Title: The XMM Cluster Survey - Scaling Relations, Cosmology and Galaxy Evolution

Date: Apr 27, 2009 03:30 PM

URL: http://pirsa.org/09040045

Abstract: The XMM Cluster Survey (XCS) is a serendipitous galaxy cluster survey being conducted using publicly available X-ray data from the XMM-Newton Science Archive. One of the primary aims of the XCS is to determine the form of the evolution of the cluster gas - knowledge of which is crucial for the use of X- ray or SZ selected clusters in constraining cosmological parameters - through measuring the X-ray scaling relations using a large, well characterised cluster sample spanning ~7 Gyr in lookback time. I will present an update on the status of the survey, discuss the expected cosmological constraints, and briefly describe some recent results from galaxy evolution studies conducted under the umbrella of the XCS project.

The XMM Cluster Survey

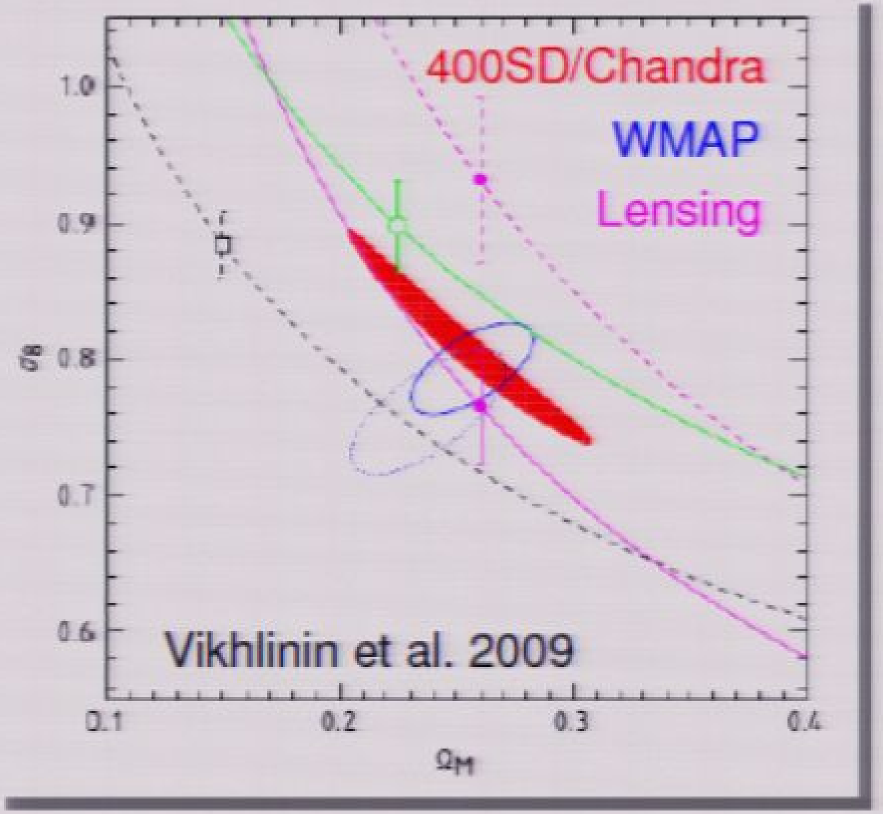
- The XMM Cluster Survey (XCS) is a serendipitous galaxy cluster survey being conducted using data from the XMM Science Archive.
- XCS has three main science goals:
  - To constrain cosmological parameters through the evolution of the cluster mass function with redshift
  - To study the evolution of the cluster gas with redshift, as traced by the X-ray scaling relations (such as between L, T)
  - To study galaxy evolution in clusters

The XMM Cluster Survey

- The XMM Cluster Survey (XCS) is a serendipitous galaxy cluster survey being conducted using data from the XMM Science Archive.
- XCS has three main science goals:
  - To constrain cosmological parameters through the evolution of the cluster mass function with redshift
  - To study the evolution of the cluster gas with redshift, as traced by the X-ray scaling relations (such as between L, T)
  - To study galaxy evolution in clusters

XMM and ROSAT

- Recently, Vikhlinin et al. (2009) showed Chandra follow-up of clusters detected in the 400SD ROSAT survey provides competitive cosmological constraints to other methods such as CMB, SNe, BAO.
- XMM has much better sensitivity and higher resolution than ROSAT, and so can reach higher redshifts and fainter fluxes – important for understanding cluster physics through scaling relation evolution (such as between L-T), and building larger samples.
- The XMM archive also provides temperatures 'for free' for many new clusters.

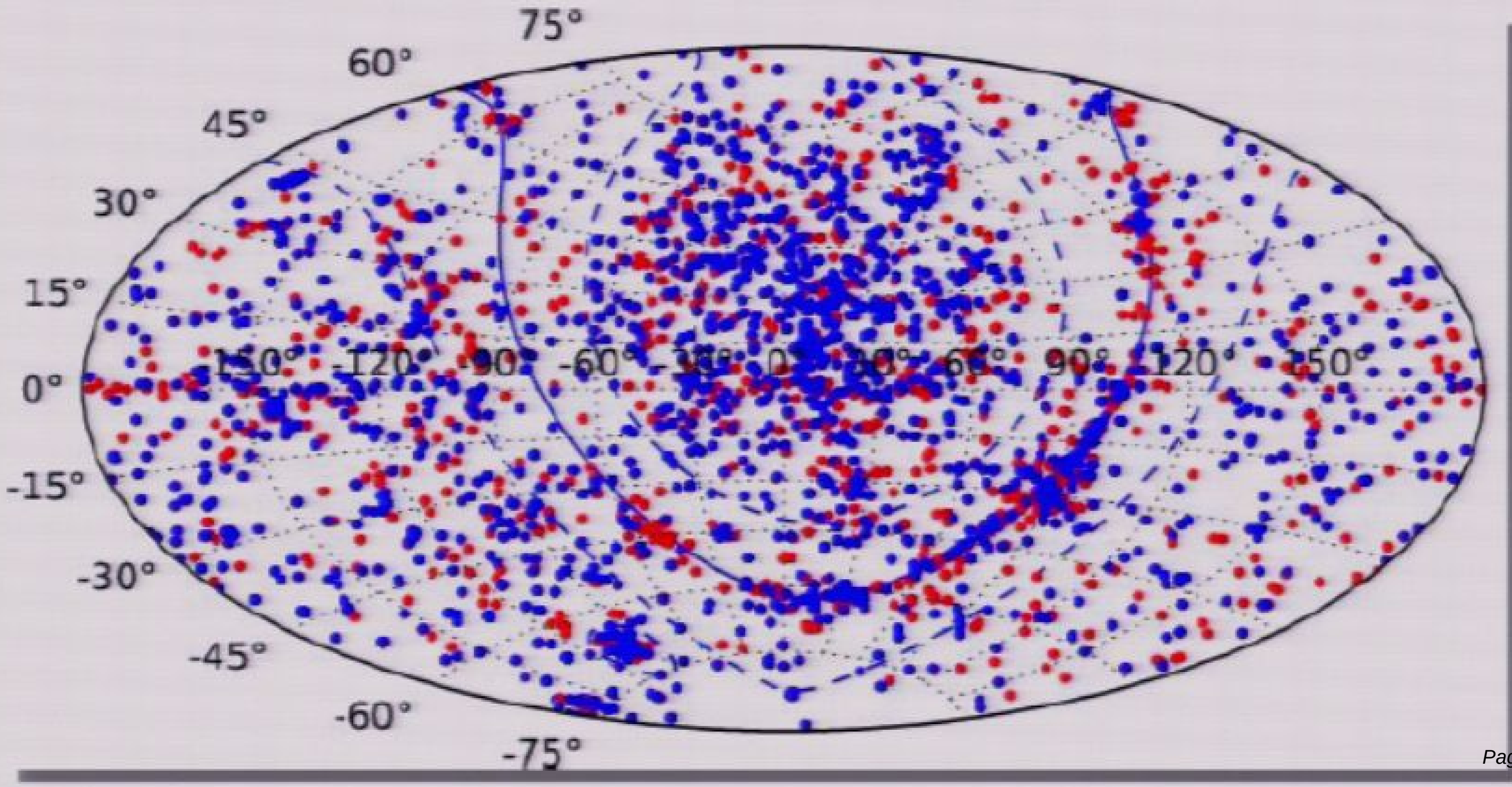


X-rays and SZ

- X-ray surveys are complementary to SZ effect surveys in several ways
- Perhaps most importantly, studies with X-rays can help to constrain how evolution in scaling relations between observables affect cosmological constraints – e.g. in X-ray, self similarity (i.e. purely gravitational collapse) predicts (e.g. Kaiser 1986):
  - $L_X \propto \Delta_v(z)^{1/2} E(z) T^2$
  - $M \propto \Delta_v(z)^{-1/2} E(z)^{-1} T^{3/2}$
  - $M_g \propto M$
- Feedback (heating/cooling) changes these relations and their evolution with redshift – L_X particularly sensitive as $\propto n_e^2$
- SZ mass proxy is also affected:
  - $Y_{SZ} \propto n_e T$

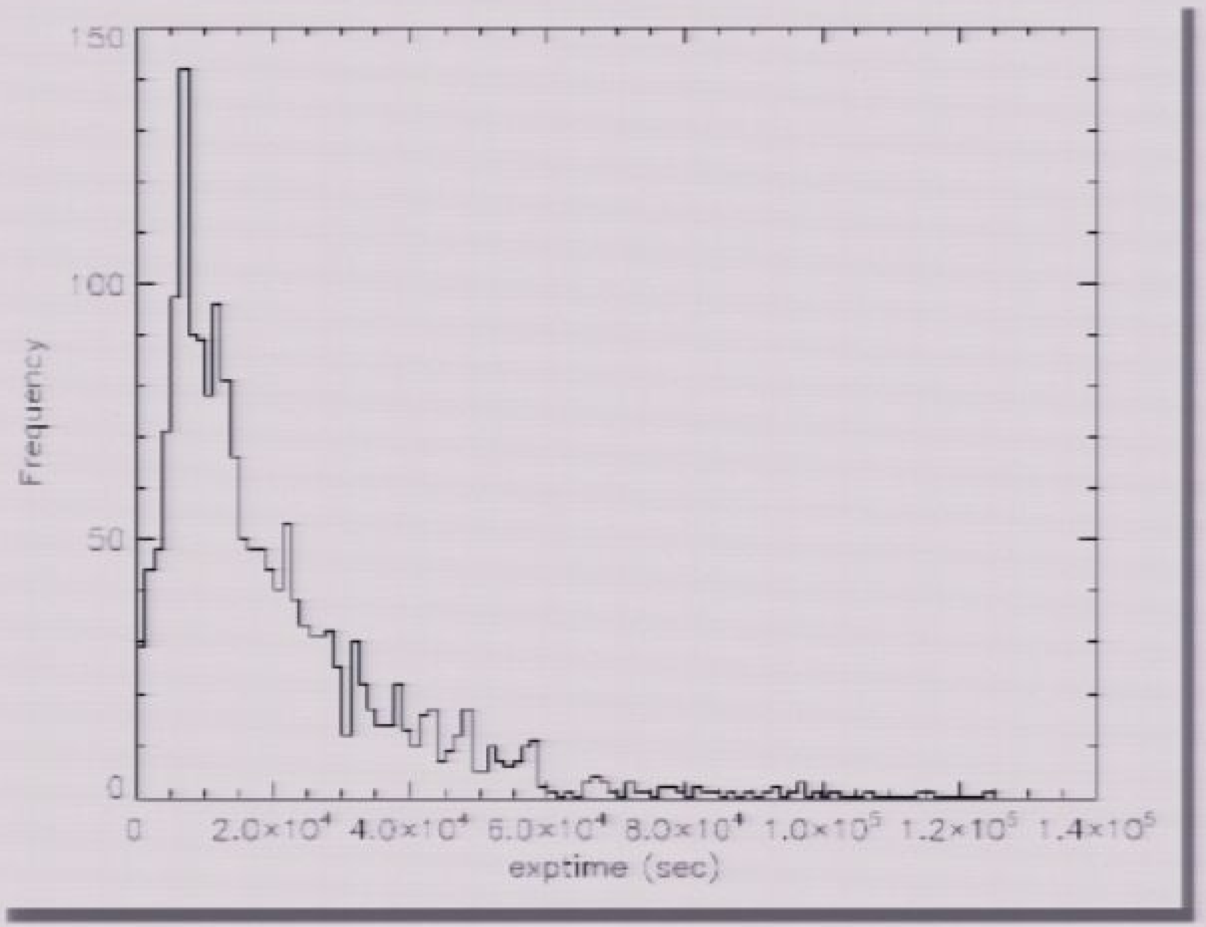
XCS Sky Coverage

- Blue: All archival XMM observations public by April 2006 (data for current XCS catalogue; 166 sq. deg suitable for cluster search)
- Red: Additional observations public by April 2009 (images created; source detection pending; 293 sq. deg suitable for cluster search)



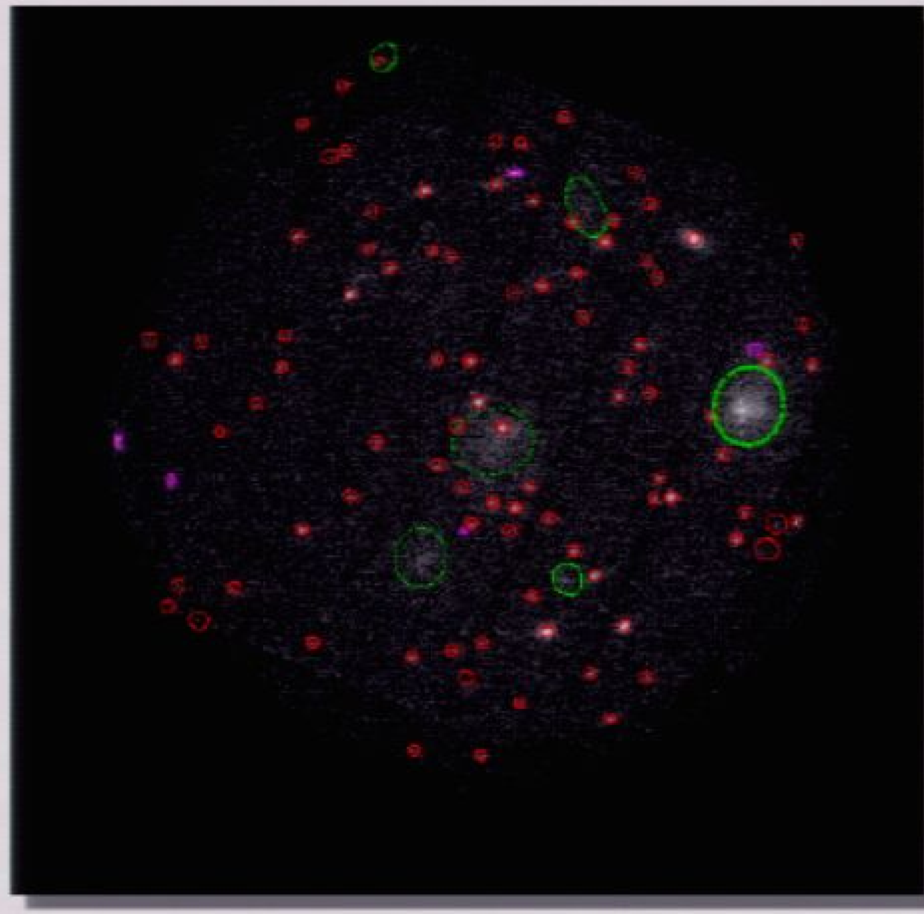
Exposure Times

- Exposure times in the XMM archive:



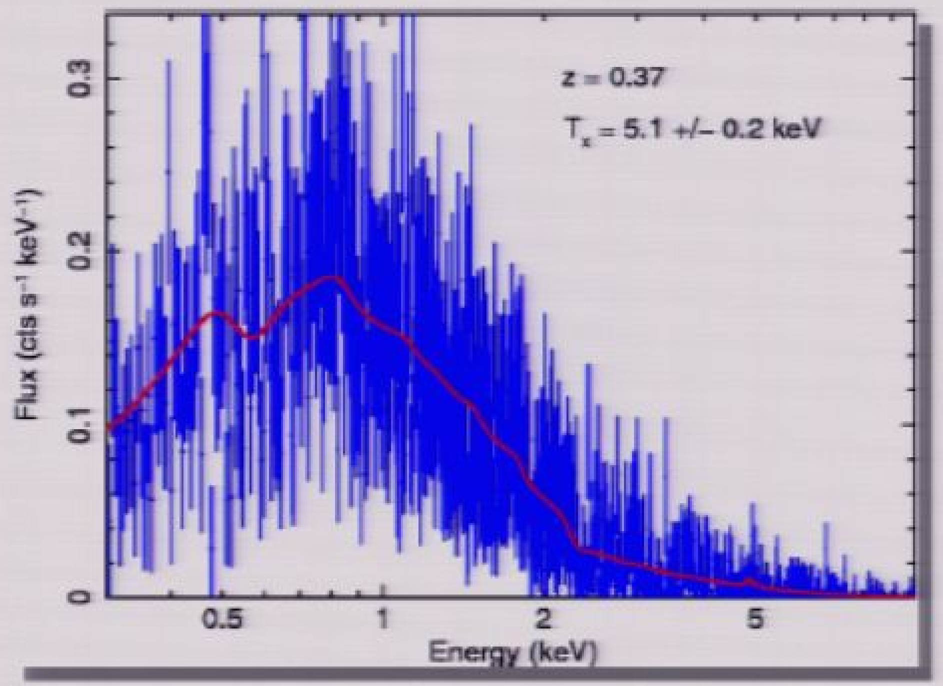
Pipelines

- Three automated pipelines:
  - Image generation from ODFs
  - Object detection, classification:
    - Wavelet based
    - Catalogue (covering 166.3 sq. deg):
      - Total candidates: 2001
      - > 300 counts: 392
      - > 500 counts: 229
  - Detailed analysis:
    - Spectral fitting for T
    - Fit surface brightness profile to measure L_X
    - Can also measure z if enough counts (Δz=0.15)



