Modelling and observing galaxy clusters up to z~1

Gabriella De Lucia

Max-Planck Institut für Astrophysik

Trieste - April 26, 2006

Outline:

- ***Semi-analytic models***

  -- substructures & galaxies

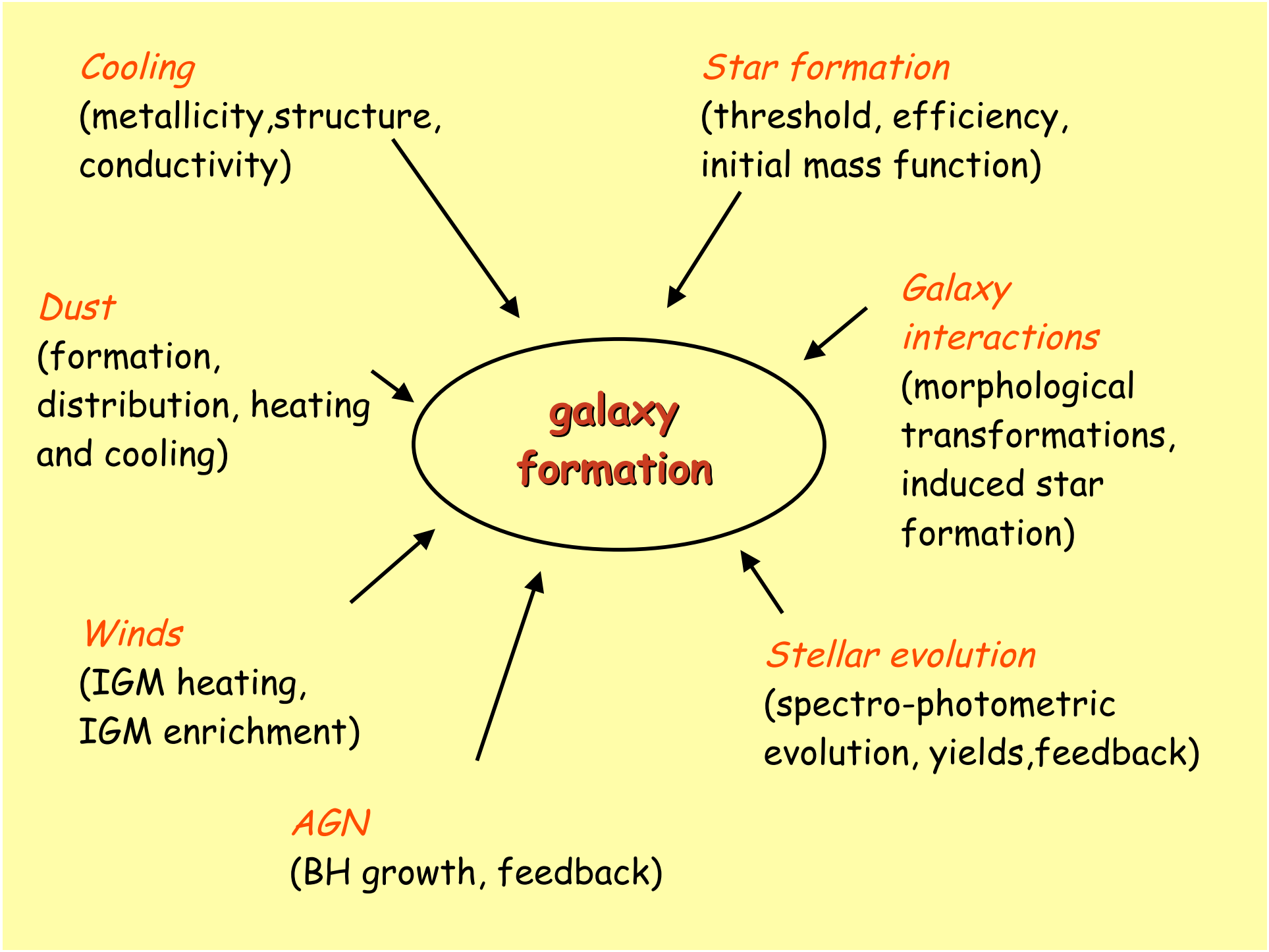
  -- hybrid models – methods, limits & aims

  -- applications

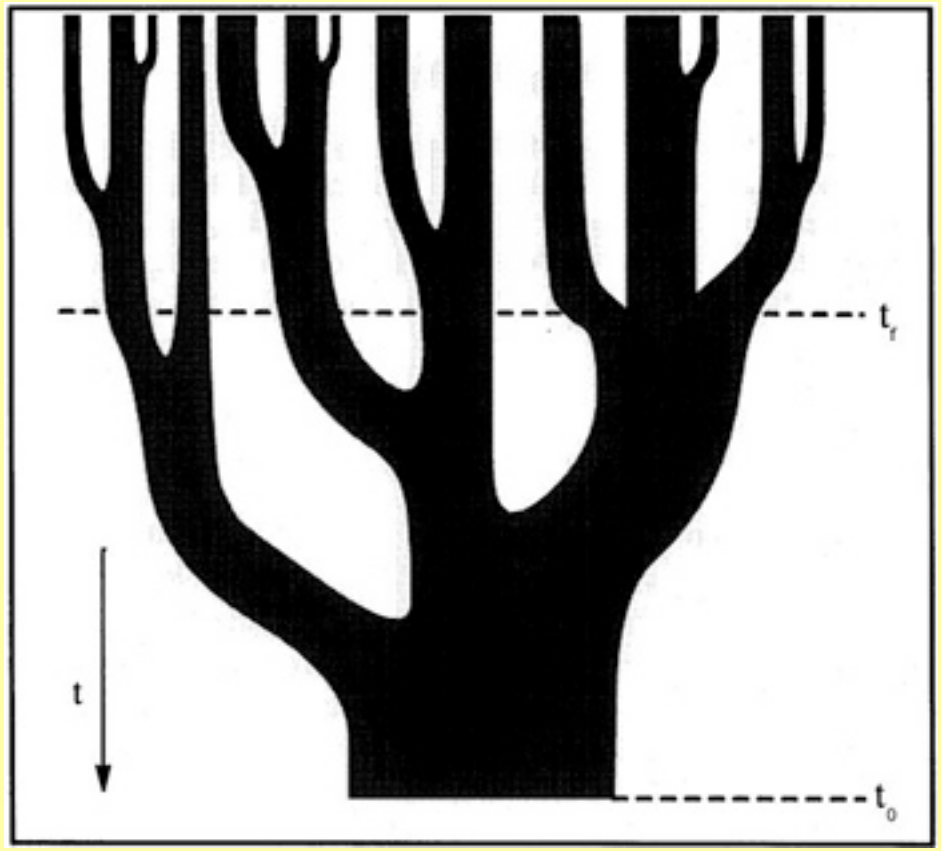
- ***The ESO Distant Cluster Survey (EDisCS)***

  -- the colour-magnitude relation

  -- cluster structure

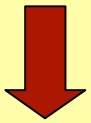

Cooling
(metallicity,structure,
conductivity)
Star formation
(threshold, efficiency,
initial mass function)
Dust
(formation,
distribution, heating
and cooling)
Galaxy
interactions
(morphological
transformations,
induced star
formation)
galaxy
formation
Winds
(IGM heating,
IGM enrichment)
Stellar evolution
(spectro-photometric
evolution, yields,feedback)
AGN
(BH growth, feedback)

The SAM – the classical models:



Lacey & Cole (1993)

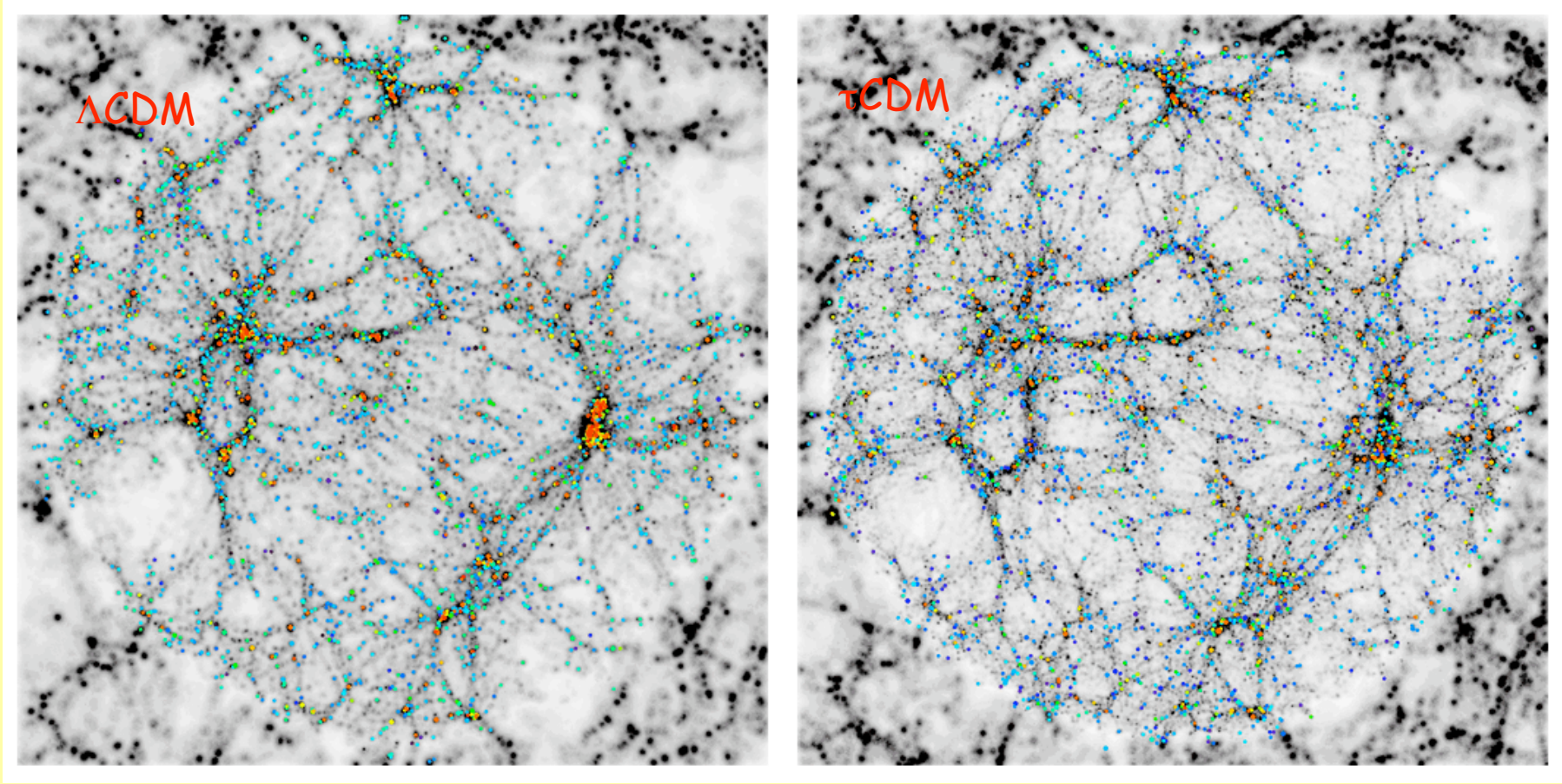
Extended Press & Schechter



"Planting" the merger trees

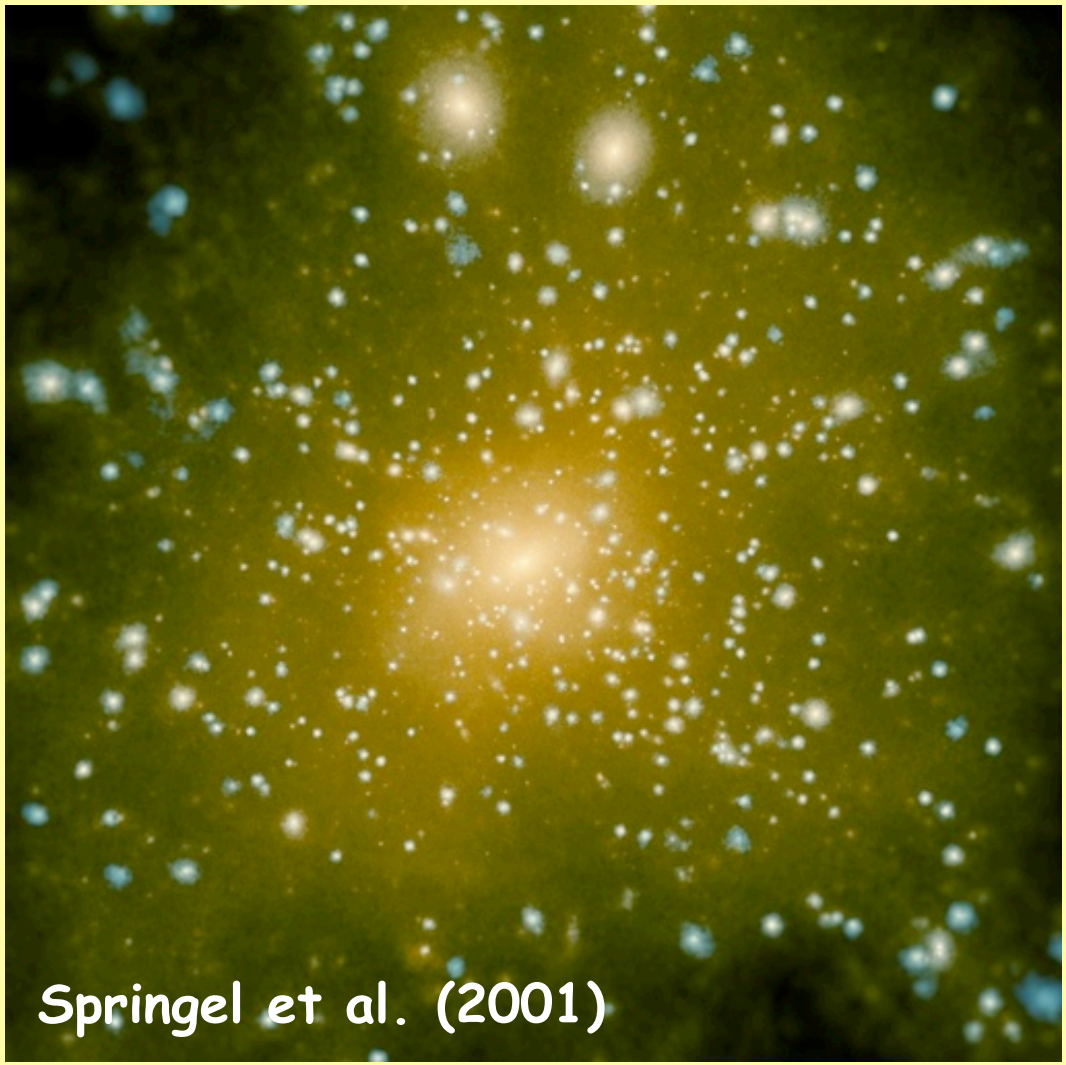
These might provide a <u>not adequate description</u> of the merger rates (Benson et al., 2005)

