Cosmology: Getting the Most out of XMM

Kathy Romer

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On behalf of the XCS collaboration

XCS Collaboration

- Sussex: Mark Hosmer, Andrew Liddle, Ed Lloyd-Davies, Nicola Merhtens, Kathy Romer, **Martin Sahlen**
- Carnegie Mellon: Kivanc Sabirli
- LJMU: Chris Collins, Matt Hilton
- Porto: Pedro Viana
- Edinburgh: Bob Mann, (Michael Davidson)
- Portsmouth: Bob Nichol, Ben Hoyle
- Manchester: Scott Kay
- NOAO: Chris Miller
- UC Davis: Adam Stanford
- Gemini: Mike West

What I hope to get across

- XMM has already detected enough clusters to allow us to measure cosmological parameters
- Surprisingly, we don't need to go to $z>1$
- Challenges:
  - Finding the clusters in the archive: solved
  - Measuring redshifts: hard; but not impossible
  - Quantifying the selection function: ditto
  - Improving the calibration of the mass-observable connection: requires more investment of XMM time
- Re-observation of serendipitous XMM clusters would be an excellent use of XMM-Newton

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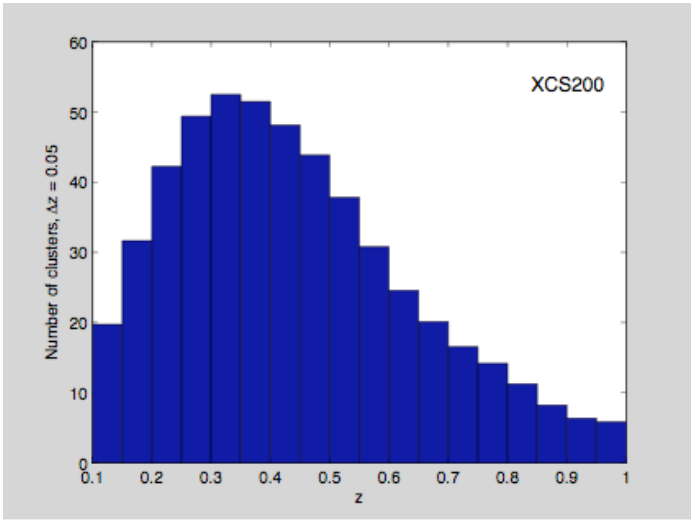
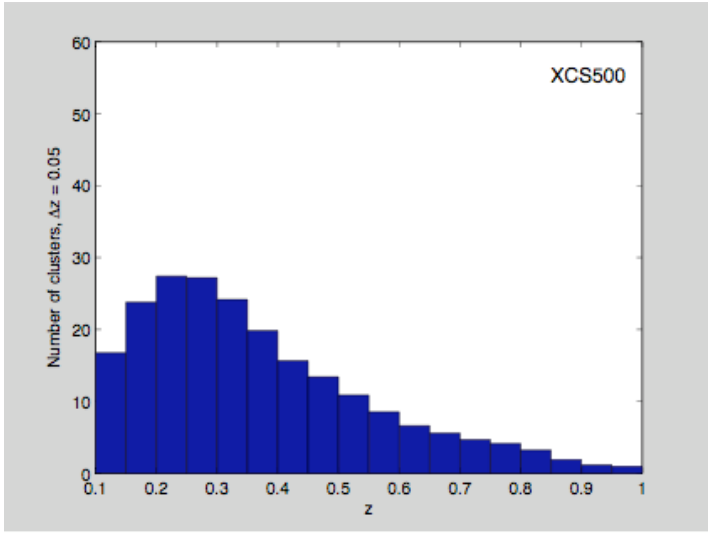
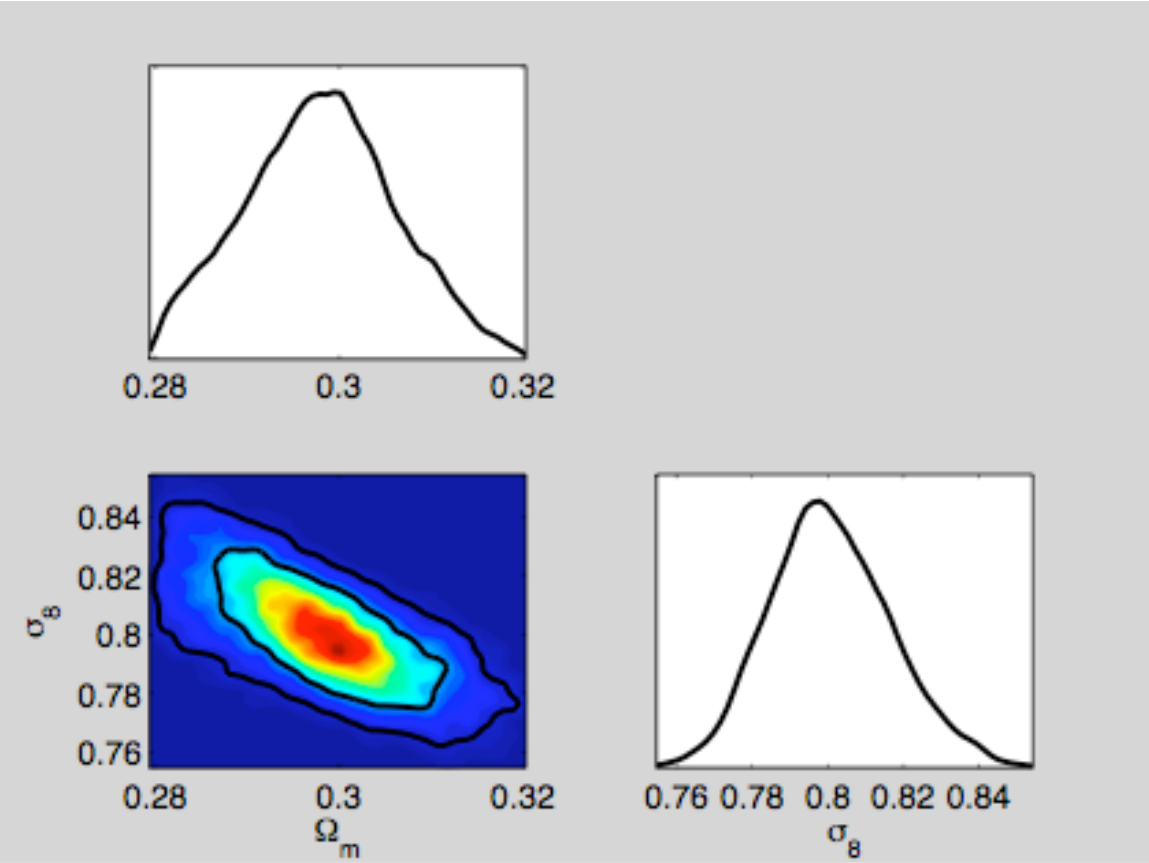
Expected Number of Clusters in the XMM archive