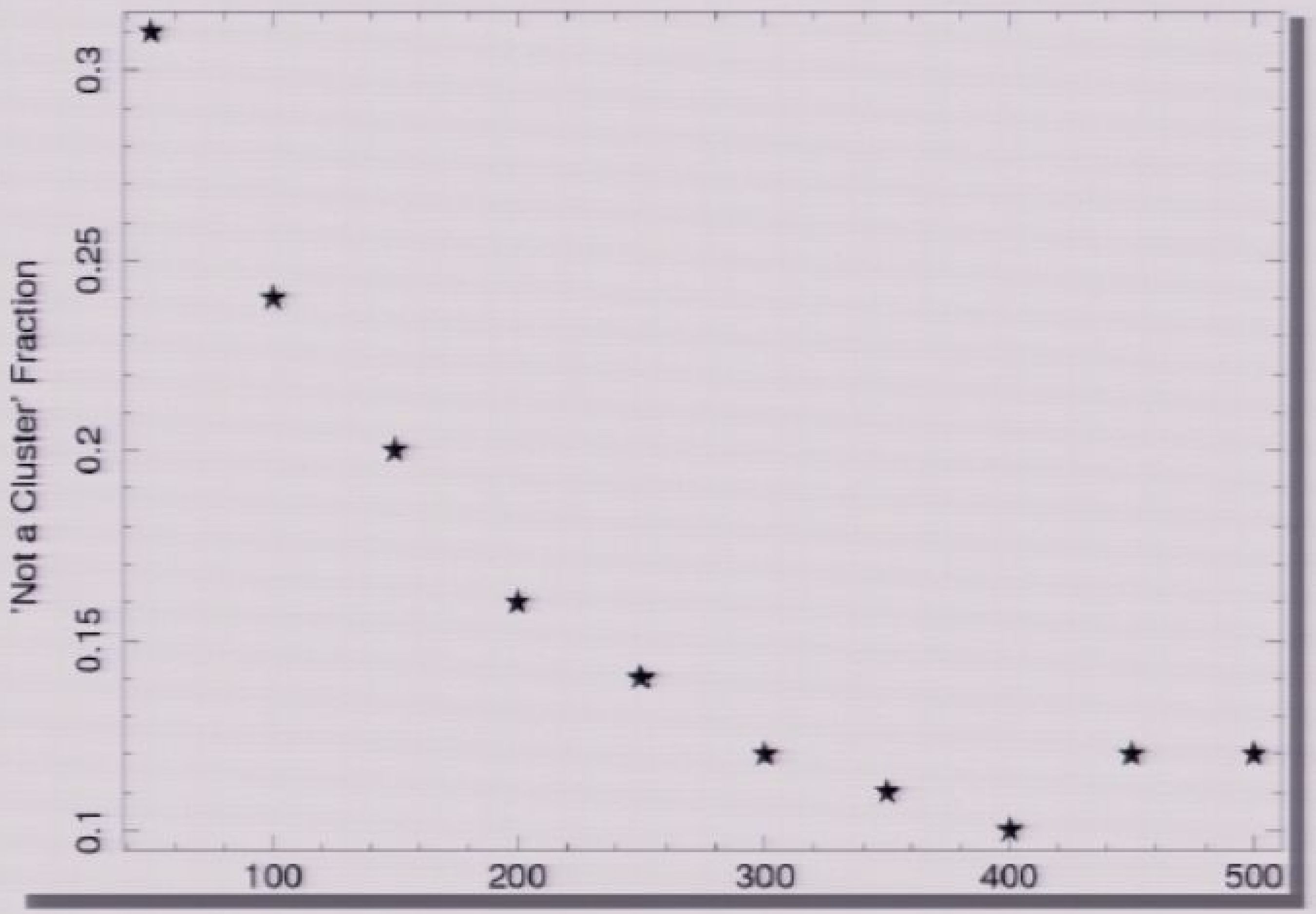
Pipelines

- Three automated pipelines:
  - Image generation from ODFs
  - Object detection, classification:
    - Wavelet based
    - Catalogue (covering 166.3 sq. deg):
      - Total candidates: 2001
      - > 300 counts: 392
      - > 500 counts: 229
  - Detailed analysis:
    - Spectral fitting for T
    - Fit surface brightness profile to measure L_X
    - Can also measure z if enough counts (Δz=0.15)



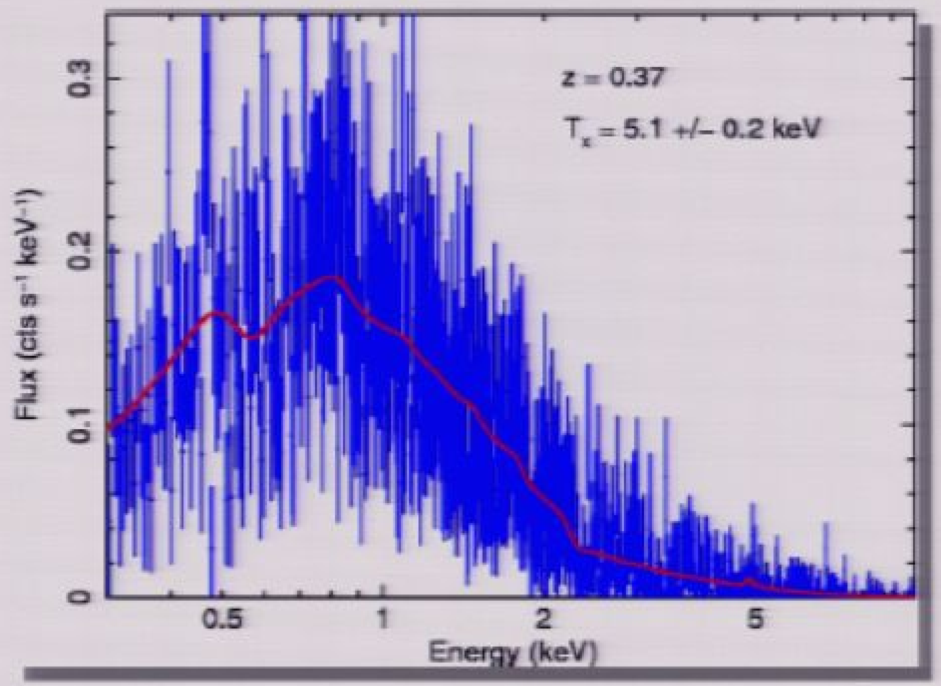
Contamination

- From eyeball classification of sources with SDSS imaging (~700 candidates) by the whole team – not great at low counts, could be improved significantly with better XMM PSF model (ongoing effort)



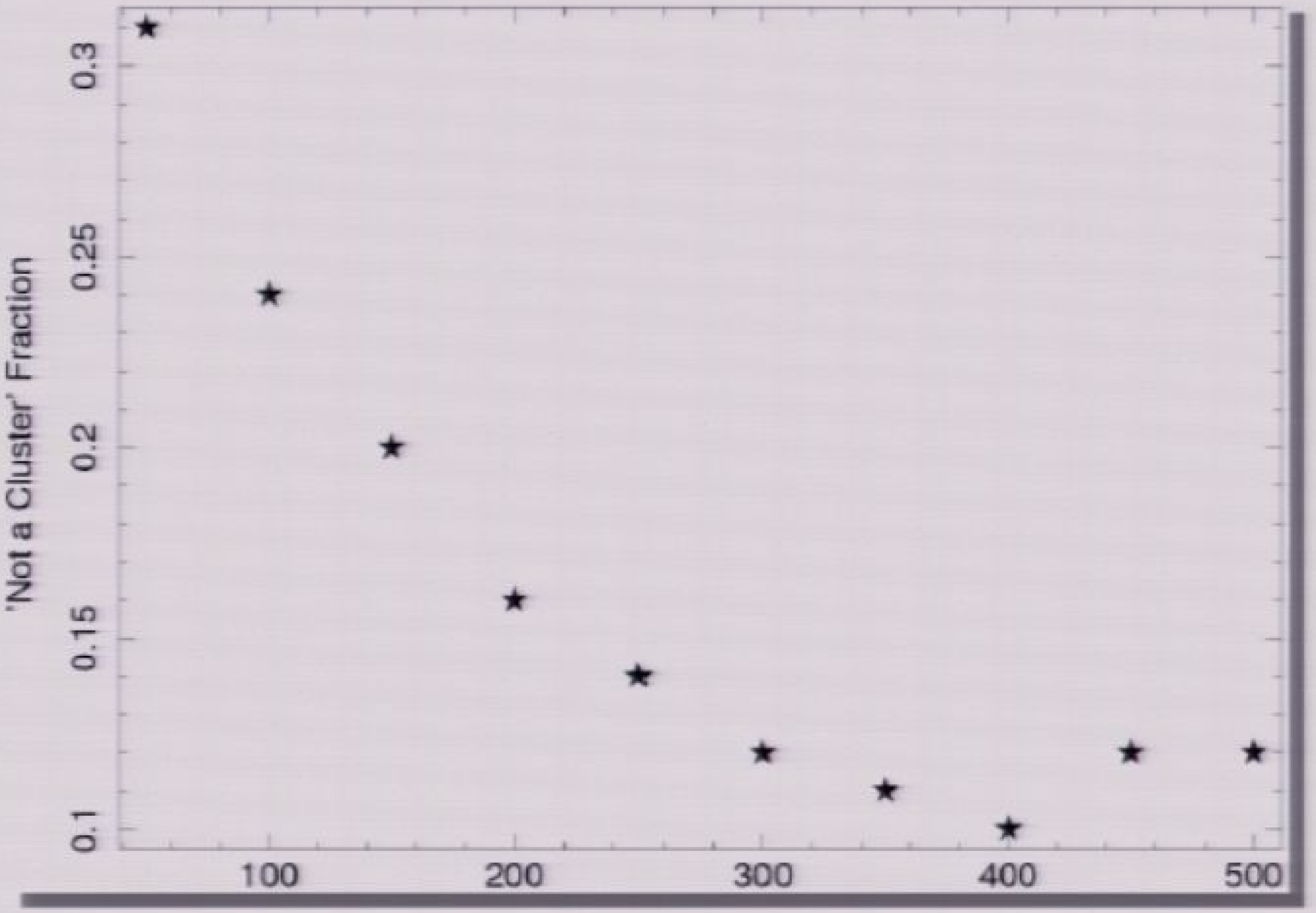
Pipelines

- Three automated pipelines:
  - Image generation from ODFs
  - Object detection, classification:
    - Wavelet based
    - Catalogue (covering 166.3 sq. deg):
      - Total candidates: 2001
      - > 300 counts: 392
      - > 500 counts: 229
  - Detailed analysis:
    - Spectral fitting for T
    - Fit surface brightness profile to measure L_X
    - Can also measure z if enough counts (Δz=0.15)



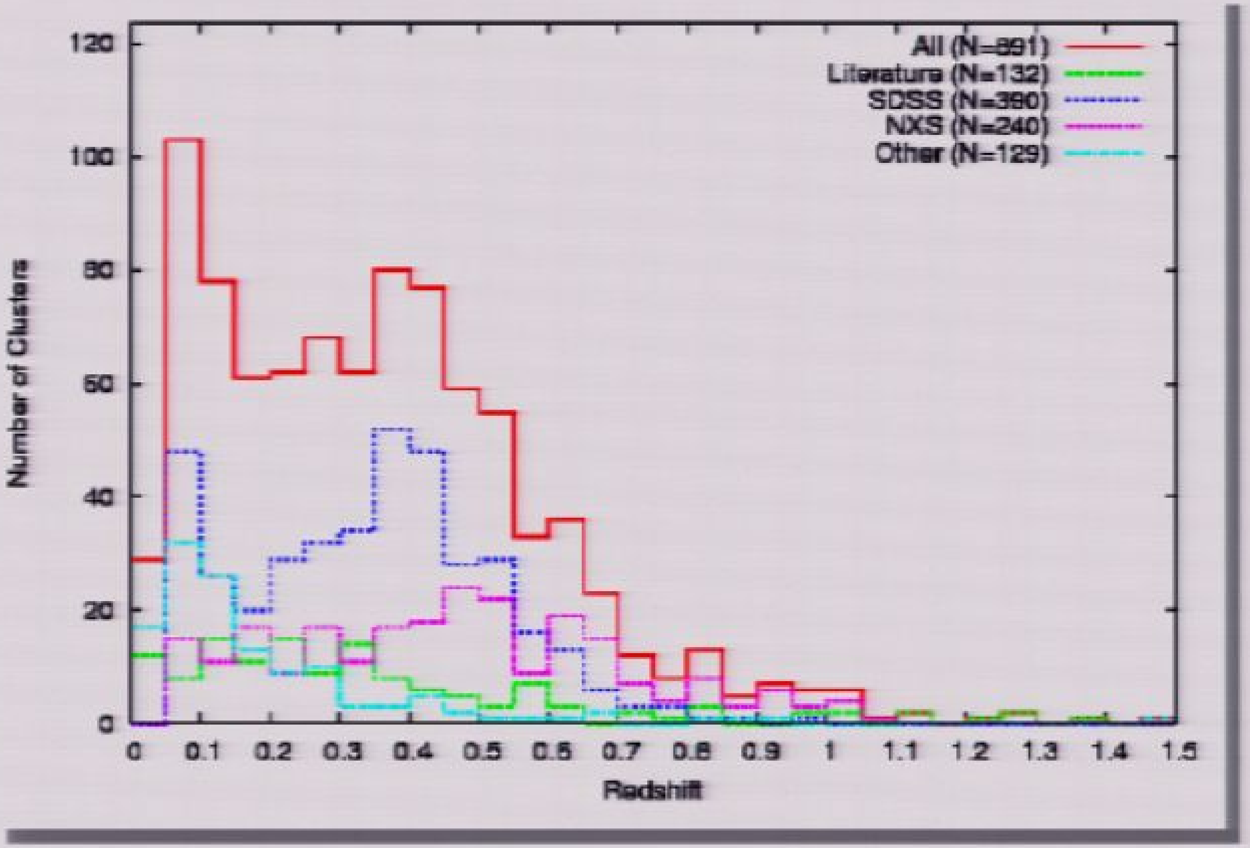
Contamination

- From eyeball classification of sources with SDSS imaging (~700 candidates) by the whole team – not great at low counts, could be improved significantly with better XMM PSF model (ongoing effort)



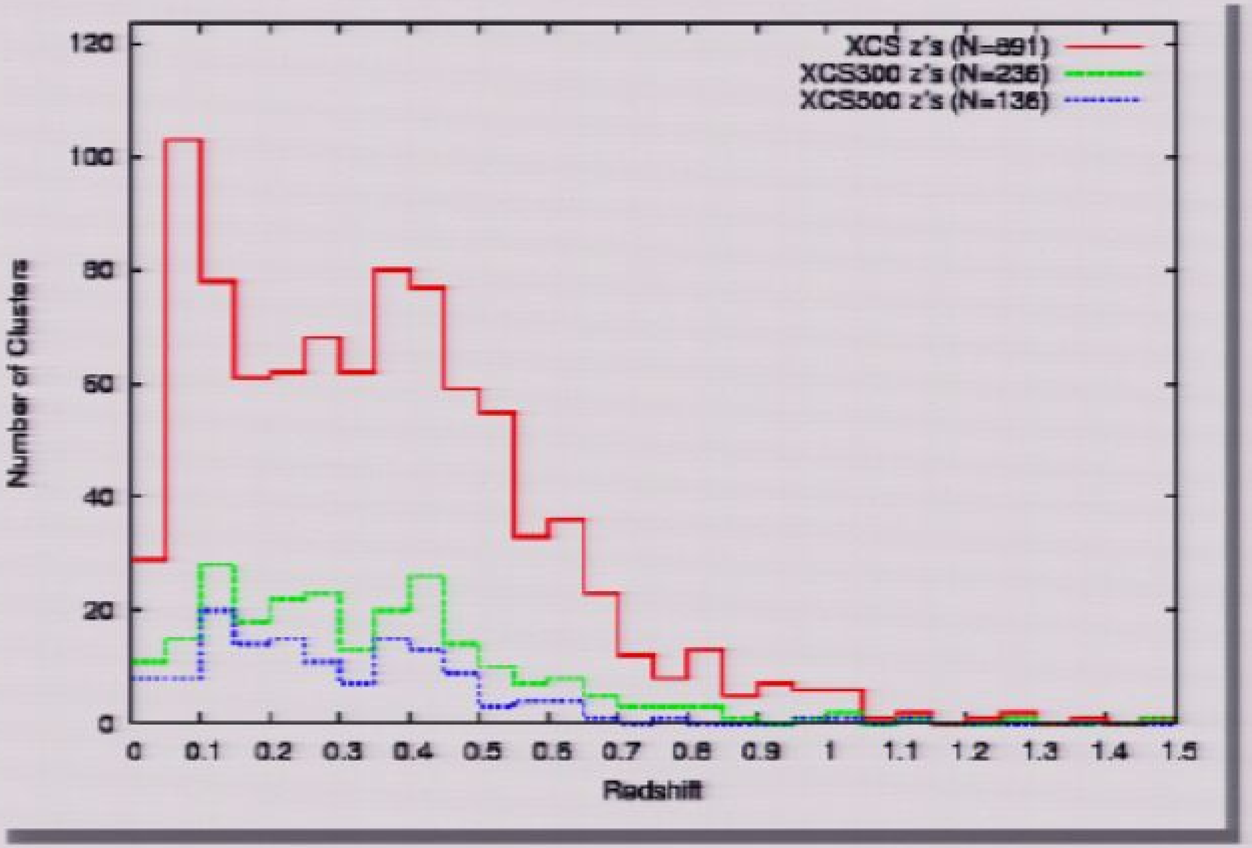
Redshifts, Redshifts, Redshifts

- Essential to be able to do anything, but a BIG task
- Redshifts from several sources – SDSS (LRGs), literature (redetections), X-ray spectra, own spectroscopic, photo-zs



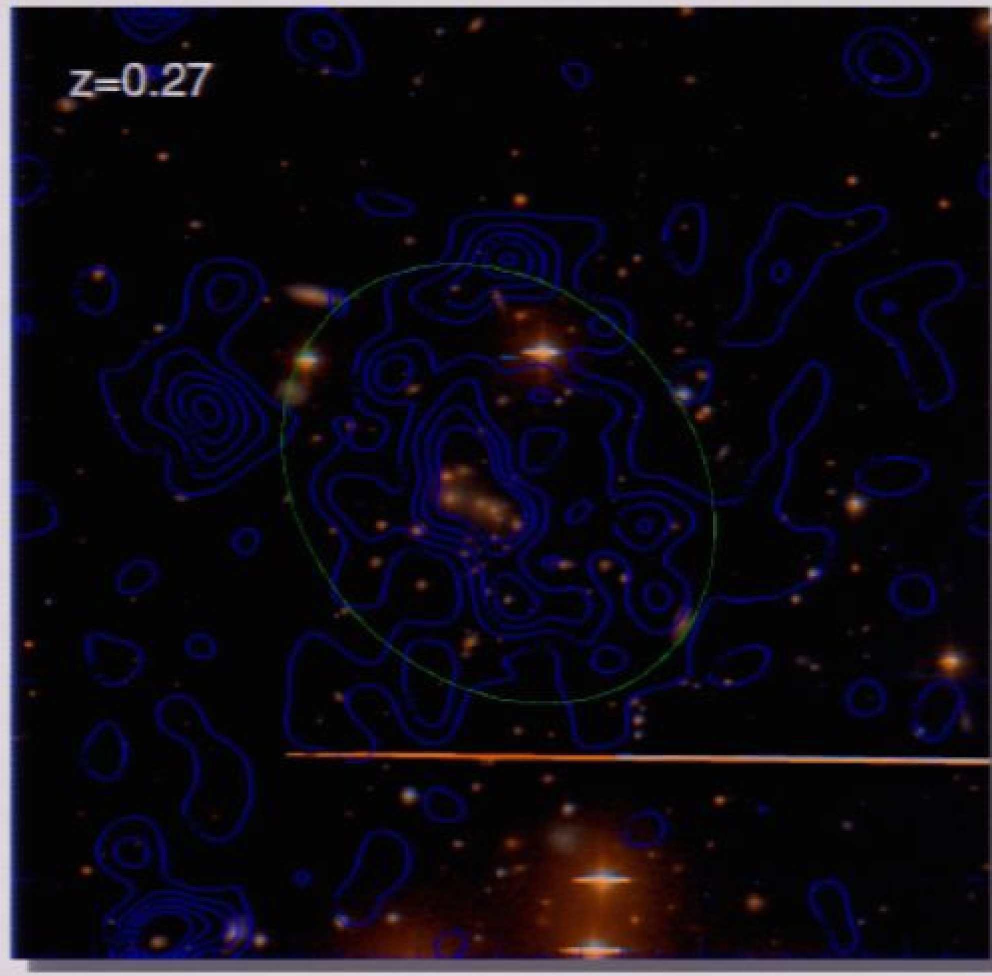
Redshifts, Redshifts, Redshifts

- Essential to be able to do anything, but a BIG task
- Redshifts from several sources – SDSS (LRGs), literature (redetections), X-ray spectra, own spectroscopic, photo-zs