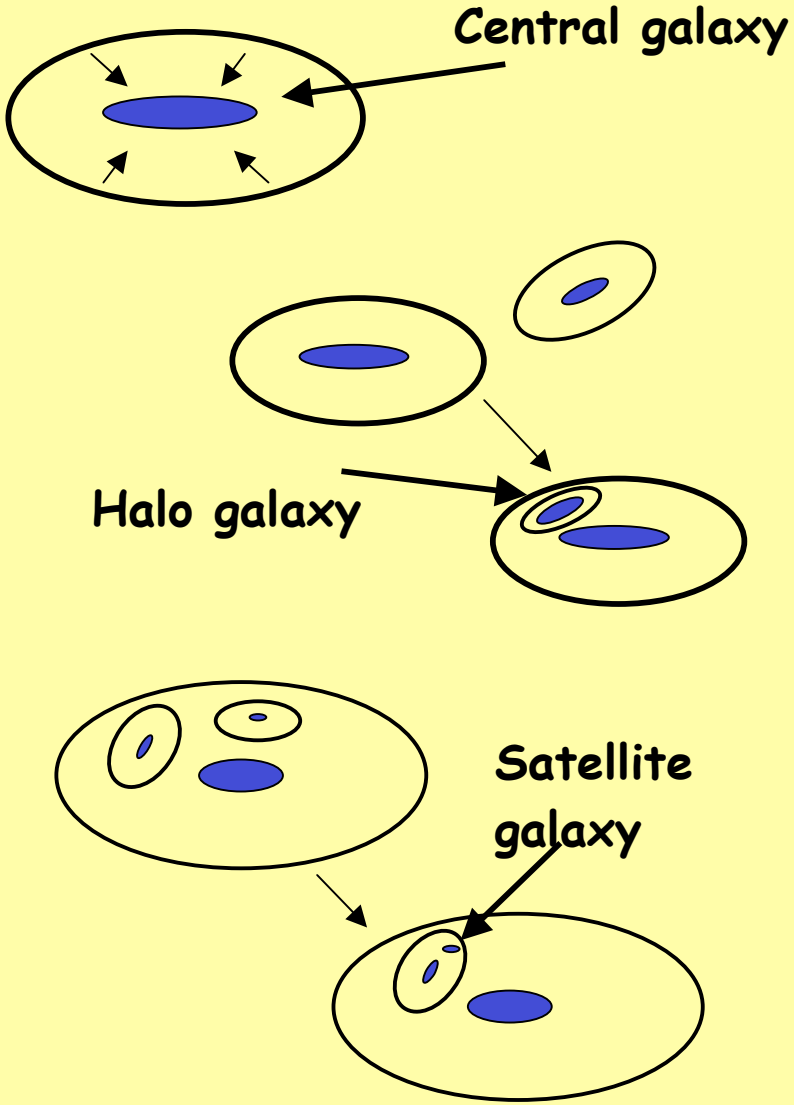
The SAM – the hybrid models :



Mathis H. et al., 2002

The SAM – the hybrid models :

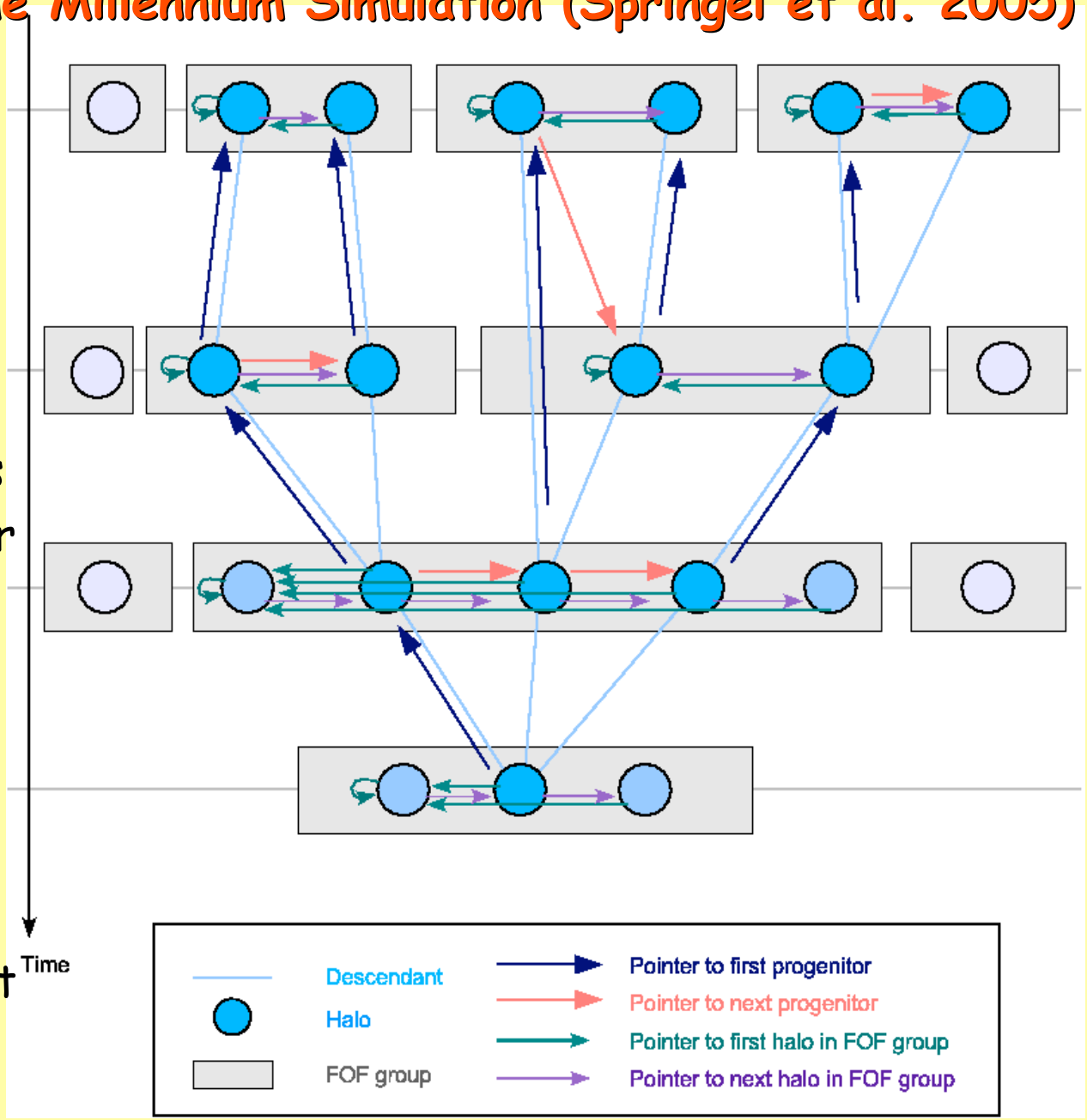




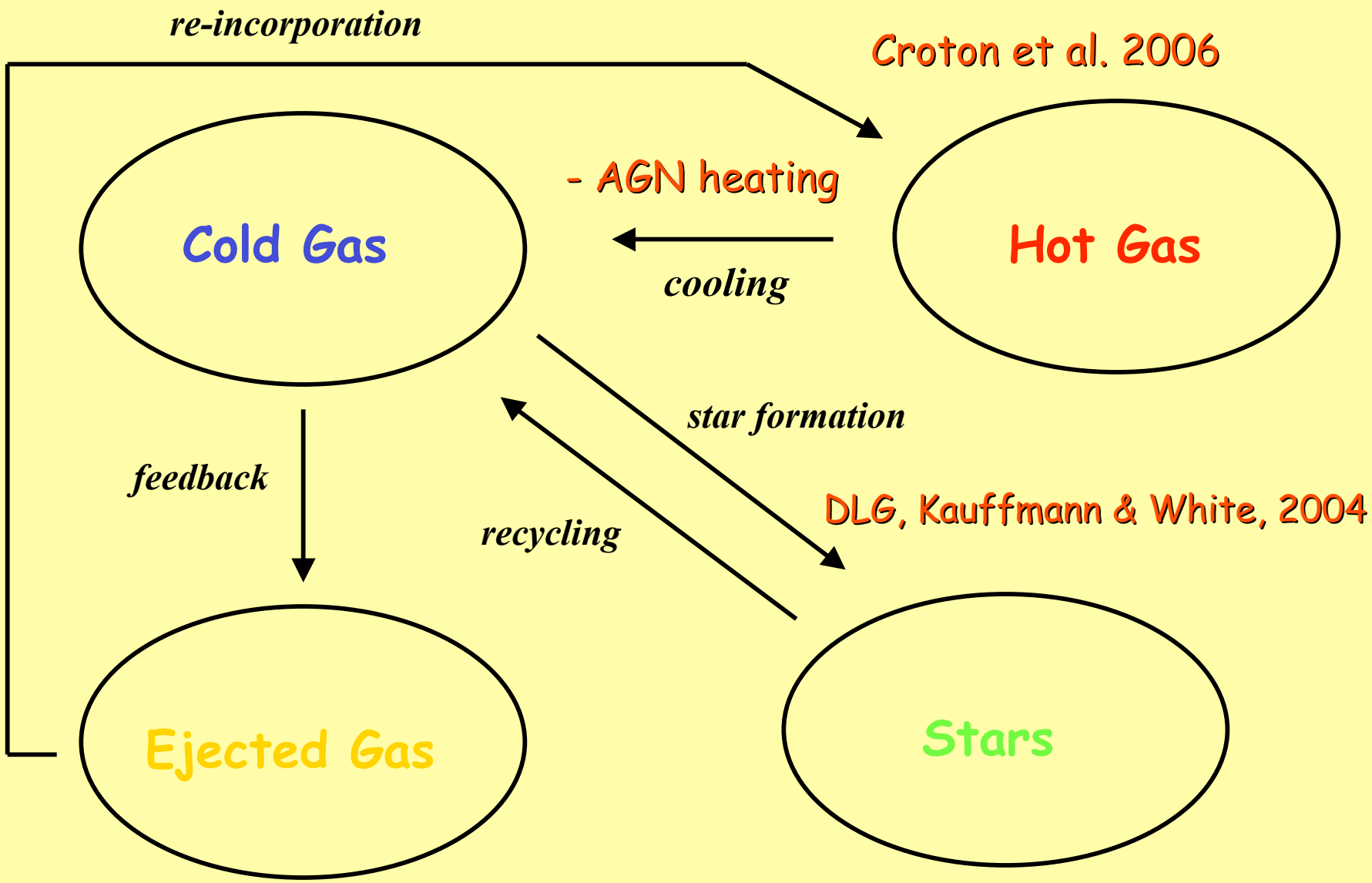
De Lucia et al., 2004

The Millennium Simulation (Springel et al. 2005)

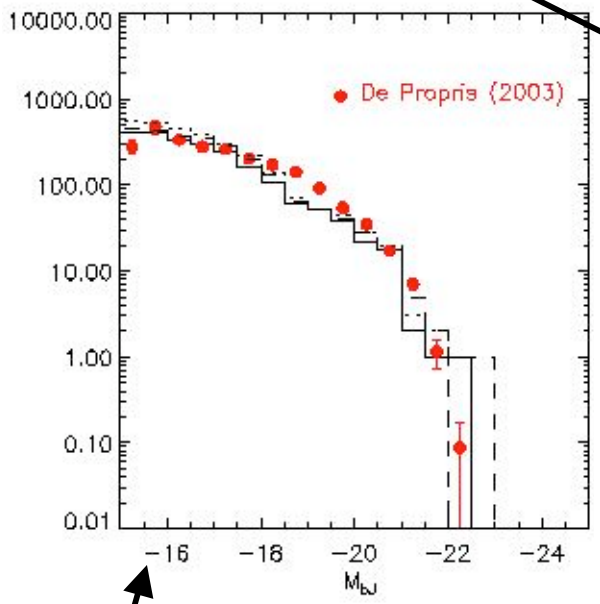
- About 800 million subhaloes
- 64 time slices stored
- Group catalogues and information about their embedded substructures used to construct merger trees
- About 20 million galaxies
- Individual trees are stored separately so that the SAM can be run for each tree sequentially

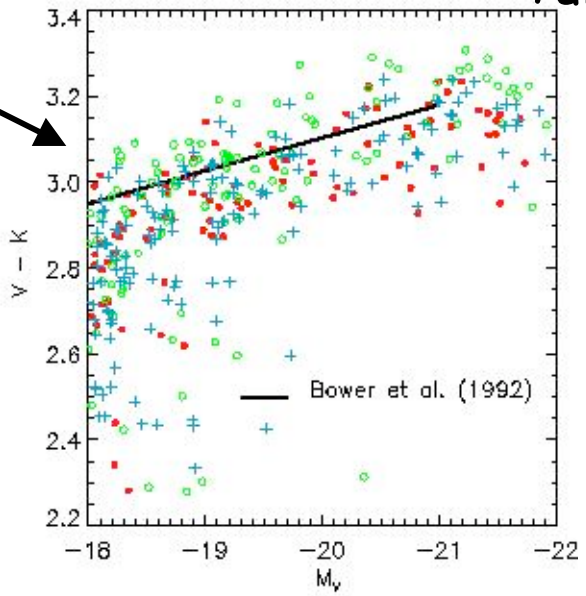


The SAM – the physics :

