Scaling Properties of Clusters at $z \sim 0.7$

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Outline

- Scaling relations
- Cluster sample
- $L_X - T$ relation
- $M_{\text{gas}} - T$ relation
- Implications for evolution
- Summary & future work

Scaling Relations

- Simple, self-similar cluster formation predicts:
  $\frac{L_X}{E(z)} \propto (kT)^2$
  $M_{\rm gas}\ E(z) \propto (kT)^{1.5}$

- Where $E(z) = \frac{H(z)}{H_0}$, allows for "standard" evolution

- $E(z) = \sqrt{\Omega_{\rm m}(1+z)^3 + 1 - \Omega_{\rm m}}$
  assuming $\Omega_{\rm m} + \Omega_\Lambda = 1$ & $W = -1$

- Local clusters ($z \lesssim 0.1$):
  $L_X \propto (kT)^{2.64\pm0.3}$ (Markevitch et al. 1998)
  $M_{\rm gas} \propto (kT)^{1.98\pm0.2}$ (Mohr et al. 1999)

The High-redshift Cluster Sample

- 22 clusters ($z > 0.5$); X-ray data in *Chandra* public archive

- Median $z = 0.7$; kT range: 3–14 keV

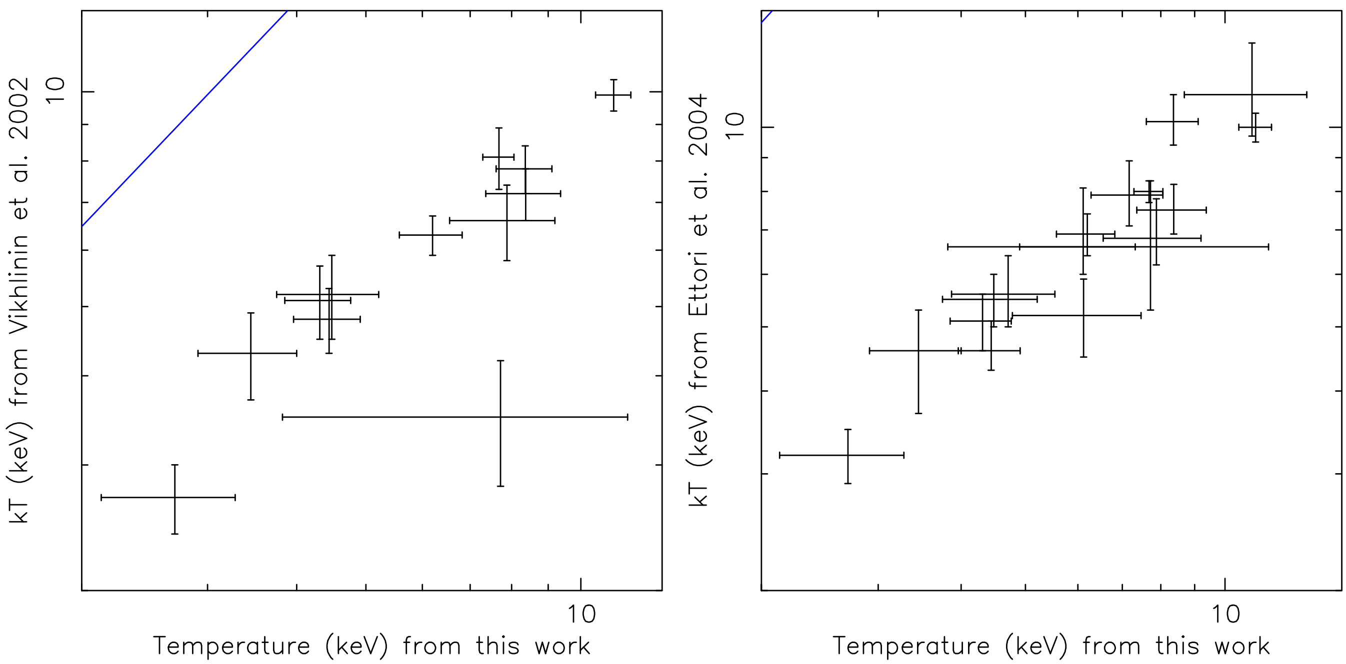
- Spectra fitted in 0.9-7 keV range (0.5-7 keV for ACIS-S data)

- Estimate R_{2500} from kT, using Allen et al. 2001 relation

- Fit 2D King profile to 0.5-2 keV images

- Low & intermediate z comparison samples:
  45 *ROSAT* clusters (Mohr et al. 1999)
  35 *Chandra* clusters (Mohr & Guerrero in prep.)

