Cluster Cosmology, Scaling Relations and Cool Cores

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Monsters Inc.

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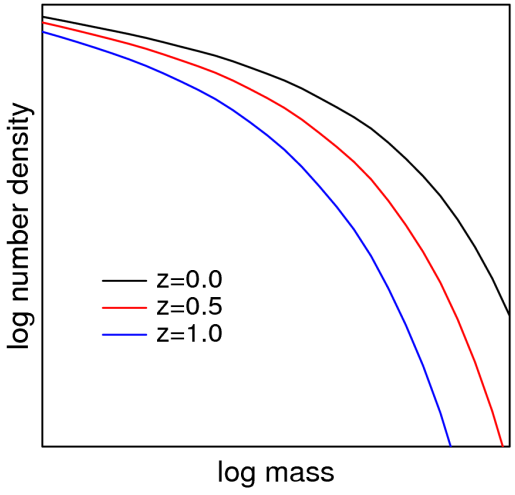
Cosmology needs scaling relations

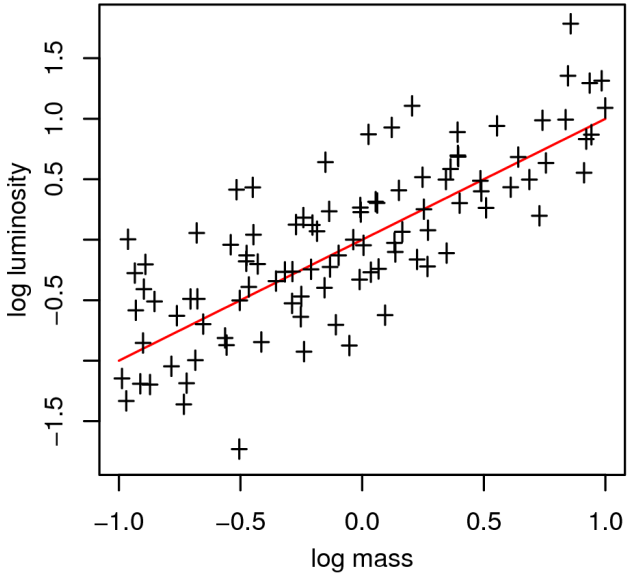
Prediction in terms of mass

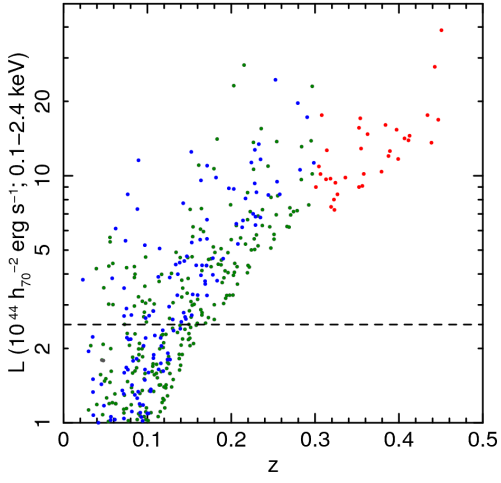
Detection via X-ray flux
(or richness, SZ flux, . . .)

$$dN/dzdM \longrightarrow dN/dzdF$$

$$P(L|M)$$







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Scaling relations need cosmology

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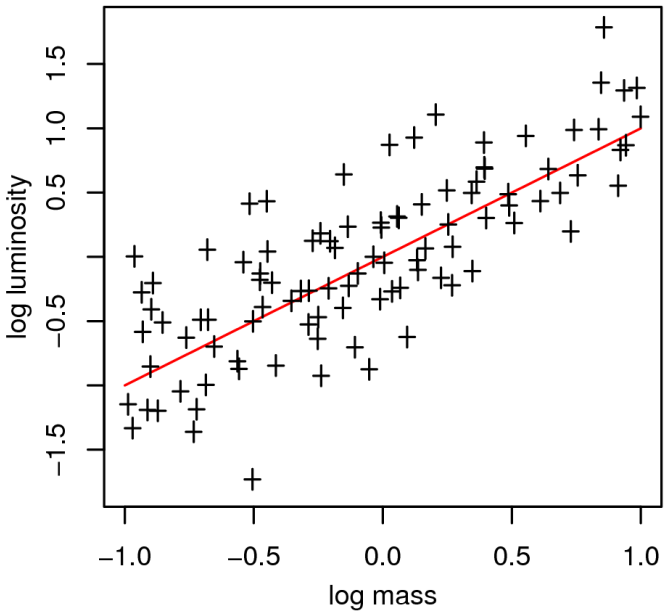
  . . . but that means modeling a population based on an incomplete, unfair sample.
- We need cosmological input to interpret scaling data – the problems don't factor.

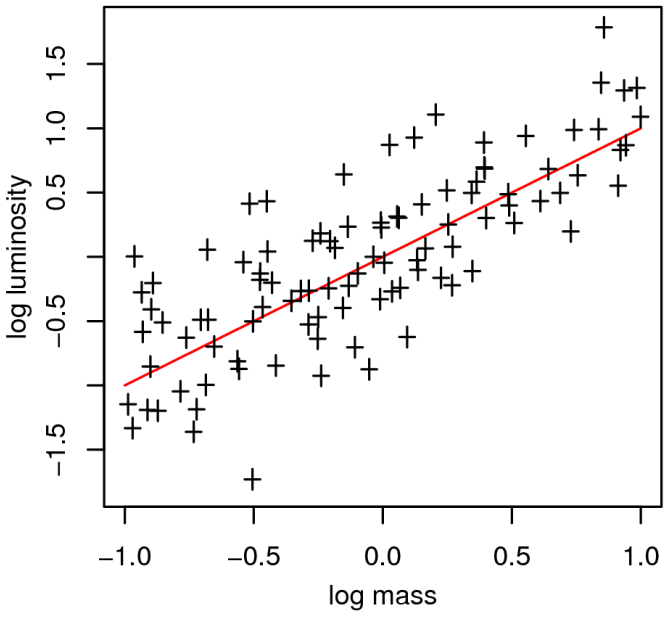
Cartoon view

Whole universe:

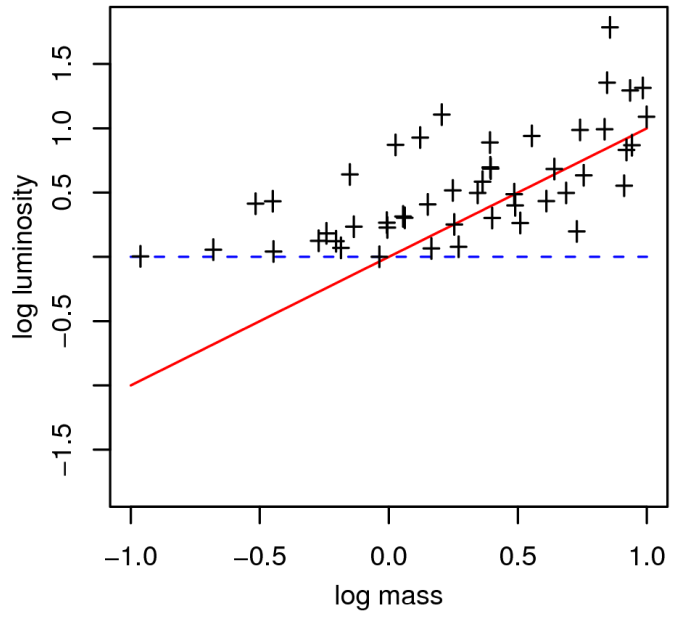


Cartoon view: selection bias

Whole universe:

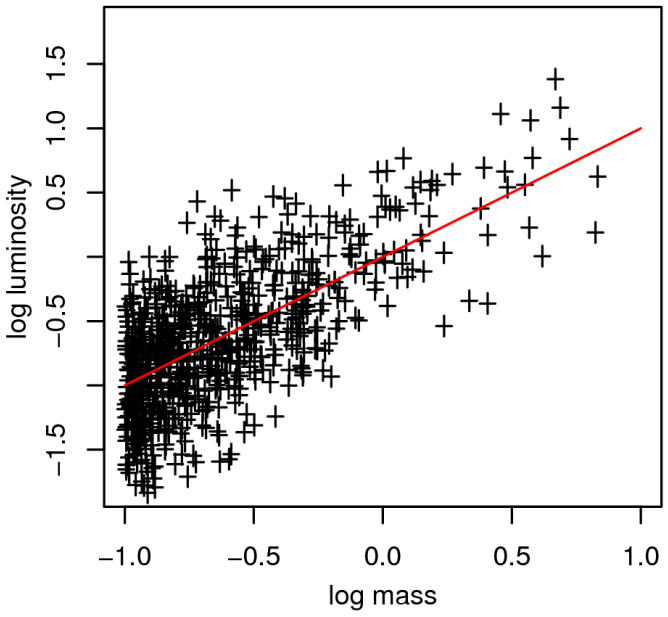


Observed universe:



Cartoon view: cosmology–scaling degeneracy

Whole universe:



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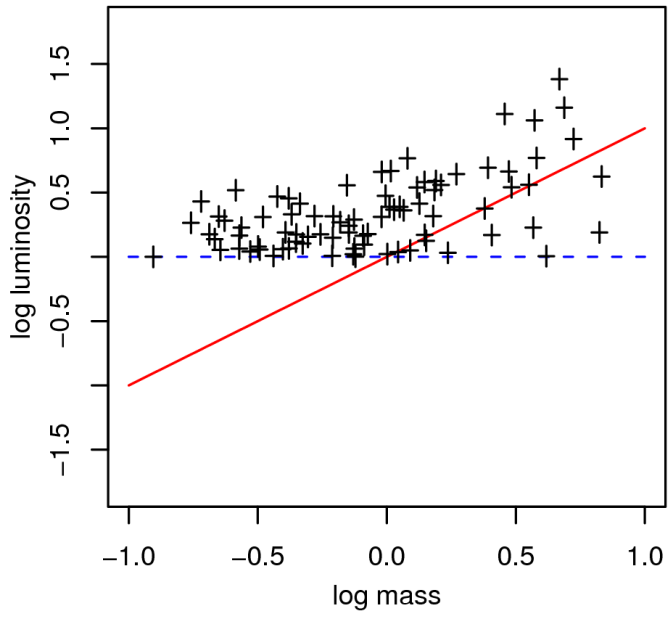
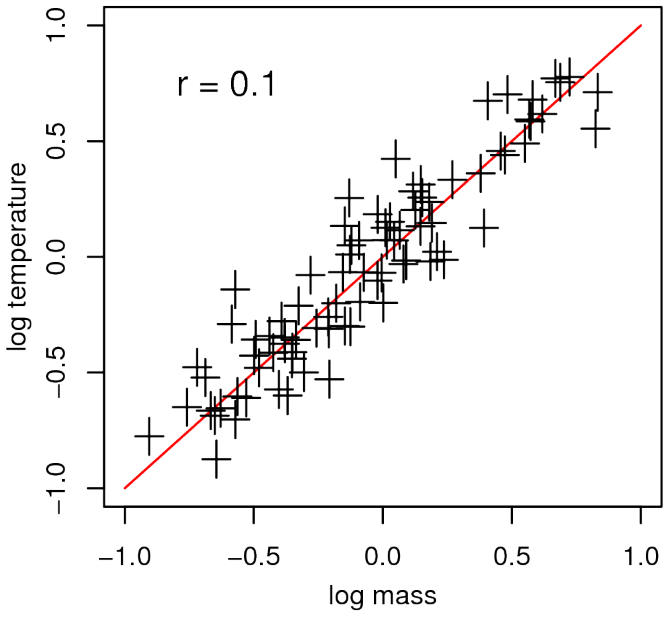


Cartoon view: intrinsic covariance

Just detected clusters:



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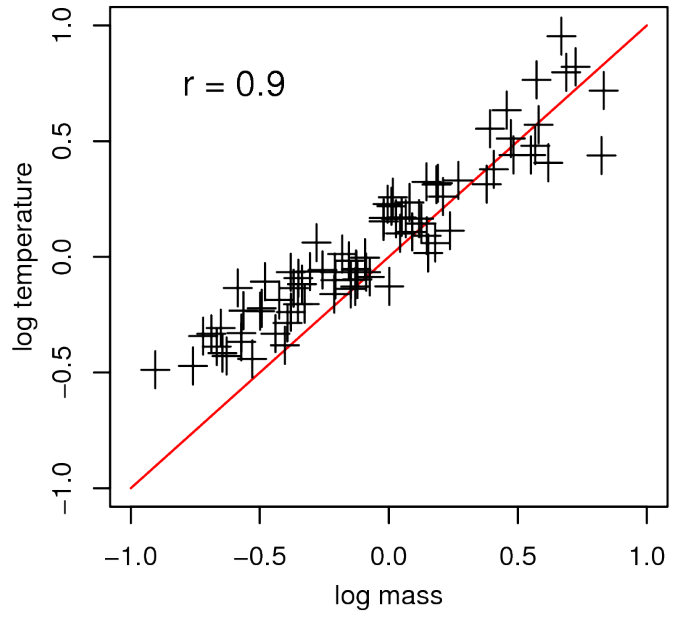

Cartoon view: measurement covariance

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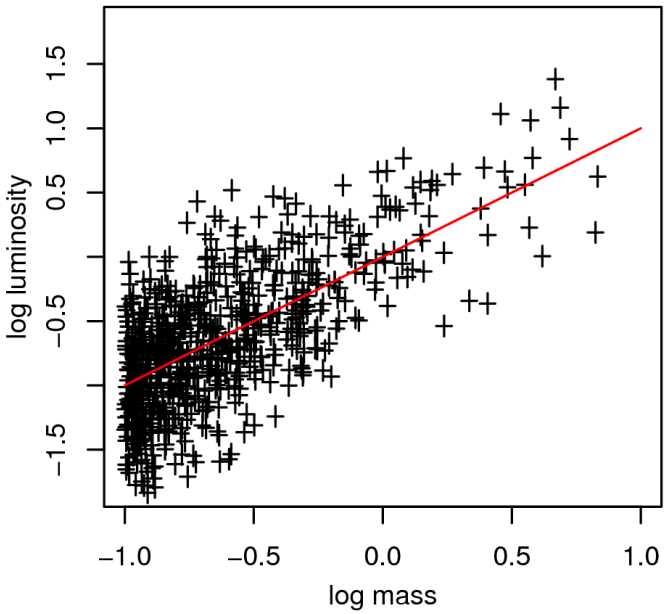

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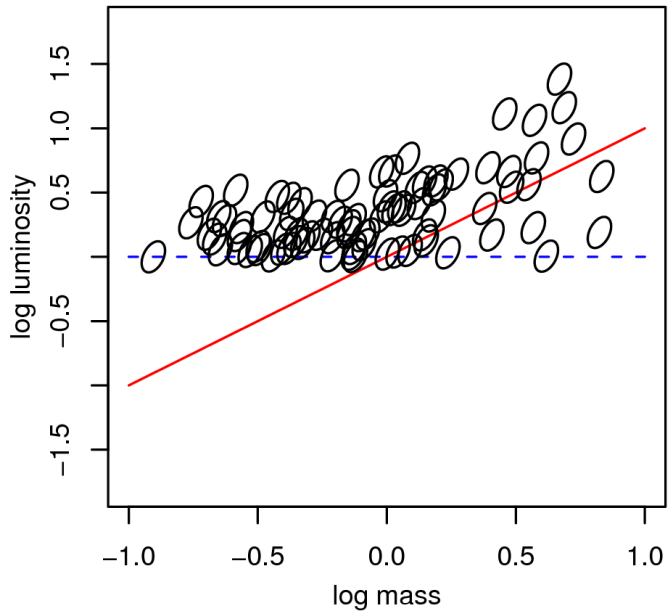


