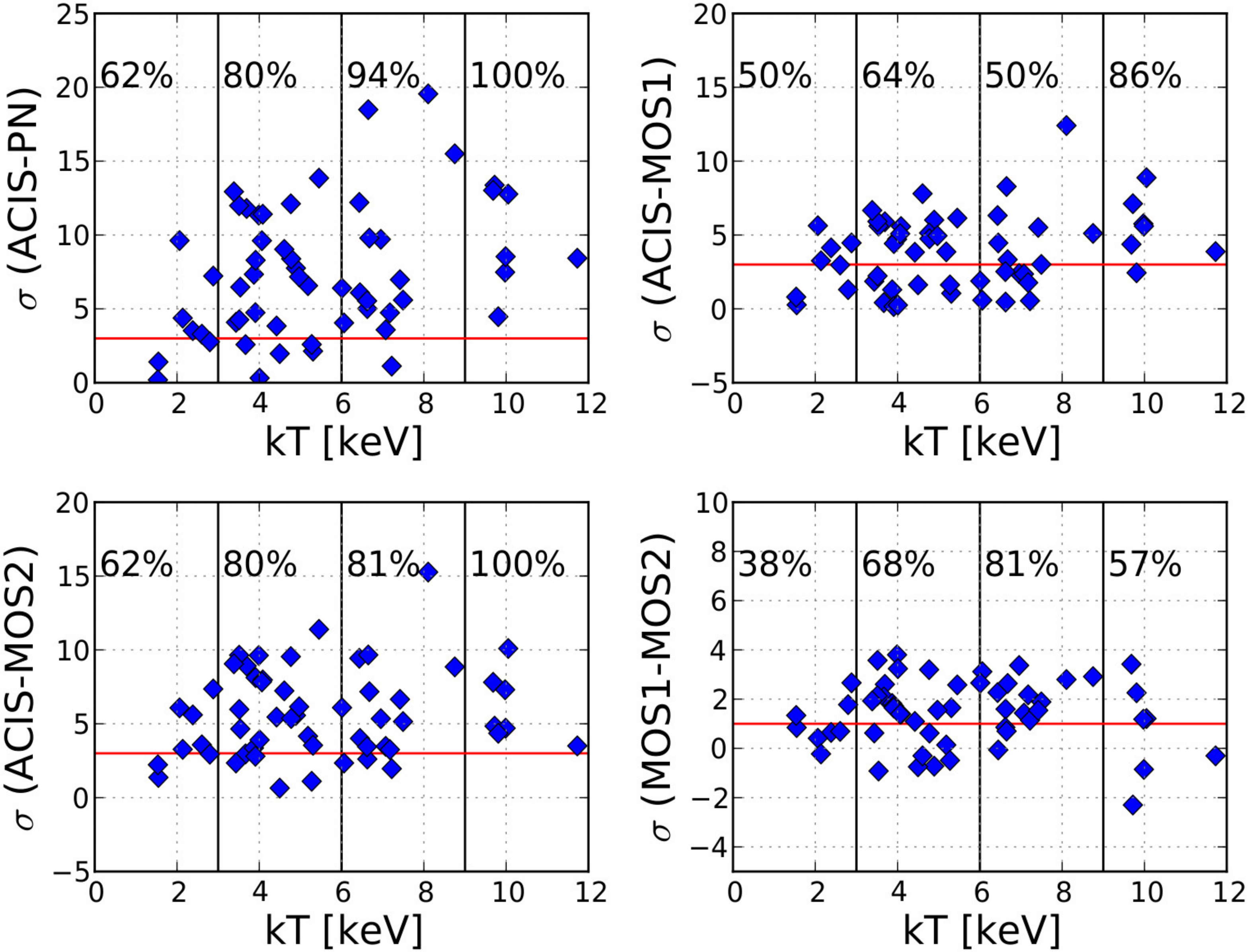
Probability for a significance below 1:

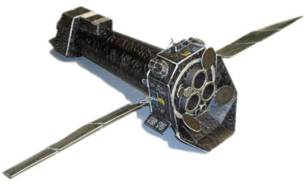
8% ACIS-PN

37% MOS1-MOS2

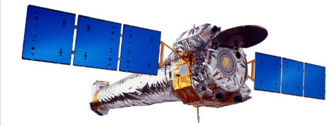


Results - Significance

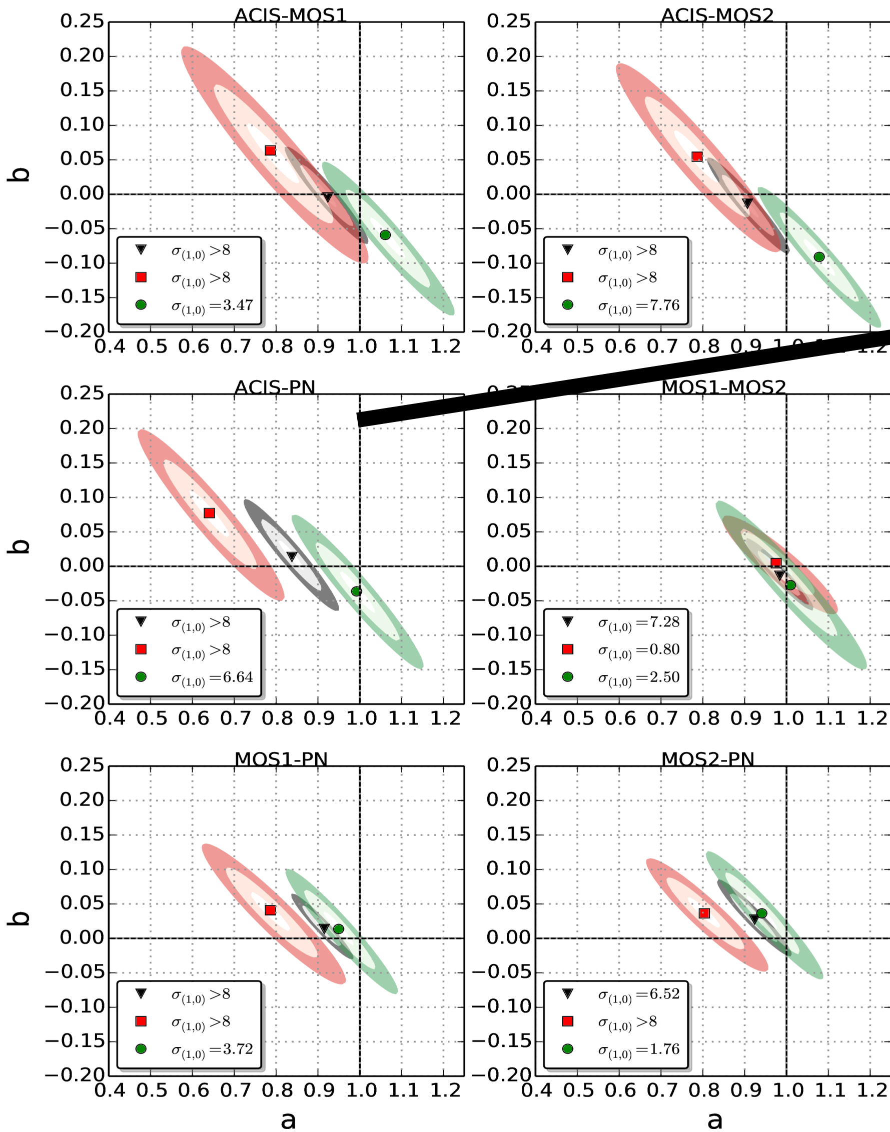


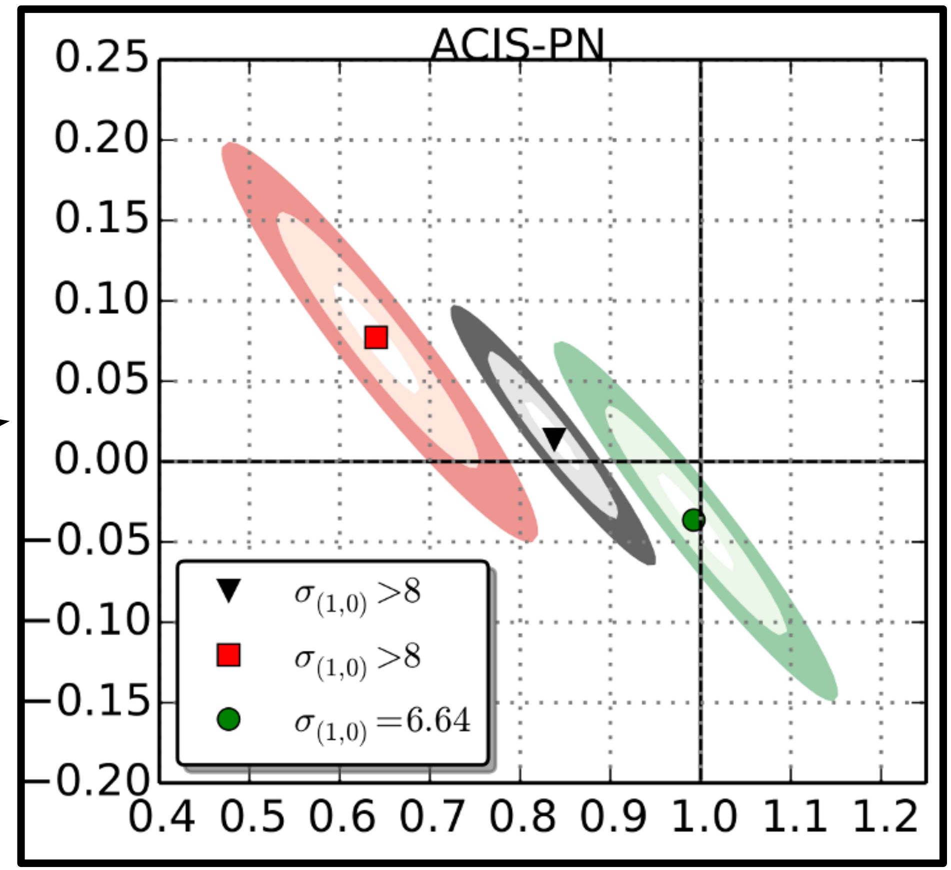


Significance

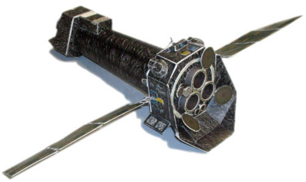


Fitting temperatures of the whole sample with powerlaw
Two detectors agree for a=1 and b=0
Red: soft band; green: hard band; black: full band
Outer region is 5 sigma