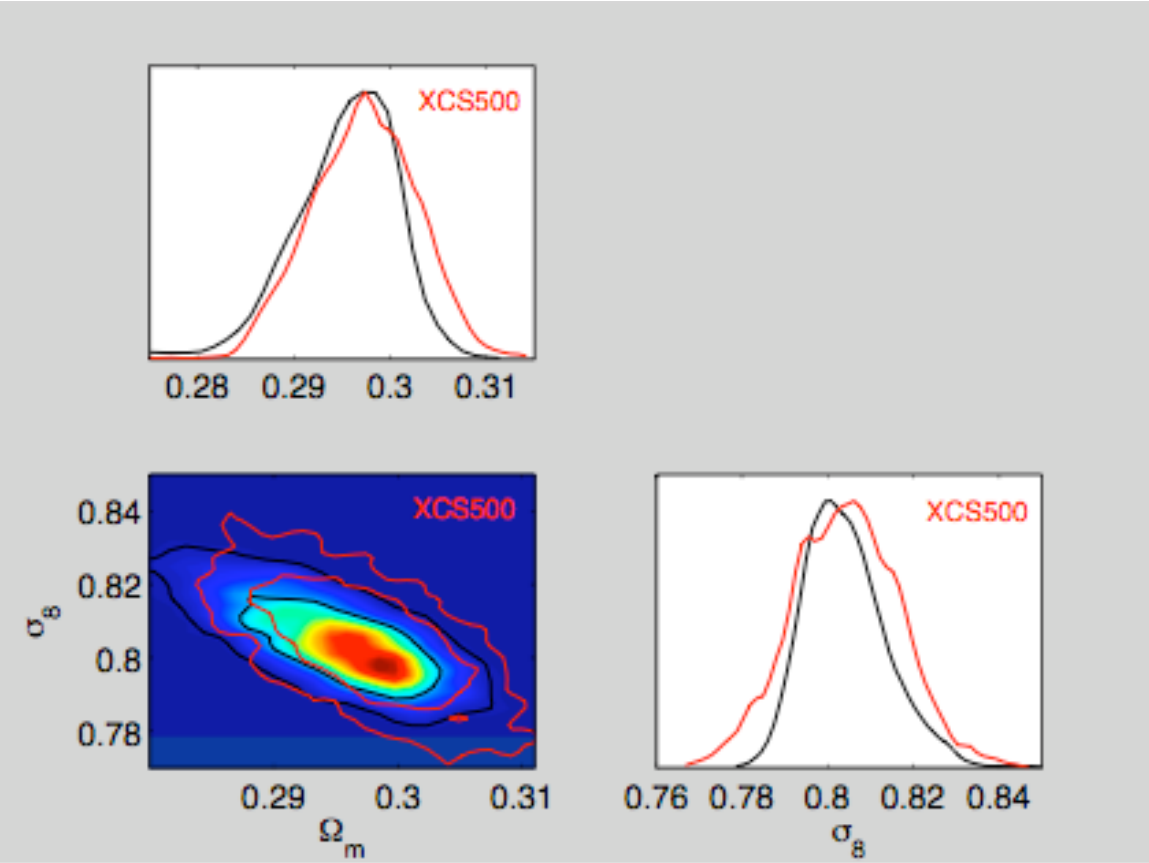


- Assuming 500 square degrees and >2 keV, plus Concordance cosmology, Jenkins Mass function, empirical XCS selection function
  - 514 with more than 250 counts
  - 215 with more than 500 counts

^{500}*XCS* Parameter Predictions



200XCS Parameter Predictions



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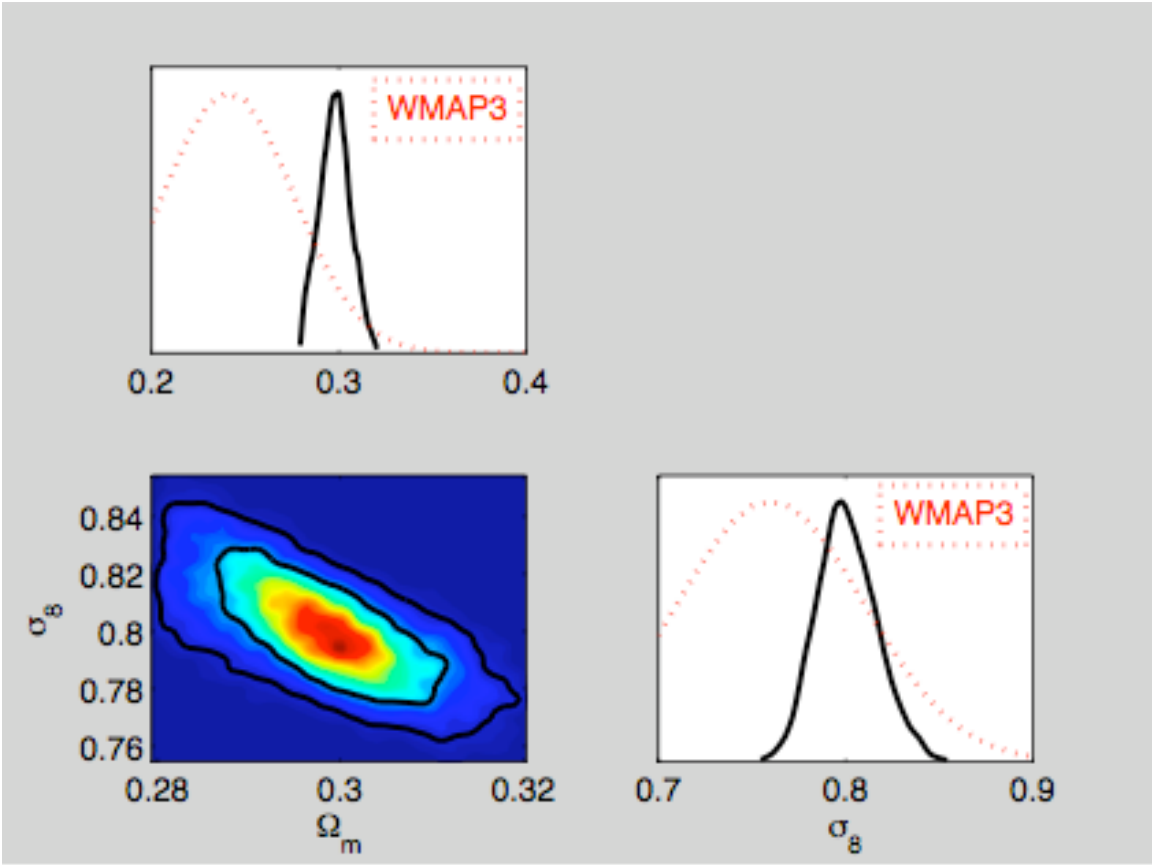

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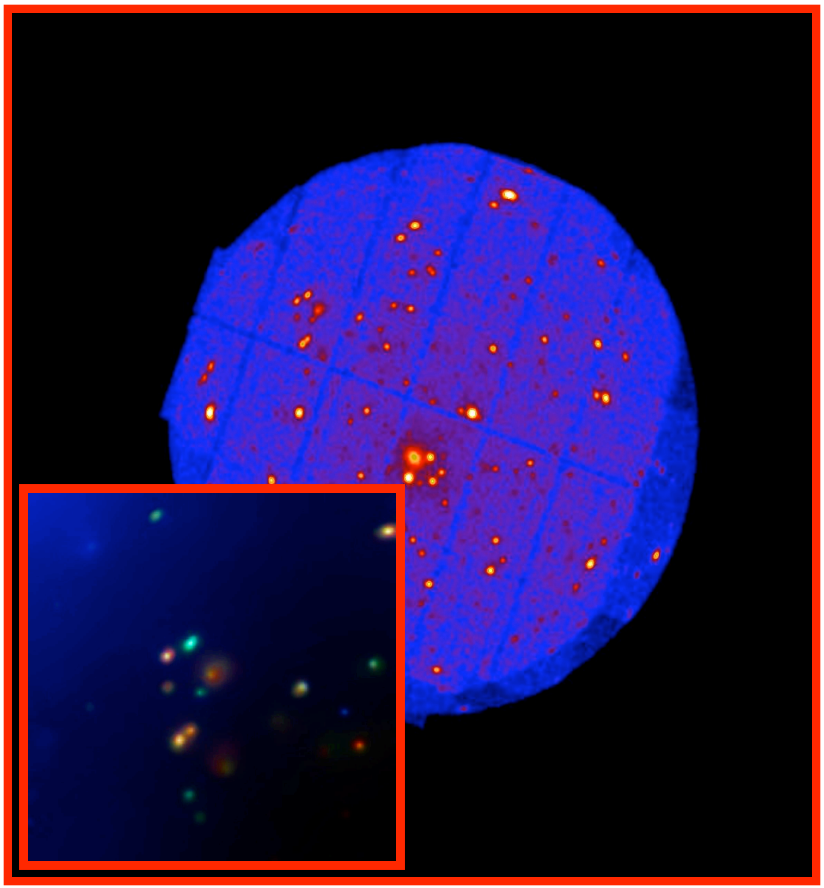
That's not to say z>1 clusters aren't interesting!



