Large Scale Structures in the GOODS-SOUTH Field up to z ~ 2.5

Marco Castellano

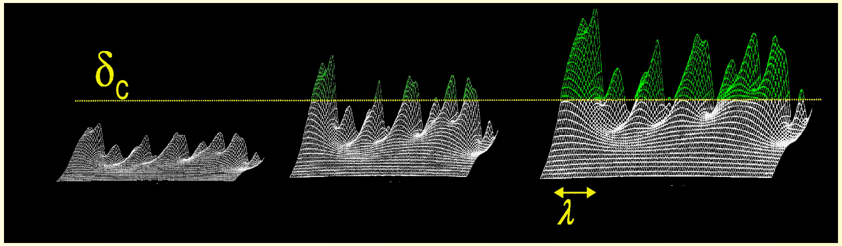
with S. Salimbeni, D. Trevese, L. Pentericci, A. Fontana, A. Grazian, N. Menci

INAF - Oss. Astronomico di Roma & Universita' di Roma “La Sapienza”

Detecting galaxy clusters in the early universe:

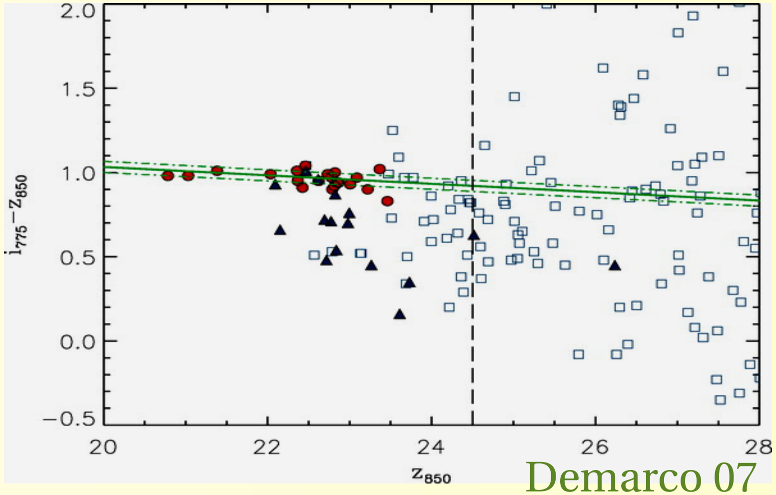
1) To distinguish heredity and environment in the evolution of galaxy properties:

- Segregation of red galaxies through biased galaxy formation ("Nature scenario")



- ...or because of environment-dependent effects (*Ram Pressure Stripping, Thermal Evaporation, Turbulent/Viscous Stripping, Tidal Truncation, Harassment* etc.) ("Nurture scenario")

2) To have a complete knowledge on the formation/evolution of red sequence galaxies and brightest cluster galaxies, a crucial test for galaxy evolution models.



3) To infer cosmological parameters from the evolution of the cluster mass function.

Cluster detection at high redshift

Various cluster detection techniques are currently employed:

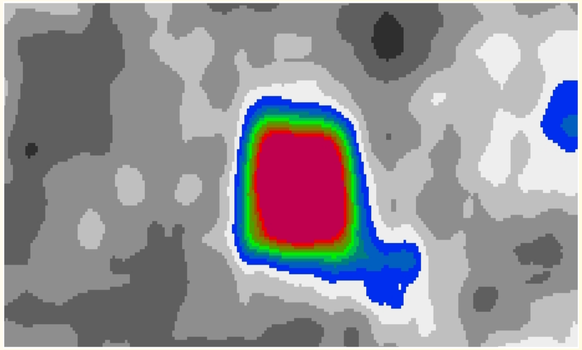
- **X-ray detections** (*e.g. Rosati 04, Mullis 05, Stanford 06, Lidman 08*)
- **Red Sequence methods** (*e.g. Gladders&Yee 05, Goto 08, Andreon 08*)
- **LBG clustering** (*e.g. Steidel 99, Peter 07, Ota 08*)
- **SZ maps** (*e.g. Staniszewski 08*)
- **Targeted searches** (*high-z radio gal., e.g. Venemans 07, QSOs, e.g. Kashikawa 07*)

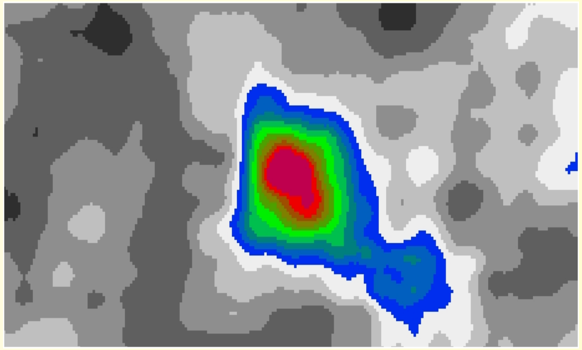
But selecting clusters as galaxy overdensities in redshift space allows unbiased selection up to the highest redshifts: it is not dependent on virialisation status, on the presence of a red sequence or of an early type population.

The use of photometric redshifts allows to reach the deepest limits in multi-wavelength surveys.

Several studies in these last years explore cluster detection through photo-z: *Botzler 2004, Scoville 07, Zatloukal 07, Mazure 07, Eisenhardt 08, Kovac 09, van Breukelen 09, Adami 09, Pello 09.*

Galaxy Space Densities through photometric redshifts





We developed a method to detect overdensities using photometric redshifts (**Trevese et al. 2007 A&A 463**).

