Clusters of galaxies as X-ray calibrators

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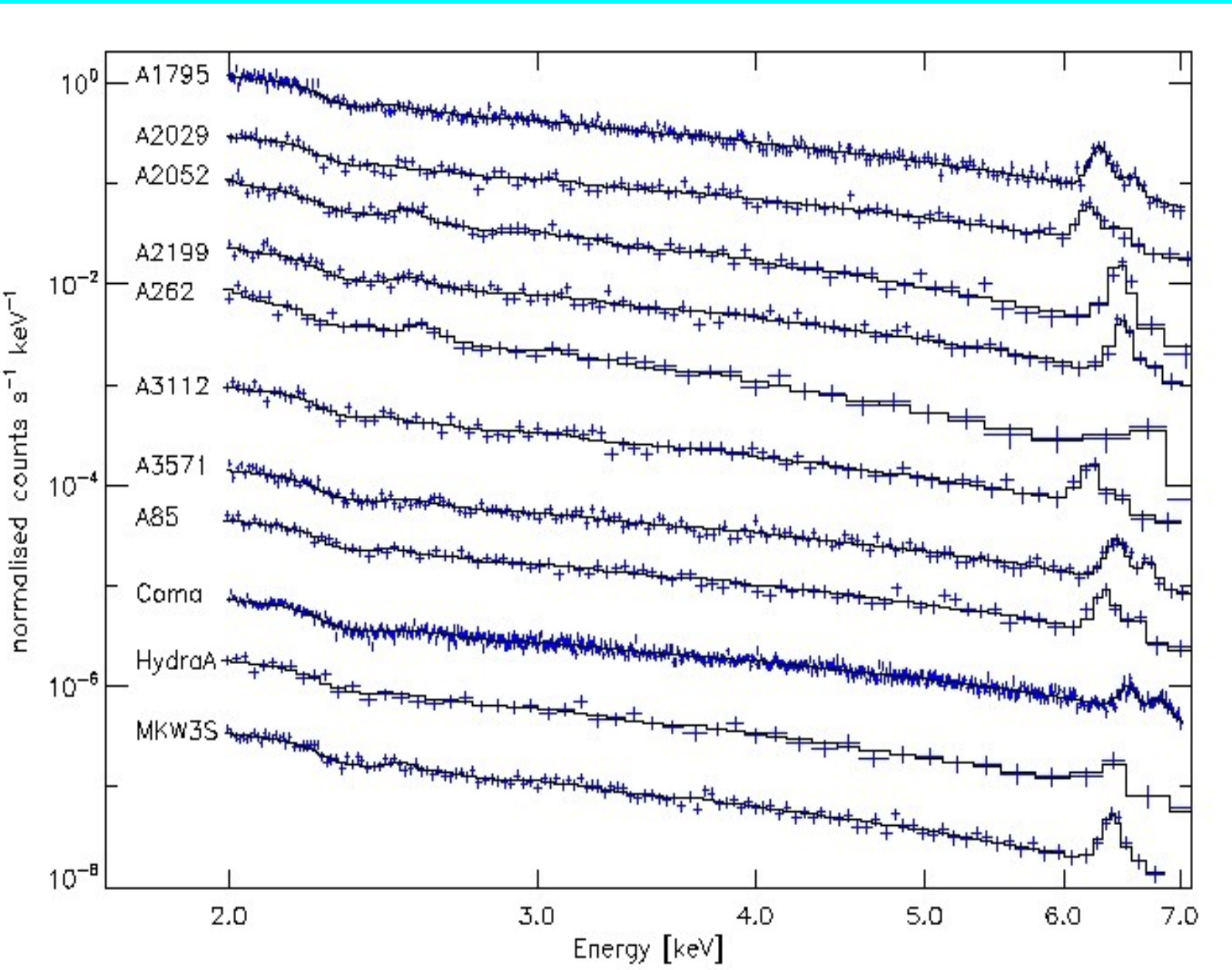
Sample

- Hard spectra (kT ~ 2-10 keV)
- Physics well understood for our cool core clusters with no merger signatures (bremsstrahlung continuum + collisionally excited line emission) → single-T modeling
- Nearby ($z<0.08$), bright (10^{-12}-10^{-11} erg s^{-1} cm^{-2}) → good statistics
- Clusters are stable → no simultaneity requirement → sample → systematic effects
- 11 clusters: A1795, A2029, A2052, A2199, A262, A3112, A3571, A85, Coma, HydraA, MKW3S
- Observed with ACIS/Chandra, EPIC/XMM-Newton, MECS/BeppoSAX → cross-calibration