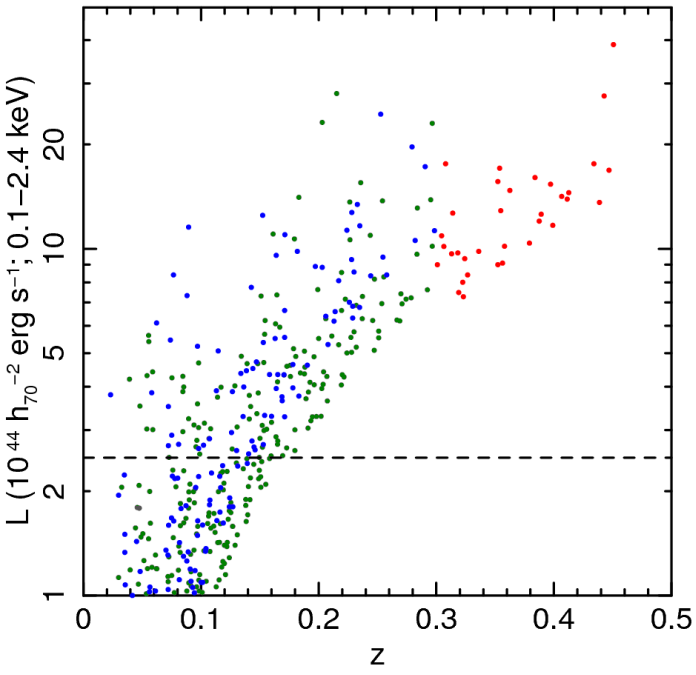
Cosmology + scaling relations

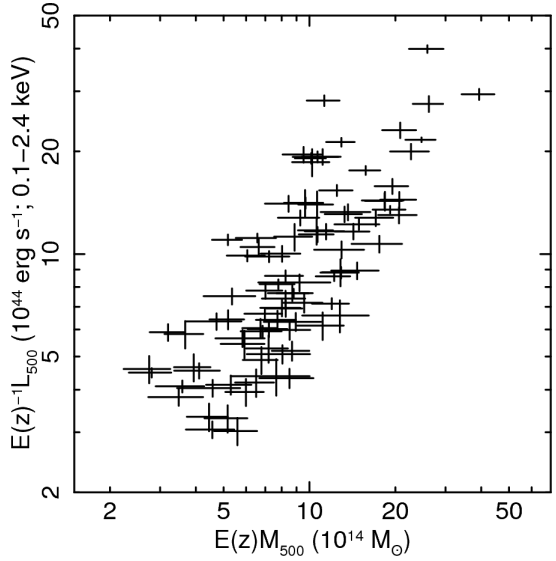
Solving this requires a joint (non-factorable) model:

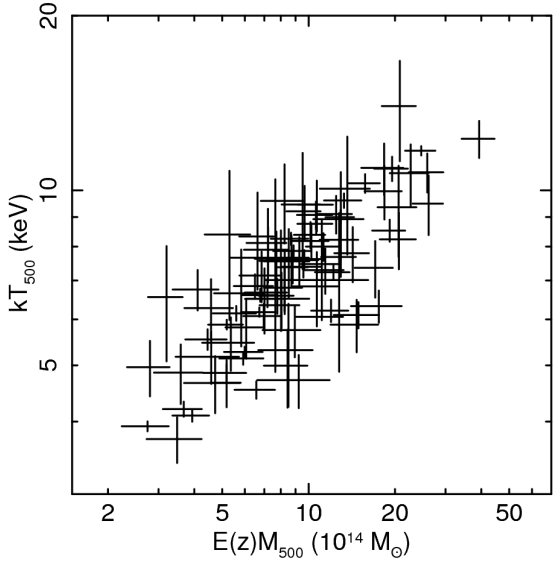
\begin{equation}

...

Fast forward: data



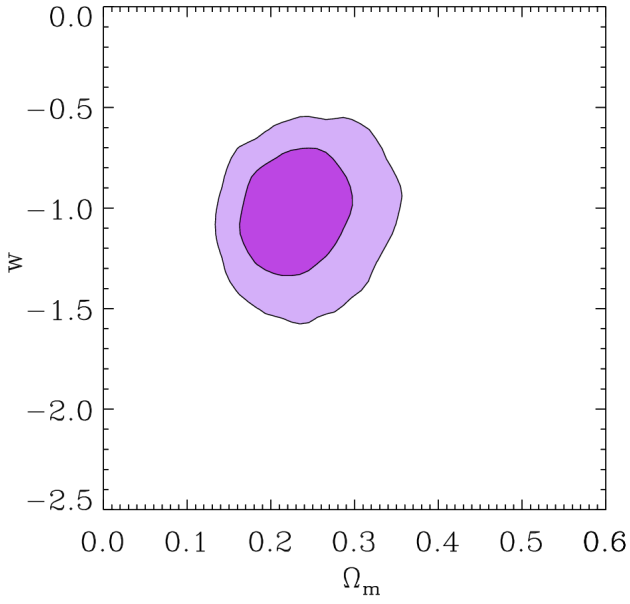


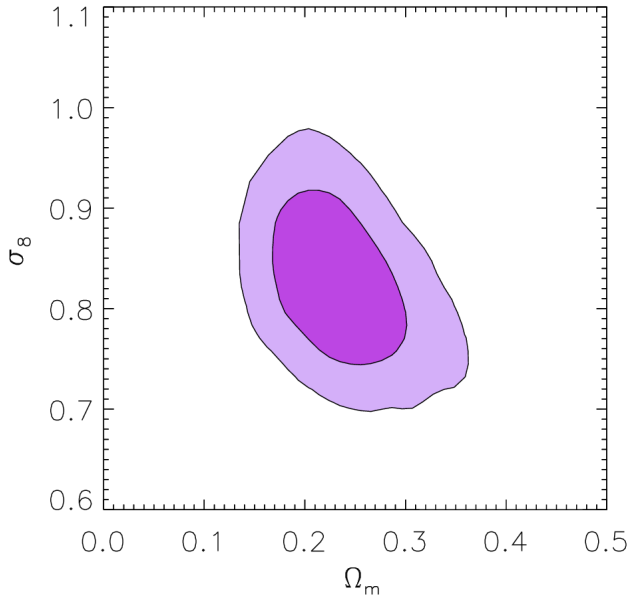


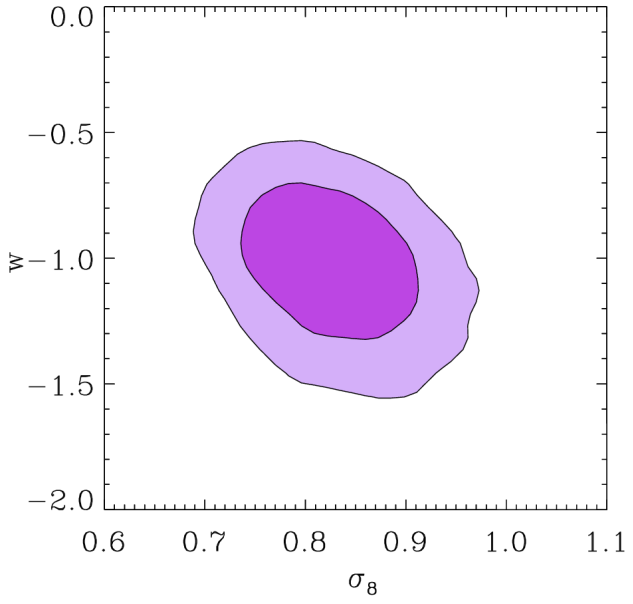
238 RASS detections

94 pointed ROSAT/Chandra

Fast forward: cosmology results







238 clusters, $z < 0.5$ (XLF)
Including systematics

$$\begin{aligned} \Omega_{\rm m} &= 0.23 \pm 0.04 \\ \sigma_8 &= 0.82 \pm 0.05 \\ w &= -1.01 \pm 0.20 \end{aligned}$$

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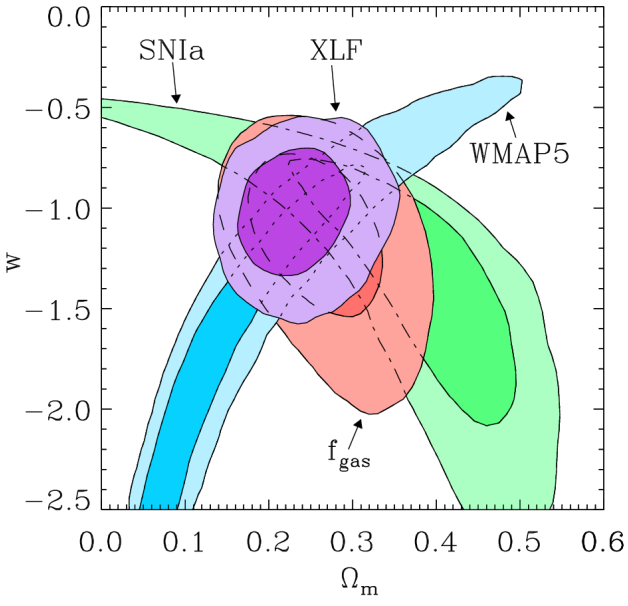