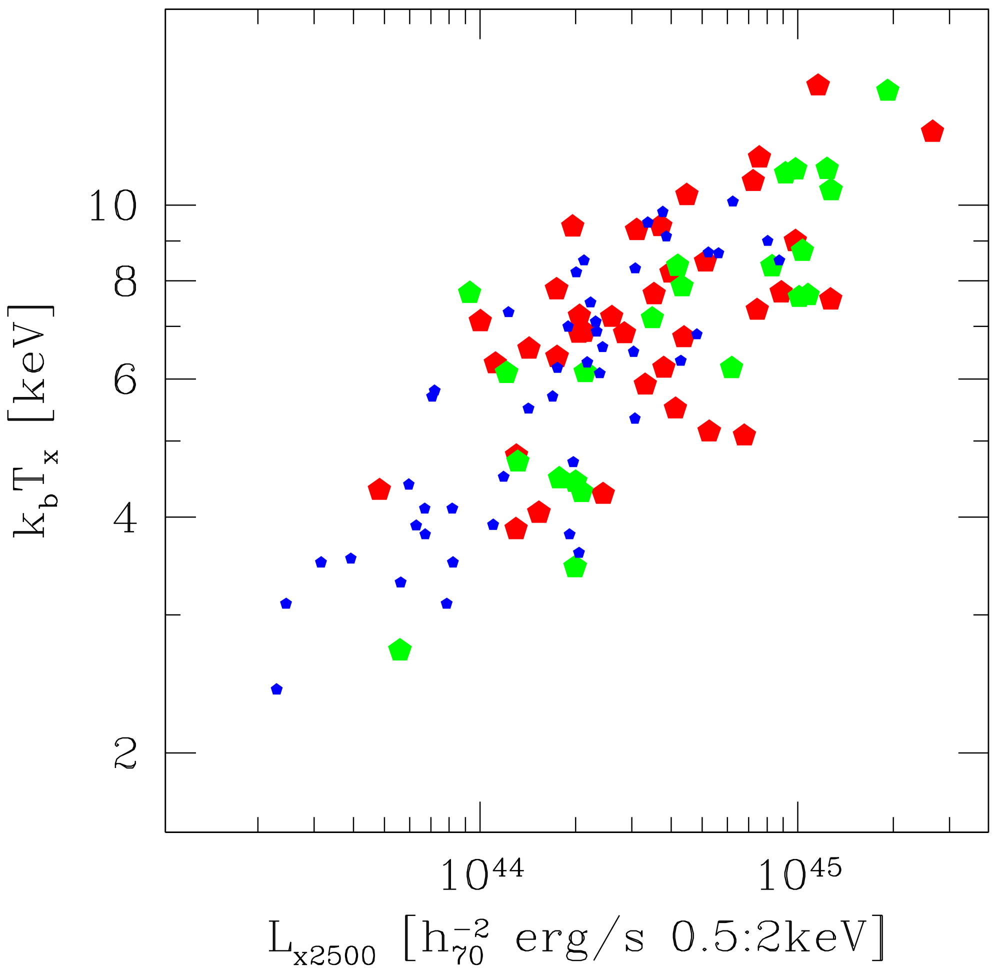
Comparison with Previous Work



Comparison of mean X-ray temperatures; the blue line is the locus of equality

- Vikhlinin et al. 2002 sample (12 overlaps), mean ratio=1.1 (σ=0.37)
- Ettori et al. 2004 sample (17 overlaps), mean ratio=0.96 (σ=0.14)

