

# How environment affects galaxy colour: a perspective from large and deep redshift surveys.

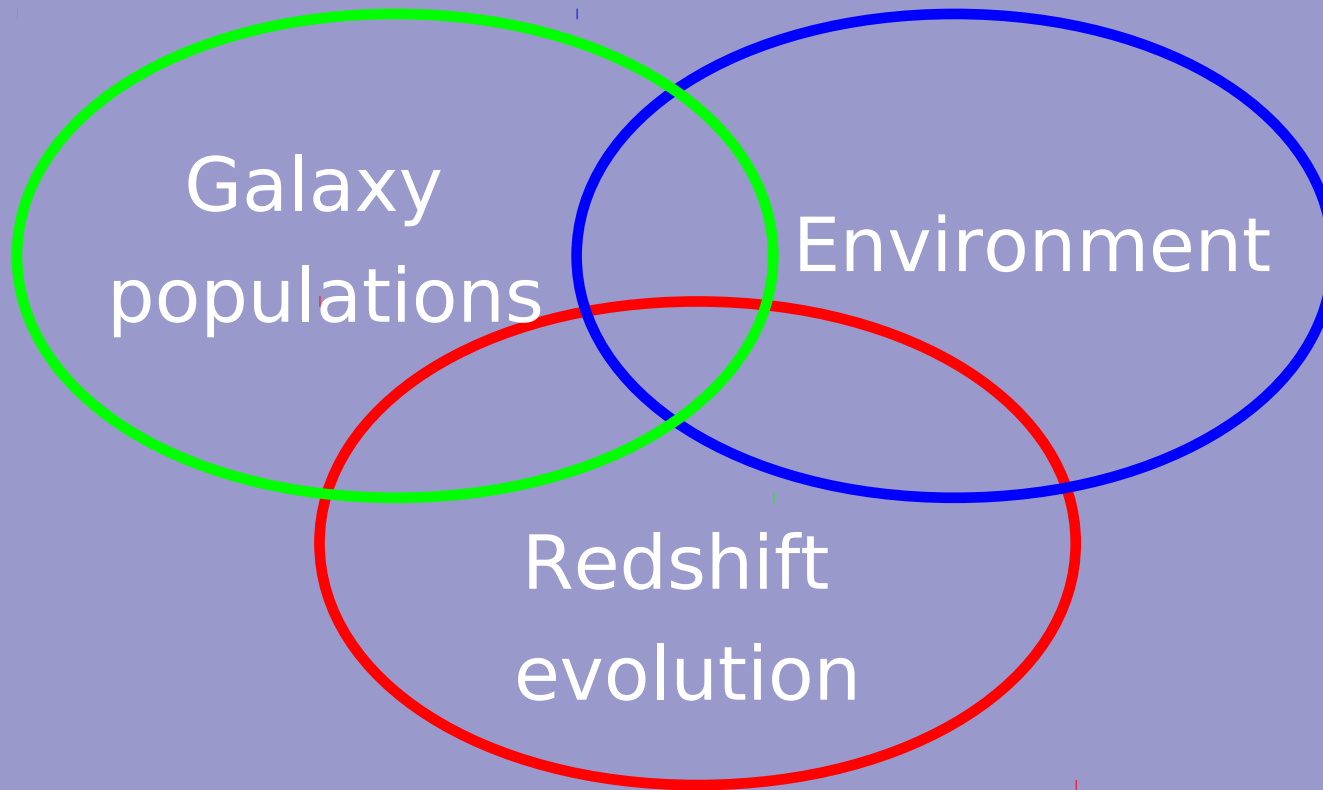
**Olga Cucciati (INAF-OATS)**

- + Angela Iovino (INAF-OABrera Milano)
- + Marco Scodeggio (INAF-IASF Milano)
- + M.Bolzonella, D.Vergani, E. Zucca, S. Bardelli, G. Zamorani (INAF-OABo Bologna)
- + K.Kovac, C.Knobel, S.Lilly (ETH Zurich)
- + L.Tasca (LAM Marseille)
- + VVDS and zCOSMOS Teams

# Outline

- Introduction
  - Ingredients
  - Open questions
- VVDS, zCOSMOS and DEEP2 surveys
- The parameterization of environment
  - local density and galaxy groups
- The colour-density relation
- The role of stellar mass
- Conclusions and future work

# Ingredients



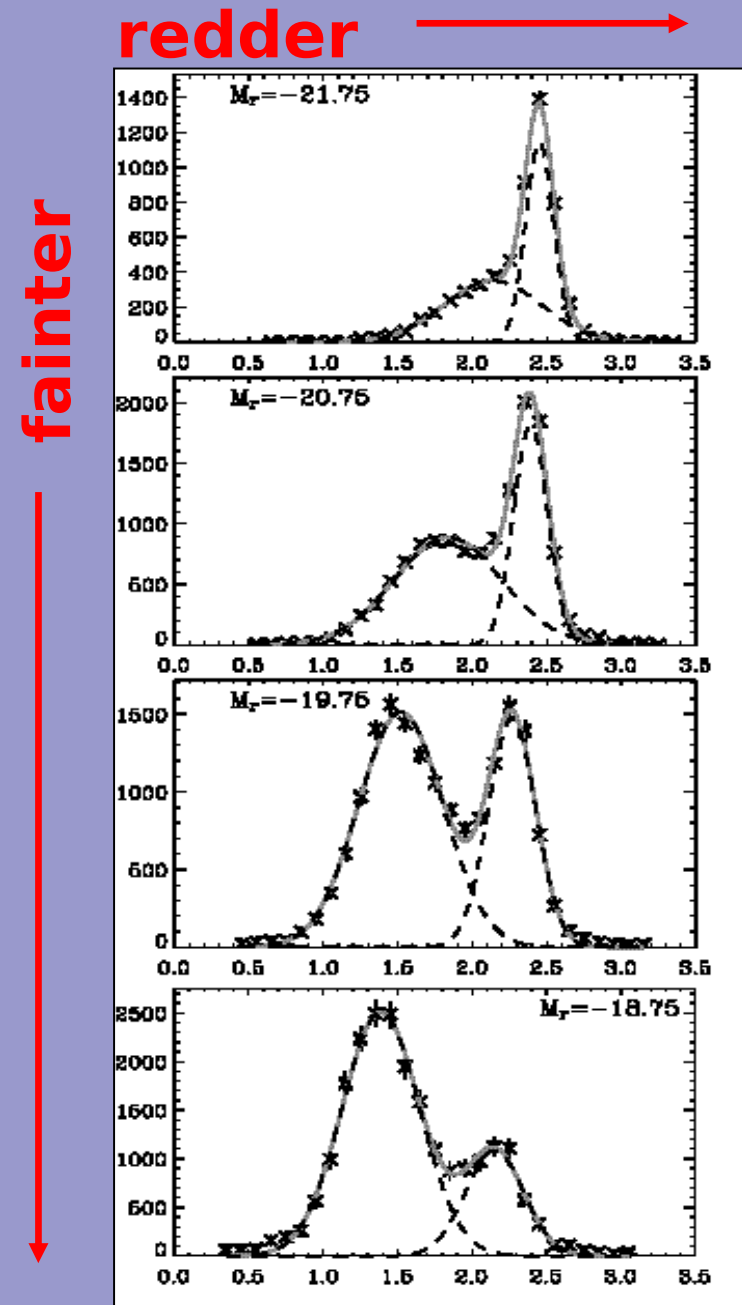
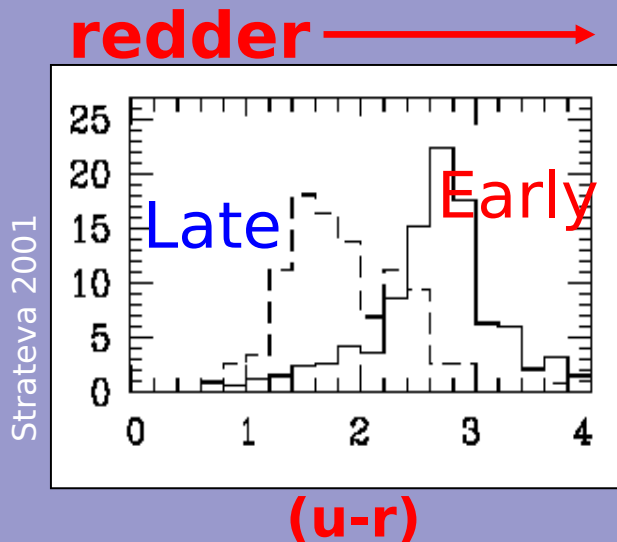
# Ingredients overview (1): Galaxy populations

Bimodal distribution in the local universe:

→ Elliptical - redder-older-brighter-passive...

→ Spiral - bluer-younger-fainter-active...

Kormendy 1977, Tully & Fisher 1977, Sandage & Visvanathan 1978, Djorgovski & Davis 1987 ... Strateva 2001, Kauffmann et al 2004, Baldry et al 2004, Balogh et al 2004, Croton et al 2005...



(u-r)

Baldry 2004

# Ingredients overview (2): Environment

Correlation between galaxy properties and environment in the local universe:

**“early red” → high densities**

**“late blue” → low densities**

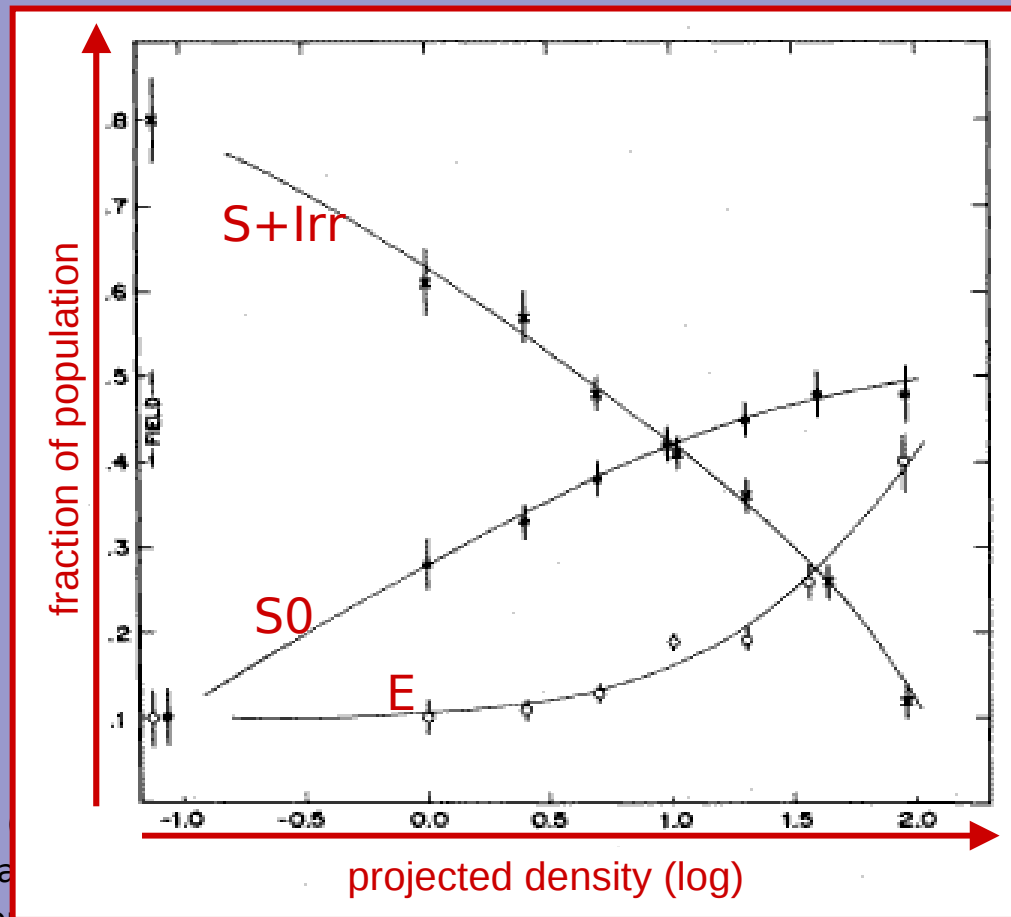
Galaxy groups and clusters

Morphology-density in groups (Dressler 1980) and in all environments (Weinmann 2006), colour-density and luminosity-density (Balogh et al. 2004, Kauffmann et al 2004...), SFR-density (Tanaka et al 2004), 2-point galaxy correlation function per colour and luminosity (Norberg et al 2002, Madgwick et al 2003), LF per type and environment (Croton et al 2005)...

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t galaxy correlation function

per type and environment (Croton et al 2005)...

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Galaxy groups and clusters

Density contrast

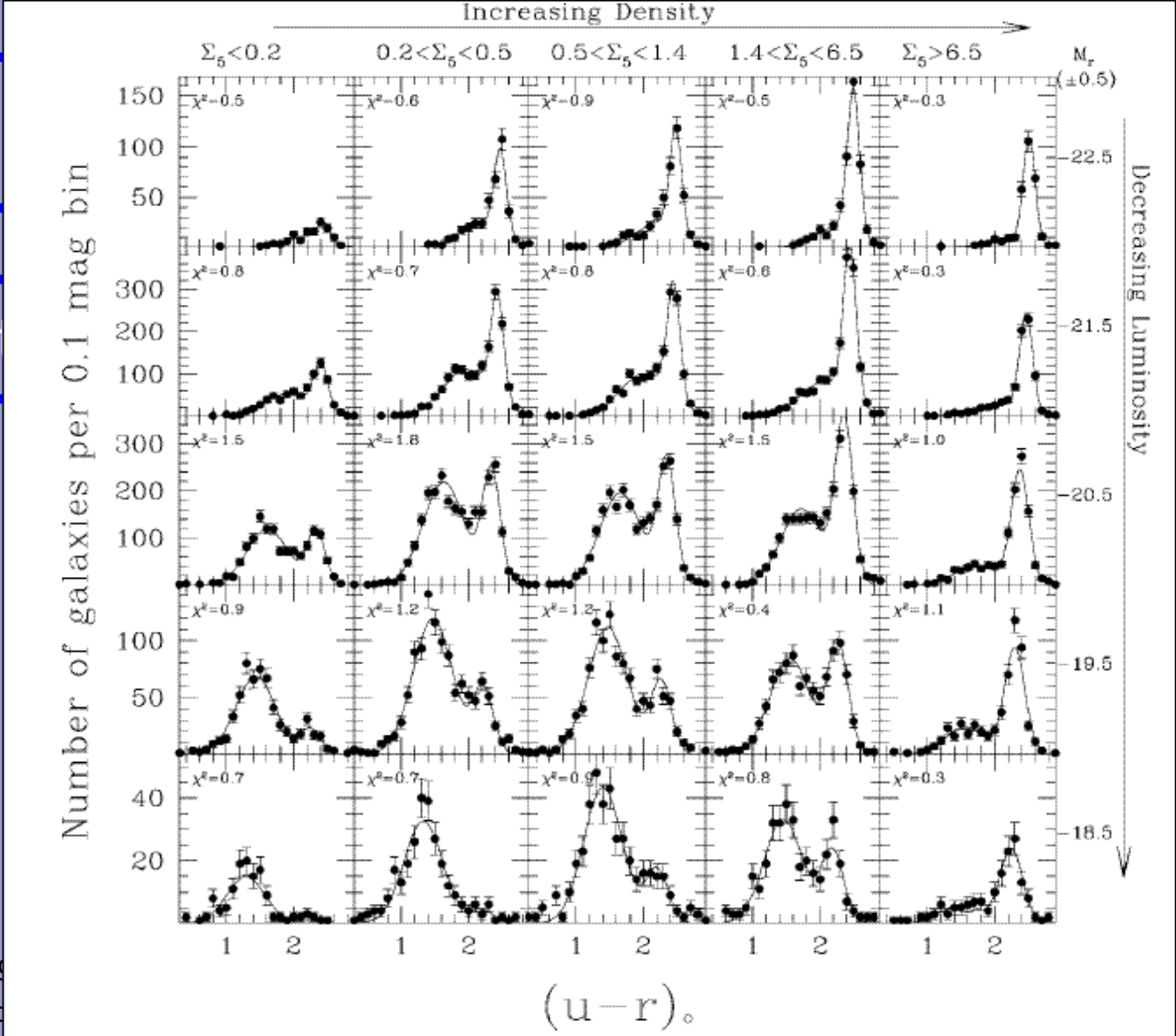
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Galaxy  
 Density contrast

