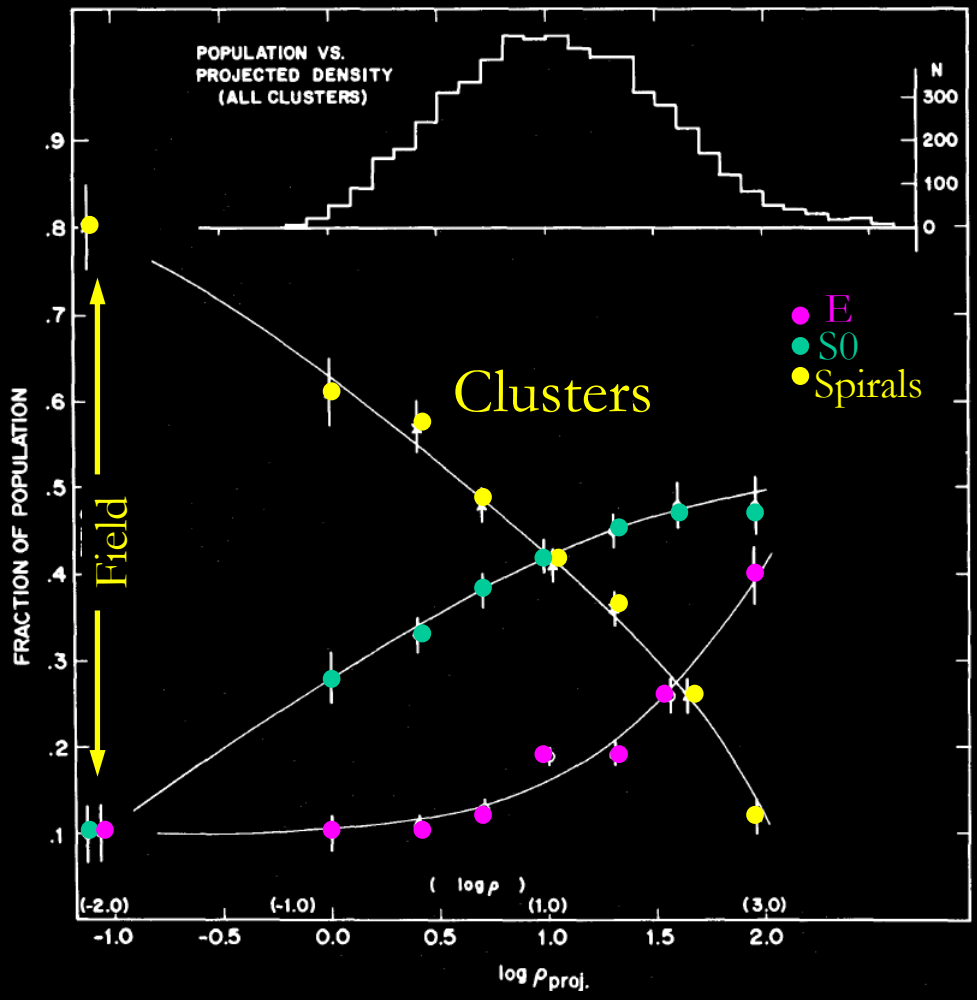
銀河の環境効果、形状と色

岡本崇 (国立天文台)

Yet another semi-analytic model

- Okamoto & Nagashima 2001
- Okamoto & Nagashima 2003
- ν GC についてちょっと

Morphology-Density Relation



Dressler 1980

Nature or Nurture?

- Nature? Elliptical galaxies only form in protoclusters at high redshift. Rest of population is due to infall.

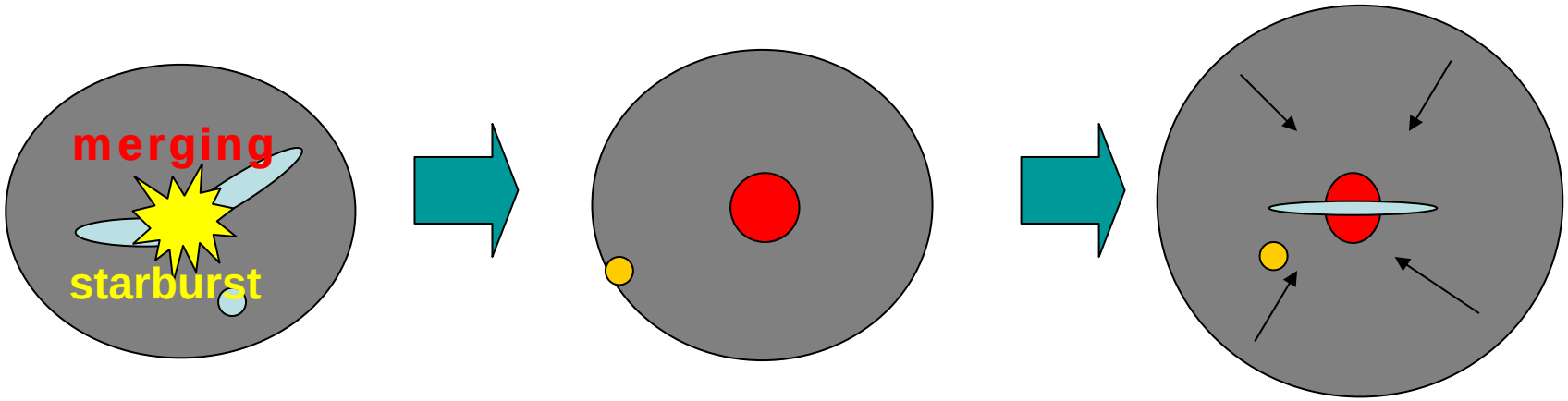
- or Nurture? Galaxy evolution proceeds along a different path within dense environments.
  - If this is true in groups and clusters, then environment could be the driving force of recent galaxy evolution…

Merger hypothesis

- Bulges form through major mergers.

Major merger

Bulge formation



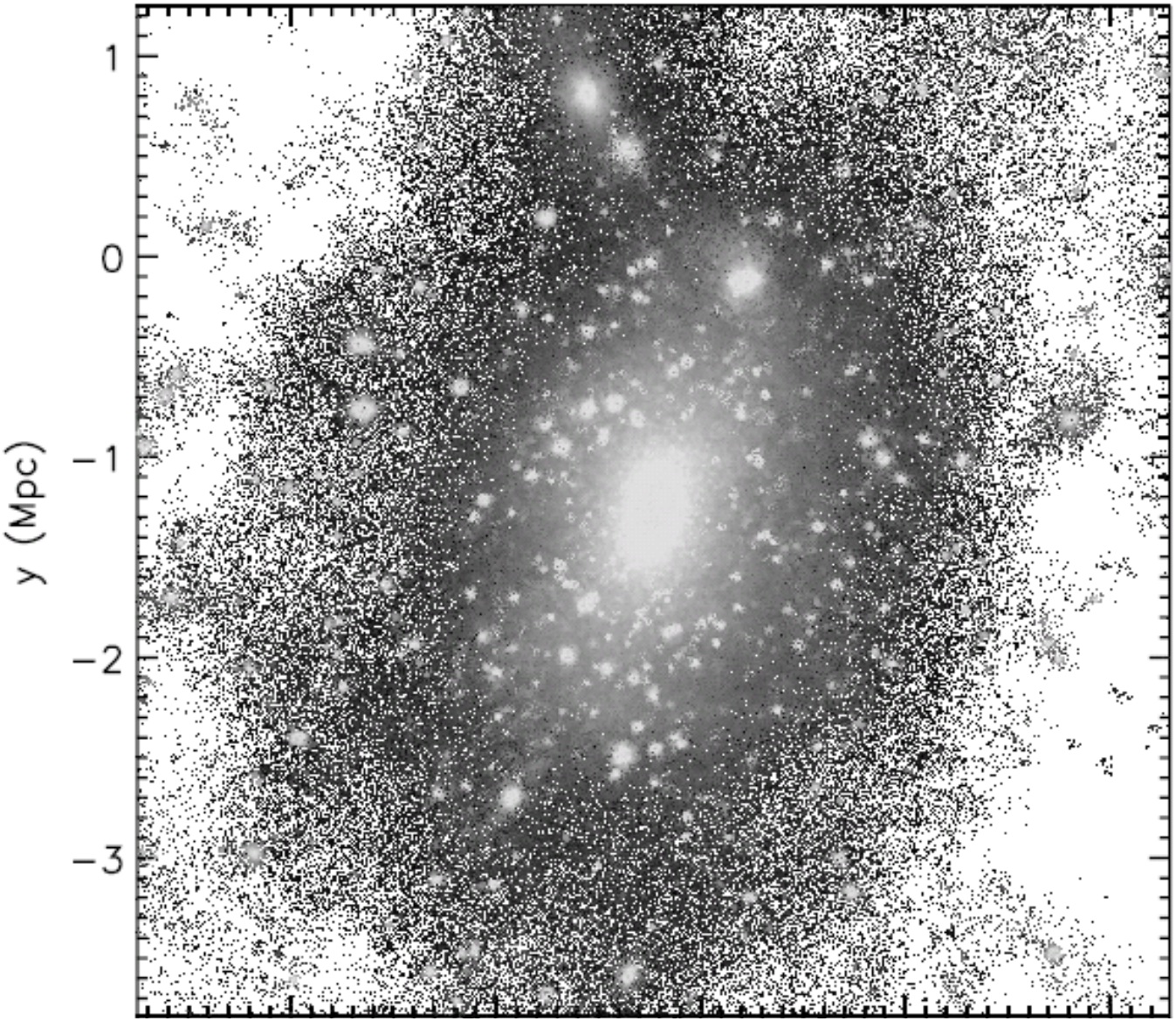
A galaxy merger destroys discs and leads to bulge formation

All gas is used up in the burst.

Further cooling forms an additional disc.

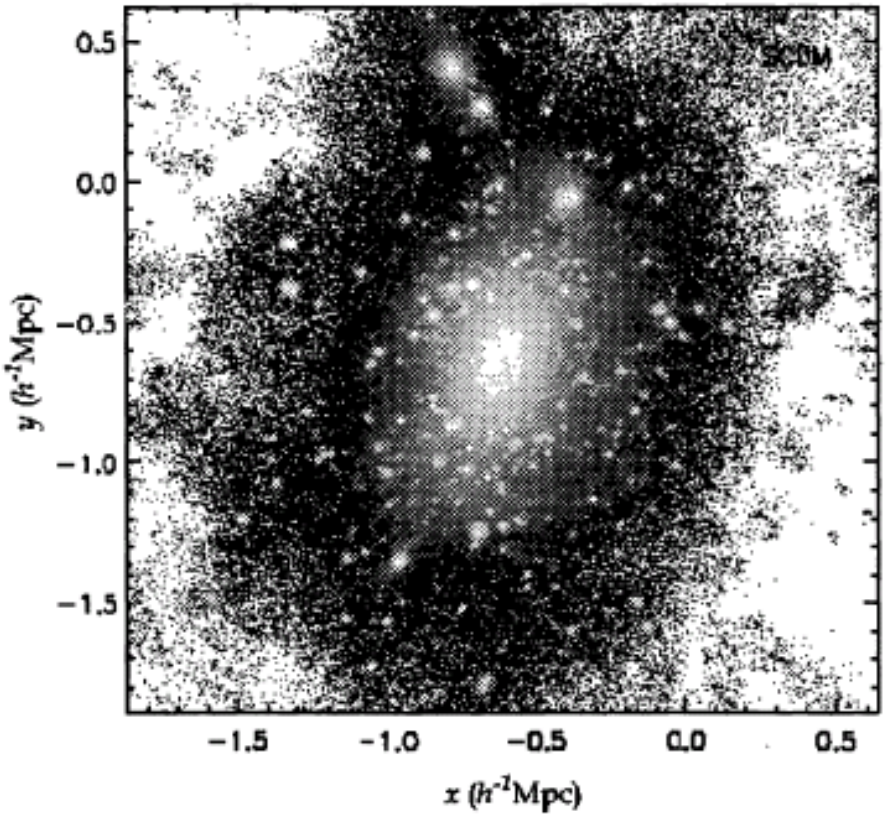
N-body + SA simulation

- Need positions and luminosities of cluster galaxies
- High-resolution cosmological simulation of a cluster formation ($\Omega_0 = 1$ and 0.3)
- Follow galaxy evolution within sub-halos using semi-analytic model.
- Can the MD-relation be reproduced by merger driven bulge formation scenario?