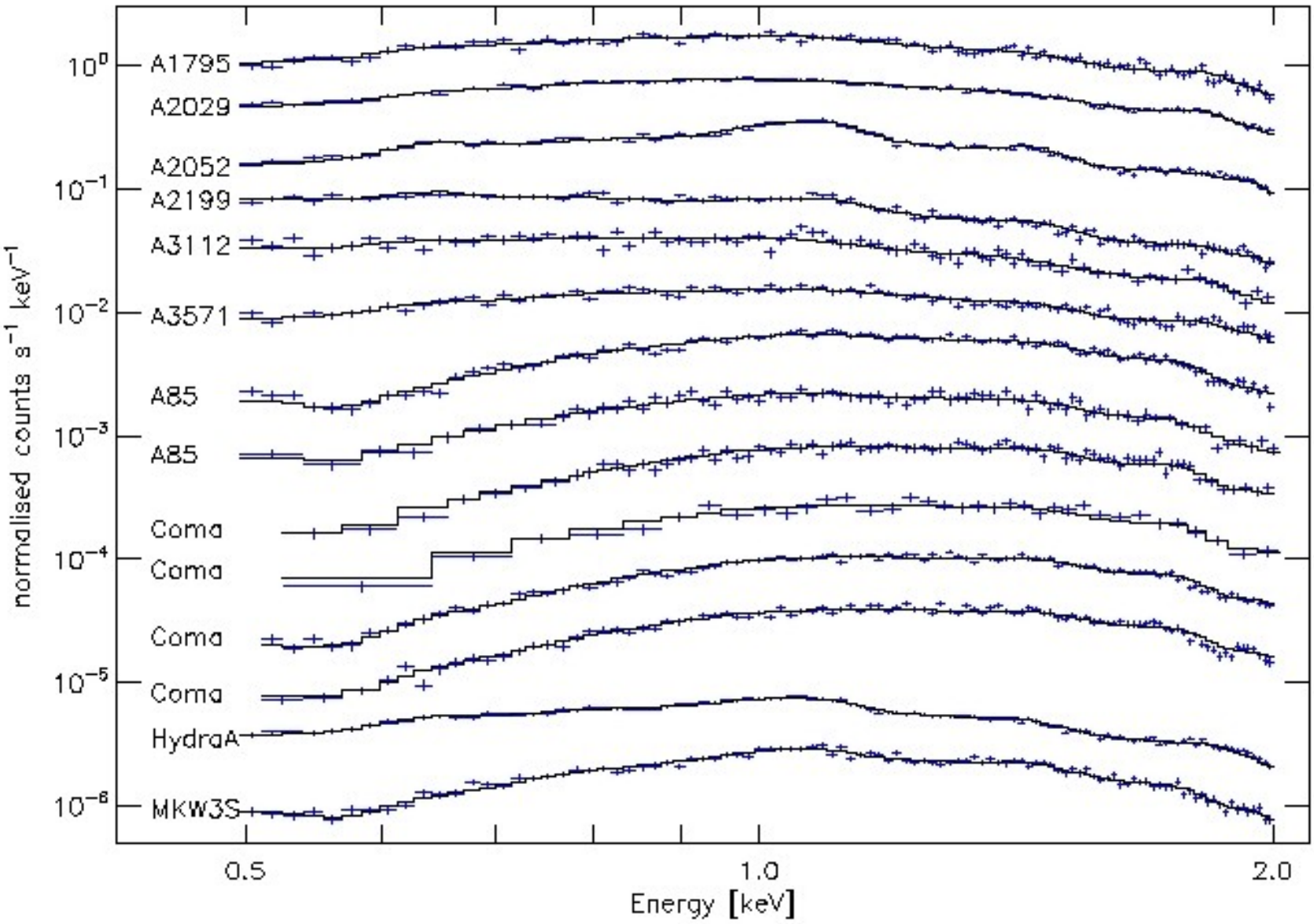
Method

- Spectral fits with 1-T MEKAL model to hard (2-7 keV), soft (0.5-2.0 keV) and wide (0.5-7.0 keV) band (could extend to 10 keV for the hottest clusters)
- Data for different instruments extracted from the same annular sky region for a given cluster
- Compare T for a given cluster obtained with different instruments → cross-calibration of the shape of the effective area (= telescope effective area × filter transmission × quantum efficiency)
- Compare fluxes → cross-calibration of the normalisation of the effective area
- Fe XXV/XXVI line ratio T measurement for the hottest clusters as an additional tool