Balogh 2004



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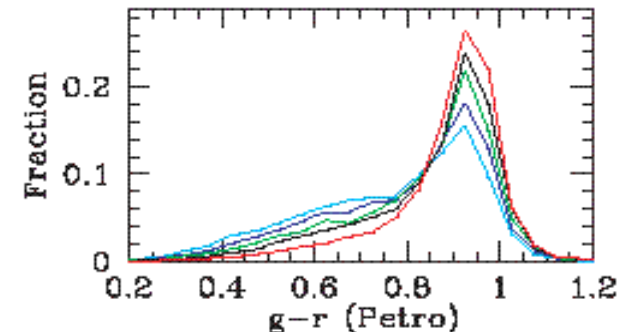
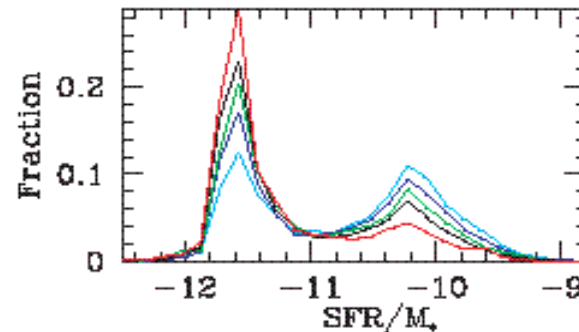
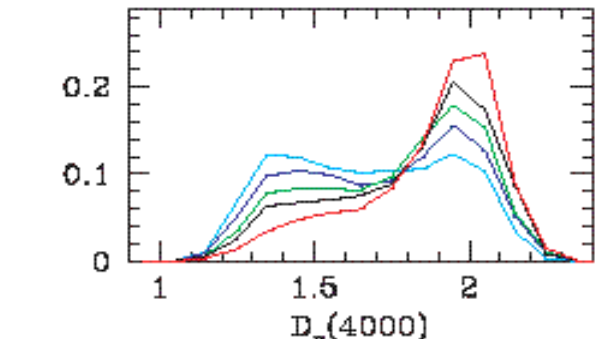
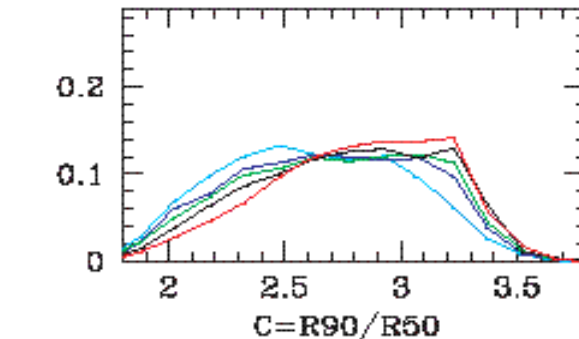
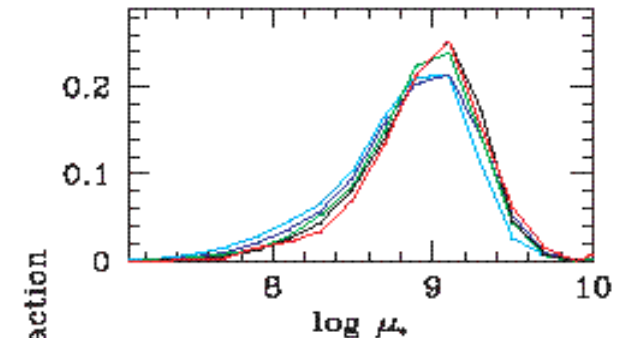
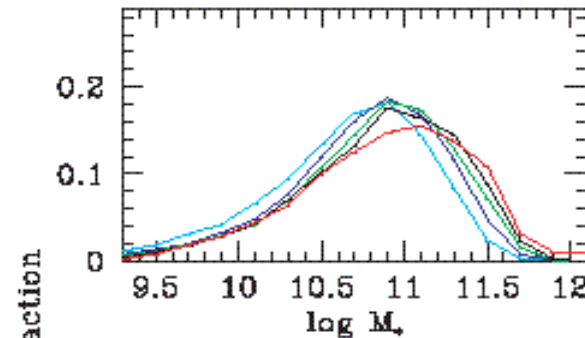
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Correlation between galaxy properties and environment in the local universe:  
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Galaxy

Density contrast

Kauffmann 2004



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Galaxy groups and clusters

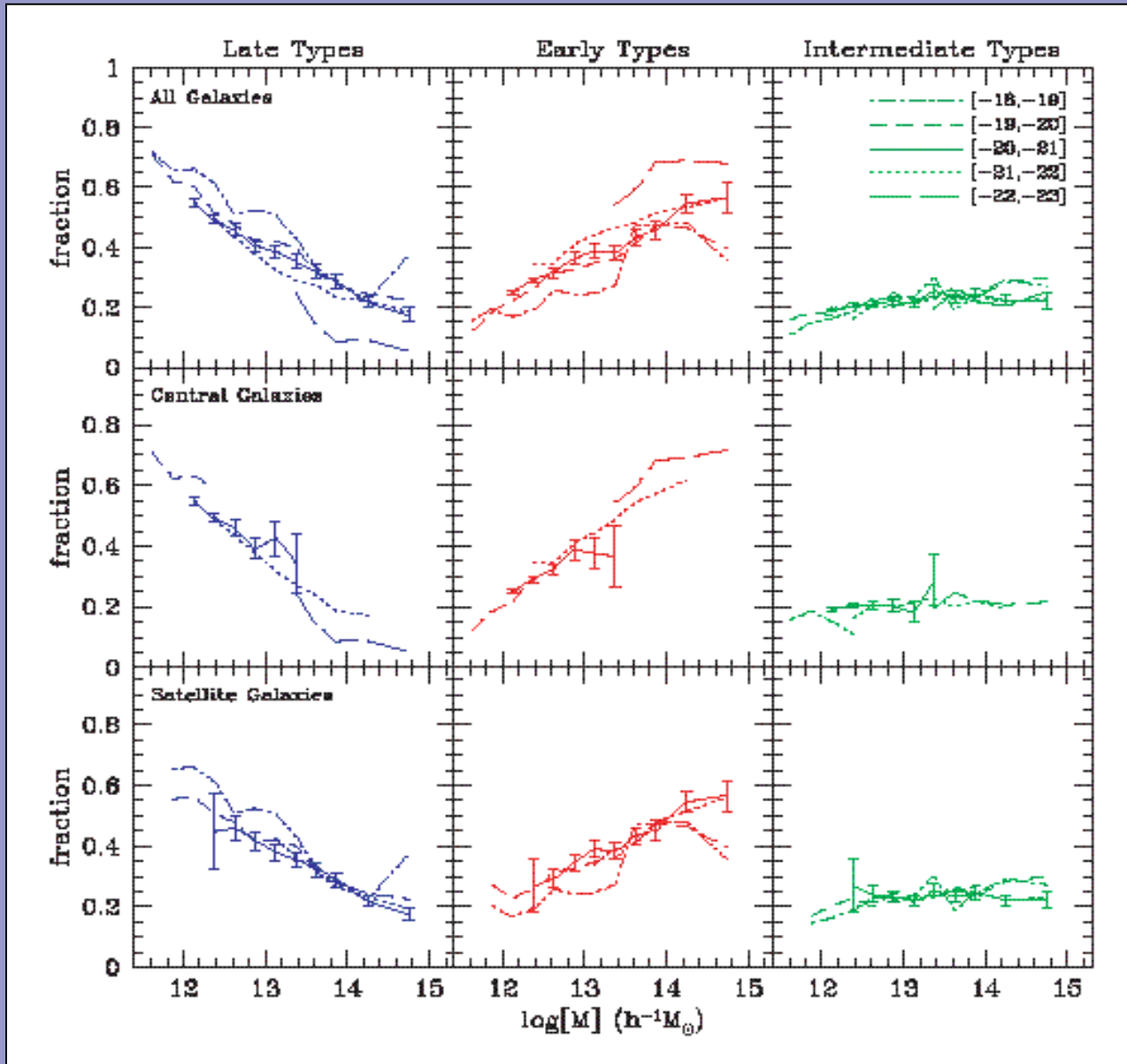
Density contrast

Halos

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Correlation between galaxy properties and environment in the local universe:  
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clusters

Halos

Weinmann 2006

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Galaxy groups and clusters

Density contrast

Halos

Large Scale Structure

Morphology-density in groups (Dressler 1980) and in all environments (Weinmann 2006), colour-density and luminosity-density (Balogh et al. 2004, Kauffmann et al 2004...), SFR-density (Tanaka et al 2004), 2-point galaxy correlation function per colour and luminosity (Norberg et al 2002, Madgwick et al 2003), LF per type and environment (Croton et al 2005)...

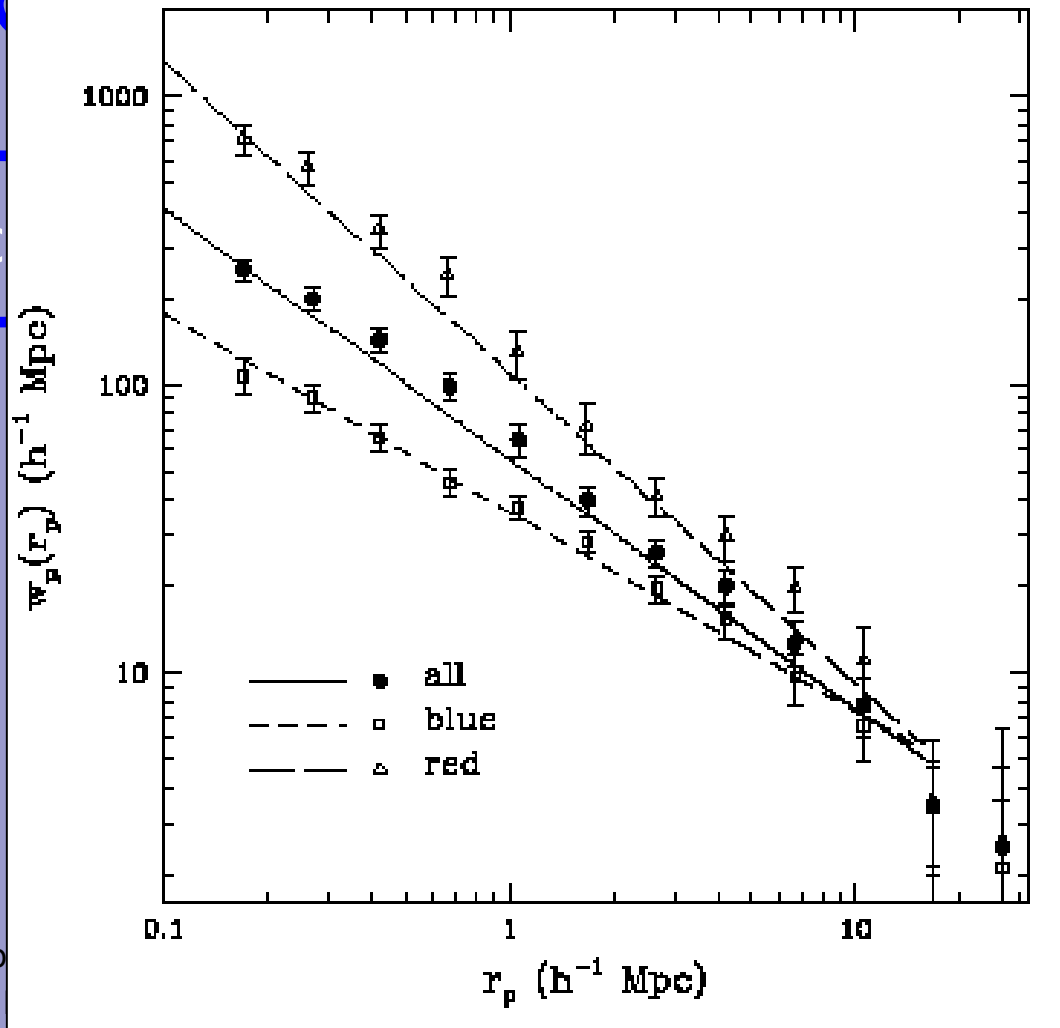
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Density c

OS

Zehavi 2005



Morphology-density in group  
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r-density and luminosity-  
galaxy correlation function

# Ingredients overview (3): Redshift evolution

Redshift evolution

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Redshift evolution

Galaxy populations

Environment

Galaxy groups  
and clusters

Density  
contrast

At higher  $z$  still bimodal distribution...  
(Bell et al. 2004, Franzetti et al. 2006,  
Menanteau et al 2006, Zucca et al.  
2006...)

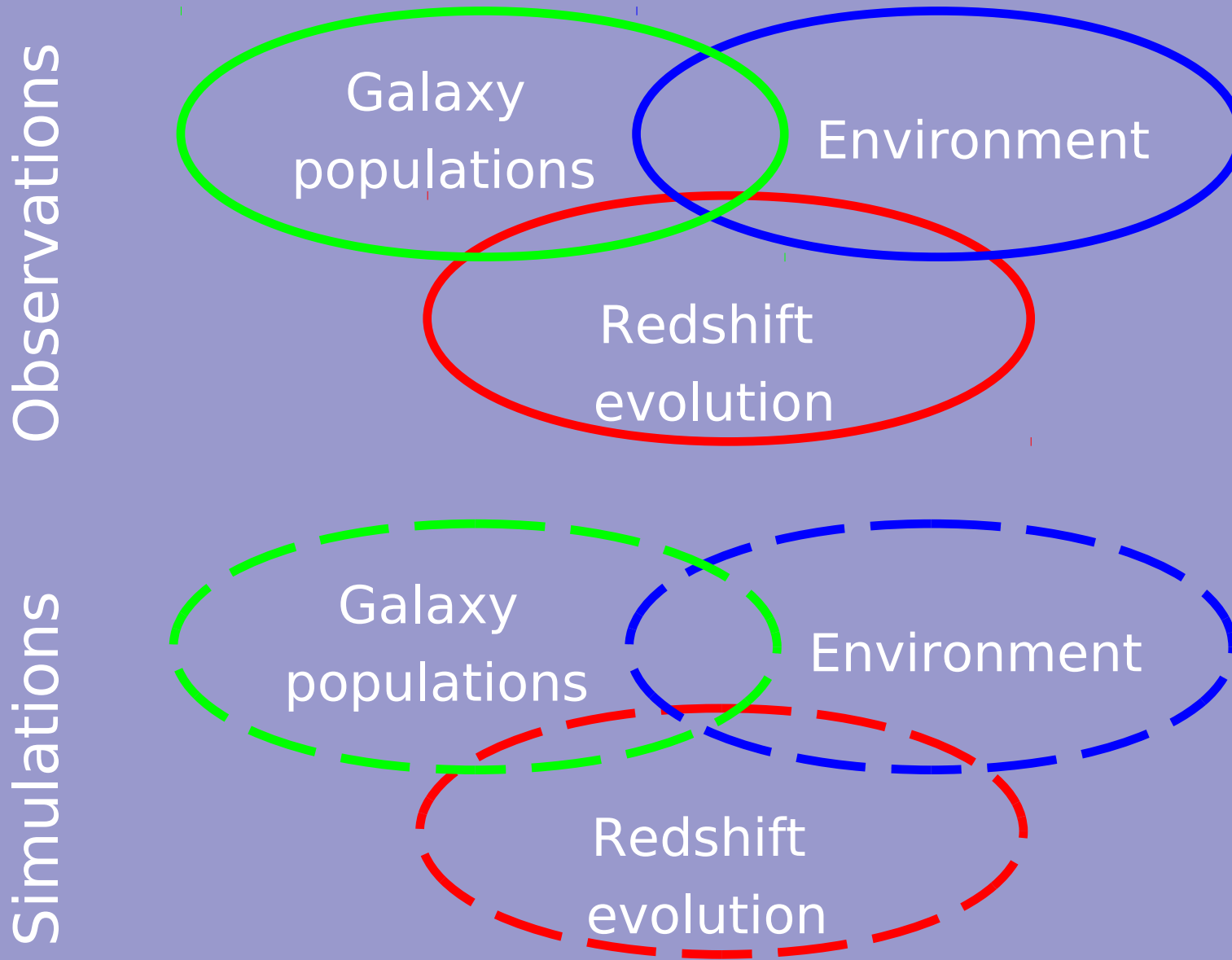
.. but presence of red star forming  
galaxies and bluer and fainter early  
type galaxies  
(Franzetti et al 2006, Menanteau et al  
2006...)

Studies of clusters: at higher  
 $z$ , **still trends with density**  
(Treu et al 2003, Poggianti et  
al 2006) , but **morph.-  
density evolves** (Dressler et  
al 1990) and evolution  
depends on environments  
(Smith et al 2005).

