Cluster mass, temperature and pressure from X-rays, gravitational lensing and Sunyaev-Zeldovich effect as a possible calibrators

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New fields of worms

- Usually cross-calibration of effective area of an X-ray instrument means a comparison of spectral models derived using different instruments for the same source
- We explore here a new method: A comparison of
  - physical quantities: 1) total mass and 2) thermal pressure derived with an X-ray instrument

  with
  - the same physical quantities derived using different methods and wavelengths

+ A possible agreement yields confidence on the X-ray calibration accuracy

− A possible disgreement can be due to uncertainties of calibration and/or of the cluster physics

1) Total mass of a cluster of galaxies

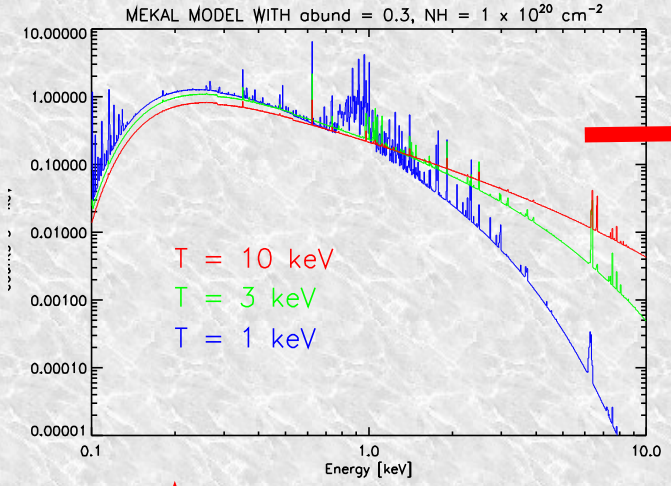
HYDROSTATIC X-RAY METHOD

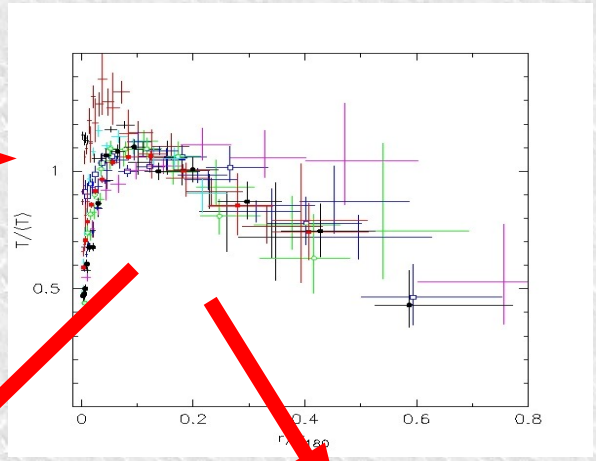
- The intracluster gas pressure gradient pulls gas particles away from the center
- The gravity pulls the gas particles towards the center
- In hydrostatic equilibrium the forces due to gas pressure gradient and gravity are in balance, matter is not moving

GRAVITY ← ❋ → GAS PRESSURE

$$M_{tot}(<r) = -\frac{k}{\mu m_p G} T_g(r) r \left(\frac{d \ln \rho_g(r)}{d \ln r} + \frac{d \ln T_g(r)}{d \ln r} \right)$$