pn hard band spectral fits

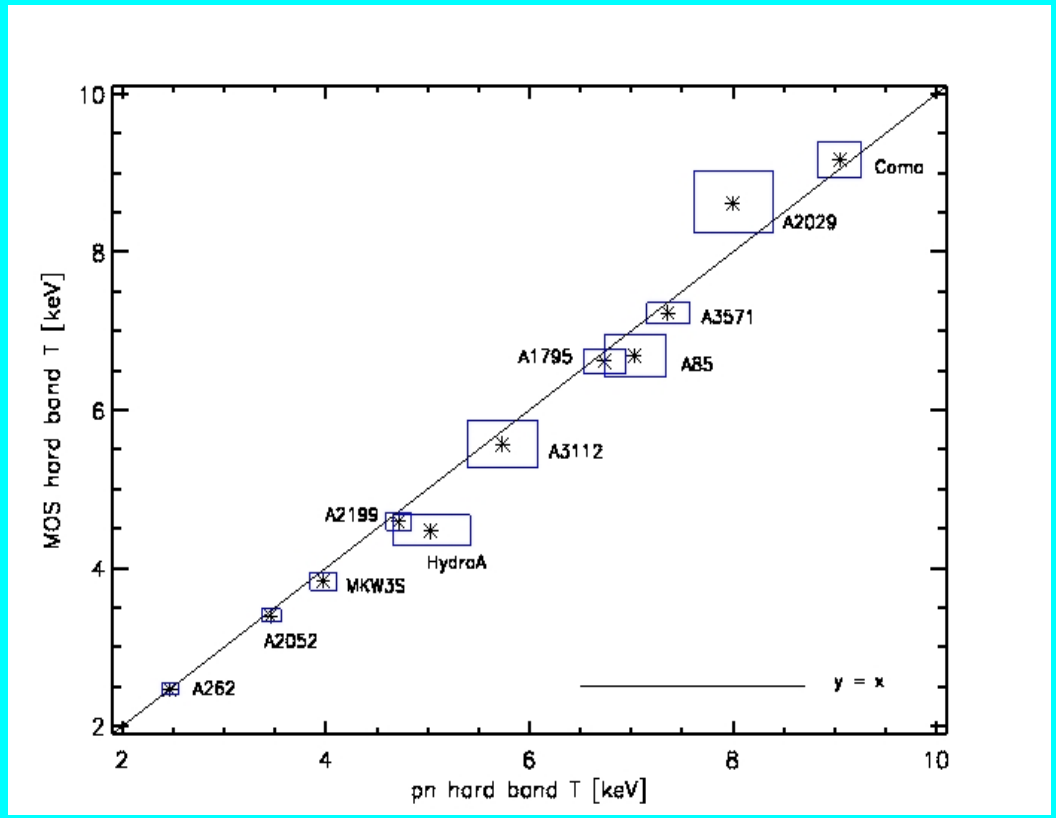


ACIS soft band spectral fits

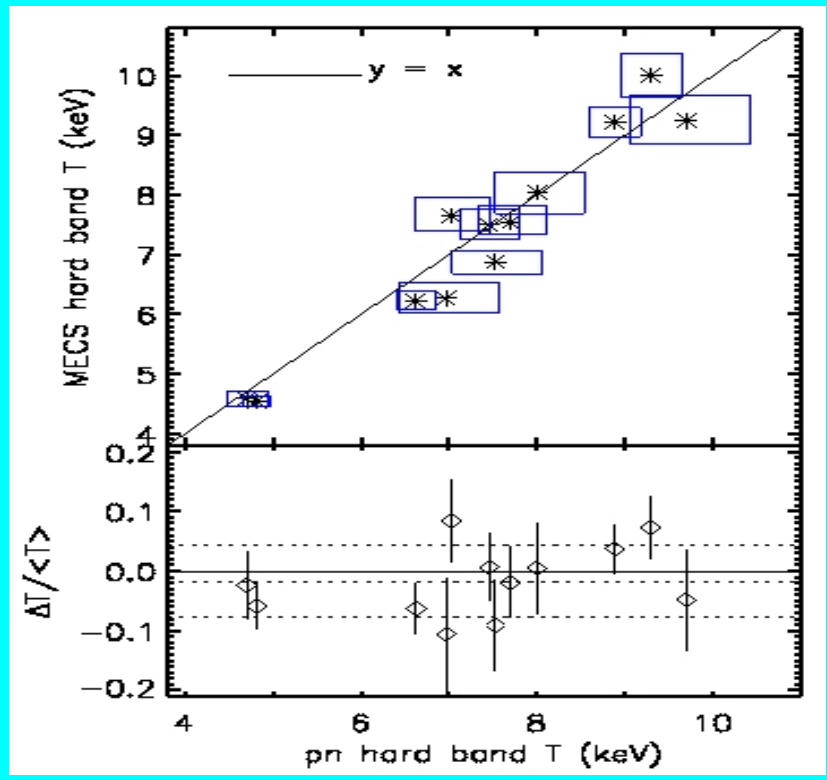


XMM/BeppoSAX hard band T

- < MOS- pn > ~-2%



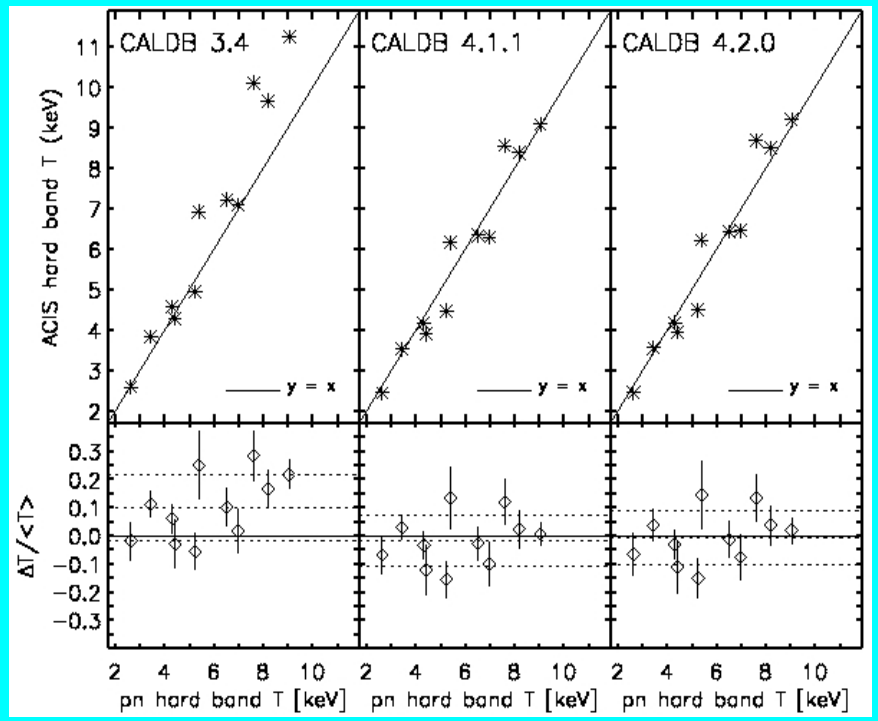
- BeppoSAX MECS temperatures from de Grandi & Molendi, 2002, ApJ 567, 163
- <MECS – pn> ~2%

