理論懇シンポ（立教大学，25/12/2006）

# 最近の遠方銀河観測による銀河形成の諸問題

## Mass assembly / Down sizing / Dust extinction

今、歴史が動いている。


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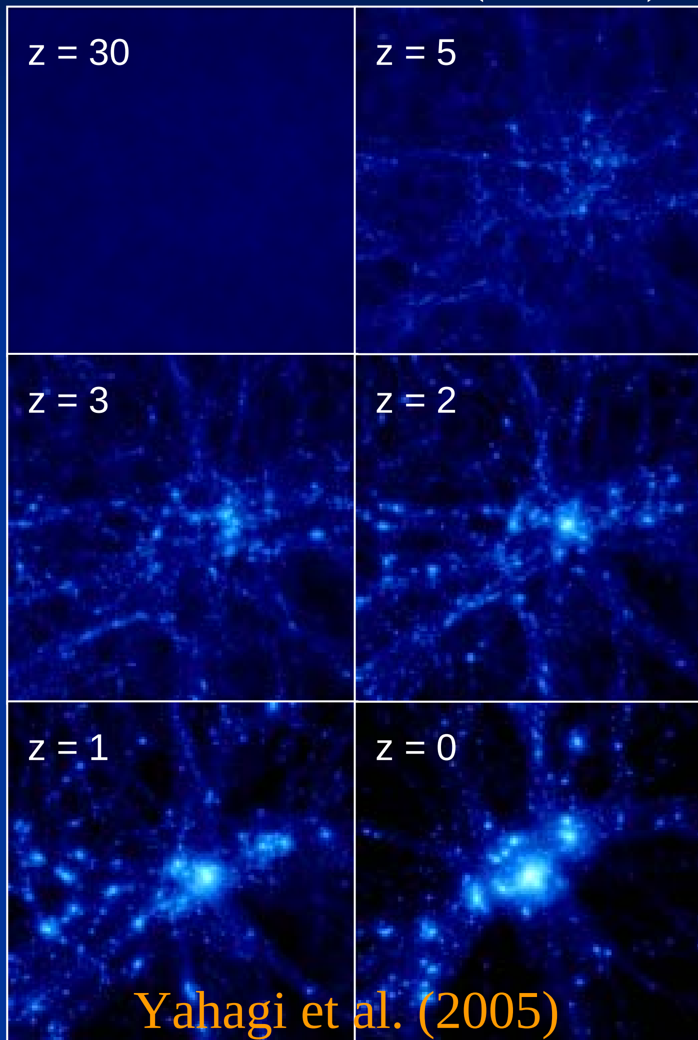
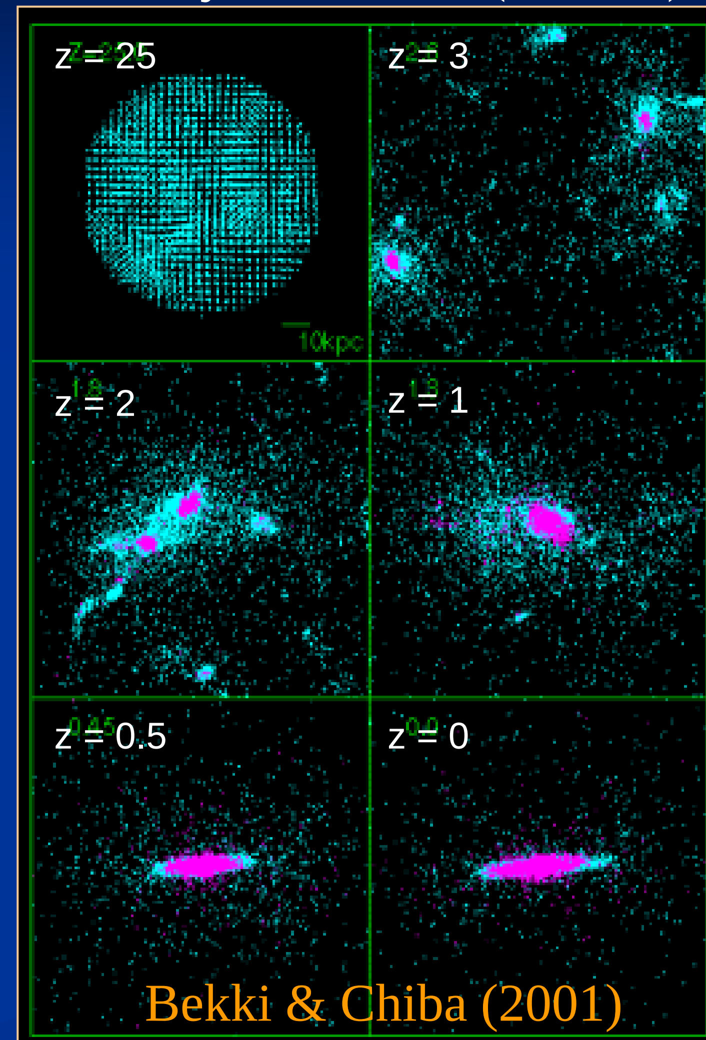
*“Panoramic View of Praha” (13/08/05)*

# Theoretical Views for Cluster / Galaxy Formation

**Cluster Formation** ($10^{15}$ Mo)




**Galaxy Formation** ($10^{12}$ Mo)



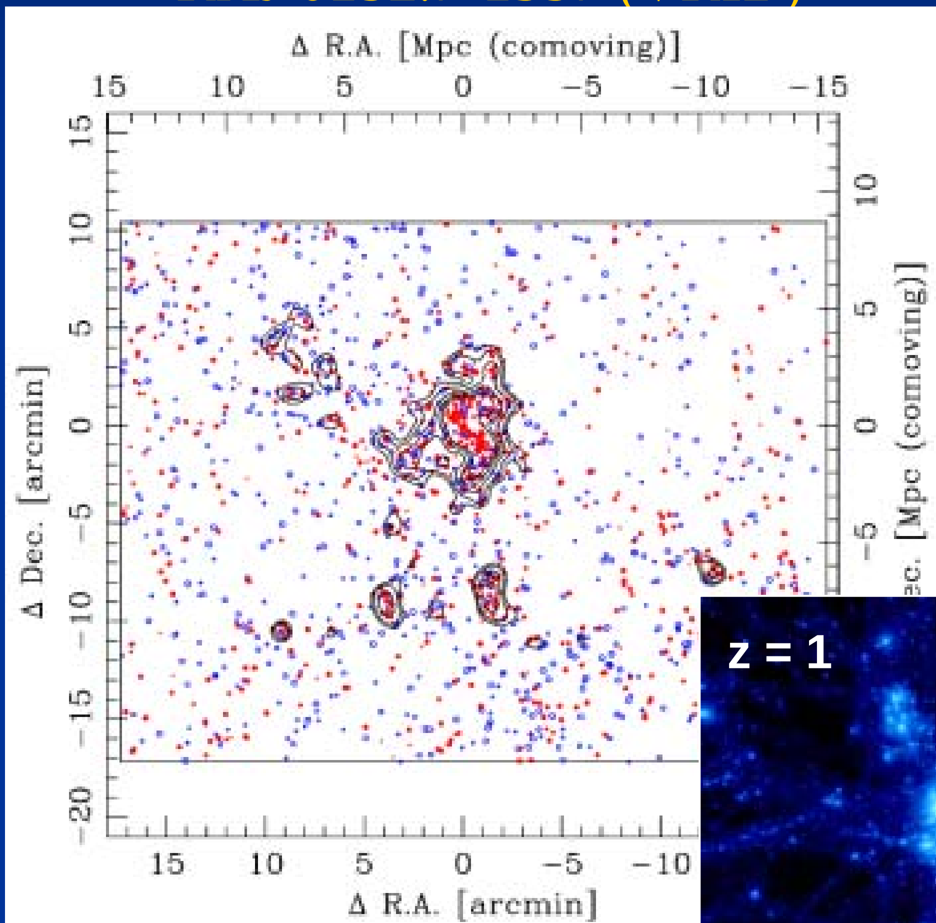

In the standard cosmological models (CDM), small scale objects collapse first and they assemble by gravity to form bigger and bigger systems with time.