HYDROSTATIC X-RAY METHOD





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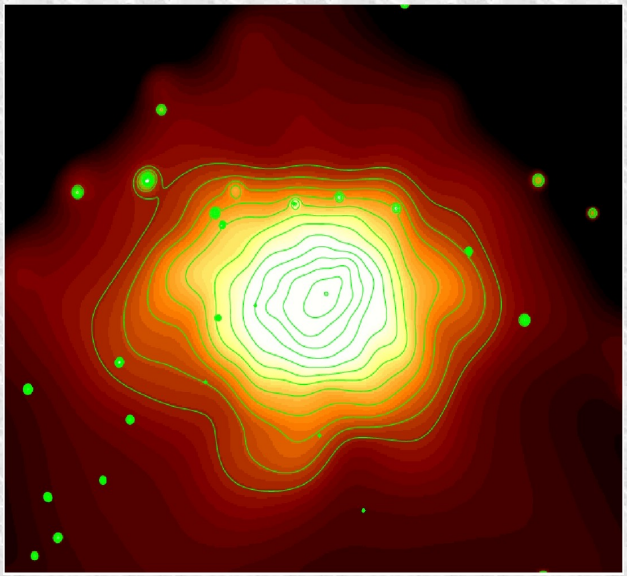
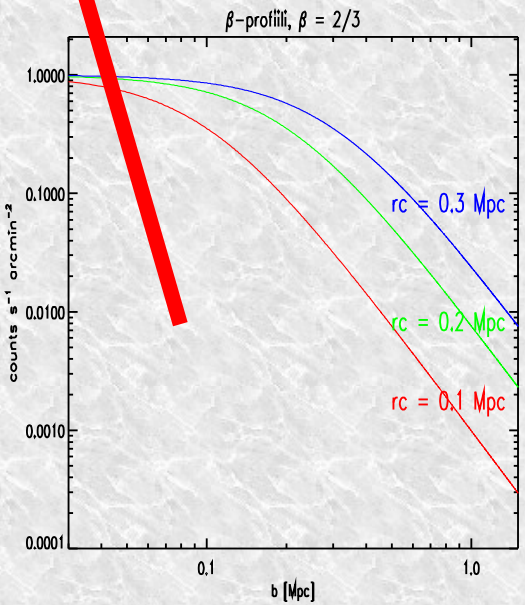
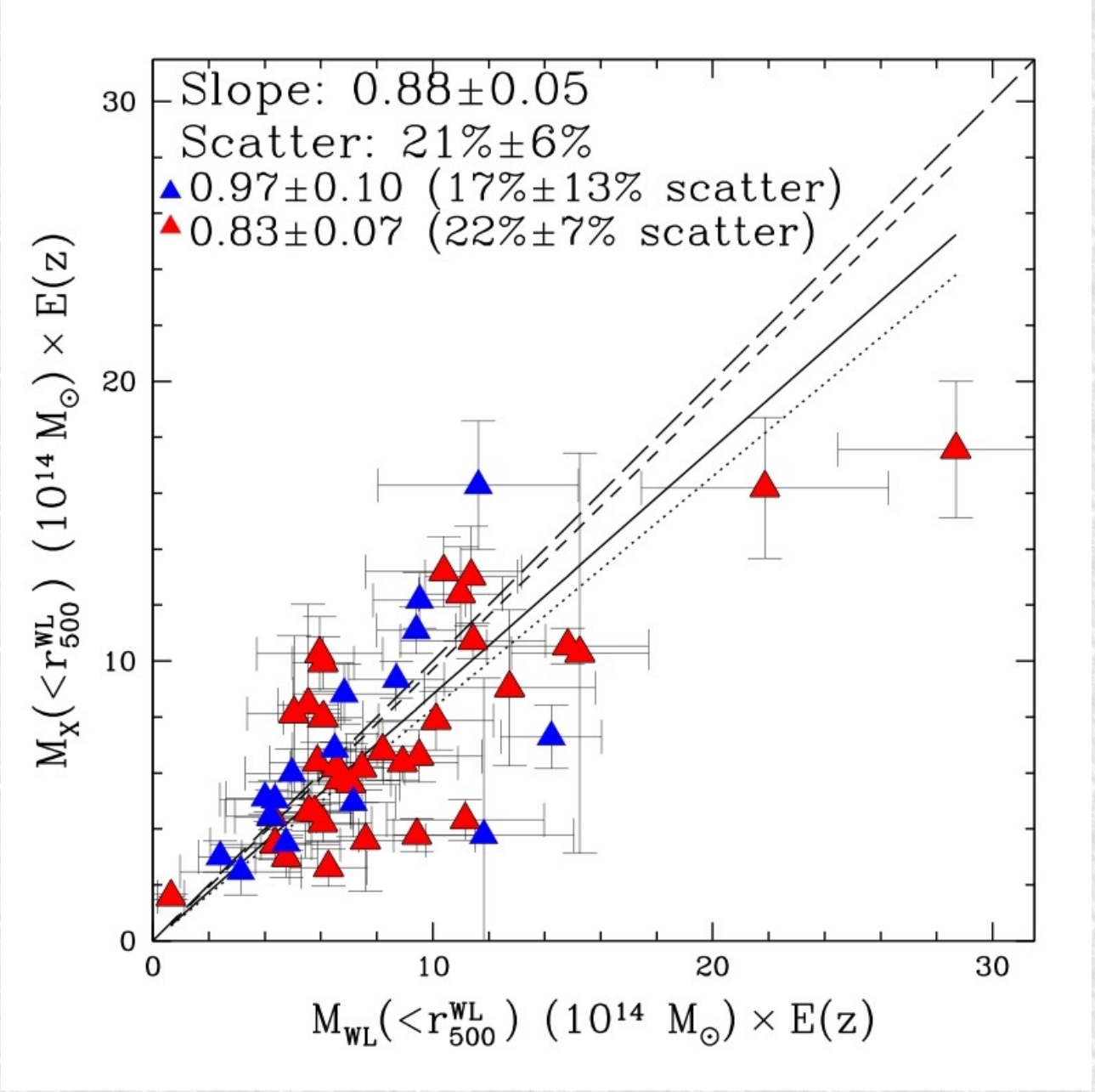