We divide the survey volume and for each cell we count neighbouring objects of increasing distance:

$$\rho = \frac{V}{n}$$

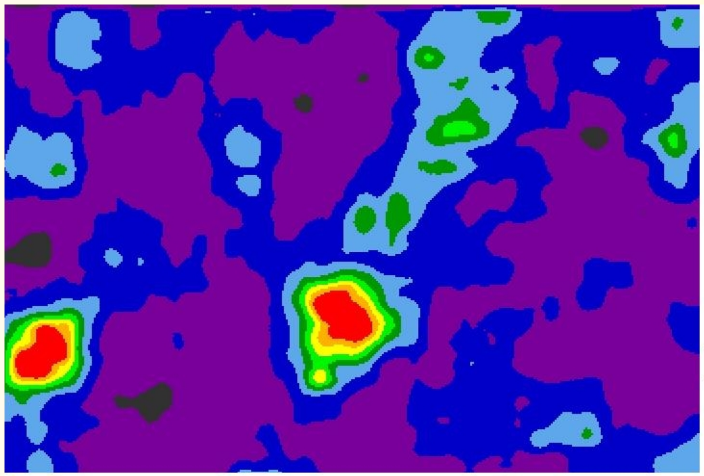
We take into account the increase of limiting luminosity with increasing redshift assigning a weight *w(z)* to each object:

$$\frac{1}{w(z)} = \frac{\int_{-\infty}^{M_{\lim(z)}} \Phi(M)\,dM}{\int_{-\infty}^{M_c} \Phi(M)\,dM}$$

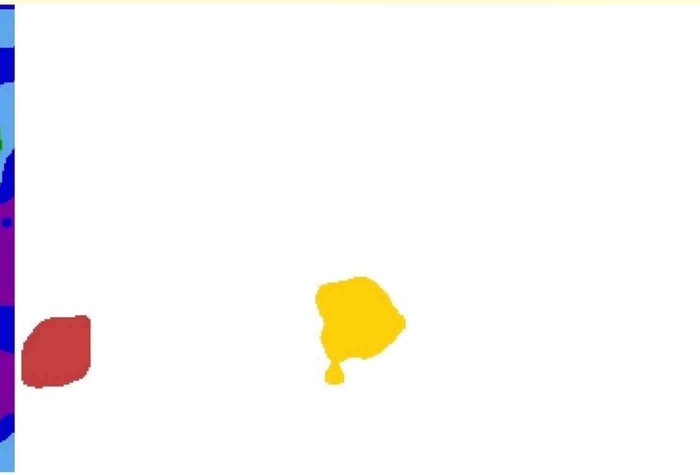
On the basis of our knowledge of the LF we assume a reference redshift z_c below which we detect all objects brighter than the relevant $M_c \equiv M_{\lim(zc)}$

Cluster detection: tests on simulations

FITS image of the density field



FITS image with the 'segmentation' of selected clusters



We tested our algorithm on simulations. In a deep survey like the GOODS field we can obtain reliable samples of clusters selected as 4σ regions of the density field

	Low Redshift (z<1.8)	*High Redshift (1.8<z<2.5)*
Purity	~95%	~75%
Completeness	~85%	~35%

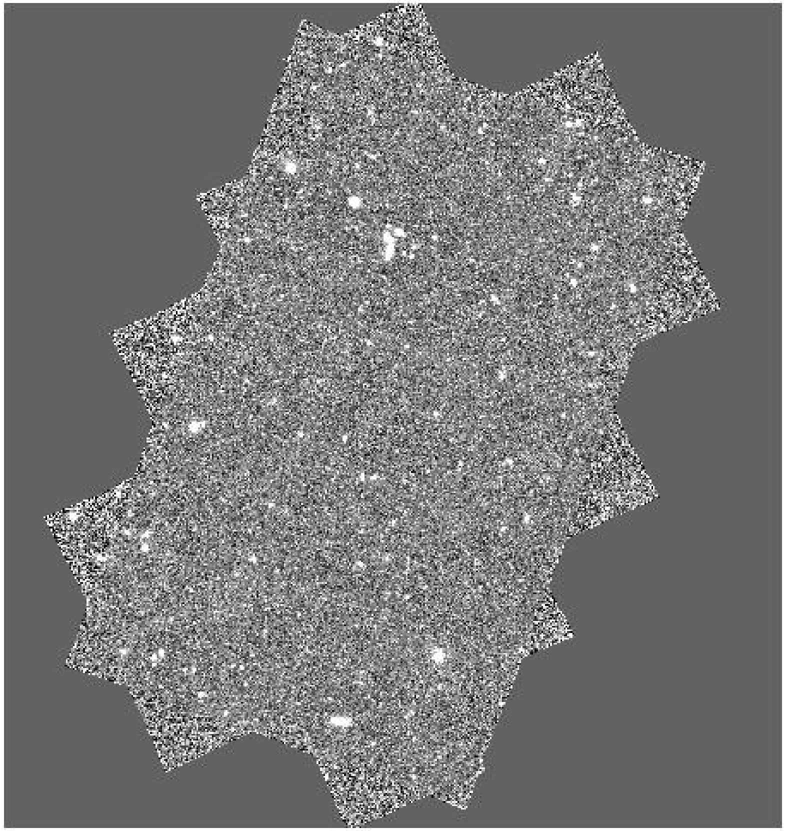
The GOODS Survey

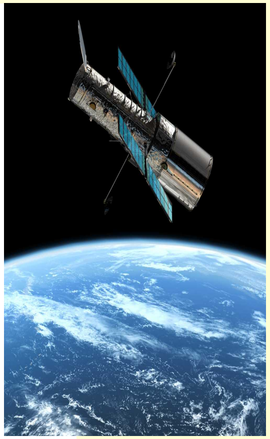
The Great Observatories Origins Deep Survey covers all the Chandra Deep Field South.