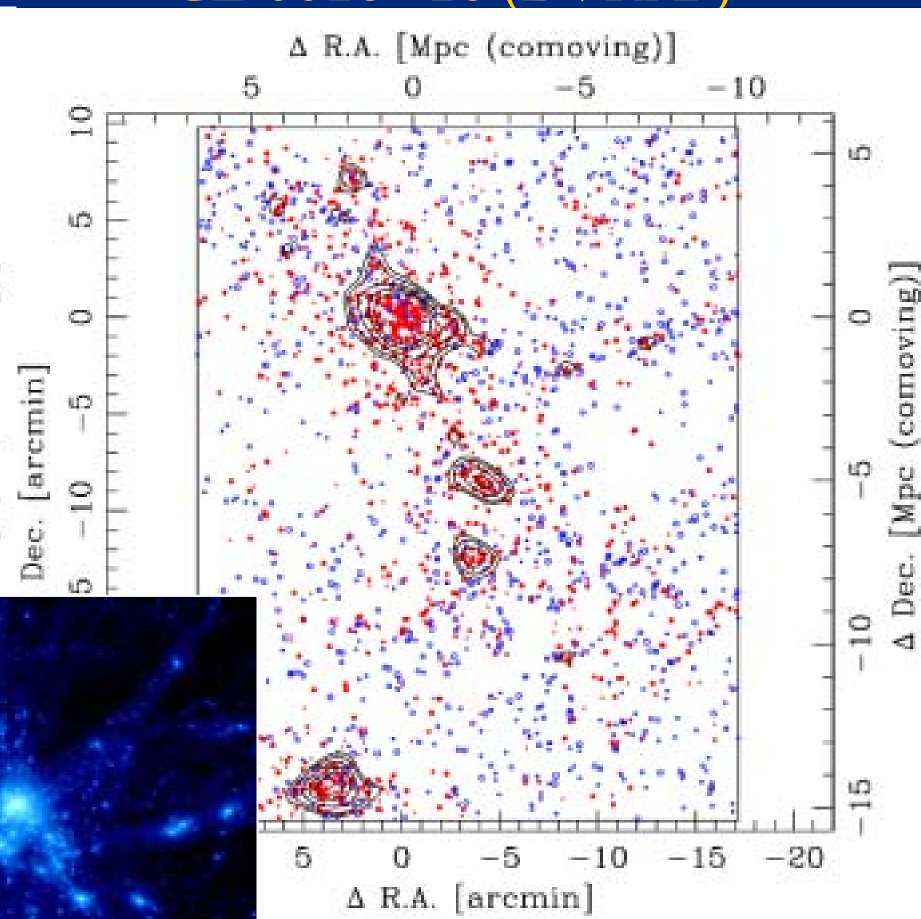
# Panoramic Views of Cluster Assembly

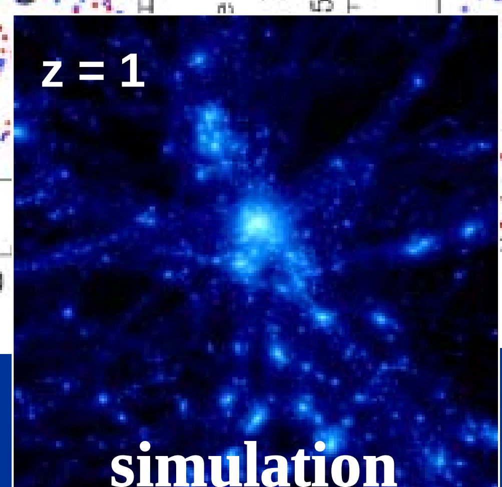
**Distribution of phot-z sliced galaxies ($\Delta z = -0.05 \sim +0.03$)**

RXJ 0152.7-1357 (VRIz’)

CL 0016+16 (BVRi’z’)




z=0.83 (*7.0 Gyr ago*)

z=0.55 (*5.4 Gyr ago*)

**Kodama, et al. (2005)**

# Unsolved Issues on Galaxy Formation and Evolution from An Observer's Point of View

- **When are the massive galaxies assembled ?**

  Is it consistent with hierarchical models ?

- **What is the origin of down-sizing ?**

  Is it consistent with the bottom-up picture ?

- **What is the sampling bias in high-z galaxies ?**

  What is the effect of dust ?