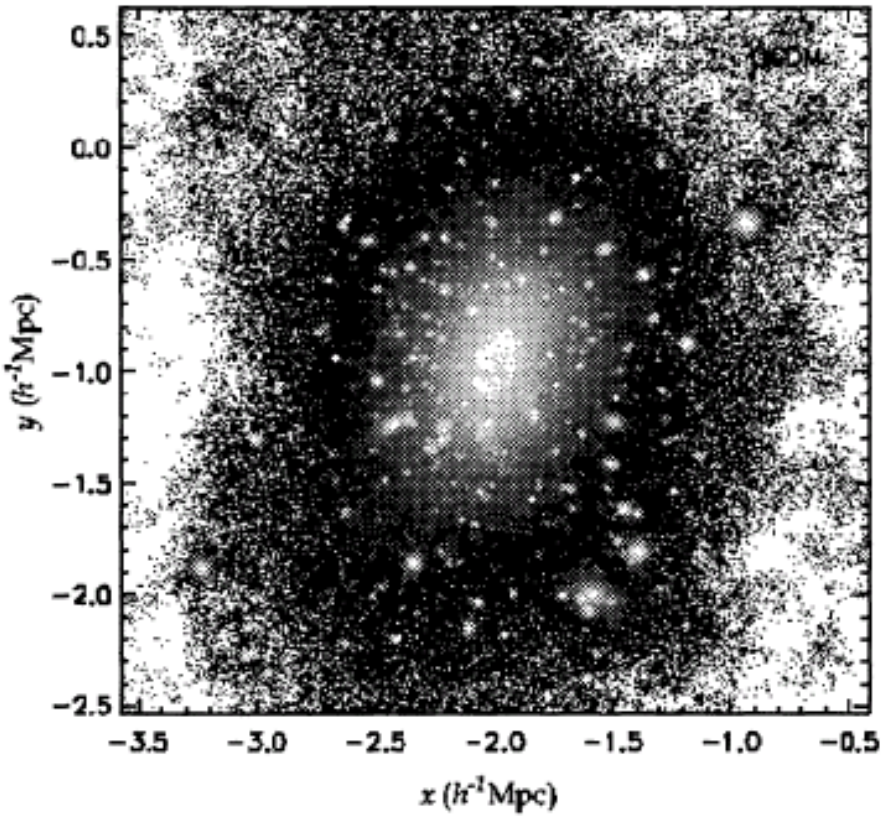


Density map of the simulated SCDM cluster

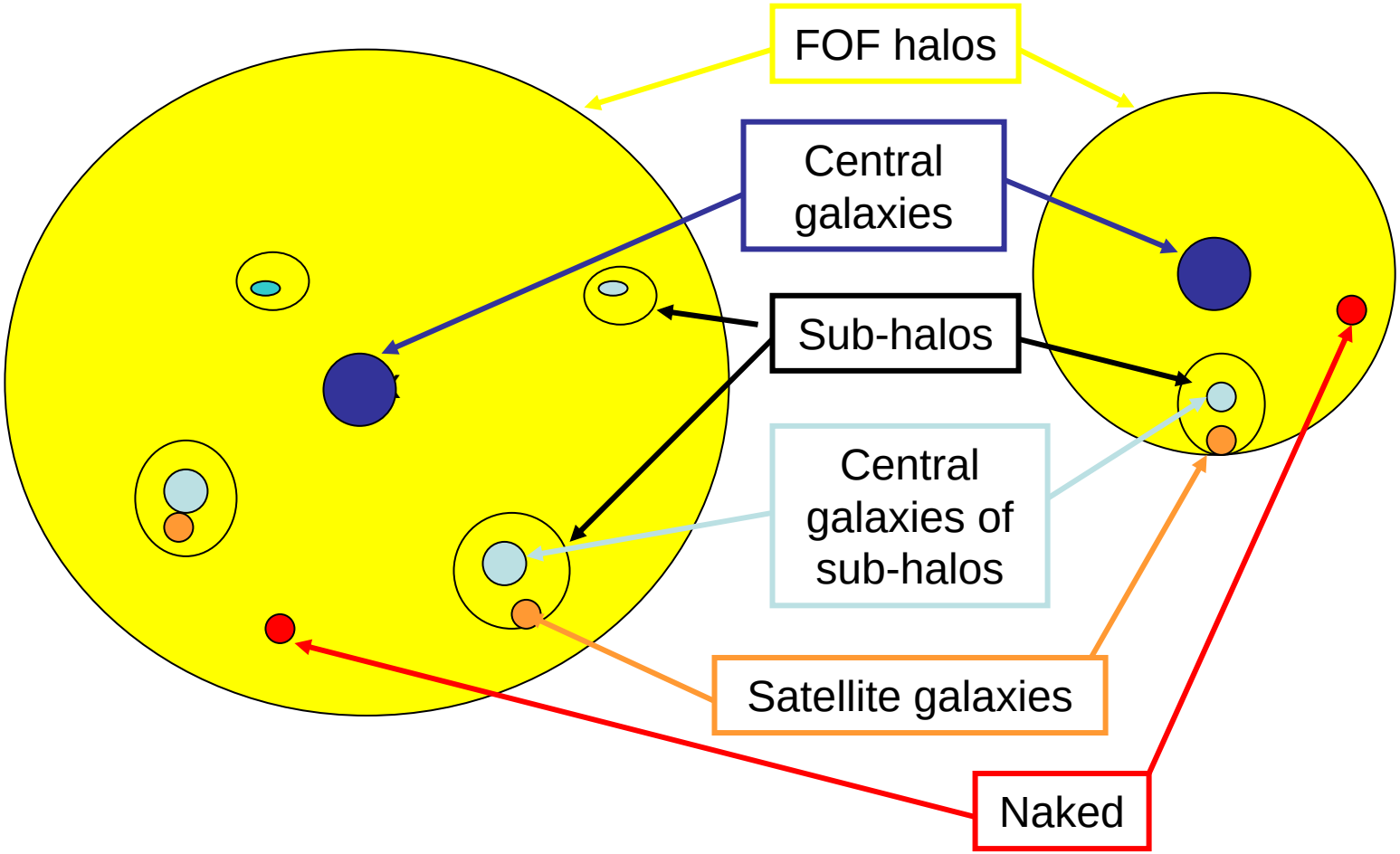
TO & Habe 1999


SCDM
0.5
0.0
−0.5
−1.0
−1.5
y (h^{-1}Mpc)
−1.5
−1.0
−0.5
0.0
0.5
x (h^{-1}Mpc)

SCDM

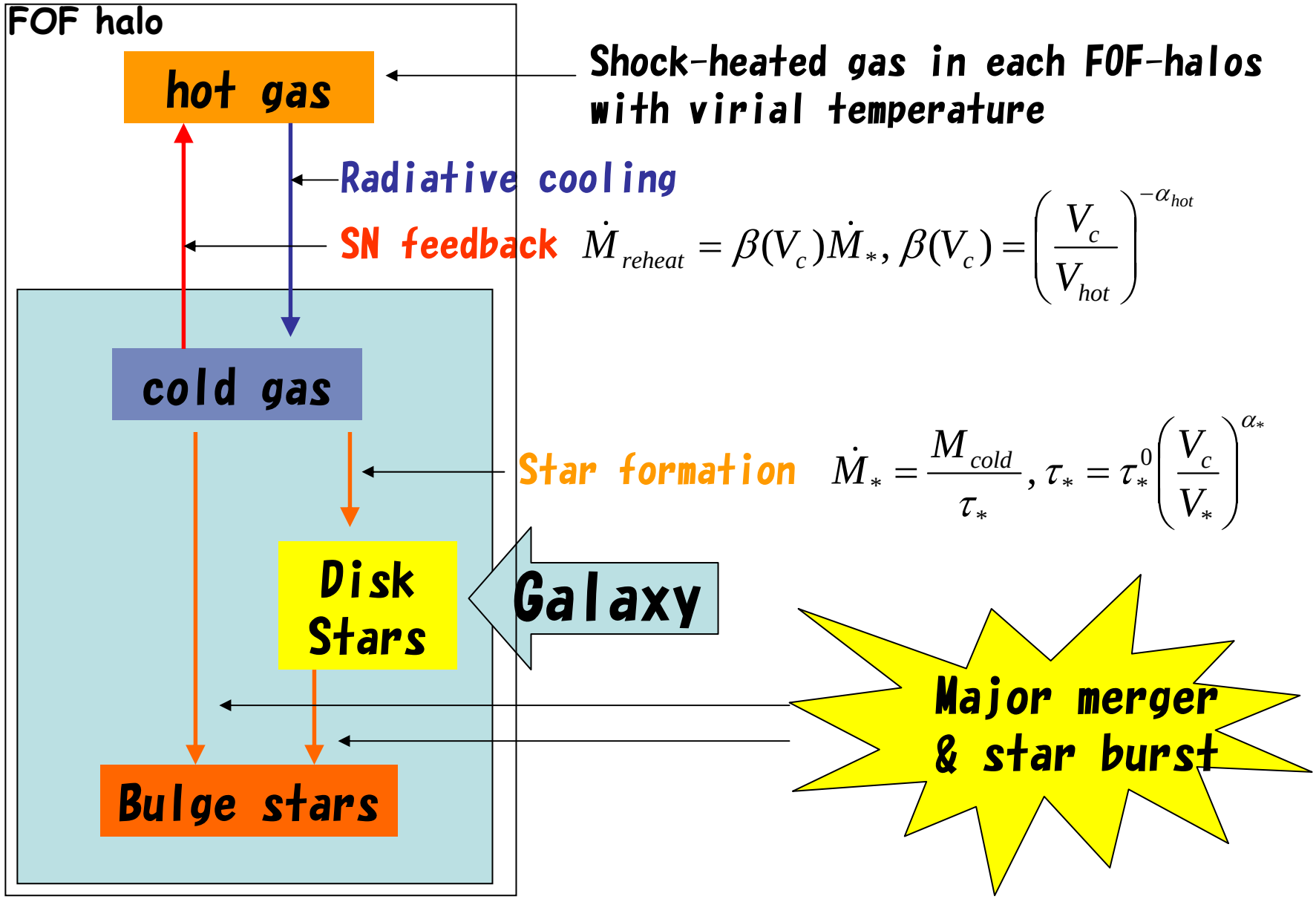

OCDM
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
y (h^{-1}Mpc)
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
−0.5
x (h^{-1}Mpc)

OCDM



- Construct sub-halo merger trees from N-body simulations
- Sub-halos must be FOF-halos in the past.
- Trace position of naked galaxies using the most bound particles

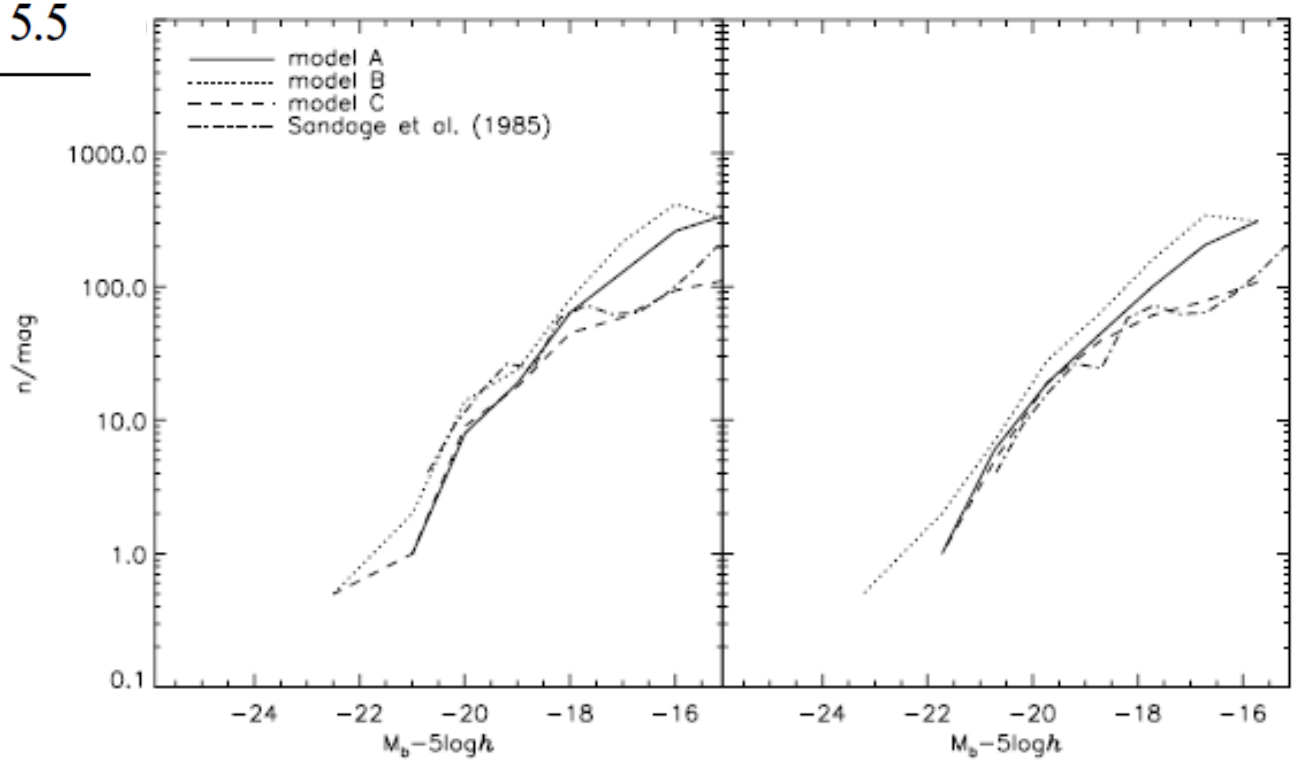
Semi-analytic model



Model parameters

FEEDBACK PARAMETERS FOR MODELS

Model	$V_{\rm hot}$ (km s^{-1})	$\alpha_{\rm hot}$
A.....	280	2
B.....	140	2
C.....	200	5.5