- XMM has produced the most distant X-ray selected cluster: z=1.45
- XMM XCS2215.9-1738
- The X-ray temperature was measured from the discovery data
- Systems like this are valuable for studies of galaxy evolution and for distant SNe surveys.
- XCS and XDCP are working hard to root them out of the archive.

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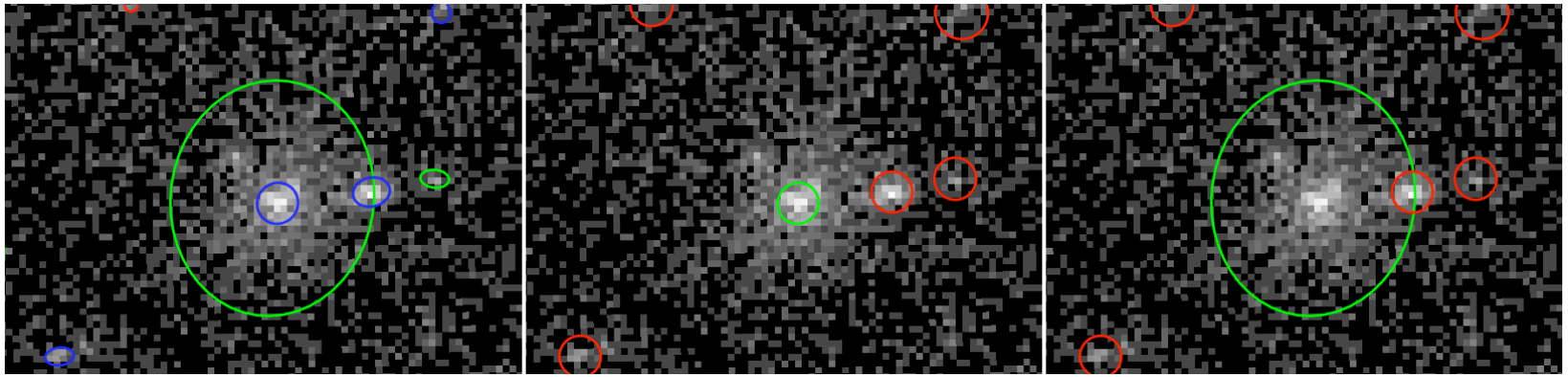
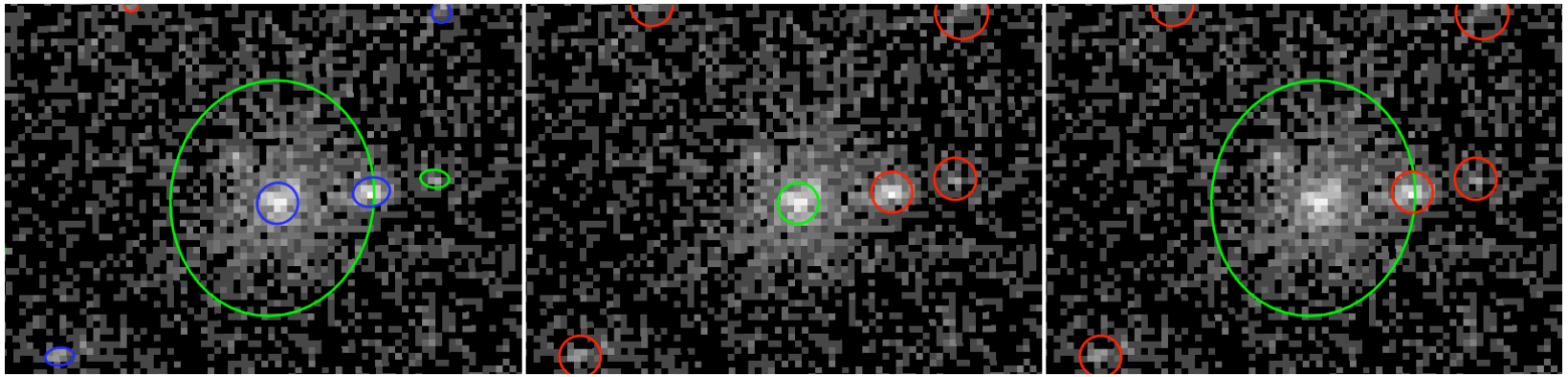
Finding and classifying extended sources



- Things weren't as easy as we predicted in Romer et al. 2001….
  - Particle background much higher than expected
  - Flares: impacted both survey area and sensitivity
  - Detector sensitivity less than expected

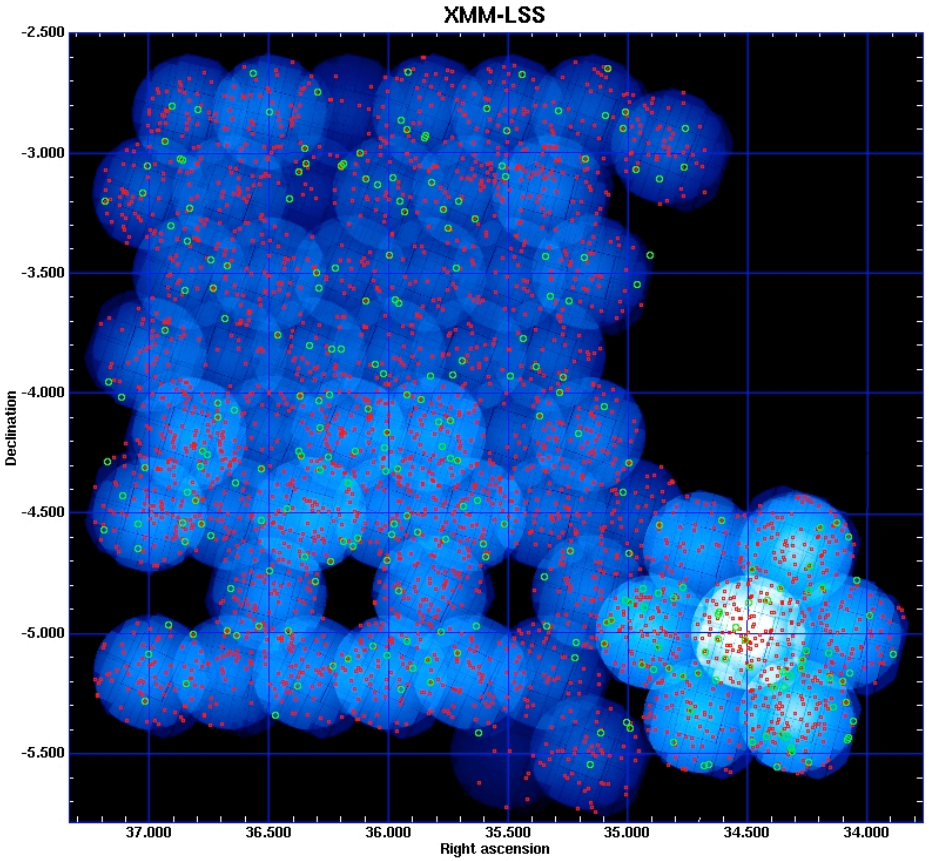
Finding and classifying extended sources