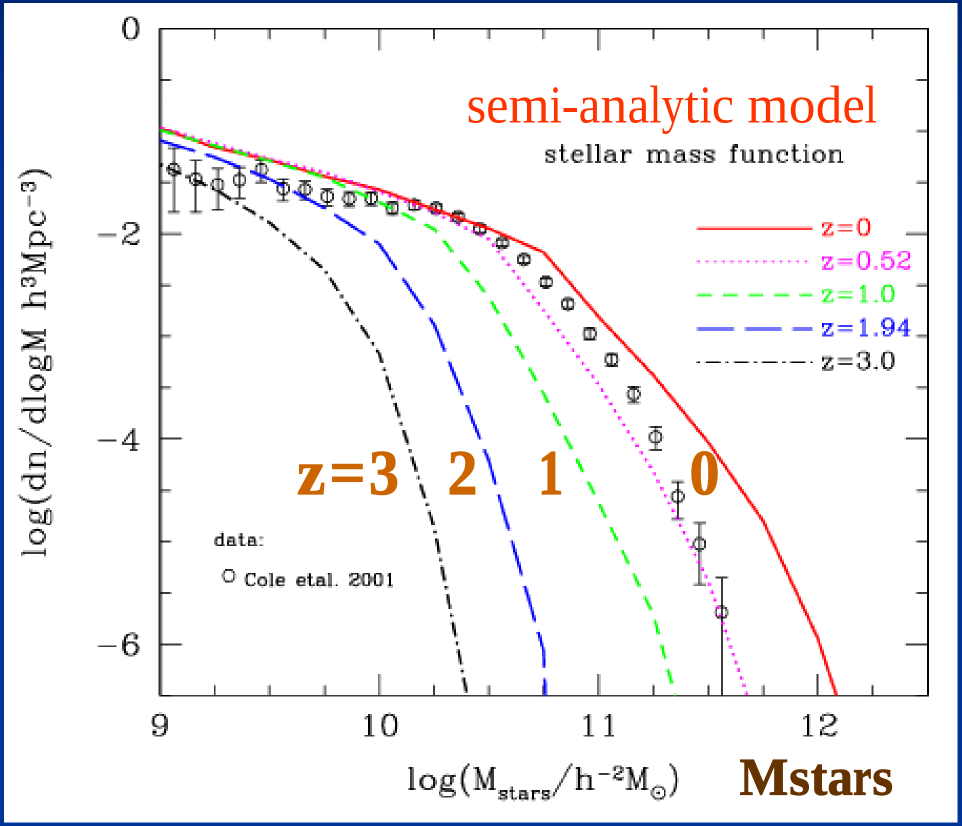
*RXJ0152.7-1357 (z=0.83), Subaru*

- **When are the massive galaxies assembled ?**

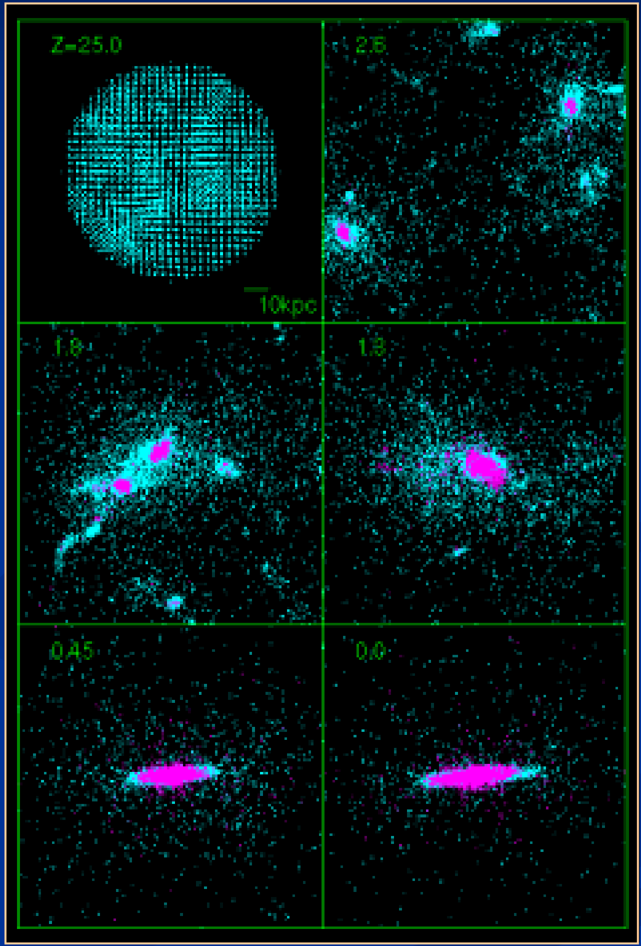
Is it consistent with hierarchical models ?

# Formation of massive galaxies: late assembly?

Baugh et al. (2002)




Bekki & Chiba (2001)

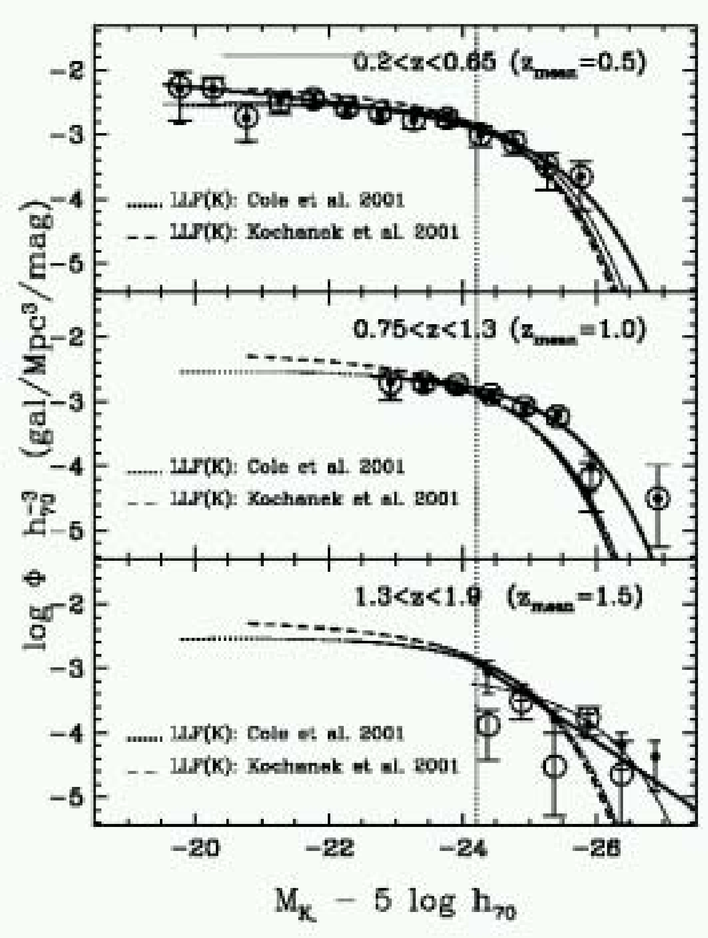



Stellar mass function is expected to dramatically change with time in the hierarchical galaxy formation models.

see also Kauffmann & Charlot (1993)

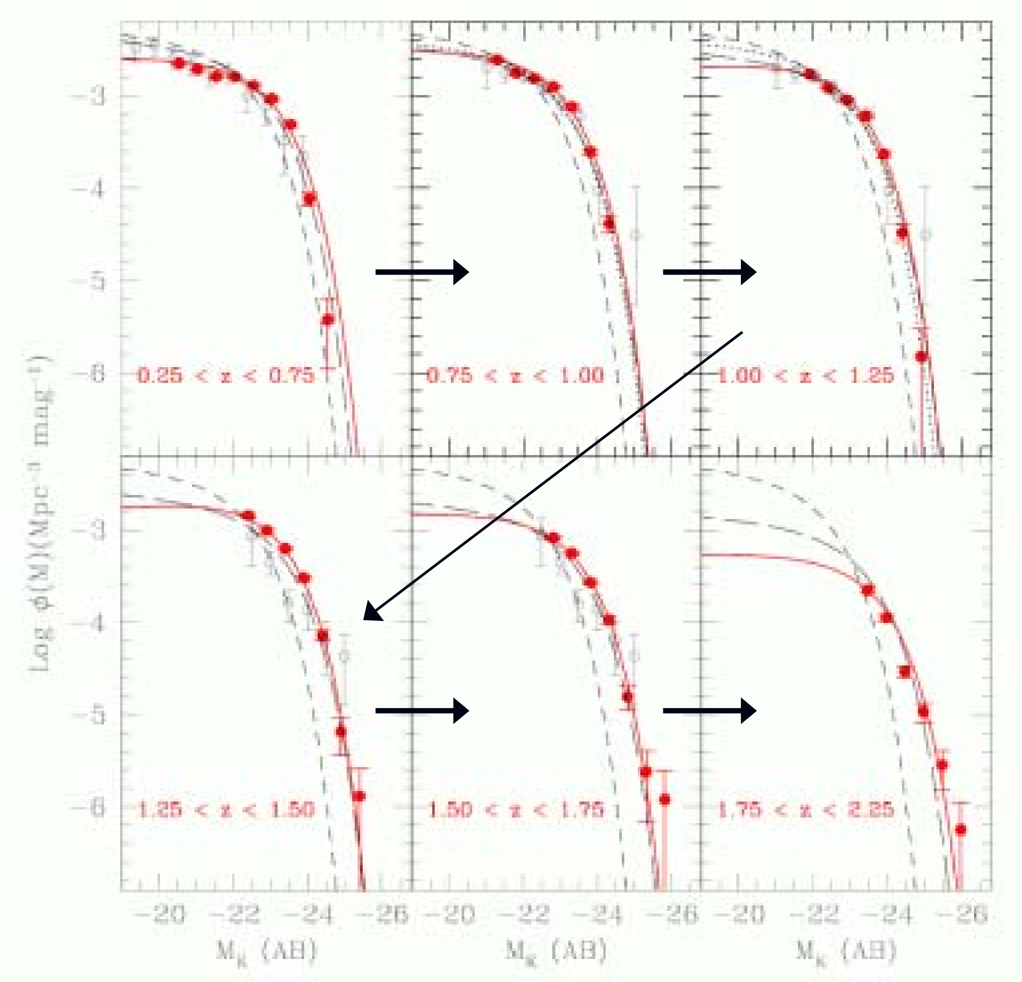
# Stellar mass evolution at z<2

**K20 (52 arcmin^2)**




Pozzetti et al. (2003)