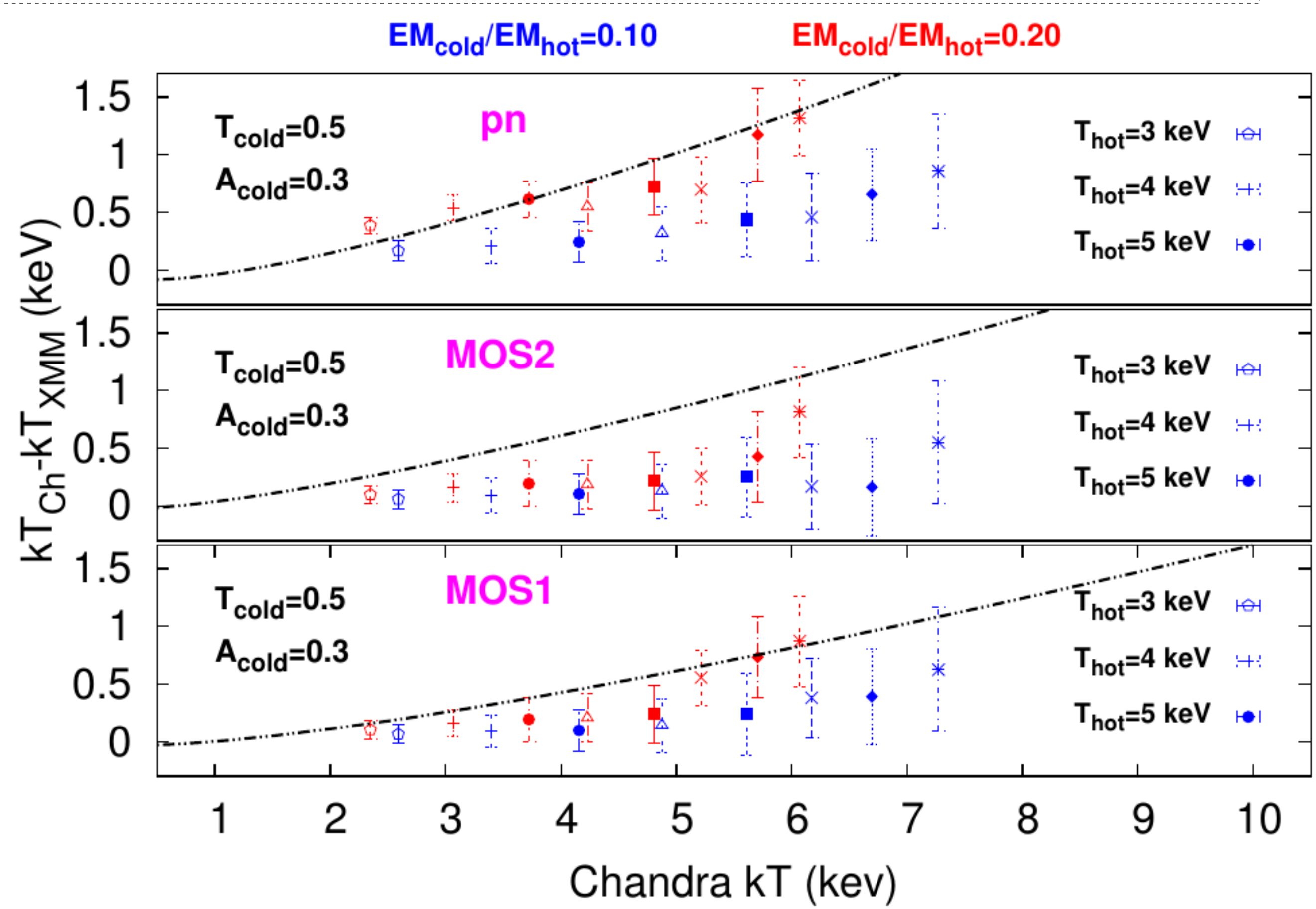
$$\log_{10} \frac{kT_{\mathrm{I_Y,band}}}{1\,\mathrm{keV}} = a \times \log_{10} \frac{kT_{\mathrm{I_X,band}}}{1\,\mathrm{keV}} + b$$

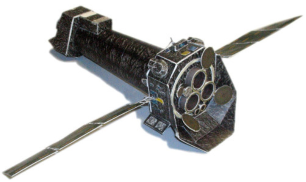


Discussion – Multiphase ICM

- Different instruments are sensitive more/less sensitive to the harder part of the spectrum (i.e. hotter component)
- Simulations with two component plasma fitted with one component

- Different temperature differences (ACIS-PN; ACIS-MOS) not recovered with the same plasma composition
- T_cold = 0.5 and EMR = 0.2 unrealistic