E+S0 fraction

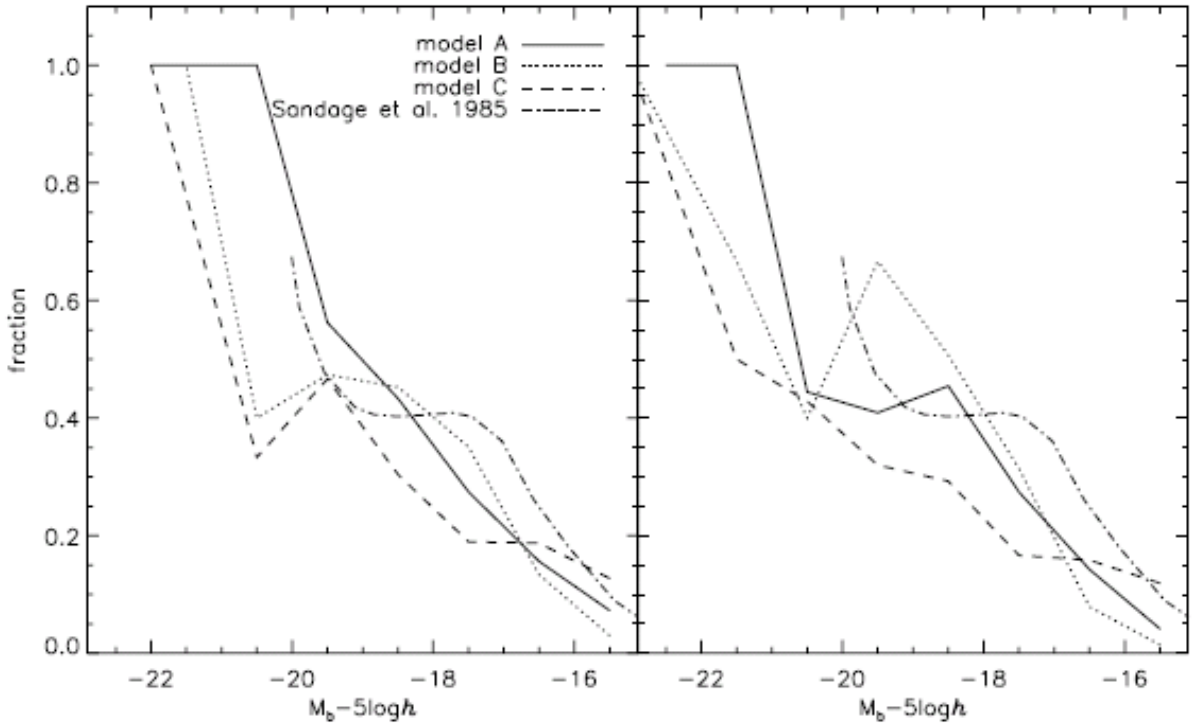
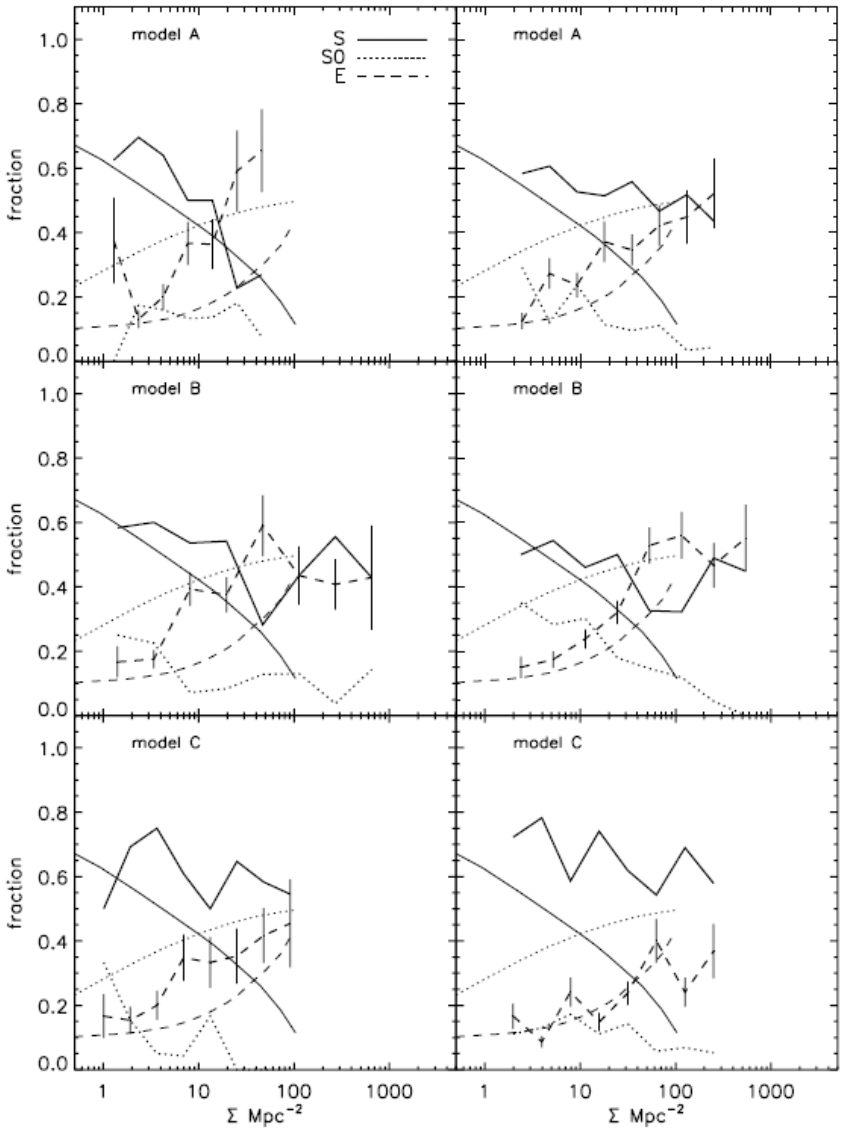


FIG. 2.—E+S0 fractions of cluster galaxies as a function of absolute B magnitude for SCDM (*left panel*) and OCDM (*right panel*). The thick solid, dotted, and dashed lines indicate the model A, B, and C, respectively. The thin dash-dotted line shows the observational result for the Virgo cluster taken from Sandage et al. (1985).

$$\langle \Delta M \rangle = 0.324(T+5) - 0.054(T+5)^2 + 0.0047(T+5)^3$$

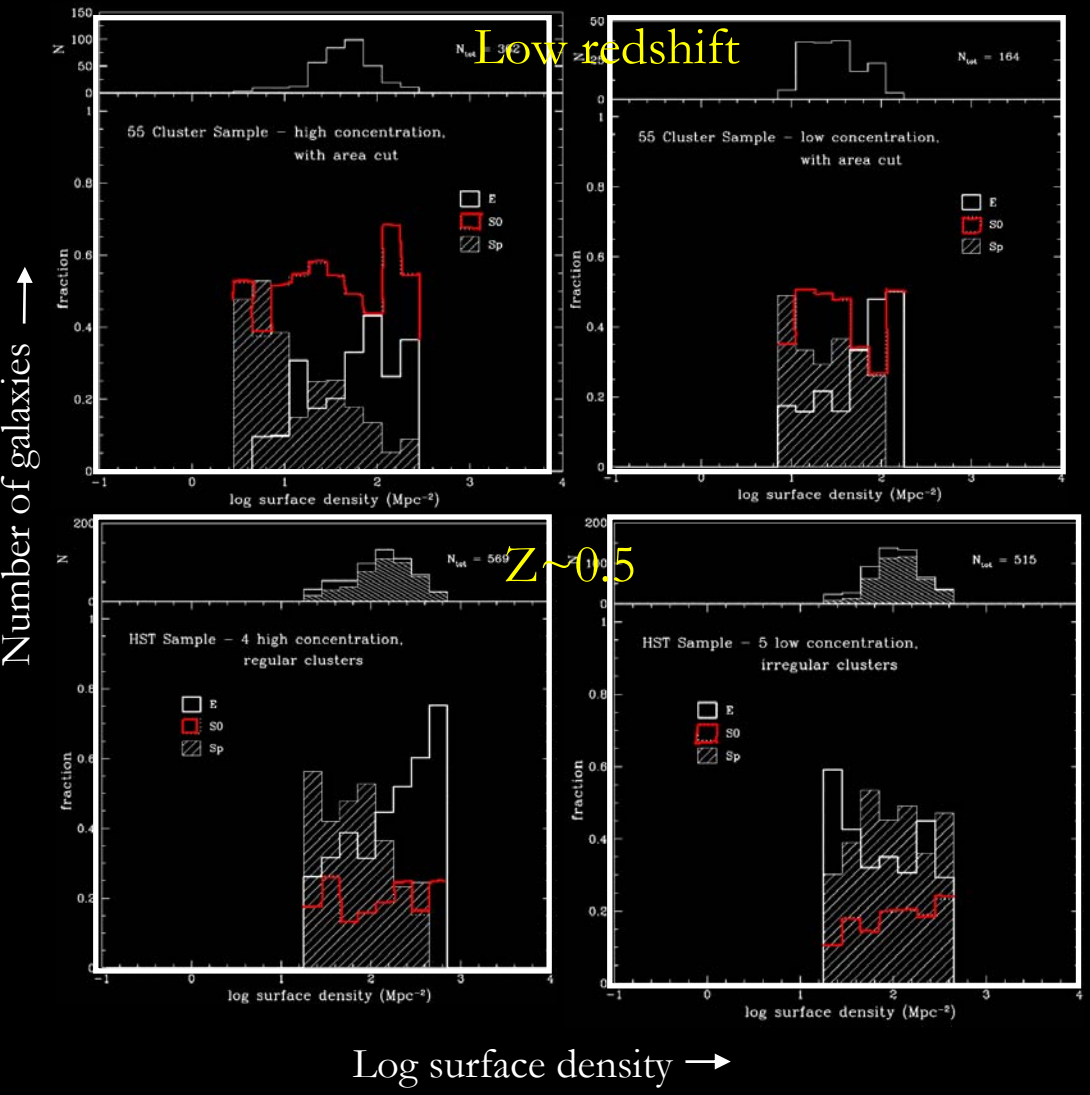
$$\Delta M \equiv M_B^{\rm bulge} - M_B^{\rm total}$$

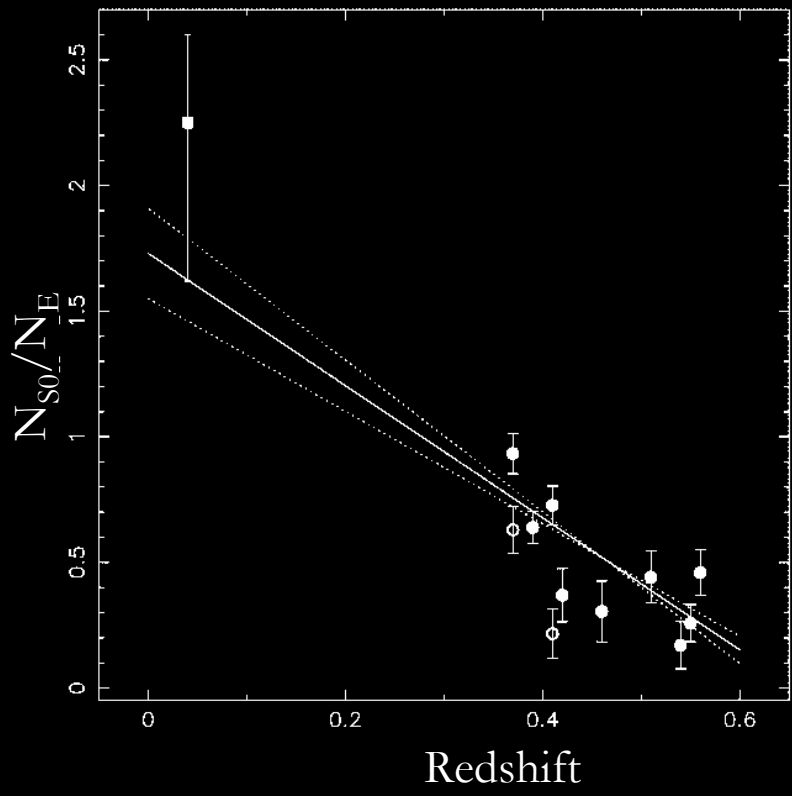
Morphology-density relation



- The observed elliptical fraction is well reproduced.
- Too few S0s (too many spirals)
- The observed trend of S0 distribution cannot be reproduced only by mergers.
- Based on the merger hypothesis galaxies are divided into two populations, i.e. almost pure disc and almost pure bulge galaxies.