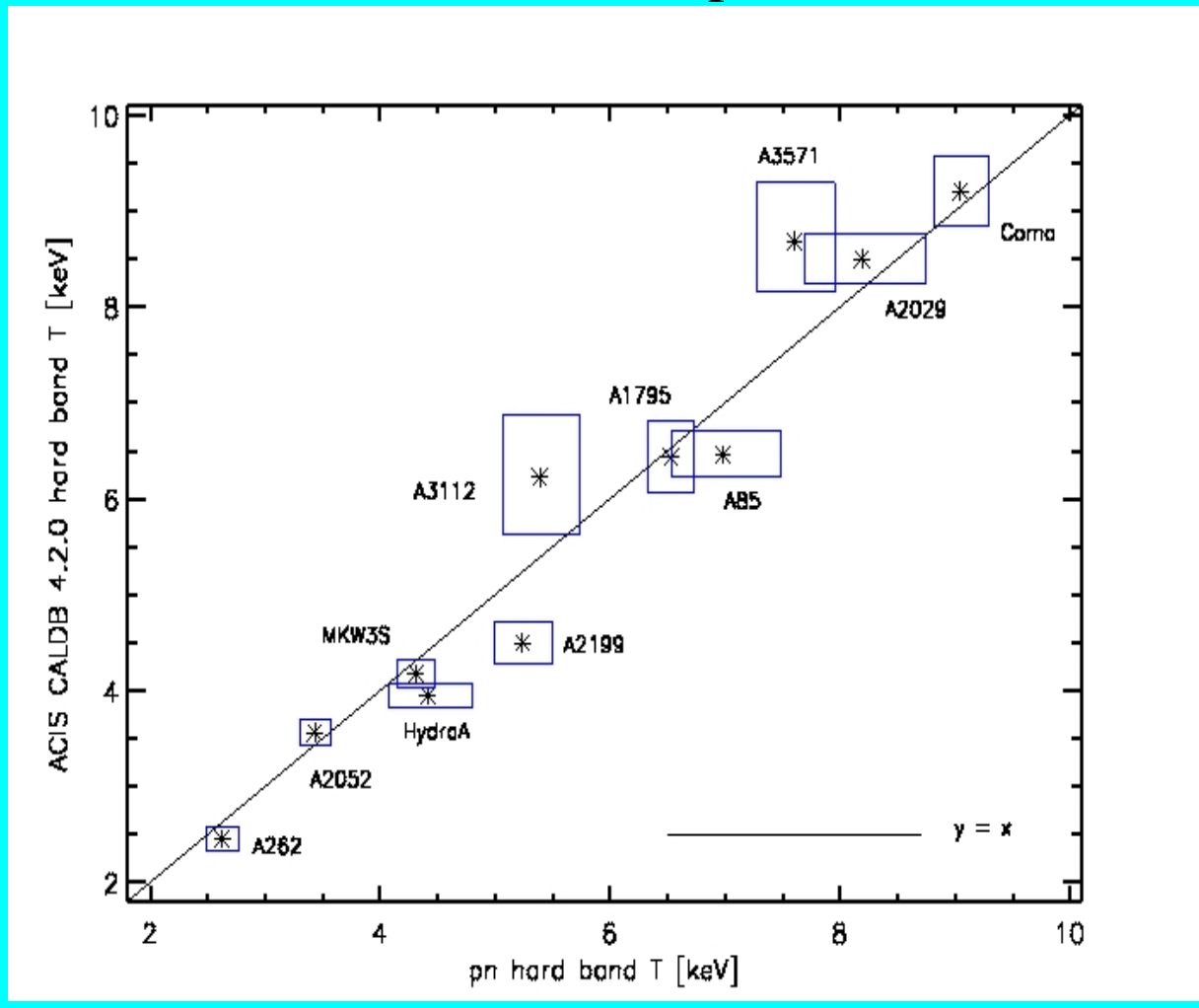


No systematic differences between the instruments

pn / ACIS hard band T

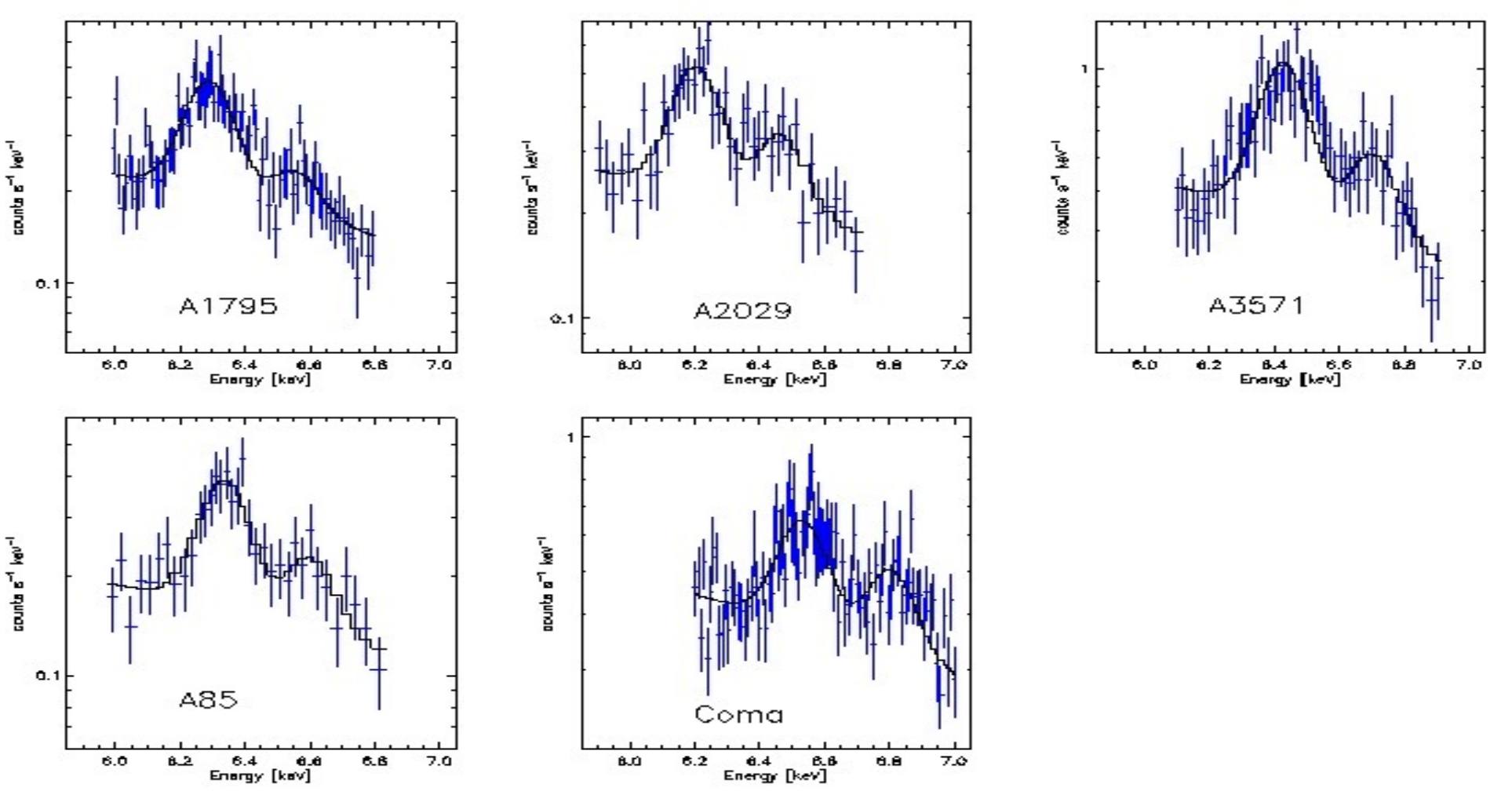
- < ACIS - pn > ~1%, no systematic difference btw. the instruments →
- The shape of the effective area is consistent btw. ACIS, pn and MOS in the hard band
- CALDB 3.4:
  < ACIS - pn > ~10%



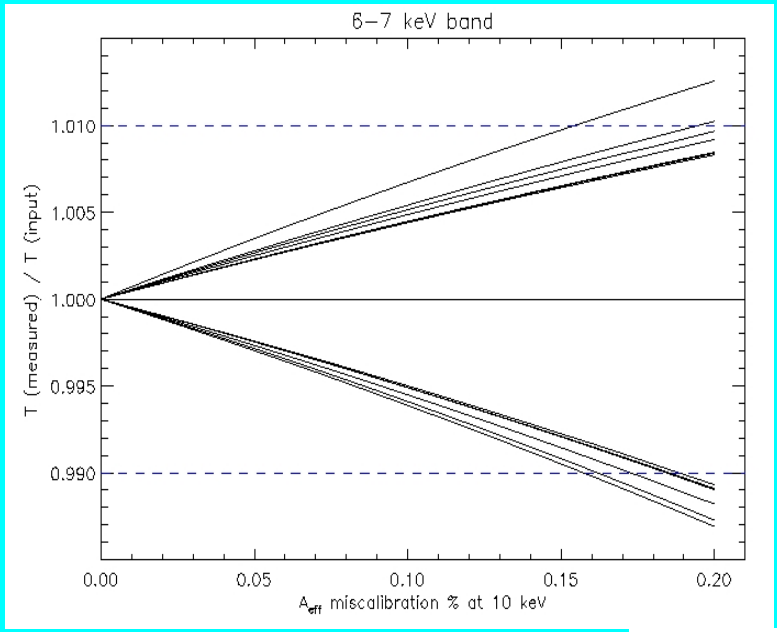


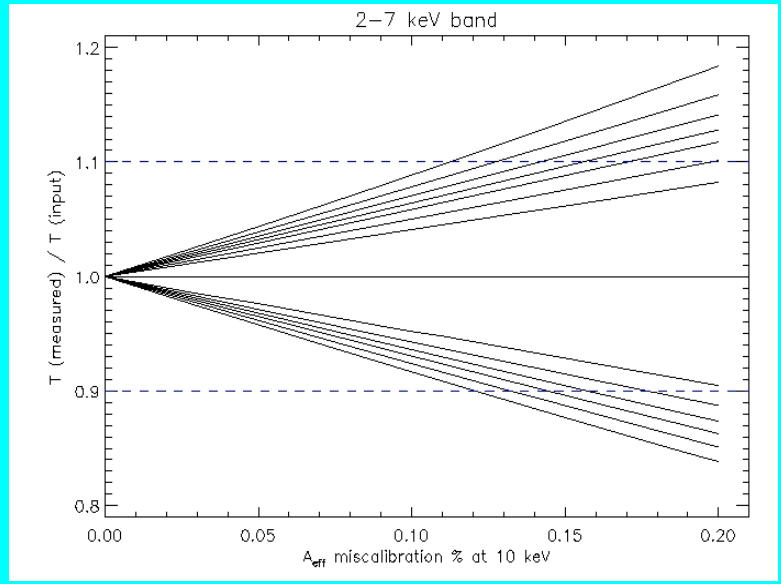
FeXXV/XXVI based T measurement

- FeXXV/XXVI line ratio decreases with higher ionisation temperature
- Fe XXVI is measurable for the hottest clusters with EPIC and ACIS resolution
- T measurement : MEKAL fit to [6.45-7.25]/(1+z) keV band