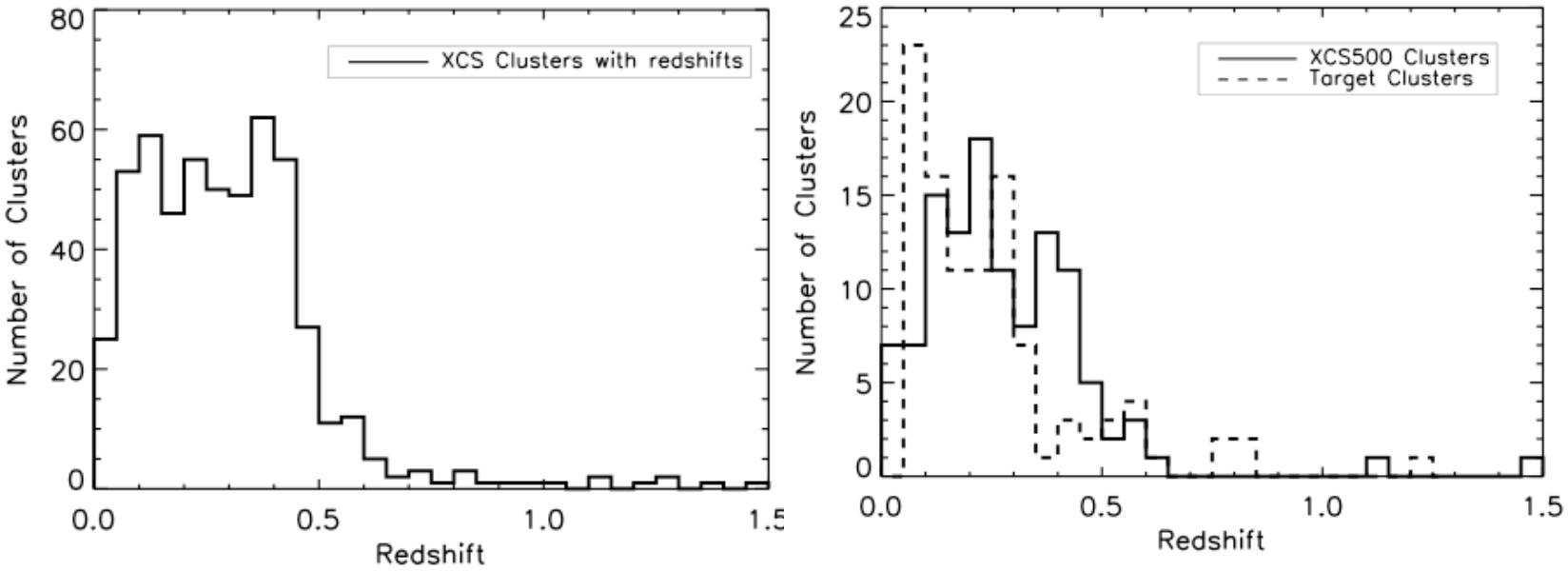
- But as it happens, it didn't change the predicted XCS cluster yield too much…..
  - Co-adding all 3 images made up for reduced PN sensitivity
  - We lowered the threshold for temperature measurements
  - Improved algorithms allowed us to find clusters at lower signal to noise and to larger off-axis angles than predicted

An XCS processed region

(To date, we have more than 200 sq. degrees processed - overlap corrected - and more than 2,000 cluster candidates catalogued)

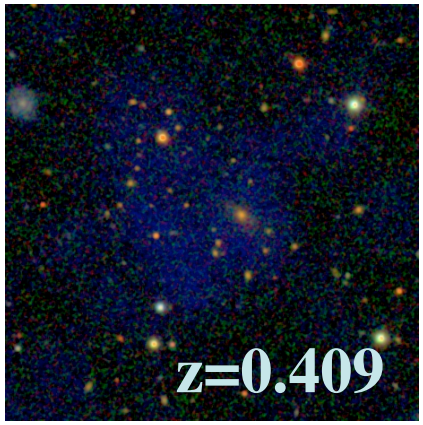


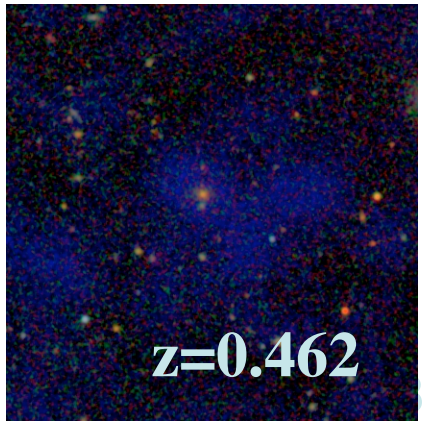
How are we doing so far?

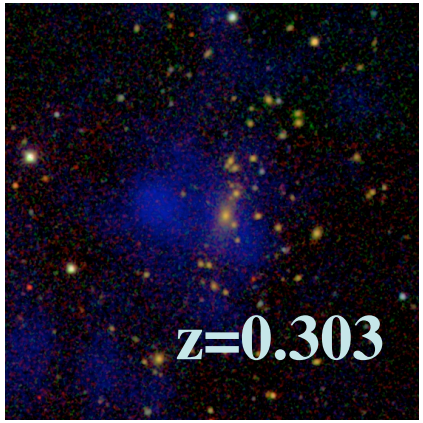


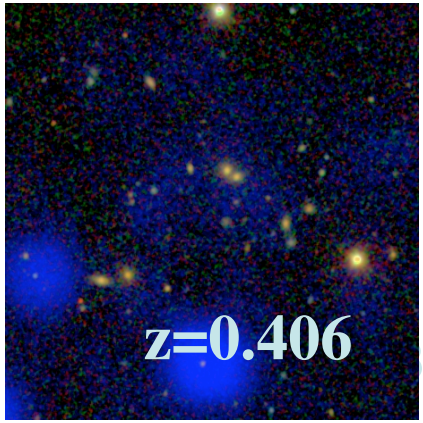
- More than 300 redshift measurements so far (136 for ^{500}*XCS* clusters)

>200 redshifts from SDSS

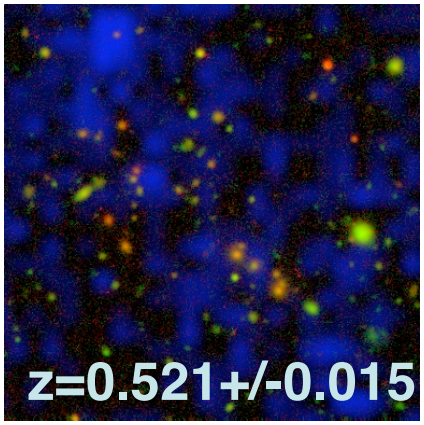


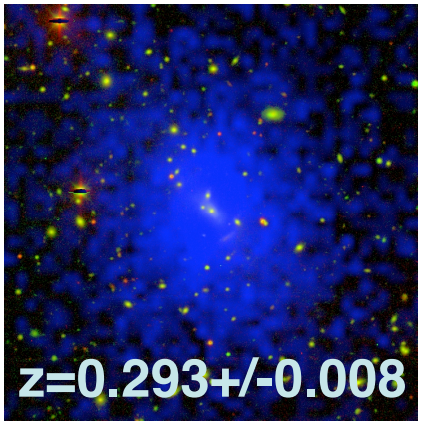


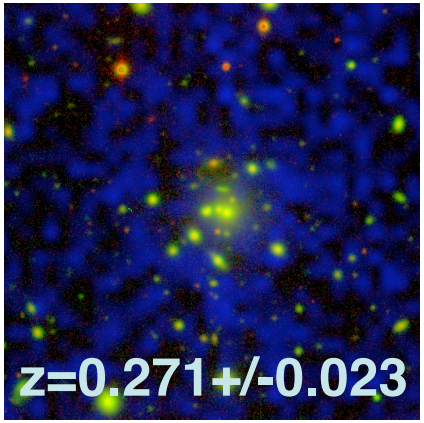


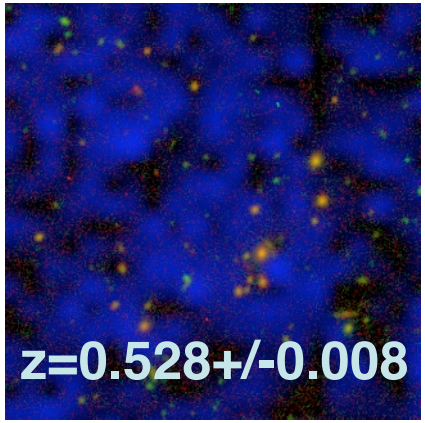


>100 ^{500}*XCS* redshifts from NOAO (more coming)