Morphology-density: evolution



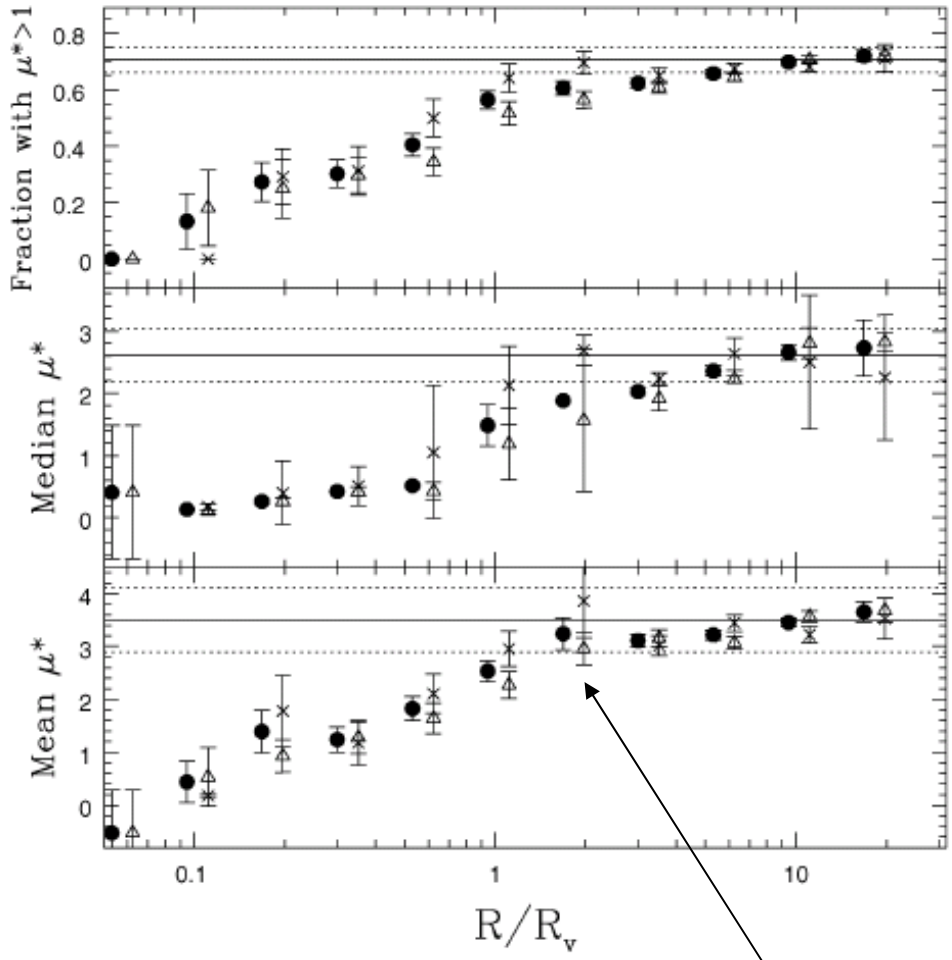


Dressler et al. 1997; Couch et al. 1994; 1998

Fasano et al. 2000

Wide field HST: Treu et al. 2003

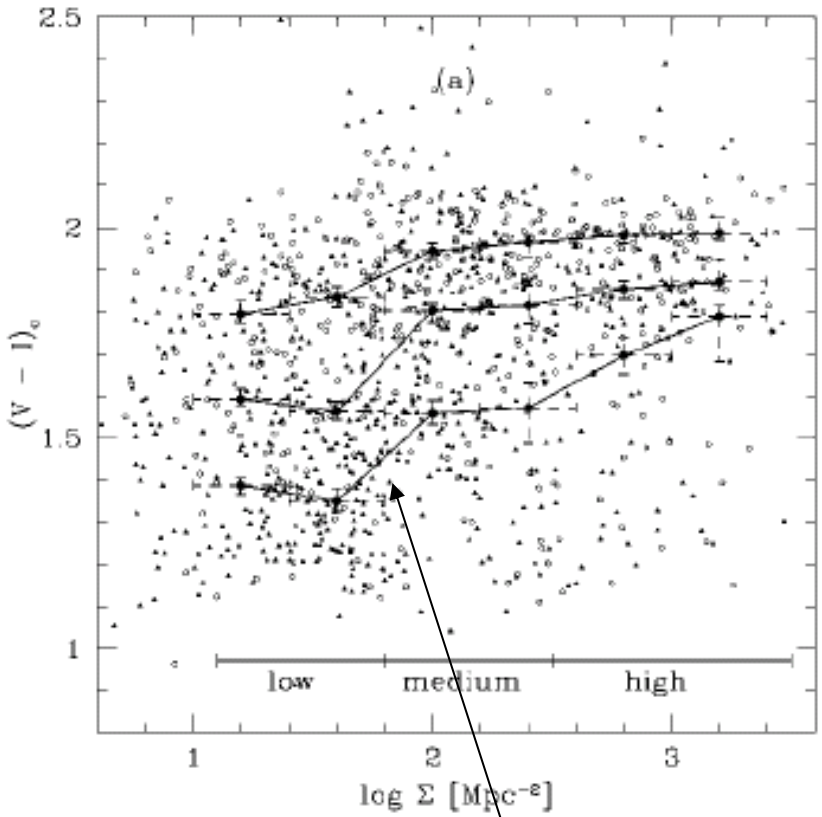
SFR-density relation

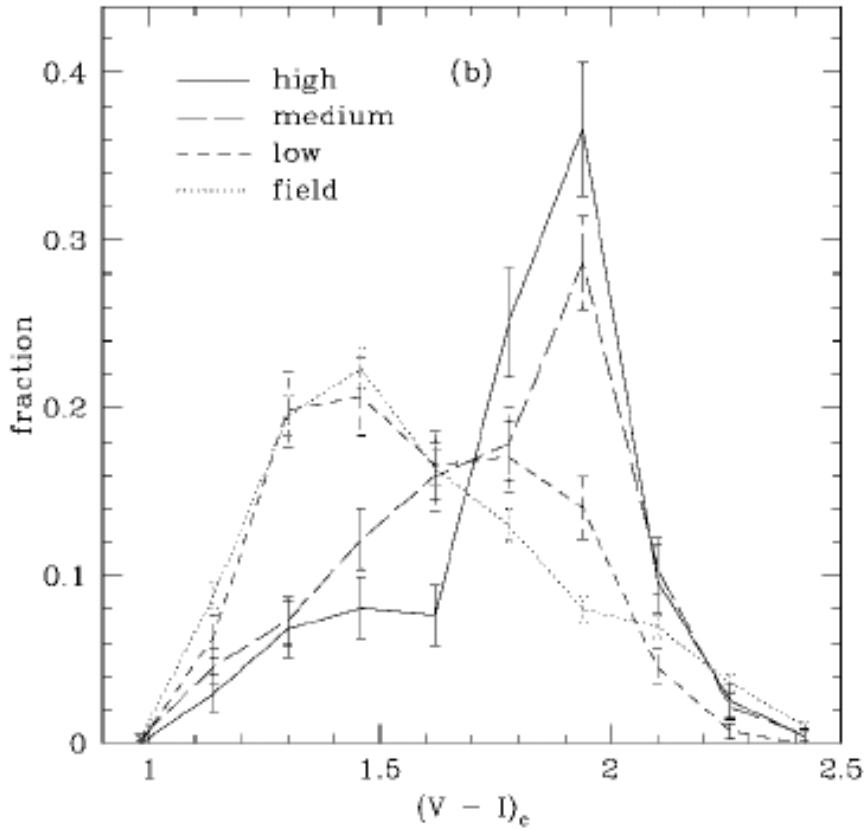


Lewis+'02

SF is suppressed within 2 R_v

colour-density relation @ z=0.41





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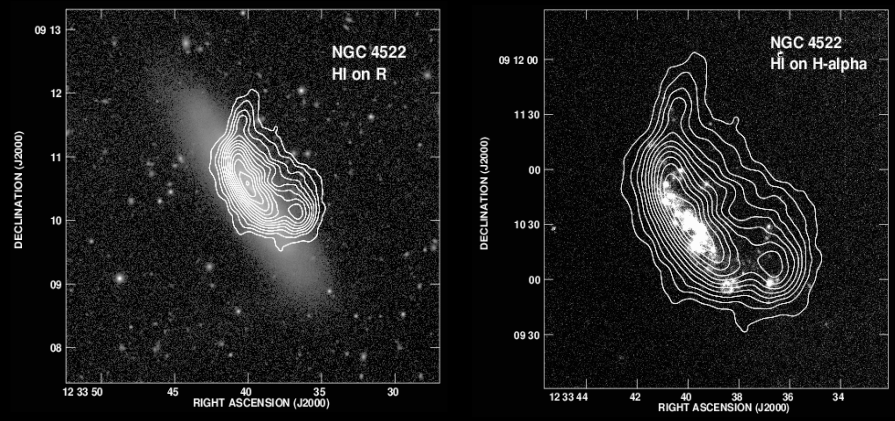
Kodama+'01

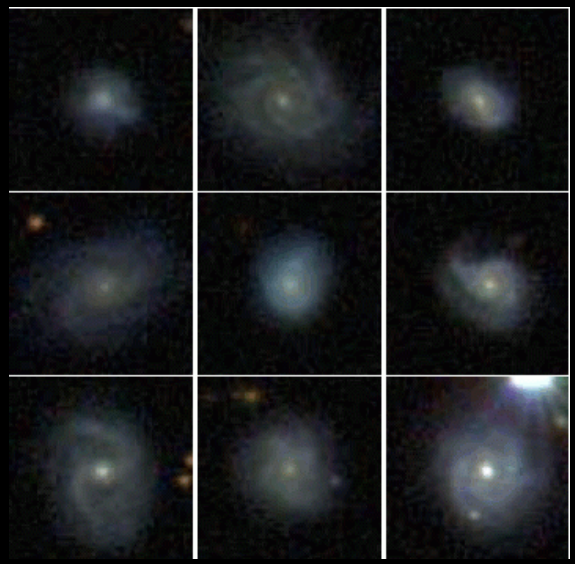
S to S0 transformation?



Kenney et al. 2003

Vollmer et al. 2004

- Ram pressure stripping of the disk could transform a spiral into a S0 (Gunn & Gott 1972; Solanes & Salvador-Solé 2001)
- Strangulation may lead to anemic or passive spiral galaxies (Shiyoa et al. 2002)



Non-SF spiral galaxies from SDSS (Goto et al. 2003)

First noted by Poggianti et al. (1999) in z~0.5 clusters

Additional physics?

- **Strangulation** (Larson+1980)
  - Long time-scale ~ t_*
- **Ram-pressure stripping** (Gunn & Gott 1972)
  - Short time-scale
- **Minor merger**
  - Minor mergers may also induce small starbursts
- Harassment (Moor+1996)
  - Cumulative effect of high-speed encounters between galaxies causes starbursts and morphological change.

Ram-pressure stripping

1. Calculate orbits of galaxies in the main cluster assuming NFW-profile.

$$\rho(r) = \frac{\rho_0}{(r/r_s)(1 + r/r_s)^2}$$

$$\Psi(r) = -4\pi r_s^2 G\rho_0 \frac{\ln(1 + r/r_s)}{r/r_s} - \frac{1}{2}H_0^2\lambda_0 r^2$$

2. Instantaneous removal of cold gas from galaxies

$$P_{\rm ram} = \rho_{\rm ICM} v_{\rm gal}^2$$

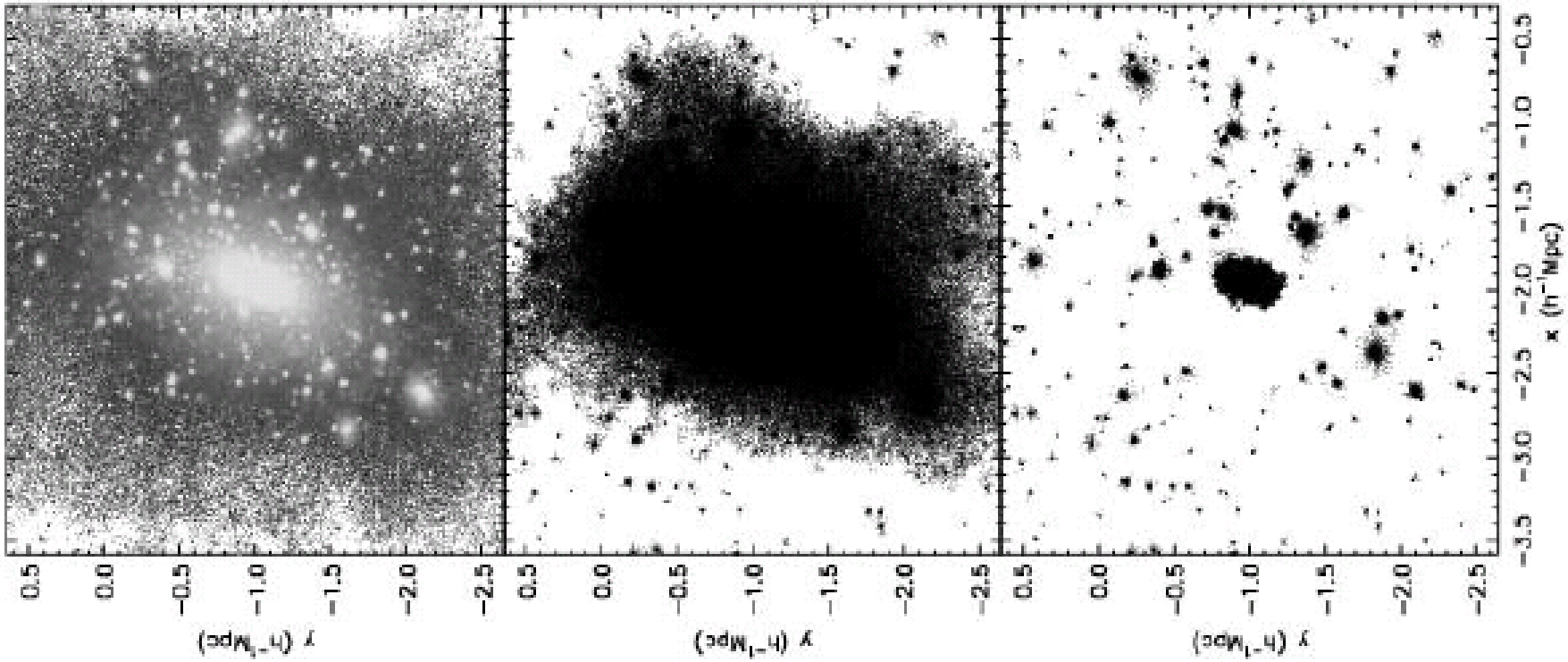
$$F_{\rm grav,\,cold} = 2\pi G \Sigma_{*,\,\rm disk} \Sigma_{\rm cold}$$

when $P_{ram} > F_{grav,\,cold}$ @ effective radius, all the cold gas is stripped from a galaxy

Minor burst

- Minor merger
  - $f_{\rm minor} < M_{\rm sat}/M_{\rm cen} < f_{\rm major}$
  - $f_{\rm major} = 0.25$ and $f_{\rm minor} = 0.1\, f_{\rm major}$
- $f_{\rm burst}\, M_{\rm cold}$ is consumed in the minor burst and added to the bulge.