→ **sparse samples**

**The colour-density  
relation evolves with  
redshift** (Cucciati et al  
2006, Cooper et al 2007),  
something happens also for  
SFR and sSFR (Elbaz 2007,  
Cooper 2008) at  $z \sim 1$

# Ingredients overview (4!!): Simulations

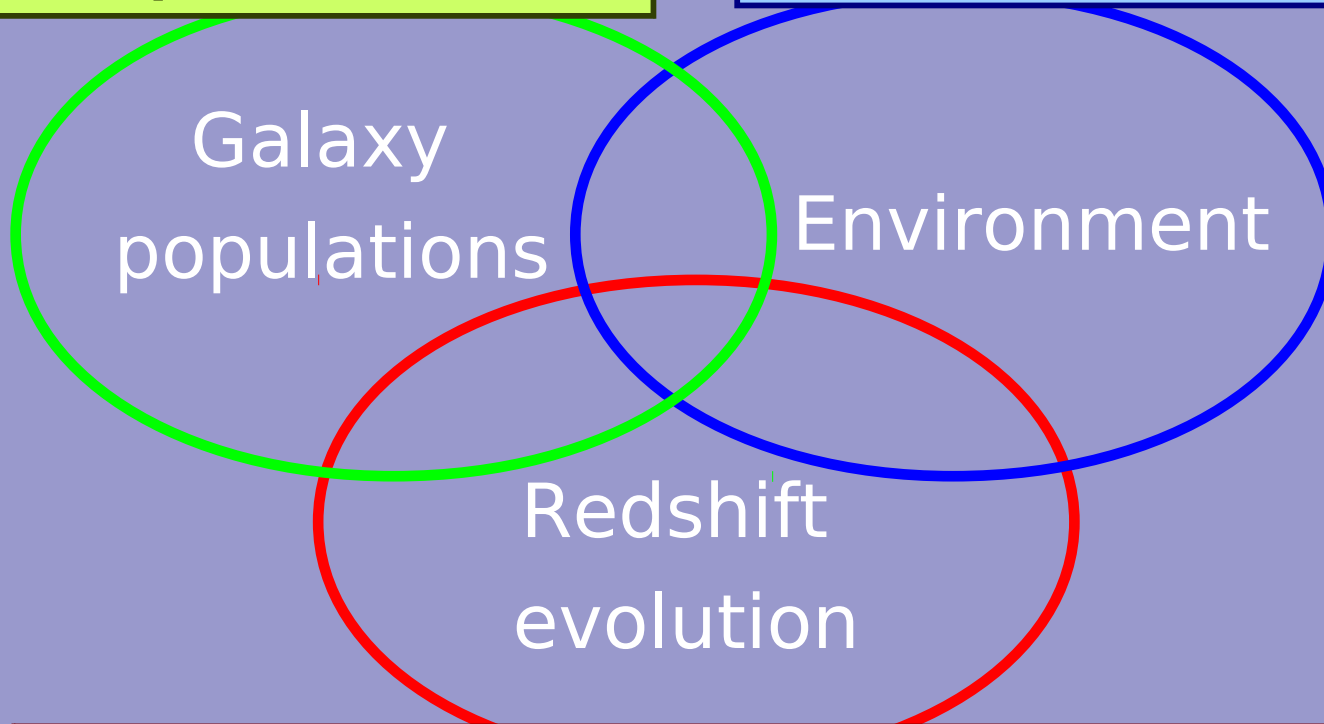




And of course, a bunch of open questions

**Does environment affect only one “driving” property?  
How do we define a galaxy sample?**

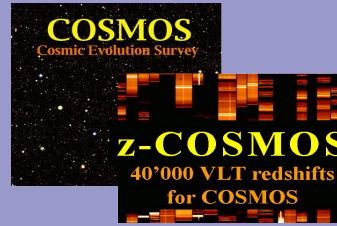
**What is environment?  
Is there a driving scale/environment?**



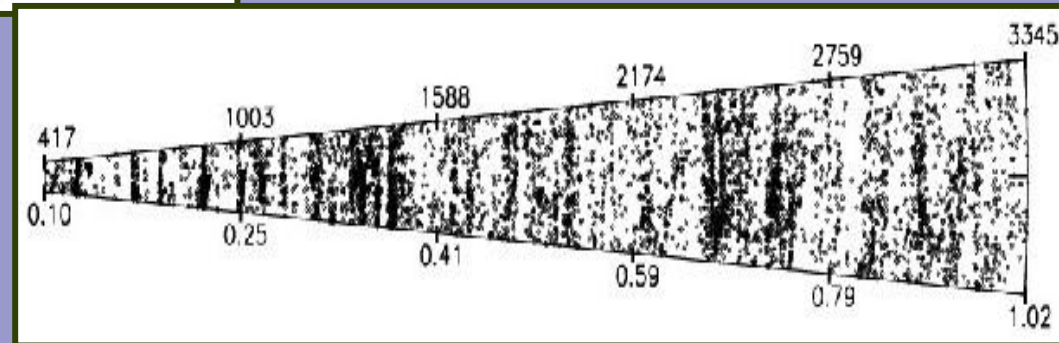
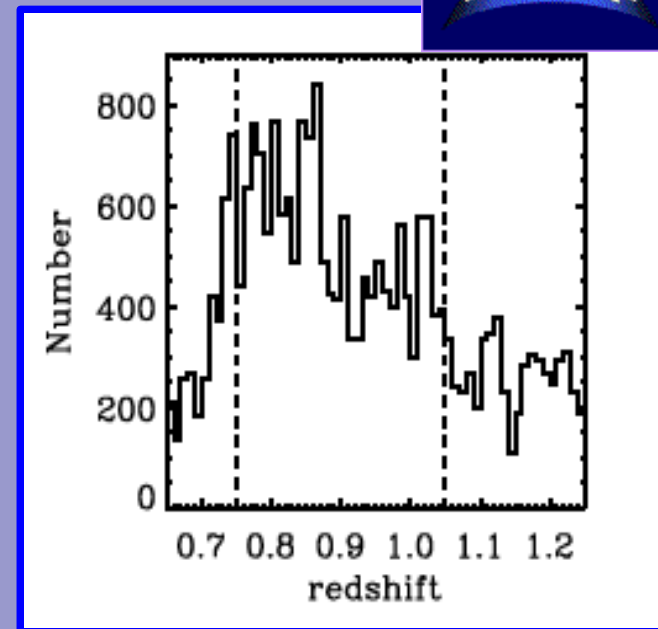
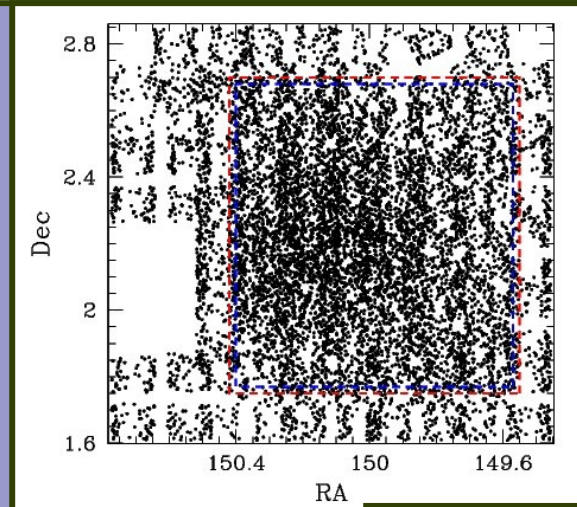
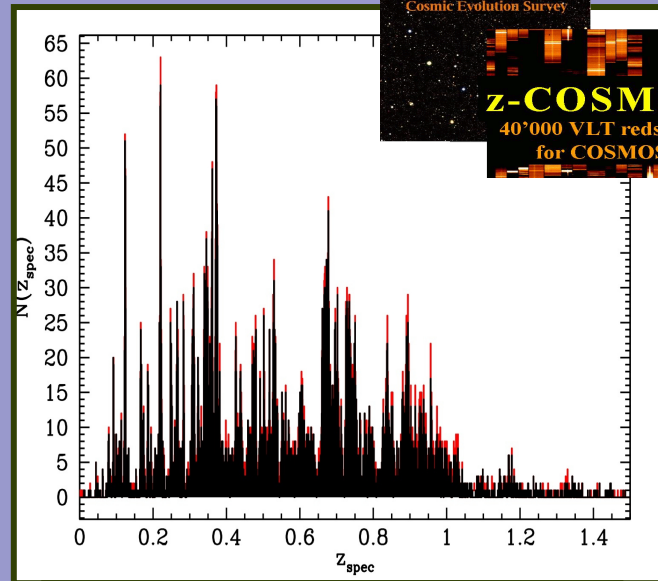
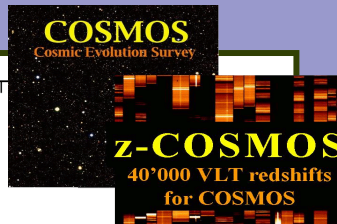
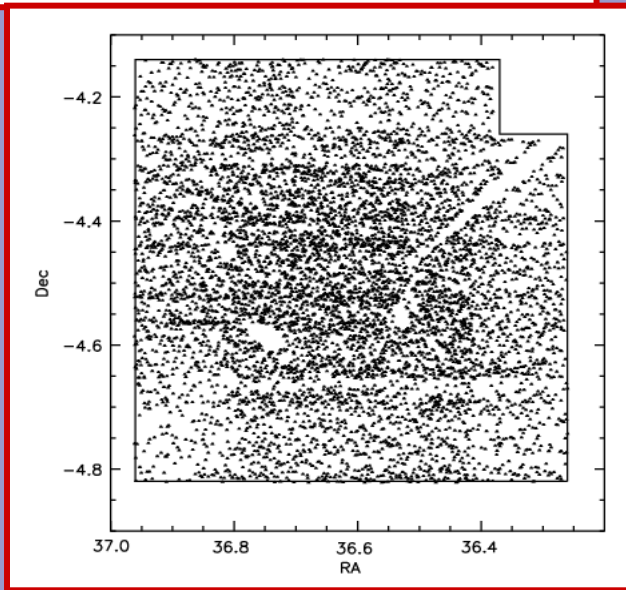
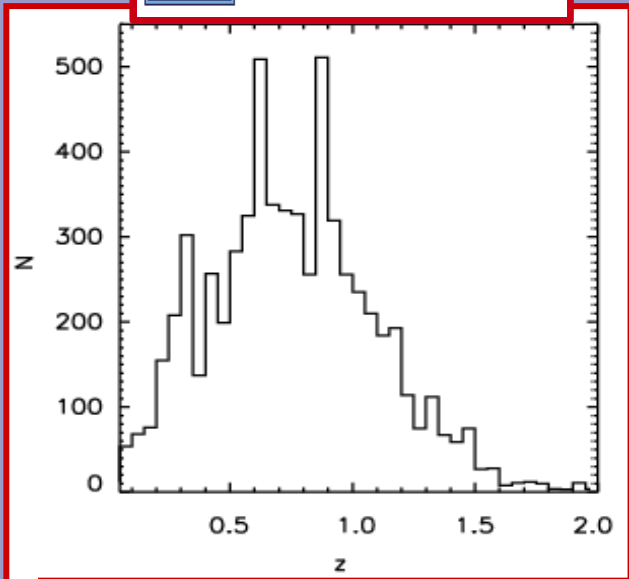
**Does environment differently affect only galaxy formation or also evolution?**

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	VVDS-Deep	ZCOSMOS Bright	DEEP2
Selection method	<b>Flux limited sample:</b> $17.5 \leq I_{AB} \leq 24$	<b>Flux limited sample:</b> $15 \leq I_{AB} \leq 22.5$	<b>Colour selected sample:</b> BRI colour-colour cut
Photometry	Complete to $I_{AB} = 24$ BVRI bands (12K camera at CFHT) $u^*, g', r', i', z'$ (CFHT Legacy Survey.)	Complete to $I_{AB} = 22.5$ Data from both space- (HST, XMM, Spitzer...) and ground-based telescopes (VLA, VLT, Subaru, CFHT)	<ul style="list-style-type: none"> <li>• Complete to <math>R_{AB} = 24.1</math></li> <li>• BRI bands</li> <li>• J and K on smaller area</li> </ul>
Sky area	<b>~0.5 deg<sup>2</sup></b>	<b>~1.4 deg<sup>2</sup></b>	<b>~4 fields: total of 3 deg<sup>2</sup></b>
Spec. Redshifts:	<ul style="list-style-type: none"> <li>- <b>6582</b> secure redshift</li> <li>- <math>\langle z \rangle \sim 0.76</math> (up to <math>z \sim 5</math>)</li> <li>- 1 arcsec wide slits</li> <li>- spectral range <math>5500 &lt; (\text{\AA}) &lt; 9400</math></li> <li>- spec. res. <math>R = 227</math></li> <li>- Redshift accuracy: 275 km/s.</li> </ul>	<ul style="list-style-type: none"> <li>- <b>8500</b> secure redshift</li> <li>- <math>\langle z \rangle \sim 0.7</math> (up to <math>z \sim 1.5</math>)</li> <li>- 1 arcsec wide slits</li> <li>- spectral range <math>5550 &lt; (\text{\AA}) &lt; 9650</math></li> <li>- spec. res. <math>R = 600</math></li> <li>- Redshift accuracy; 100 km/s.</li> </ul>	<ul style="list-style-type: none"> <li>- <b>23000</b> secure redshift</li> <li>- <math>\langle z \rangle \sim 1</math> (up to <math>z \sim 1.4</math>)</li> <li>- 1 arcsec wide slits</li> <li>- spectral range <math>6500 &lt; (\text{\AA}) &lt; 9100</math></li> <li>- spec. res. <math>R = 5000</math>.</li> <li>- Redshift accuracy: 68 km/s.</li> </ul>



# Environment parameterization

## Density contrast field

- Smoothing filter
- Density field for all galaxies

## Galaxy groups

- Group-finding algorithm
- Group catalogue: in or out!

# Environment (1): density contrast

3D galaxy density contrast  
(spherical or cylindrical volumes):

$$\delta(r,R) = \frac{\rho(r,R) - \overline{\rho(r)}}{\overline{\rho(r)}}$$

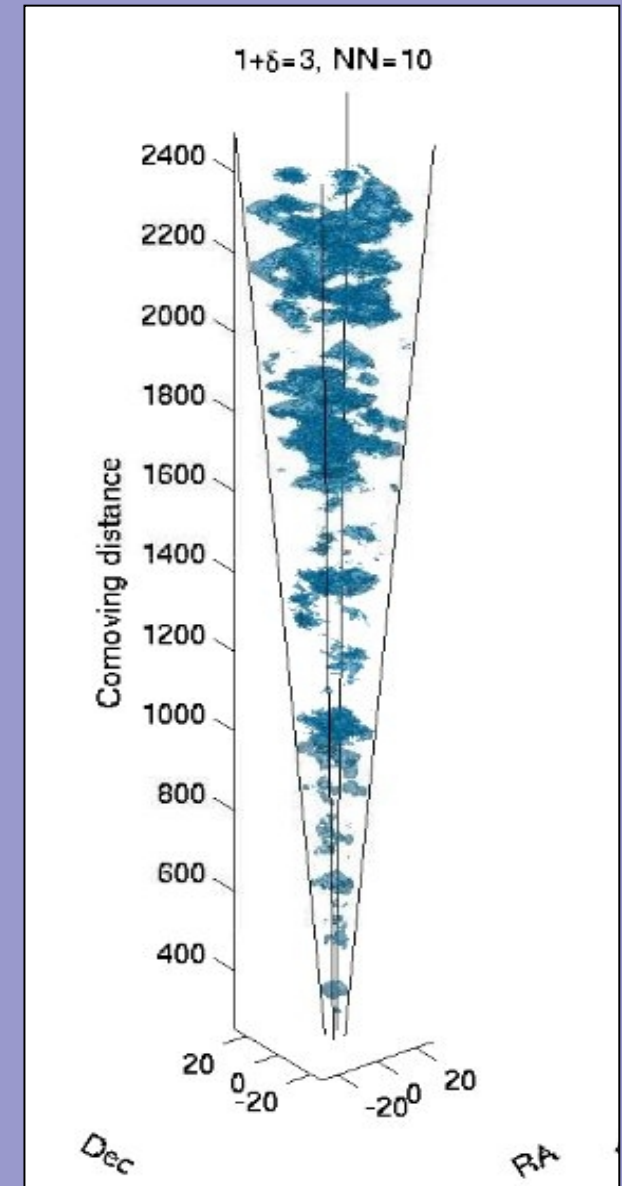
$$\rho(r) = \sum \frac{m_i W(|r-r_i|, R)}{\Phi_i}$$