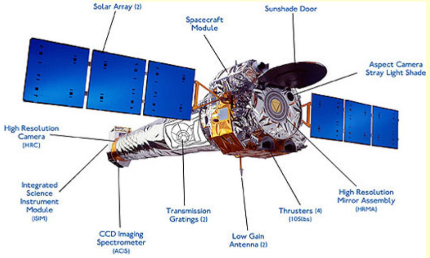
The GOODS-MUSIC catalogue (Grazian et al. 2006, A&A 449) uses 14 bands photometry of 14847 extragalactic objects, selected either in the z_{850} or in the K_s band. E.g. limiting magnitude z_{850} ~ 26 (AB).

The average dispersion of its photo-z is very good : $\langle|\Delta z/(1+z)|\rangle = 0.03$ up to redshift z = 2.

z-band ACS image

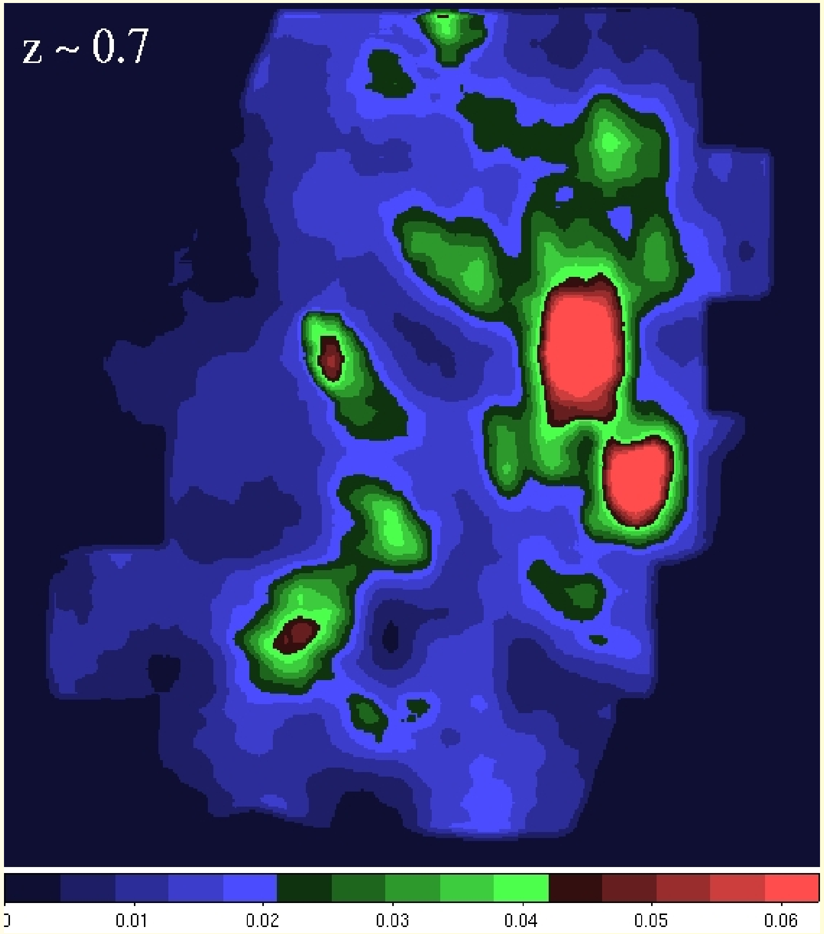






Clusters in the GOODS-South Field

We built a comprehensive catalogue of structures in the GOODS-South field up to z ~ 2.5 (Salimbeni et al. 2009). We find over-densities at z ~ 0.7 at z ~ 1, at z ~ 1.6 and z ~ 2.2 :