Sub-halos in a ΛCDM cluster

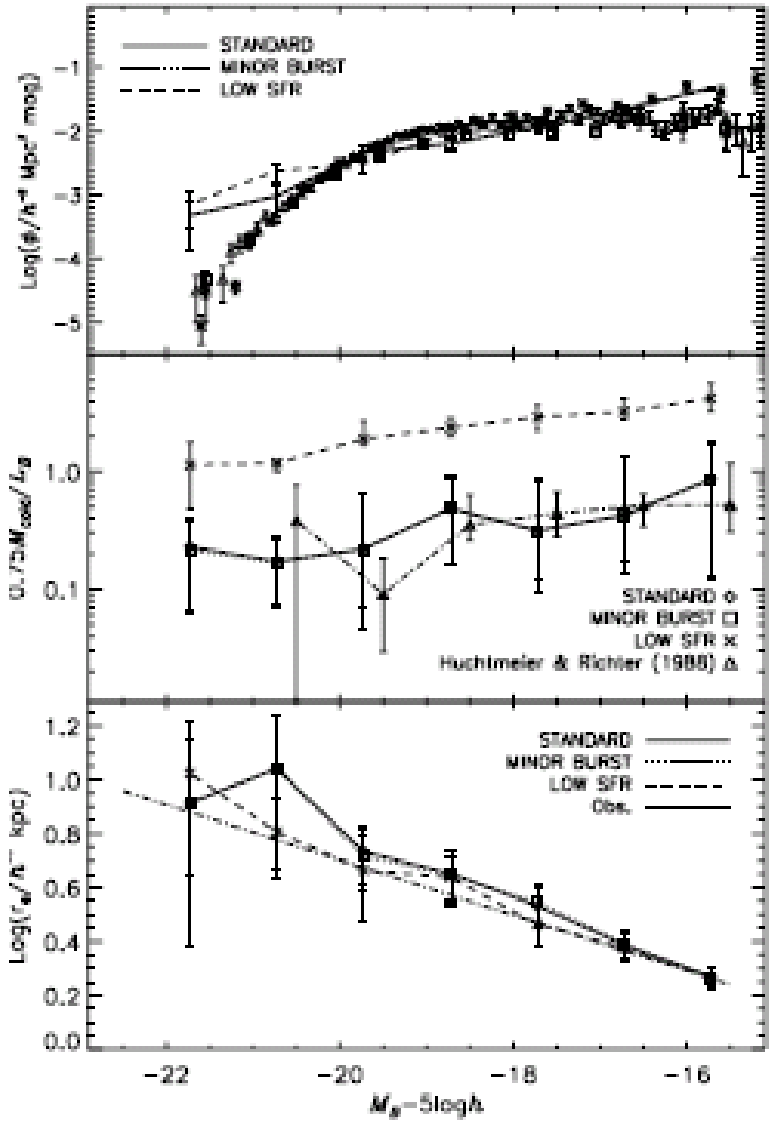


Parameters and models

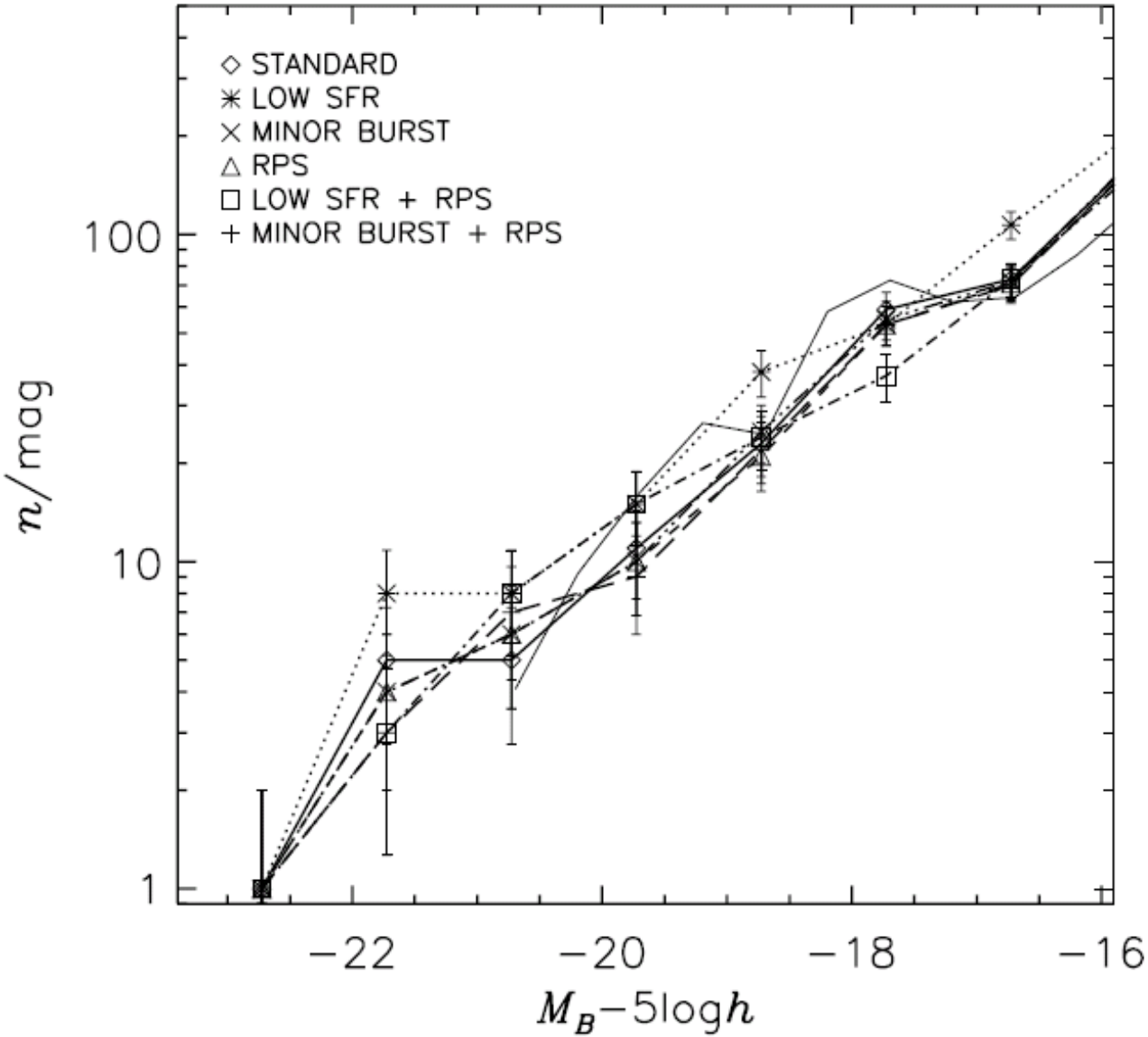
Parameter	Value
$V_{\rm hot}$ (km s^{-1})	200
$\alpha_{\rm hot}$	2.0
τ_*^0 (Gyr)	2.0
$\alpha*$	−1.3
$f_{\rm major}$	0.2
y ($Z_\odot$).....	3.0

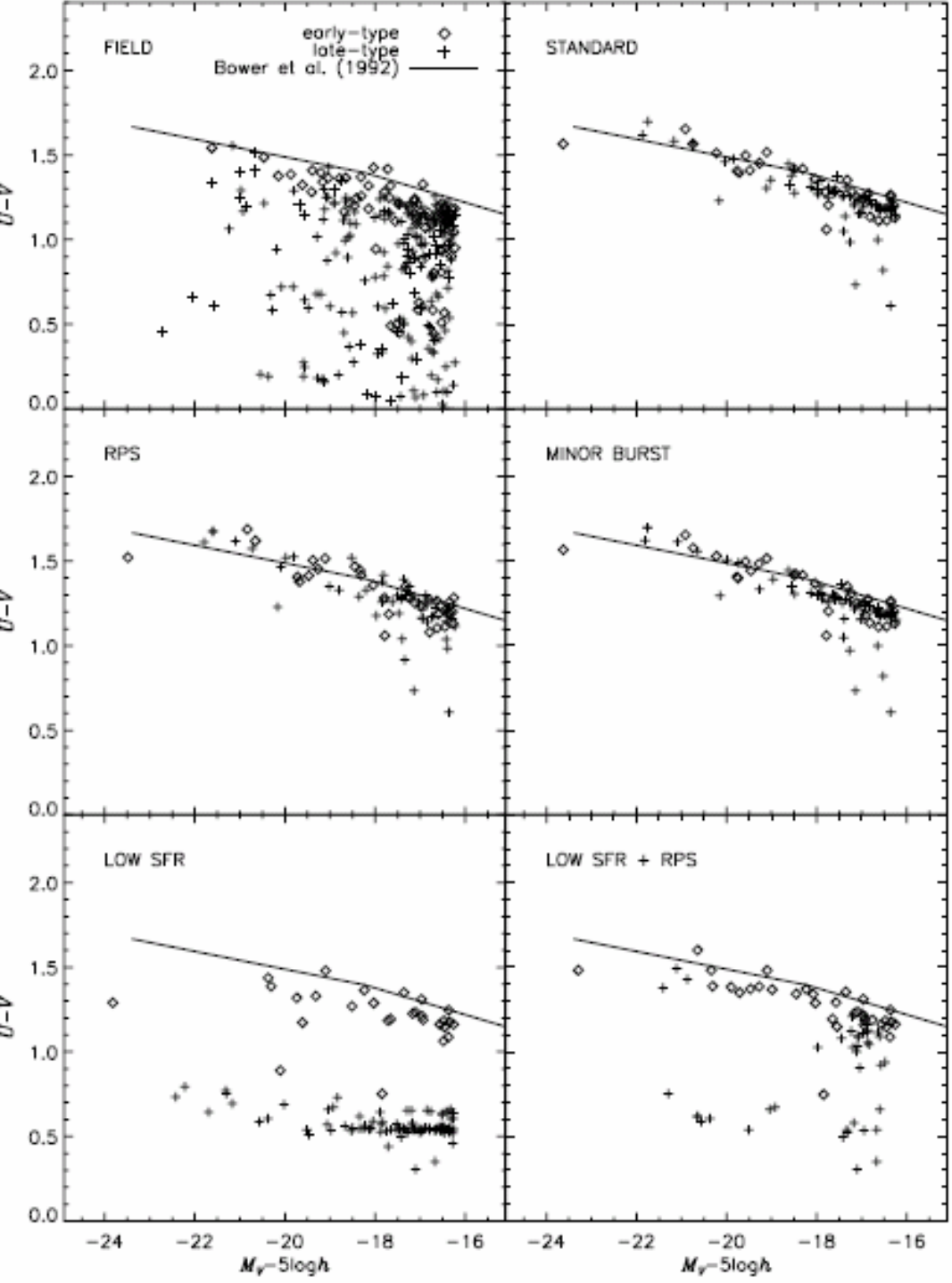
- Standard
  - Strangulation + major merger
- Ram-pressure
  - Standard + RPS
- Minor-burst
  - Standard + minor burst
- Low-SFR
  - Standard but with 4 times longer τ_*

Field galaxies



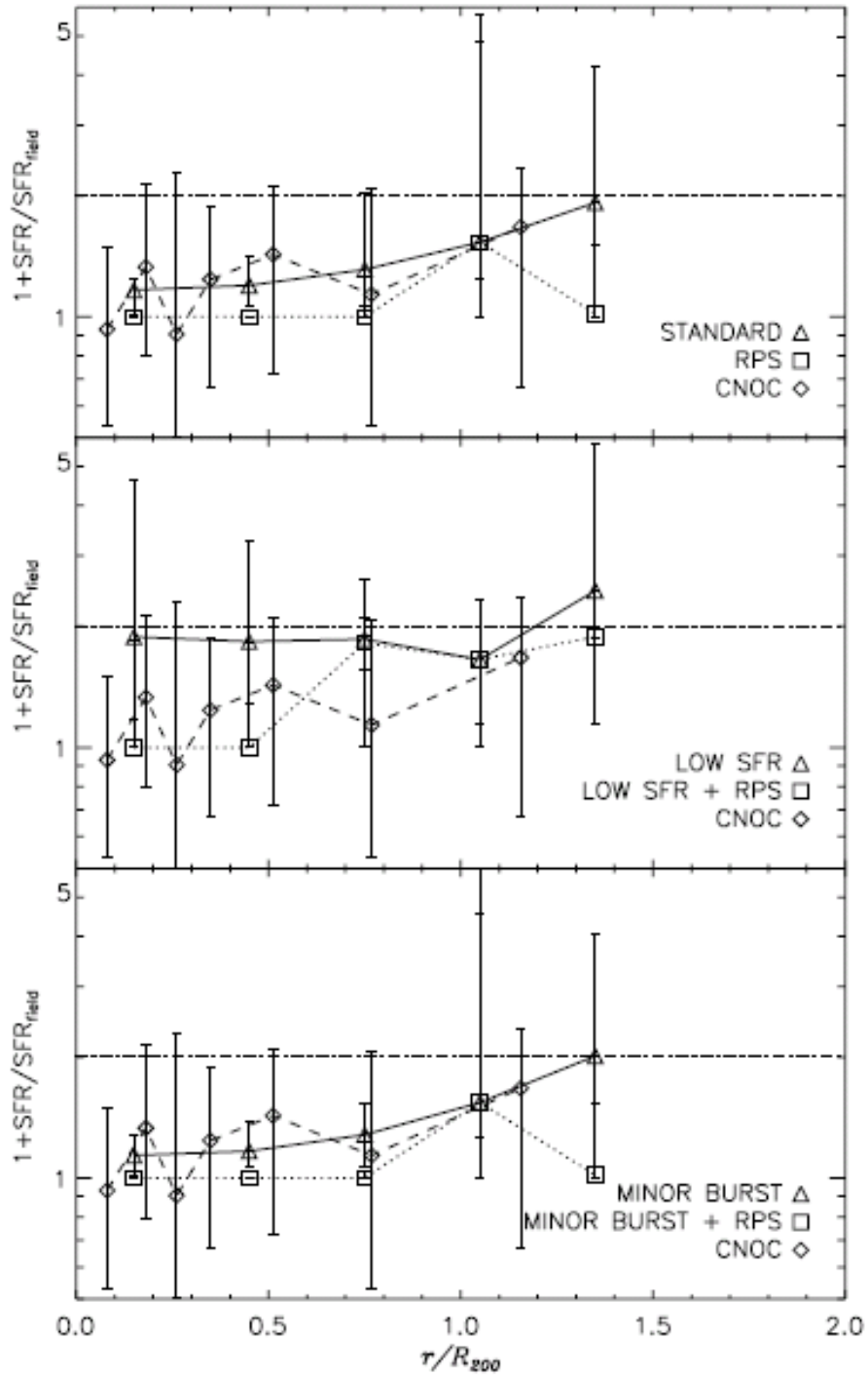
LFs of simulated cluster galaxies





Colour-magnitude relation

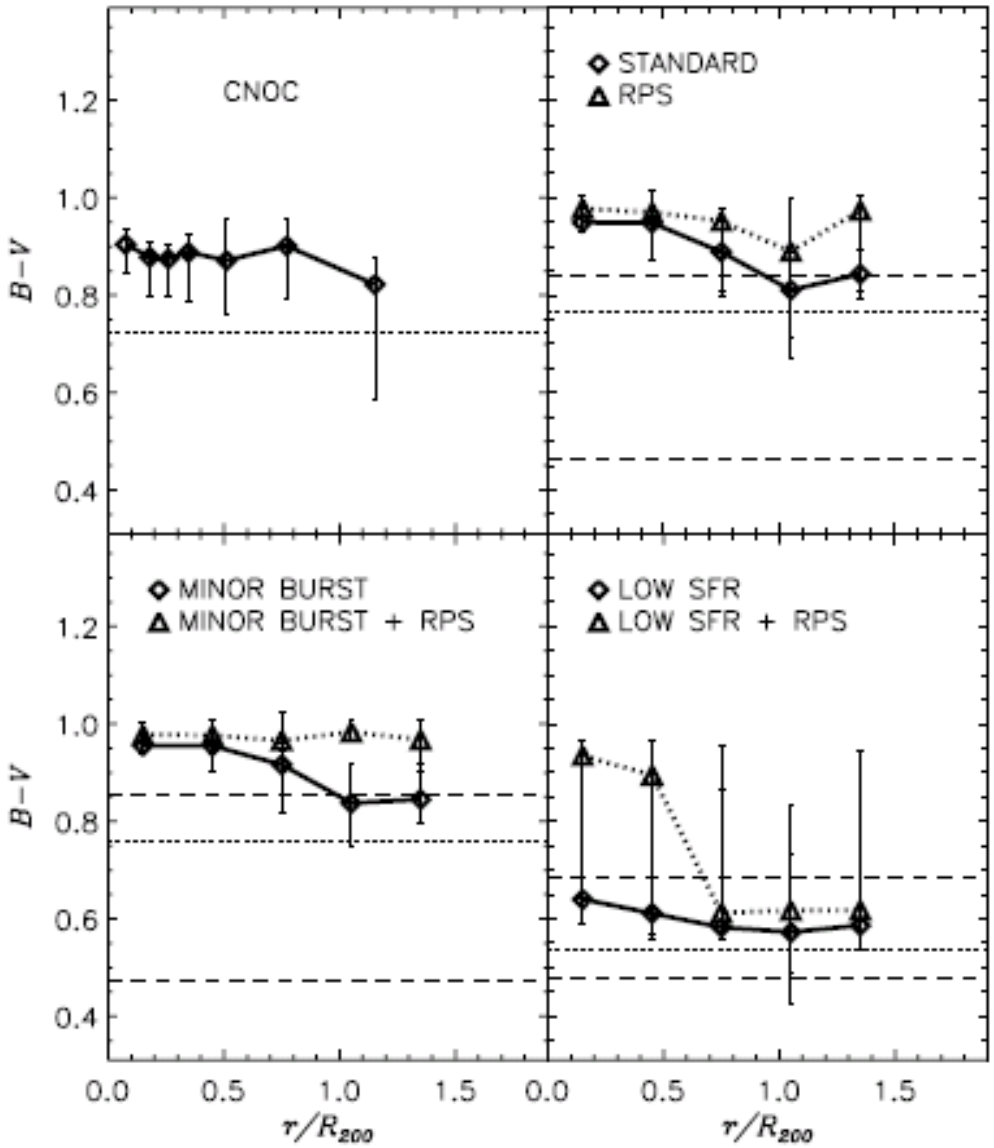
- Early-type galaxies are always on the red sequence.
- Standard, RPS, and Minor-burst models look the same on this plane.