$W(r,R)$  → filter

$m$  → weighting function

$\Phi$  → selection function

$R$  → filter radius: fixed or  $n^{\text{th}}$  n.n. distance



**Density reconstruction reliability tested with simulations**

(VVDS: Cucciati et al 2006; zCOSMOS: Kovac et al 2009; DEEP2: Cooper et al 2006)

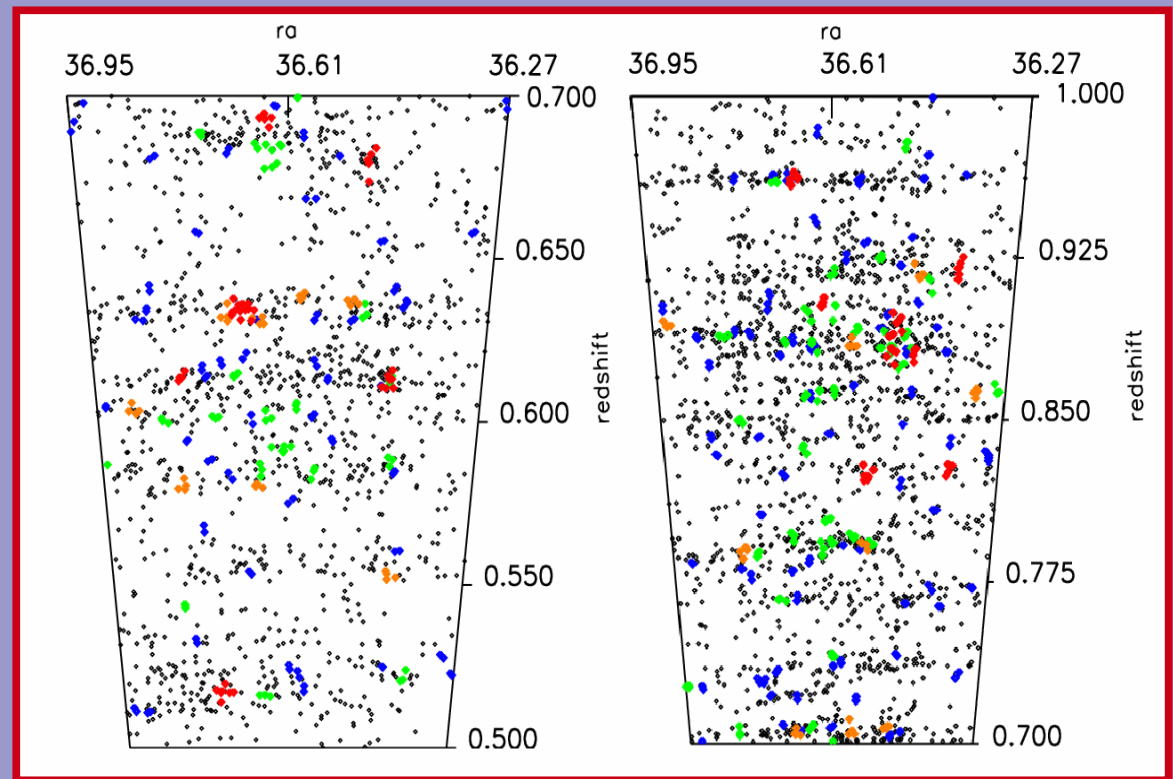
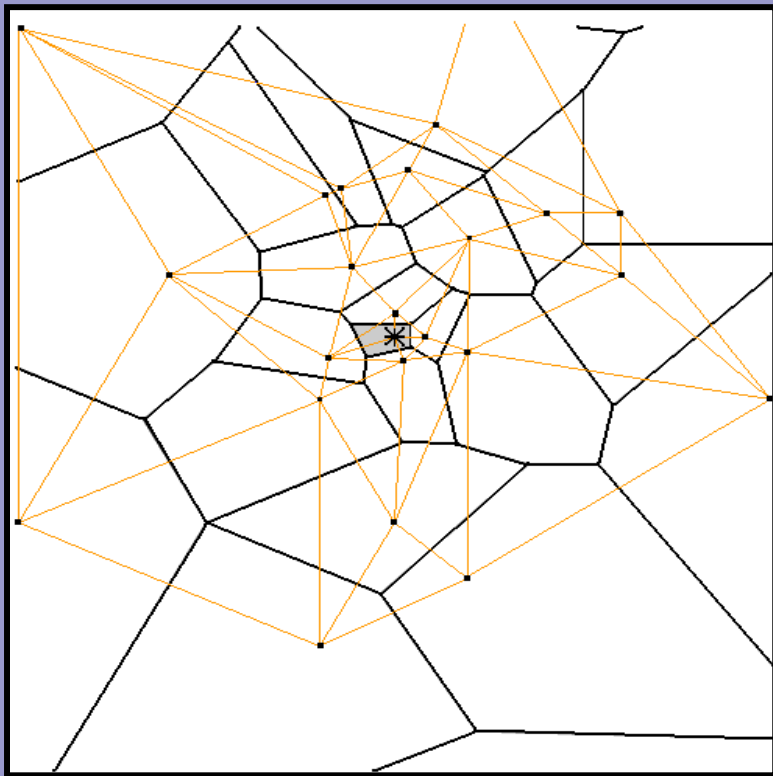
# Environment (2): optically detected galaxy groups

Finding groups algorithms

- **Friend of Friend**
- **Voronoi-Delaunay** tessellation

VVDS:  $\sim 300$  groups in  $0.2 < z < 1$   
ZCOSMOS:  $\sim 800$  groups in  $0.2 < z < 1$   
DEEP2:  $\sim 900$  groups in  $0.7 < z < 1.4$

Algorithms tuned with simulations: **completeness, purity...**

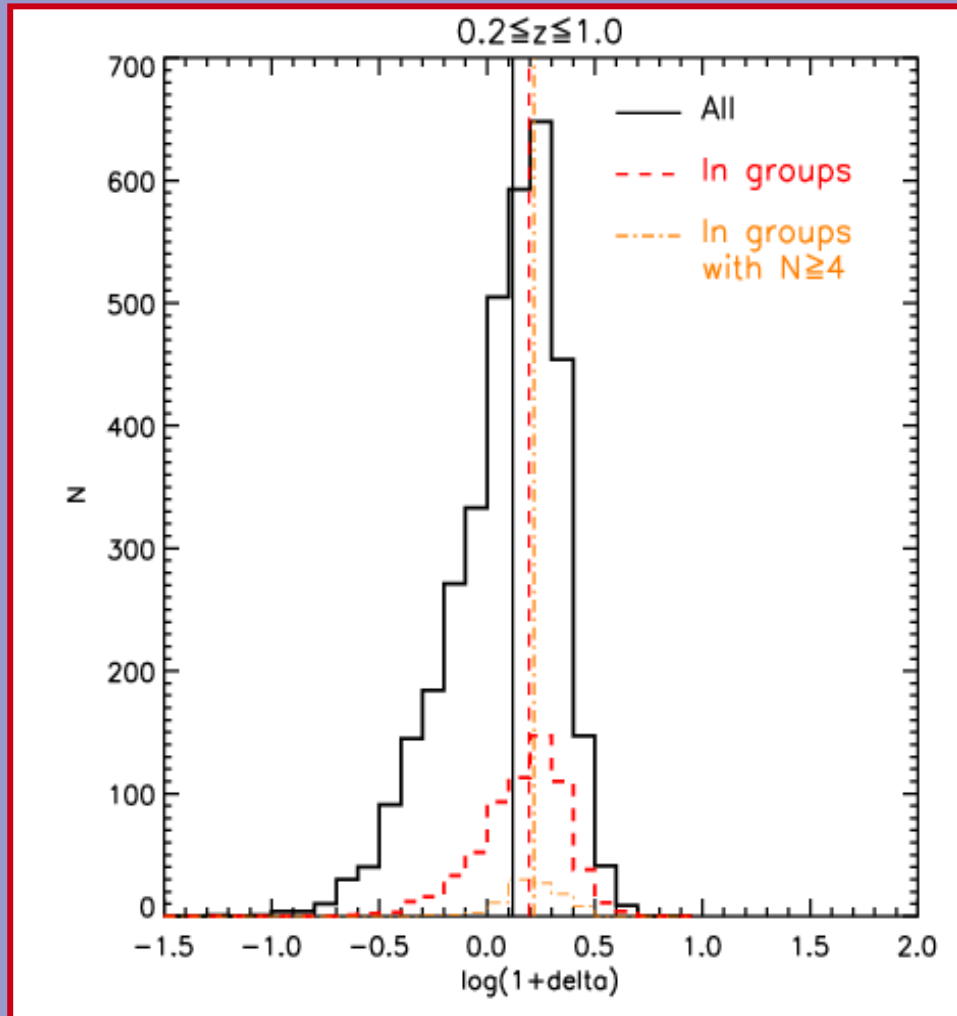


Cucciati et al 2010a

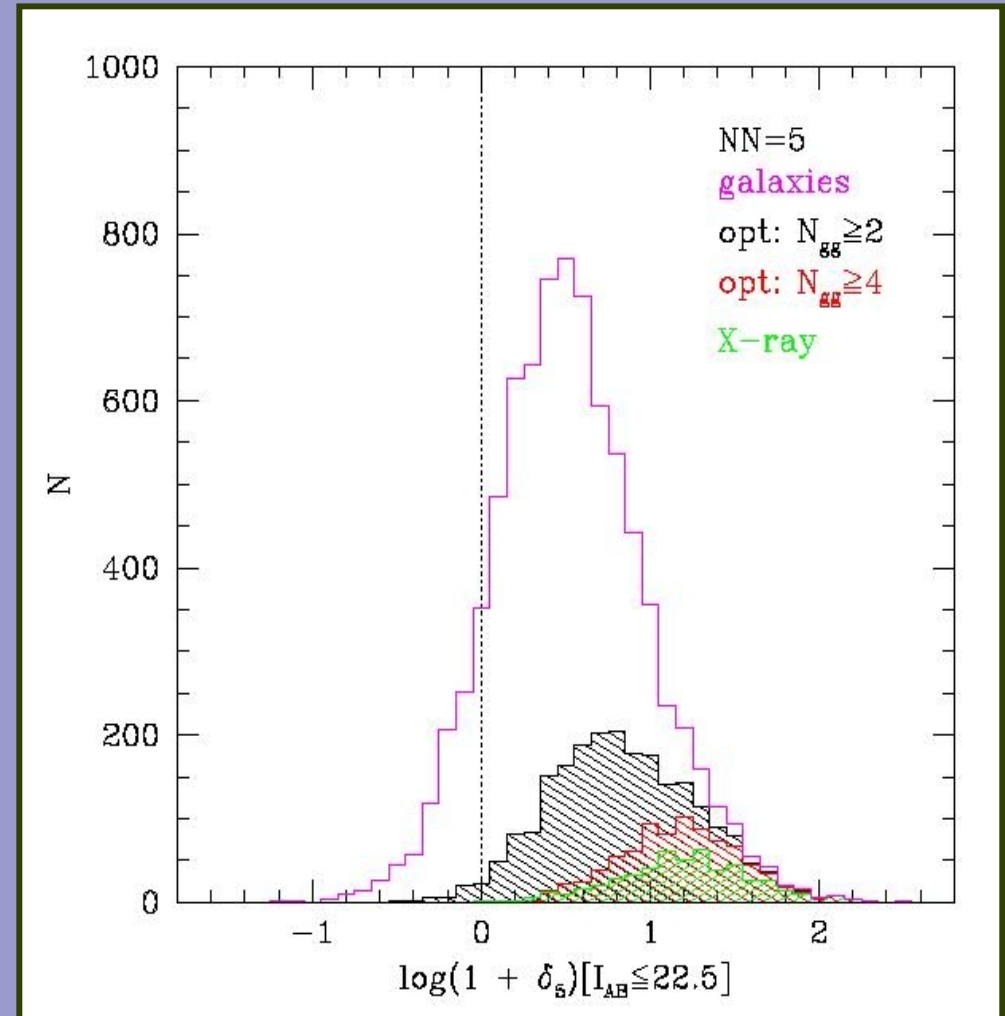
(VVDS: Cucciati et al 2010a; zCOSMOS: Knobel et al 2009; DEEP2: Gerke et al 2005)

# Environment (3): density contrast vs galaxy groups

VVDS



zCOSMOS

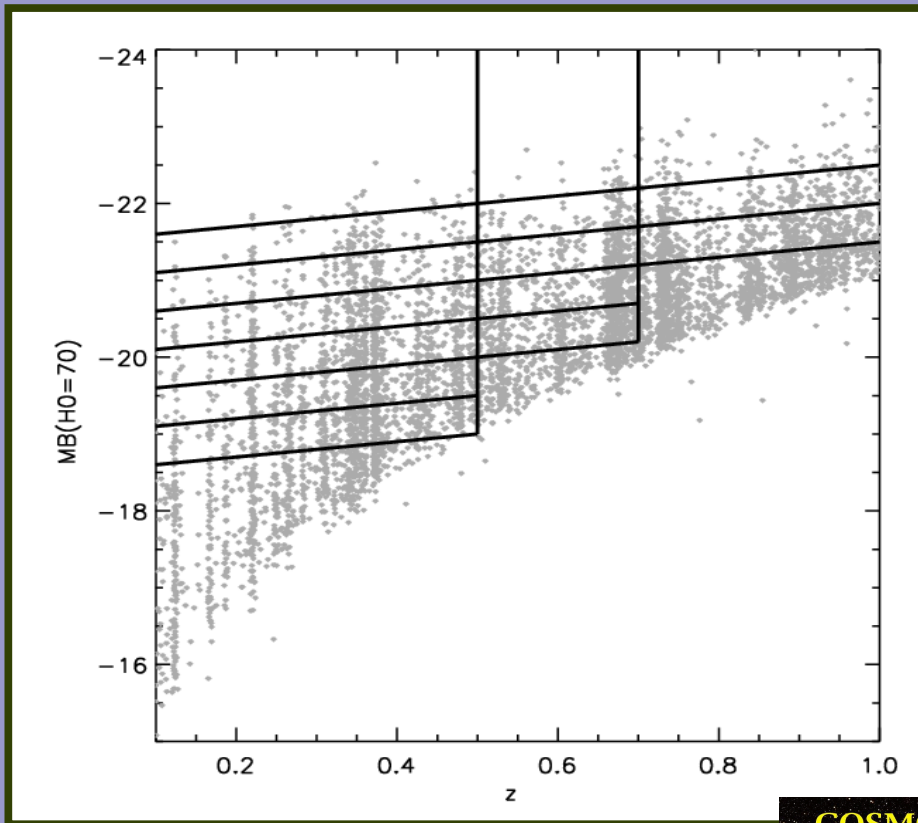




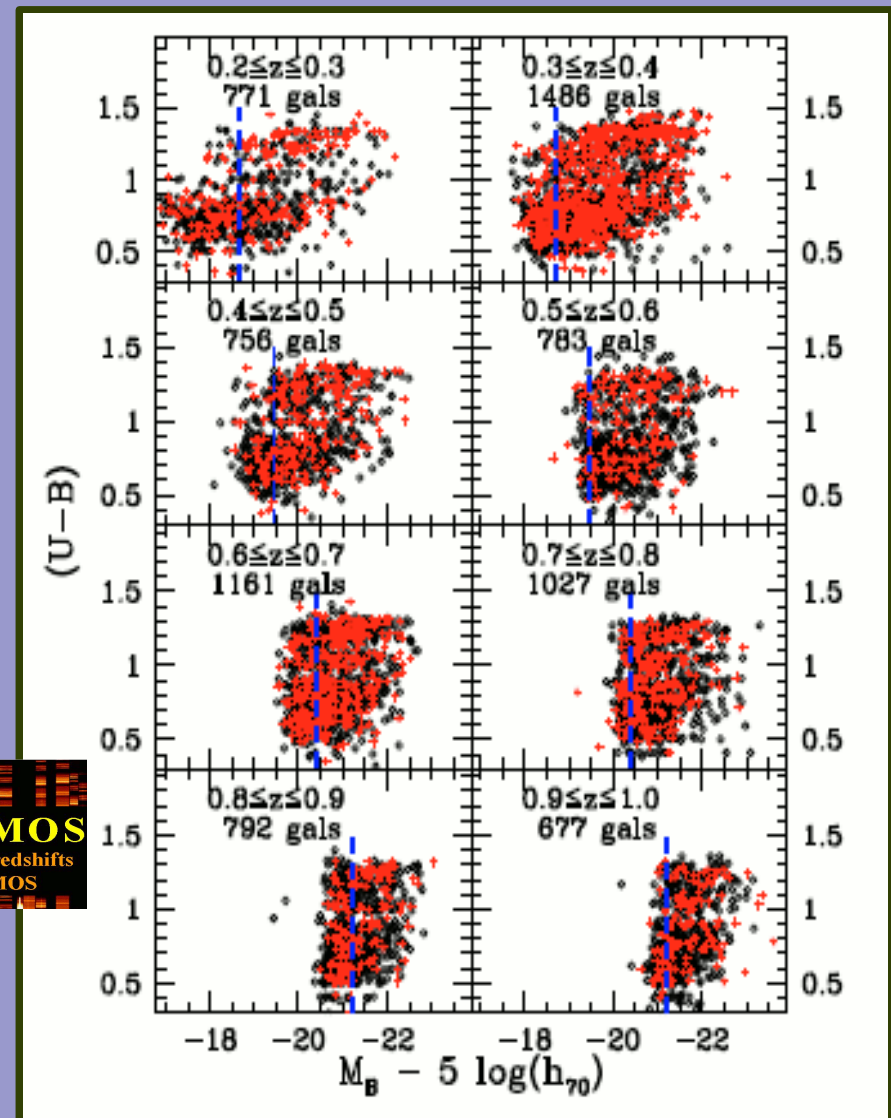
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# The colour-density relation: luminosity- limited samples