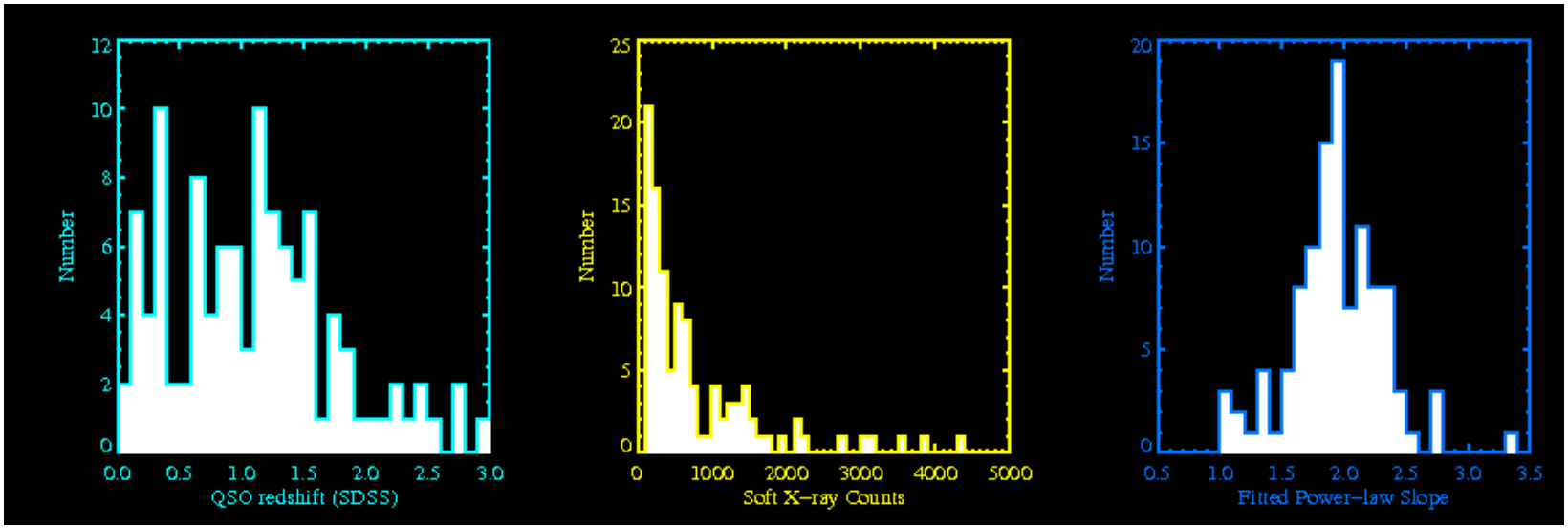








Asside: SDSS QSOs in XCS



(courtesy Chris Miller and Sebastian Jester)

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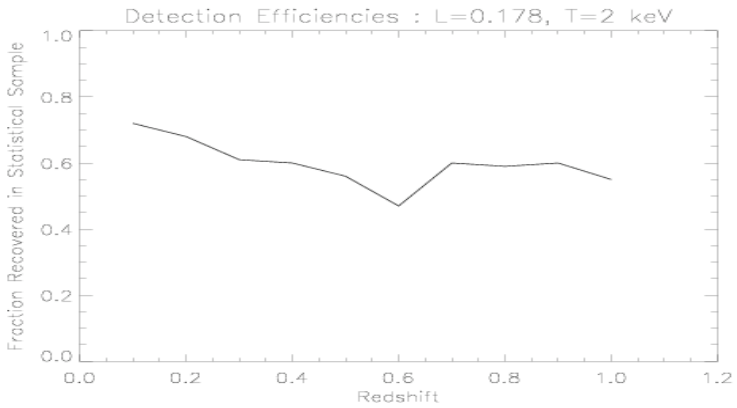
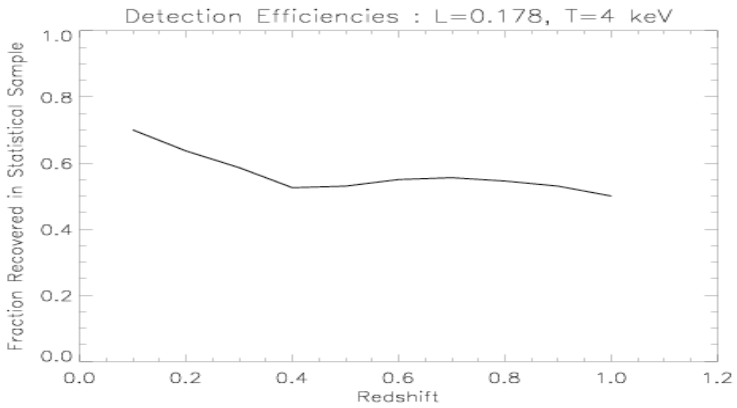
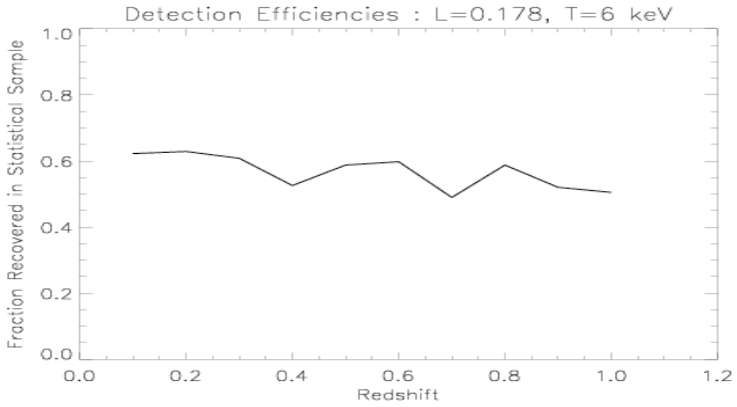
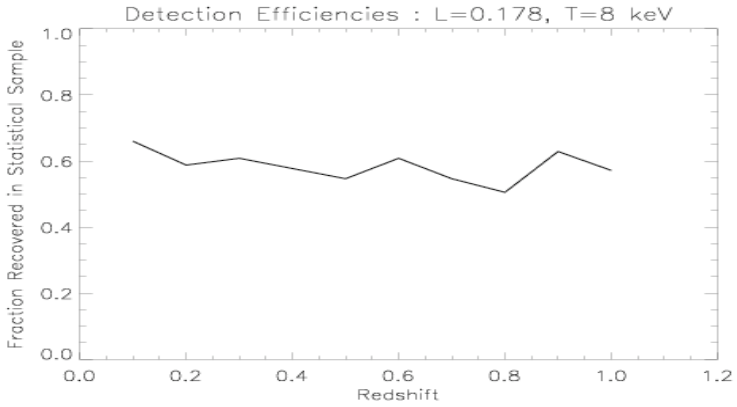
XCS Selection Functions
(these take months to calculate)









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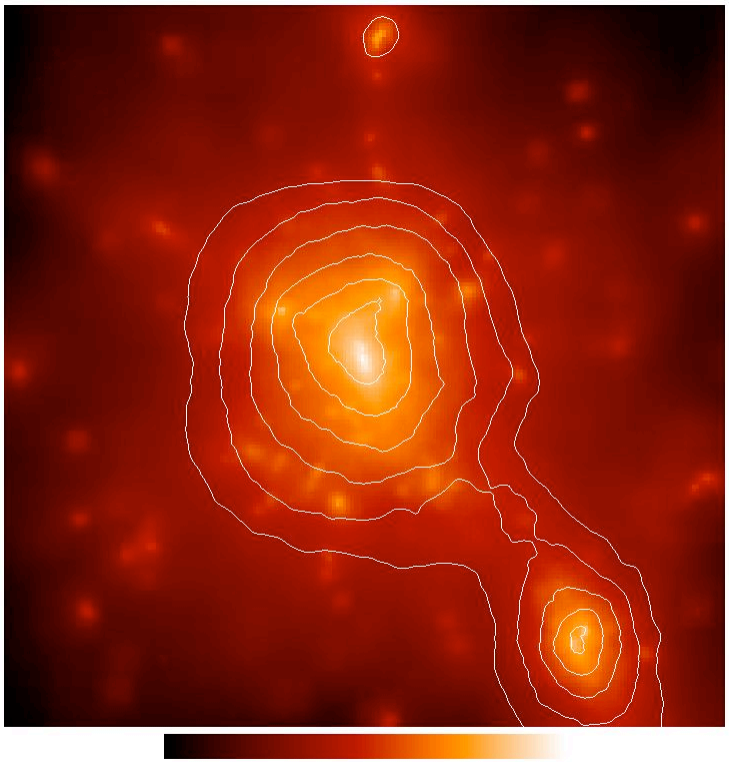