NOAO Survey (NXS)

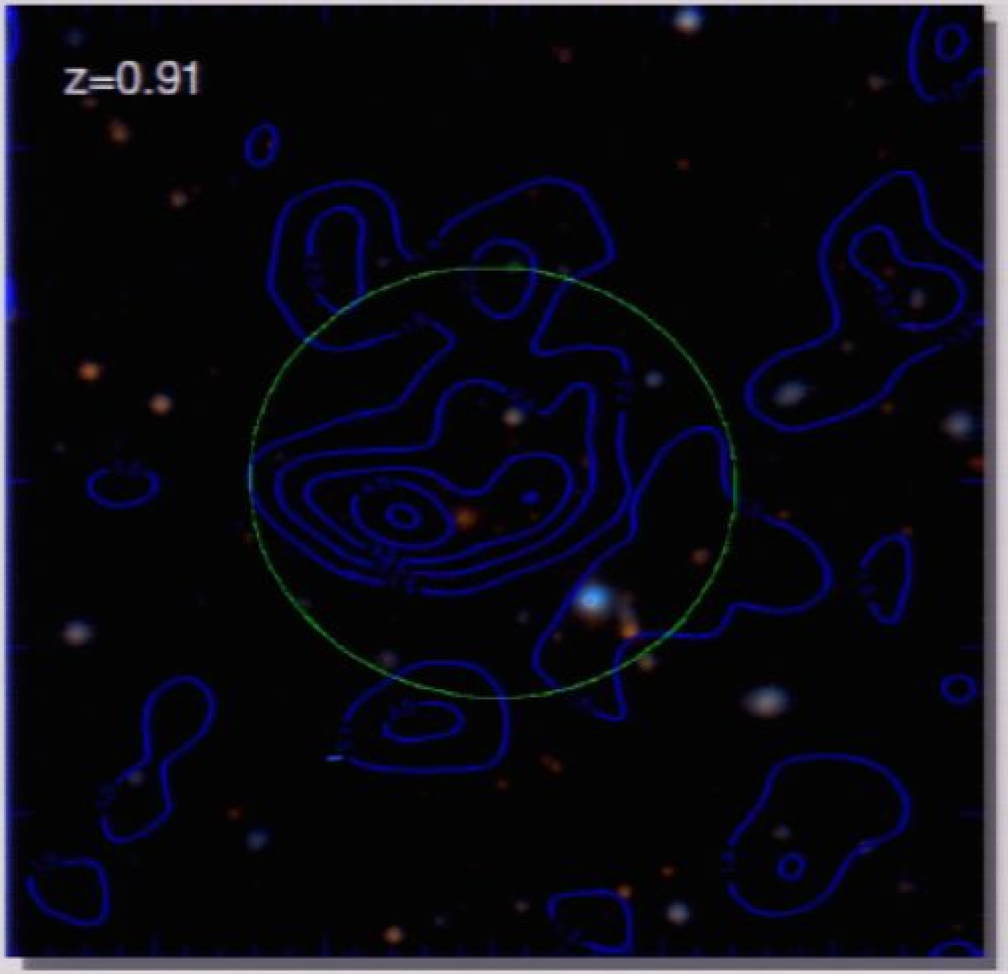
- XCS NOAO survey programme (PI: Chris Miller) observing XMM pointings in r, z to get photo-zs using red-sequence technique (Gladders & Yee 2000, 2005)
- Image processing and redshifts by Nicola Mehrtens
- Used MOSAIC-I/II (KPNO, CTIO 4m)
- Fields observed: 149
- Nights: 46 (24 really)
- Depth (5σ, AB): r~25.0, z~23.8
- Seeing: r~1.39", z~1.23"
- Redshift range: 0.2 < z < 1
- Redshift accuracy: σ_z~0.05



2.4'x2.4'

NOAO Survey (NXS)

- XCS NOAO survey programme (PI: Chris Miller) observing XMM pointings in r, z to get photo-zs using red-sequence technique (Gladders & Yee 2000, 2005)
- Image processing and redshifts by Nicola Mehrtens
- Used MOSAIC-I/II (KPNO, CTIO 4m)
- Fields observed: 149
- Nights: 46 (24 really)
- Depth (5σ, AB): r~25.0, z~23.8
- Seeing: r~1.39", z~1.23"
- Redshift range: 0.2 < z < 1
- Redshift accuracy: σ_z~0.05



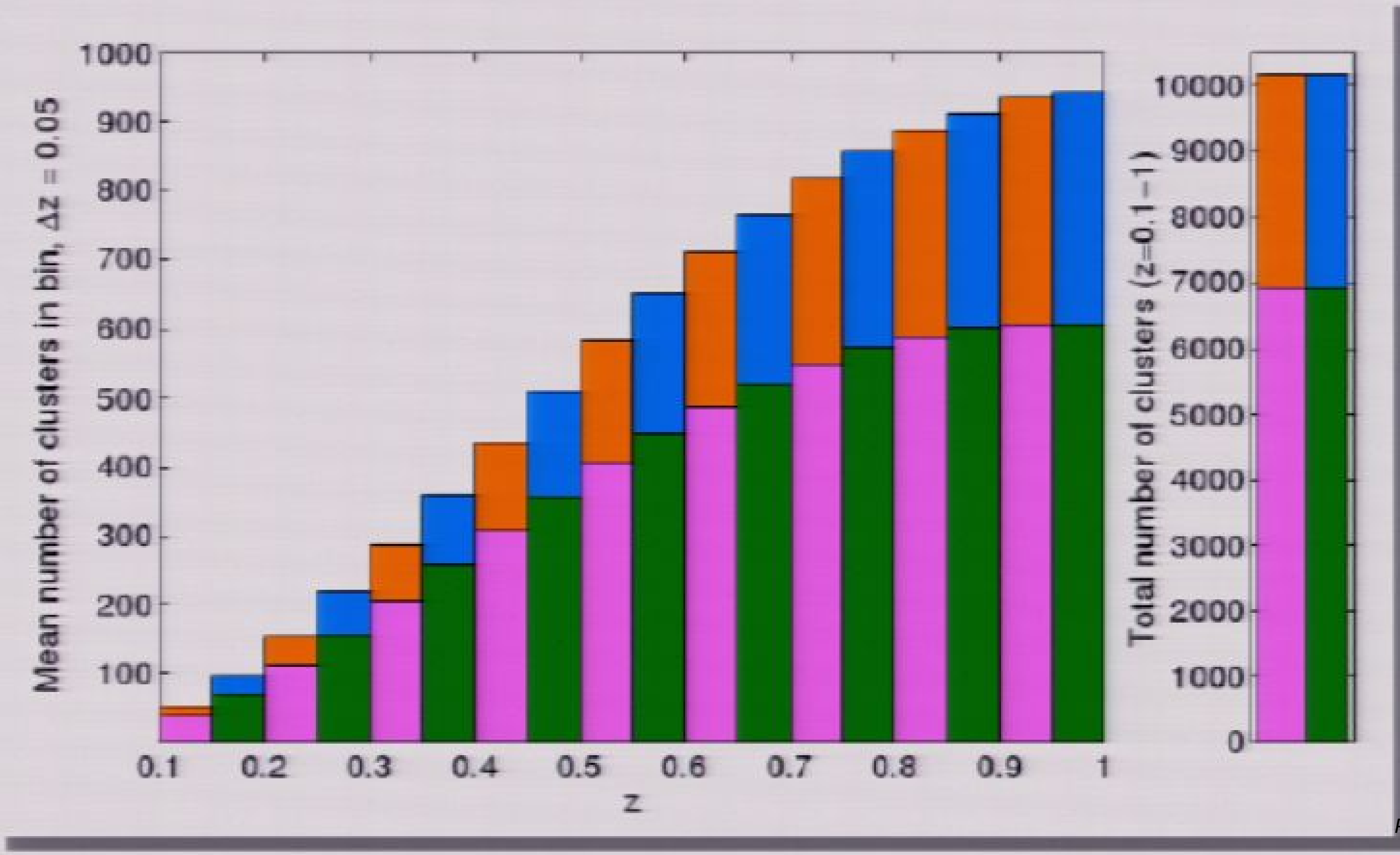
1.4'x1.4'

Predicted Cosmological Constraints

- From Sahlén et al. 2009 (MNRAS, in press, astro-ph/0802.4462)
- For a final XCS area of 500 sq. deg
- Using temperature as a mass proxy, XCS500 sample
- Include XCS selection function, measurement errors in T, photo-zs
- Assumed flatness
- Tested:
  - Effect of different L-T relation evolution assumptions (constant or self-similar)
  - Effect of scatter in scaling relations (10% M-T; 30% L-T)
  - Self-calibration (fit for L-T evolution from T, z number counts)

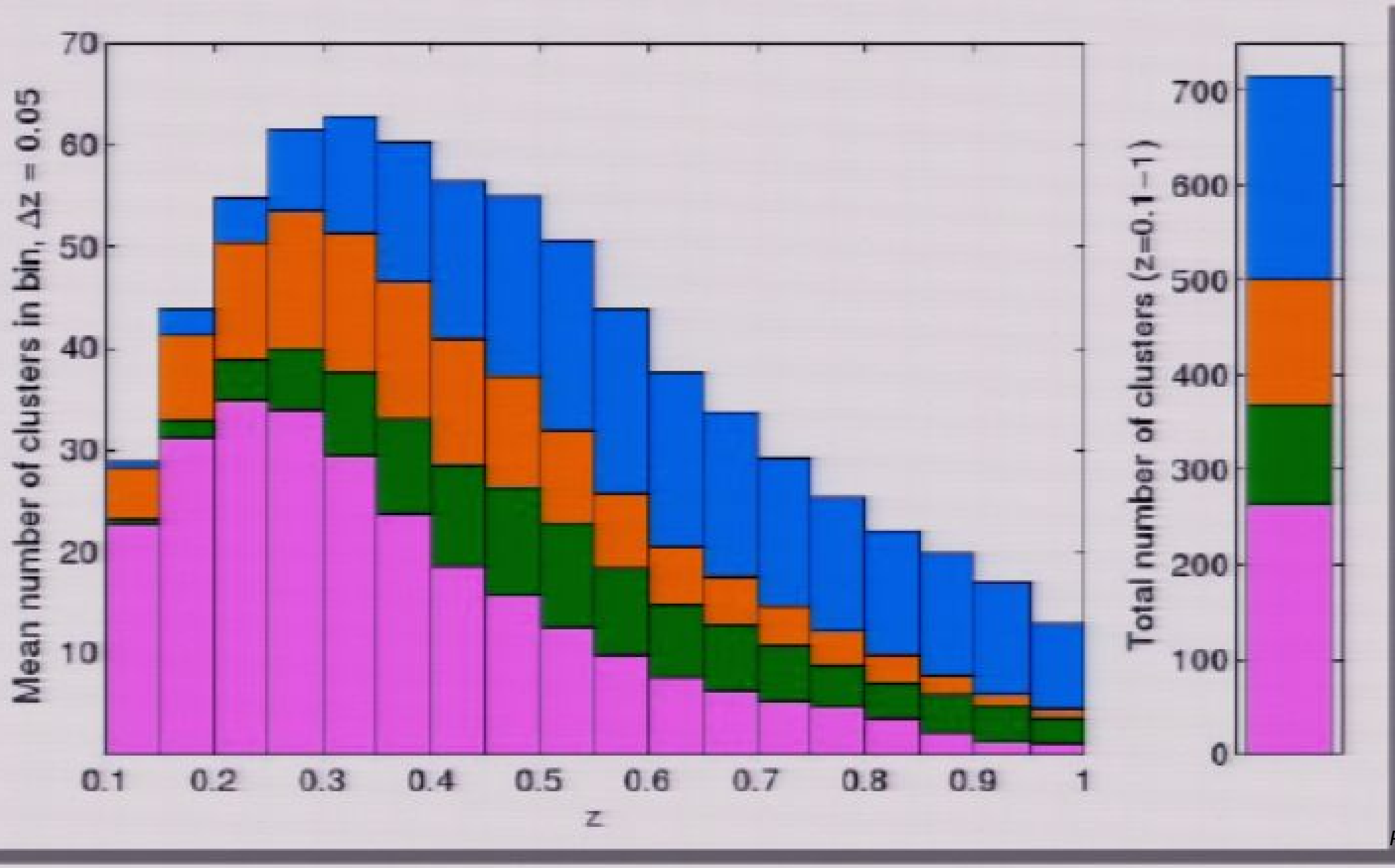
Cluster Distributions

- Pink = no scatter, constant L-T; Green = no scatter, self-similar L-T; Orange = with scatter, constant L-T; Blue = with scatter, self-similar L-T
- Underlying distributions:



Cluster Distributions

- Pink = no scatter, constant L-T; Green = no scatter, self-similar L-T; Orange = with scatter, constant L-T; Blue = with scatter, self-similar L-T
- After folding in selection function:



Selection Function

- Selection function work by Mark Hosmer
- Currently very simplistic: inserting β-model clusters into random ODFs, only considering flat cosmologies at present
- Not unreasonable though: inserting clusters from the CLEF simulations (Kay et al. 2007) gives similar detection efficiencies
- Not biased against clusters with unrelaxed morphologies

Selection Function

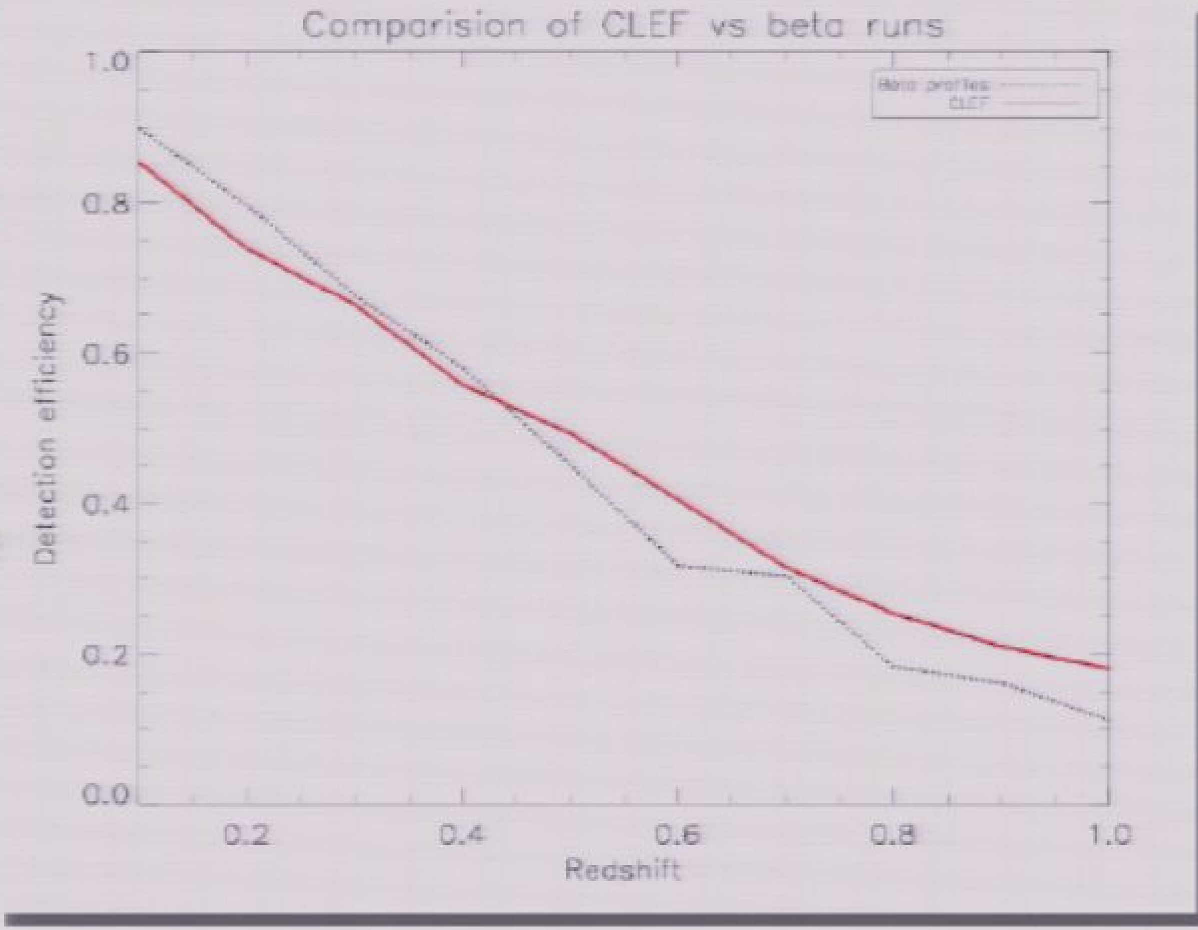
- Selection function work by Mark Hosmer
- Currently very simplistic: inserting β-model clusters into random ODFs, only considering flat cosmologies at present
- Not unreasonable though: inserting clusters from the CLEF simulations (Kay et al. 2007) gives similar detection efficiencies
- Not biased against clusters with unrelaxed morphologies

Selection Function

- Selection function work by Mark Hosmer
- Currently very simplistic: inserting β-model clusters into random ODFs, only considering flat cosmologies at present
- Not unreasonable though: inserting clusters from the CLEF simulations (Kay et al. 2007) gives similar detection efficiencies
- Not biased against clusters with unrelaxed morphologies