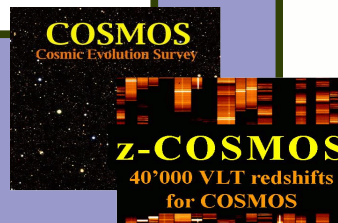


## Flux limited survey



## Subsamples:

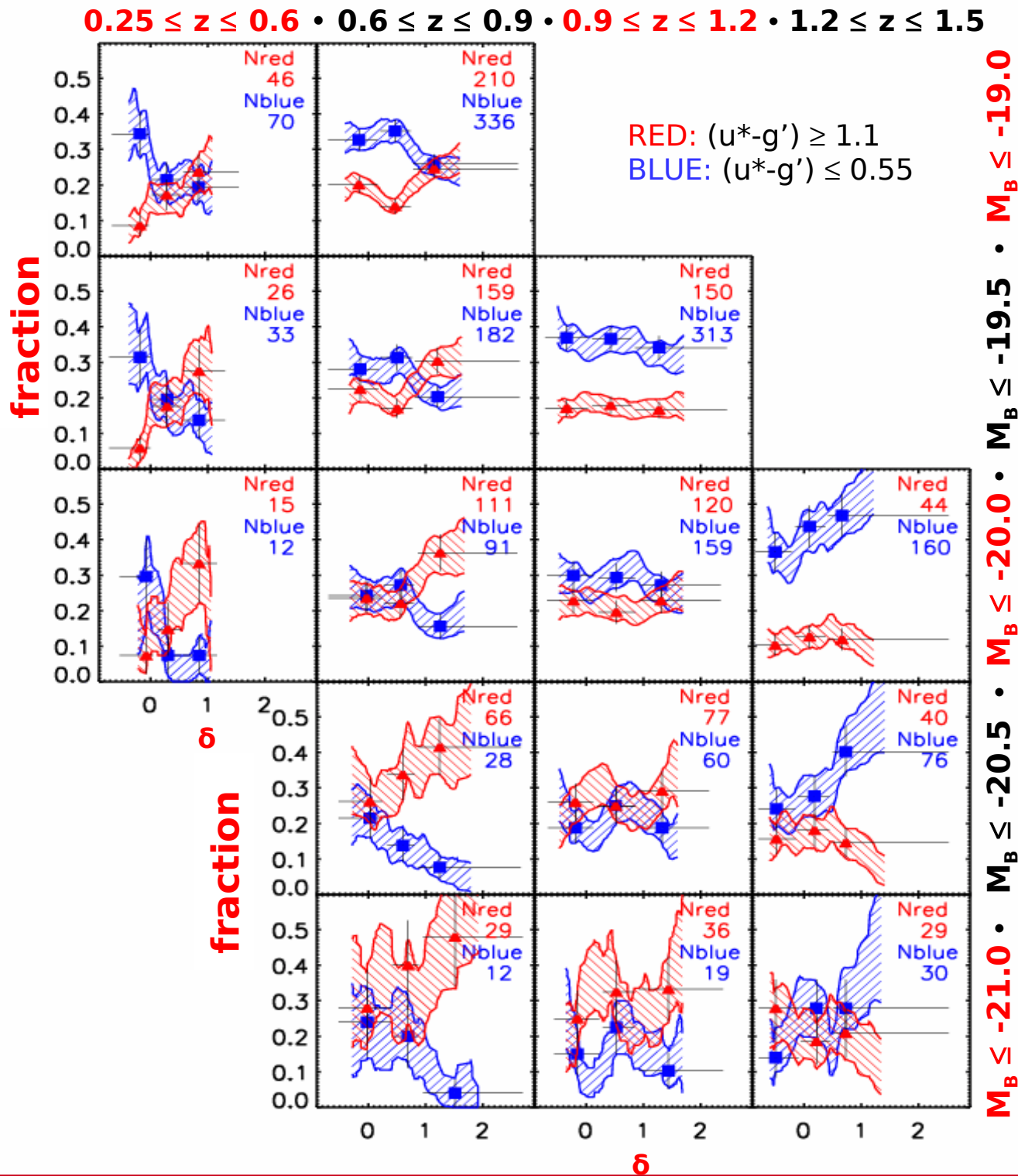
- Luminosity limited
- Complete (in mag & colour)
- follow the same galaxy populations at all  $z$



# VVDS data: Colour-density evolution

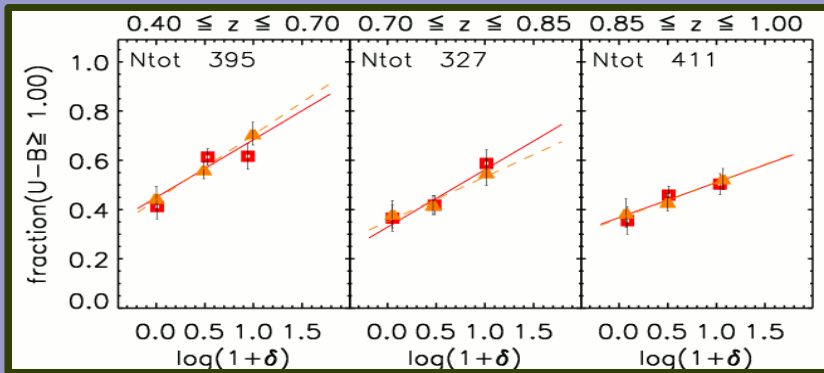
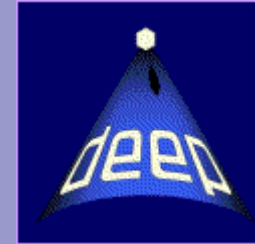
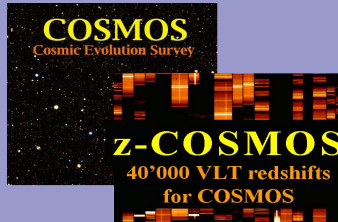
Cucciati et al 2006

Density has a role  
to play in  
determining galaxy  
colours at fixed  
redshift/luminosity

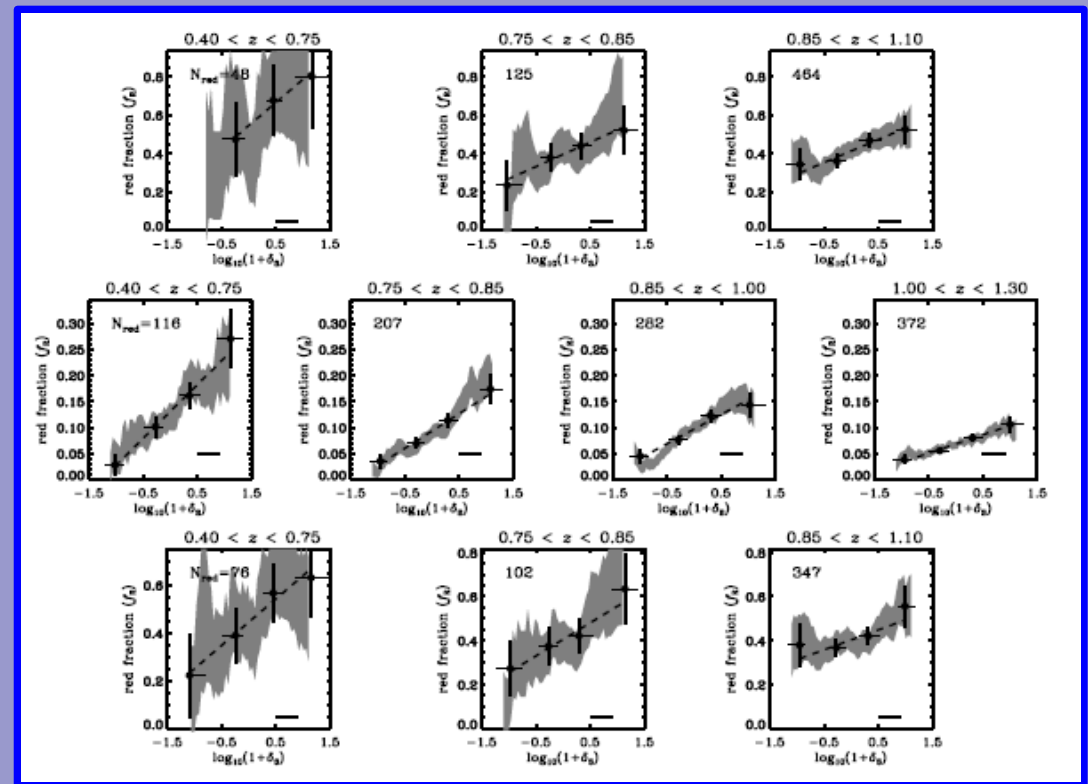


# The colour-density relation.

## Evolution with redshift: density contrast



Cucciati et al 2010b

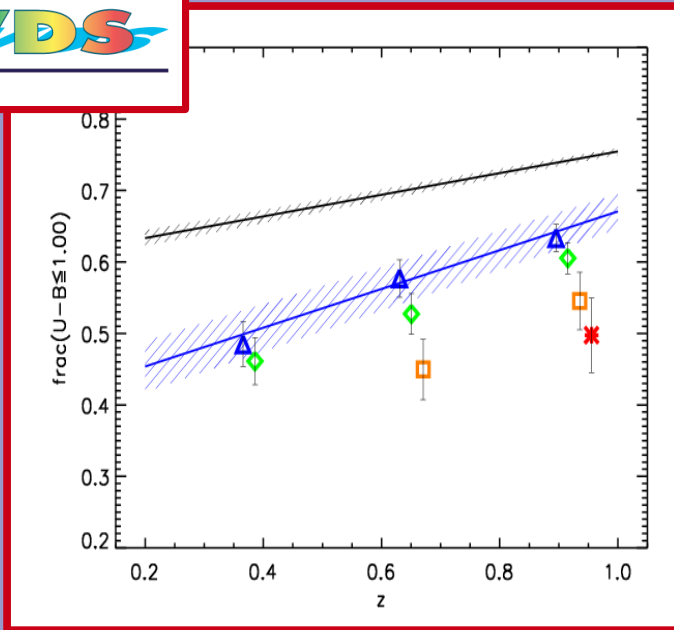


Cooper et al 2007

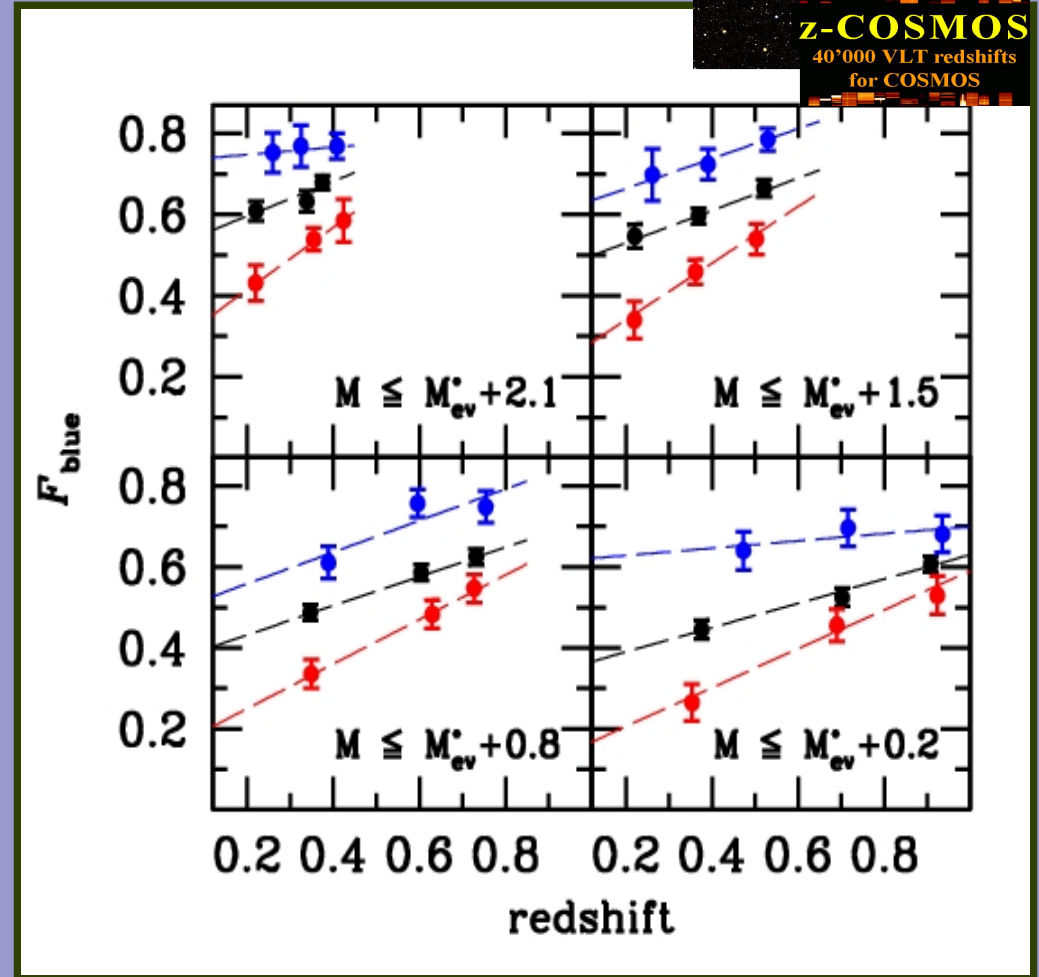
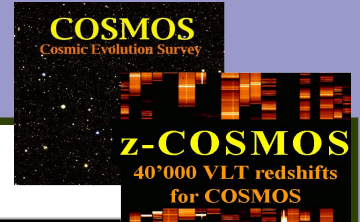
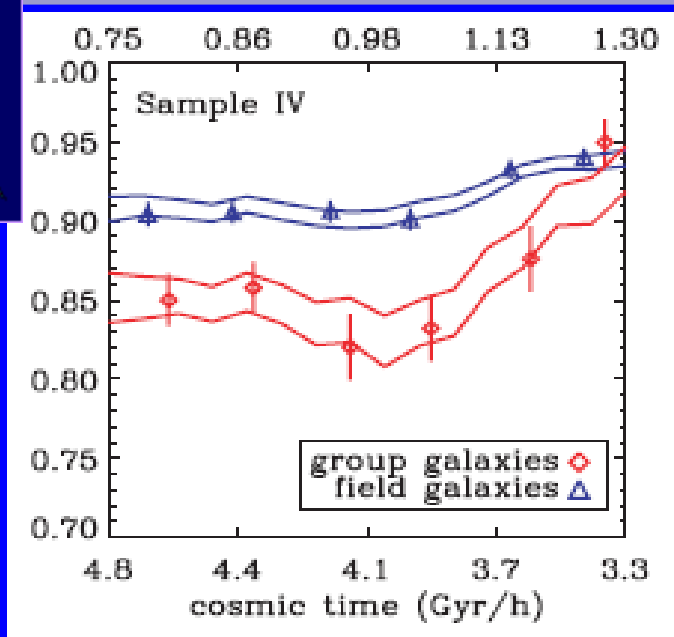
# Evolution with redshift: galaxy groups