**UKIDSS-UDS (0.6 deg^2)**



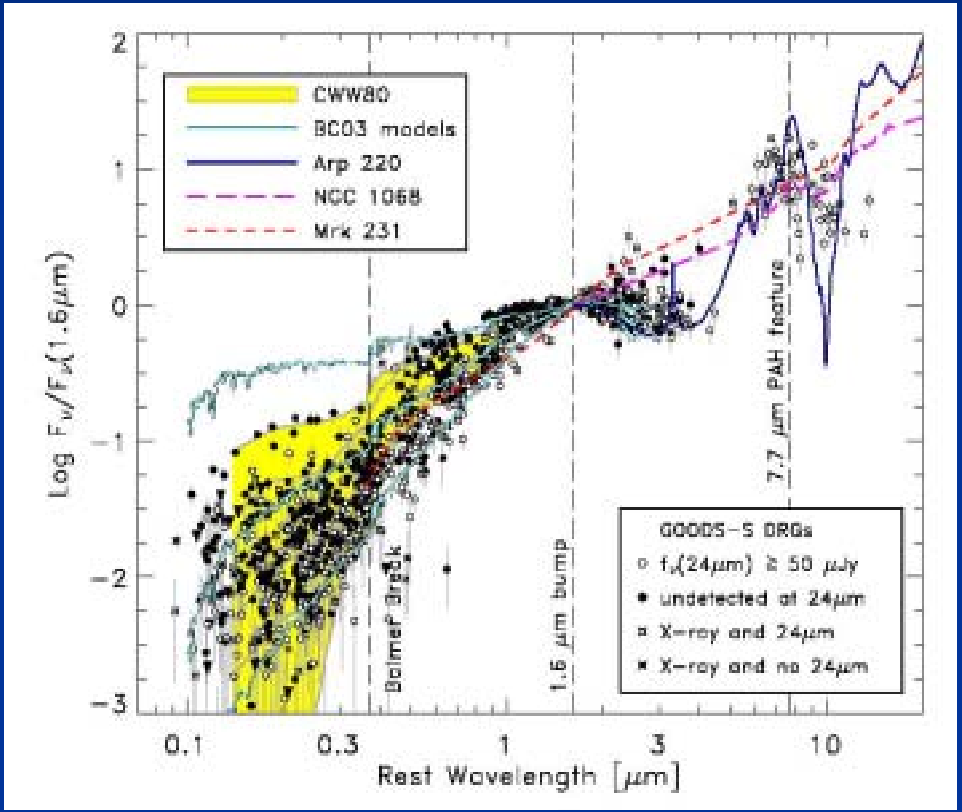

Cirasuolo et al. (2006)