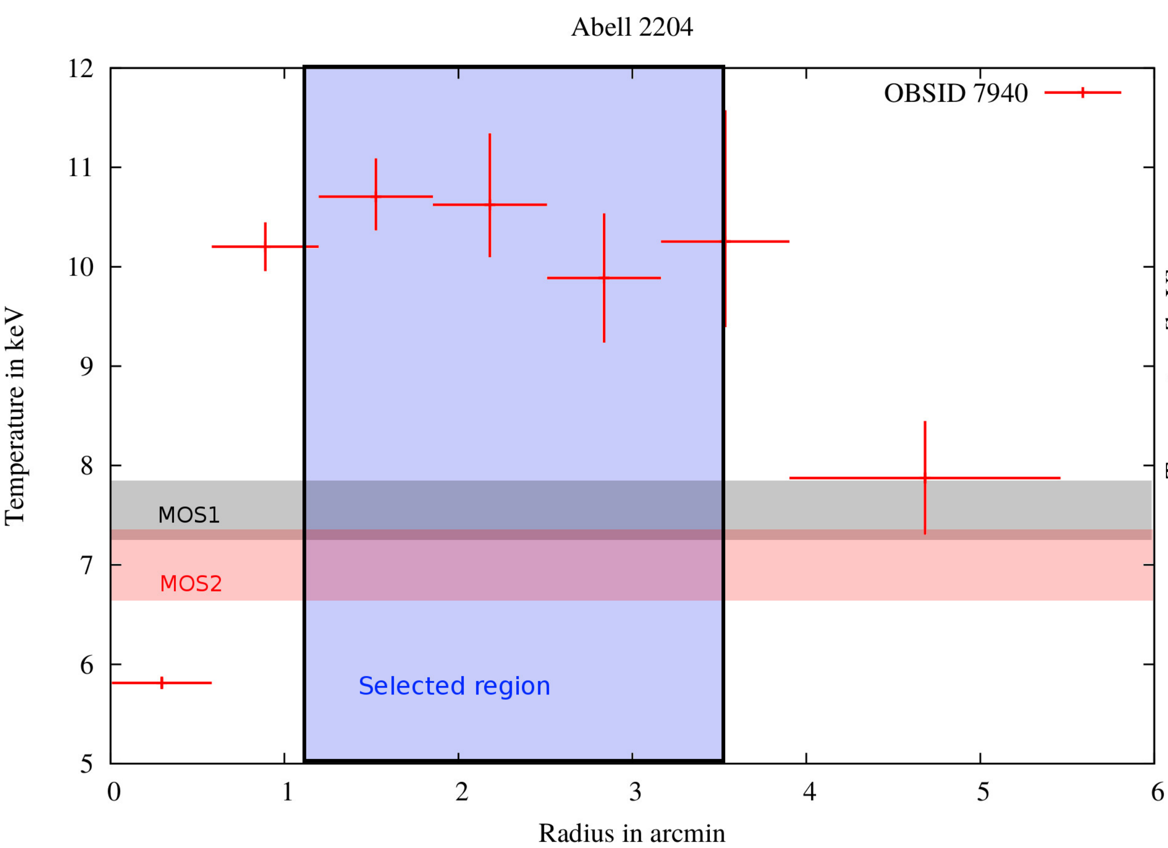


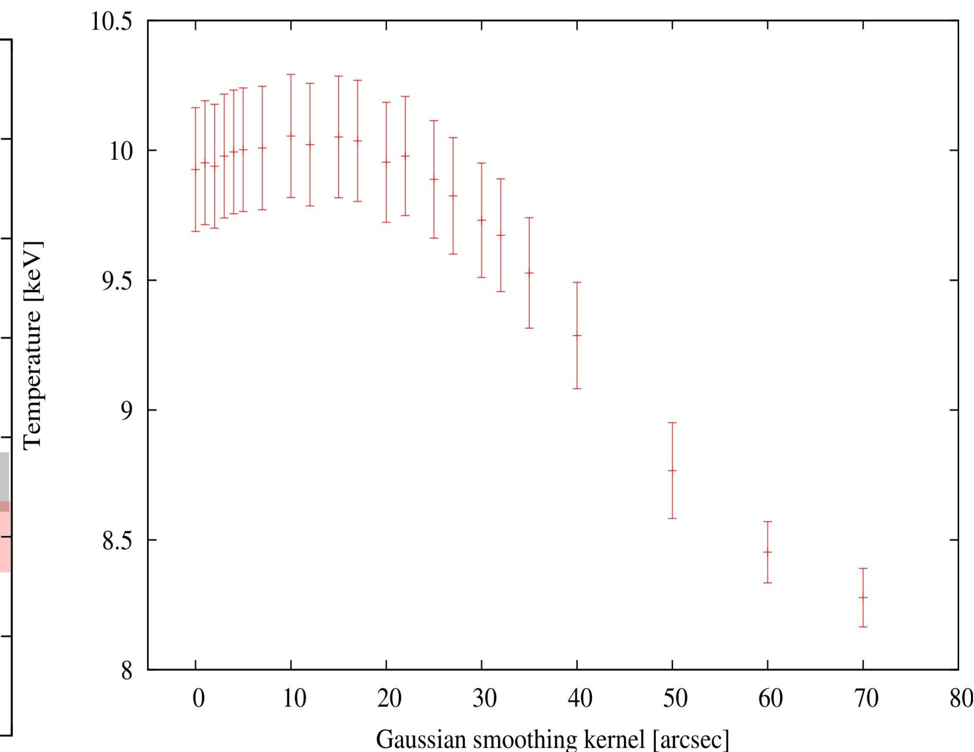


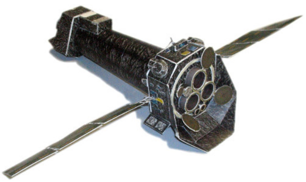
Discussion – Multiphase ICM

PSF effects:

- Cold gas from the core scattered into the region by the XMM PSF? → Smooth a Chandra events file