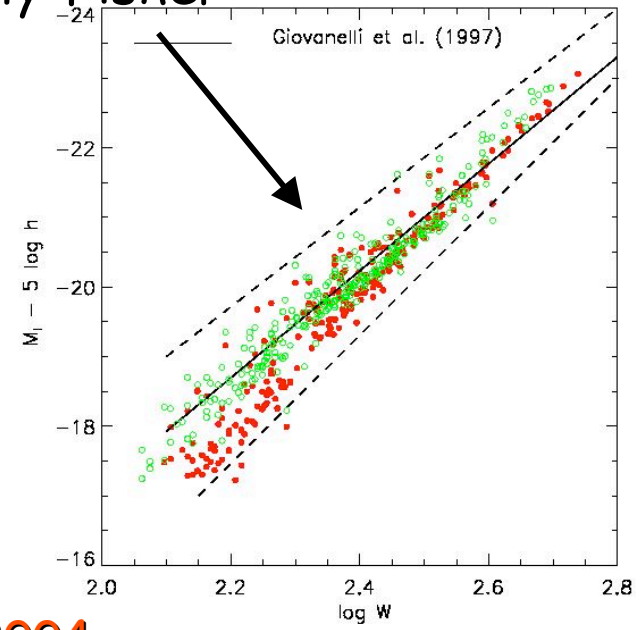


Colour-magnitude



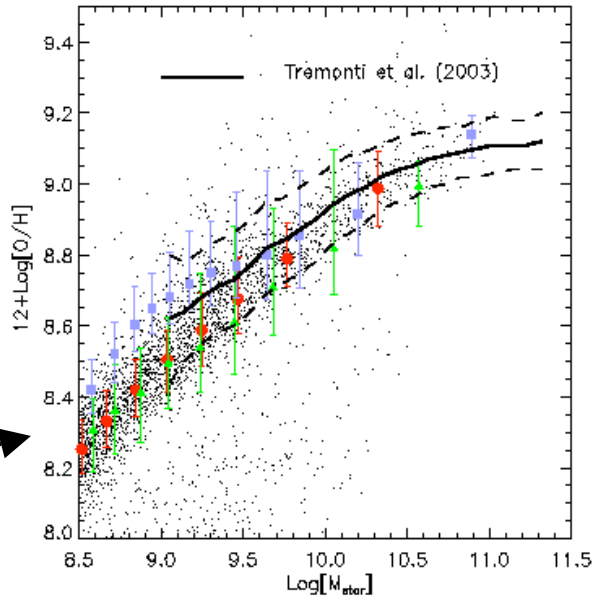


Tully-Fisher

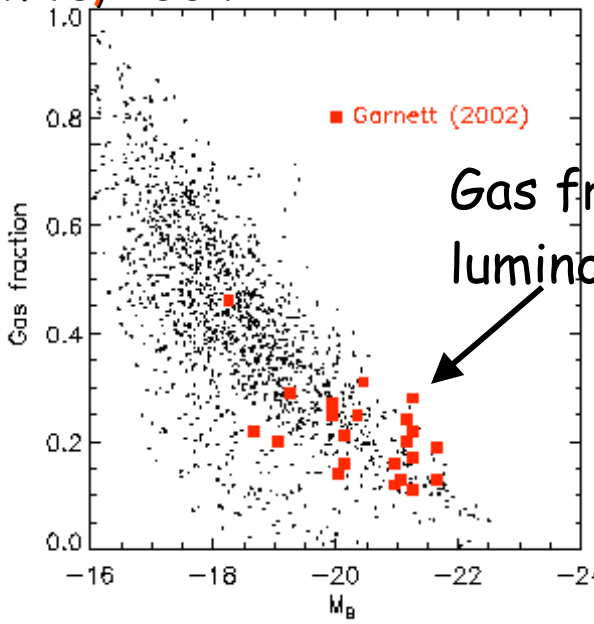


DLG, Kauffmann & White, 2004

Luminosity function

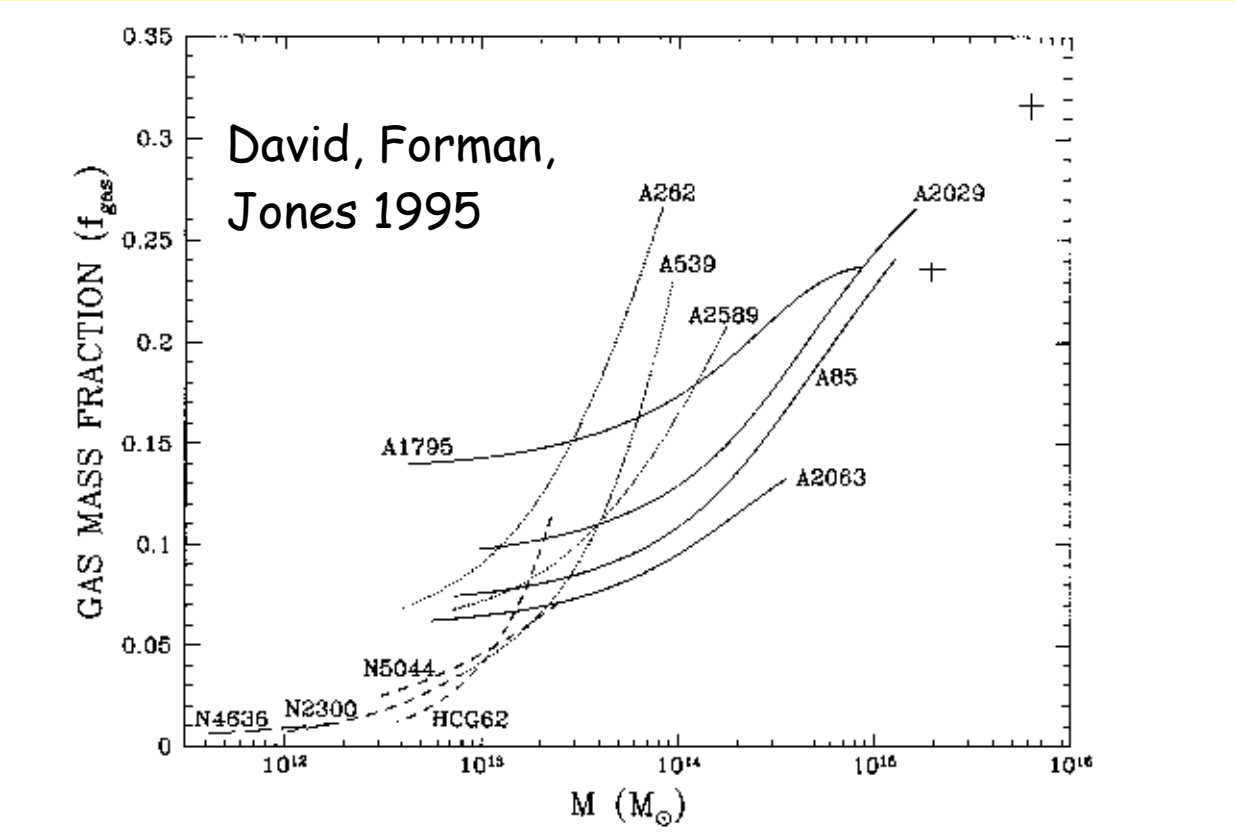


Metallicity-mass



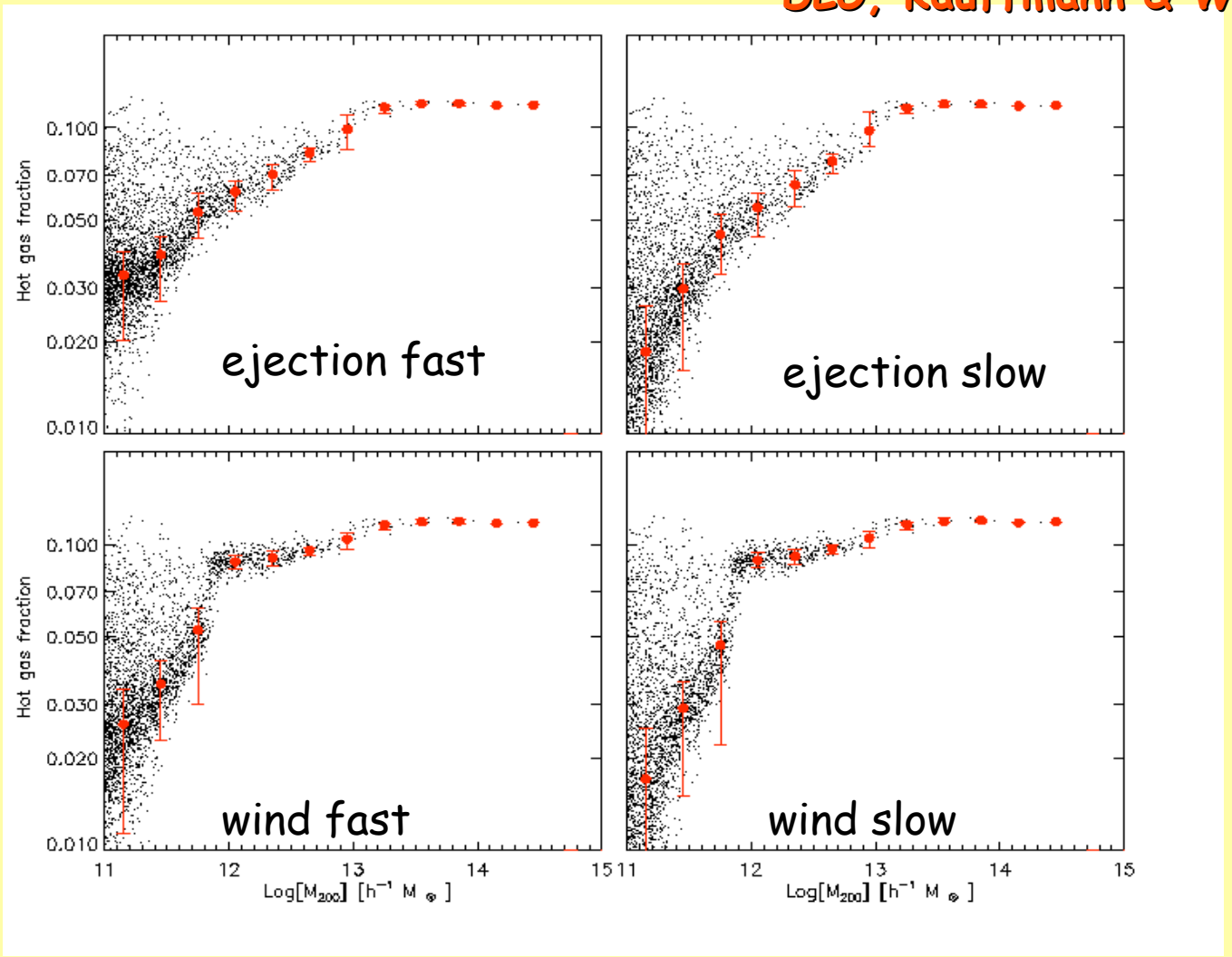
Gas fraction-luminosity

Observational signature of different feedback models #1:

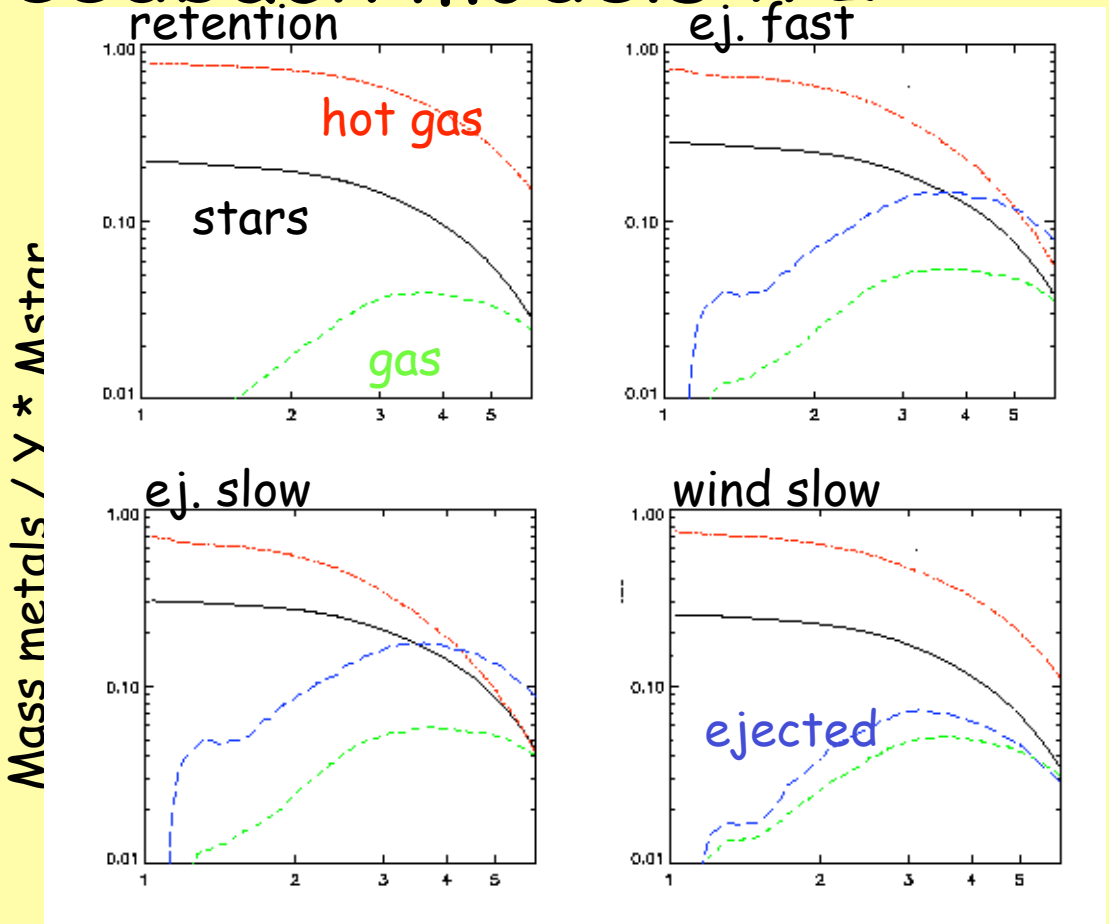


Observational signature of different feedback models #1:

DLG, Kauffmann & White, 2004



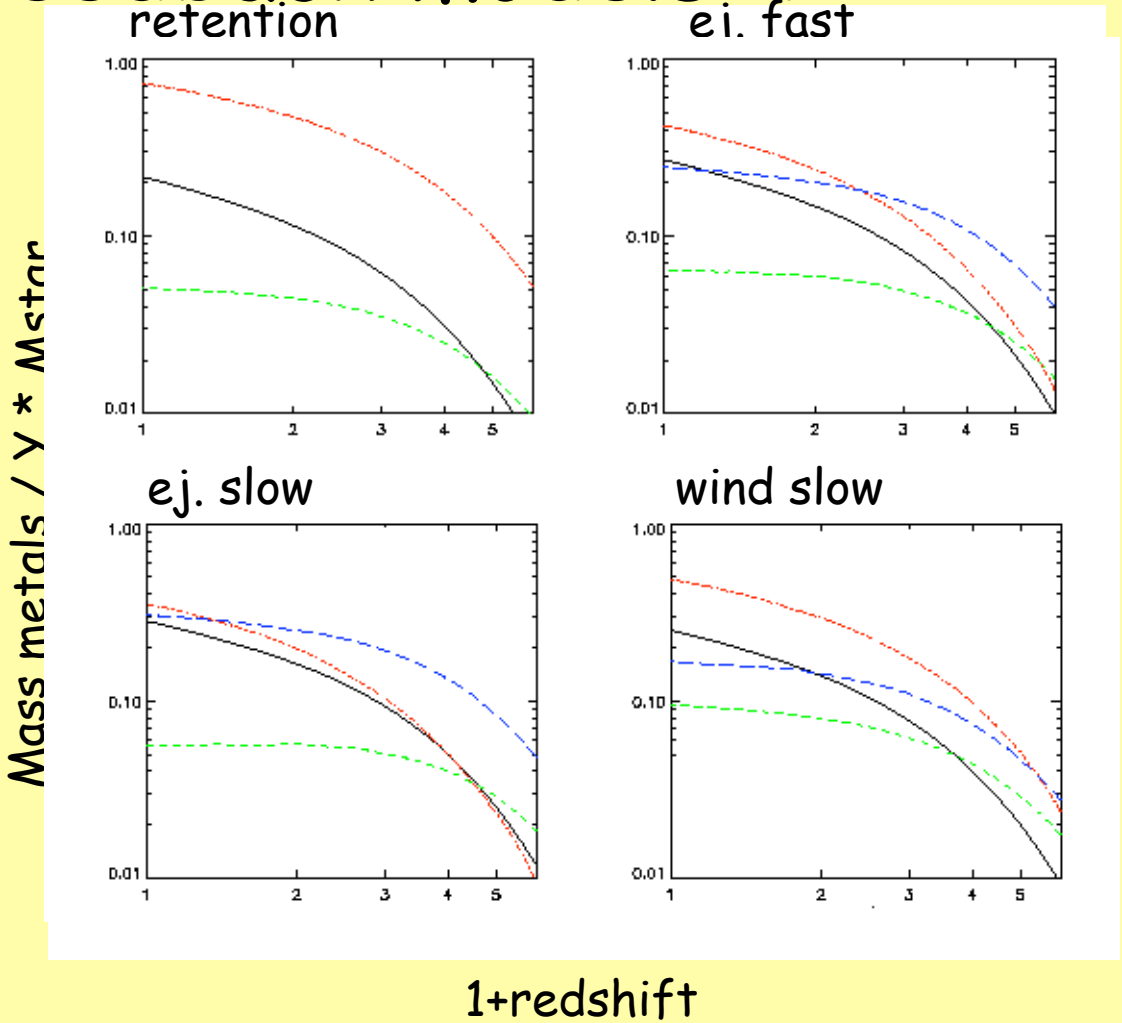
Observational signature of different feedback models #2:



The cluster metal budget

DLG, Kauffmann & White, 2004

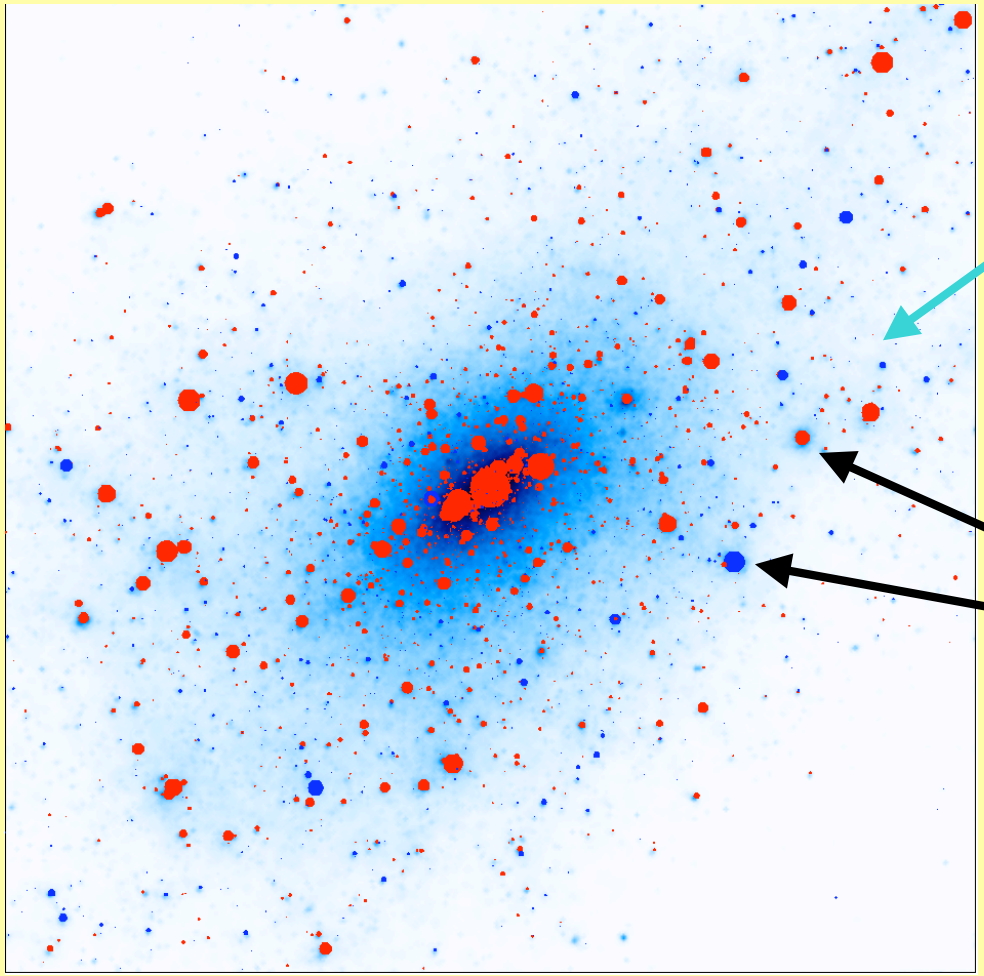
Observational signature of different feedback models #2:



The field metal budget

DLG, Kauffmann & White, 2004

A simulated cluster ($M \sim 10^{15}\ M_{\odot}$)



DM density map

Cluster galaxies

B-V > 0.8

B-V < 0.8

4 Mpc

Gabriella De Lucia, PhD Thesis

The Eso Distant Cluster Survey

A detailed follow-up of 20 clusters from LCDCS (Gonzalez et al. 2001)

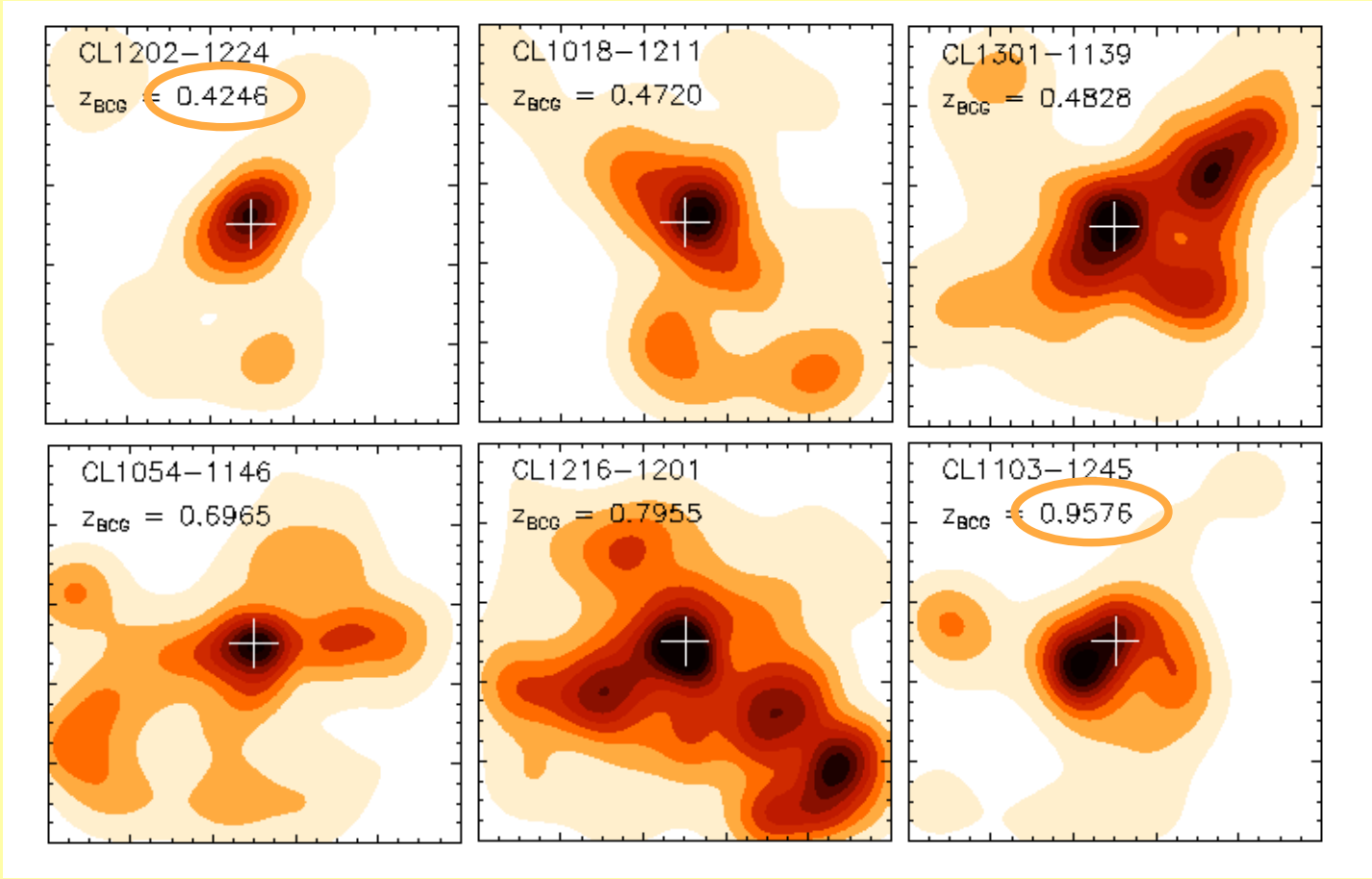
20 (19) clusters from $z \approx 0.5$ to $z \approx 0.8$

➡ study of cluster structure and cluster galaxy evolution over more than 50% of cosmic time

- ✓ deep optical photometry from VLT (14 nights)
- ✓ near-IR photometry from NTT (20 nights)
- ✓ multi-object spectroscopy with FORS2 on VLT (25 nights)
- ✓ 80 orbits of HST to image 10 high-z clusters!!!
- ✓ WFI R (120m), V, I (60m)

http://www.mpa-garching.mpg.de/galform/ediscs

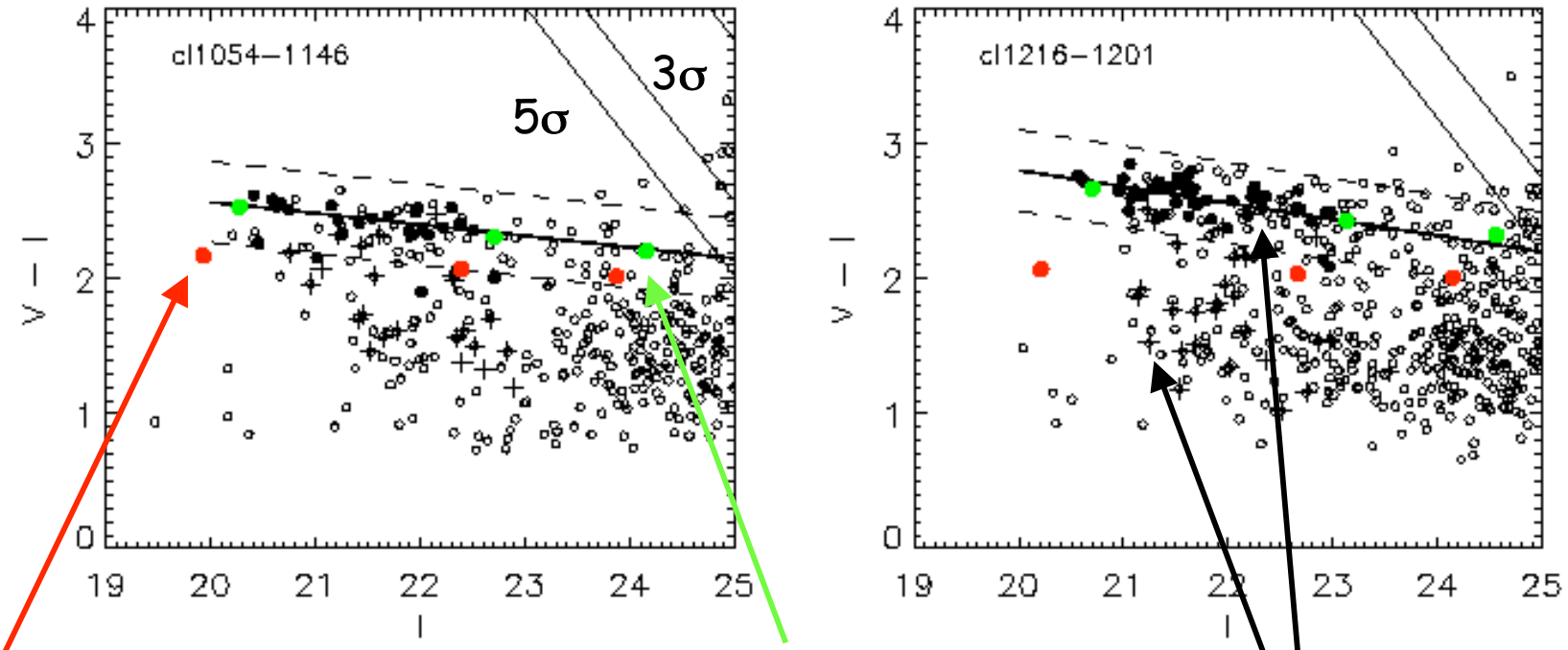
EDisCS clusters



A wide range of masses and structural properties

White et al., 2005

The CM of 2 EDisCS clusters



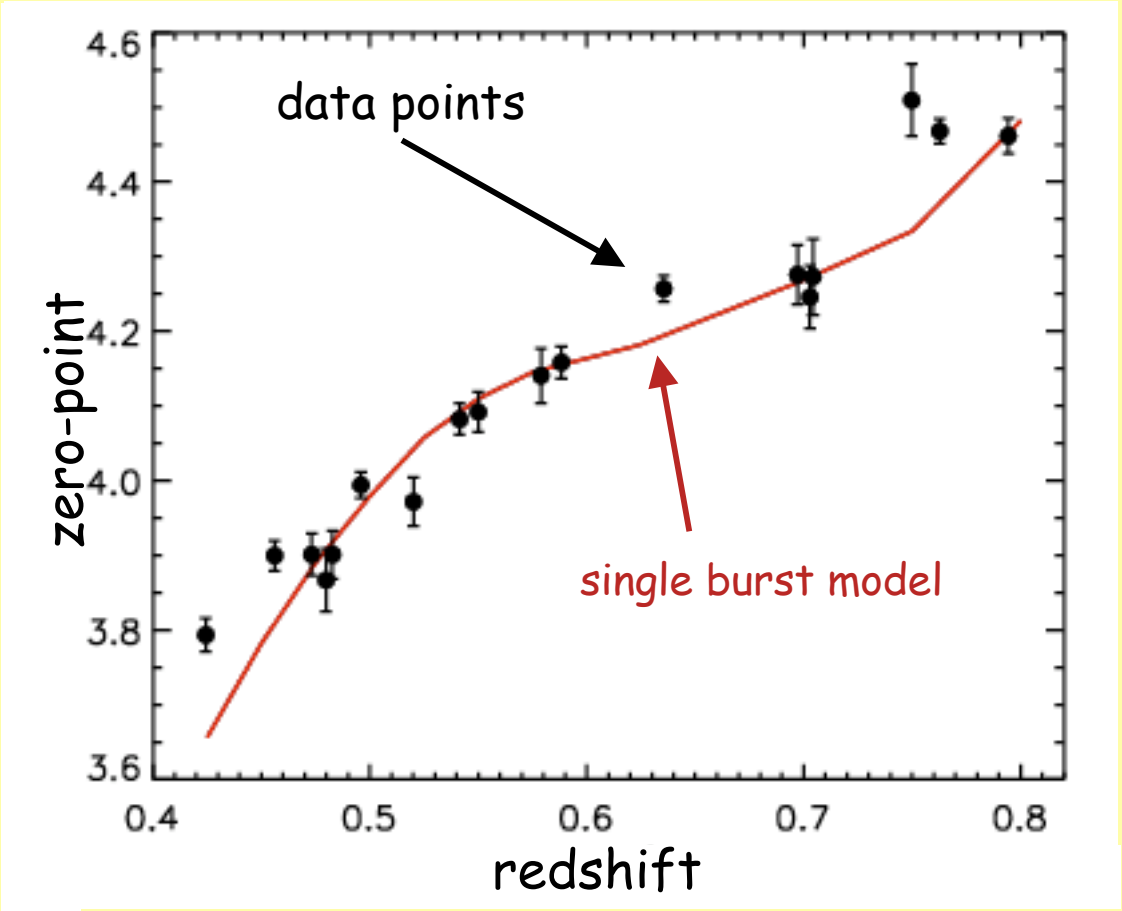
exp. s.f.r. z=3

single burst z=3

spec. conf. members

De Lucia et al., ApJL, 2004

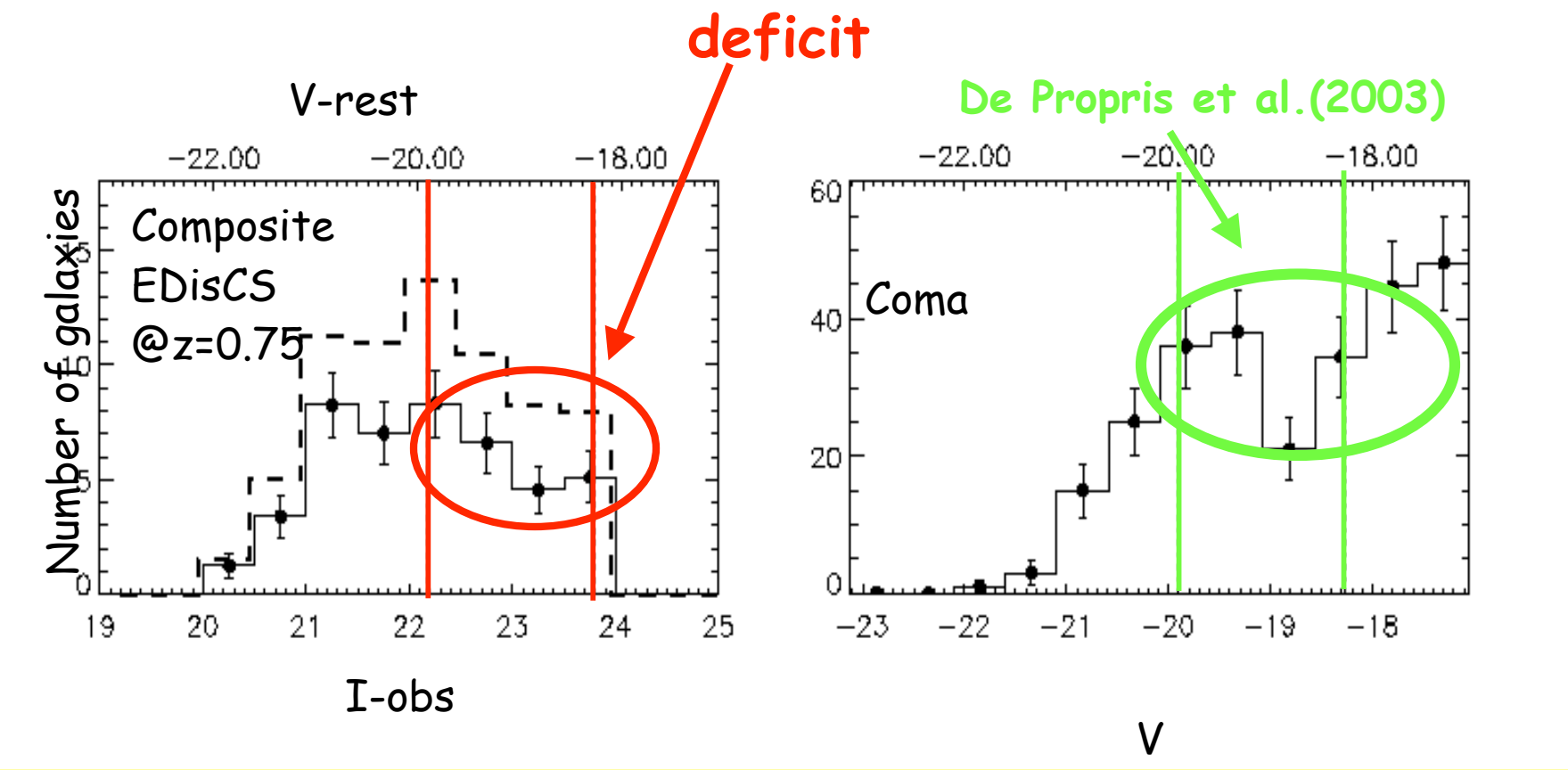
The CM of EDisCS clusters



- The location of the CM sequence observed in distant clusters requires high redshift of formation