Gravitational lensing

- Gravitational lensing also yields the total mass M_{tot} for clusters of galaxies
- **Assuming that gravitational lensing is bias-free !!!**, comparison of X-ray total masses obtained using different instruments can be used to judge which gives T right, and thus has the effective area shape accurately calibrated
- Mahdavi et al: The Canadian Cluster Comparison Project (CCCP) , 50 clusters
- Gravitational lensing mass from Hoekstra et al. (2012), which contains a weak lensing analysis of CFH12k and Megacam data from the Canada-France-Hawaii Telescope
- Most observed with both XMM and Chandra

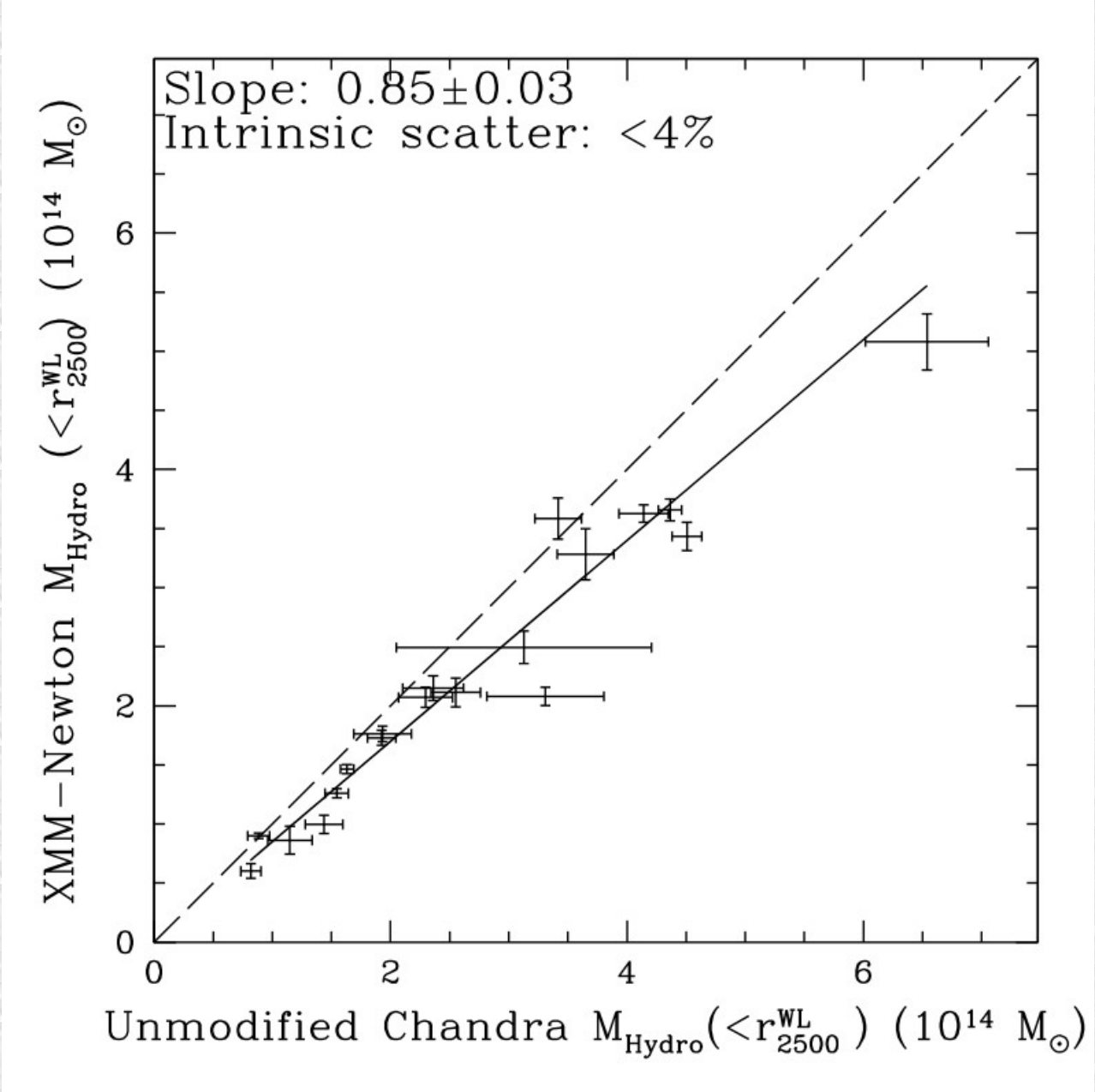
- Using XMM data **(pn or MOS?)** , CCF:s from Jan 2012, M_{grav} and $M_{X\text{-}ray}$ agree:



- Since Chandra gives higher temperatures, the hydrostatic X-ray masses derived from Chandra data are ~15% bigger than XMM values