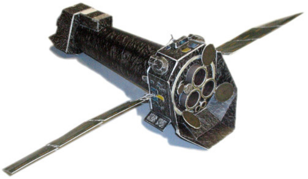




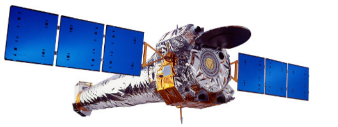
Discussion – Multiphase ICM

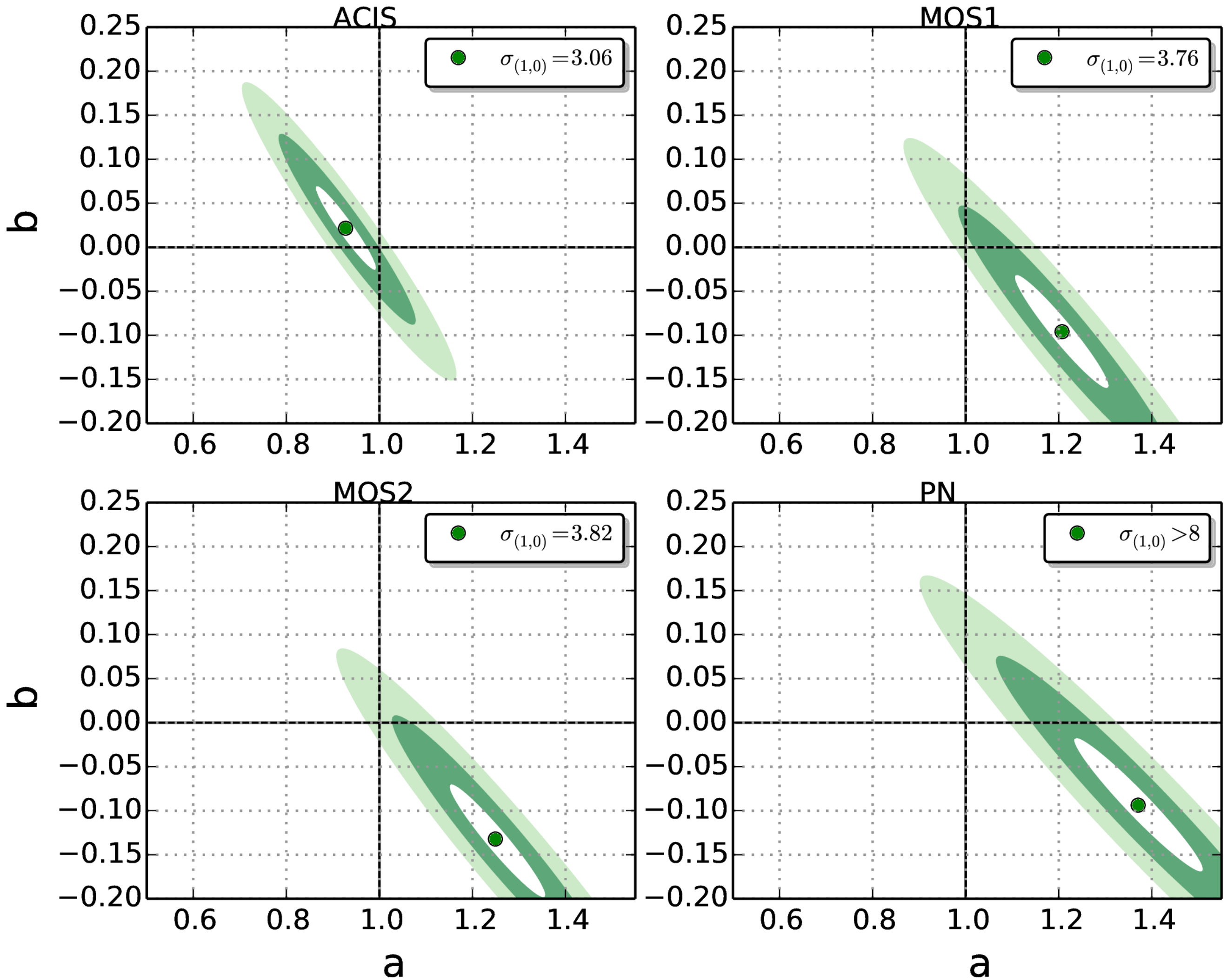
- Temperature – Abundance degeneracy
  - Freeze XMM abundance to the Chandra determined one for the fitting process
  - → EPIC-PN temperature increases on average 0.8%

- Two temperature component fits
  - Cold component frozen to 0.5 keV
  - Normalization of cold component 1-5% (20% required)
  - Freezing Normalization to 20% → χ^2_{red} above 4