- The slope is consistent with a correlation between galaxy metal content and luminosity

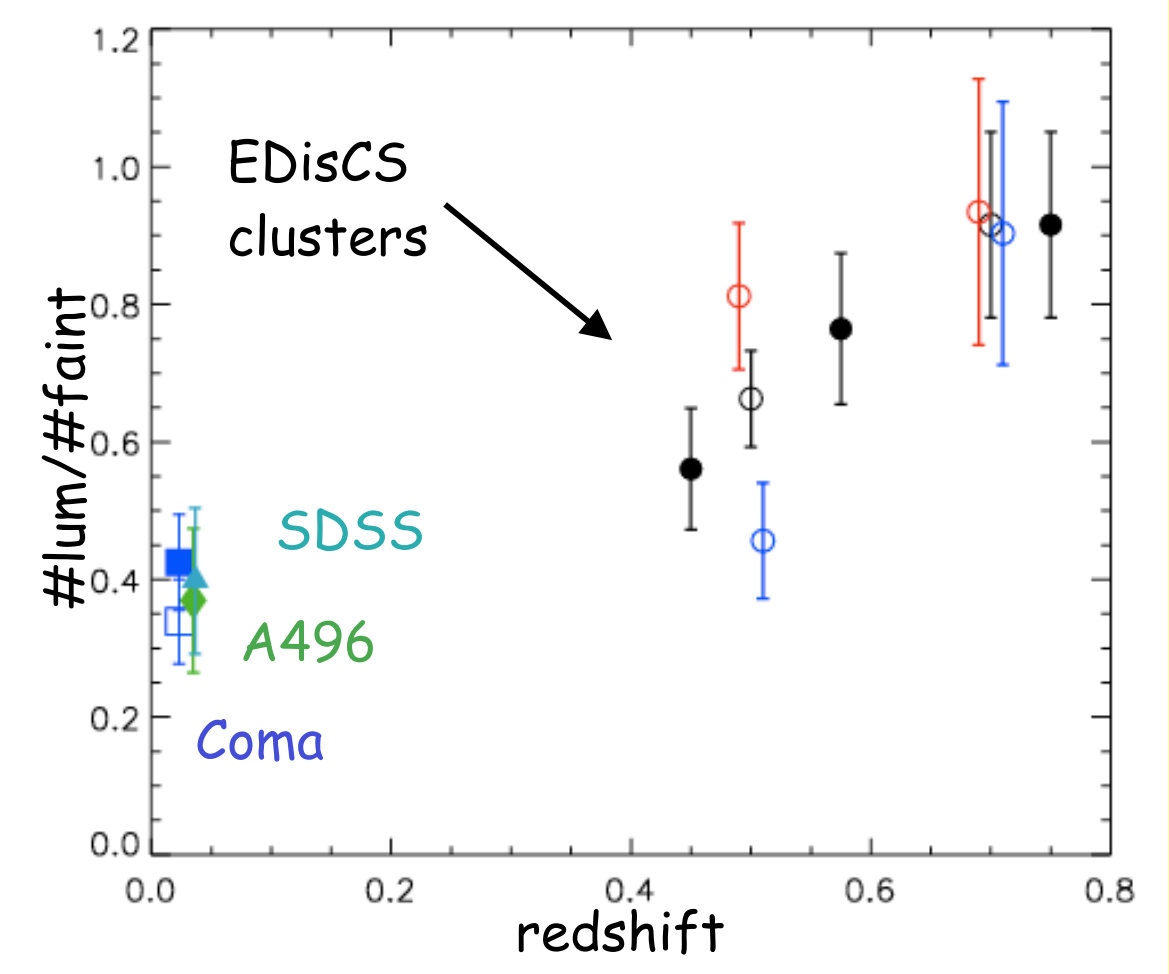
The red-sequence LF



Robust result – also present in the full photometric catalogue!

De Lucia et al., ApJL, 2004 (see also Kodama et al. 2004)

The build-up of the CM relation



There is a clear increase in the luminous-to-faint ratio with increasing redshift

De Lucia et al., in prep.

A "cosmic down-sizing" (Cowie, 1996).

A problem for the hierarchical paradigm?

Ellipticals in a hierarchical model :

- AGN model for suppression of the cooling-flows (Croton et al., 2005)

Three channels to make bulges:

- In a 'minor' merger the stellar mass of the merged galaxy is transferred to the bulge of the central galaxies + burst of a fraction of the combined cold gas
- A 'major' merger completely destroys the disc of the central galaxy + burst of a fraction of the remaining gas
- Disk instability (Mo, Mao & White 1998)

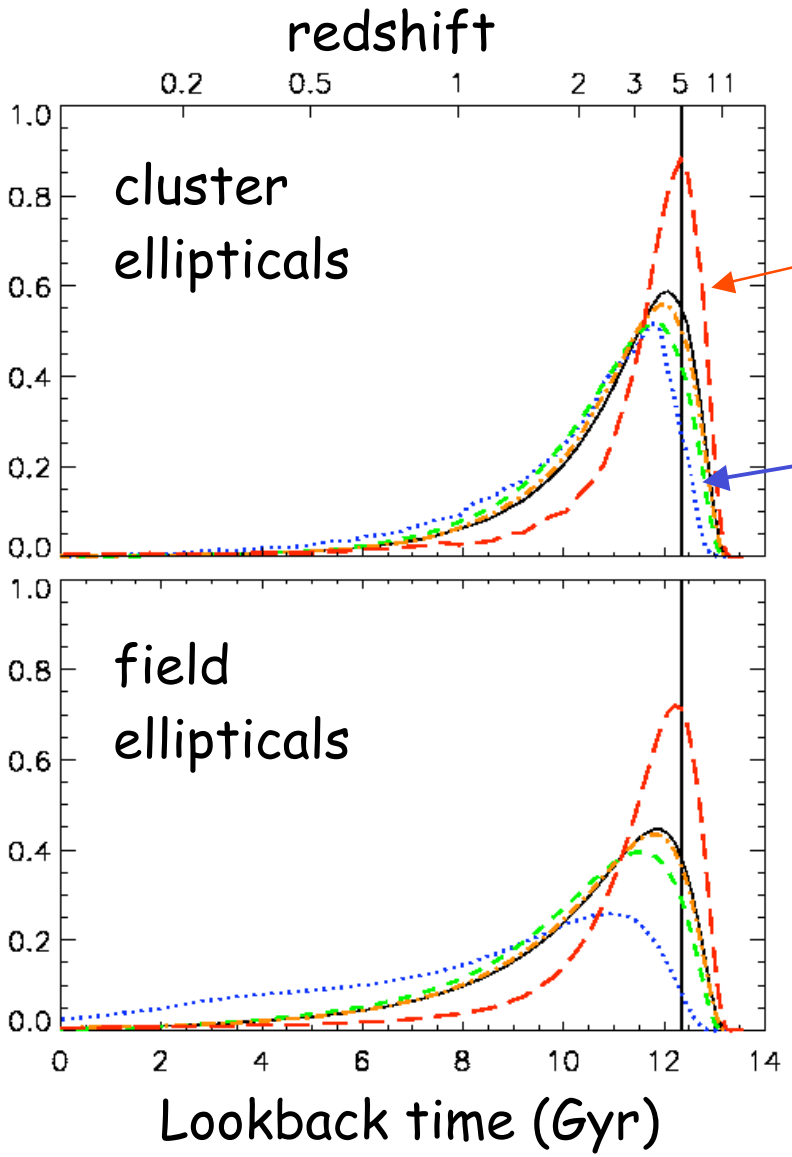
↓ De Lucia et al., 2006

1,031,049 (810,486) Es with Mstar > 4×10^9 (1×10^{10}) Msun

16% Es / 66% Sp / 18 % S0 (MV < -18)

(13%, 67%, 20% Loveday et al., 1996)

The star formation histories:



$M_{star} = 10^{12} M_{sun}$

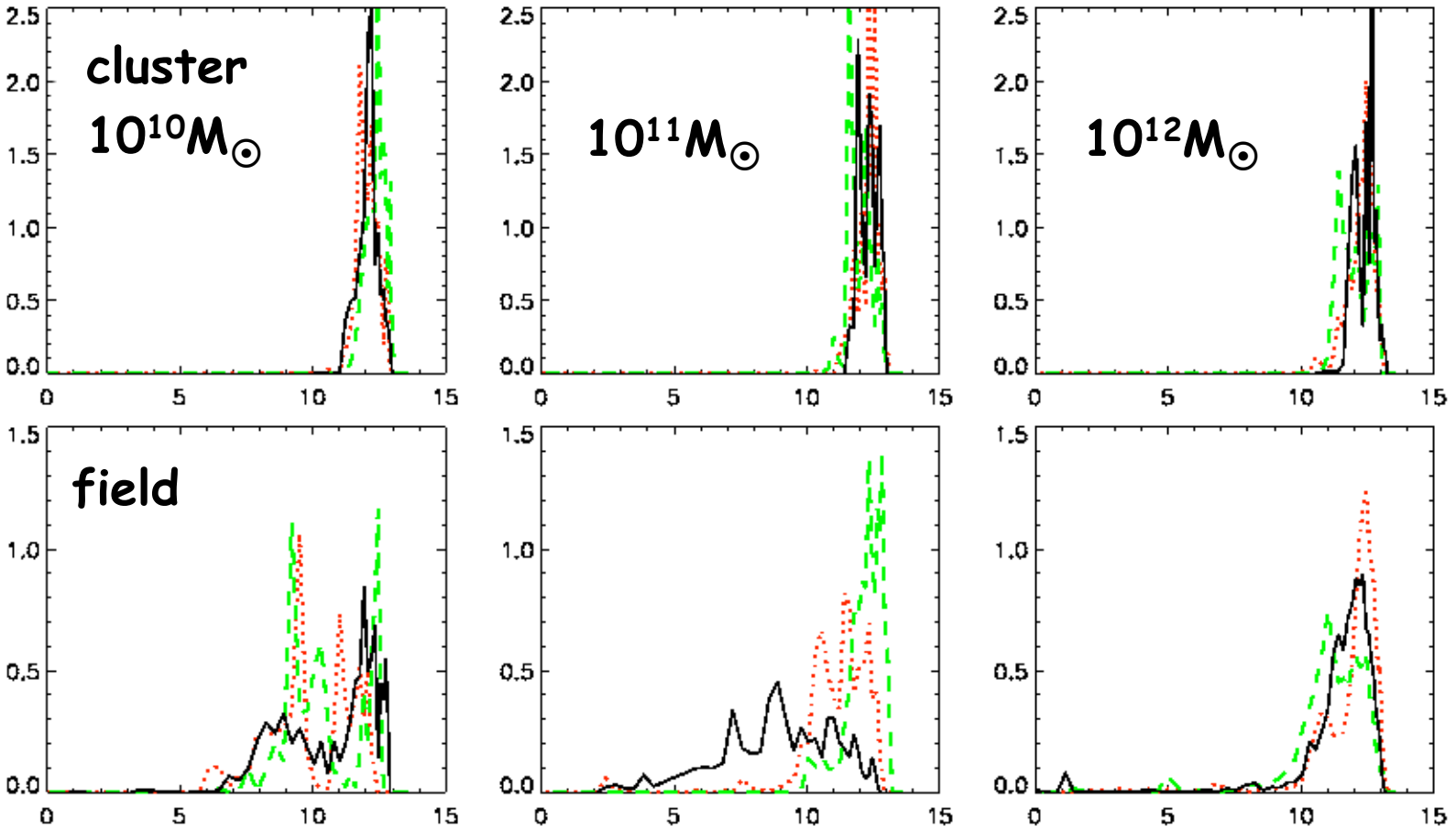
$M_{star} = 10^{9} M_{sun}$

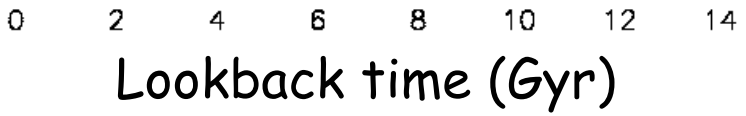
Elliptical galaxies also have a shorter formation timescale!

This is "anti-hierarchical"!!!