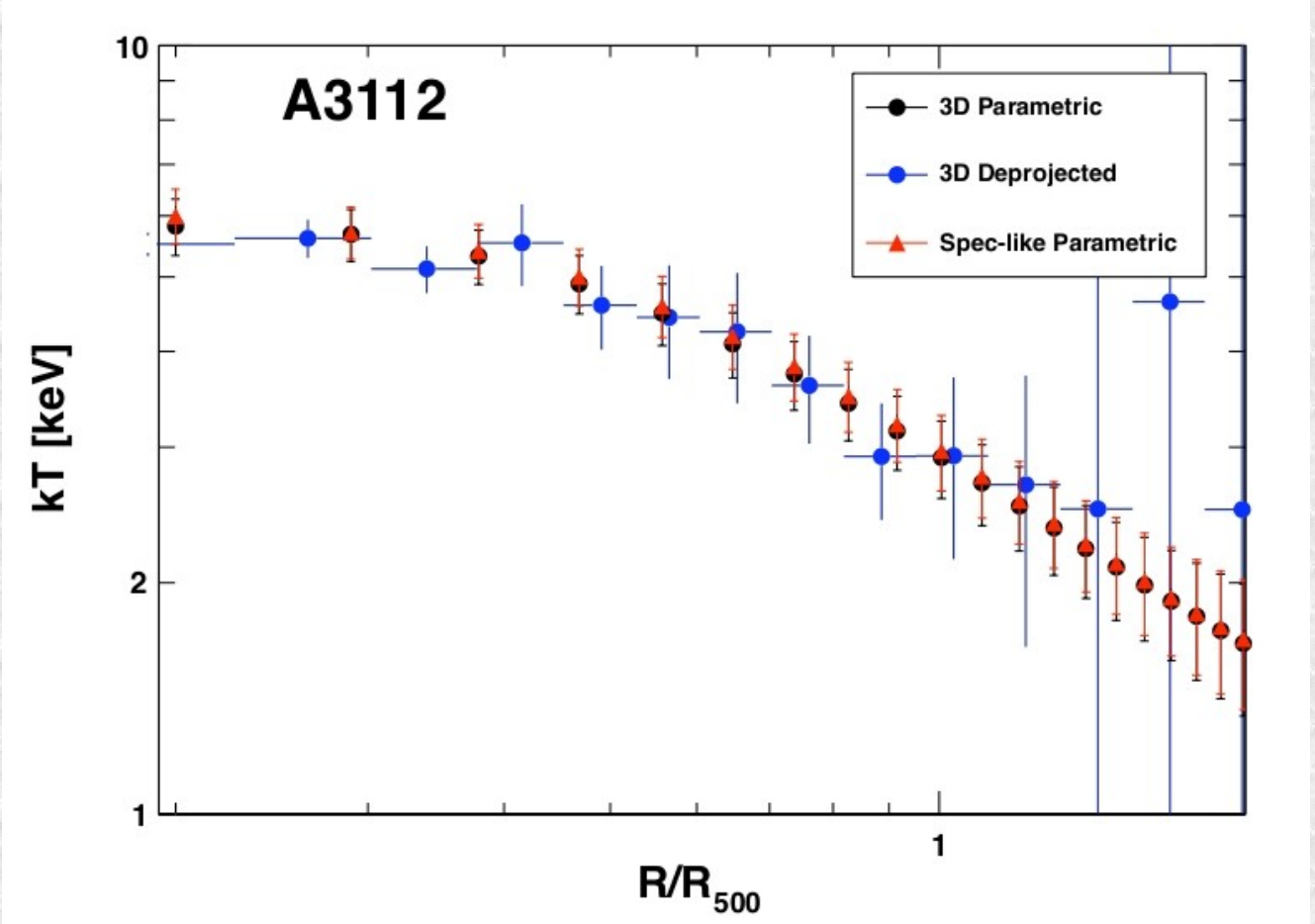
➔ Chandra X-ray mass 15% bigger than M_{grav}