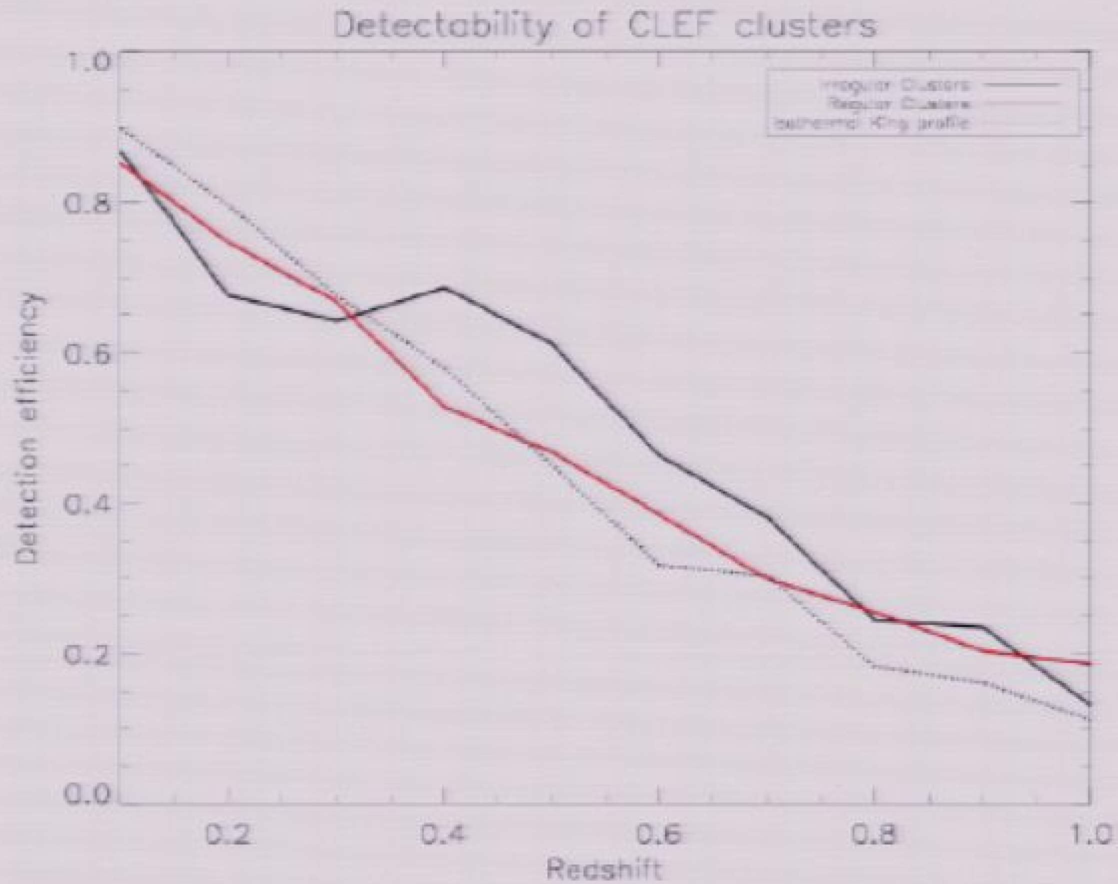
Selection Function

- Selection function work by Mark Hosmer
- Currently very simplistic: inserting β-model clusters into random ODFs, only considering flat cosmologies at present
- Not unreasonable though: inserting clusters from the CLEF simulations (Kay et al. 2007) gives similar detection efficiencies
- Not biased against clusters with unrelaxed morphologies



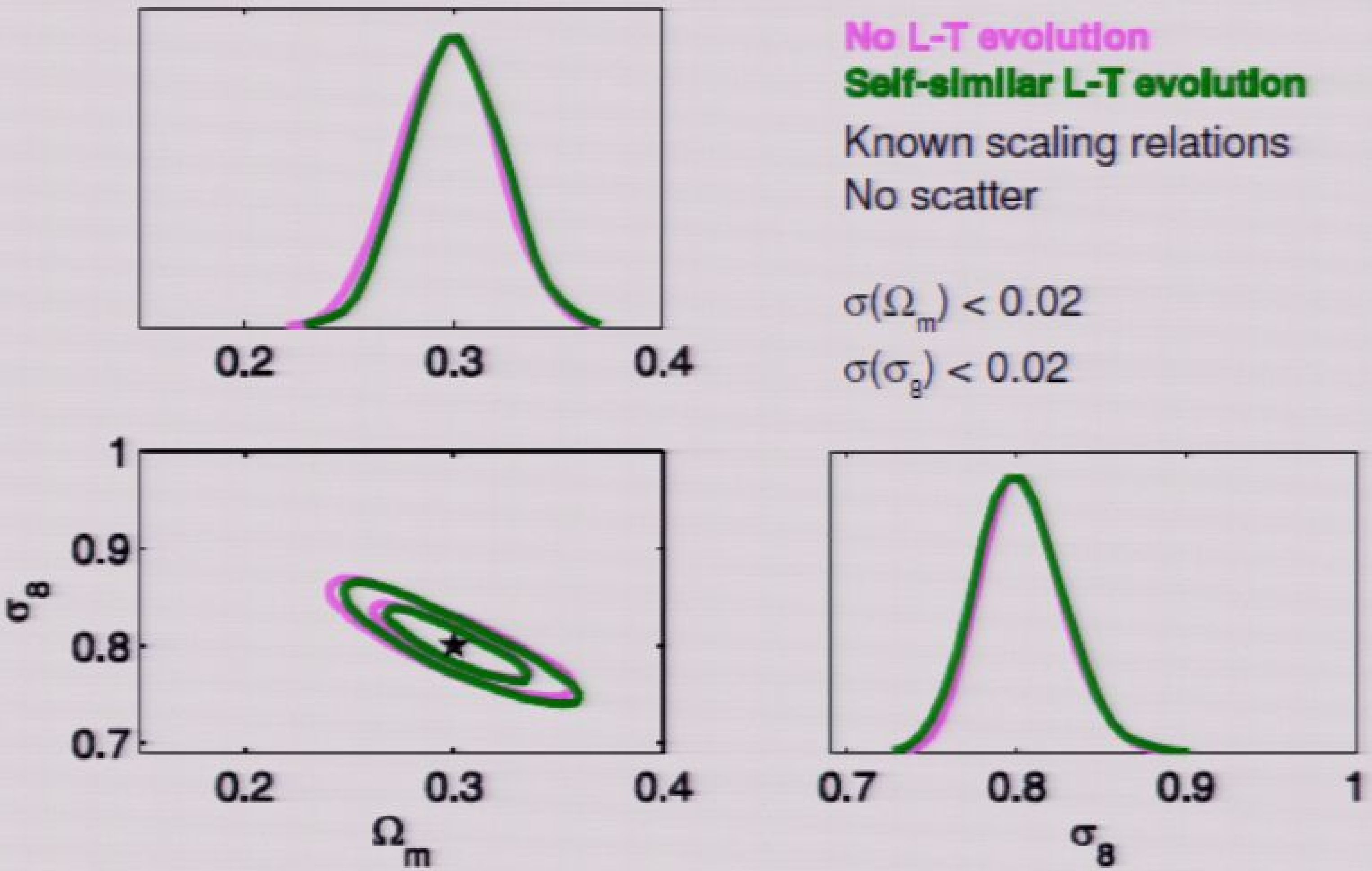
Selection Function

- Selection function work by Mark Hosmer
- Currently very simplistic: inserting β-model clusters into random ODFs, only considering flat cosmologies at present
- Not unreasonable though: inserting clusters from the CLEF simulations (Kay et al. 2007) gives similar detection efficiencies
- Not biased against clusters with unrelaxed morphologies



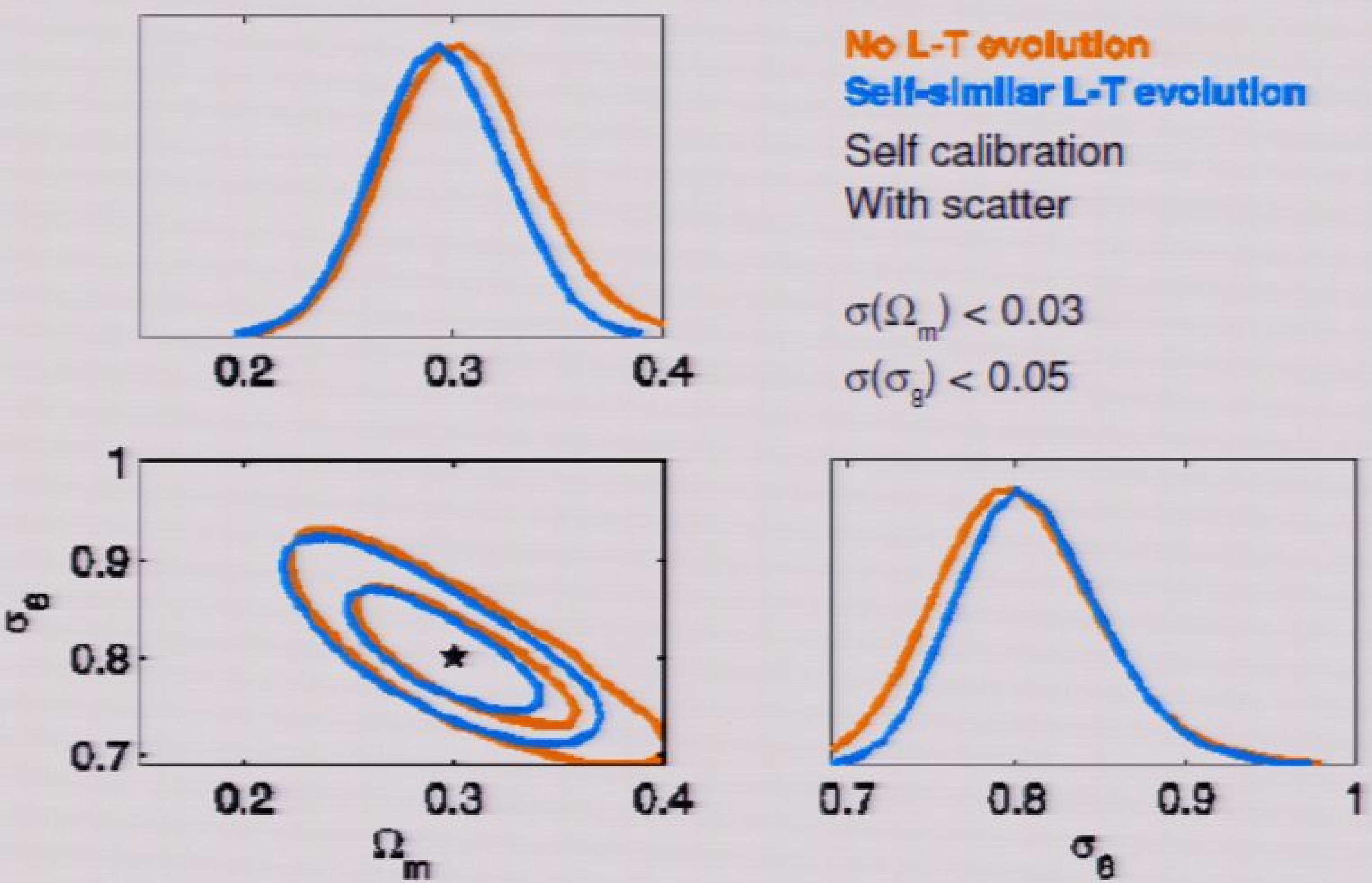
Expected Constraints

- Not including measurement errors (T, z):



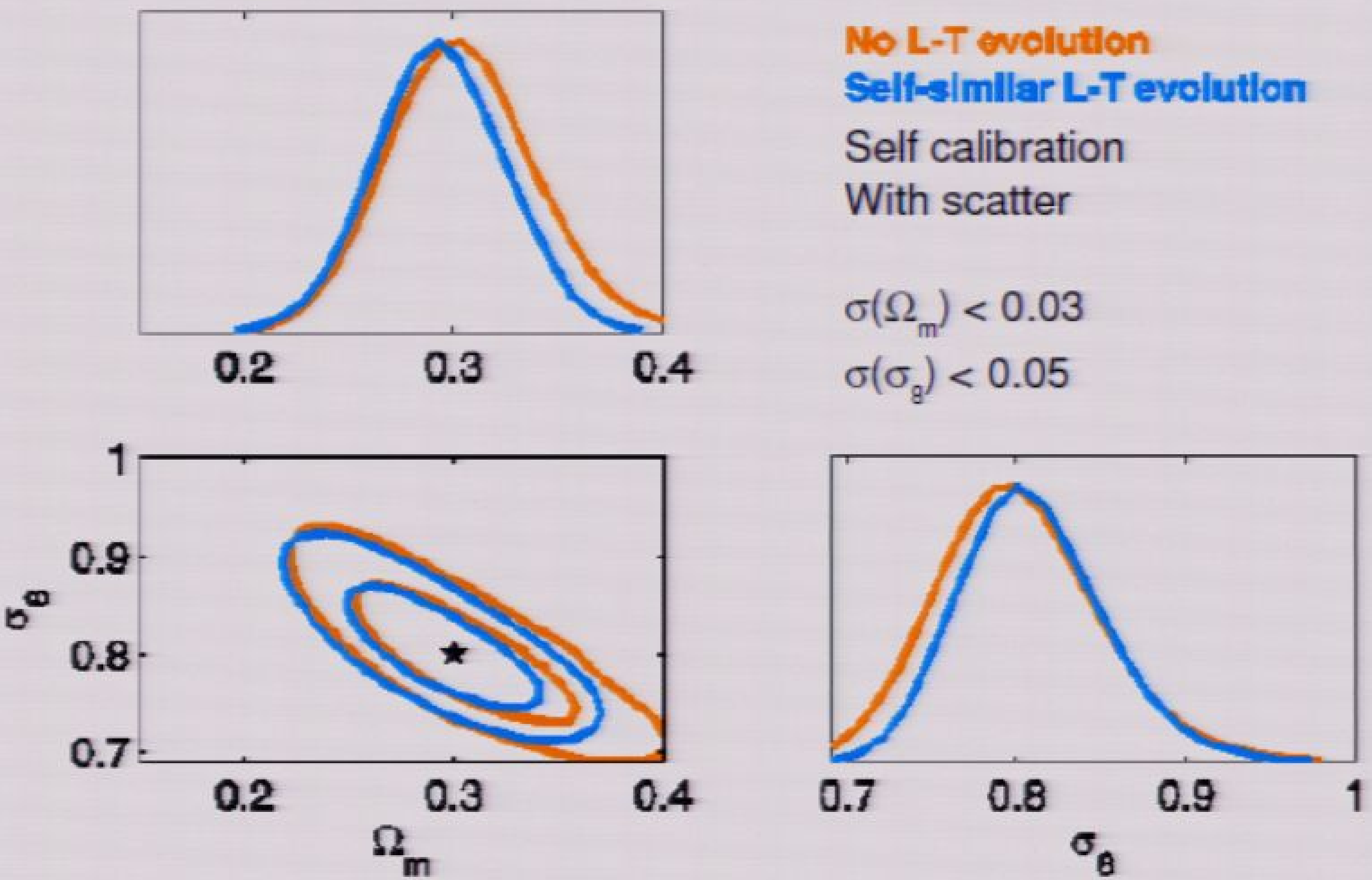
Expected Constraints

- Not including measurement errors (T, z):



Expected Constraints

- Not including measurement errors (T, z):

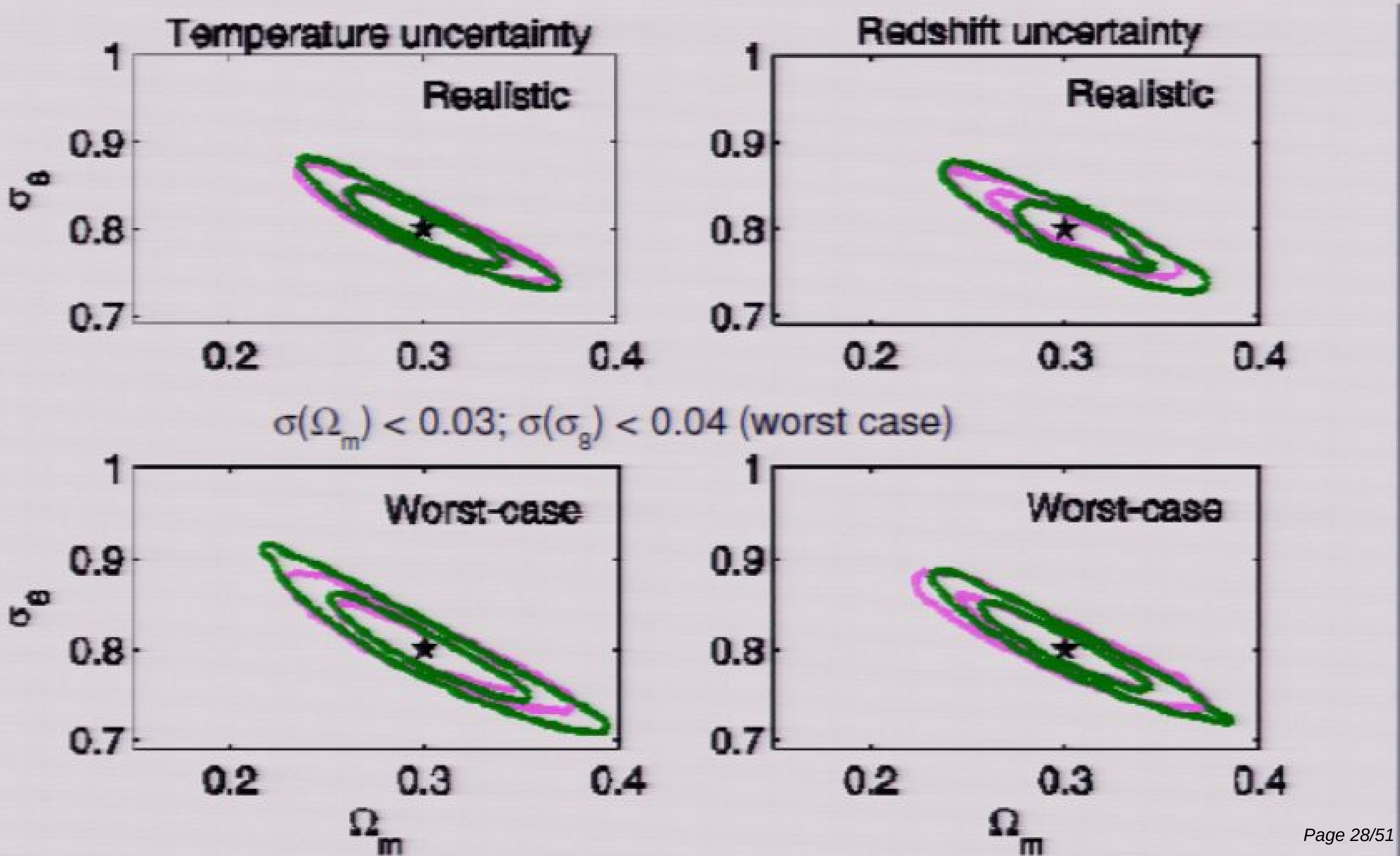


No L-T evolution
Self-similar L-T evolution
Self calibration
With scatter

$\sigma(\Omega_m) < 0.03$
$\sigma(\sigma_8) < 0.05$

Expected Constraints

- Including measurement errors (T, z), known scaling relations:

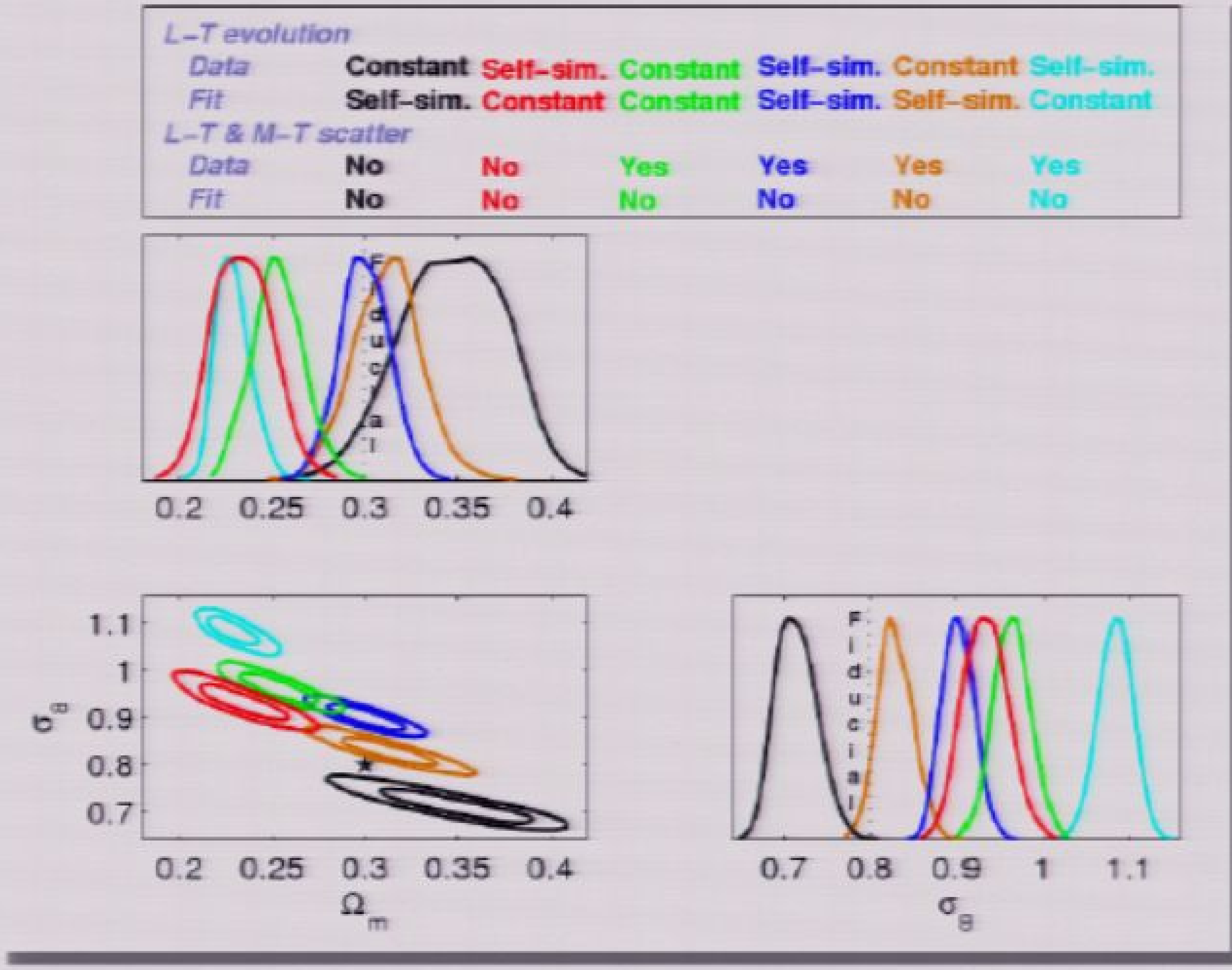


Notes on Constraints

- Despite the fact that we expect a 500 sq. deg. XCS to contain ~400-700 clusters, the predicted constraints appear only a factor of ~2 better in Ω_m (and comparable in σ_8) compared to the values quoted in Vikhlinin et al. 2009 (400SD/Chandra – 49 + 37 clusters)
- This is largely because of the adoption of a prior on h from the HST key project used in Vikhlinin et al. 2009, which is not used in the XCS predictions (Γ is fixed instead)
- Other things we will investigate:
  - other mass proxies (Mg, Y_X) (dark energy constraints; Vikhlinin et al. 2009)
  - lower counts (300 counts T error ~25%, compared to ~20% for 500 counts)
  - directly fitting for L-T relation evolution

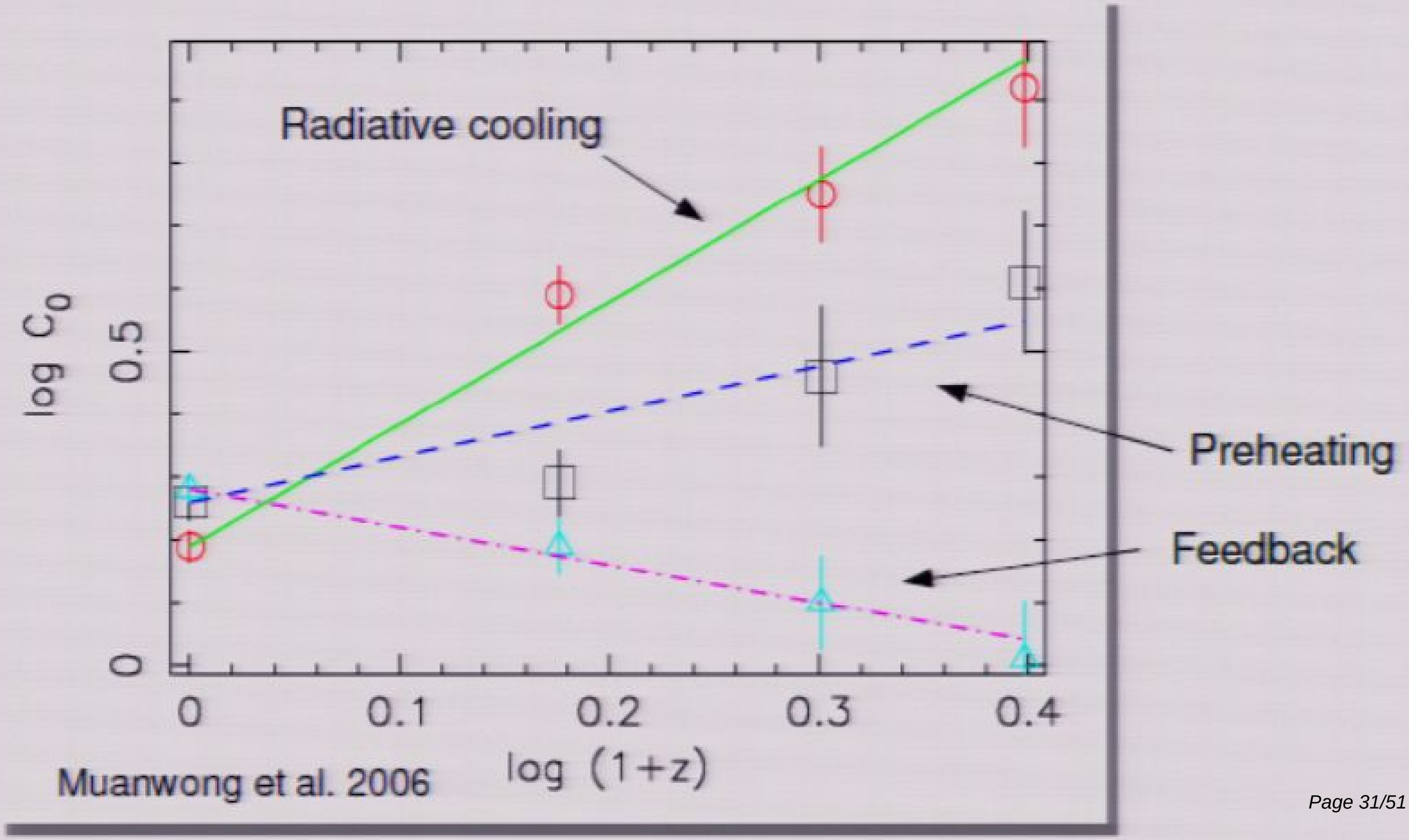
Cosmology and Scaling Relations

- Making incorrect assumptions about the evolution of scaling relations leads to large systematic errors in derived cosmological parameters (Sahlén et al. 2009)



L-T Relation Evolution: Models

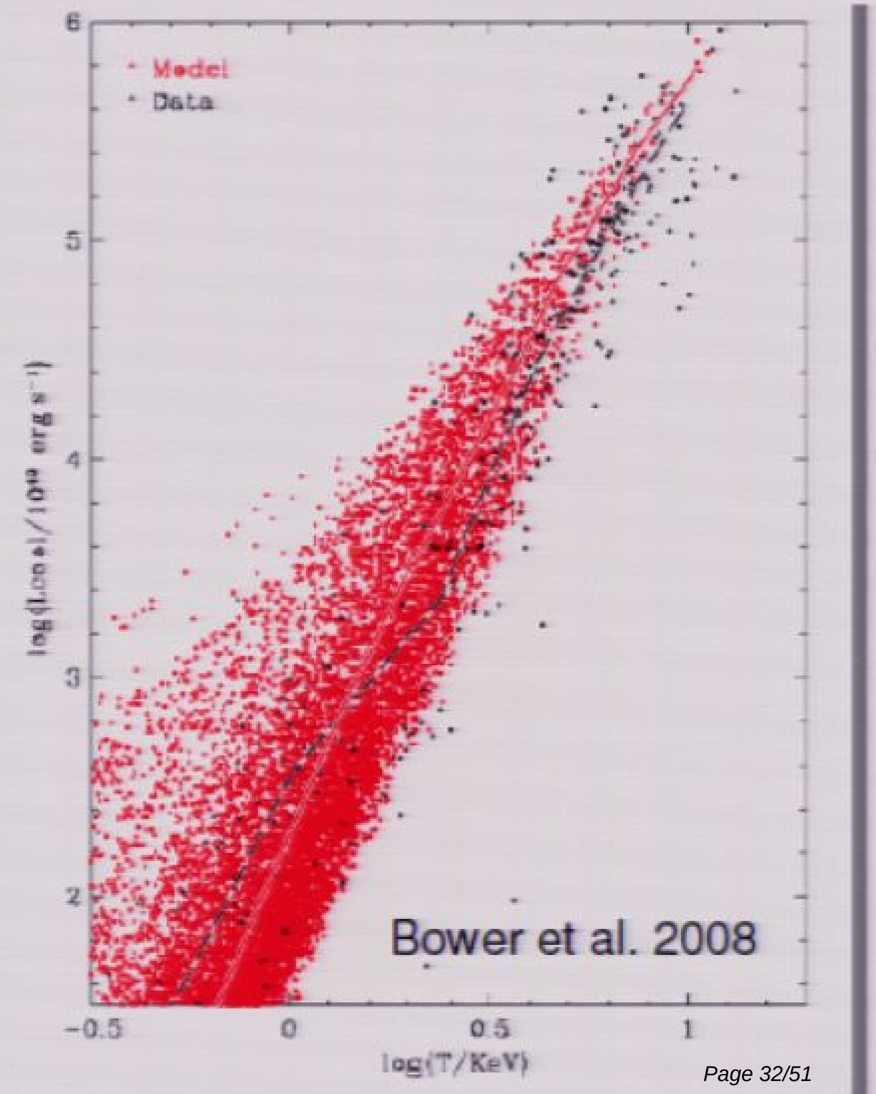
- Different models of cluster heating and feedback can reproduce the observed scaling relations at z=0, but evolve differently with redshift (Muanwong, Kay & Thomas 2006; Voit 2005):



Muanwong et al. 2006

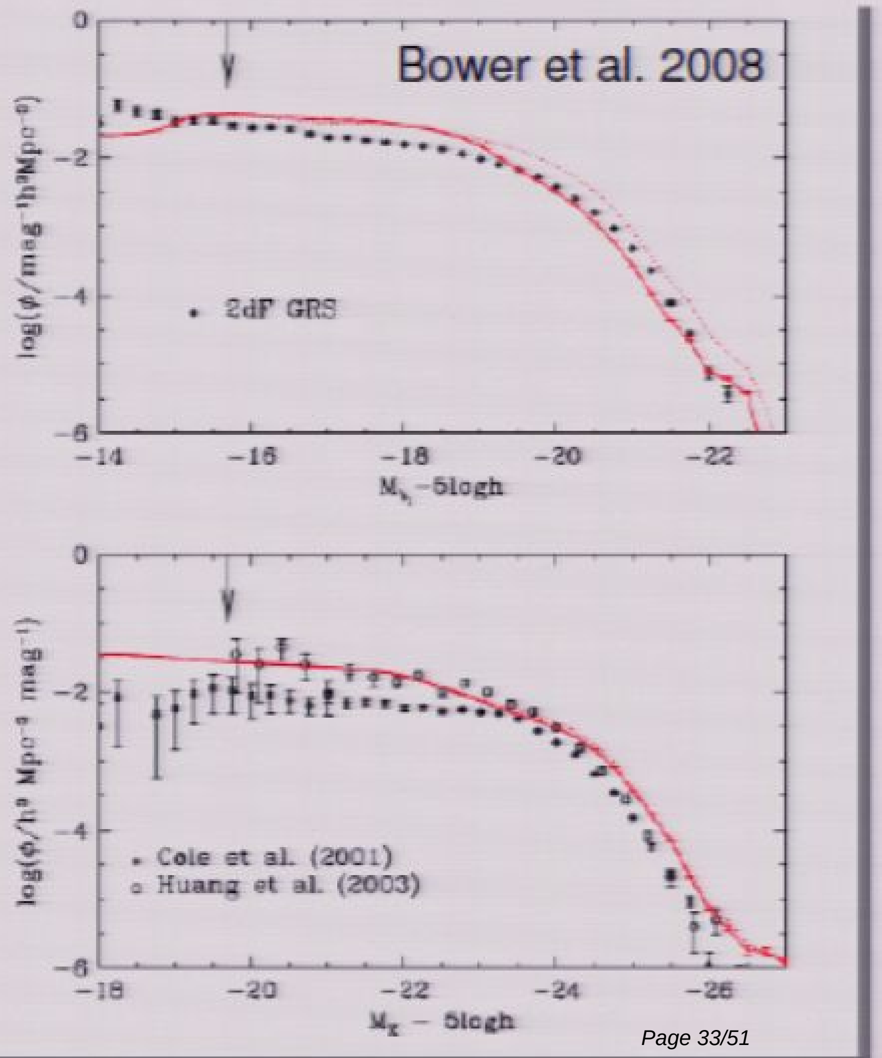
Scaling Relations and Galaxy Evolution

- The evolution of the L-T relation can also be used to constrain models of galaxy formation, as it provides information on the level and mode of feedback from e.g. AGN
- e.g. Bower et al. 2008 – this model attempts to reproduce both the observed L-T relation and the galaxy luminosity function
- The previous Bower et al. 2006 model reproduces the galaxy LF very well, but fails for the L-T relation



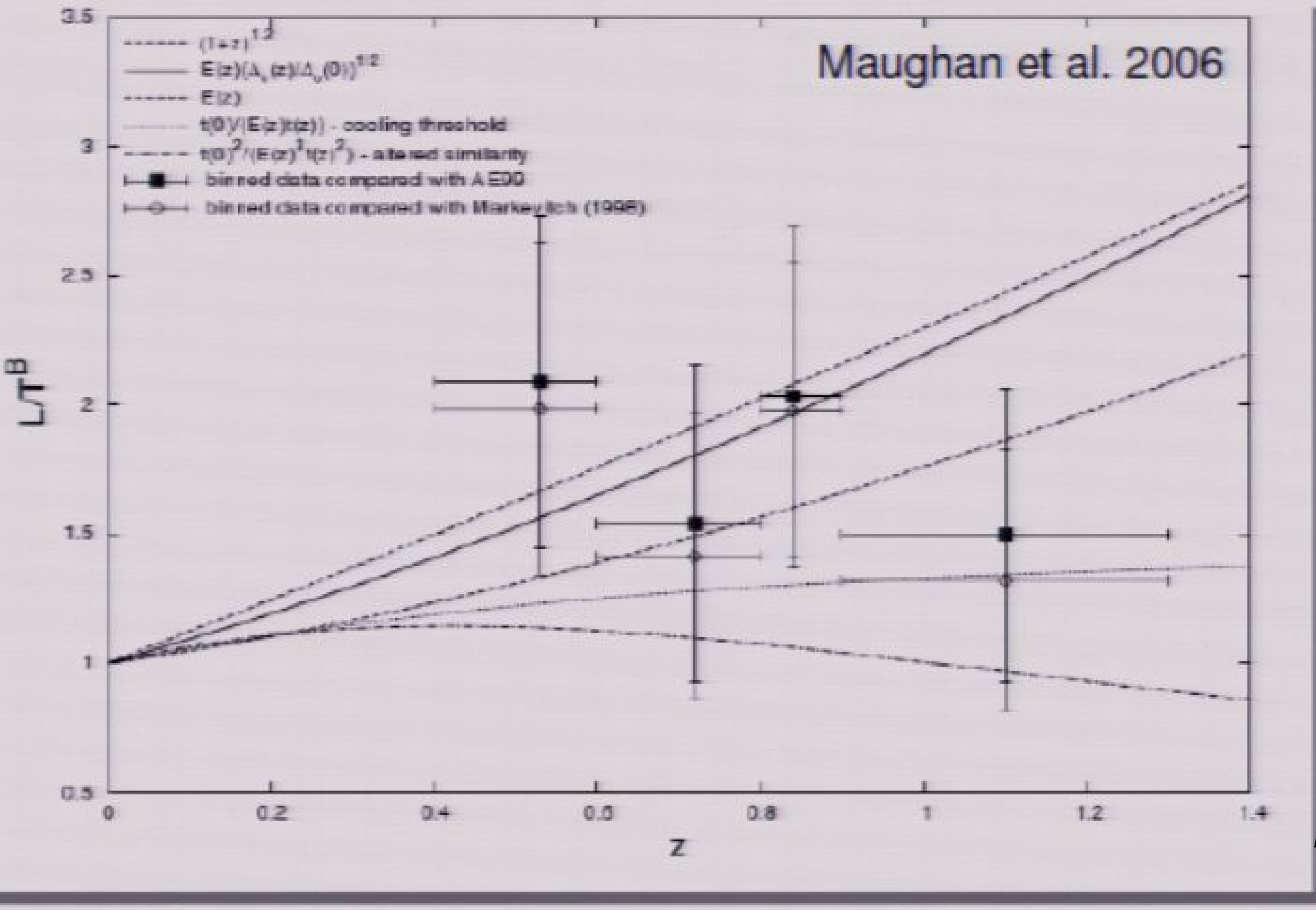
Scaling Relations and Galaxy Evolution

- The evolution of the L-T relation can also be used to constrain models of galaxy formation, as it provides information on the level and mode of feedback from e.g. AGN
- e.g. Bower et al. 2008 – this model attempts to reproduce both the observed L-T relation and the galaxy luminosity function
- The previous Bower et al. 2006 model reproduces the galaxy LF very well, but fails for the L-T relation