**No significant evolution at the massive-end of SMF out to z~1.5**

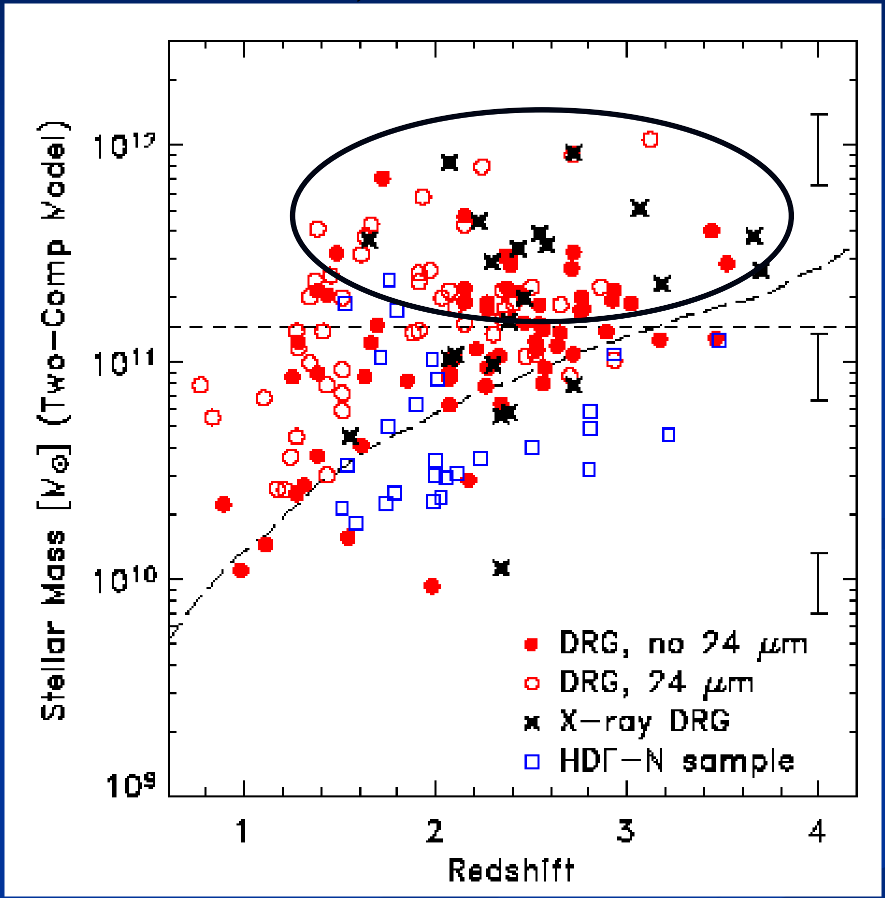
# Stellar mass evolution at z>2

## Distant Red Galaxies (J-K>2.3; DRG) at 2<z<3

153 DRGs in GOODS-S



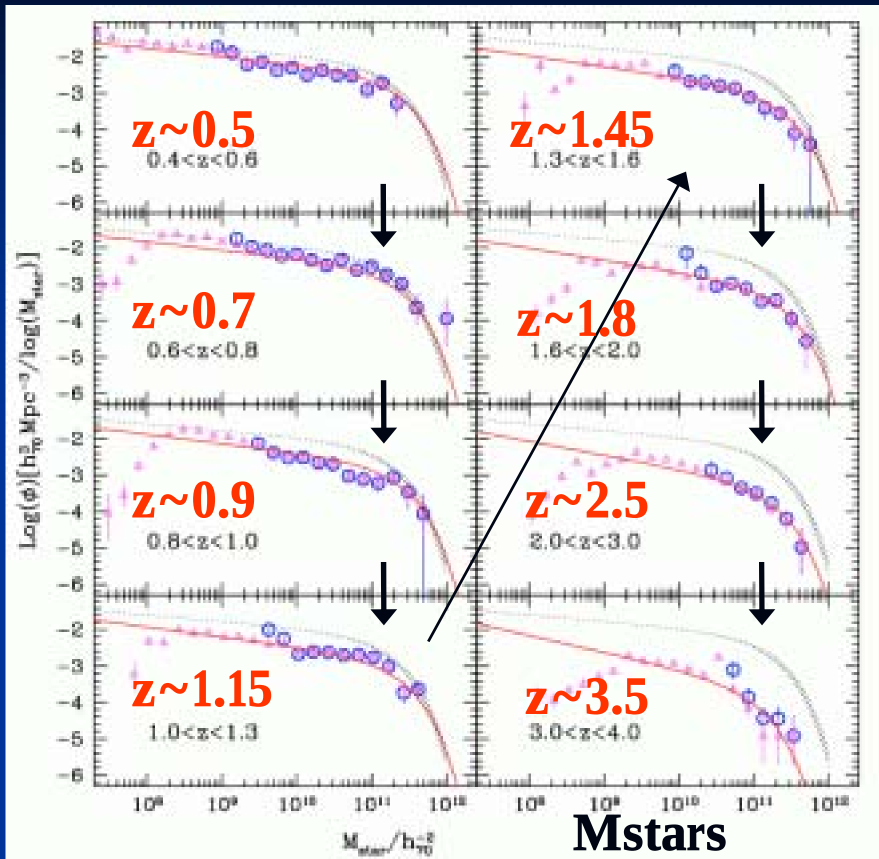

**Papovich et al. (2006)**




**Many of them have stellar masses greater than 10^11 Msun !**
**Host ~80% of stellar mass at 2<z<3.**

Franx+ (03), van Dokkum+ (03; 04; 06), Foerster Schreiber+ (04)…

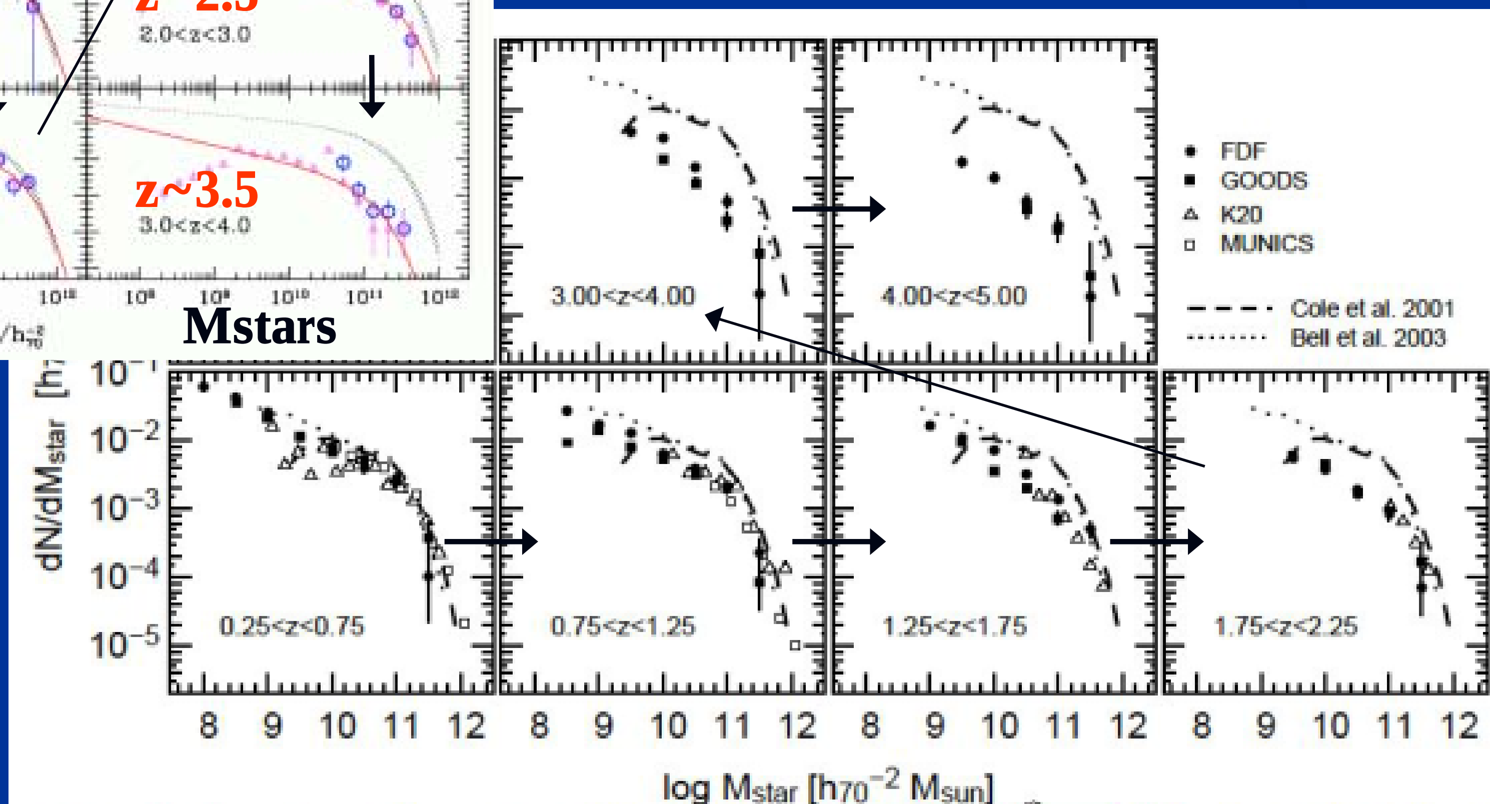