- ***This indictes that XMM is accurate***
- Collaboration with Mahdavi going on



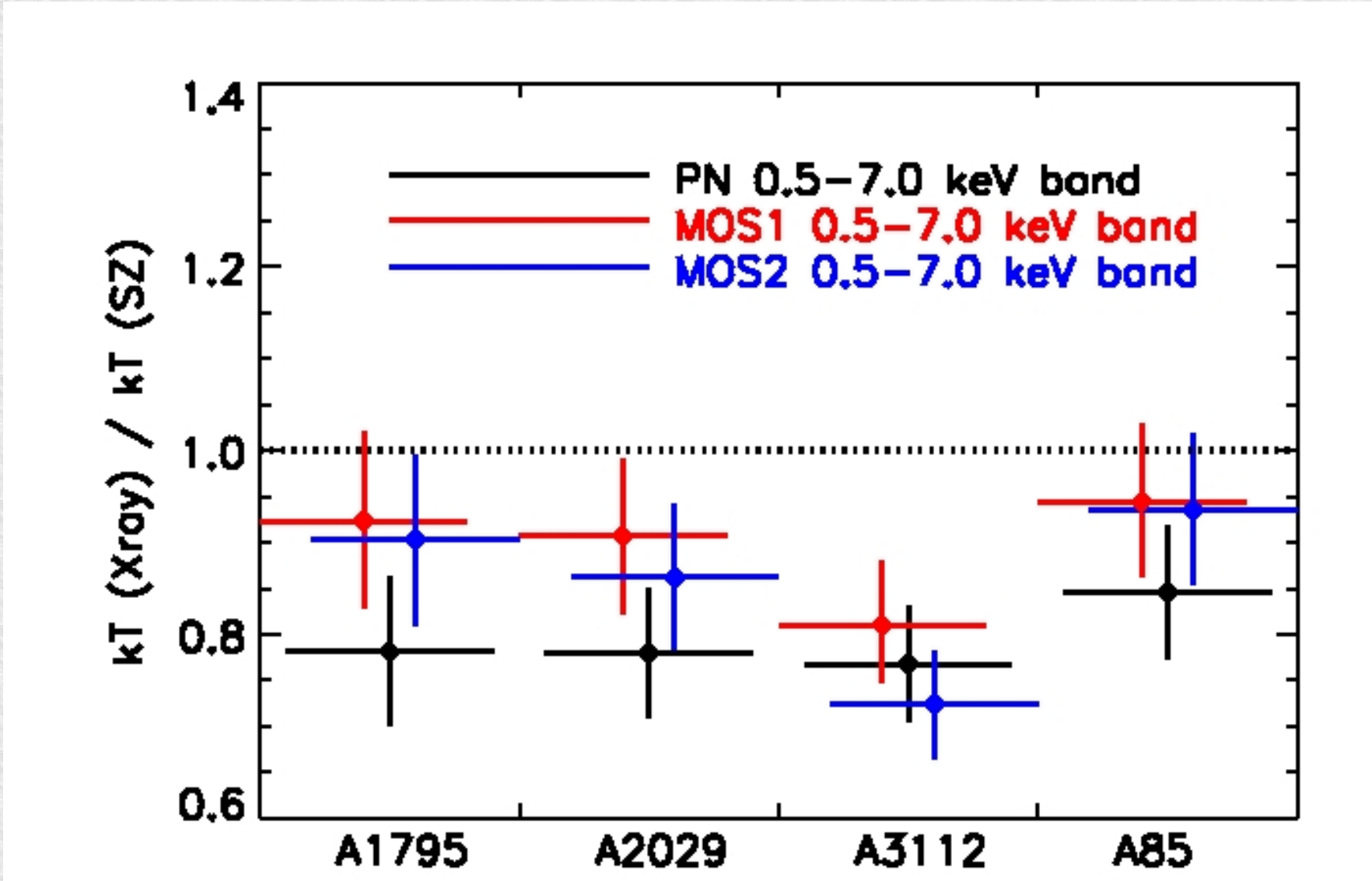
2) Sunyaev – Zeldovich effect

- Sunyaev-Zeldovich effect measured with Planck within r_{500} yields electron pressure $P(r_{500})$
- P(r) distribution modeled with universal profile (Arnaud et al. 2010) and scaled to $P(r_{500})$
- Electron density $n_e(r)$ derived using ROSAT PSPC
- Electron temperature profile derived using $P(r) = k\, n(r)\, T(r)$



- Electron temperature also derived via X-ray spectroscopy
- Collaboration with Eckert: XMM-Newton / Planck+ROSAT comparison of temperatures for A1795, A2029, A3112 and A85 (A2204 TBD) at 0.2-0.4 r500

- In 0.5-7.0 keV band XMM gives too small temperatures
- ACIS temperatures 10-20% higher → ACIS would match Planck+ROSAT well → ***This indictes that ACIS is accurate***



Conclusions

- XMM is better than Chandra based on X-ray / Grav lens masses
- Chandra is better than XMM based on SZ/X-ray thermal pressure