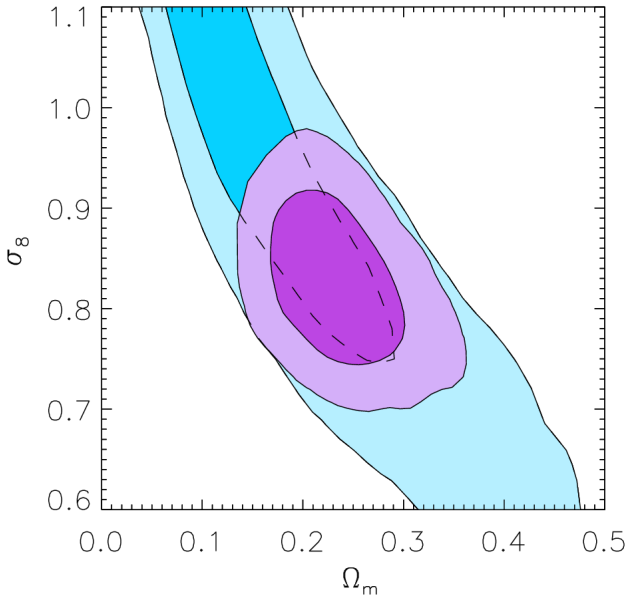

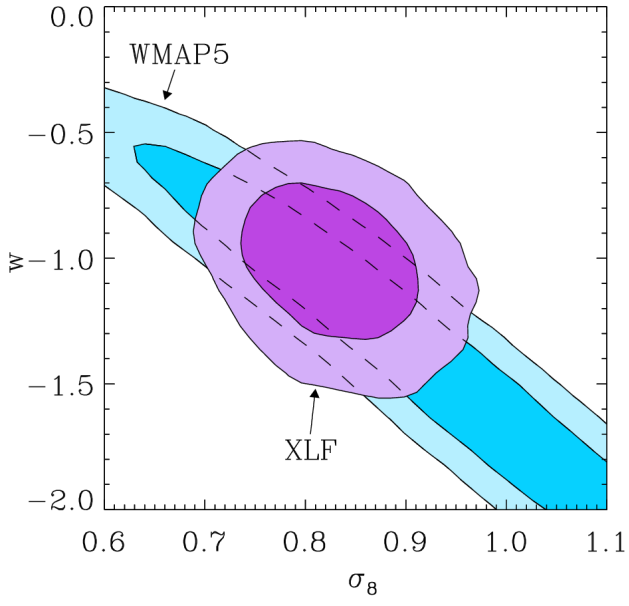

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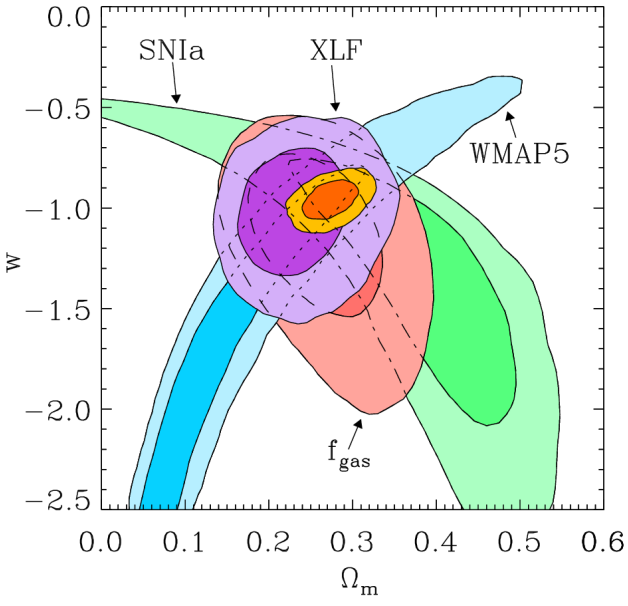

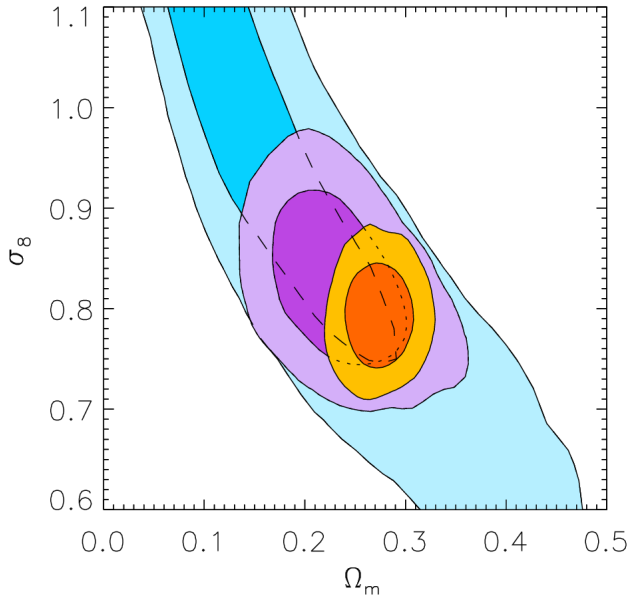

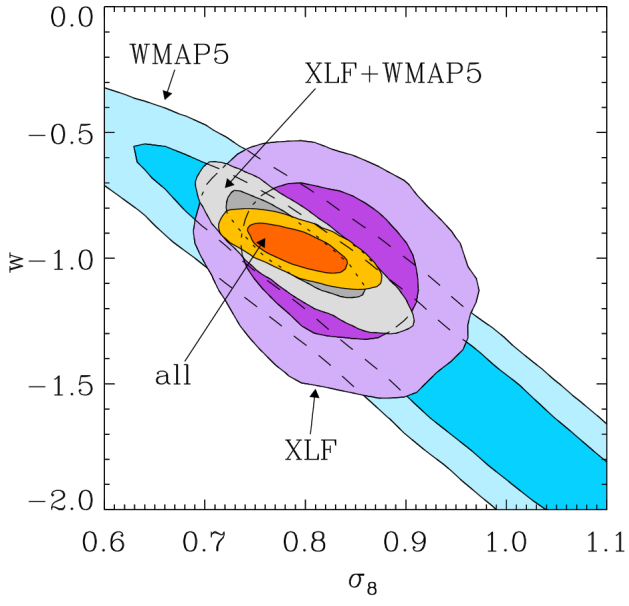

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XLF+WMAP5+SNIa+$f_{\rm gas}$+BAO

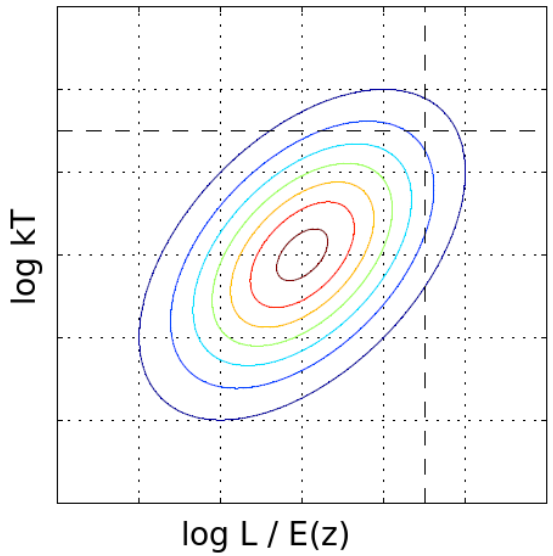
$$\begin{aligned} \Omega_{\rm m} &= 0.272 \pm 0.016 \\ \sigma_8 &= 0.79 \pm 0.03 \\ w &= -0.96 \pm 0.06 \end{aligned}$$