# Stellar mass evolution at z>2



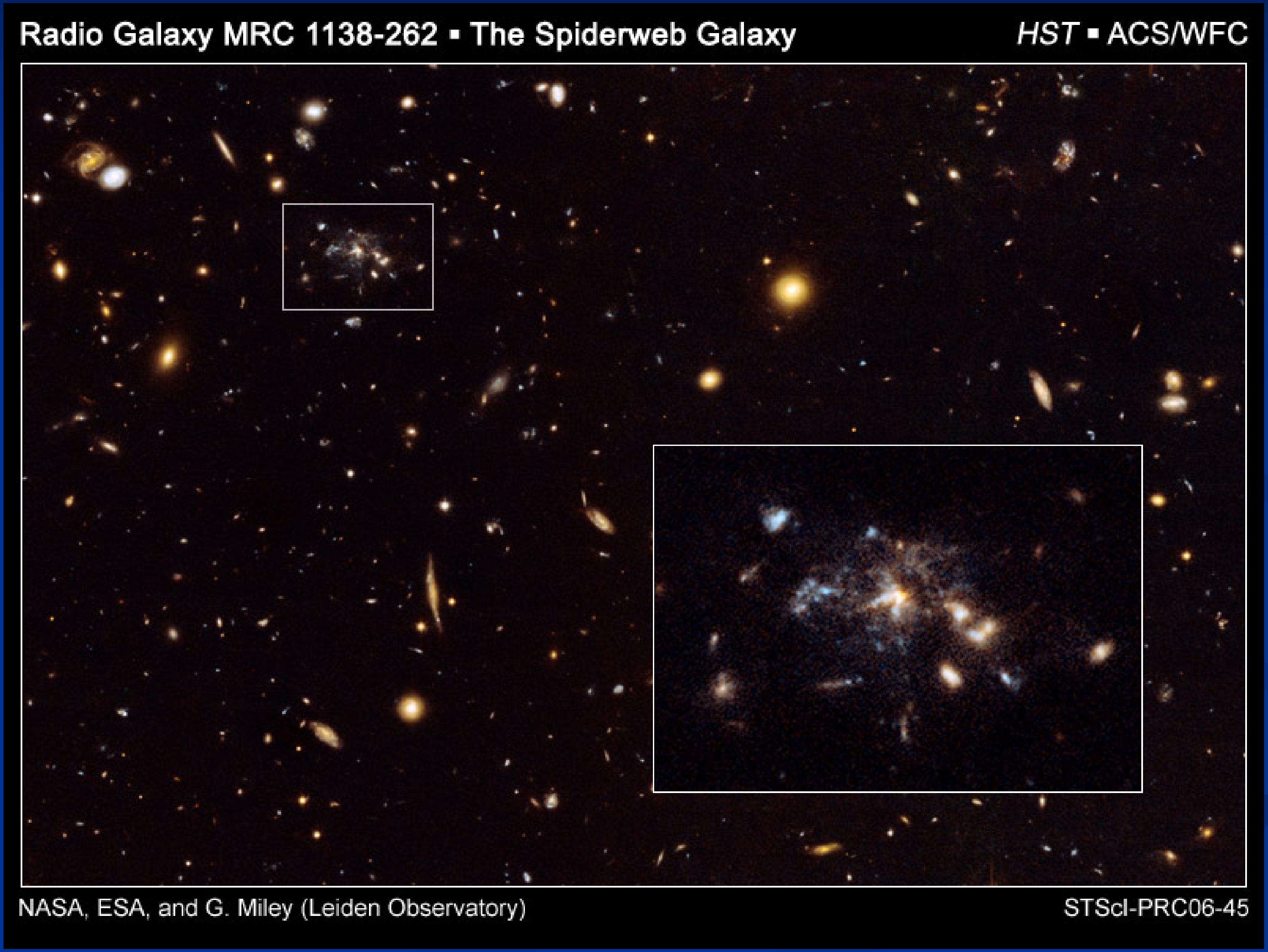

**GOODS-MUSIC (160 arcmin^2) with Spitzer bands.** Fontana et al. (2006)

**At z>1.5-2, co-moving number density of massive galaxies starts to decrease.**

**FDF+GOODS-S (90 arcmin^2), U to K** Drory et al. (2005)



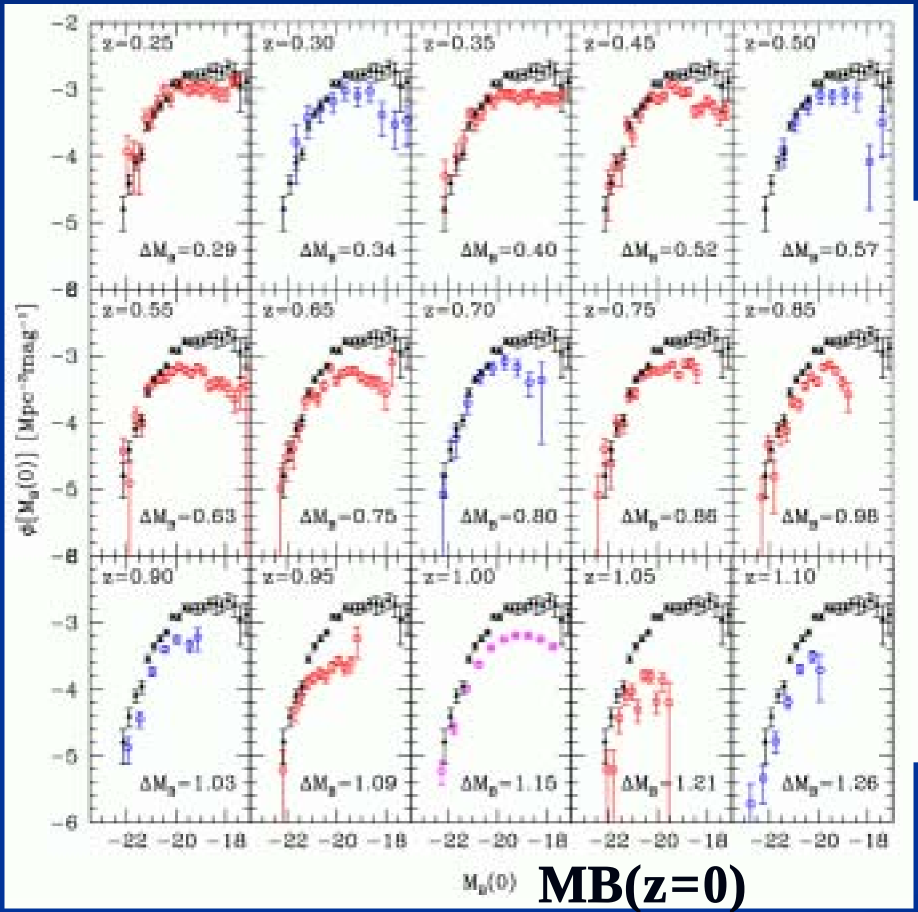
# The spider-web galaxy (witnessing the assembly of a cD at z=2.16)



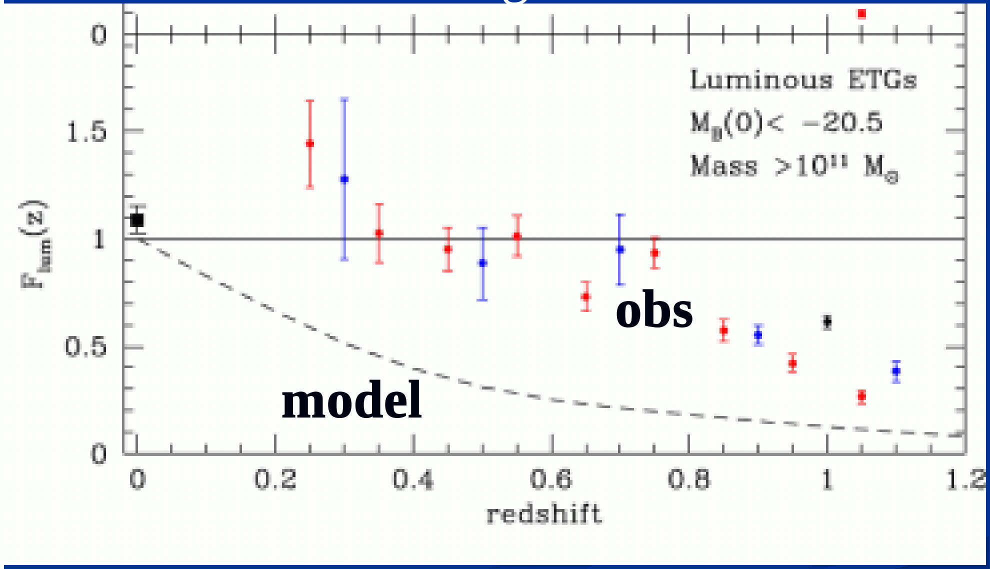

Miley et al. (2006)