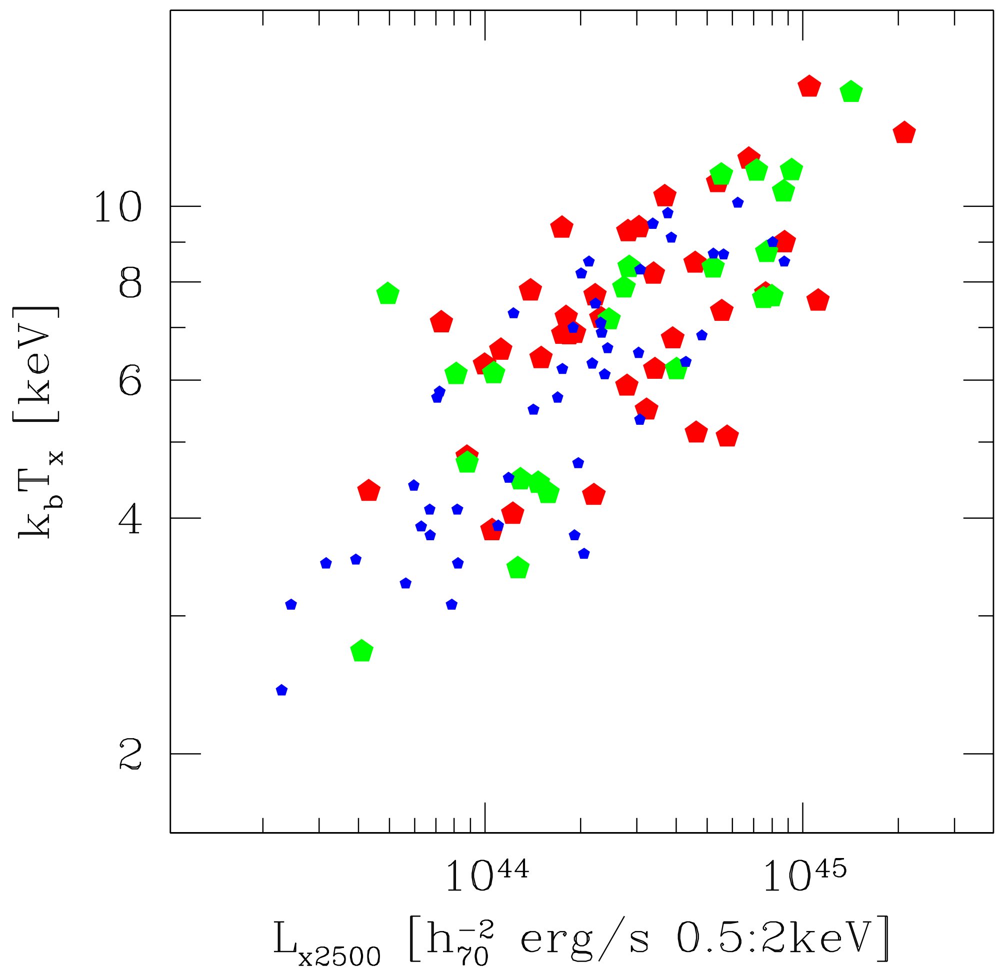
$L_X - T$ with No Evolution Correction



- Green points = this sample (median $z = 0.7$)
- Red points = *Chandra* sample (median $z = 0.3$)
- Small blue points = low-z *ROSAT* sample