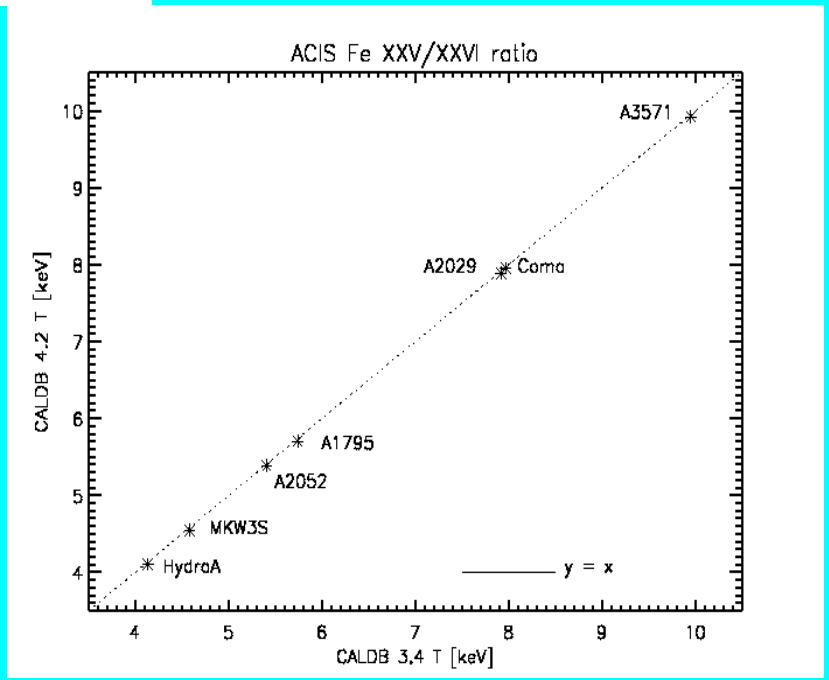


- Fe XXV/XXVI lines cover a narrow → independent of possible problems with the total efficiency shape calibration: linear bias of 0% at 1 keV, 15% at 10 keV changes T by 1%



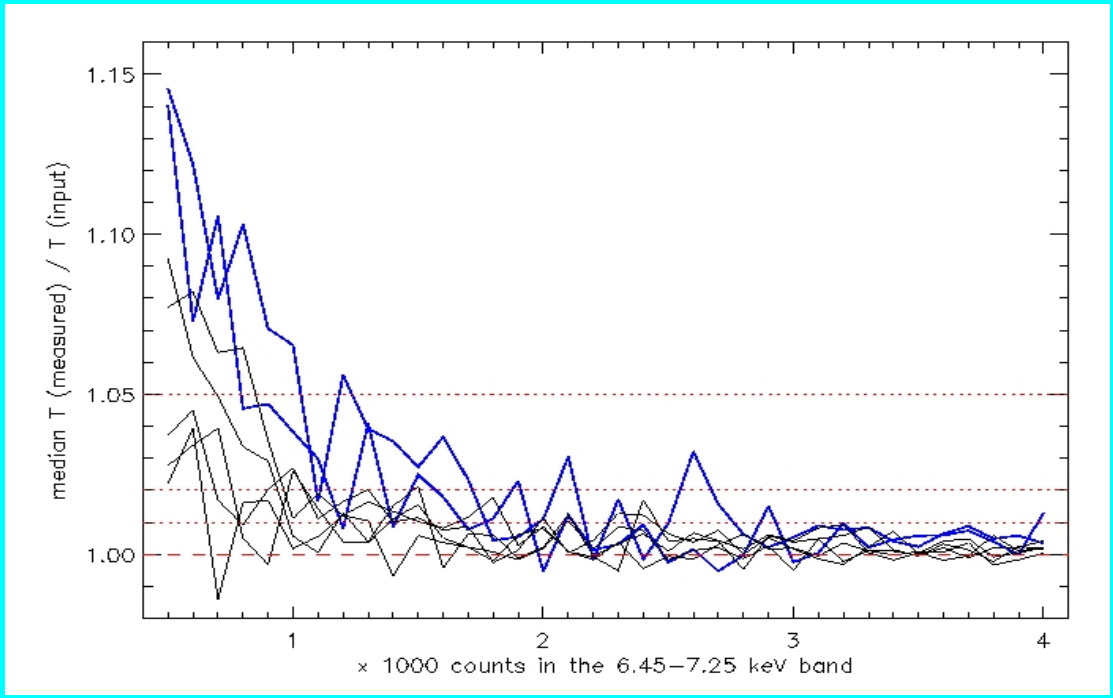


- ACIS best-fit T identical using CALDB 3.4 or CALDB 4.2.0



Fe XXV/XXVI systematics

- Low counts yield bias:
  2% accuracy requires 1000 counts for
  T> 6 keV clusters → 8 EPIC clusters,
  only 2 ACIS



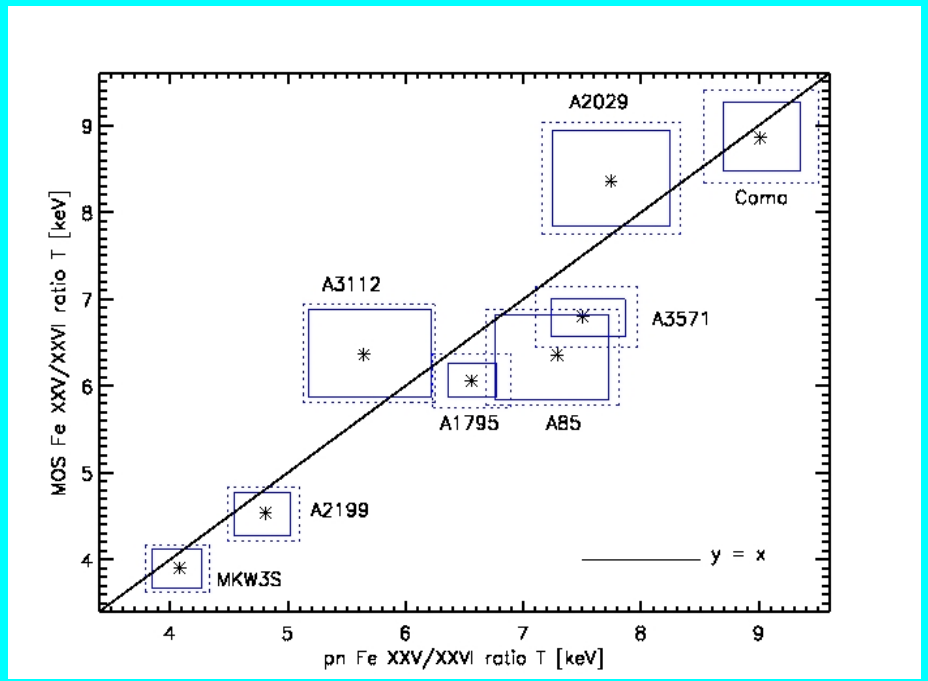
- Additional calibration problems: energy resolution and redistribution, energy scale →
  EPIC analysis (gsmooth a la Molendi, gain fit): T uncertainty ~2%
- Details on the physics of the lines (MEKAL / APEC): T uncertainty ~2%
- Total systematic uncertainty of Fe XXV/XXVI based T measurement in EPIC sample ~4%