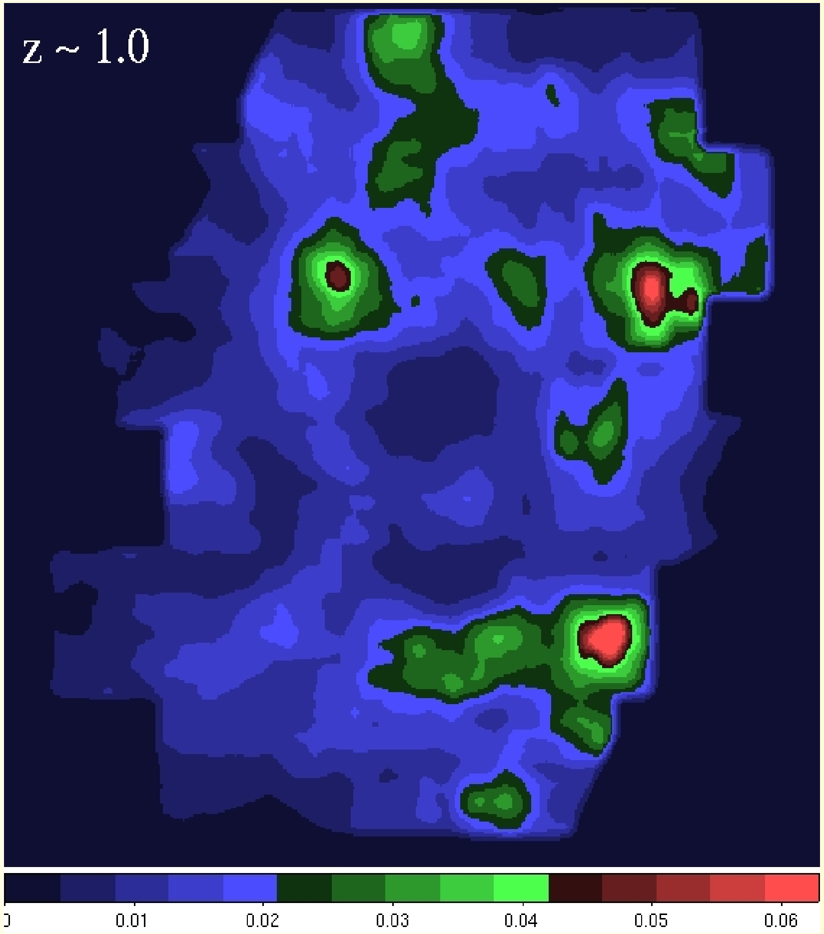


Spectroscopically confirmed.

Density maps at increasing redshift

Clusters in the GOODS-South Field

We built a comprehensive catalogue of structures in the GOODS-South field up to z ~ 2.5 (Salimbeni et al. 2008). We find over-densities at z ~ 0.7 at z ~ 1, at z ~ 1.6 and z ~ 2.2 :

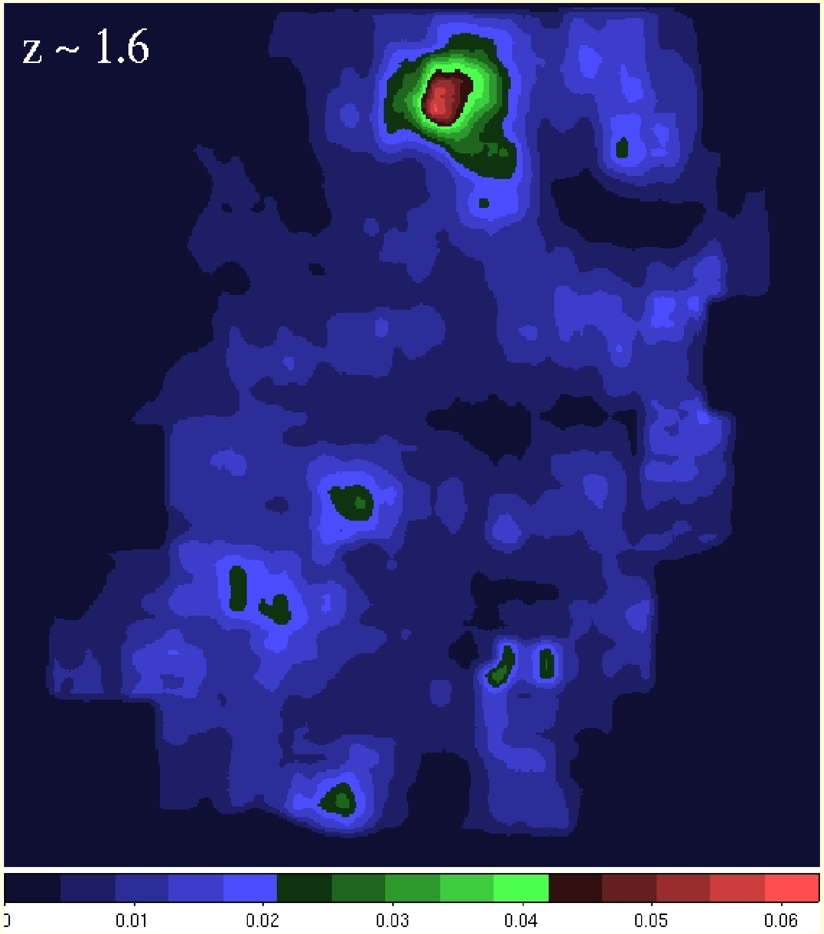


Two of them already spectroscopically confirmed.

Density maps at increasing redshift

Clusters in the GOODS-South Field

We built a comprehensive catalogue of structures in the GOODS-South field up to z ~ 2.5 (Salimbeni et al. 2009). We find over-densities at z ~ 0.7 at z ~ 1, at z ~ 1.6 and z ~ 2.2 :