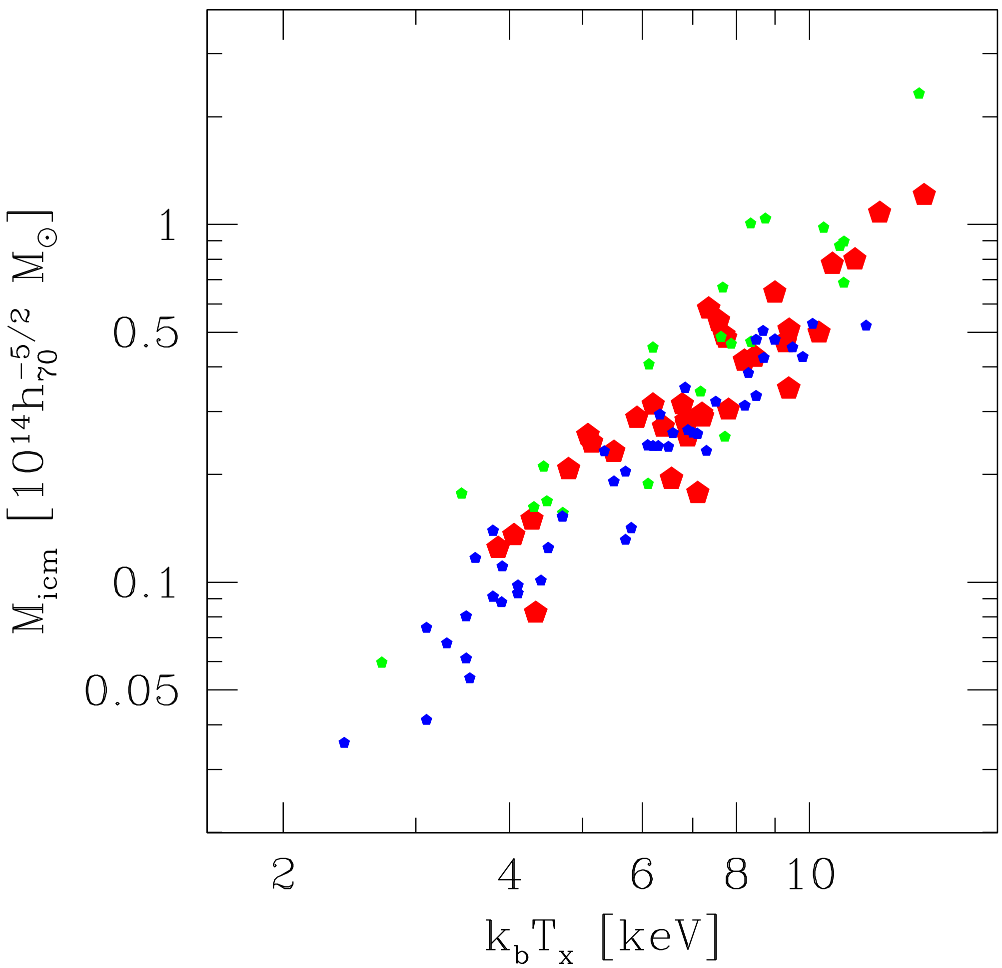
- L_X measured within R_{2500},
  in rest-frame 0.5-2 keV band

Corrected $L_X - T$



- Green points = this sample (median $z = 0.7$)
- Red points = *Chandra* sample (median $z = 0.3$)
- Small blue points = low-z *ROSAT* sample
- Best-fit power law (unweighted, 1σ errors):
  $L_X \propto (kT)^{2.44 \pm 0.27}$
  $L_X \propto (kT)^{2.47 \pm 0.32}$
  $L_X \propto (kT)^{2.37 \pm 0.17}$