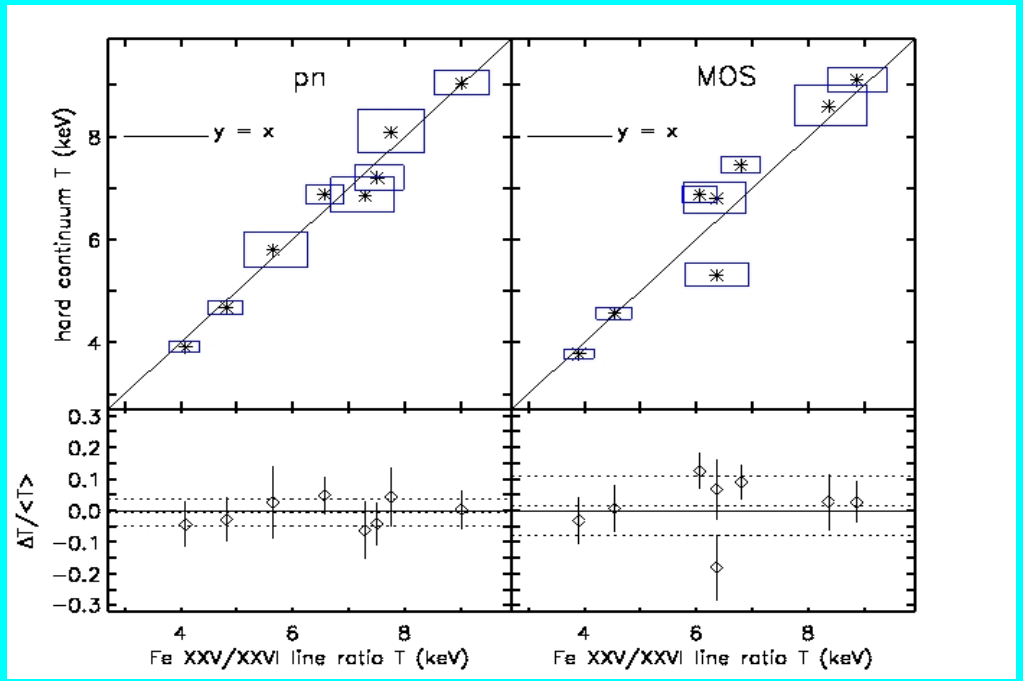
Fe XXV/XXVI EPIC results

- Emission measure and metal abundance are highly degenerate in the ~6-7 keV band → emission measure constrain
- <MOS / pn> ~-3% , values agree within 1σ
- Fe XXV/XXVI based T agrees with 2-6 keV continuum fit T →

  - hard band calibration OK

- no significant deviations from ionisation equilibrium state and Maxwellian electron velocity distribution in the sample → Fe XXV/XXVI useful for calibration



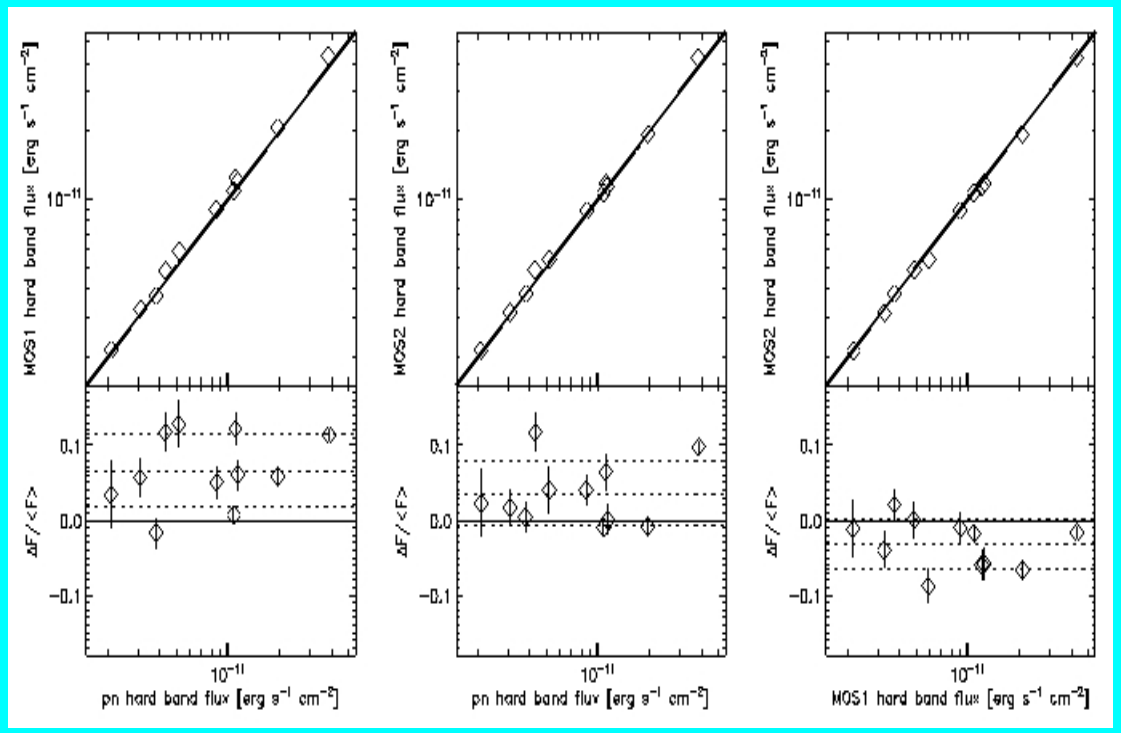


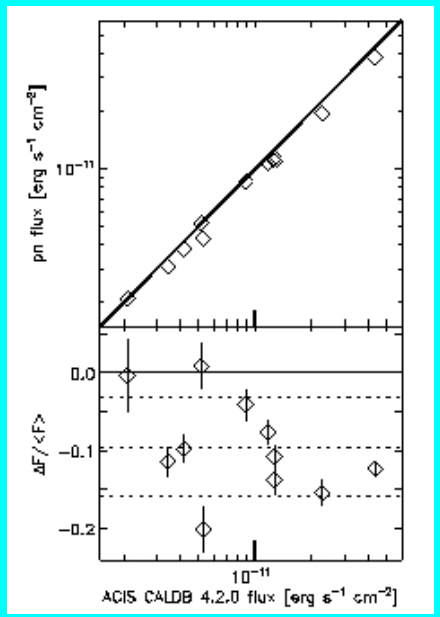
Hard band flux

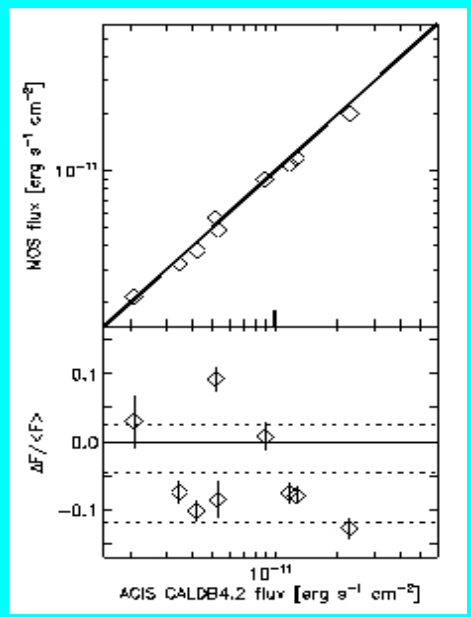
- pn, MOS, ACIS regions a little different due to CCD gaps and bad pixels: covering fraction ~85% (pn), ~95 (MOS), ~100% (ACIS) ➔ measured fluxes scaled linearly with the area to correspond a full annulus