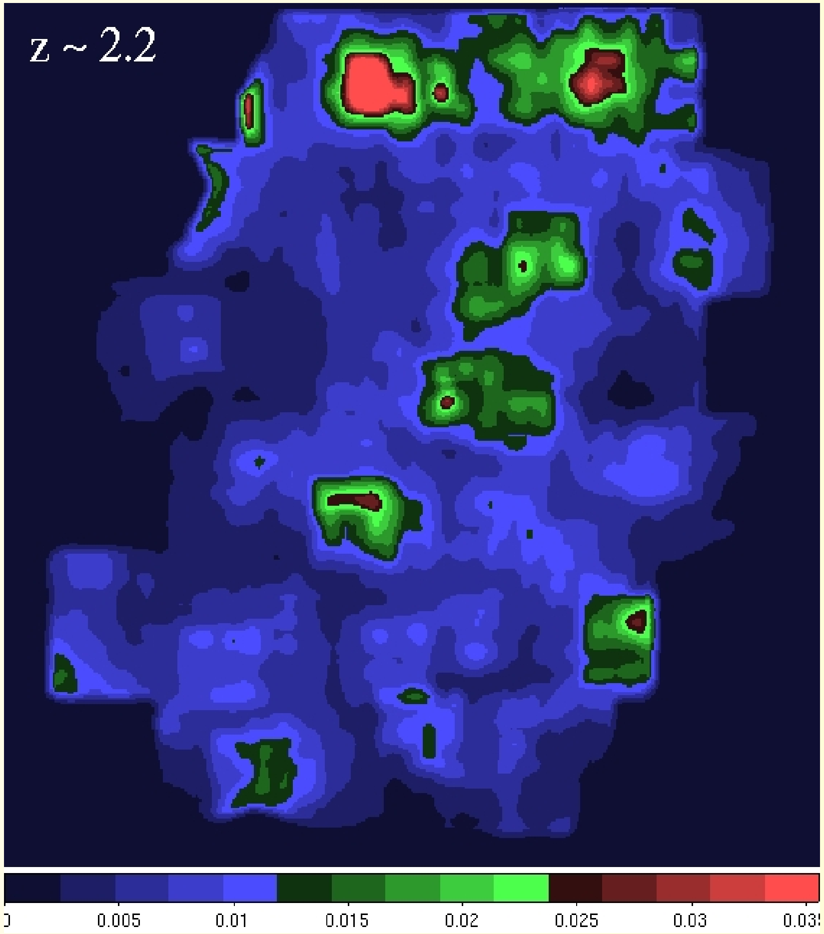


Spectroscopically confirmed (Kurk et al. 09)

Density maps at increasing redshift

Clusters in the GOODS-South Field

We built a comprehensive catalogue of structures in the GOODS-South field up to z ~ 2.5 (Salimbeni et al. 2009). We find over-densities at z ~ 0.7 at z ~ 1, at z ~ 1.6 and z ~ 2.2 :



Awaiting spectroscopic data from GEMINI South!

Density maps at increasing redshift

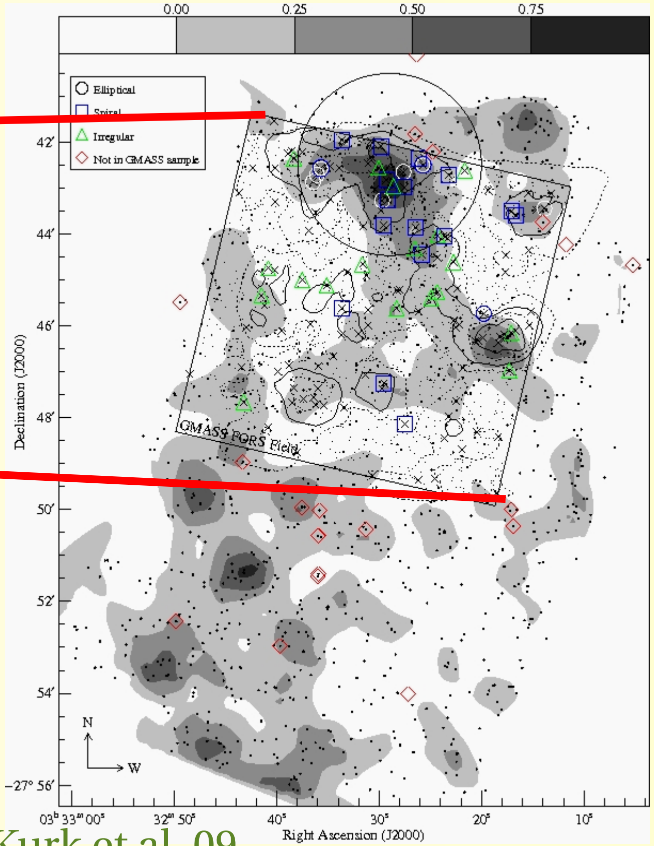
A forming cluster at z ~ 1.6

We analysed in depth the forming cluster at z~1.6 (RA=$03^h 32^m 29.28^s$, DEC=-27° 42' 35.99'') (Castellano et al. 2007). It is embedded in a diffuse structure at z~1.61 known from spectroscopic observations (e.g. Vanzella et al. 2005, 2006).

We estimate an M_{200} mass in the interval $1.3 \times 10^{14} - 5.7 \times 10^{14}\ M_{sun}$

The cluster has been later <u>spectroscopically confirmed</u> in the context of the GMASS survey (Kurk et al. 2009): velocity dispersion of ~ 500 Km/s