Fast forward: simple scaling relation model fits the data

Nominal $L(M)$ and $T(M)$ as power laws with self-similar evolution:

$$\frac{L_{500}}{E(z)} \propto [E(z)M_{500}]^{\beta_L} \qquad kT_{500} \propto [E(z)M_{500}]^{\beta_T} \qquad E(z) = H(z)/H_0$$

Intrinsic scatter in $L, T|M$ as bivariate log-normal:



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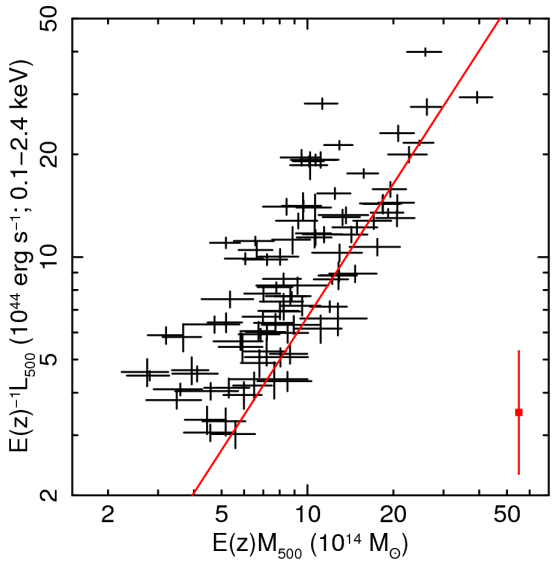

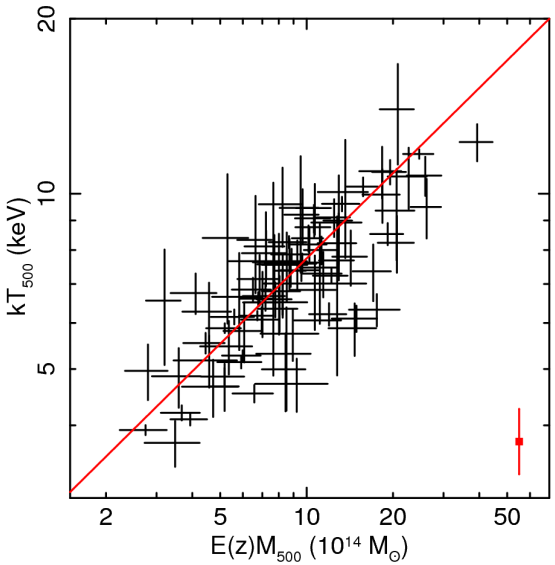

Constrain cosmology as much as possible (flat ΛCDM, use CMB et al.)

Test how well best fitting model predictions match the data

- Fold in cosmology, selection function, ...
- Check cluster abundance, survey distribution, measured masses, luminosities, etc.

Result: The ΛCDM+self-similar evolution model is acceptable (to these data).

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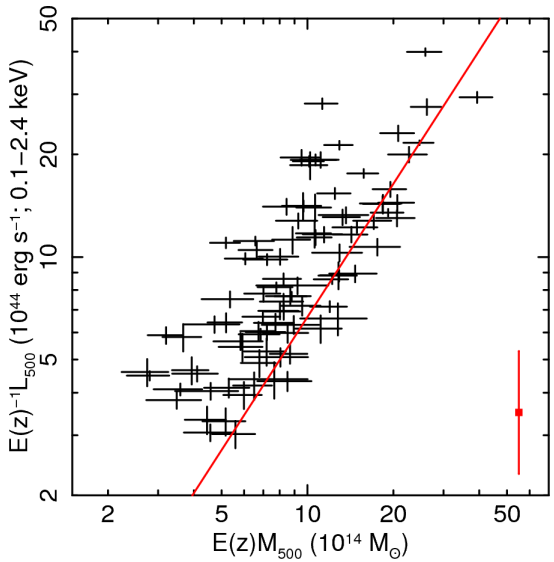
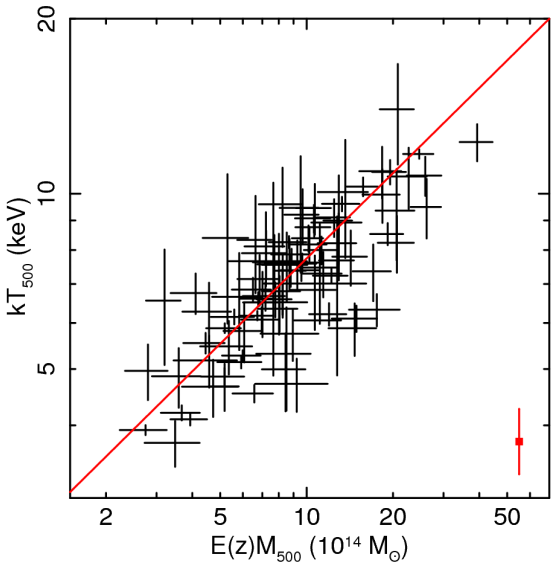
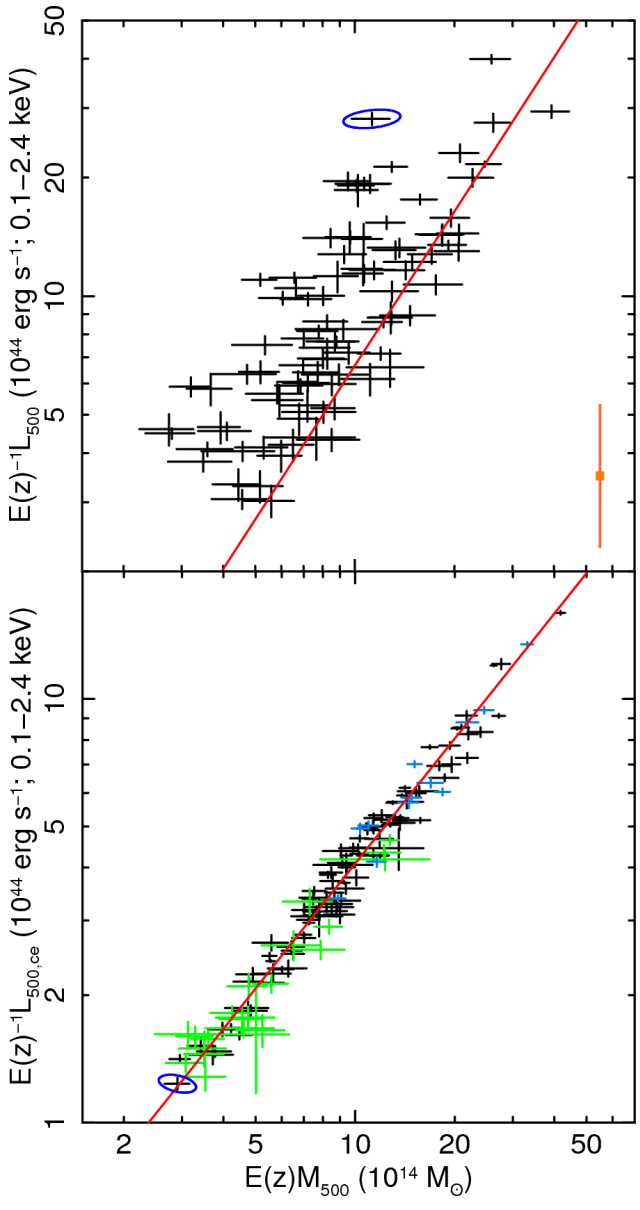




For good measure, there is no preference for

- departures from self-similar evolution
- evolution in the intrinsic scatter
- asymmetry in the intrinsic scatter

Center-excised scaling relation



The L–M relation has

- large scatter ($\sim 40\%$)
- slope $>$ self-similar ($4/3$)

Exclude the central $0.15r_{500}$ from L ...
(e.g. Zhang '07, Maughan '07)

The $L_{\rm ce}$–M relation has

- small scatter ($< 10\%$)
- slope 1.30 ± 0.05
- self-similar evolution with redshift

Cluster centers

Connection to astrophysics:

- Cool cluster cores are also **bright** cluster cores.
  - Up to 50% of the flux within $0.05 r_{500} \sim 50$–$100\,\mathrm{kpc}$