De Lucia et al., 2006

The star formation histories:





De Lucia et al., 2006

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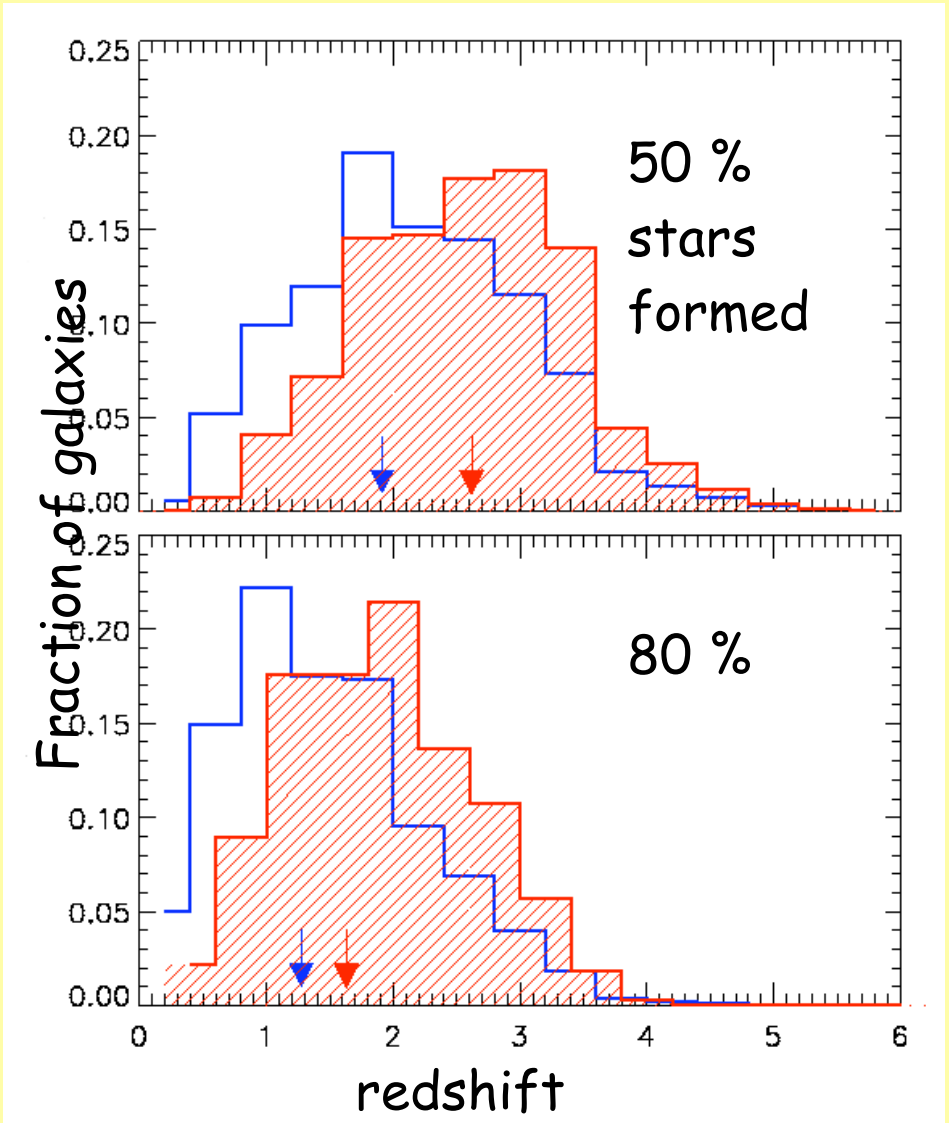
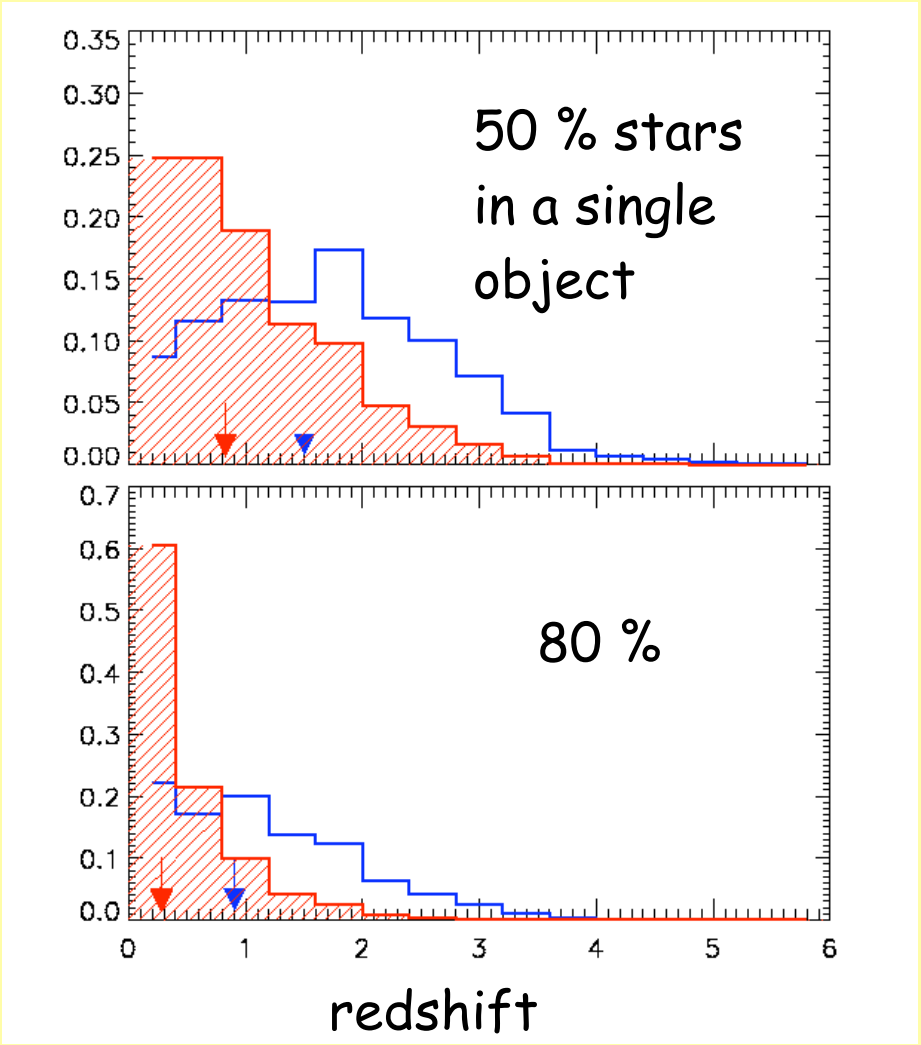
...l"!!!

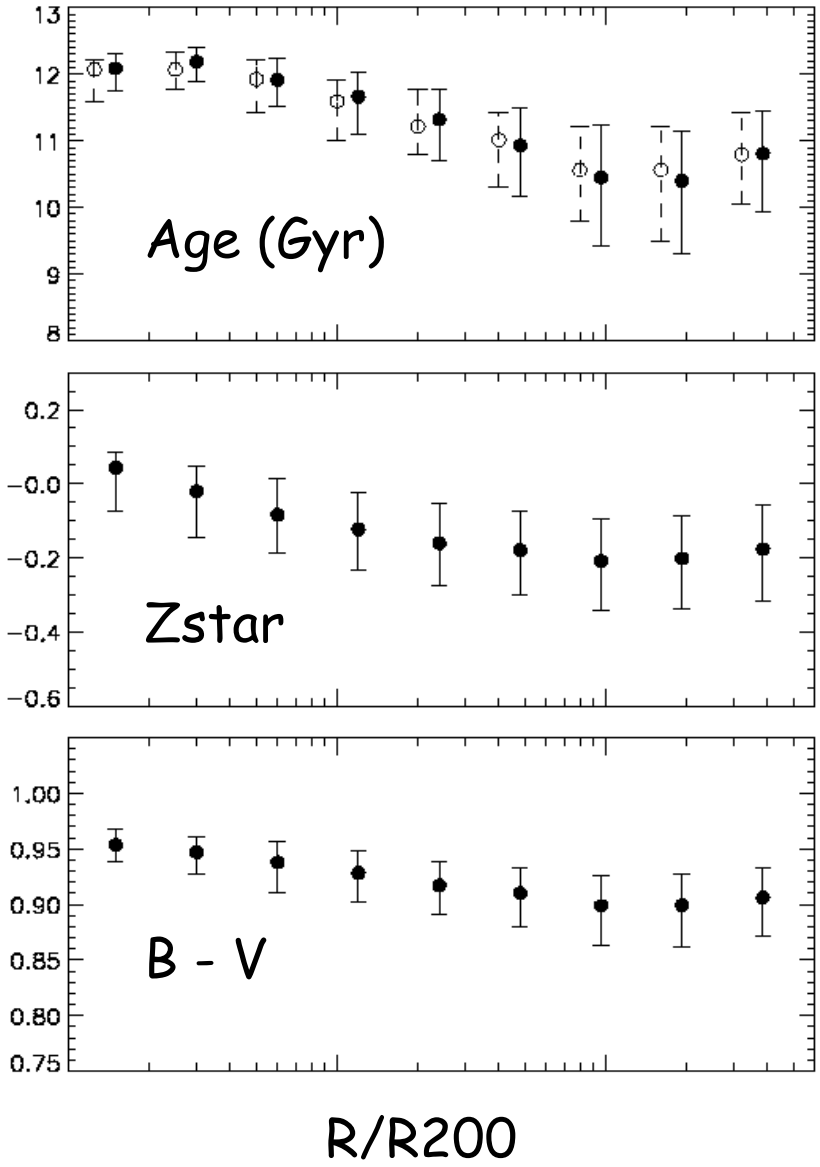
Ellipticals: formation & assembly:



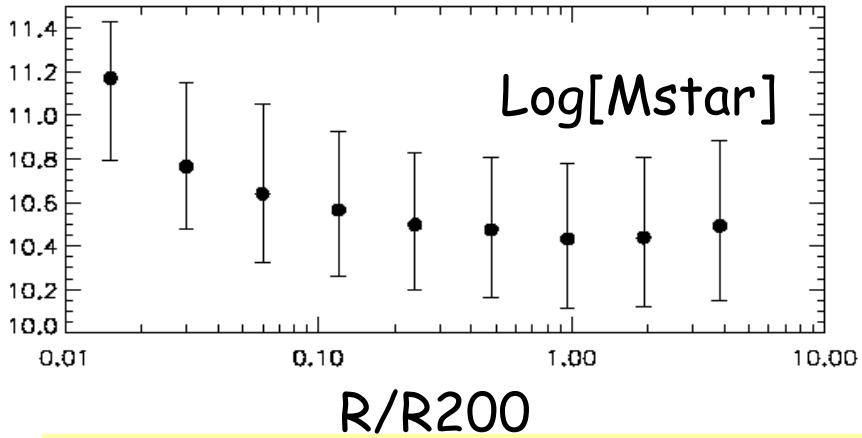


De Lucia et al., 2006

Ellipticals in clusters

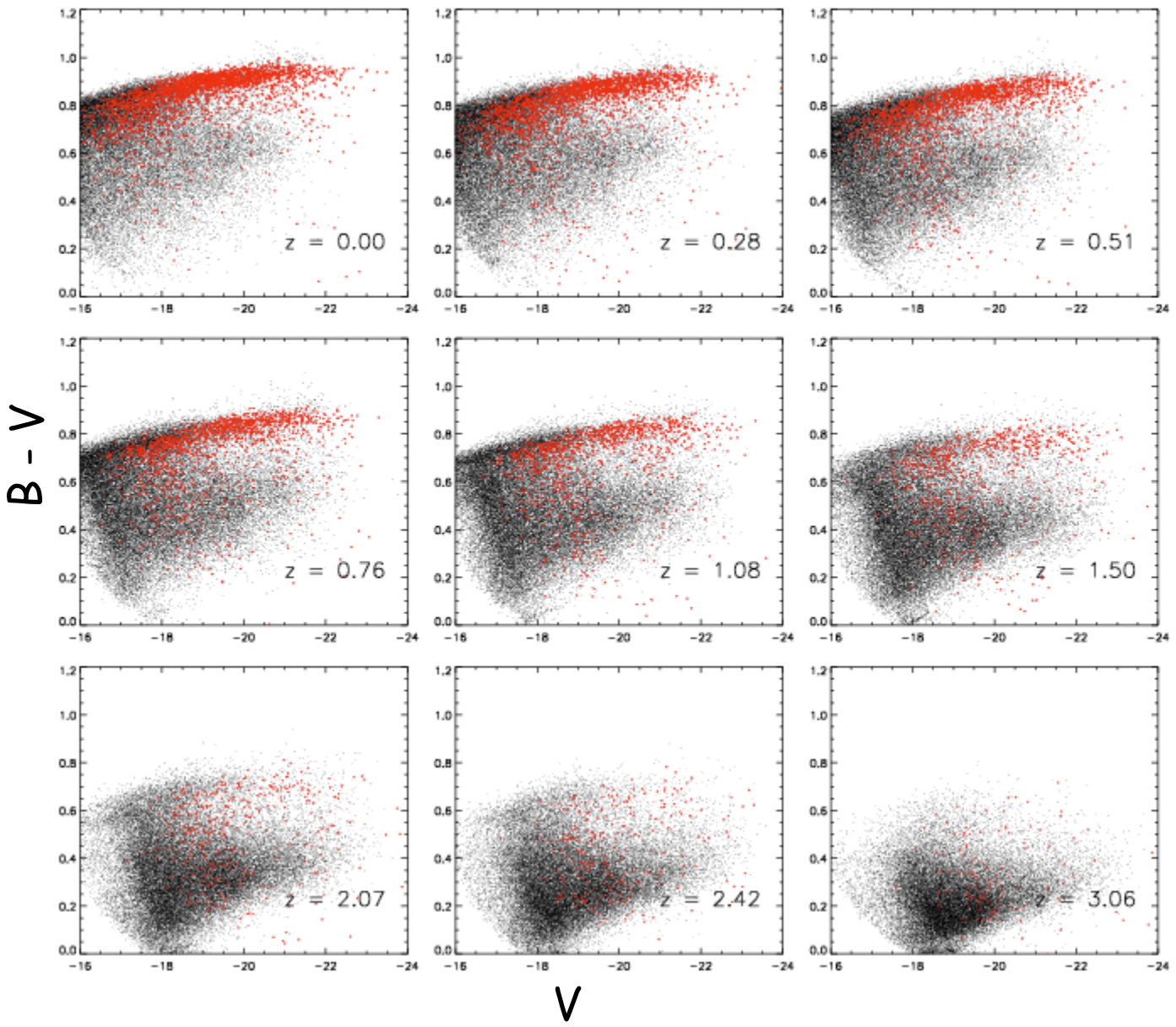


51 haloes with $M_{200} > 8 \times 10^{14} M_{\odot}$



see Diaferio (2001)