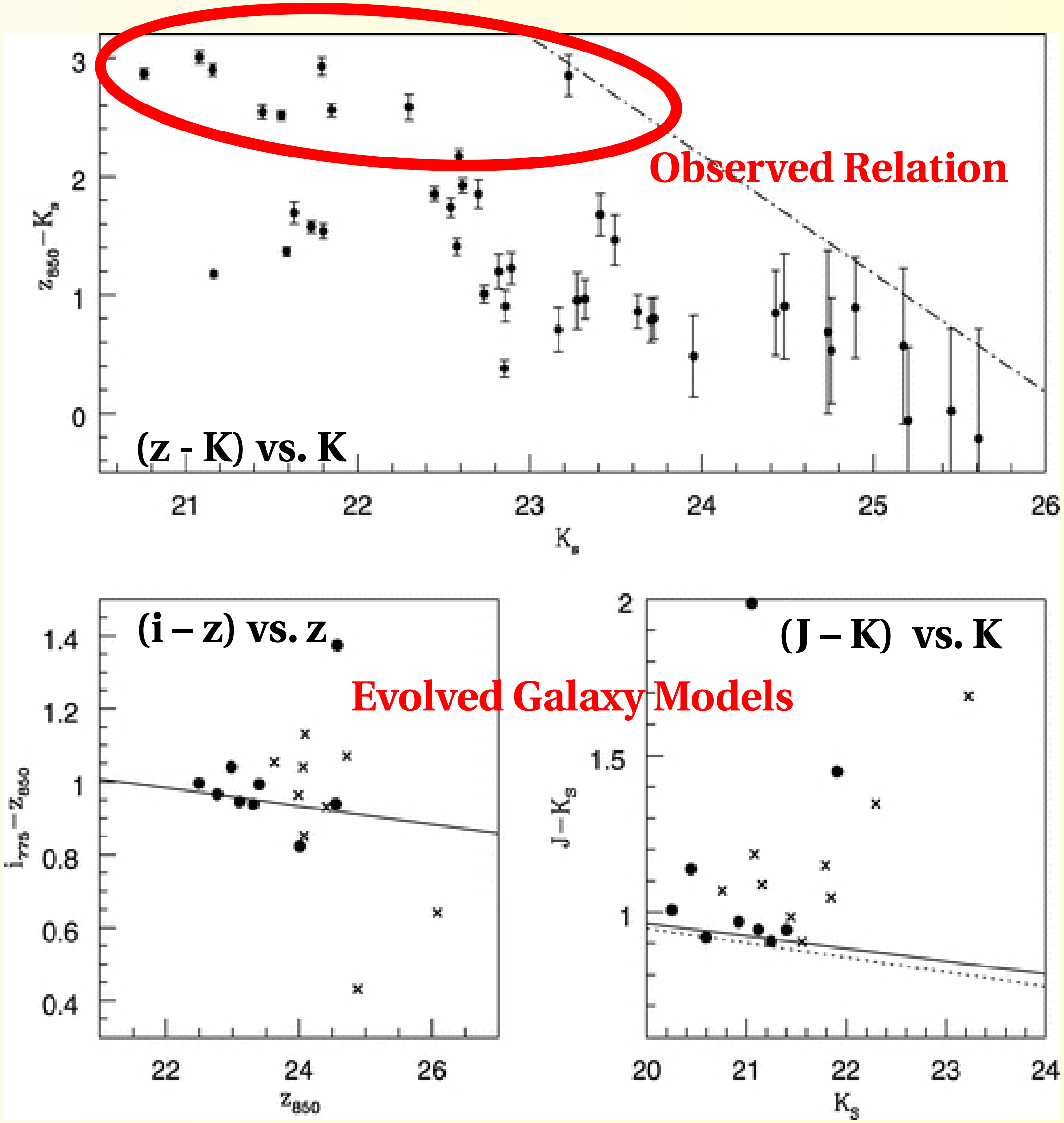
Castellano et al. 07



Kurk et al. 09

A forming cluster at z ~ 1.6 - C-M diagram

If we evolve the colors of of the 9 reddest galaxies we find a good agreement with the red sequence of a spectroscopically detected massive cluster at z =1.24 (e.g. De Marco et al. 2007).