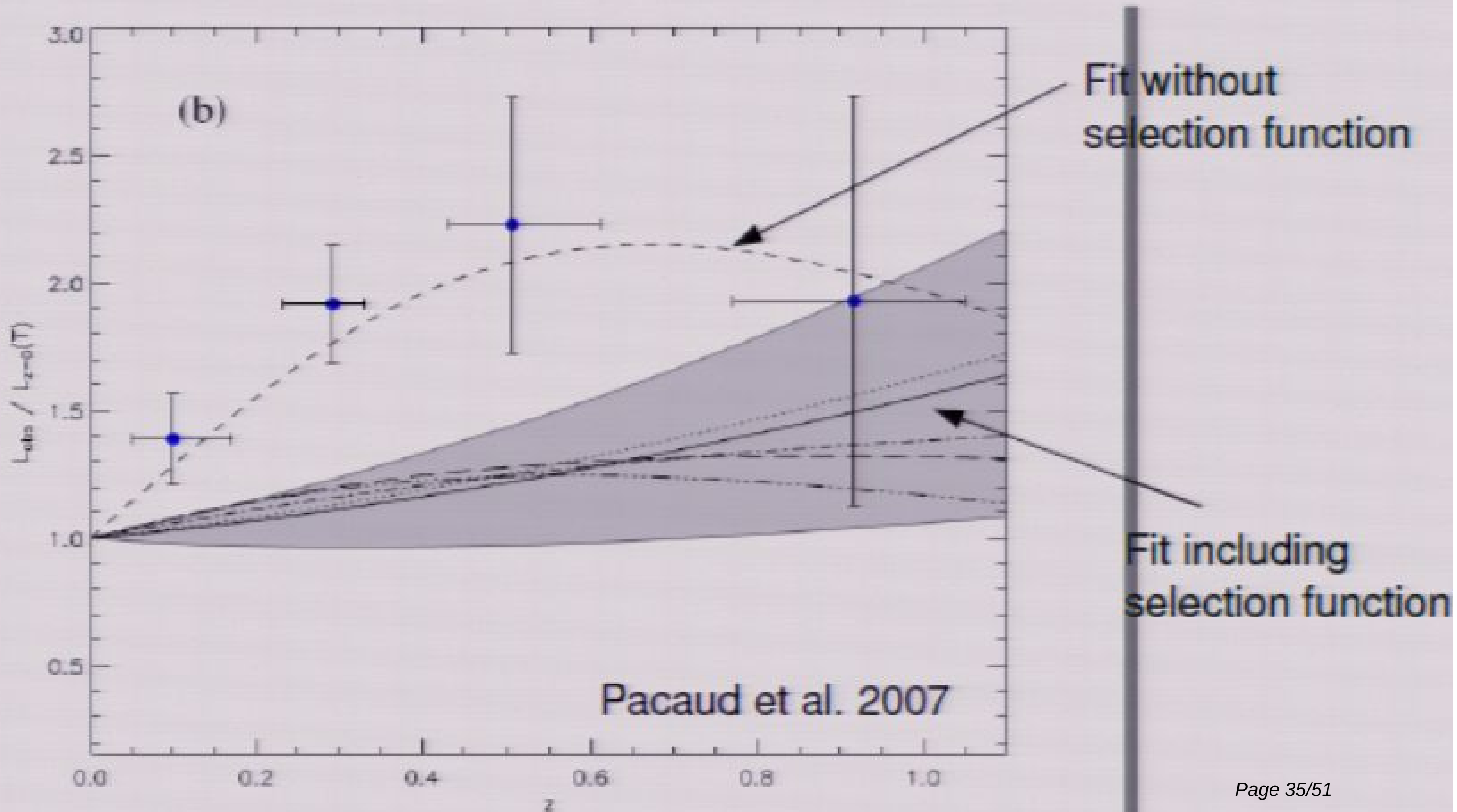
L-T Evolution: Observations

- Current observations do not place strong constraints on the evolution of the normalisation of the L-T relation at high-z (Maughan et al. 2006):



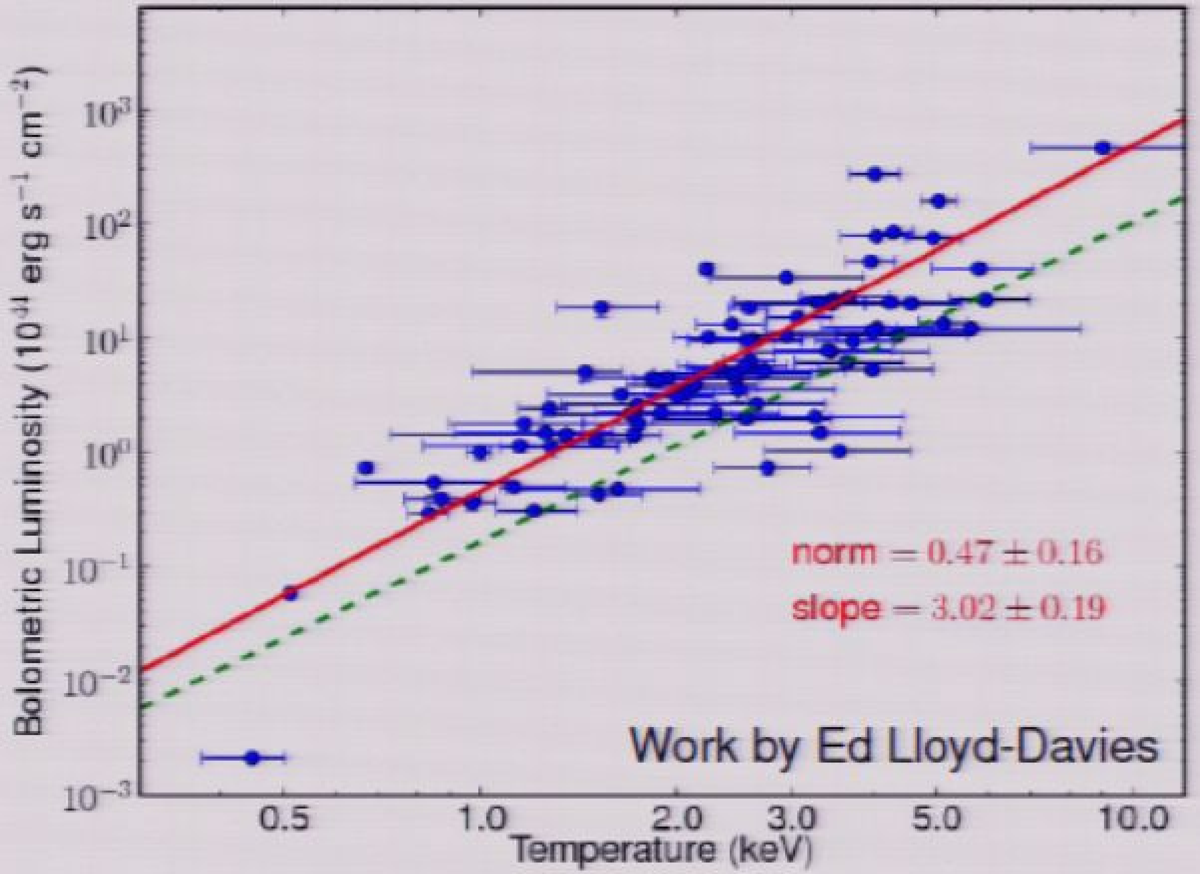
L-T Evolution: Selection Effects

- As well as being essential for deriving cosmological constraints, knowledge of the selection function is also required to interpret the evolution of the scaling relations – as shown by e.g. Pacaud et al. 2007 (XMM-LSS):



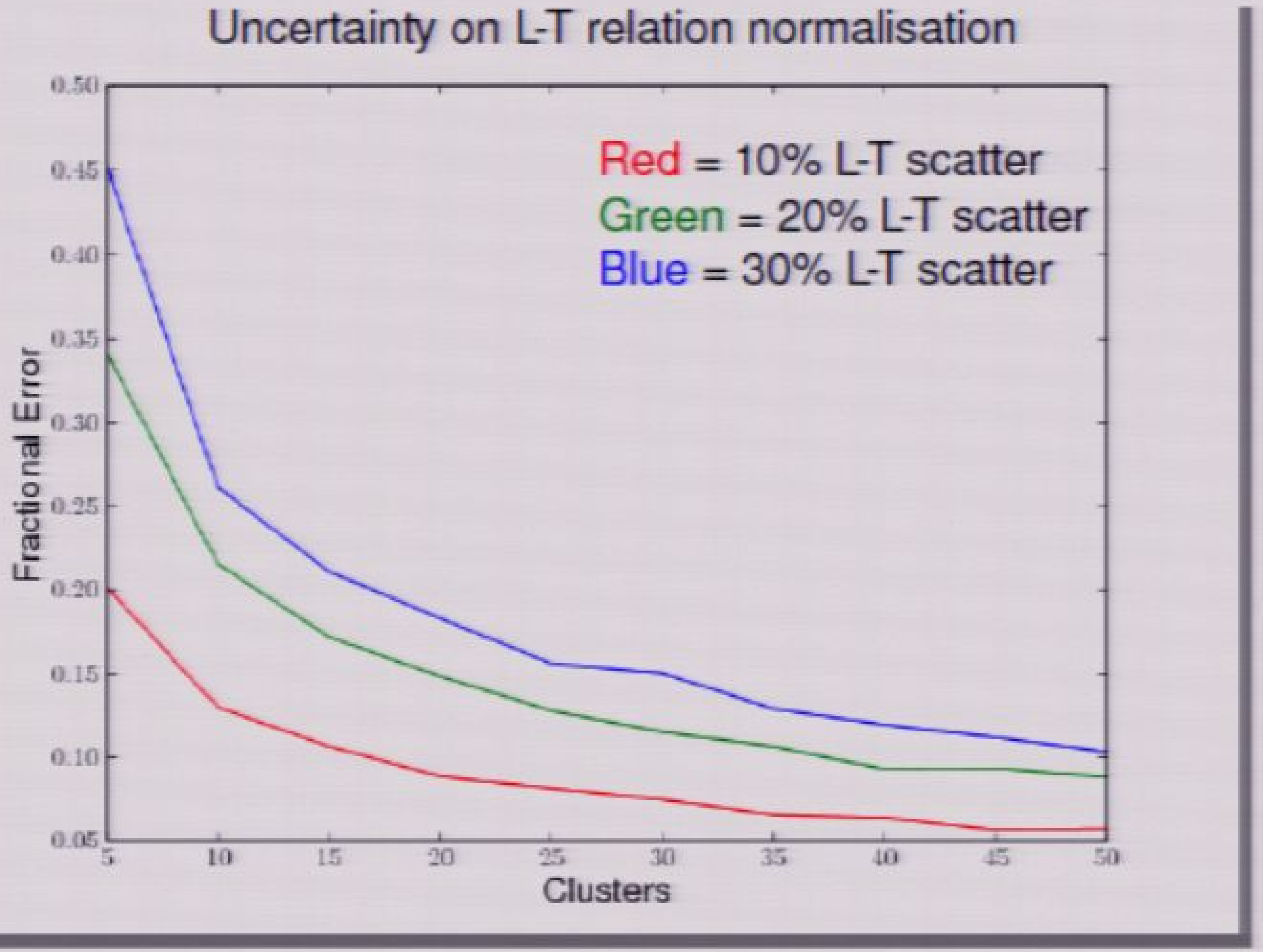
Preliminary XCS500 L-T

- Very preliminary – no selection function information included (red = fit to data; green = L-T relation in CLEF simulation (Kay et al. 2007):



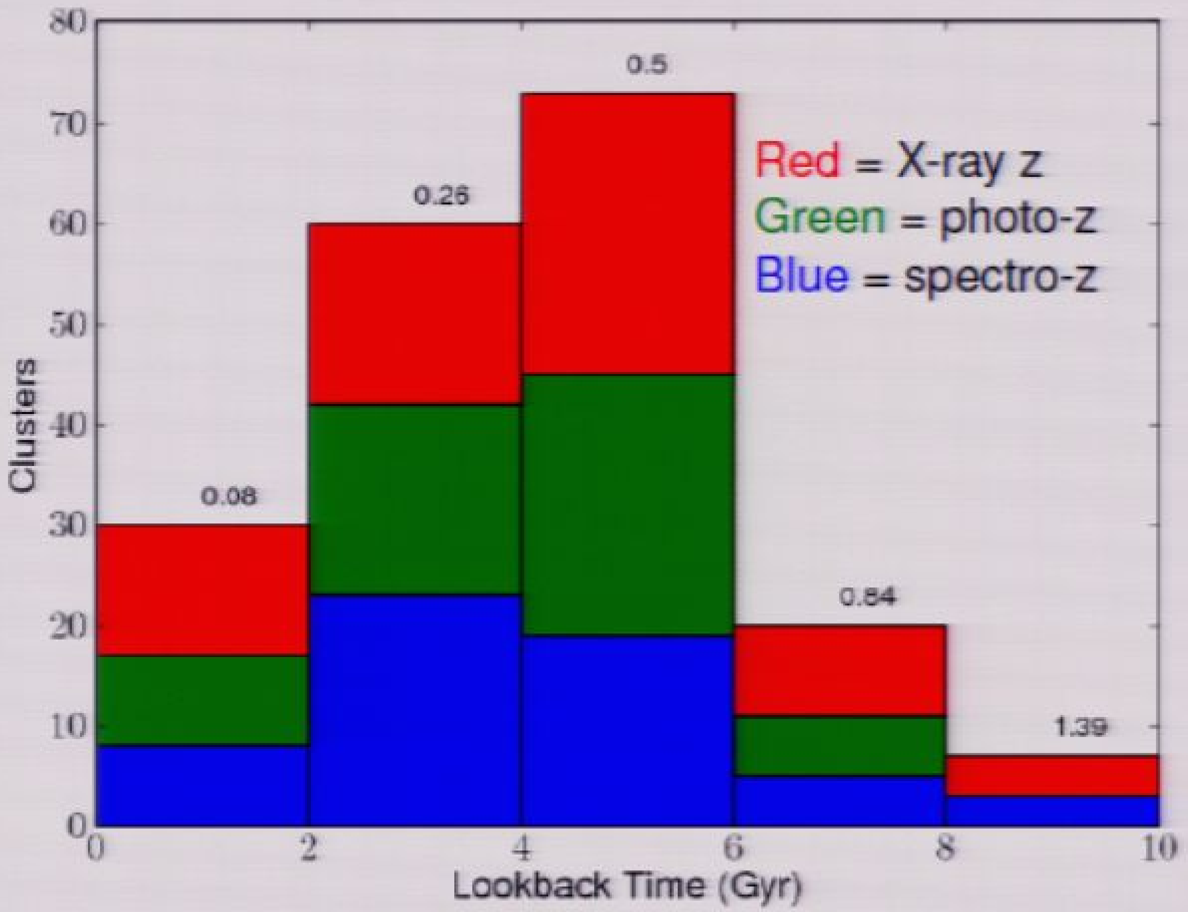
L-T Evolution with XCS

- Will study as a function of lookback time using the current XCS sample:



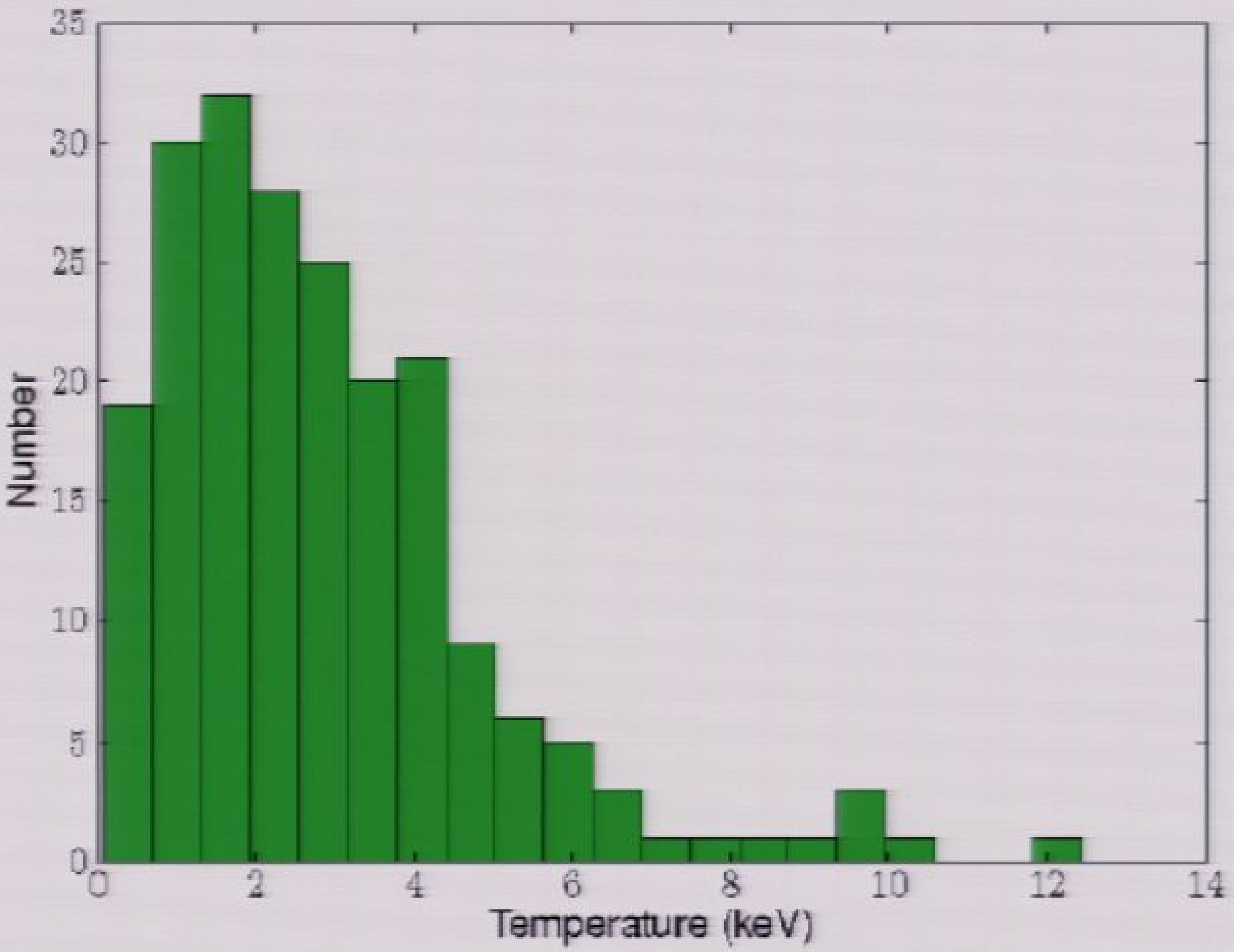
L-T Evolution with XCS

- Will study as a function of lookback time using the current XCS sample:



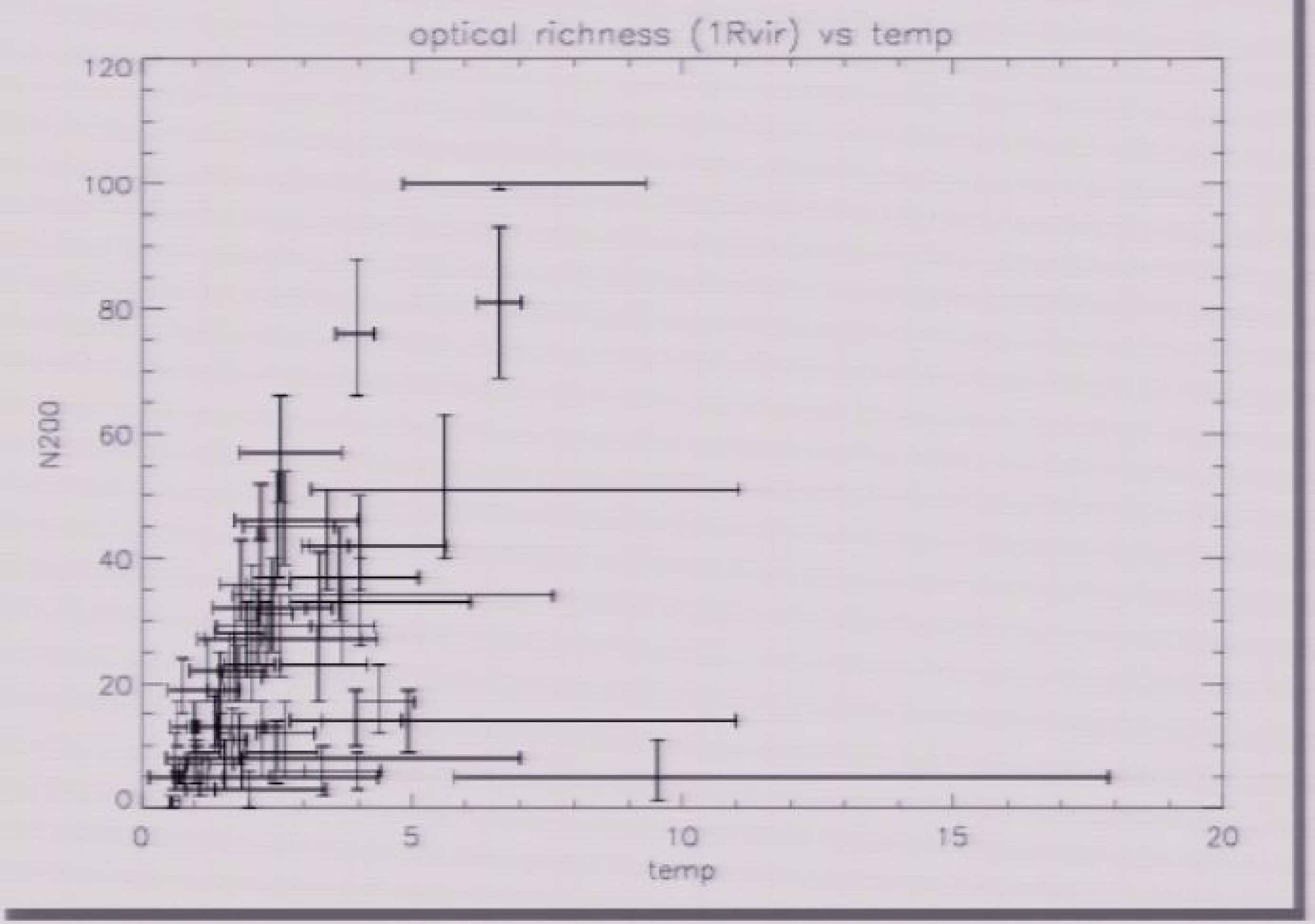
Temperature Distribution

- For current XCS sample:



X-ray-Optical Relations

- XCS can also be used to help calibrate mass estimation in optical cluster surveys (e.g. from DES) – e.g. ongoing work by Nicola Mehrtens on N200-T relation from NXS clusters:



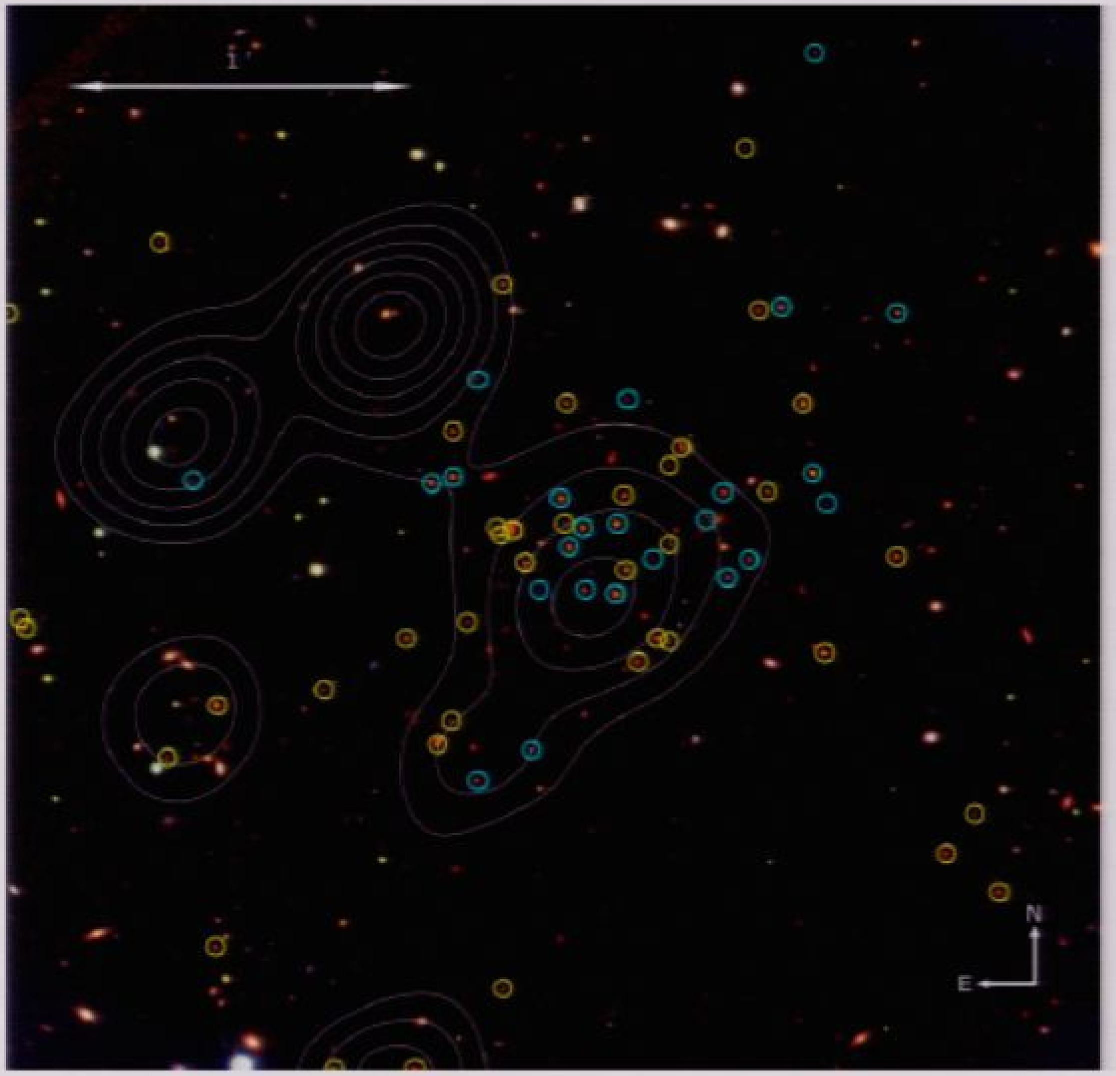
Galaxy Evolution in High-z Clusters

- XCS also allows us to study galaxy evolution in some of the most distant galaxy clusters known
- Still relatively few clusters are known at $z > 1$, although this is changing (in particular with Spitzer surveys)
- SZ effect is nearly independent of z, and so SZ surveys can help to increase the number of $z > 1$ clusters, characterise the high redshift cluster population, and constrain galaxy formation models

Name	z	Instrument	Reference
XMMXCS J2215.9-1738	1.46	XMM	Stanford et al. 2006
ISCS J1438.1+3414	1.41	Spitzer	Stanford et al. 2005
XMMU J2235.3-2557	1.39	XMM	Mullis et al. 2005
ISCS J1434.7+3519	1.37	Spitzer	Eisenhardt et al. 2008
ISCS J1432.6+3436	1.35	Spitzer	Eisenhardt et al. 2008
SpARCS J003550-431224	1.34	Spitzer	Wilson et al. 2008

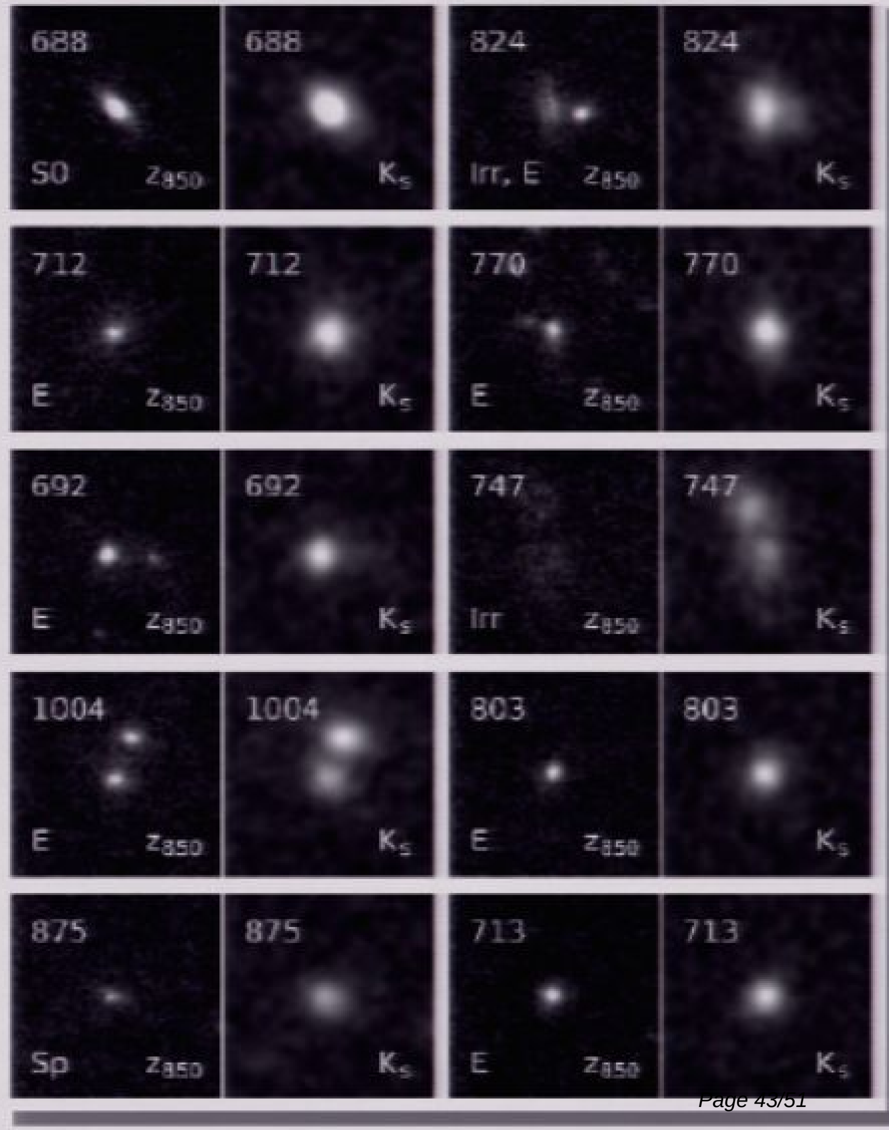
The Most Distant X-ray Cluster

- The most distant spectroscopically confirmed cluster is J2215.9-1738 at z=1.46 (Stanford et al. 2006; Hilton et al. 2007)
- This corresponds to a lookback time ~9 Gyr (2/3 age of universe)
- We performed the first study of galaxy morphologies and the colour-magnitude relation in a cluster at z~1.5 (Hilton et al. 2009, ApJ, in press, astro-ph/0903.1731).



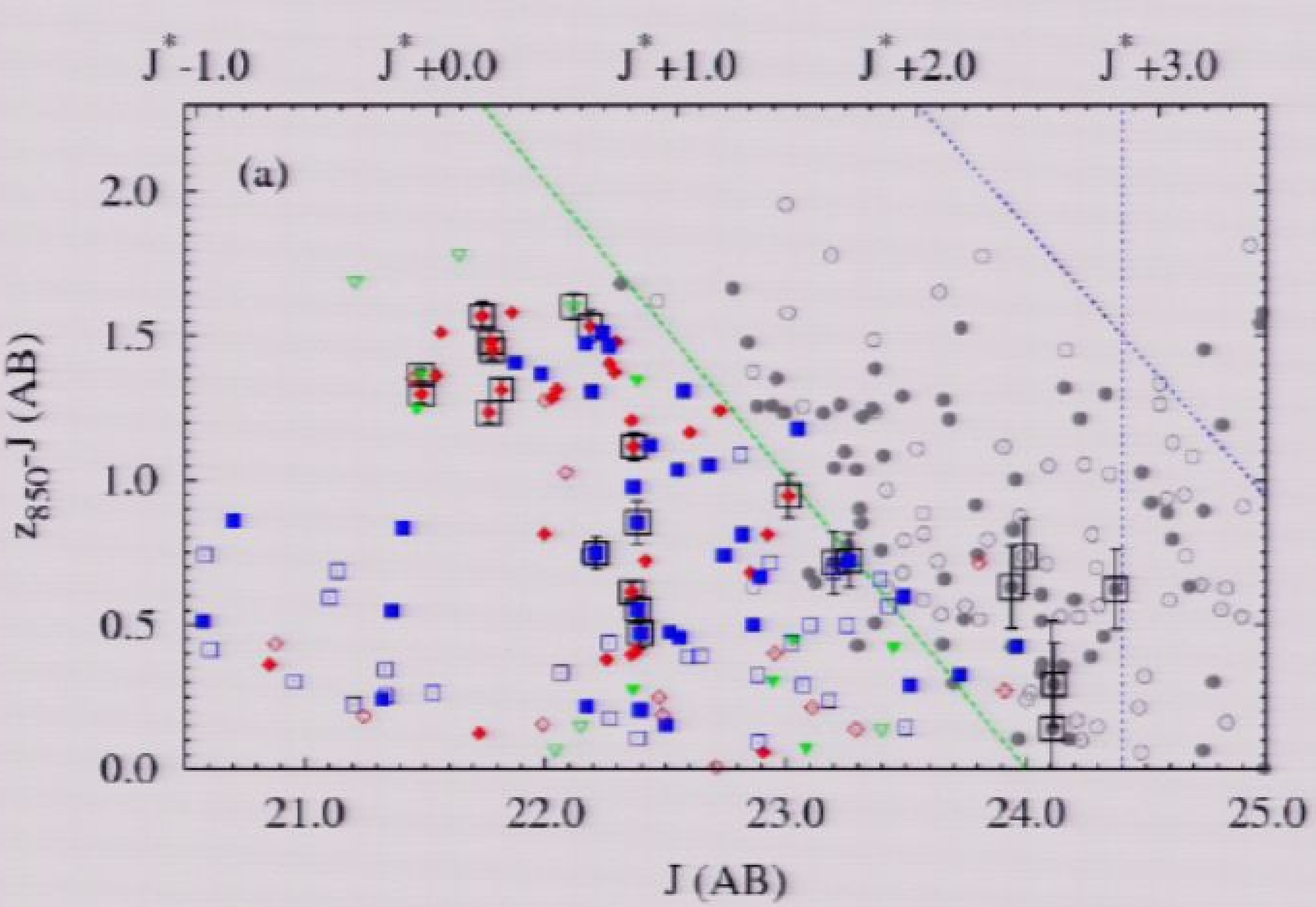
Morphologies

- Visual classification by a team of five classifiers for all galaxies with $z_{850} < 24$ using the Hubble data
- Within radius 0.5 Mpc:
  - Ellipicals = 0.54±0.17
  - S0s = 0.08±0.07
  - Spirals/irregulars = 0.38±0.15
- Typical of clusters at z~1 (e.g. Postman et al. 2005; Smith et al. 2005) at similar magnitude limit
- Locally, E+S0 fraction is ~0.75-0.90, depending on density.



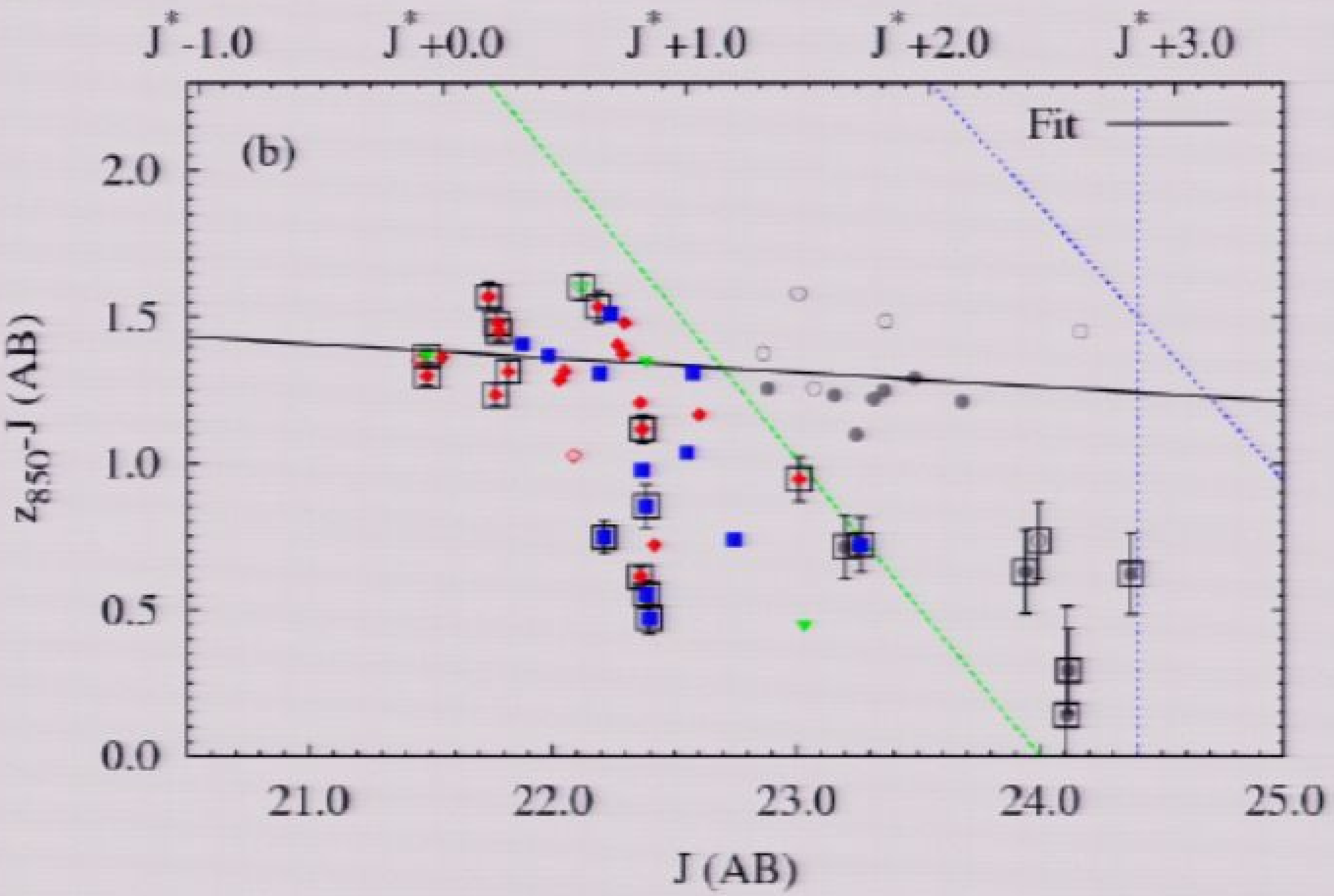
Colour-Magnitude Diagram

- z850-J, J – all galaxies:
- Symbols: red = elliptical; green = S0; blue = spiral or irregular