SFR-radius relation

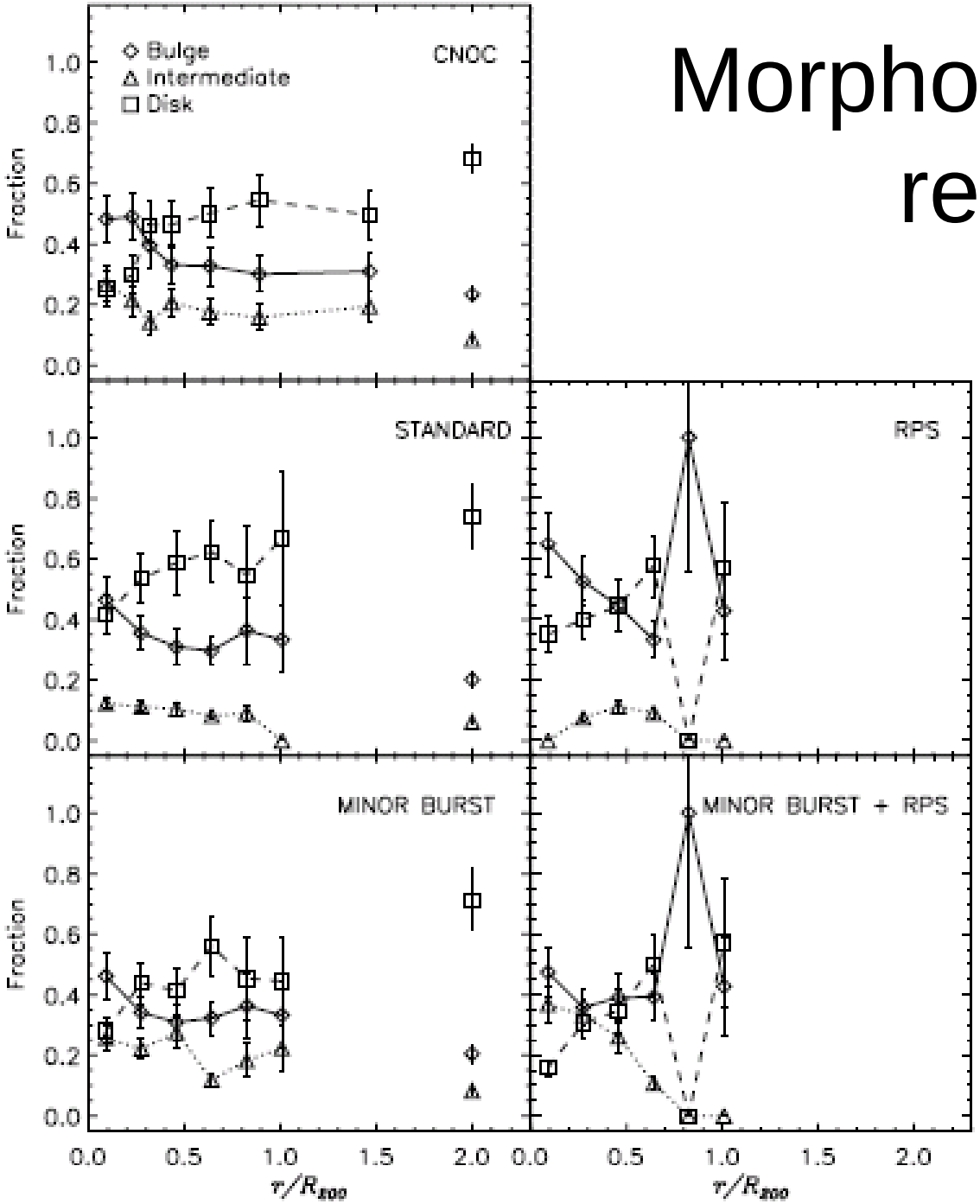
- Effects of the RPS on SFR is only seen in the LOW-SFR model:
  the strangulation sufficiently suppresses the SFR in the cluster.

Colour-radius relation



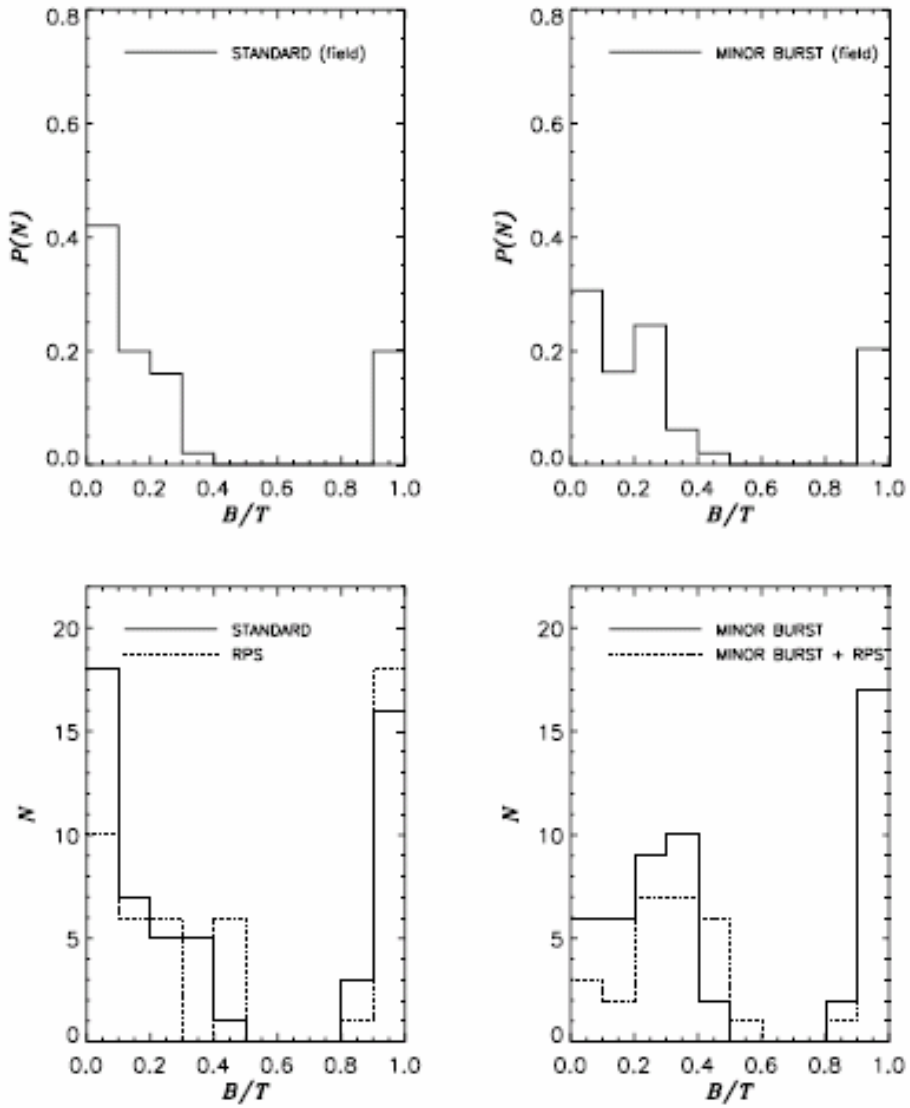
- With the standard parameter set, the effects of the RPS is negligible in the core.
- Inefficient strangulation makes the signal of the RPS detectable, but field galaxies are too blue.

Morphology-radius relation



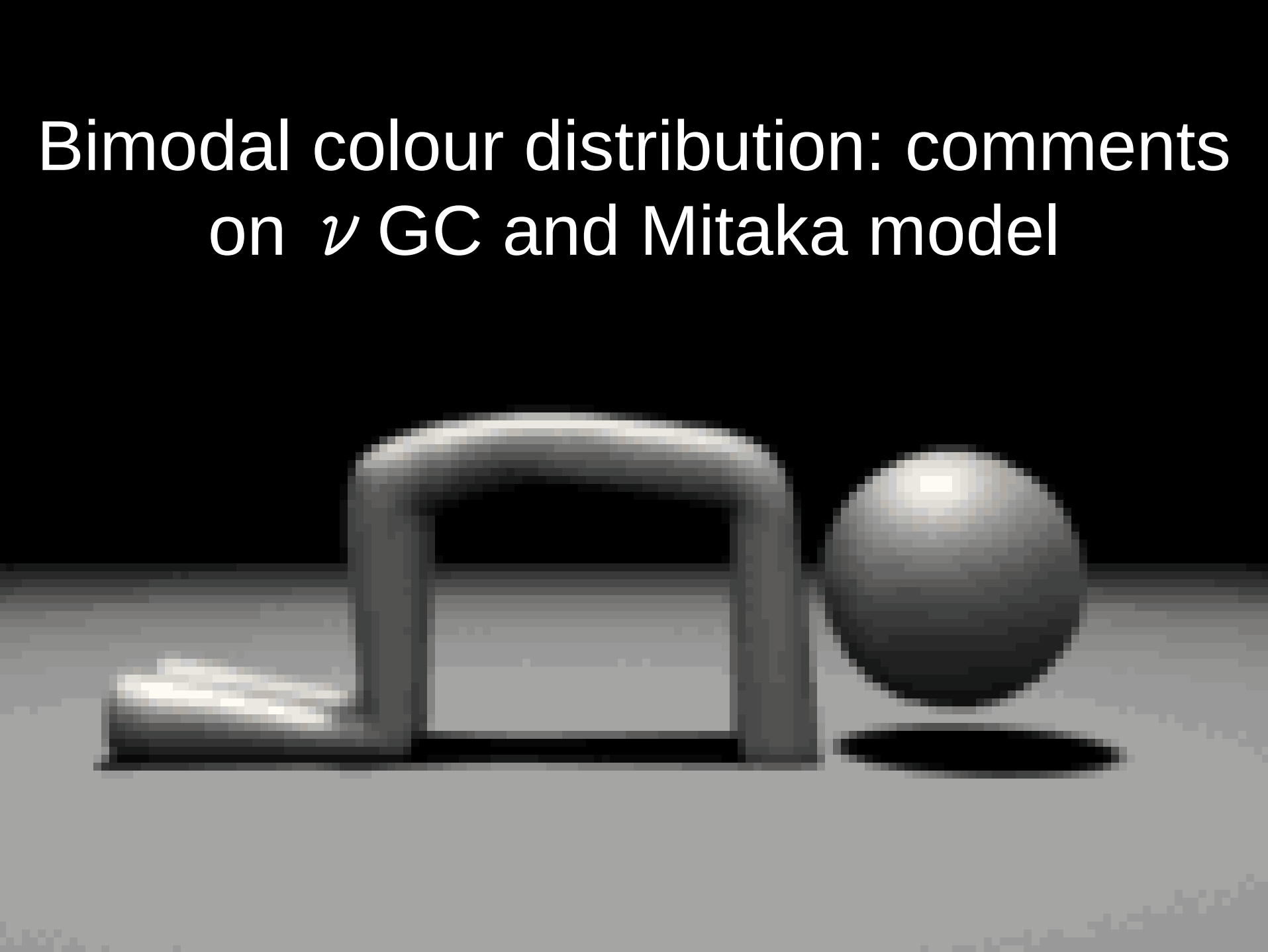
- Consistent with what was found by TO & Nagashima ’01.
- The RPS alone can’t increase the intermediate fraction.
- The Minor-burst model reproduces the morphological fraction reasonably well.

Bimodality in morphology!!



- seems common in semi-analytic models but not seen in the real universe.
- Minor bursts make the gap narrower.
- RPS can’t help.