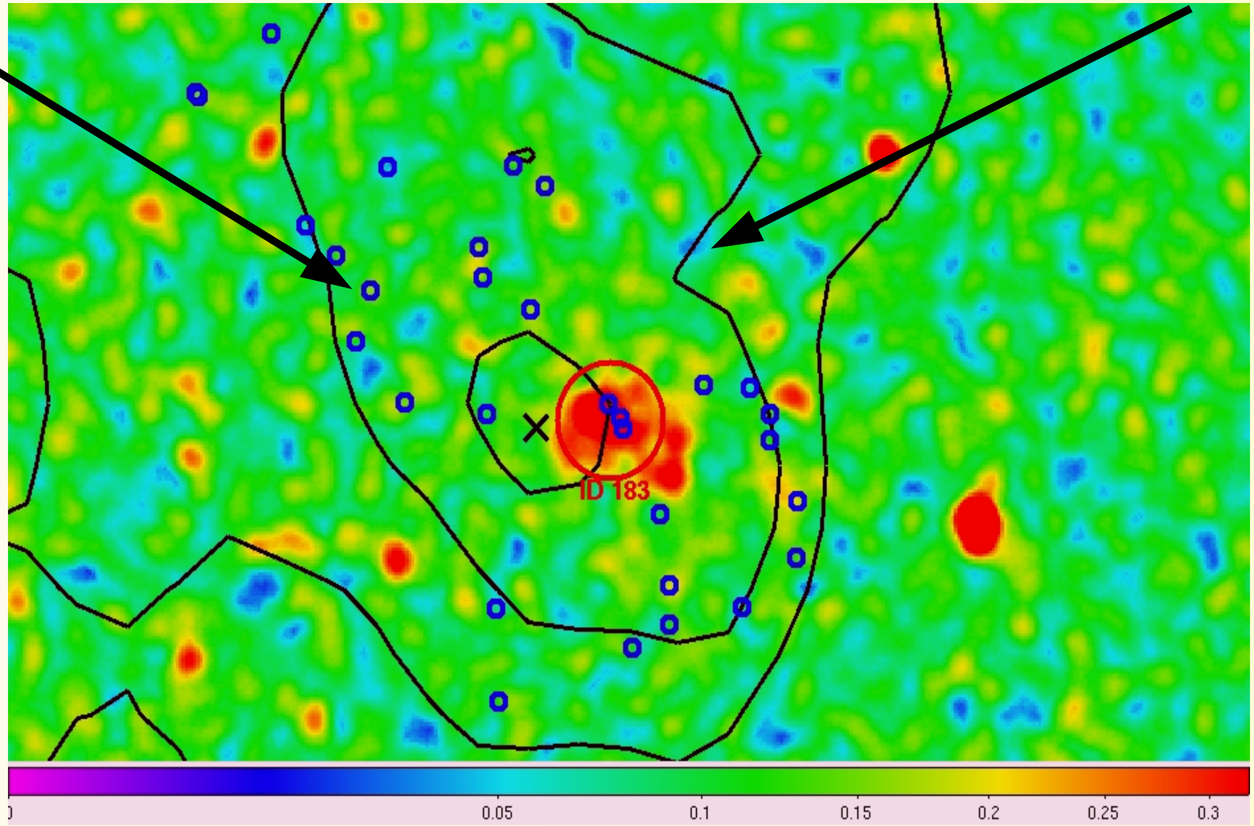


Castellano et al. 07

X-ray properties - I

cluster members

galaxy isodensity lines



Chandra soft X-ray image

A group at z~0.96 is associated to an extended X-ray source of the 2Ms CDFS catalogue (Luo et al. 08) with L_X=0.86-2.3 10^{43} erg/s in the interval 0.1-2.4 keV (Raymond Smith models with T=3-1 keV respectively).

X-ray properties - II

The two most massive groups (z~0.7 and z~1.6) are X-ray underluminous if we look at their position in a standard M_{200}-L_X diagram.

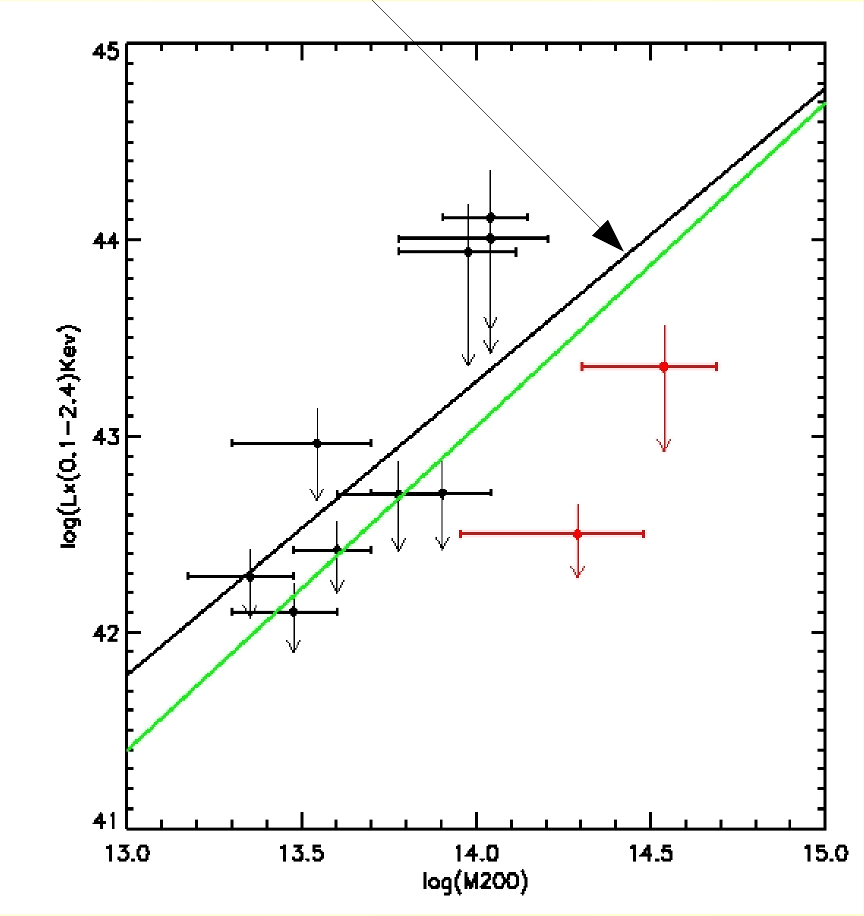
(Masses are estimated from the galaxy density contrast according to Steidel et al. 1998)

Best fit relations found from X-ray detected clusters by ***Reiprich*** *08 and* ***Rykoff*** *02*

Table 5. X-ray observations.

ID	Count Rate 0.3–4 keV (10^{-5})	Flux[a] 0.5–2 keV (10^{-16} erg s^{-1} cm^{-2})	L_X[a] 0.1–2.4 keV (10^{43} erg s^{-1})	S/N[b]
1	8.49	6.80–9.01	0.12–0.26	u.l.
2	5.56	4.45-5.90	0.08–0.18	u.l.
3	10.1	8.15–10.98	0.16–0.37	u.l.
4	11.2	9.04–12.31	0.19–0.44	u.l.
5	23.7	19.31–29.21	0.86–2.36	11.3
6	5.90	3.04–4.14	0.26–0.76	u.l.
7	5.77	2.97–4.05	0.26–0.74	u.l.
8	9.88	5.10–6.91	0.47–1.37	u.l.
9	5.68	3.08–4.14	0.83–3.67	u.l.
10	9.37	5.39–7.54	3.50–22.43	u.l.
11	5.72	3.29–4.69	2.27–15.06	u.l.
12	6.70	3.85–5.50	2.66–17.64	u.l.