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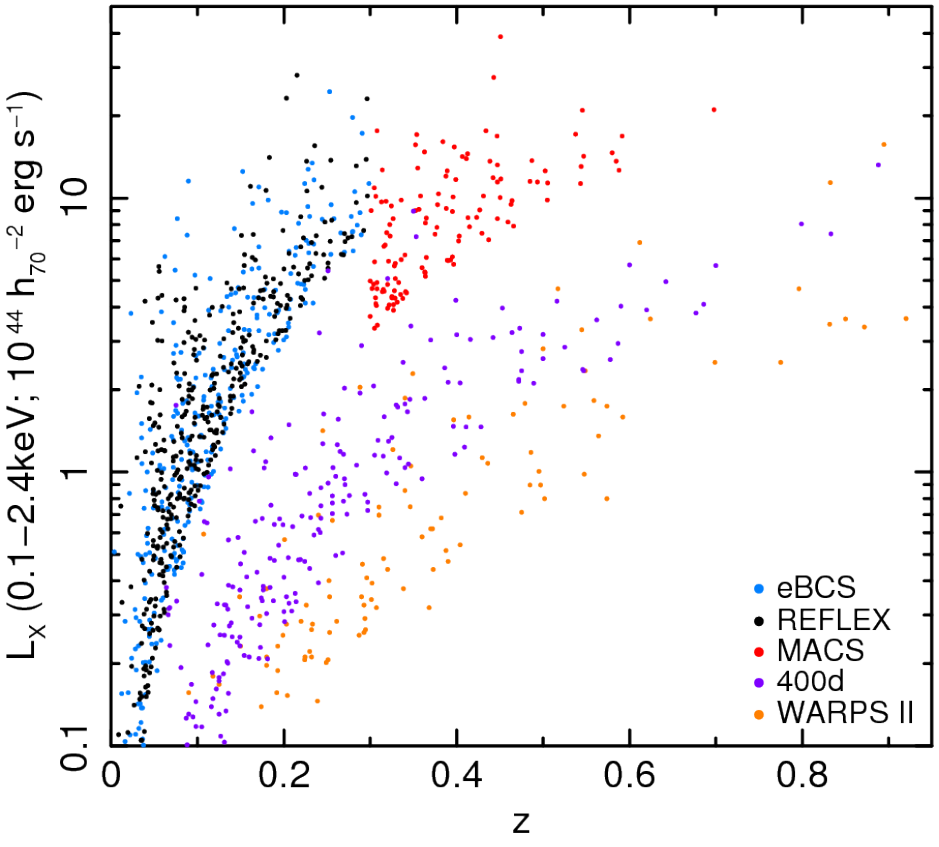
- Their prevalence/development in the mass-limited population should be reflected in the shape/evolution of the scaling intrinsic scatter.
- In practice, the data aren't up to constraining this yet. We can look at selection-biased samples, but have to **always remember the bias!**

Cluster centers: X-ray selection



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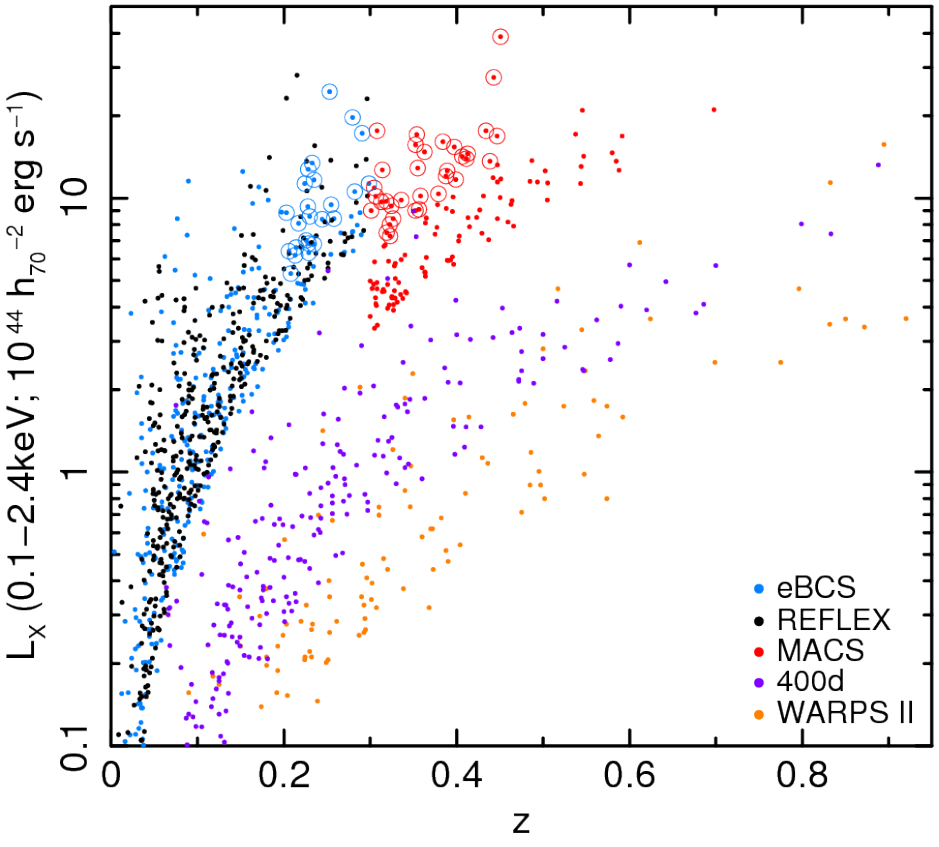

BCS (23 at $0.2 < z < 0.3$)

MACS (32 at $0.3 < z < 0.5$)

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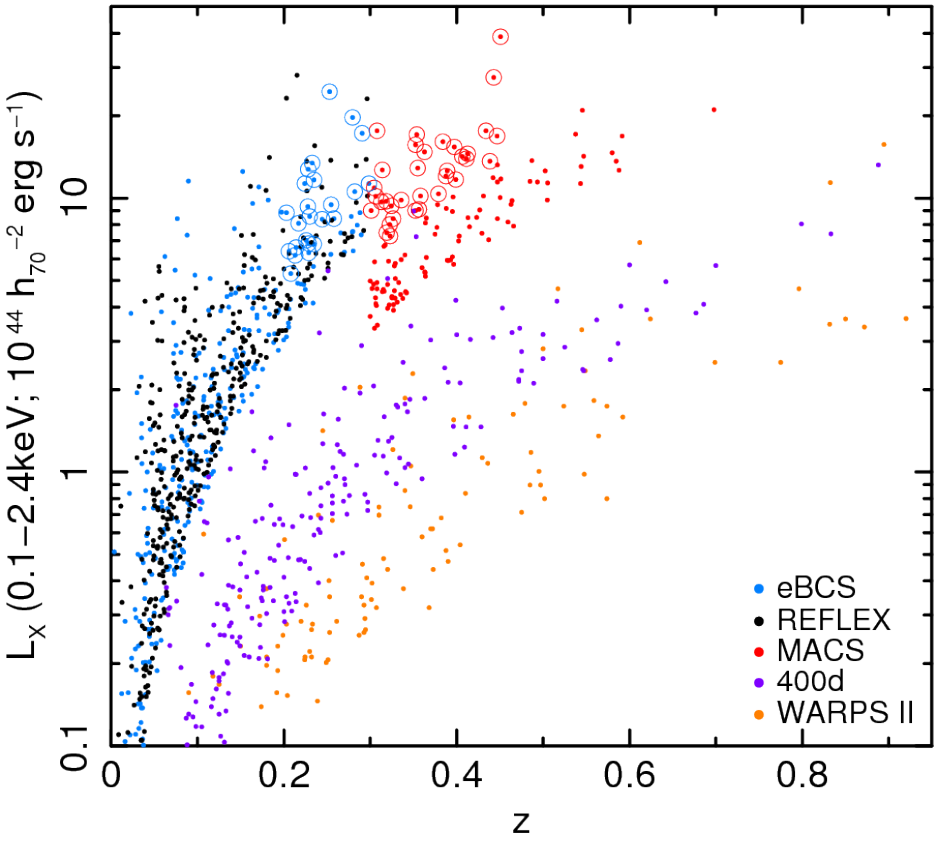

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- No cut on ROSAT extent.
- Exhaustive optical confirmation.
- (Near) complete Chandra follow-up.
- Similar mass range.