Cucciati et al 2010a



Gerke et al 2007

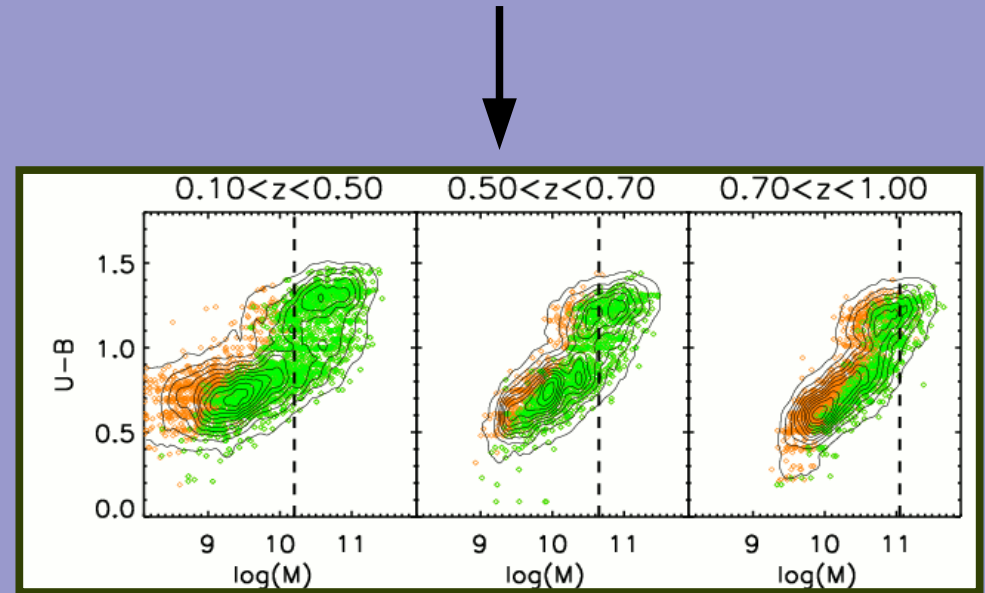
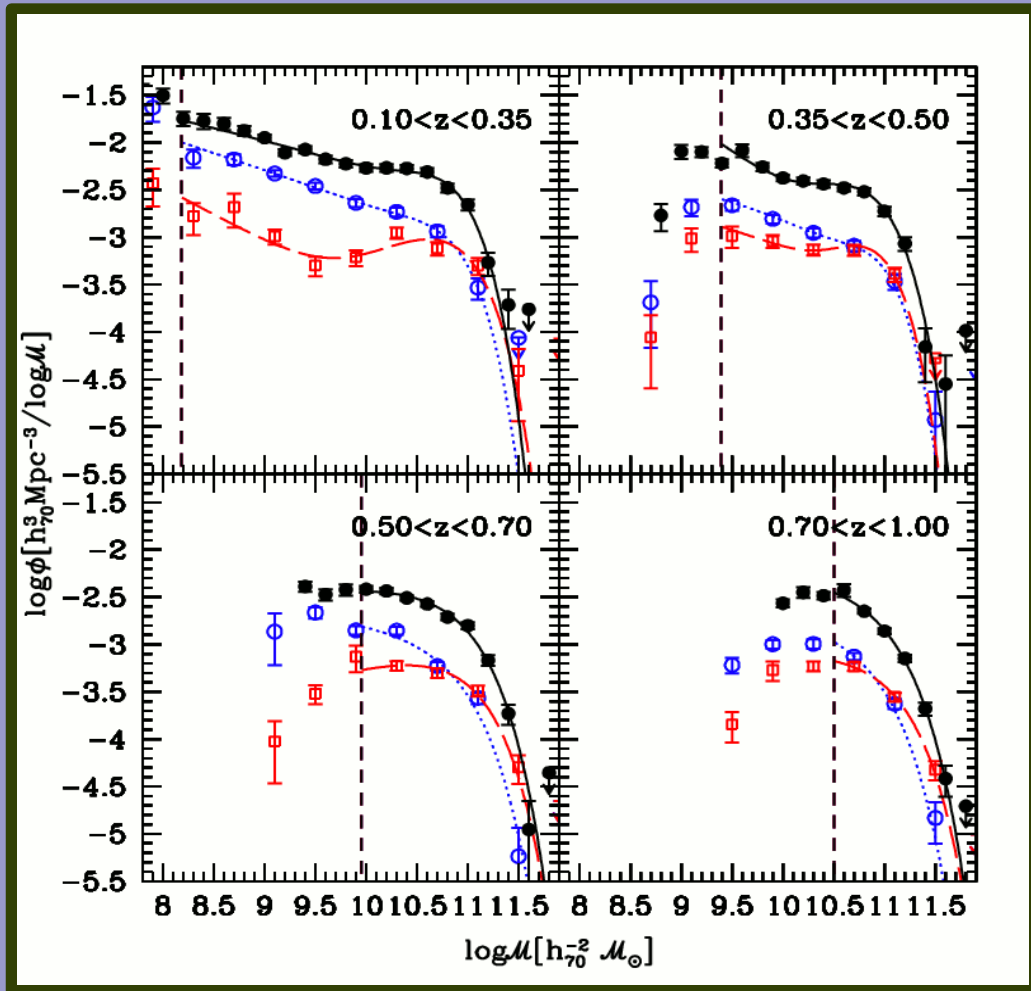


Iovino, Cucciati et al 2010

# The role of stellar mass

Mass segregation as  $f(\delta)$  → we define mass-complete samples

(Bolzonella et al 2010)

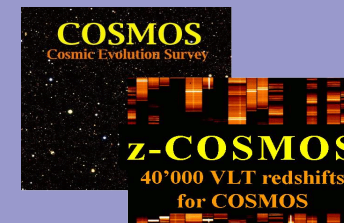


In a luminosity-limited sample we miss the red counterparts of low-mass blue galaxies

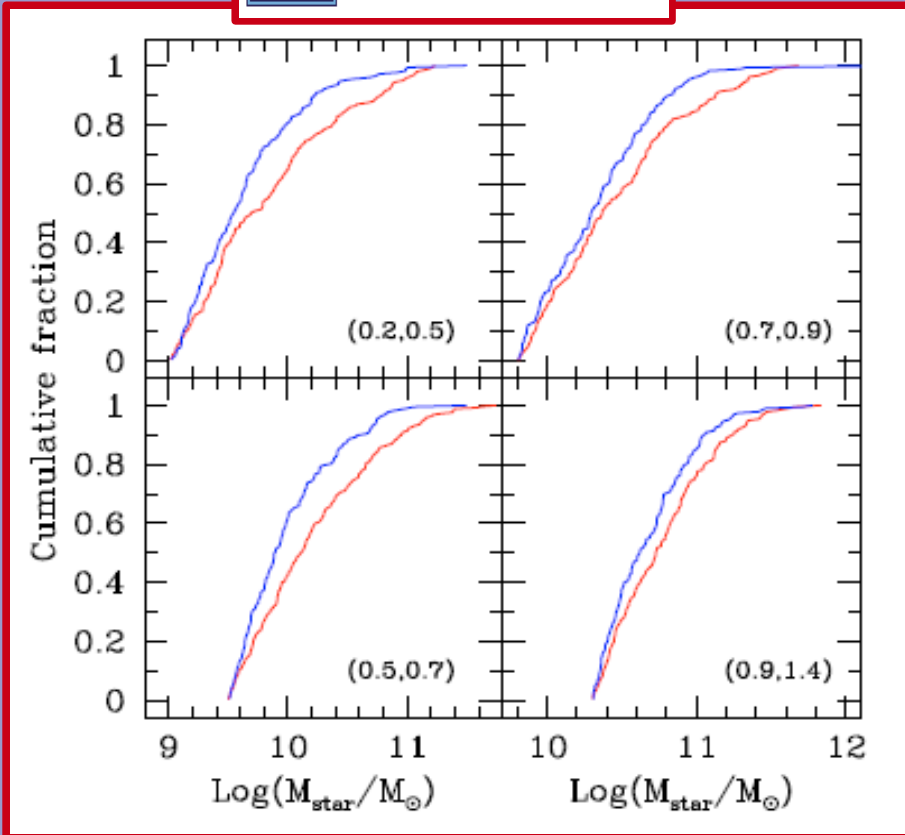
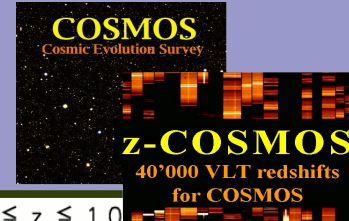
Black: total GSMF

Blue: GSMF in lowest density quartile

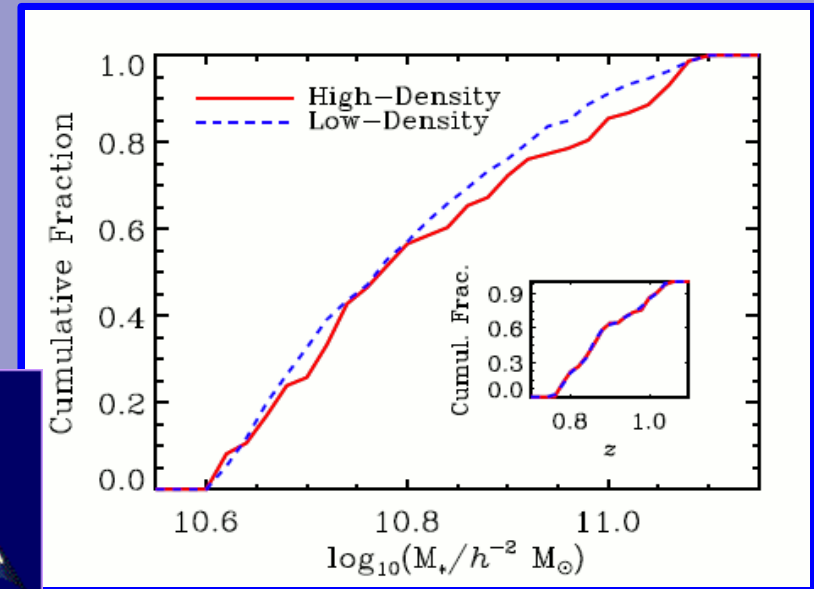
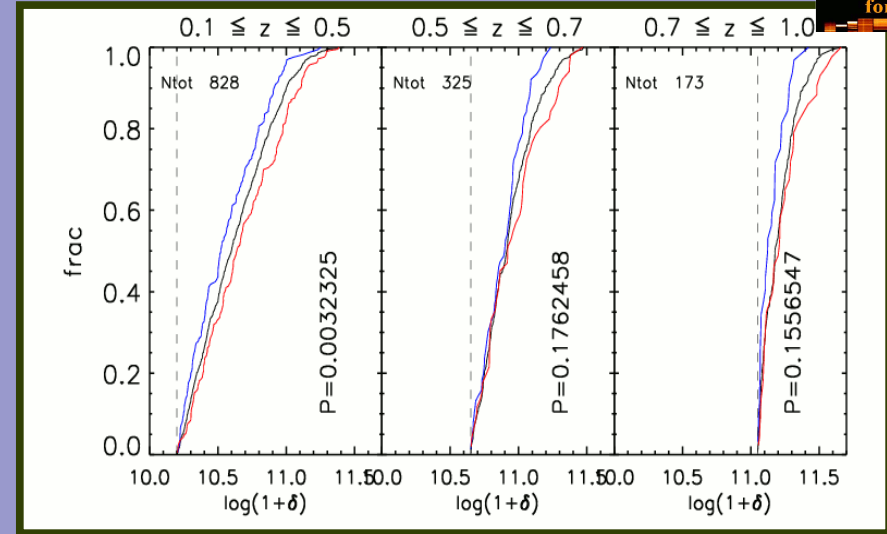
Red: GSMF in highest density quartile