Mock cluster from the Millennium Simulation

- To date, we have used spherical beta-profiles to model the clusters
- Now moving to a more realistic approach: pasting simulated clusters from hdro-simulations into XMM observations and then running them through the XCS pipelines

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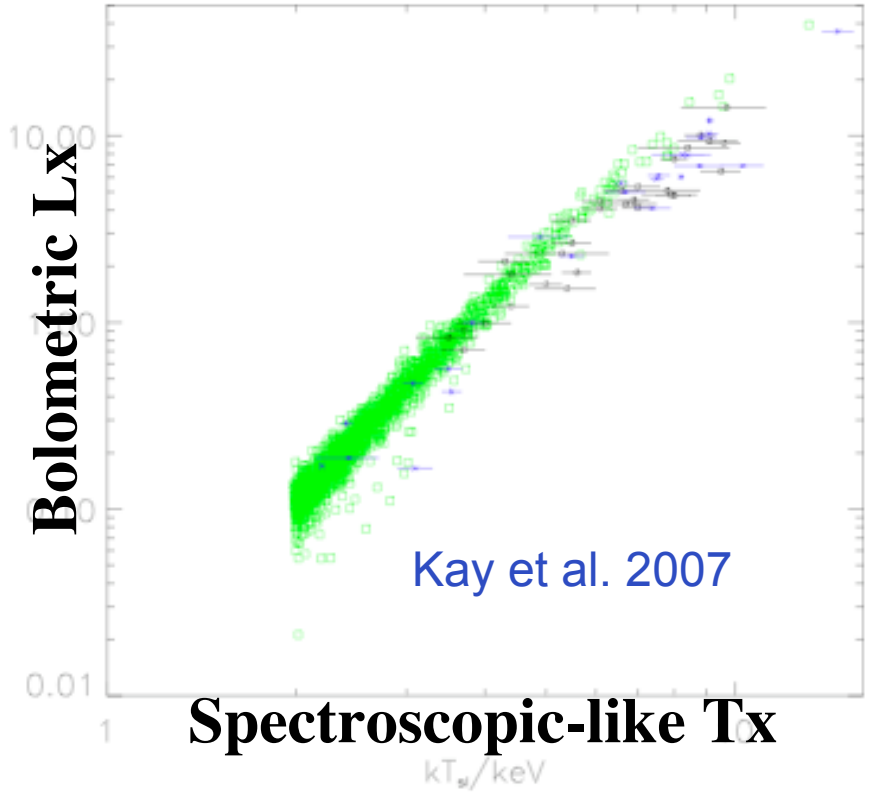
Improving the Mass-Observable connection

- X-ray cluster surveys take advantage of the tight scaling relations (right) that relate mass to observables
- But we still do not know enough about these relations to be confident about our ability to relate measured N(z) to the N(m,z) predicted by theory.



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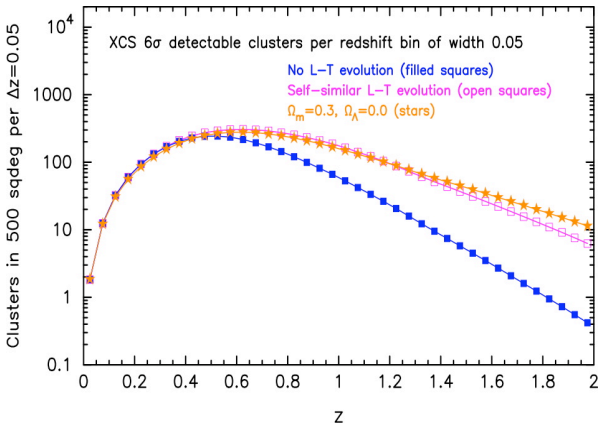
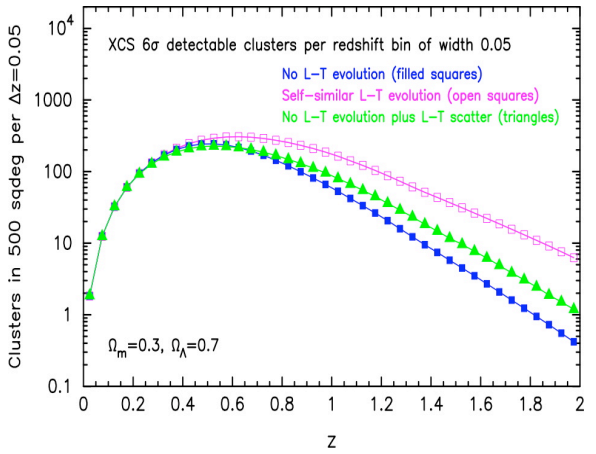
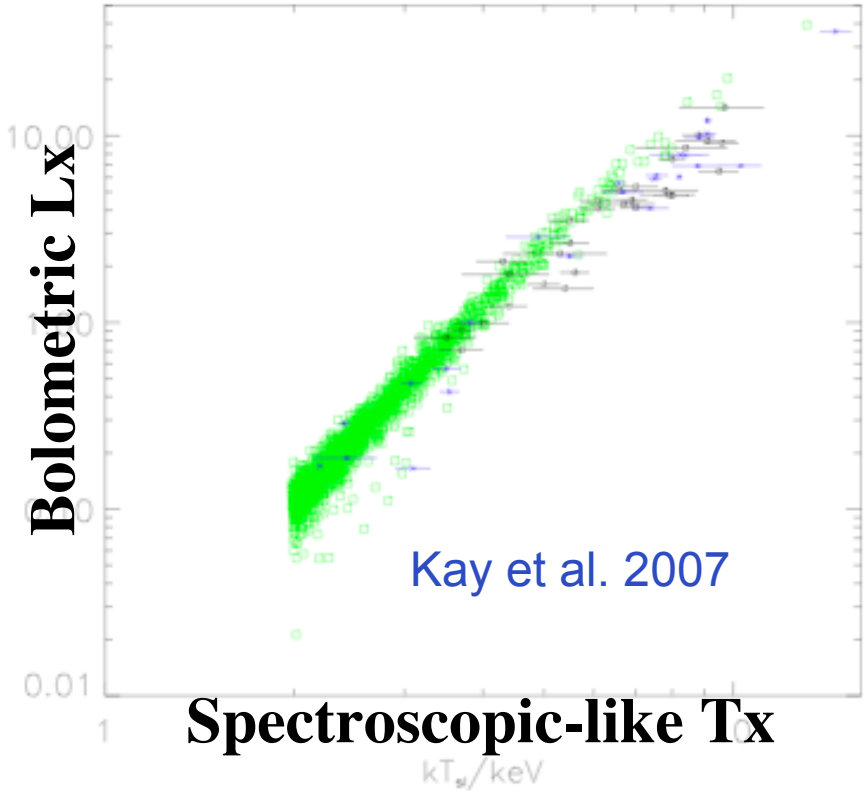




Improving the Mass-Observable connection

- Simulations, such as CLEF (right) and the Millennium-with-Gas project now produce synthetic cluster samples that probe the same redshfit and temperature range as XCS
- The XCS scaling relations will be based on larger, and better understood, samples than has been possible in the past