Bimodal colour distribution: comments on ν GC and Mitaka model

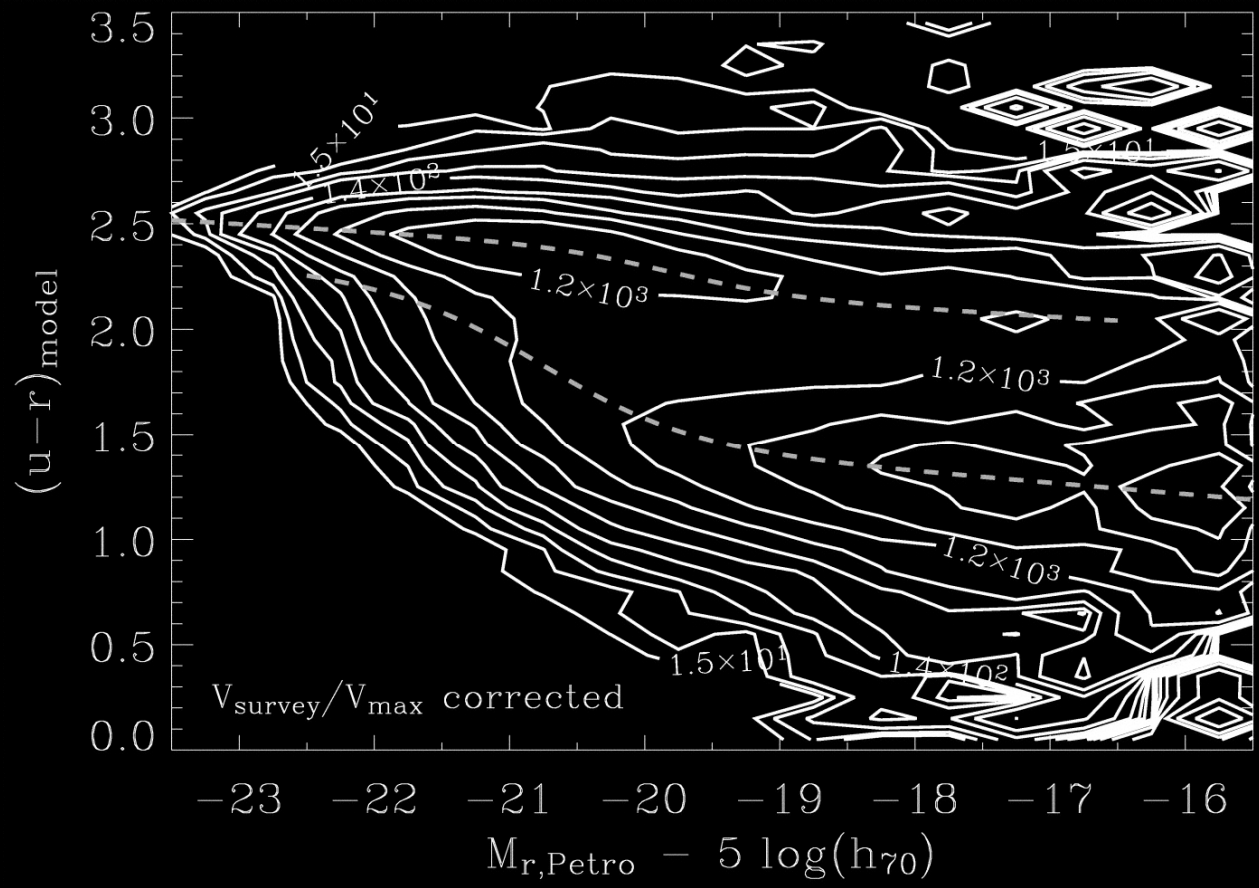


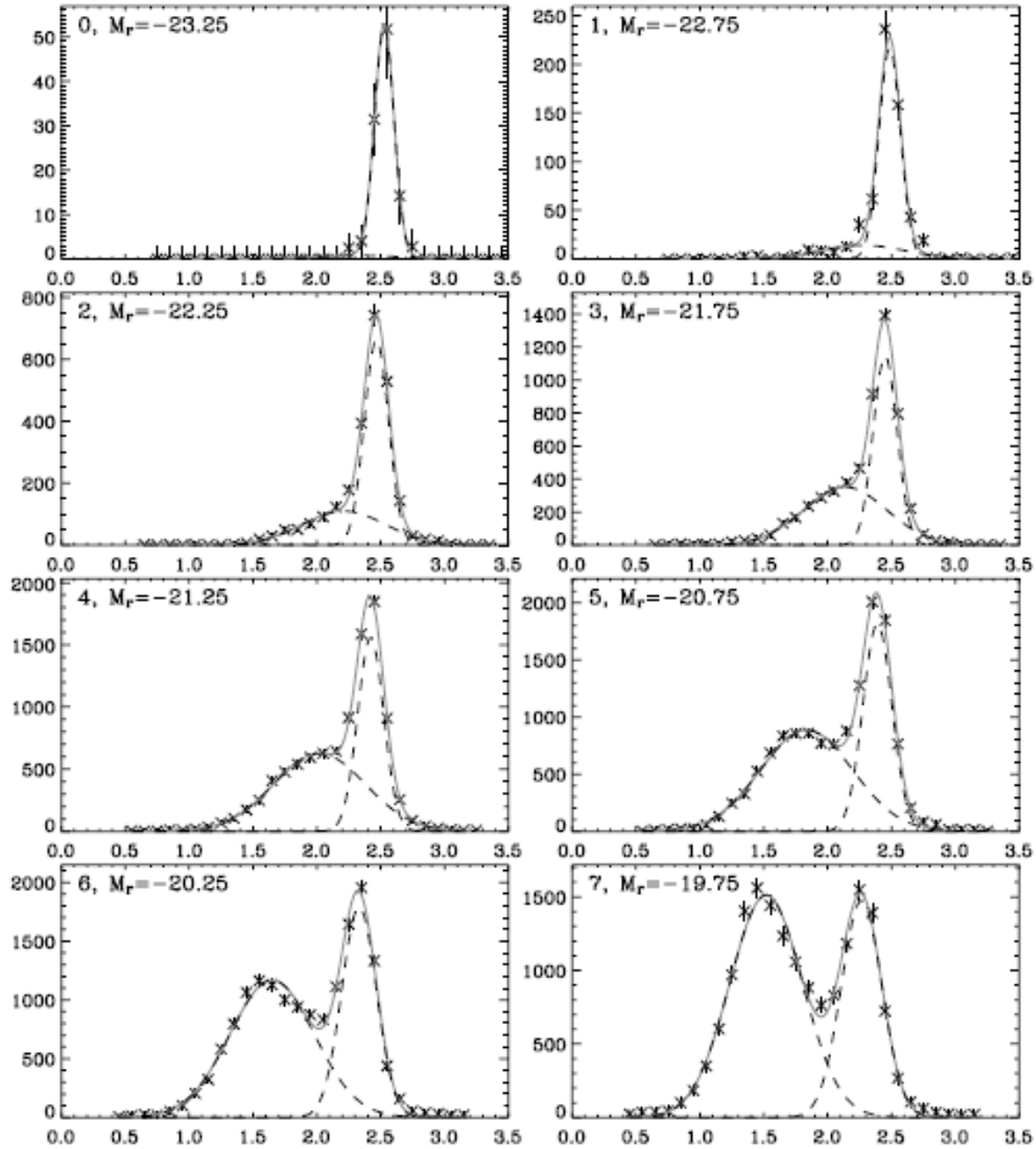
Colour-magnitude relation

CMR for spiral galaxies also observed (e.g. Chester & Roberts 1964; Visvanathan 1981; Tully, Mould & Aaronson 1982)

SDSS allows full distribution to be quantified with high precision (Baldry et al. 2003; Hogg et al. 2003; Blanton et al. 2003)

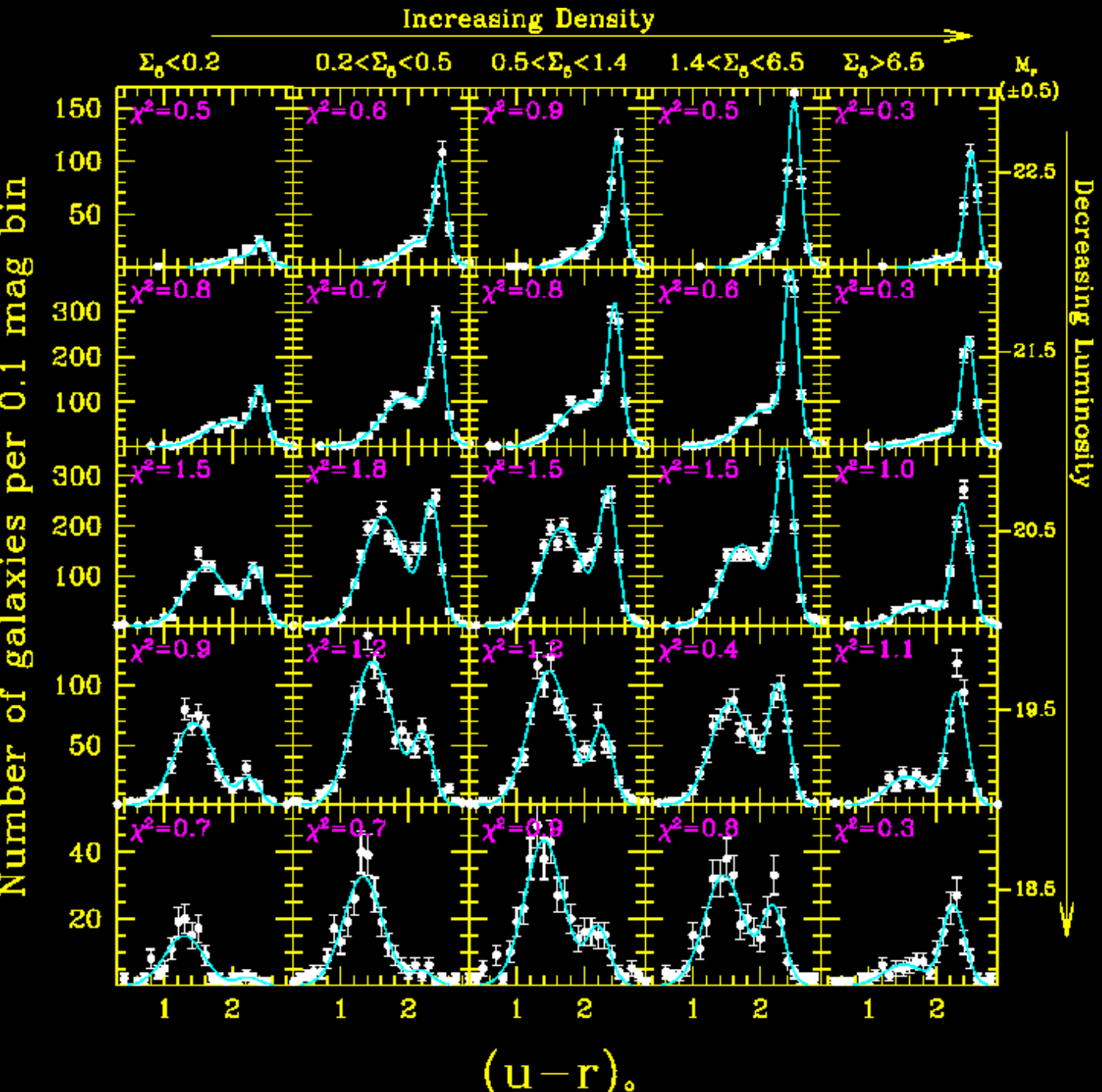
Sloan DSS data





- Red population always exists.
- Blue population dominates in faint galaxies.

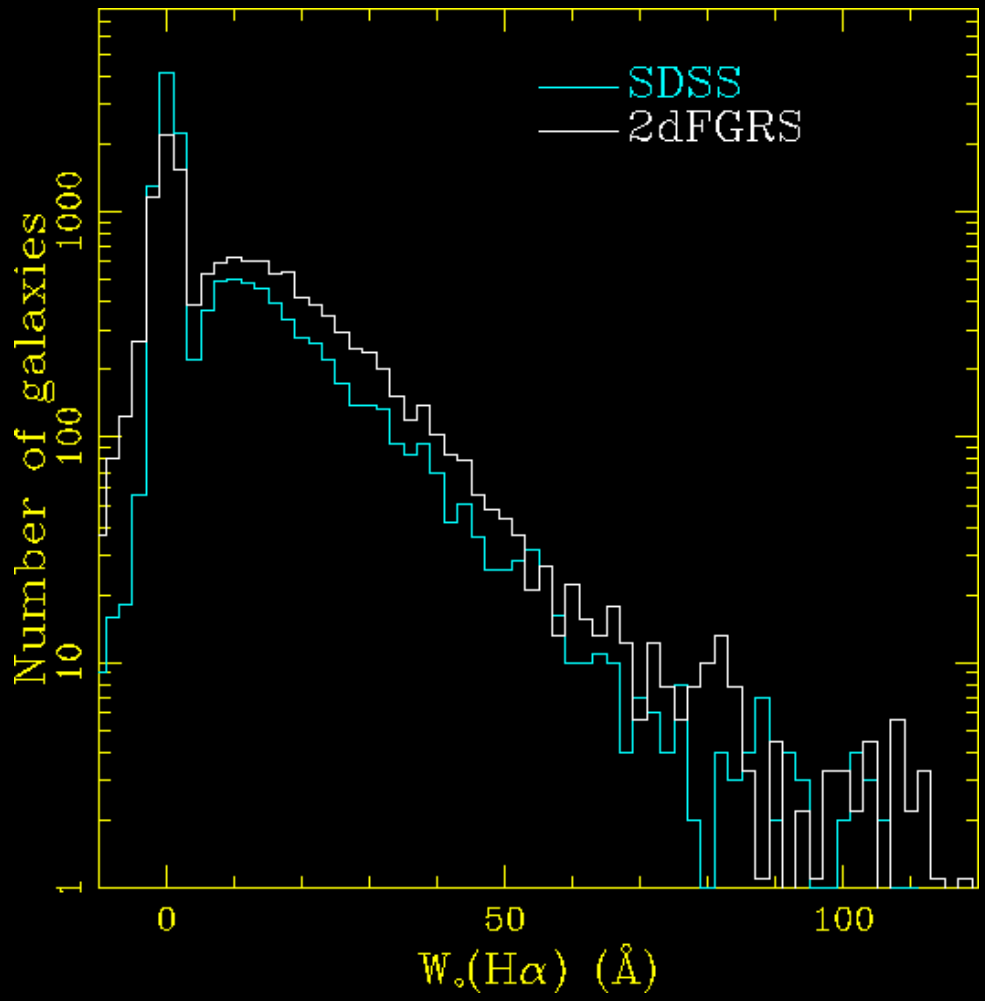
Baldry+'04



- 24346 galaxies from SDSS DR1. magnitude limited with $z<0.08$
- density estimates based on $M_r<-20$