- MOS flux exceeds that of pn by ~4-7% (consistent with Mateos et al. (2009) 2XMM catalogue analysis)

ACIS flux exceeds that of pn by ~10% consistent with Tsujimoto et al. (2010) G21.5-09 analysis







Hard band flux scatter

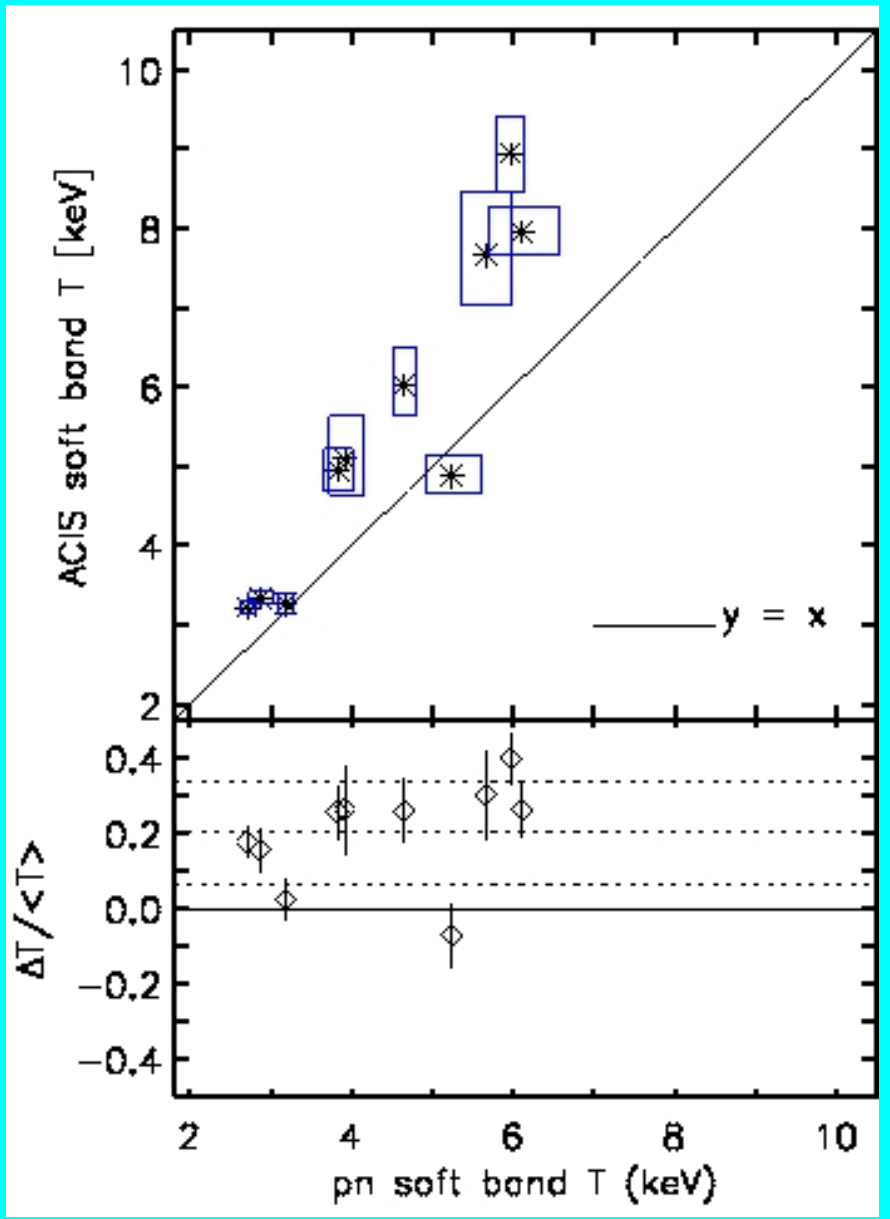
- Large ~5% scatter on the flux values
- Perhaps due to small differences in the models? We tested this using best-fit pn models, and fitted only the normalisation with MOS and ACIS data → no effect
- Perhaps due to different regions? We tested this using smaller gap free regions (covering fraction 100% in all instruments) →