# Hierarchical models tend to under-predict massive galaxies even at z<1

**Cimatti et al. (2006)**




fraction of massive galaxies vs redshift

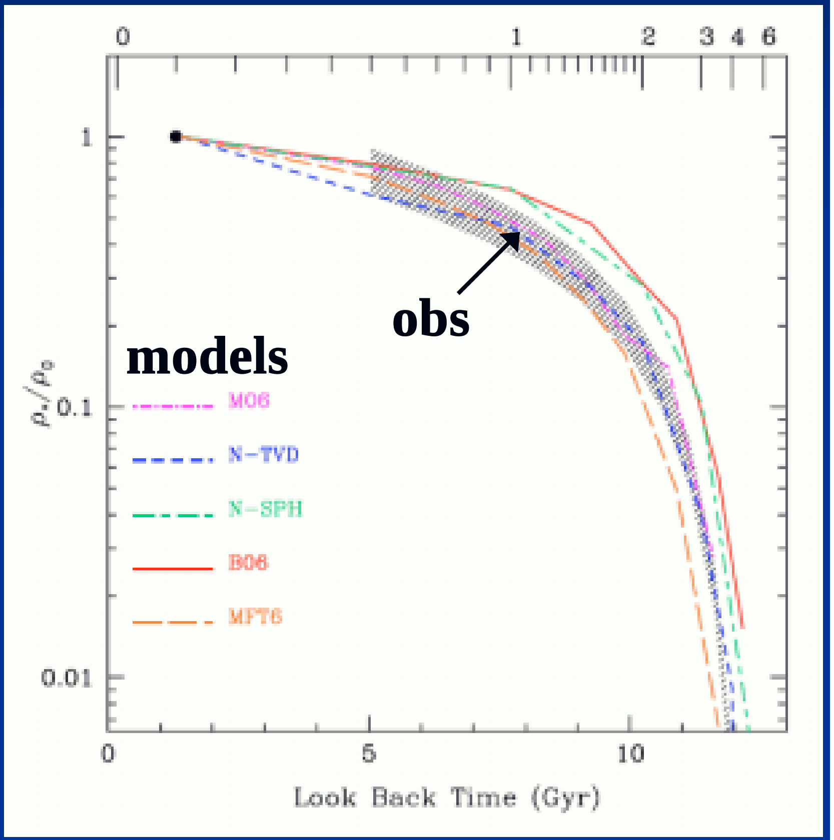



Obs vs Semi-analytic Model (De Lucia+ 06)

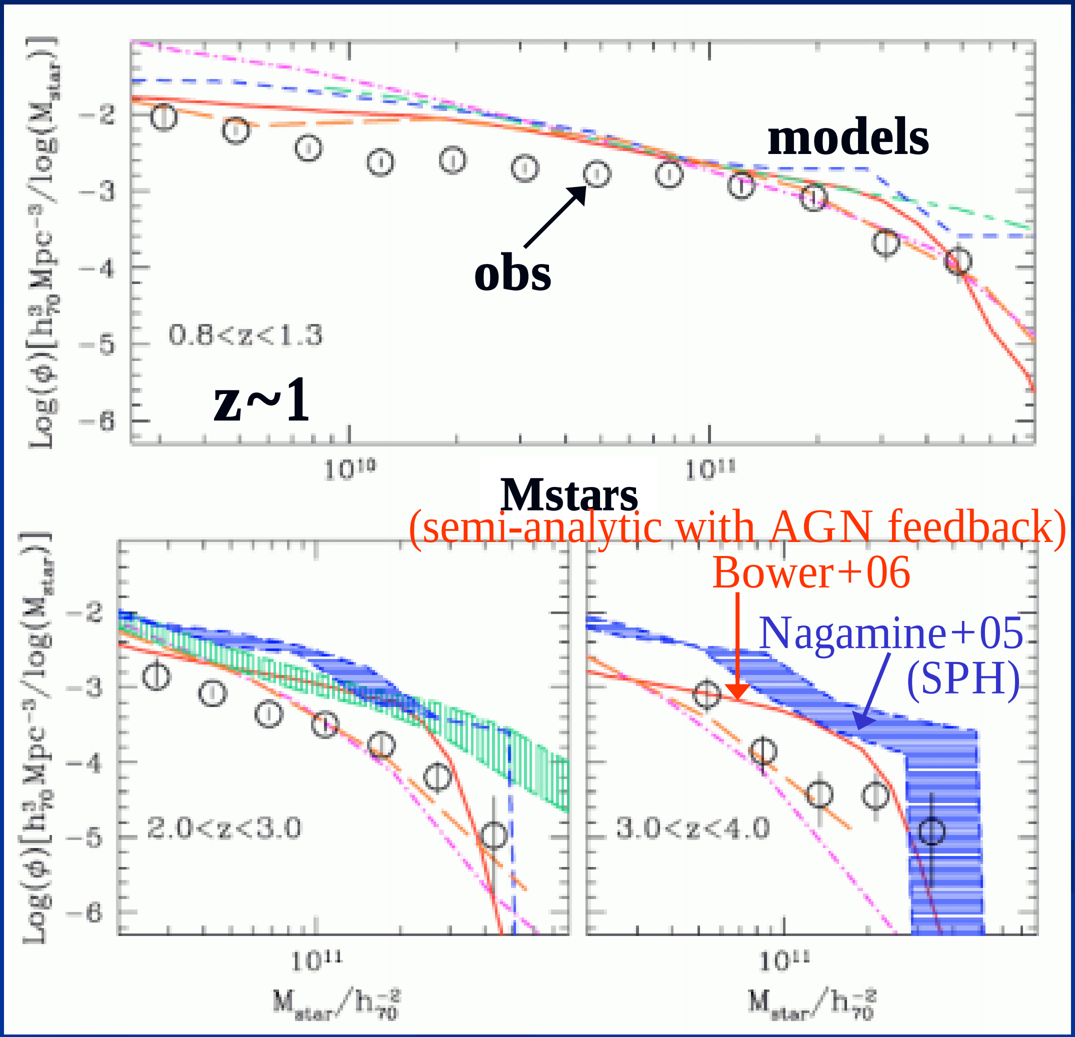
SDSS(z~0) vs. COMBO17(0.2<z<1) vs. DEEP2(0.3<z<1.1) vs. SXDS (z~1)