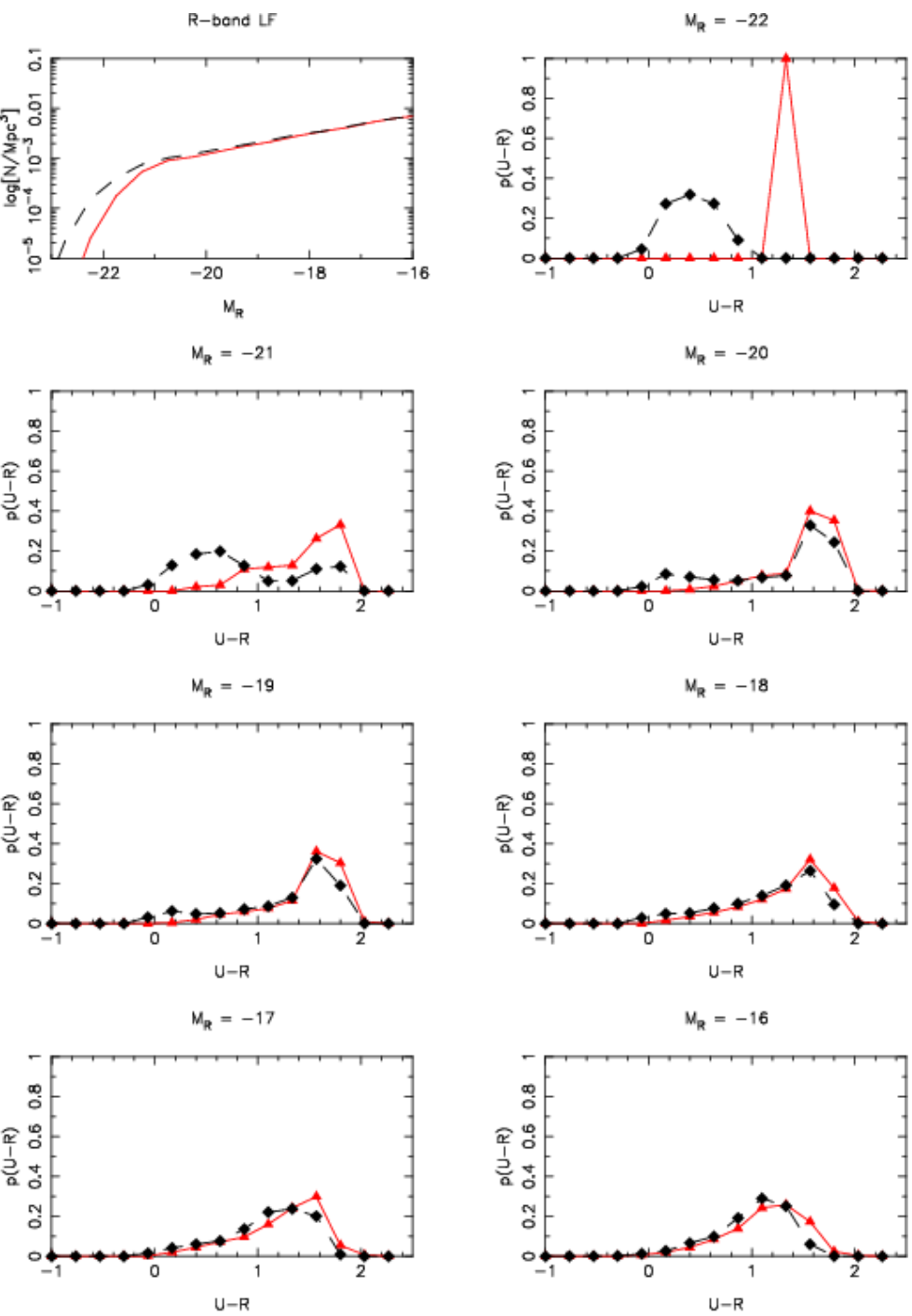
Balogh et al. 2004

Hα distribution

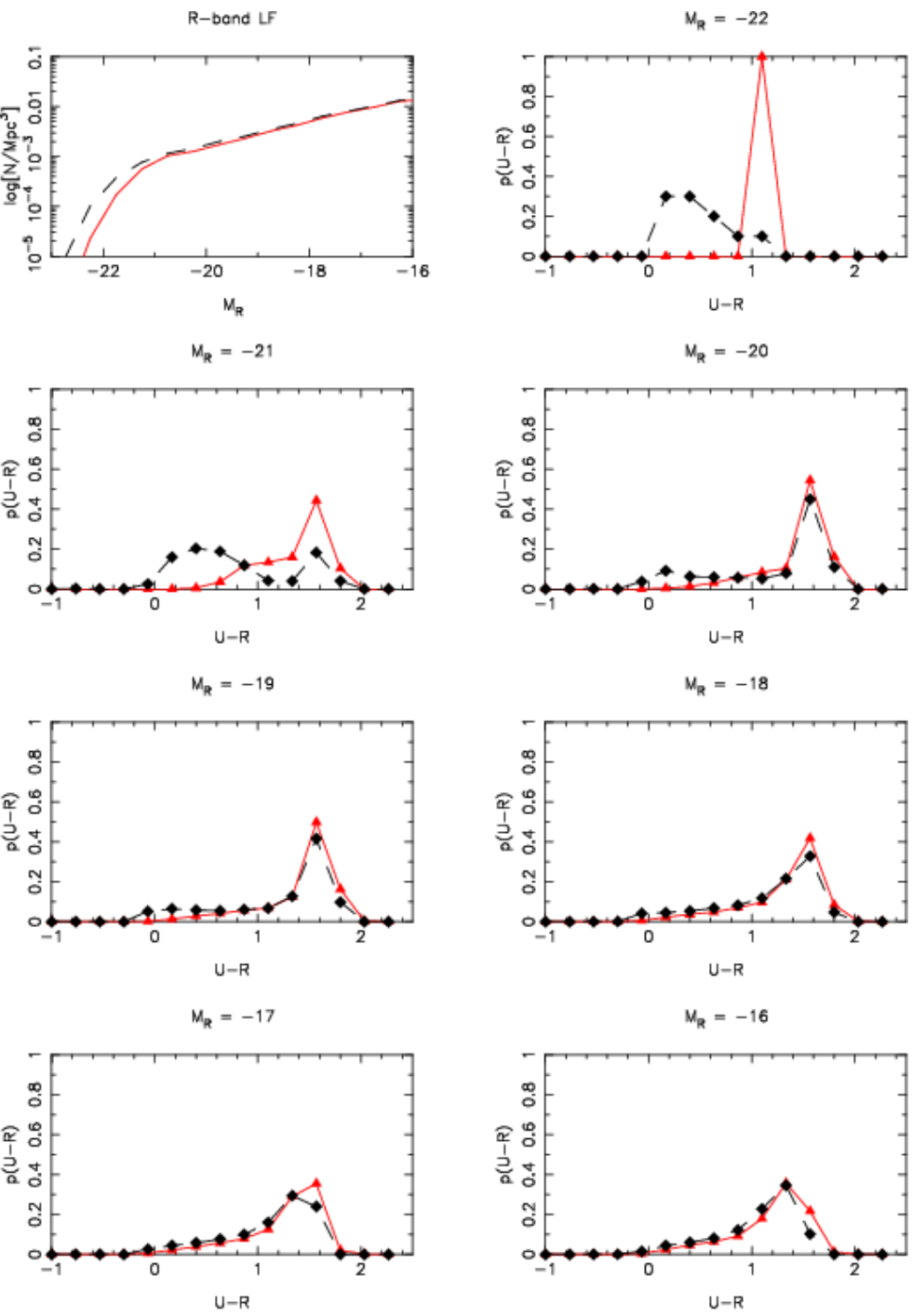


- Hα distribution shows a bimodality: mean/median of whole distribution can be misleading

Balogh et al. 2004

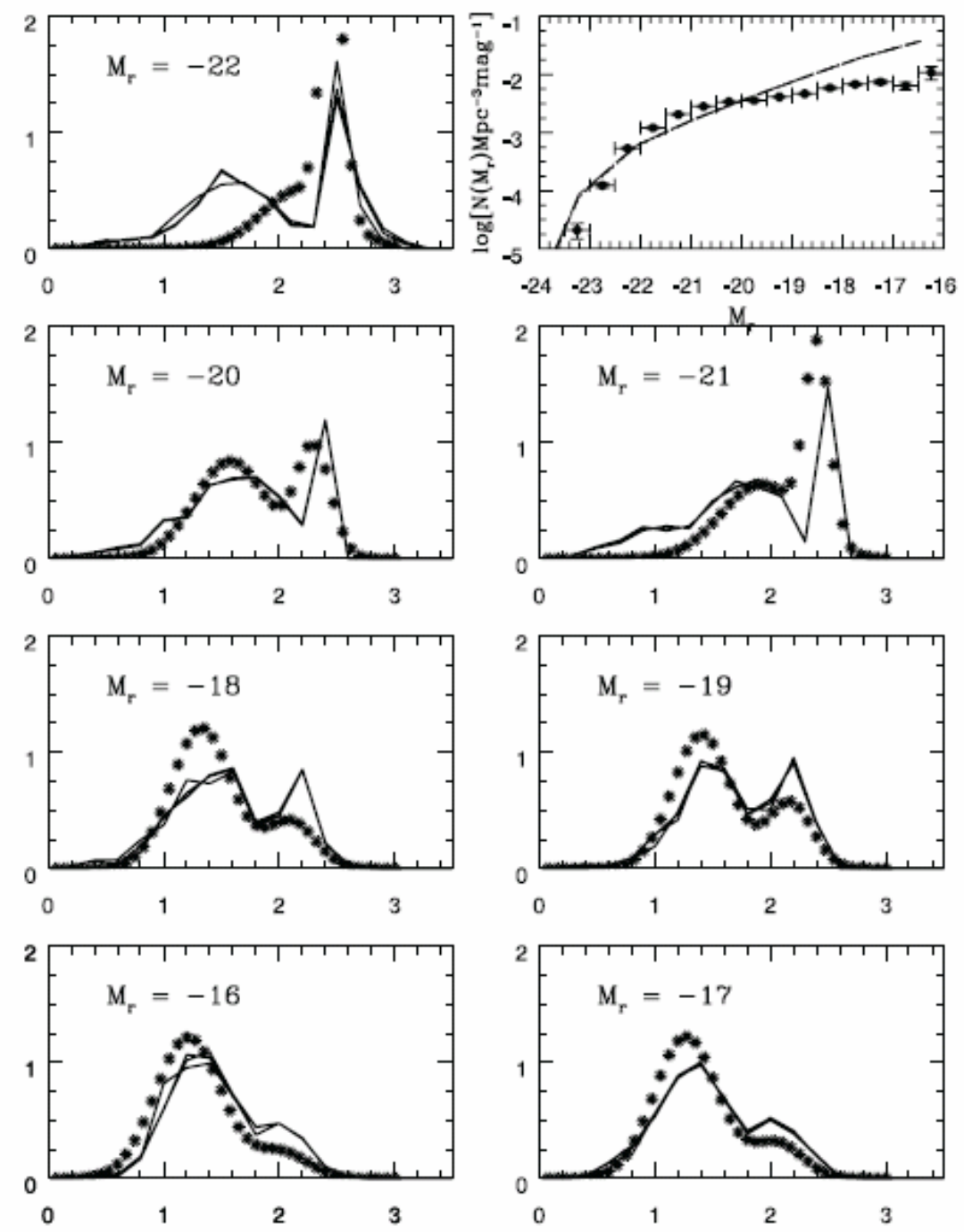


- lp211_V14
- solid – with dust
- dashed –without dust
- Blue population only exists in bright galaxies without dust…



- lp221_V14

- Fix it!!

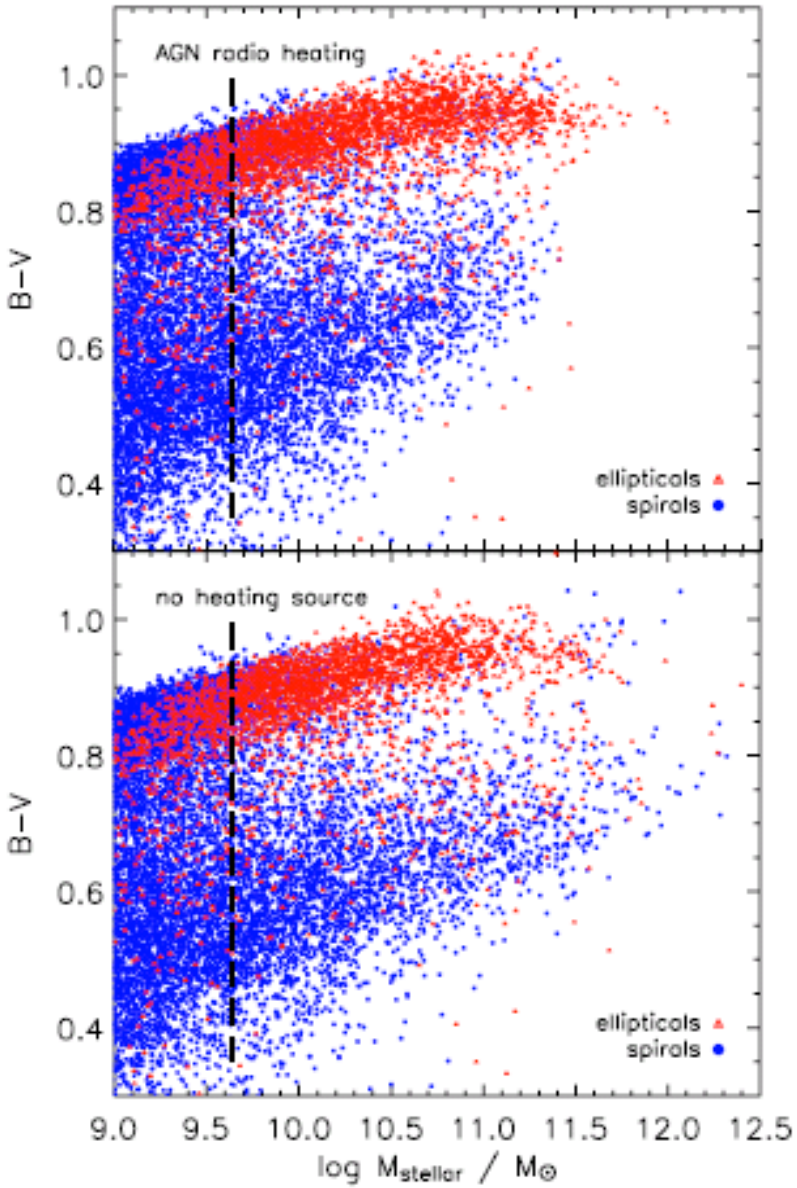


Other models I

- Except for the brightest galaxies, the bimodality is well reproduced.

Menci+'04

Other models II



- Virtually two populations

Croton+'06

SF in Menci et al.

$$\dot{m}_* = \frac{m_c}{q\tau_d}, \text{ where } \tau_d = \frac{r_d}{v_d},$$

and

$$r_d = r_v g(v_c).$$

from Mo+'98

$$g(v_c) \approx \frac{\lambda}{\sqrt{2}} \frac{j_d}{(m_c/m)} f_c(v_c)^{-\frac{1}{2}} f_R(v)$$

Authors insist this is the key!

Summary

- To my knowledge, GALFORM and Mitaka model fail to reproduce the bimodal colour distribution.
- Morphology of galaxies in SA models often shows bimodality that we don’t want.
- At least some SA models successfully reproduce the bimodality in colour.