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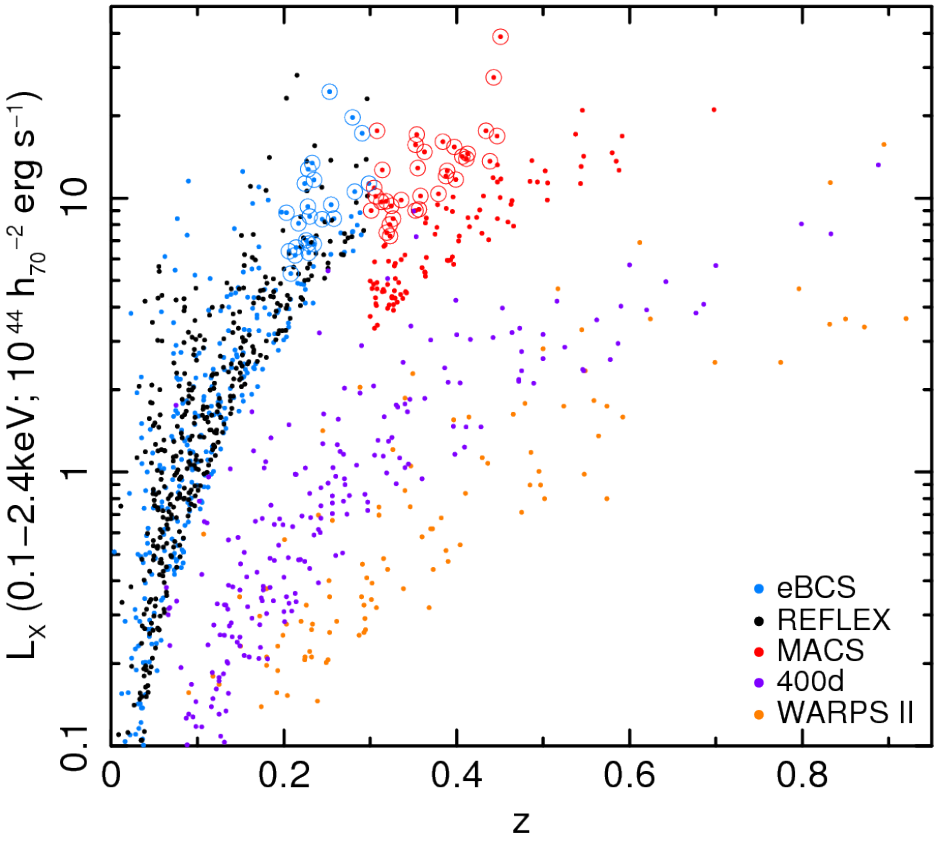

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For later:
400d (13 at $0.35 < z < 0.5$, $L > 2.5 \times 10^{44}\,\mathrm{erg/s}$)
Somewhat lower masses
(but not too much)

Cluster centers: bright–cool correspondence

Adopt the fiducial radius $0.05r_{500}$ (50–100 kpc),
look at the luminosity ratio $L(< 0.05r_{500})/L(< r_{500})$
(similar to Santos et al. $c_{\rm SB}$)

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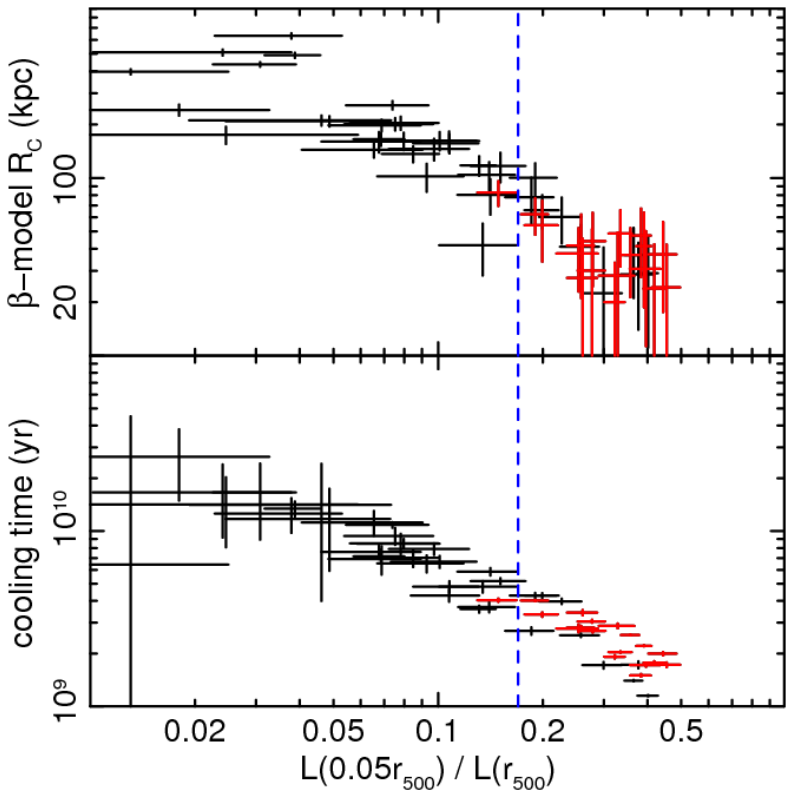

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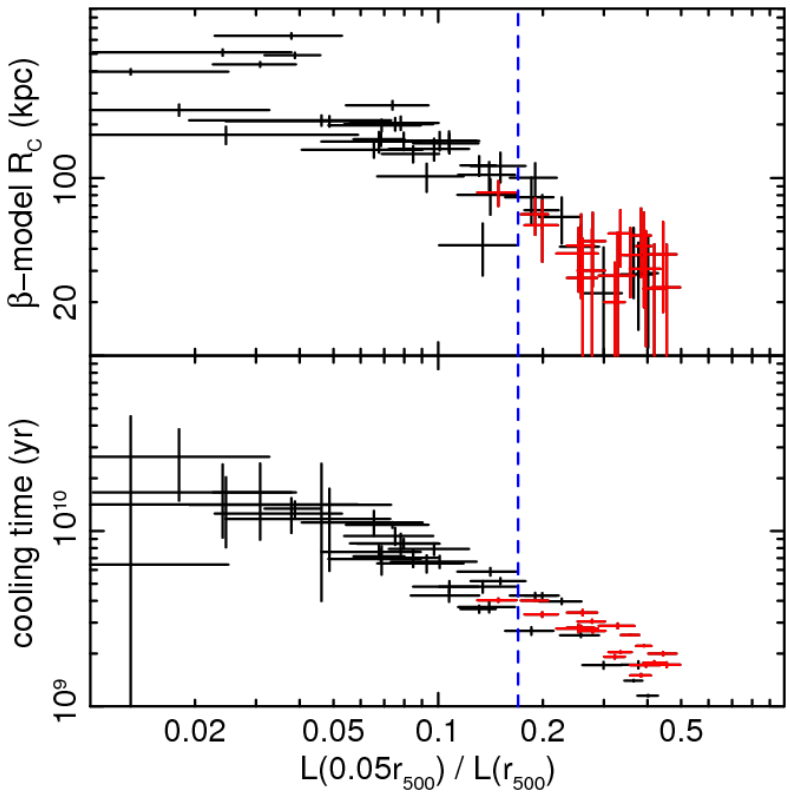