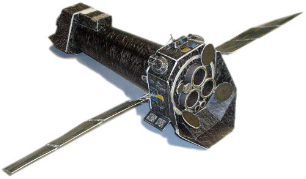


Discussion

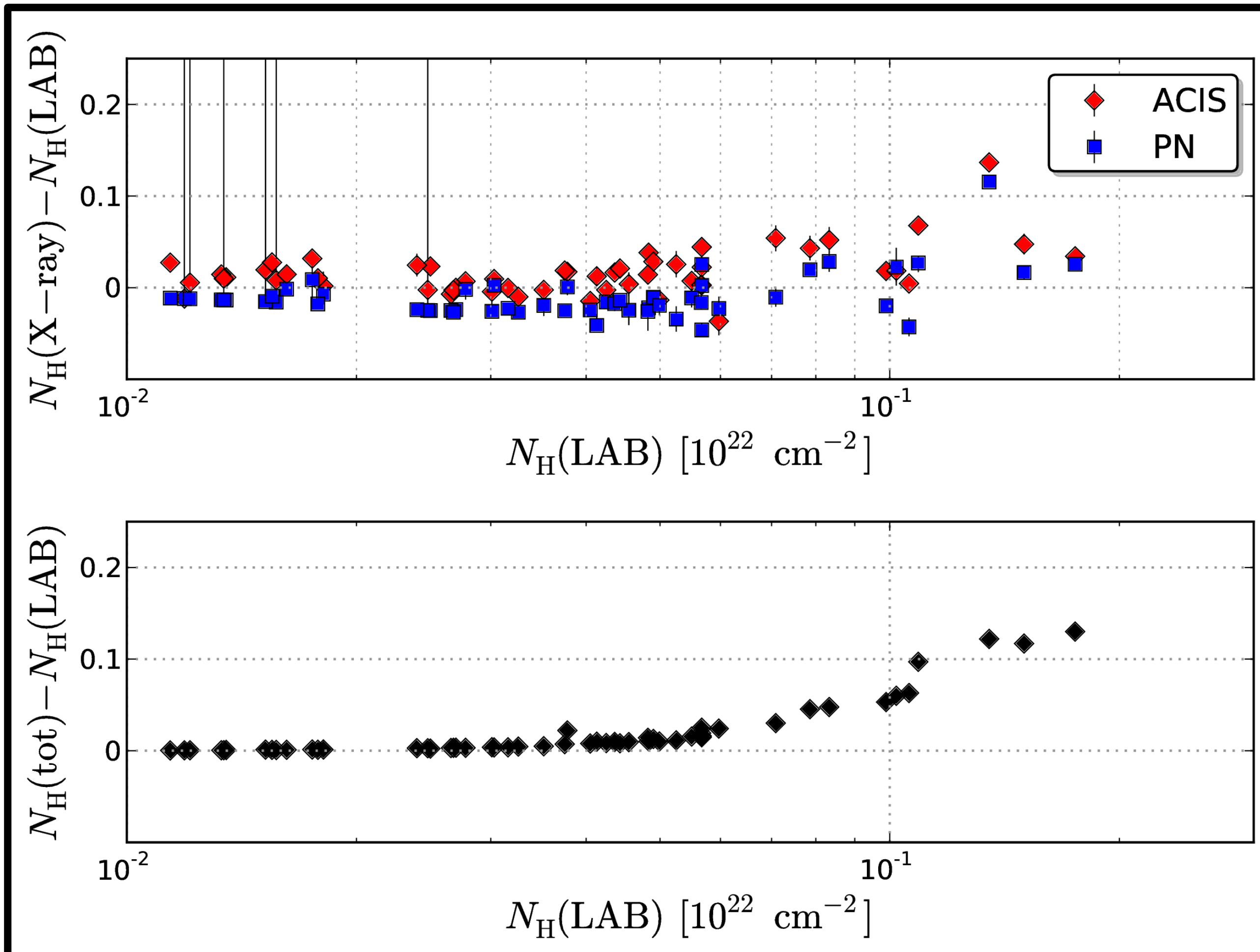




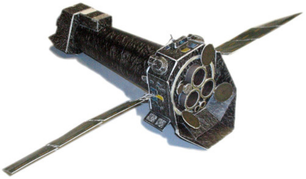
Self-consistent test:
Soft vs. hard band of the same instrument