Ellipticals: the evolution of the CM

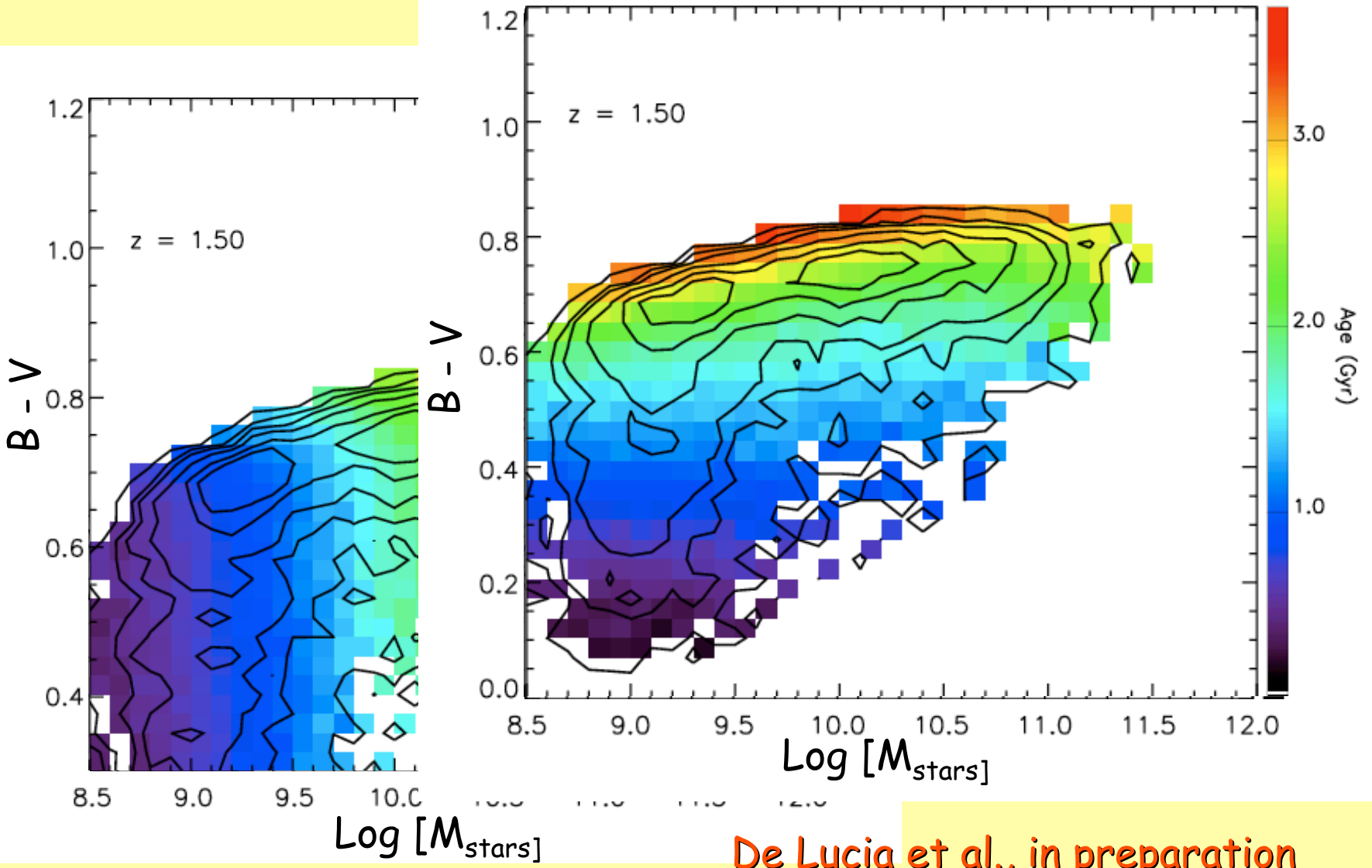


A well defined CM up to z~2

A clear bimodal distribution up to z~2

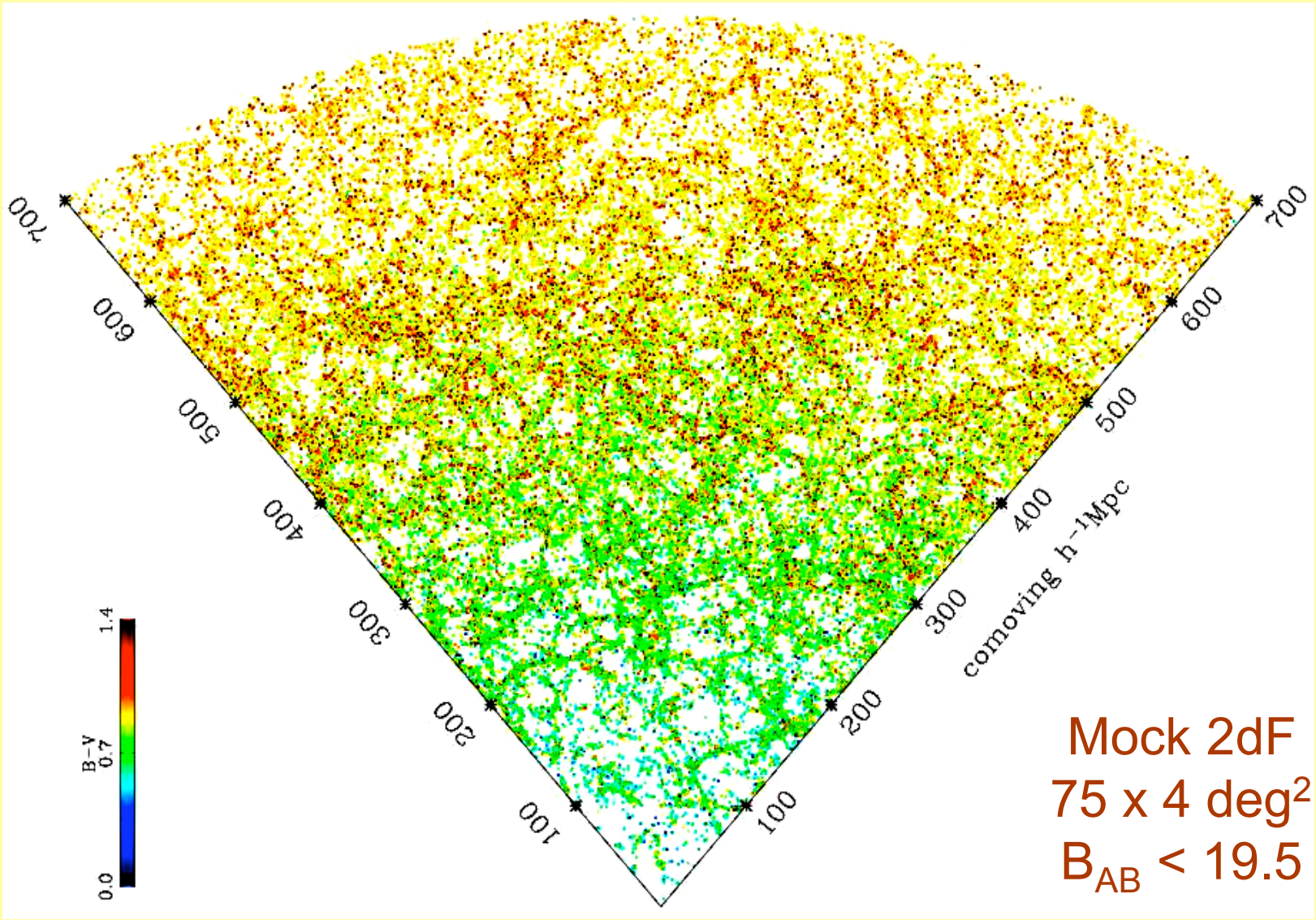
De Lucia et al., in preparation

The origin of the colour-magnitude:



De Lucia et al., in preparation

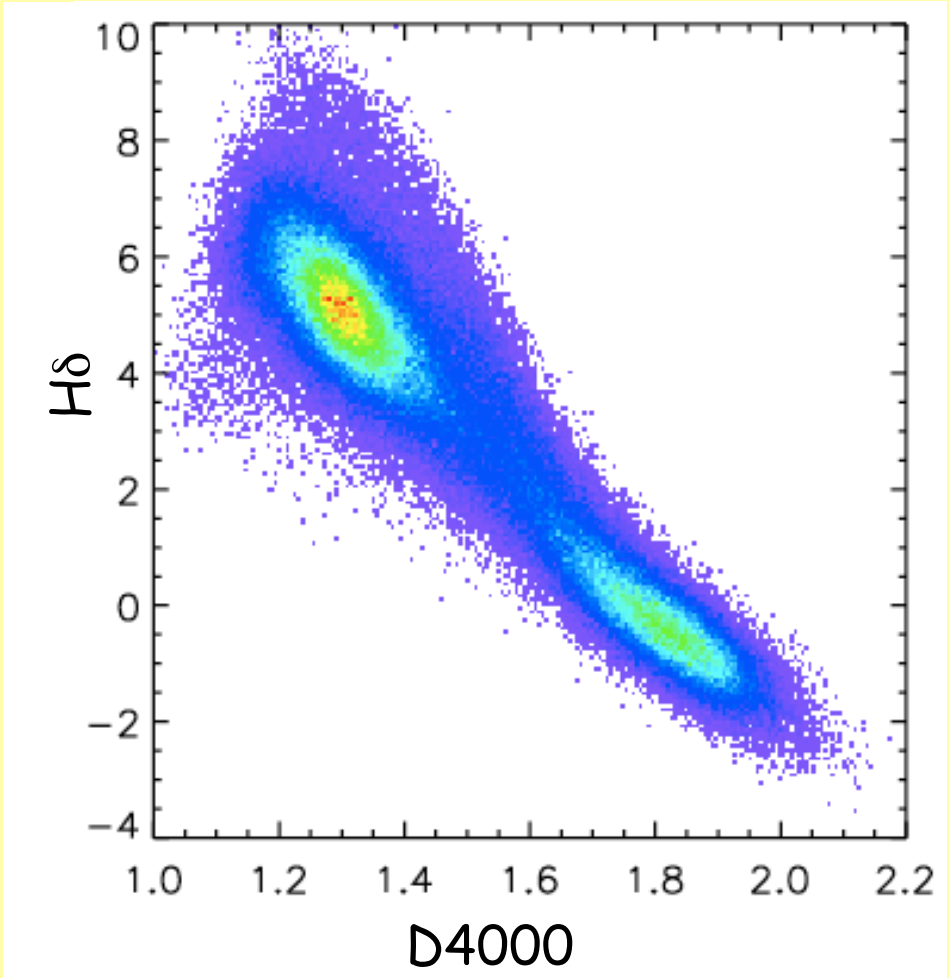
Tools to observe ideas :

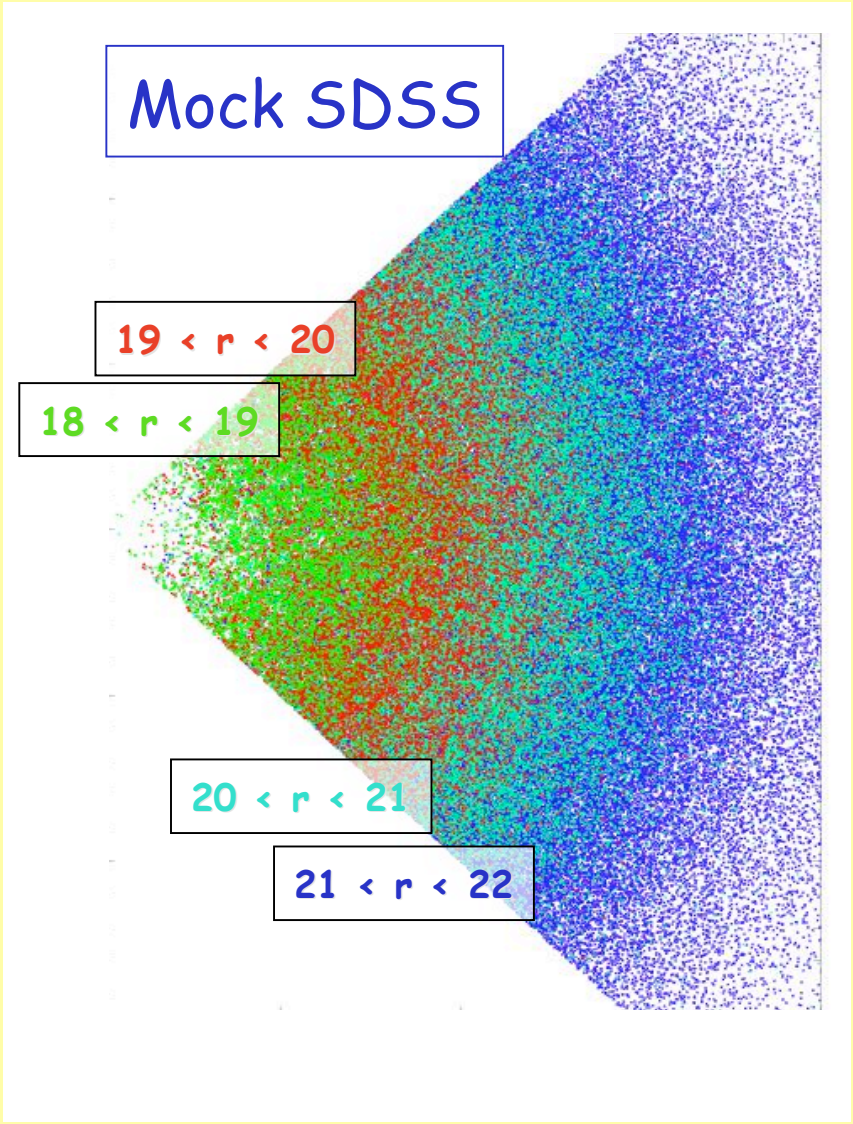


Mock 2dF
75 x 4 deg^2
B_{AB} < 19.5

Blaizot et al. 2005: MoMaF

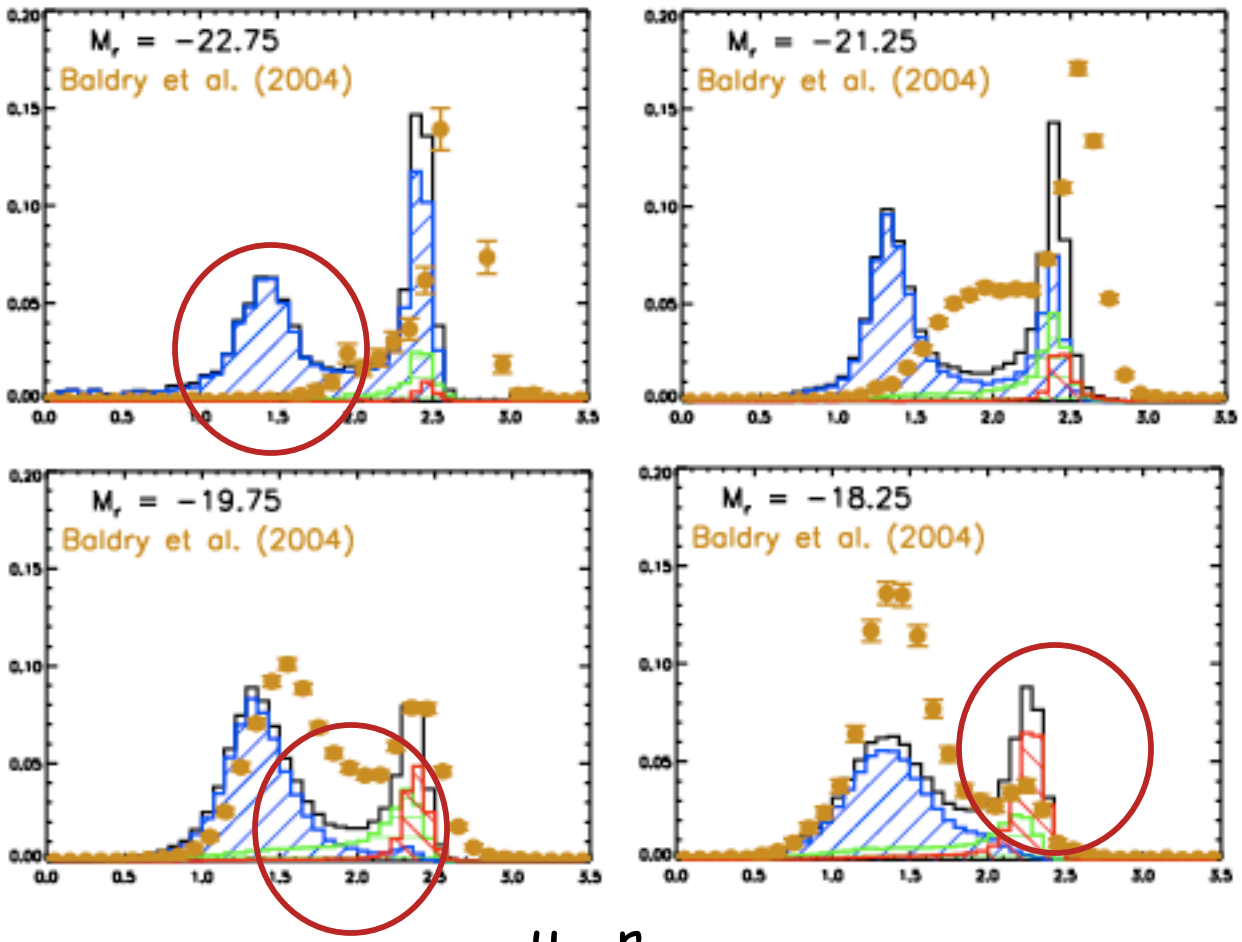
Tools to observe ideas :