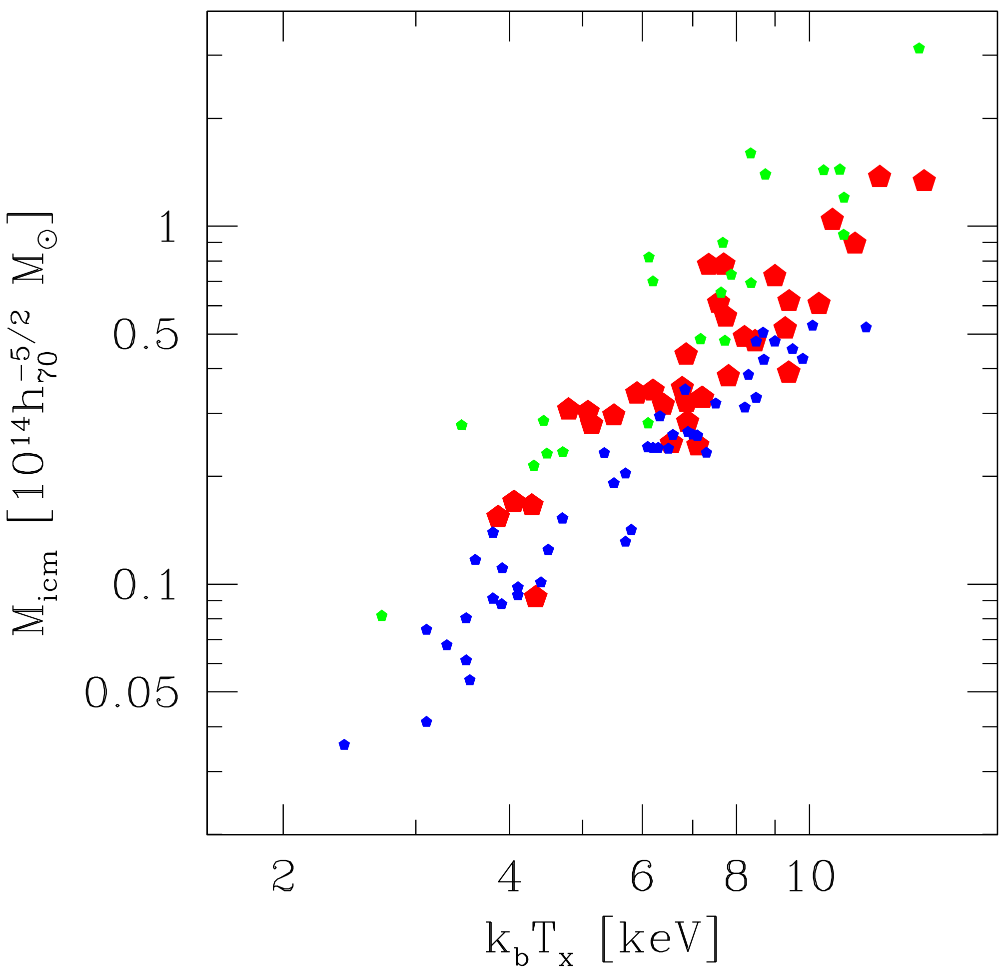
$M_{\text{gas}} - T$ No Evol. Correction



- Green points = this sample (median $z = 0.7$)
- Red points = *Chandra* sample (median $z = 0.3$)
- Small blue points = low-z *ROSAT* sample

- M_{gas} measured within R_{2500}

Corrected $M_{\text{gas}} - T$



- Green points = this sample (median $z = 0.7$)
- Red points = *Chandra* sample (median $z = 0.3$)
- Small blue points = low-z *ROSAT* sample
- Best-fit power law (unweighted, 1σ errors):
  $M_{\text{gas}} \propto (kT)^{2.05 \pm 0.16}$
  $M_{\text{gas}} \propto (kT)^{1.90 \pm 0.16}$
  $M_{\text{gas}} \propto (kT)^{1.87 \pm 0.08}$

Implications for Evolution

- $L_X - T$ slope similar at all z & marginally consistent with self-similarity

- $M_{\text{gas}} - T$ slope at high-z only steeper by $\sim 1\sigma$

- However, $M_{\text{gas}} - T$ relation within R_{2500} clearly inconsistent with self-similarity at all z
  $\Rightarrow$ extra gas physics

- $M_{\text{gas}} - T$ relation normalization appears to increase with z
  $\Rightarrow$ inconsistent with standard evolution

Summary & Future Work

- $M_{\text{gas}} - T$ normalization within R_{2500} appears to be inconsistent with standard evolution

- 5 more clusters with $z > 0.5$ in *Chandra* archive

- Investigate other scaling relations, e.g. isophotal size vs. temperature relation

- Quantify non-standard evolution with simple parametrization