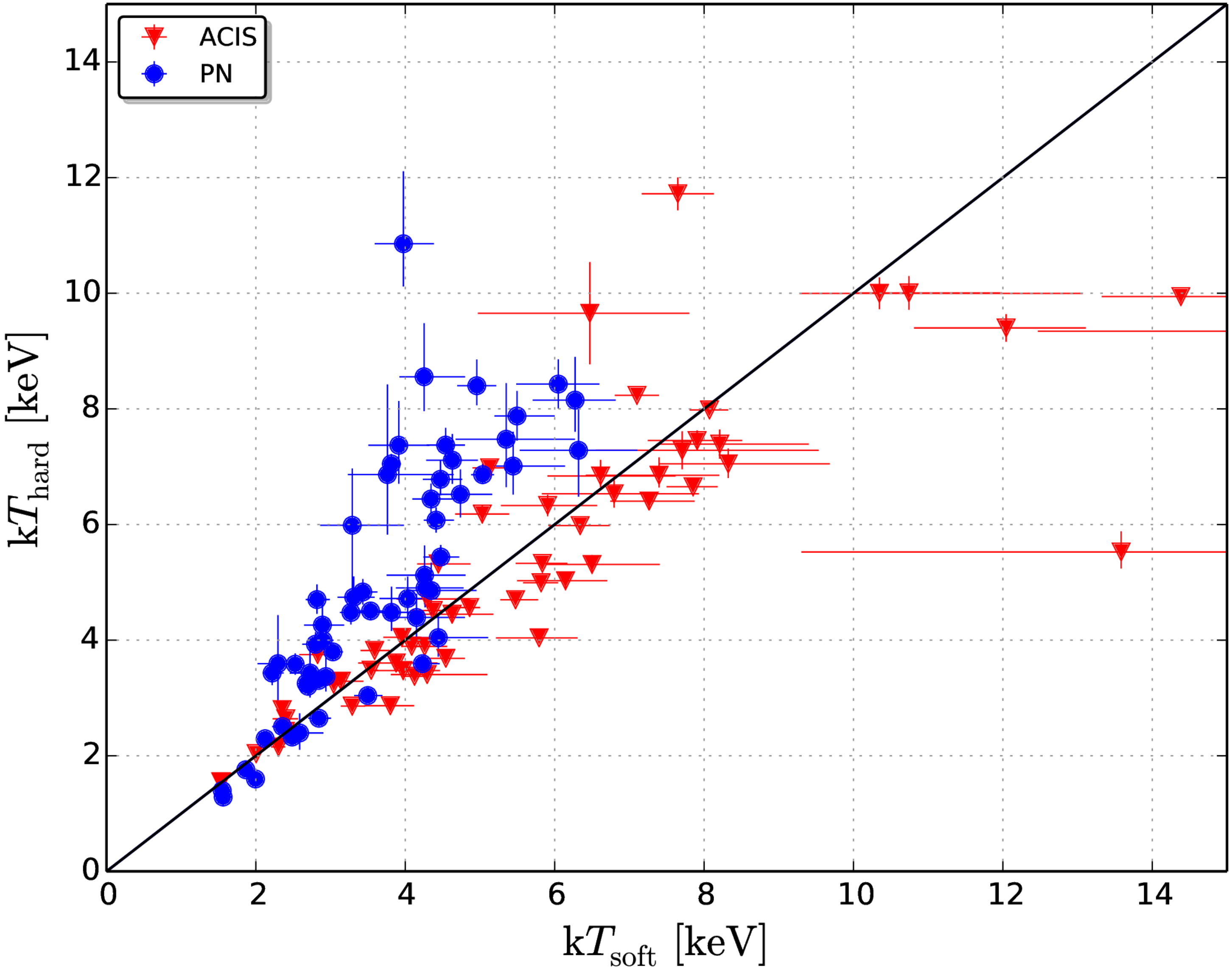
Discussion



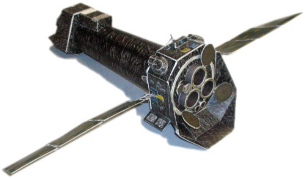
Free-NH test



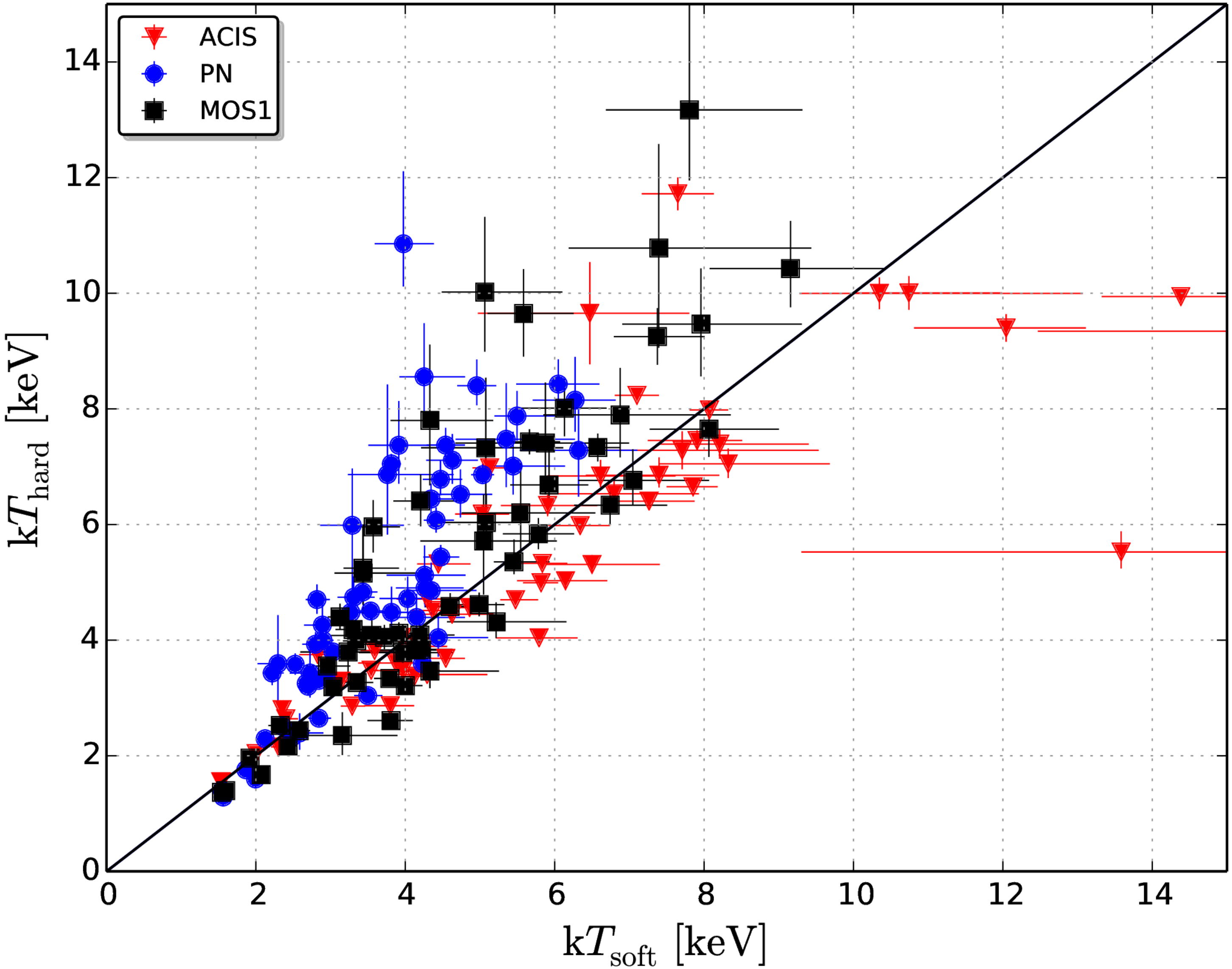
Soft vs Hard

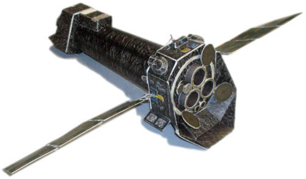


ACIS
PN
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
$kT_{\rm hard}$ [keV]
$kT_{\rm soft}$ [keV]



Soft vs Hard





Cosmology

What does this mean for cosmology?

- How do Sigma8, OmegaM change when switching from Chandra to XMM-Newton?
- Tension in the Planck 2013 results:
  - CMB primary anisotropies
  - Sunyaev Zel'dovich cluster counts using XMM-Newton derived scaling relation