[a] Values for a Raymond-Smith model with assumed temperature respectevelly of 3 keV and 1 keV and metallicity 0.2 $Z_\odot$.
[b] u.l. indicates structures with a 3σ upper limit in the flux.

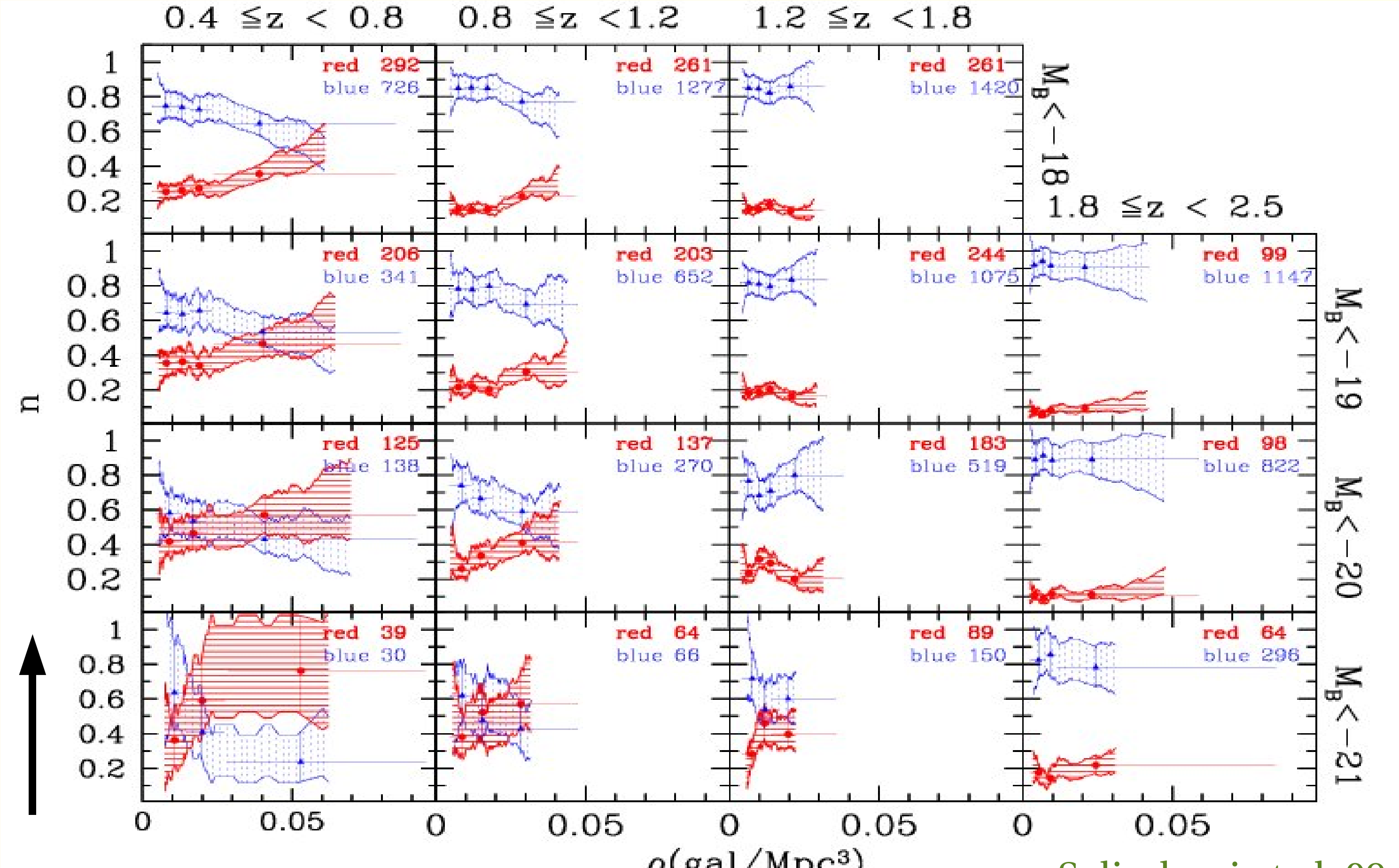


Galaxy properties as a function of density - III

We find that the color segregation progressively disappears at high redshift

Our analysis confirms and extend previous studies limited at z~1.5 (e.g. Cucciati et al. 2007, Cooper et al. 2007):

Redshift



Salimbeni et al. 09

Luminosity

Fraction of Red/Blue Galaxies

Density

Conclusions

- It is possible to study high redshift galaxy environment, and to individuate galaxy clusters, with photometric redshifts.

- We built a comprehensive **catalogue of structures in the GOODS-South field**. 'Sheets' of diffuse overdensities, with embedded groups/clusters, appear up to the highest redshifts probed.

- Among them we **detected an high redshift small cluster** later confirmed with spectroscopy. It shows the characteristics of a **forming cluster** and a forming red sequence.

- The most massive clusters in our sample seem to be X-ray underluminous.

- We found that **color segregation** with density is higher at lower redshift and brighter magnitudes but it **seems to disappear, also for the brightest galaxies, between z~1.5 and z~2.0.**