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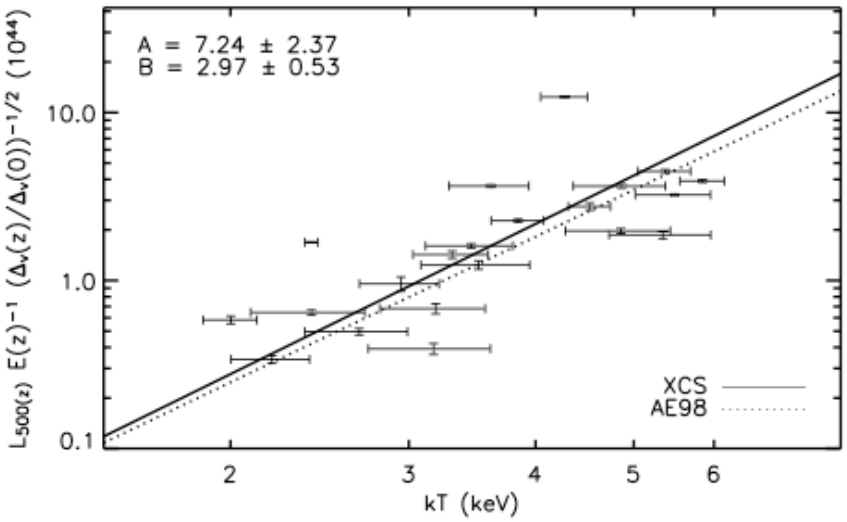
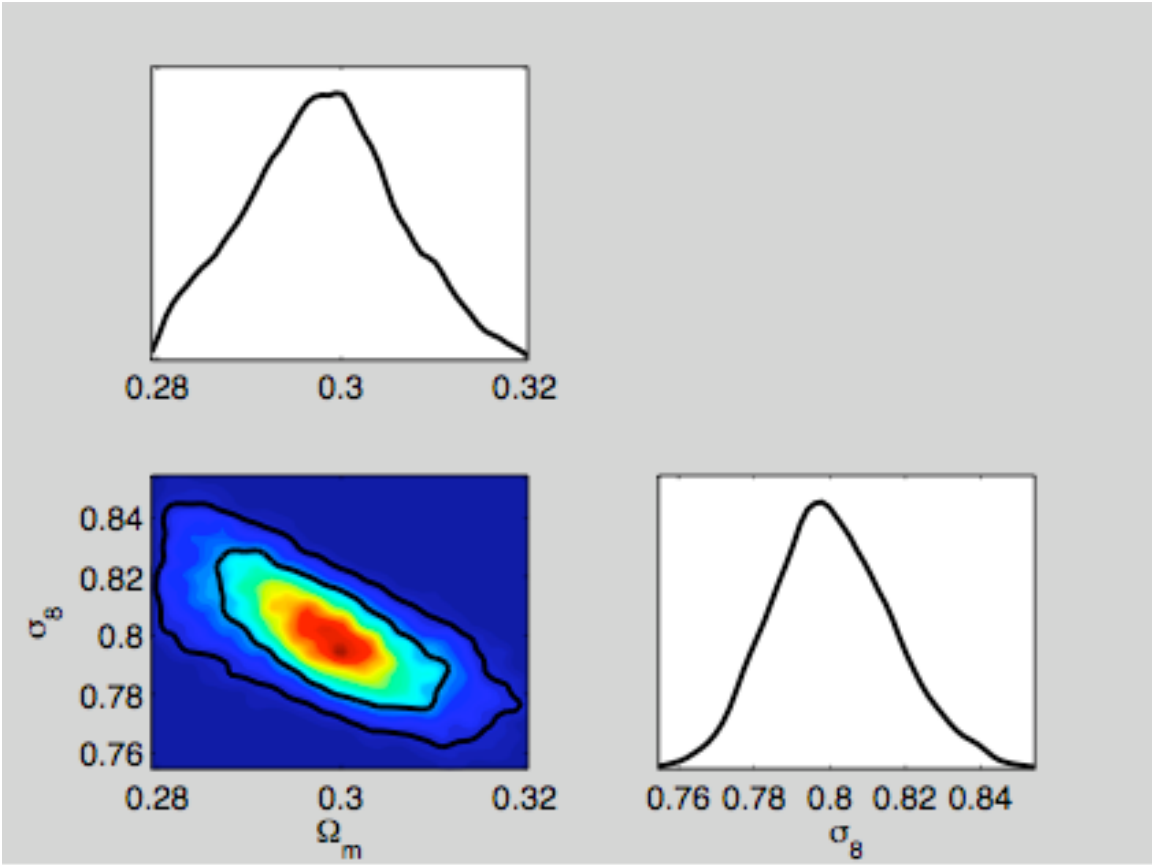


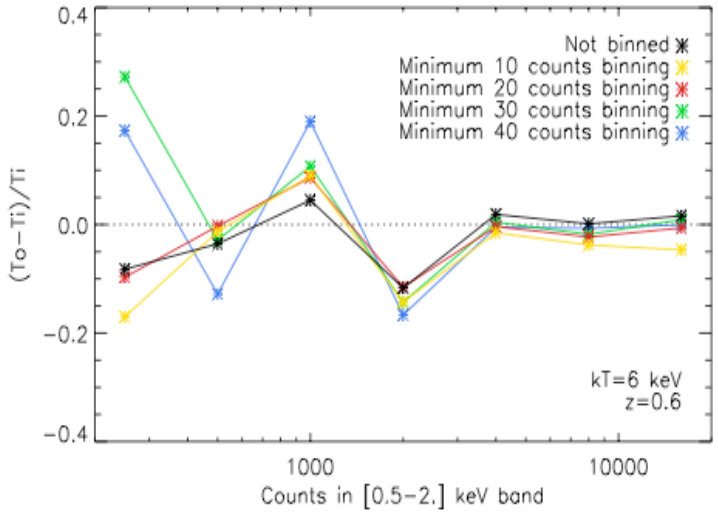
Preliminary XCS L-T relation: 21 clusters after Lx correction for self-similar evolution, compared with Arnaud and Evrard (1998) best fit at z=0

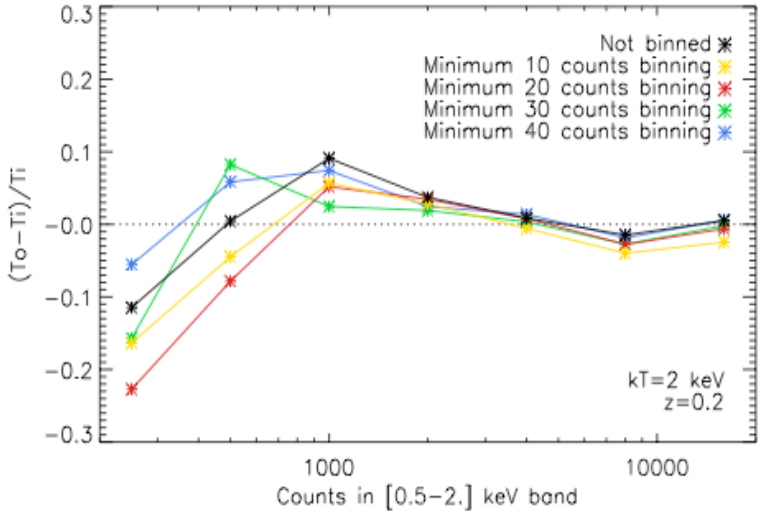
^{500}*XCS* Parameter Predictions

So far we have not accounted for Tx errors



XCS Temperature Accuracy





- Temperature fits are not great with 500 [250] counts, but they aren't terrible, e.g.
  - @2keV: 2.01keV $^{+0.16/-0.13}$ (<10%) [$1.77^{+0.18/-0.14}$]
  - @6keV: 5.79keV $^{+0.79-0.59}$ (<15%) [$5.51^{+1.05/-0.76}$]