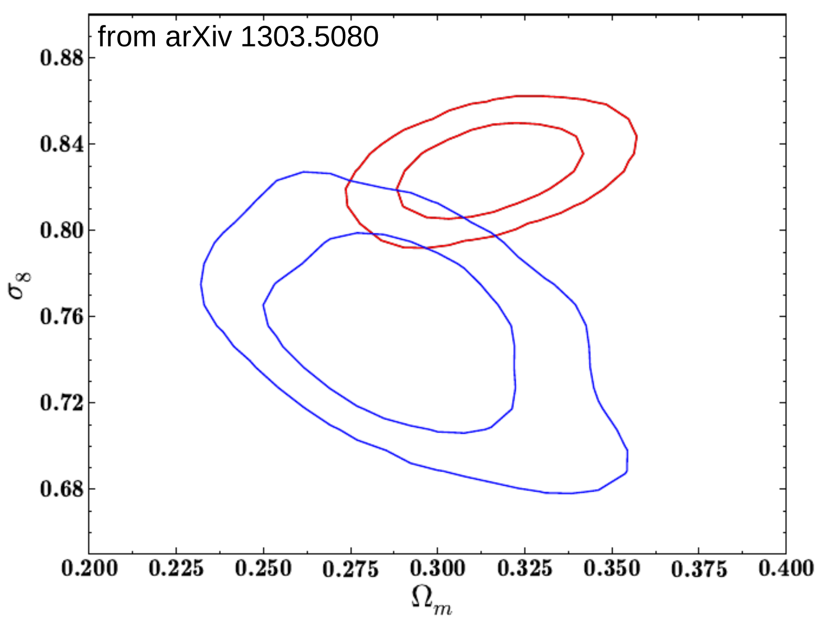
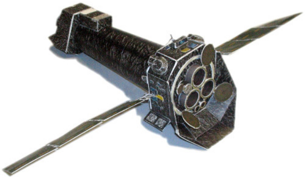


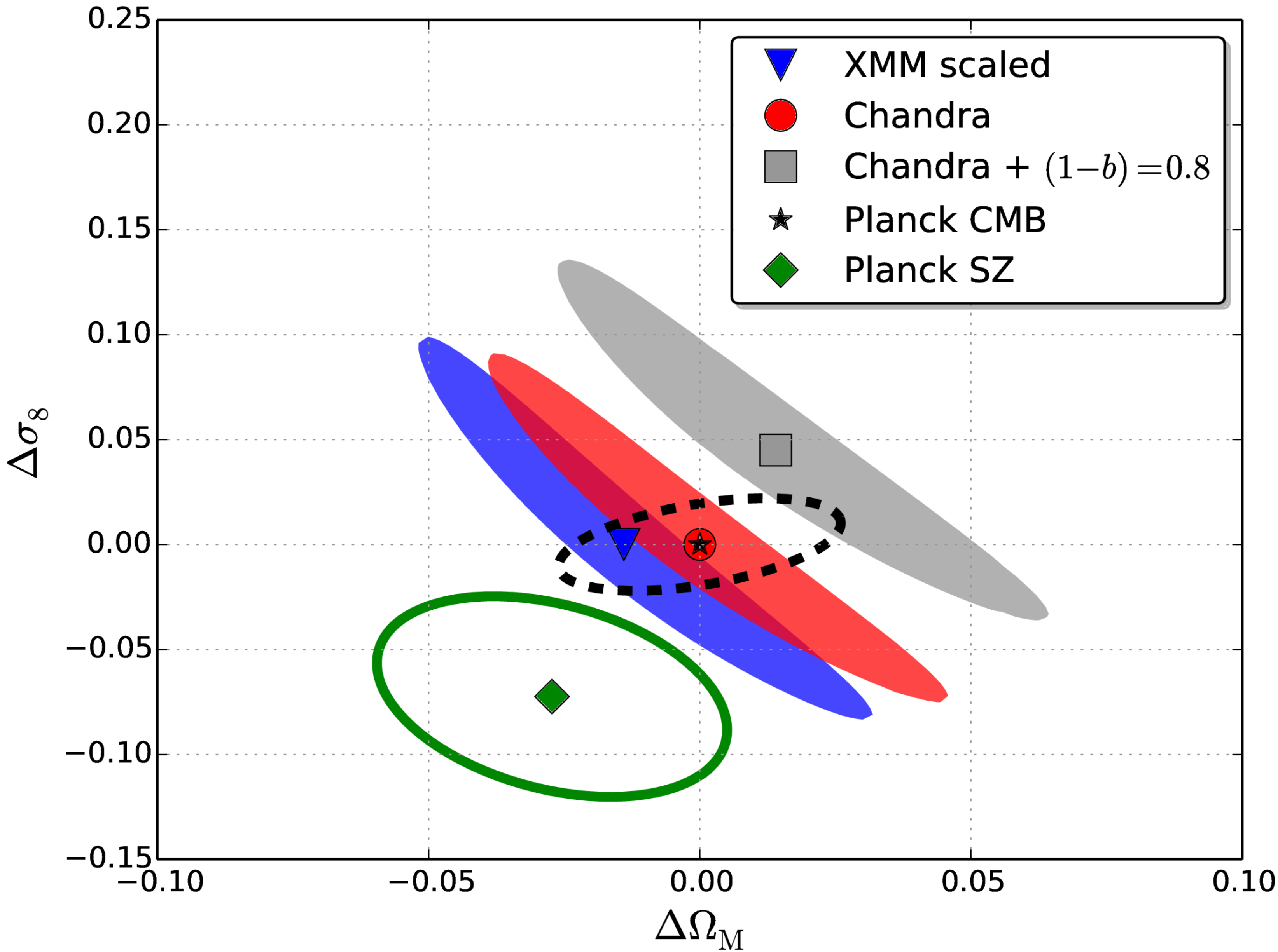
Fig. 11. 2D Ω_m–σ_8 likelihood contours for the analysis with *Planck* CMB only (red); *Planck* SZ + BAO + BBN (blue) with $(1 - b)$ in [0.7, 1].

What is a hydrostatic bias?

- Hydrostatic masses only account for gravity
- Non-gravitational effects
- Other (e.g., Weak Lensing) analyses reveal higher cluster masses
- Often discussed: (1-b)=0.8 means X-ray masses are 20% lower
- Recent results (Israel+14) raise doubts on the existence of a hydrostatic bias



Cosmology


XMM scaled
Chandra
Chandra + $(1-b)=0.8$
Planck CMB
Planck SZ
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.10
−0.05
0.00
0.05
0.10
$\Delta\sigma_8$
$\Delta\Omega_M$