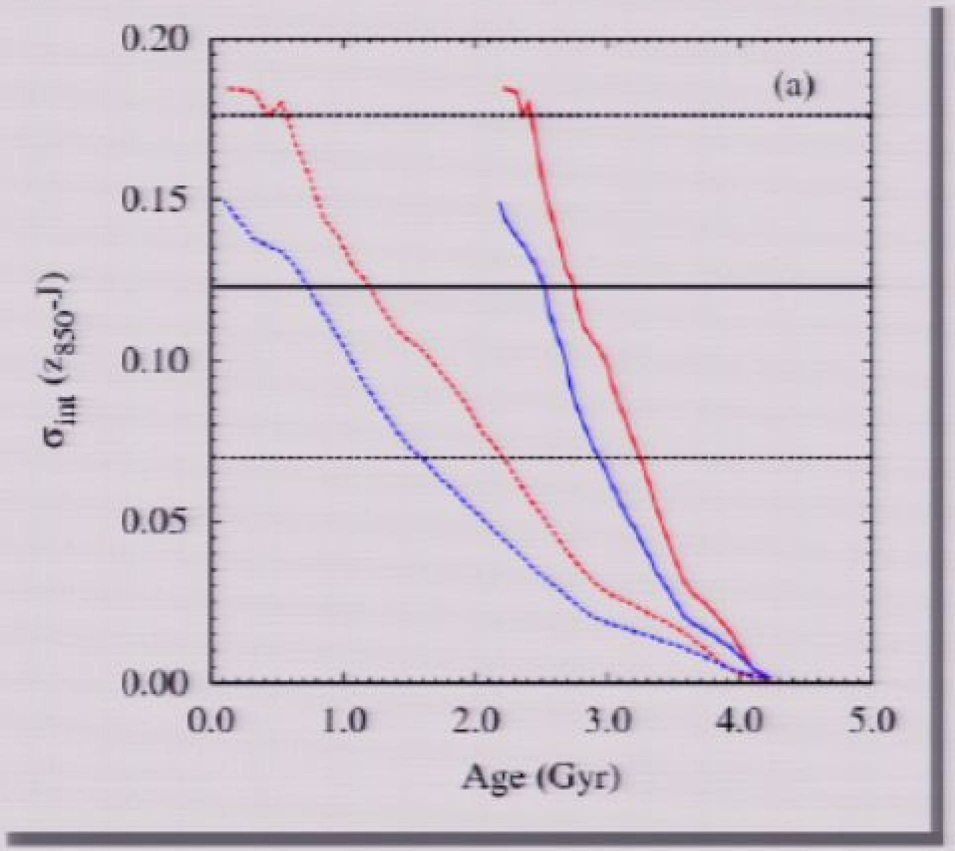
Colour-Magnitude Diagram

- z850-J, J – member galaxies only (note: lack of very bright galaxies; lack of faint red galaxies):
- Symbols: red = elliptical; green = S0; blue = spiral or irregular



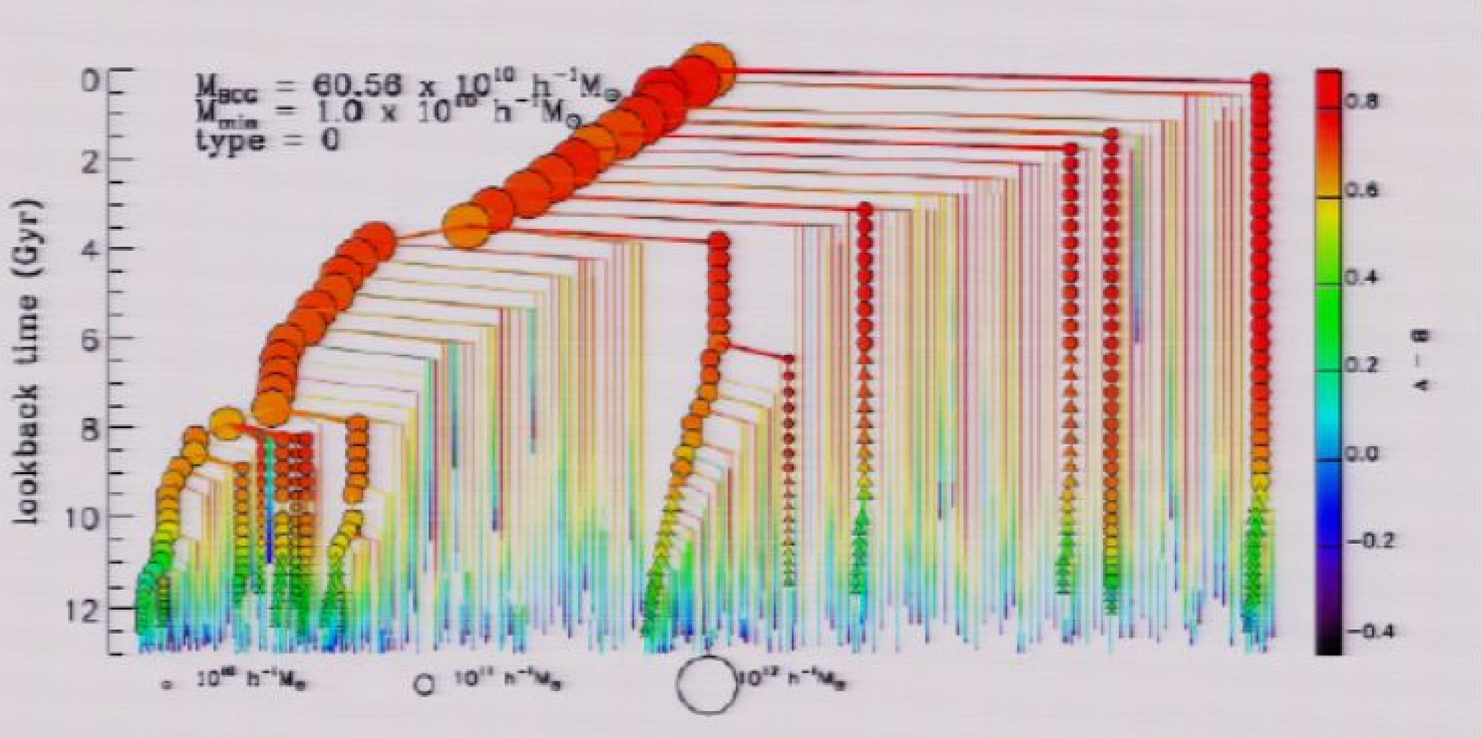
Galaxy Ages

- Derived from comparison of the scatter about the colour-magnitude relation with simulations – shown here for morphologically selected sample of E+S0 galaxies
- We find mean luminosity weighted stellar population age = 2.8±0.4 Gyr
- This corresponds to a mean formation redshift of z_f = 4.0+1.1-0.7
- This is in agreement with studies of clusters up to z ~1.3 (e.g. Mei et al. 2006; Blakeslee et al. 2003)



Semi-Analytic Models and BCGs

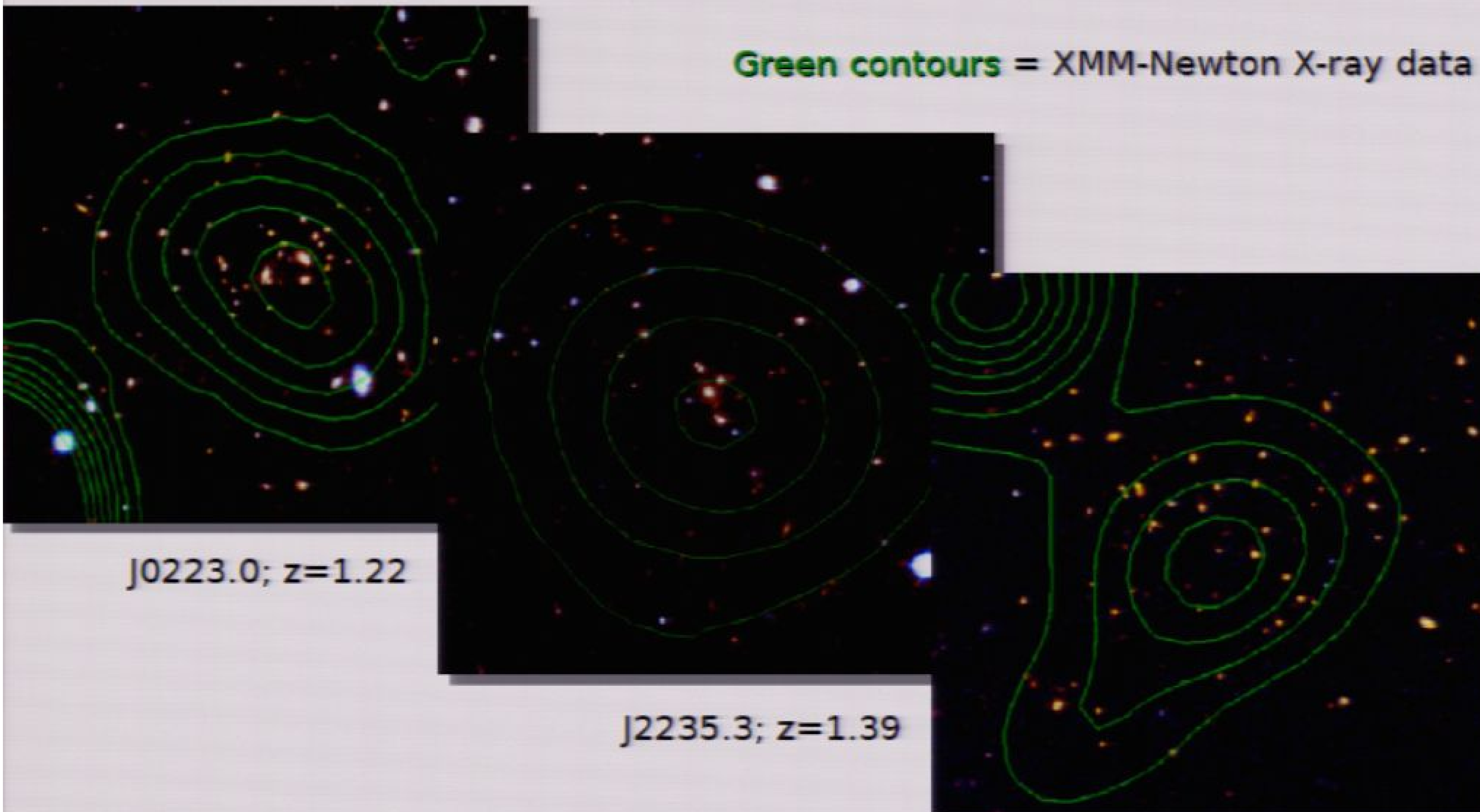
- In the latest semi-analytic models of galaxy formation (based on the Millennium Simulation), dramatic evolution in stellar mass is expected, and this is most apparent for Brightest Cluster Galaxies
- We tested this using Subaru observations of z >1 clusters (Collins et al. 2009, Nature 2nd April, astro-ph/0904.0006)



De Lucia & Blaizot 2007

The Clusters

Green contours = XMM-Newton X-ray data



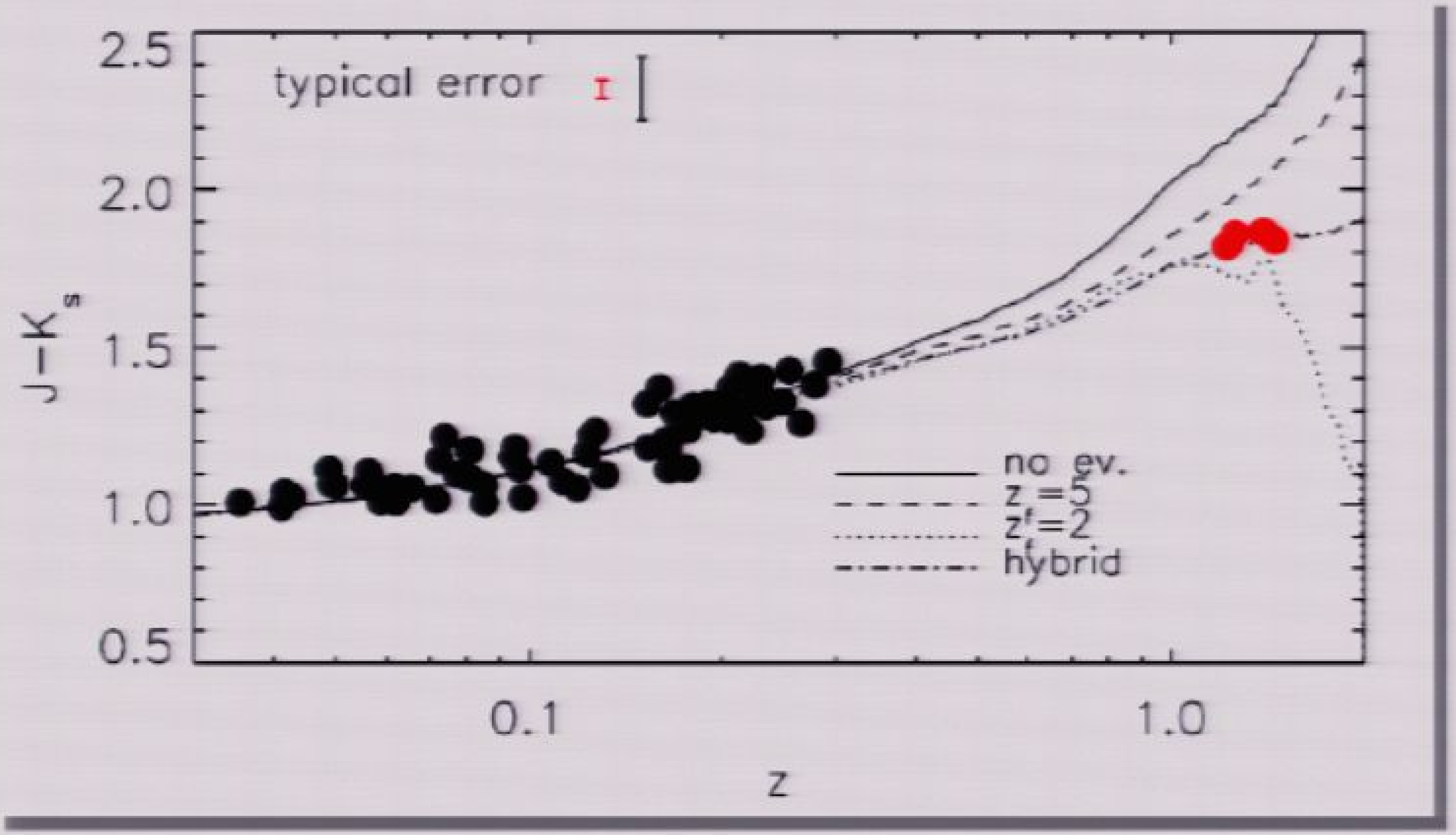
J0223.0; z=1.22

J2235.3; z=1.39

J2215.9; z=1.46

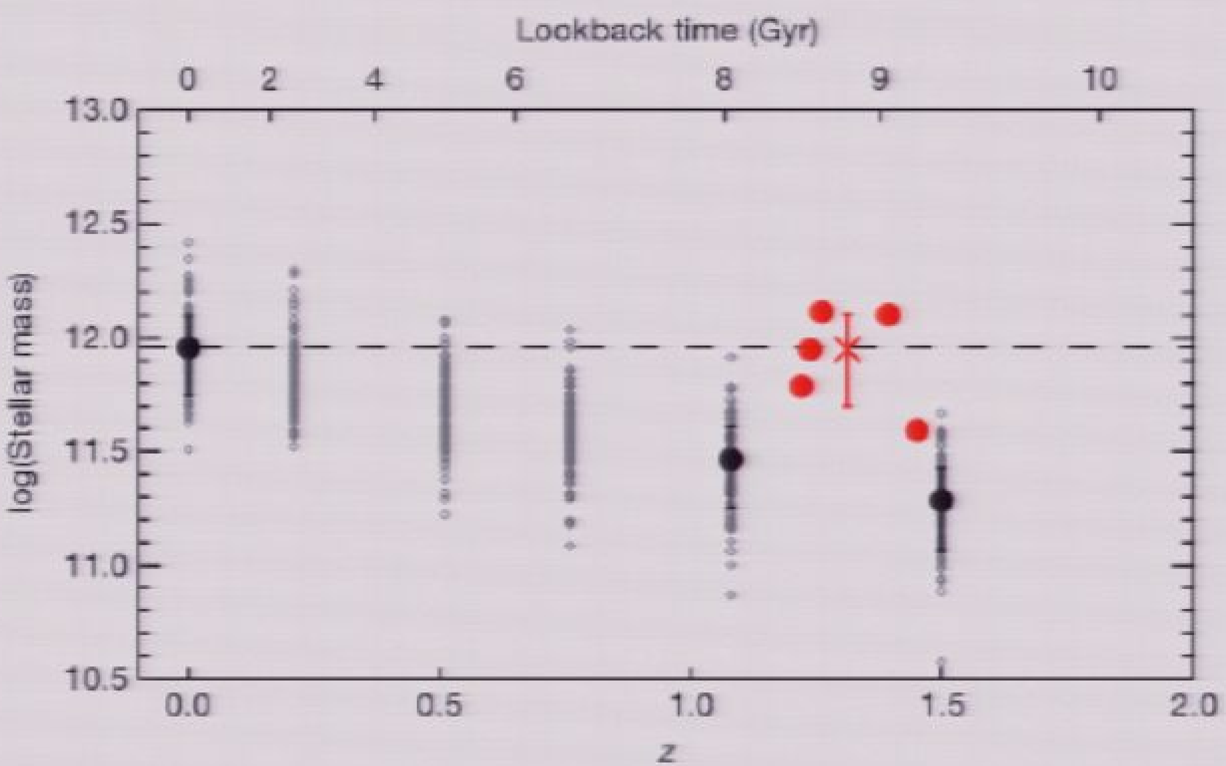
Colours

- The colours of our BCGs are consistent with the De Lucia & Blaizot (2007) hierarchical model, as well as stellar population models.



Stellar Masses

- Using the K-band light as a proxy for stellar mass, we find the high redshift BCGs have 80% of their expected z = 0 stellar mass already by z~1.4.
- The De Lucia & Blaizot (2007) model predicts they should have assembled 20% of their z = 0 stellar mass by this time.



Summary

- XCS currently:
  - Covers 166 sq. deg (processed); 2001 candidates; 229 with > 500 counts which will yield temperature measurements (~60% redshift completeness at present)
  - Processing of additional 130 sq. deg. is underway.
- For a final survey area of 500 sq. deg., XCS is predicted to measure Ω_m to 10%, σ_8 to 6% from the cluster data alone (assuming flatness).
- Progress is being made towards measuring the redshift evolution of the scaling relations, which will be a good test of models of feedback in clusters (and therefore also help to constrain galaxy formation models).
- Follow-up galaxy evolution studies based on XCS clusters are ongoing. Recent work includes a study of galaxy morphologies and the CMR in J2215 at z=1.46, and a comparison of semi-analytic model predictions with observations of BCGs at z > 1.