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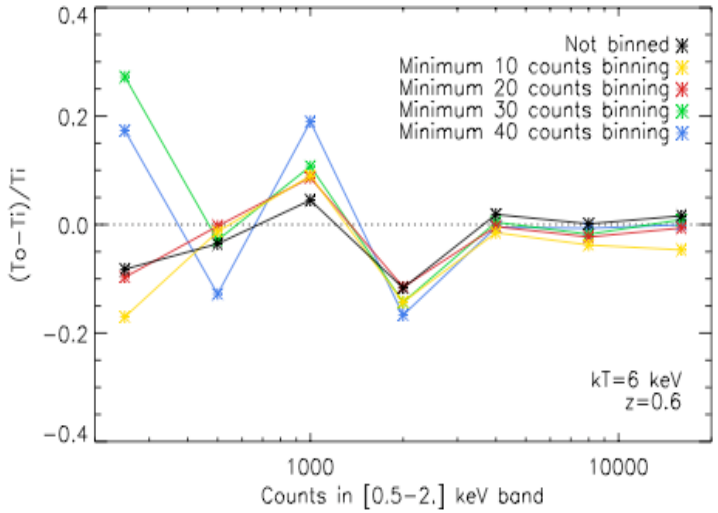
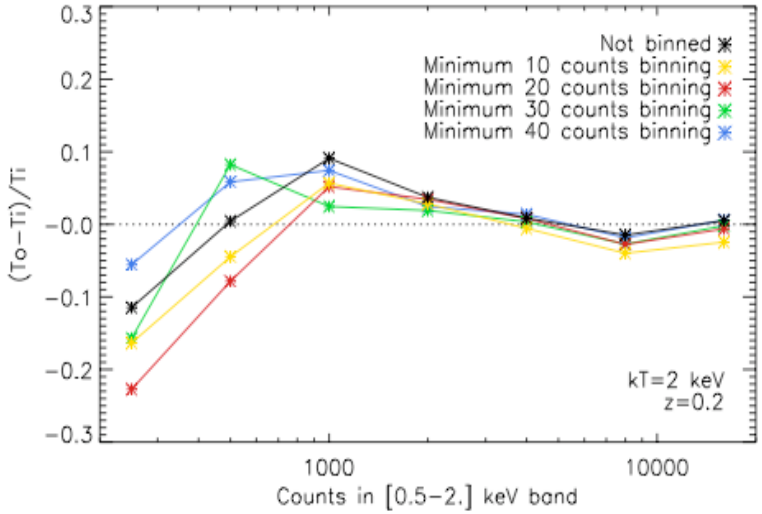
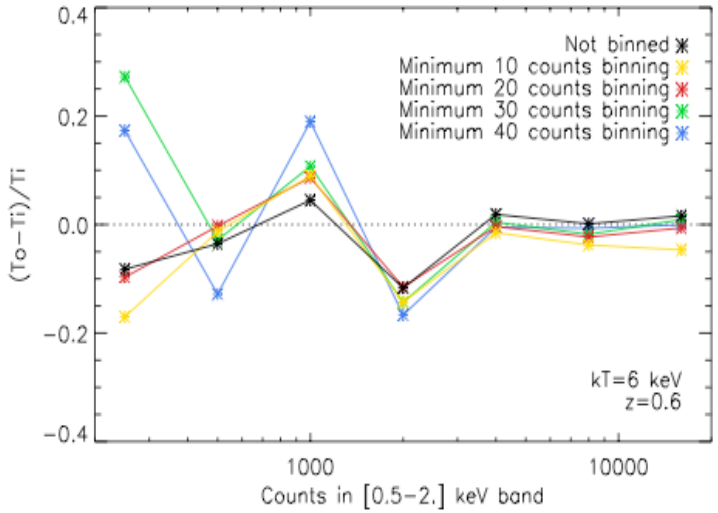
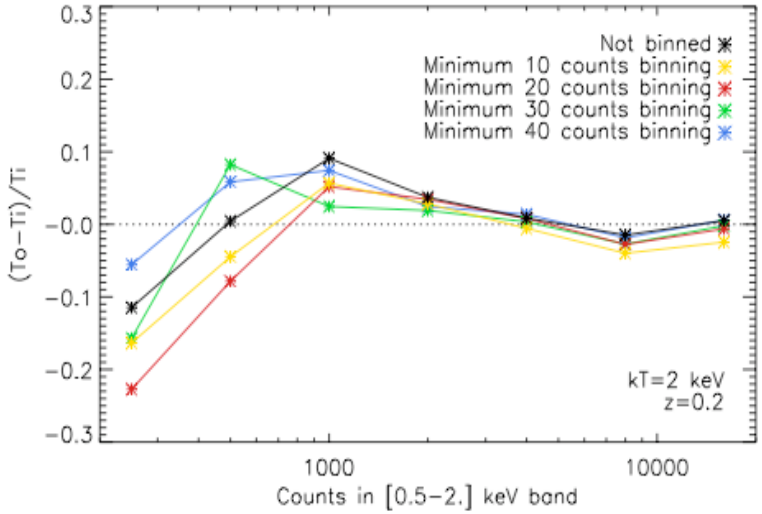




- We would like to improve photo statistics for the *500XCS* sample so that all clusters have <10% Tx errors (i.e. less that the intrinsic scatter in the scaling relations): 500 counts is OK @2keV, we need 1000+ counts @6keV

Extra XMM time/modes required





- 2 Msec to get 1000 counts for all ^{500}*XCS* clusters
- 10 Msec to get 500 counts for all ^{250}*XCS* clusters

- Large programmes that span more than 1 AO cycle are required

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From XCS to Dark Energy

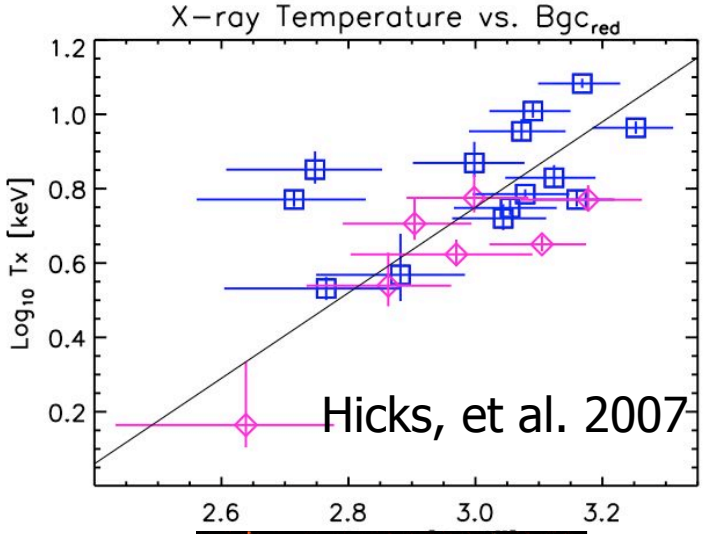
South Pole Telescope

- XCS is not able to make competitive constraints on Dark Energy (DE) evolution
- New cluster surveys have the potential to measure DE, e.g.
  - Optical; Dark Energy Survey
  - SZ; South Pole Telescope Survey
- But the mass-observable relations have to be robust

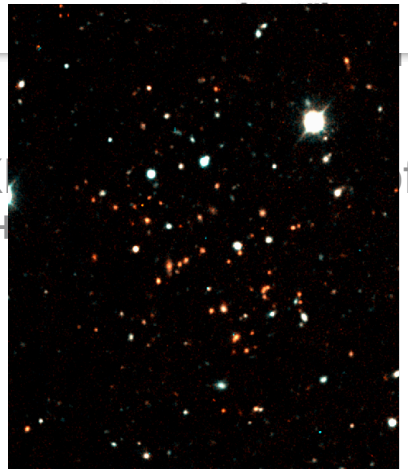
Some Ideas

- Calibrate the optical mass estimates using X-ray temperatures via a strategic alliance between XMM and RCS (later DES):
  - *i.e.* have the RCS team run their cluster finders and mass estimators over CCD images of *^{500}XCS* fields.
  - This strengthens case for the proposed XMM re-observations of *^{500}XCS*
  - Thanks to Erica Ellingson, for supplying the figures
  - Last minute addition: helps eRosita also with mass-observable relation

RCS/CNOC Tx vs richness



- An X[illegible] of the SPT+



RCS cluster at z=1.1

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  - XCS selection functions can be used to bootstrap to more general relations
  - Possibly higher risk for XMM

- An XMM Slew Survey of the SPT+DES region

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  - Measuring redshifts: hard; but not impossible
  - Quantifying the selection function: ditto
  - Improving the calibration of the mass-observable connection: requires more investment of XMM time
- Re-observation of serendipitous clusters would be an excellent use of XMM-Newton