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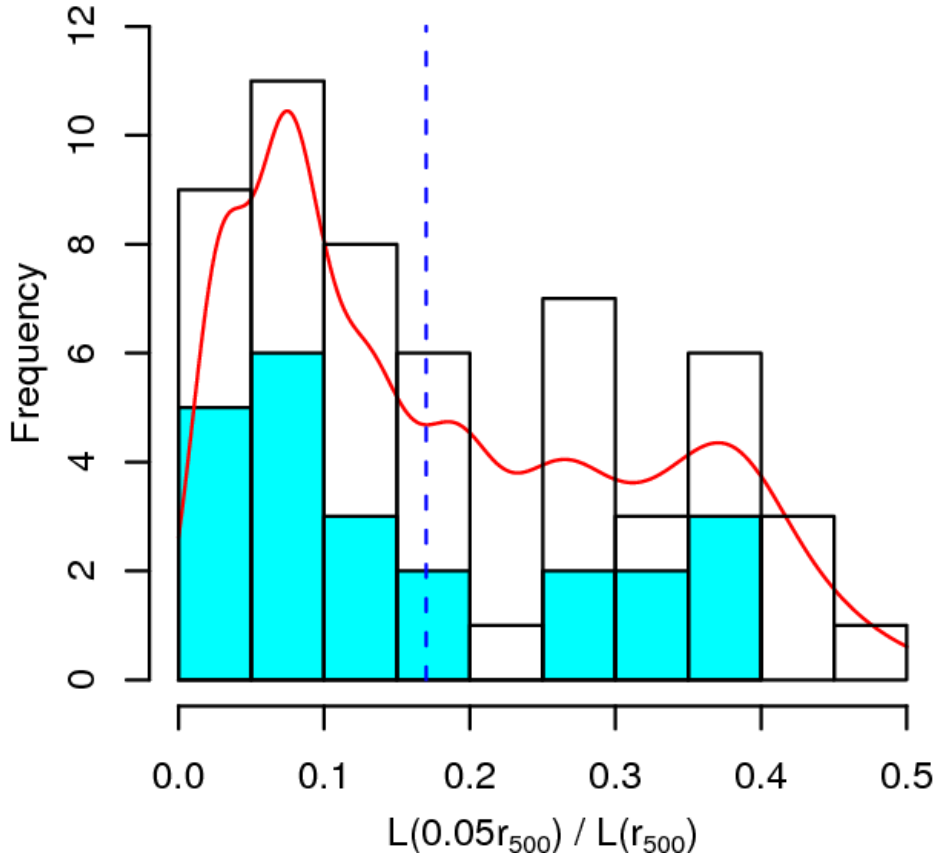
Call ratio > 0.17 "bright core" clusters

$t_{\rm c} \lesssim 4\,{\rm Gyr}$

$r_{\rm c} \lesssim 80\,{\rm kpc}$

Cluster centers: brightness distribution

Peak + tail? Hard to say given the biases. . .



BCS

BCS+MACS

Smoothed

Cluster centers: prevalence of bright cores

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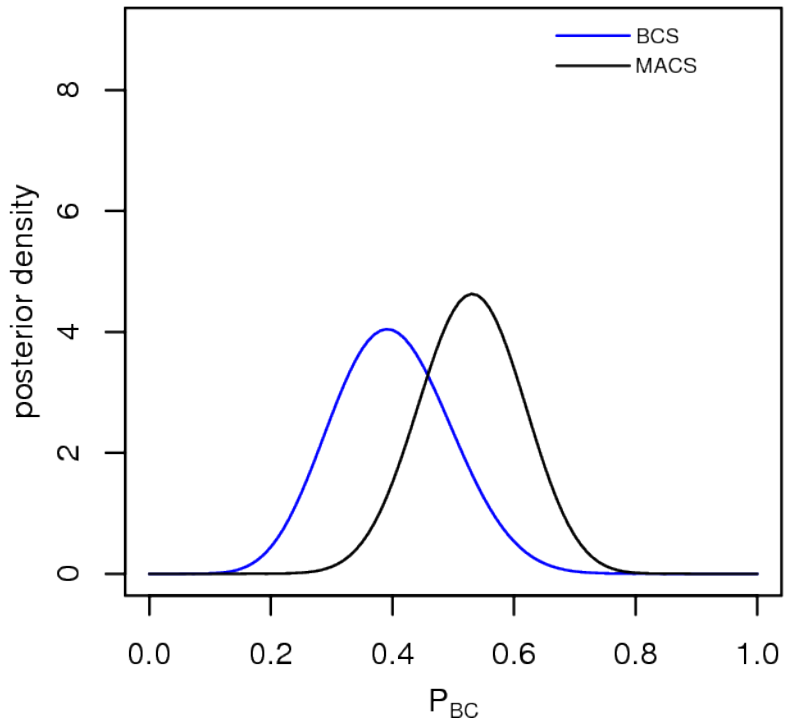

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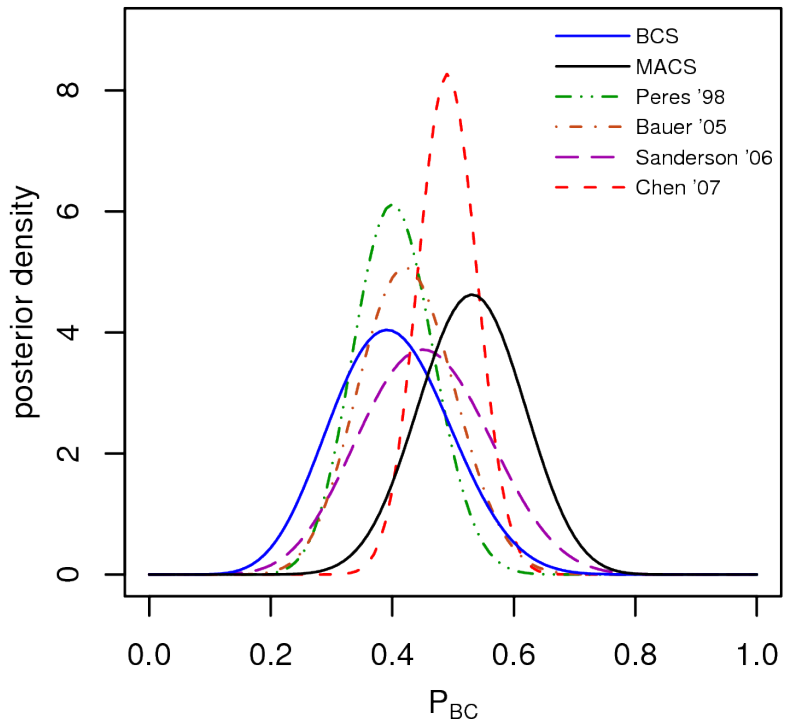

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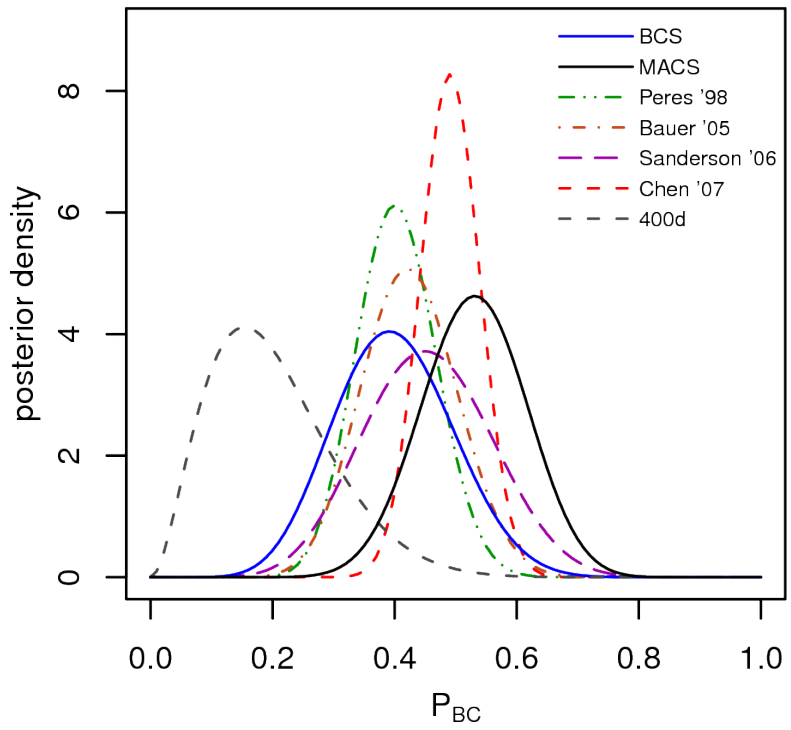

Conclusions

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But. . .

- Most X-ray samples at $z < 0.5$ look similar.
- Lots of bright cores out to $z = 0.5$,
  including some impressive cooling systems in MACS
  (see Anja's talk for slightly more detail).