# Mass segregation as a function of environment



Scodreggio et al 2009

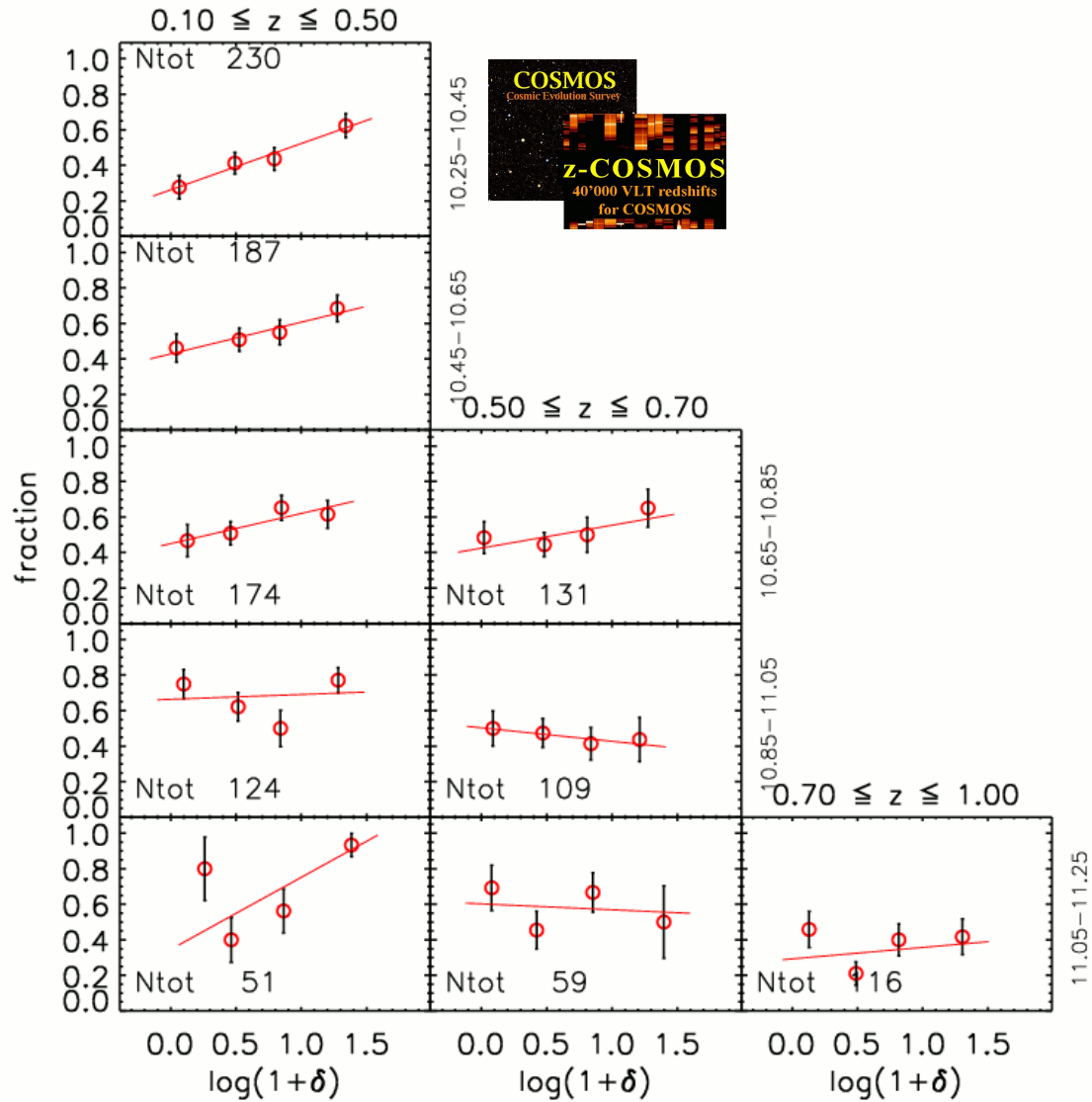


Cooper et al 2010



# Stellar mass, colour and environment: the colour-density relation in mass bins

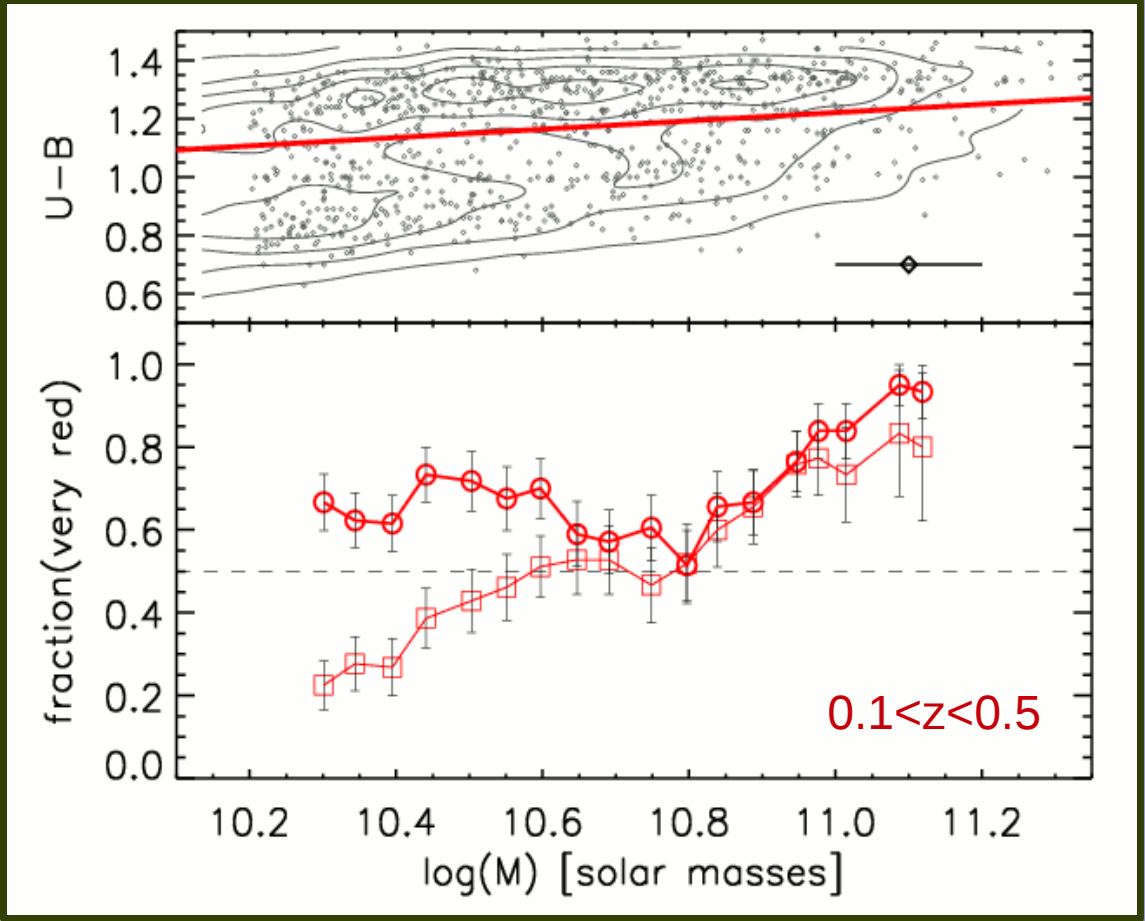
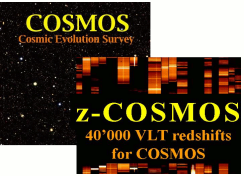
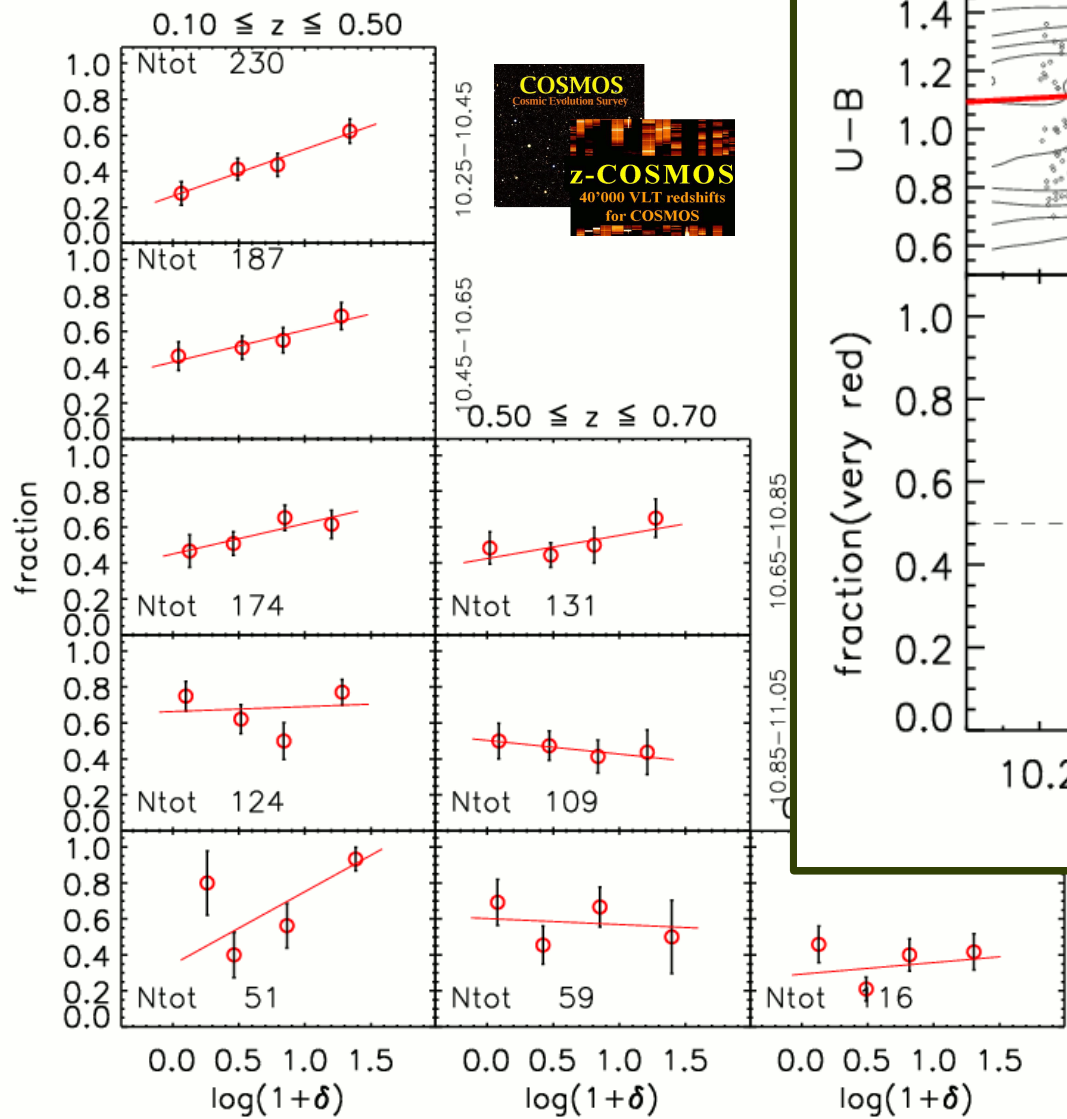
Cucciati et al 2010b





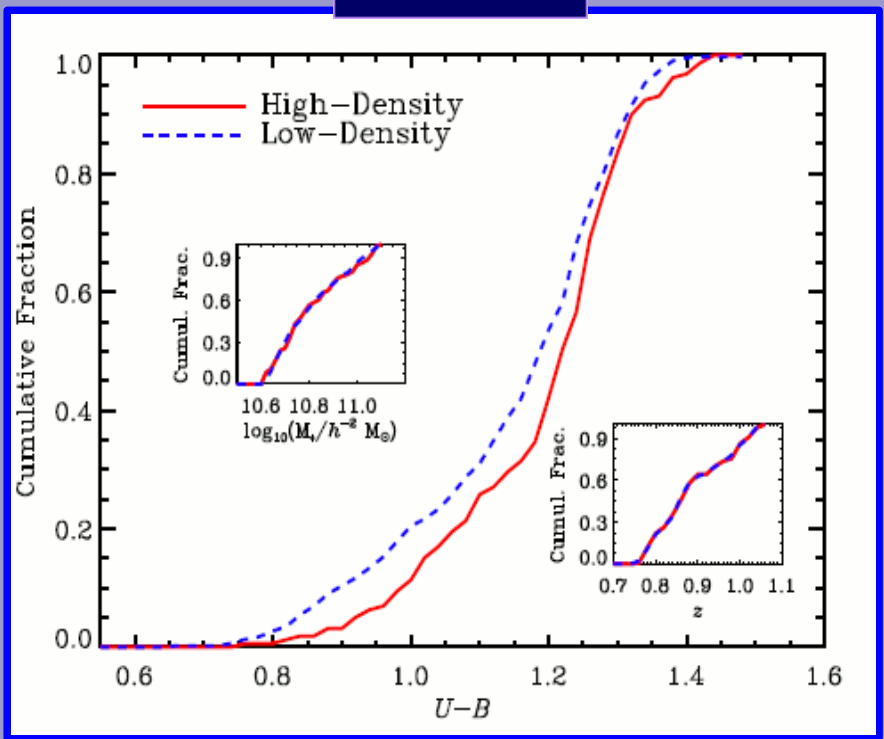
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Cucciati et al 2010b

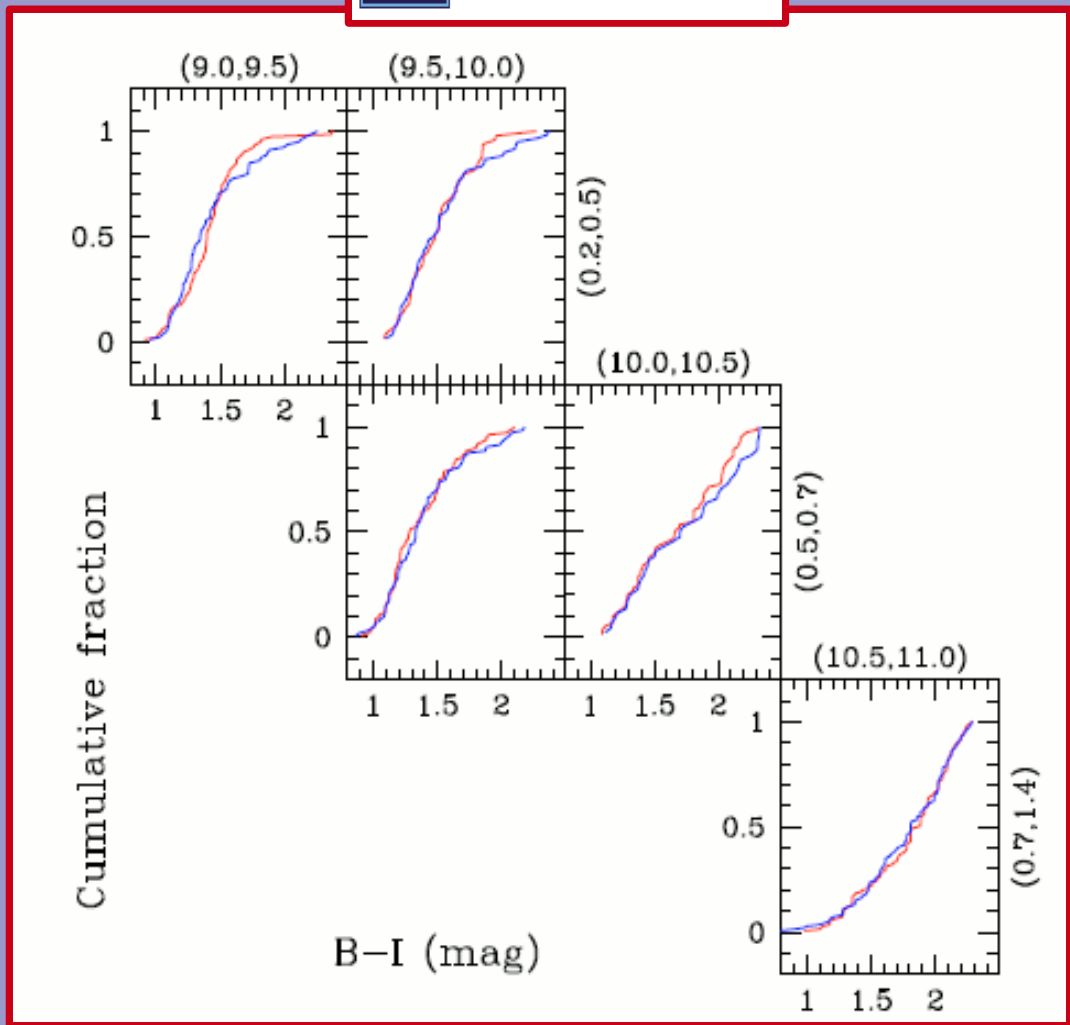


**The local density modulates the dependence of colour on mass** ( $\rightarrow$  see also Peng et al 2010)

# Stellar mass, colour and environment: the colour-density relation in mass bins

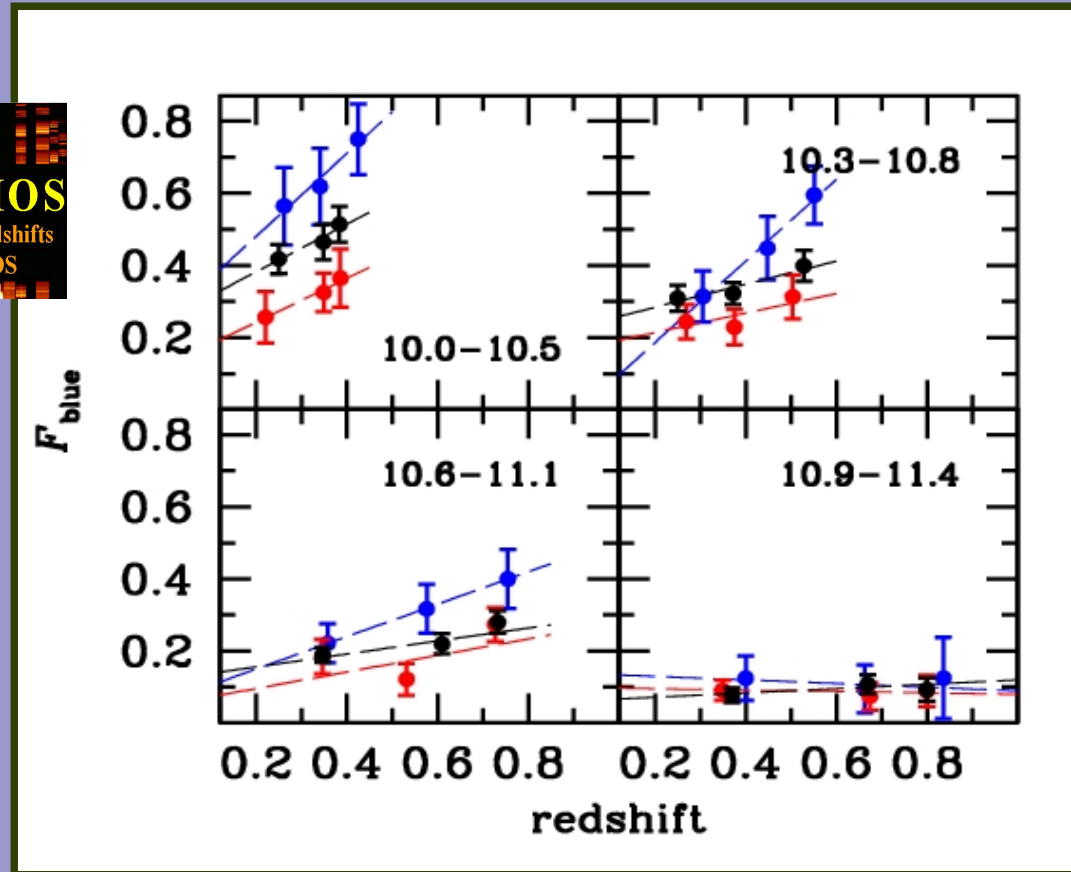
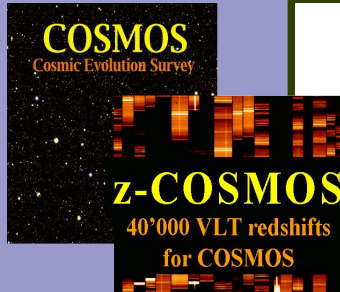