  - no effect on the scatter

  - ACIS – pn difference remains at 10%

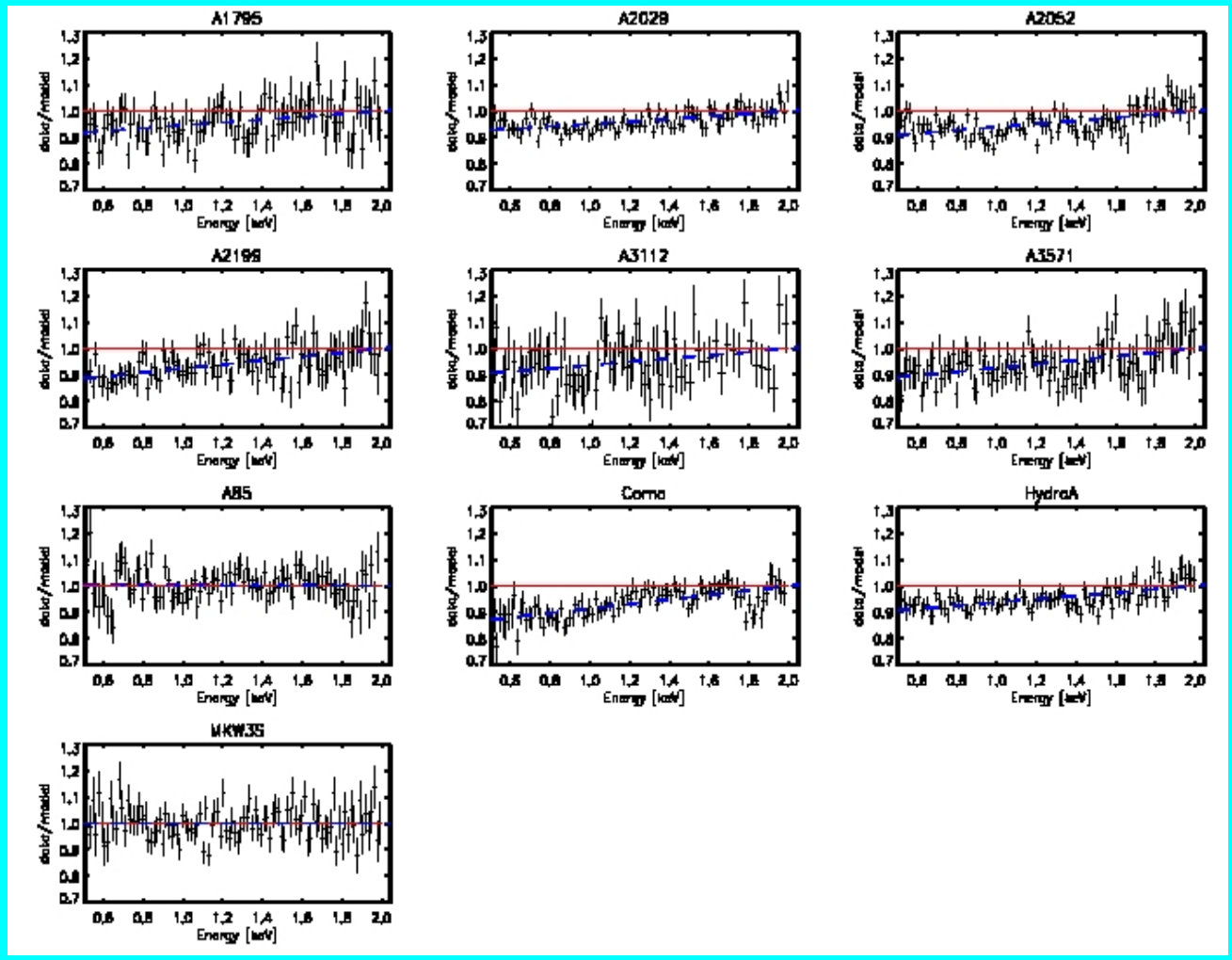
ACIS / pn soft band T

- In the soft band, ACIS temperatures exceed those of pn by 20% →
- cross-calibration uncertainty at this level



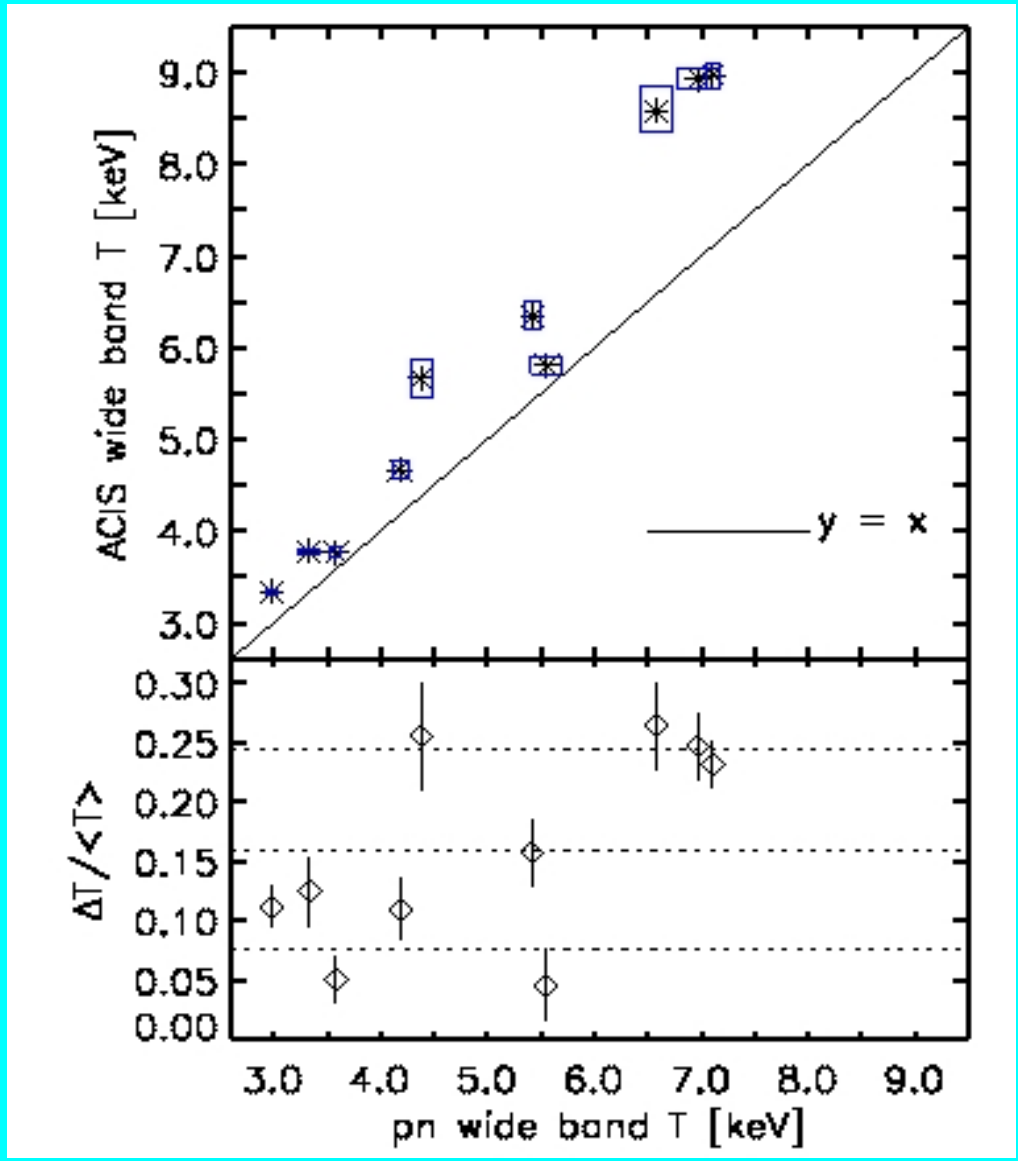
ACIS / pn soft band T

- Quantification of the cross-calibration problem:
  pn soft band best-fit model folded through ACIS responses, compared to ACIS data → 10% difference at 0.5 keV, goes linearly to 0 at 2 keV (by definition)



ACIS / pn wide band T

- Hard band accurately calibrated, but most of the photons are in the soft band where calibration more uncertain →
- ACIS wide band temperatures exceed those of PN by ~15%
- Scientific analysis of cluster wide band (0.5-7 keV) problematic:
- The absolute cluster models (T and flux) uncertain by 10-15% at the moment



Conclusions

- The calibration of the shape of the effective area of ACIS, pn and MOS accurate within a few % in the hard band (2-7 keV)
- No significant deviations from ionisation equilibrium state and Maxwellian electron velocity distribution in the sample in the hard band → standard candle
- Relative normalisation of the ACIS/pn hard band effective area uncertain at ~10% level
- Relative ACIS/pn effective area off by 10% at 0.5 keV (if assumed equal at 2 keV)
- Cluster absolute temperatures and fluxes in the 0.5-7.0 keV uncertain by ~10% at the moment