with Jeremy Blaizot

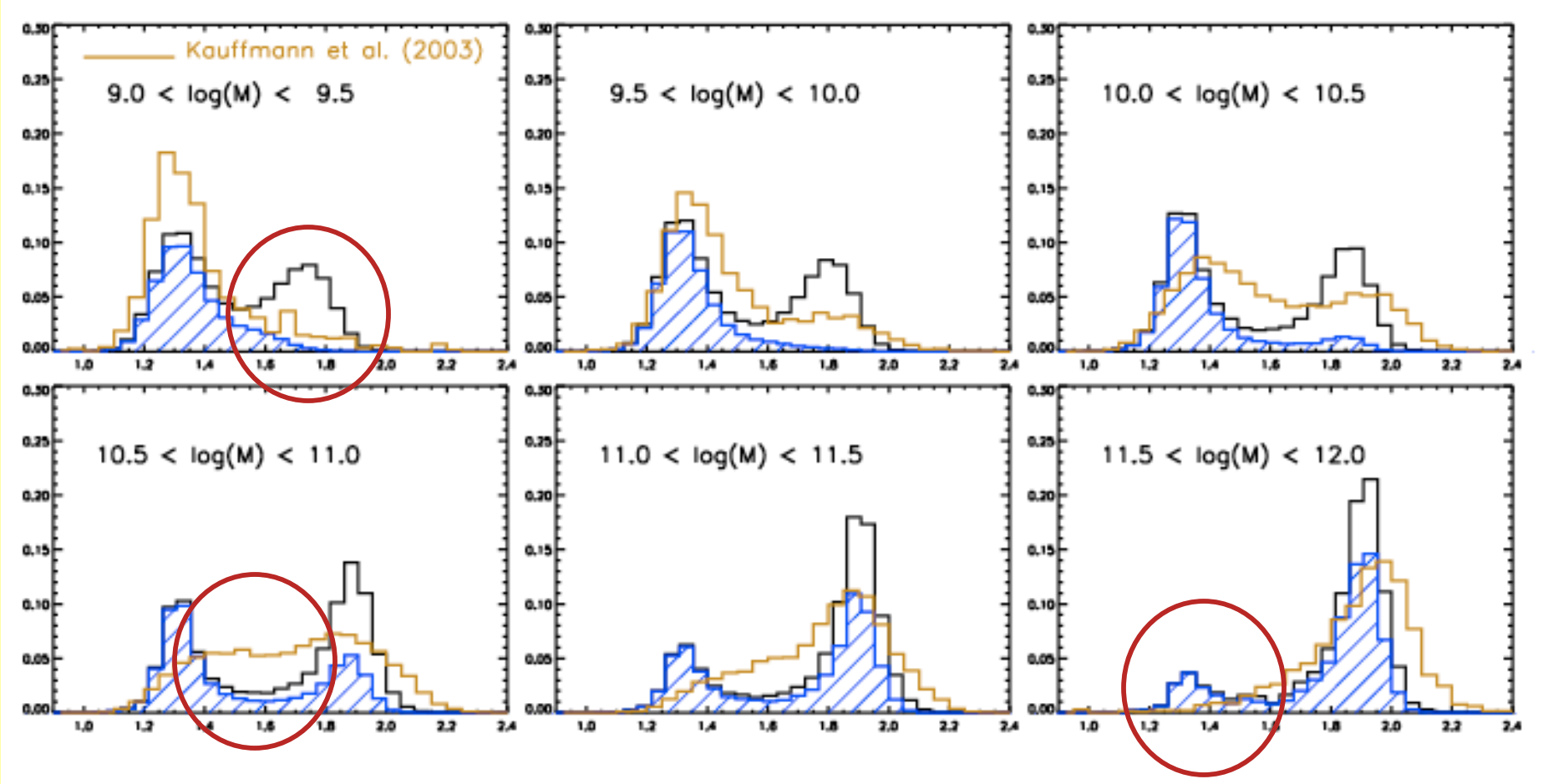
The colour-magnitude bimodality:



- Tail of blue bright objects
- Transition region not well populated
- Excess of faint red satellites

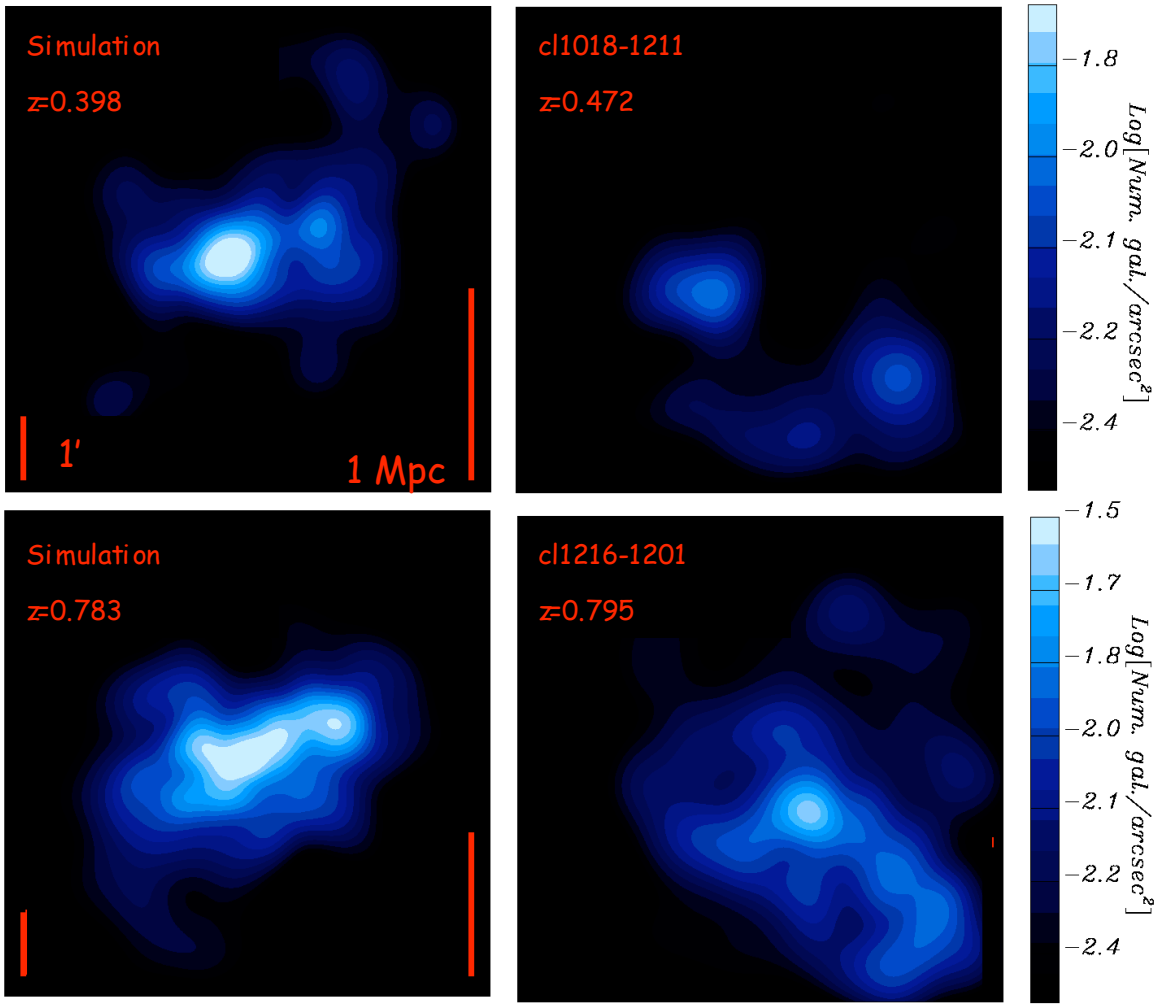
➡ Quantitatively the CM bimodality is not well reproduced

The D4000 distribution:



➡ Same problems are visible in the distribution of D4000

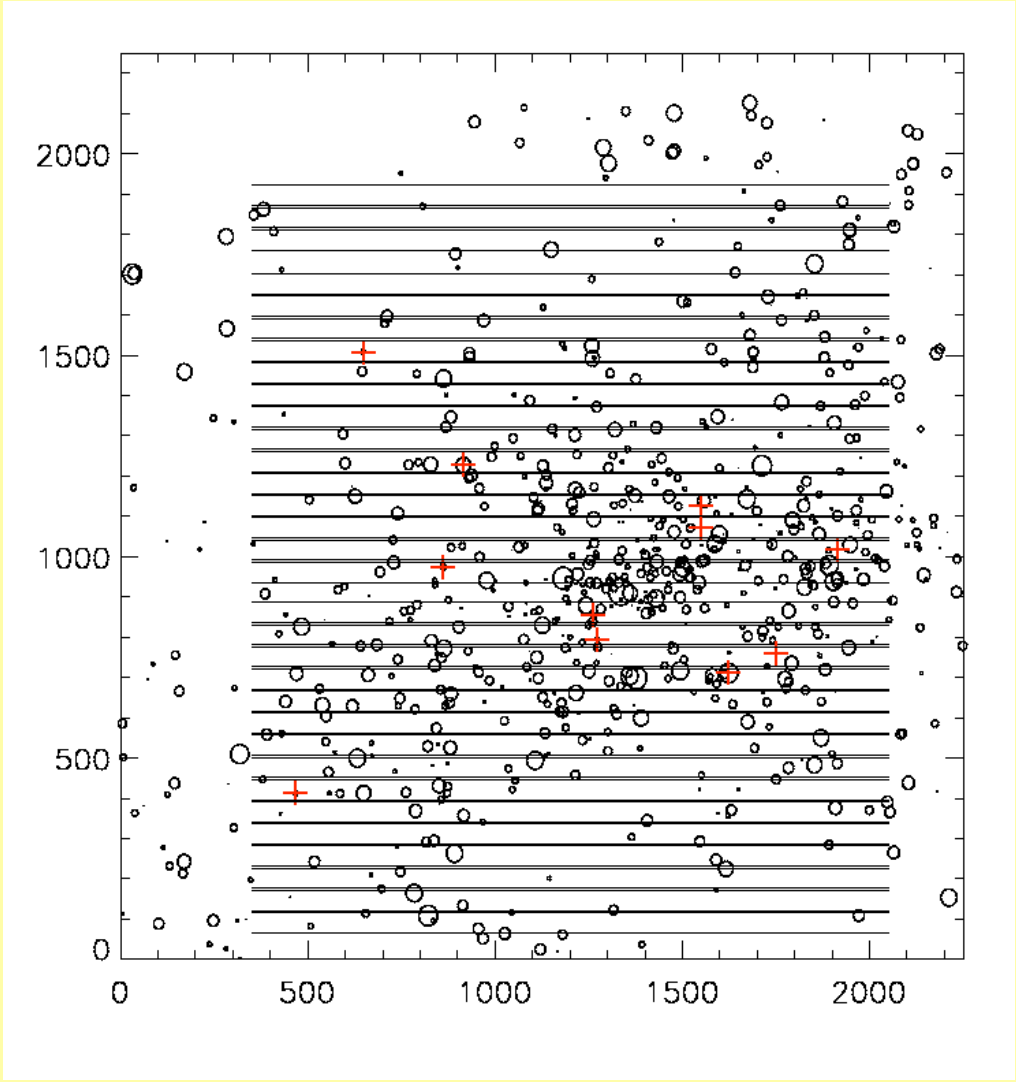
Simulated and real clusters



Full information about the spatial and redshift distribution of model galaxies

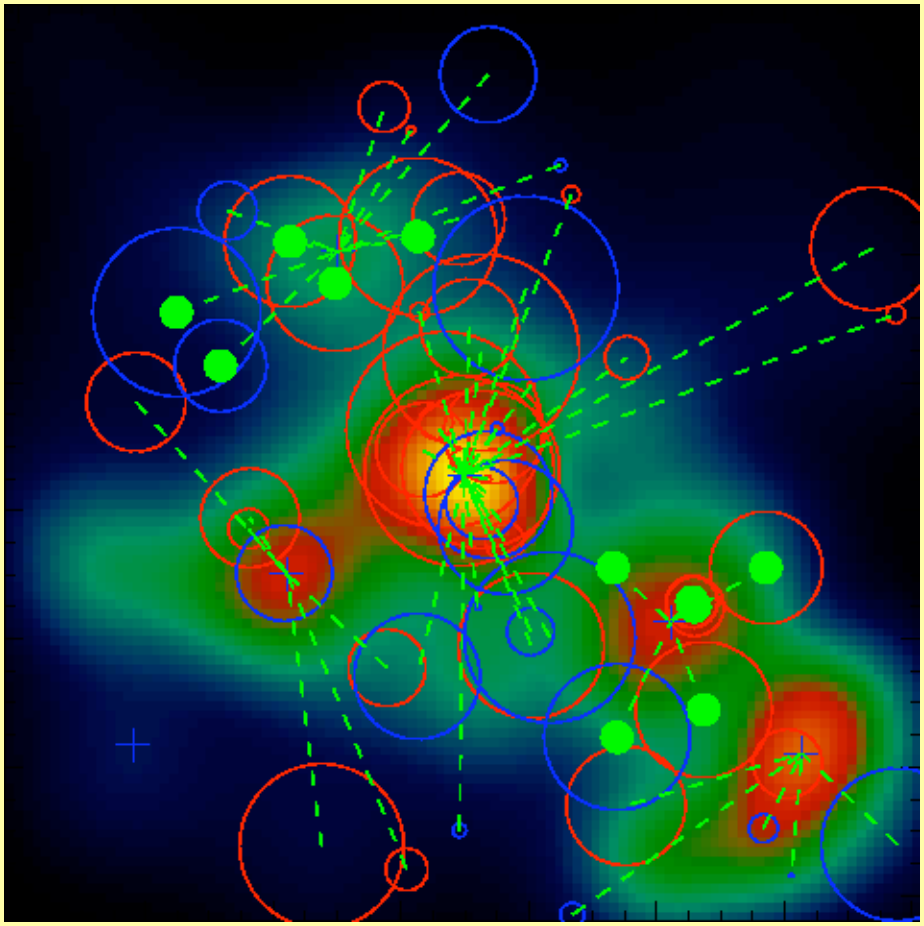
construction of simulated catalogues of galaxies including luminosity, colour, bulge-to-disc ratio etc.

Observing a simulated cluster

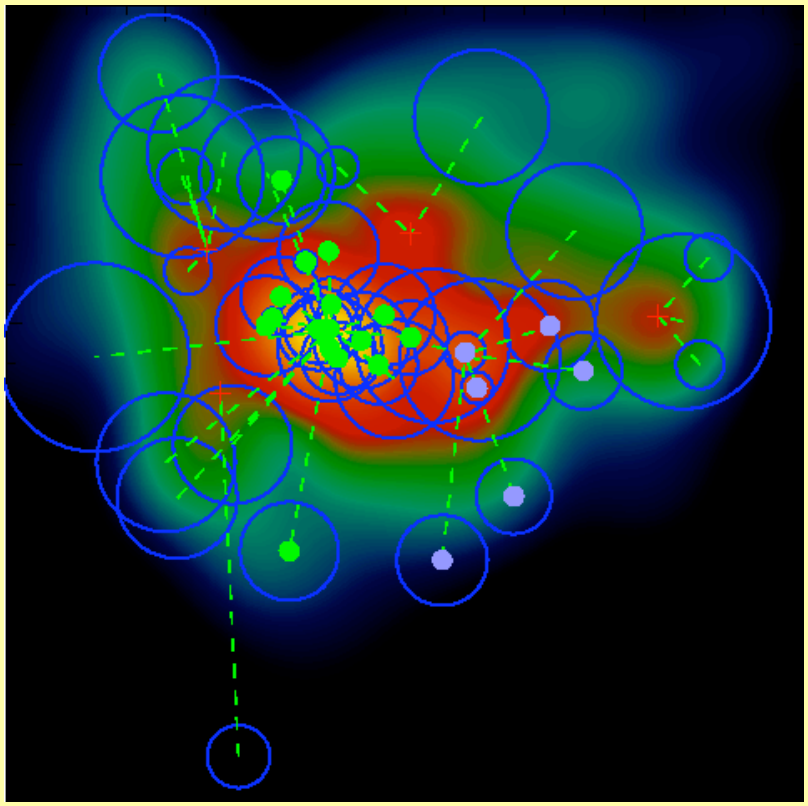


Model results can be treated with exactly the same methods used for the observational data

Structure comparison



cl1216-1201 @ z= 0.8



a simulated cl @ z=0.8

De Lucia et al., in preparation

Conclusions:

- Semi-analytic models *are a* ***technique*** for studying galaxy formation - *they are not meant to be definitive*!

- A ***self-consistent approach*** that takes into account the spectro-photometric AND chemical evolution is necessary

- The ever more detailed picture of our Universe also requires a ***more complex modelling*** and the ***development of new tools*** for a more straightforward comparison with observational data

- Comparison with observational results (expecially at ***high redshifts***) will provide important constraints on physical processes and missing physics.

- Watch out: everything is ***coming online***