Cooper et al 2010



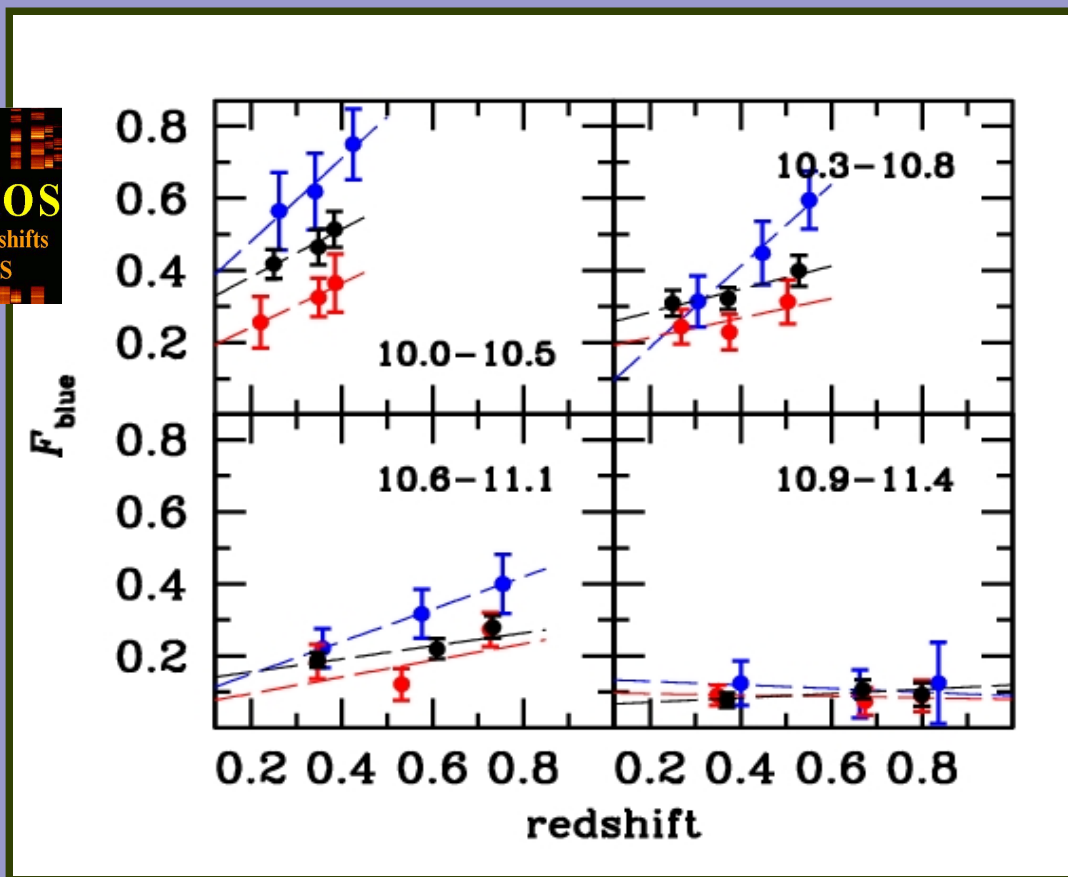
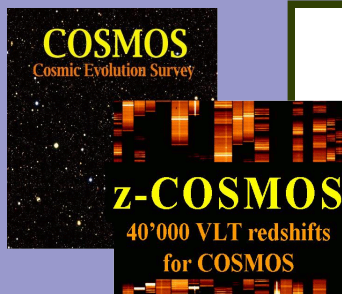
Scodreggio et al 2009

# Galaxy groups: the colour-density relation in mass bins



Iovino, Cucciati et al 2010

# Galaxy groups: the colour-density relation in mass bins



Iovino, Cucciati et al 2010

Same results using morphological classification

red--> early ; blue--> late

Tasca et al 2009, Kovac et al 2010

# Conclusions (1)

- **Colour-density relation already in place at  $z=1$  , considering both the density contrast and the group environment**
- **Colour-density relation still survives when mass-dependence is removed**
  - **Galaxy stellar mass does not tell the full story!**

## Conclusions (2)

We suggest a scenario in which the colour depends primarily on stellar mass, but at least for an intermediate mass regime ( $10.2 < \log(M/M_{\text{sun}}) < 10.7$ ) the local density modulates this dependence.

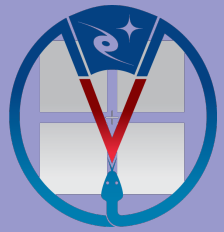
→ these relatively low mass galaxies formed more recently, in an epoch when more evolved structures were already in place, and their longer SFH allowed environment-driven physical processes to operate during longer periods of time.

# Next steps

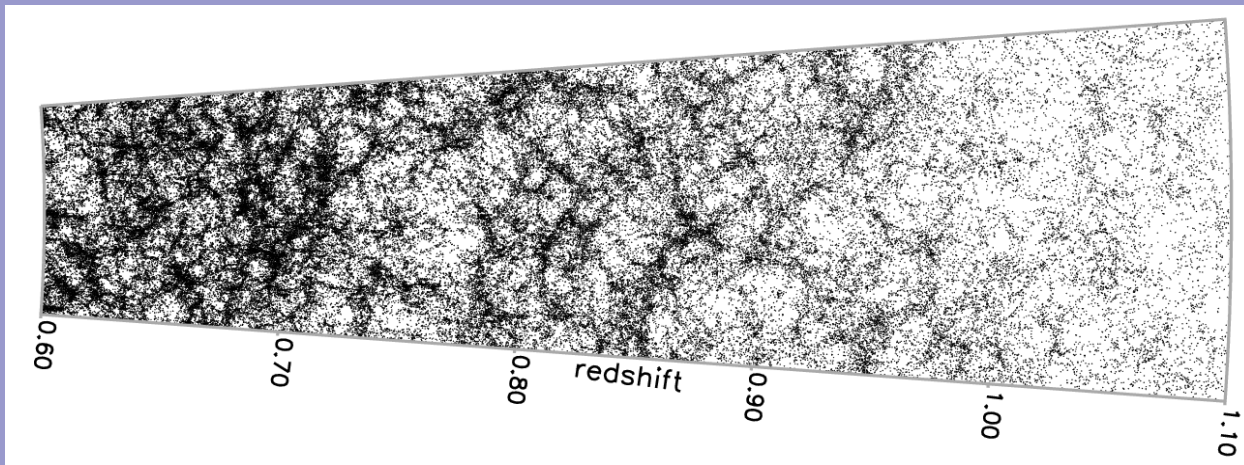
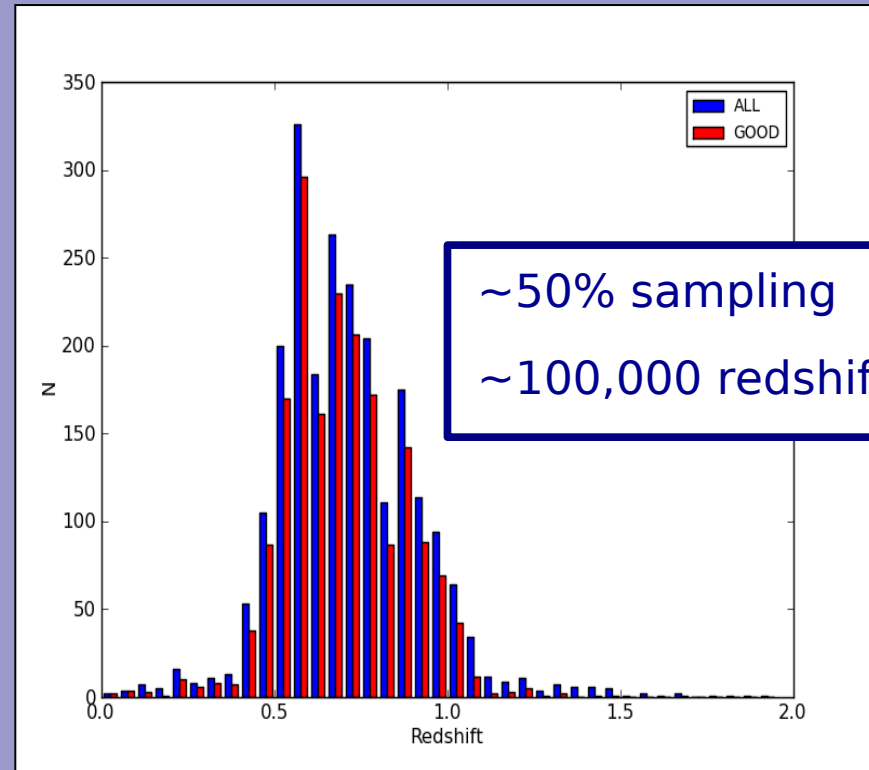
- 1) Verify the suggested scenario studying more in details the SFH and ages of galaxies as a function of environment
- 2) Study of environment
  - in more complete samples (lower masses, higher sampling rate etc): future survey(s)!
  - with higher statistics: VIPERS
- 3) Comparison with simulations: MILLENNIUM “vs” VVDS

# VIPERS: VIMOS Public Extragalactic Redshift Survey

<http://vipers.inaf.it/>



- 440.5 VLT hours
- $\sim 24 \text{ deg}^2$  in the CFHTLS wide fields:
  - $\sim 2 \times 8 \text{ deg}^2$  slice in W1
  - $\sim 2 \times 4 \text{ deg}^2$  slice in W4
- $I_{AB} < 22.5$ , LR Red grism, 45 min exp.
- $z > 0.5$  color-color pre-selection
- PSF + SED -based star-galaxy separation (AGN color recovery)

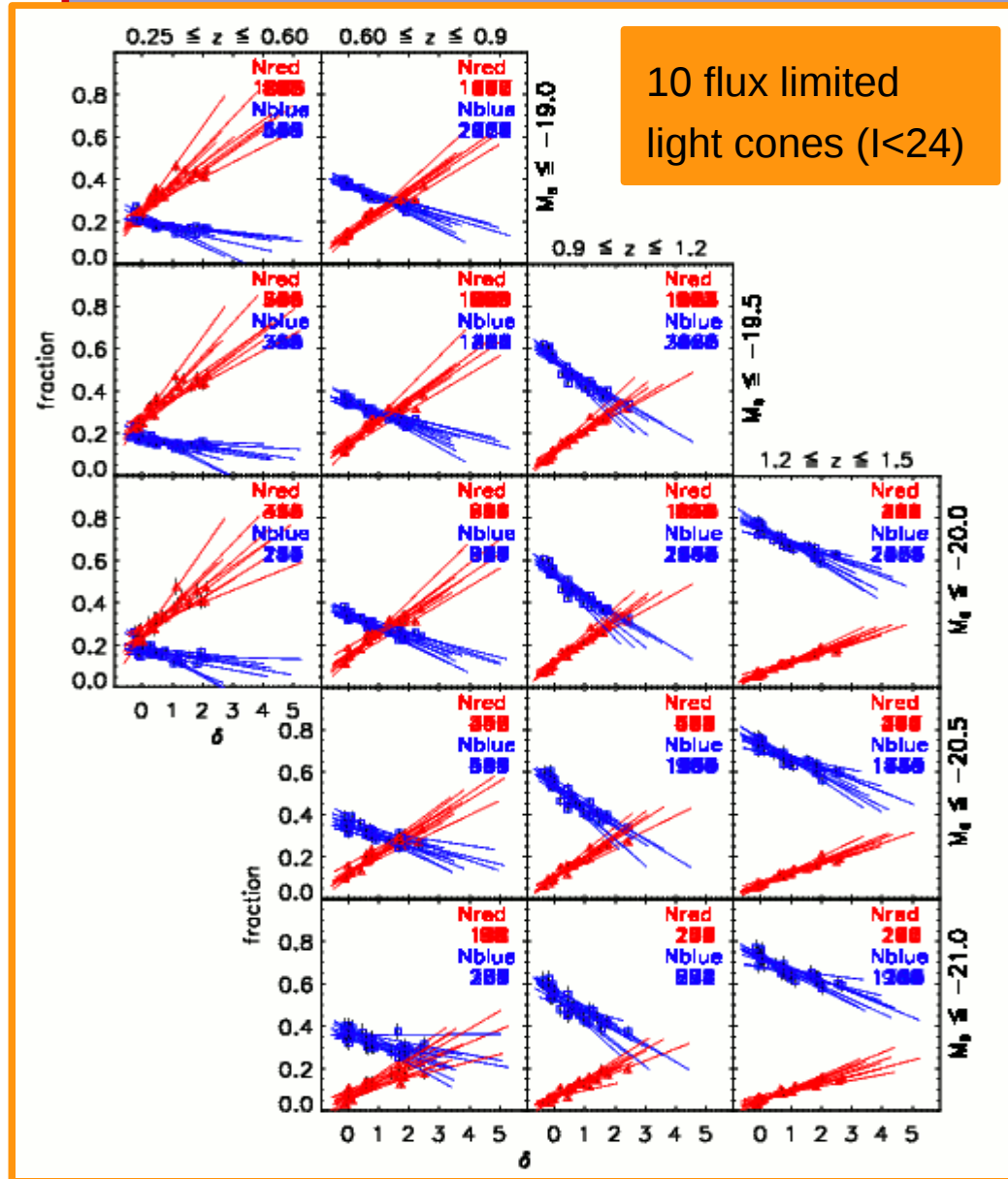
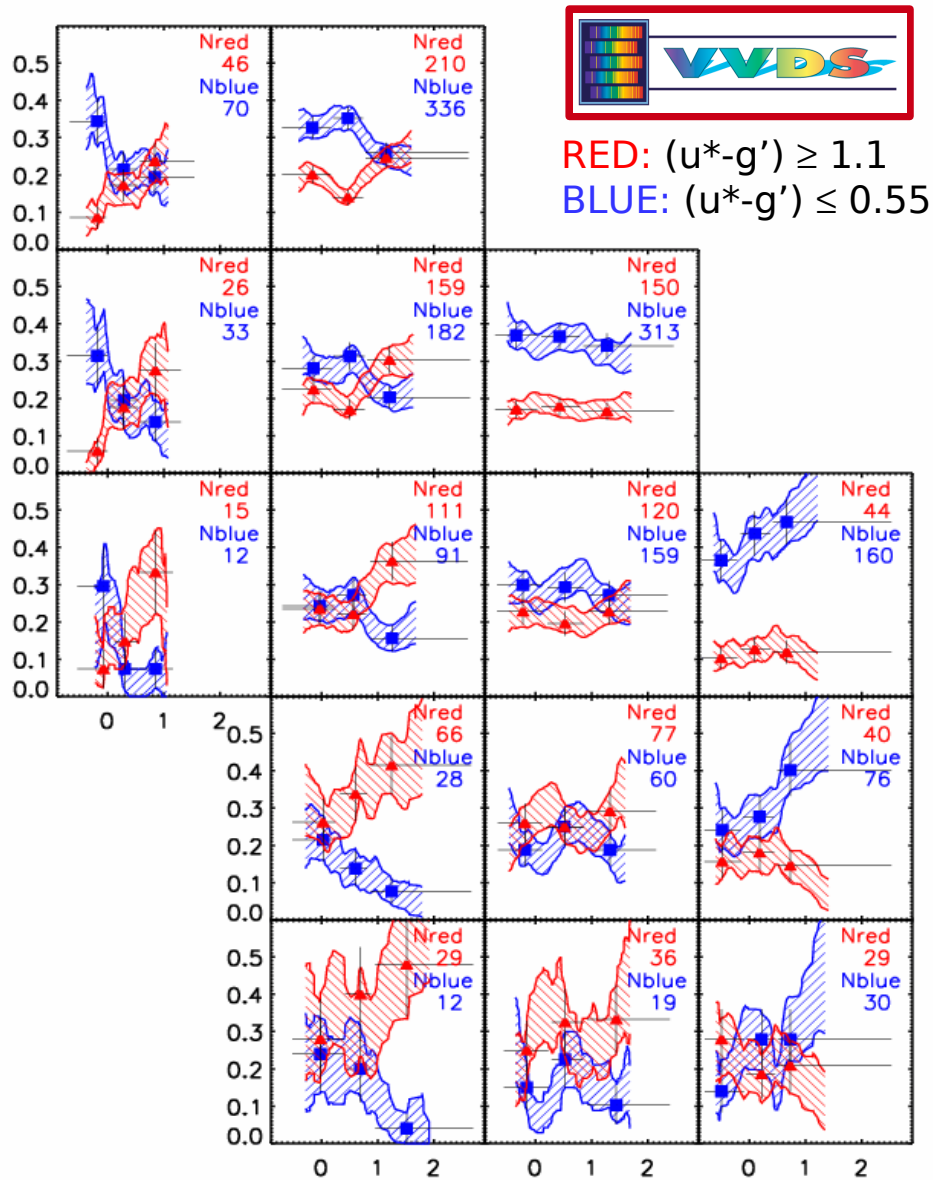


**VIPERS 2x8  
deg<sup>2</sup> slice in  
CFHTLS W1  
field** (mock  
sample by J.  
Blaizot & G. De  
Lucia)



# Colour-density relation: Observations/simulations comparison

Gabriella De Lucia, Elena Zucca, Jeremy Blaizot, Angela Iovino, Micol Bolzonella, Lucia Pozzetti...  
(see also Meneux et al 2008 and de la Torre et al 2010)



**Thank you!**