# Recent models do a better job

Stellar mass density




Stellar mass function

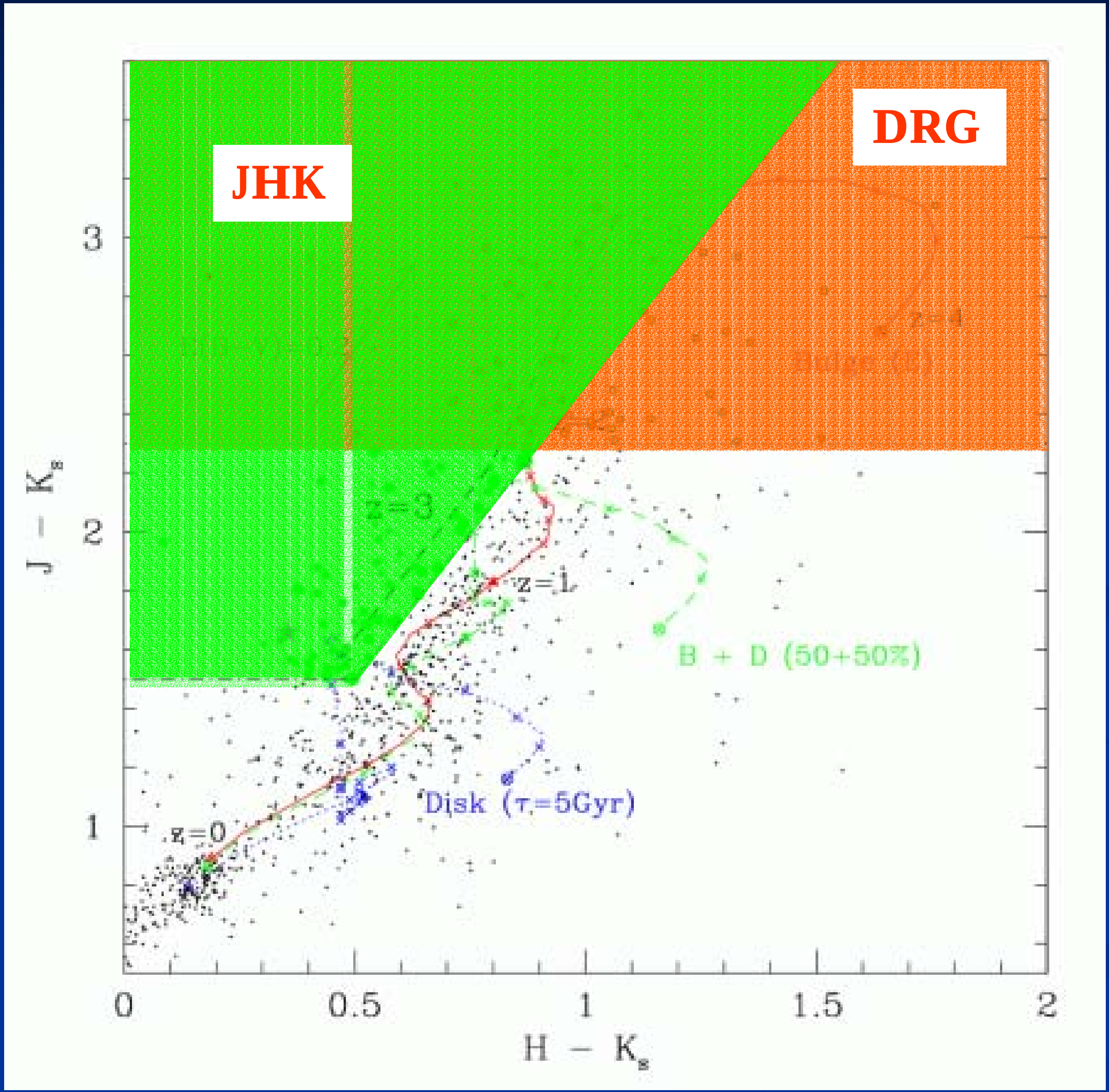



**Fontana et al. (2006)**

GOODS-MUSIC

~8000 galaxies with Ks<23.5 (AB)

# JHK selection of 2<z<3 galaxies




Kajisawa et al. (2006), Kodama et al. (2006)

**Classical criteria (DRG):**

J-K>2.3

passive / dusty gals at z>2

↓

**Our new criteria (JHK):**

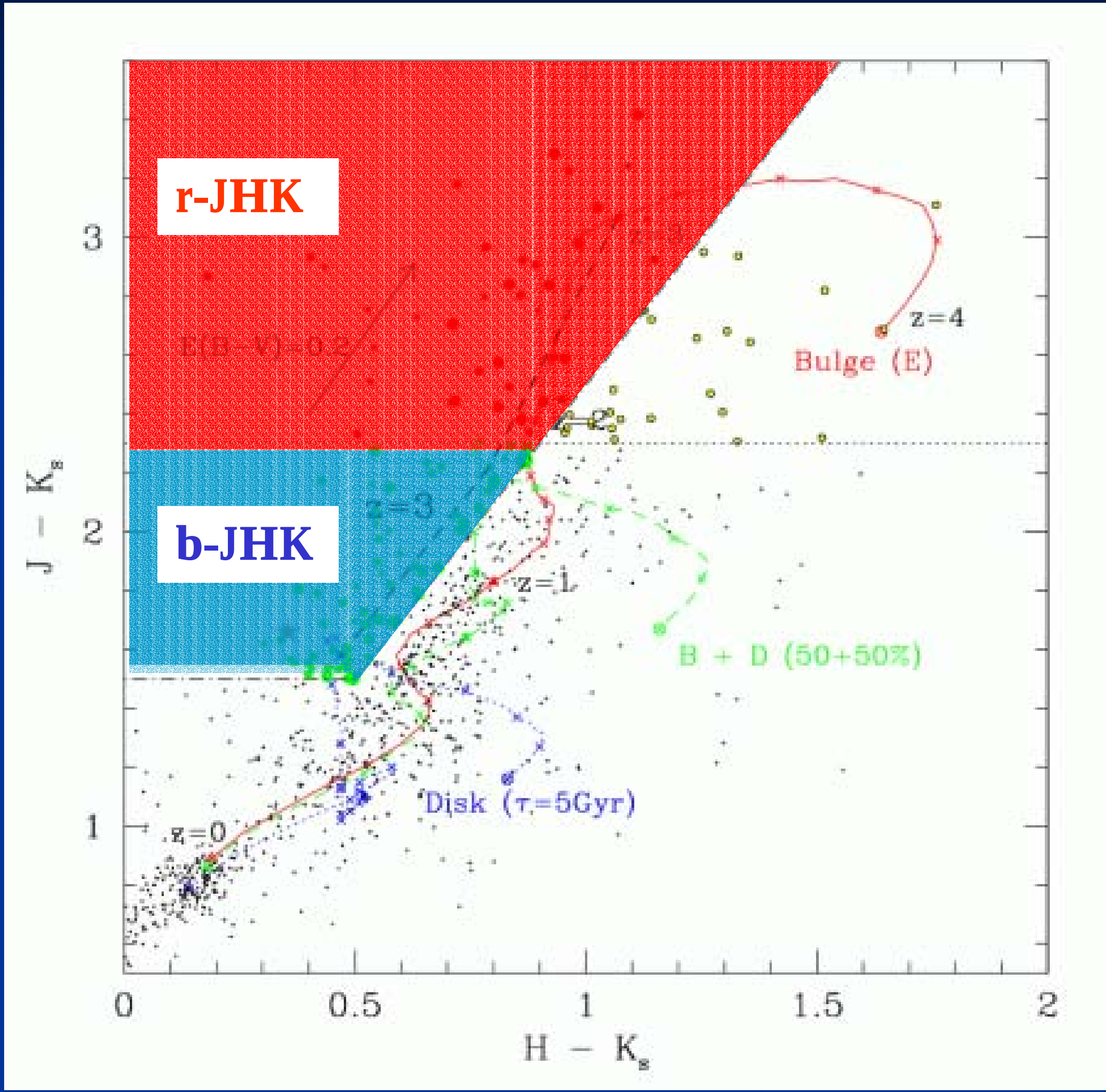
(J-K)> 2(H-K)+0.5

&& J-K>1.5

passive / dusty +

star-forming gals at 2<z<3

# JHK selection of 2<z<3 galaxies




Classical criteria (DRG):

J-K>2.3

passive/dusty gals at z>2

↓

Our new criteria (JHK):

(J-K)> 2(H-K)+0.5

&& J-K>1.5

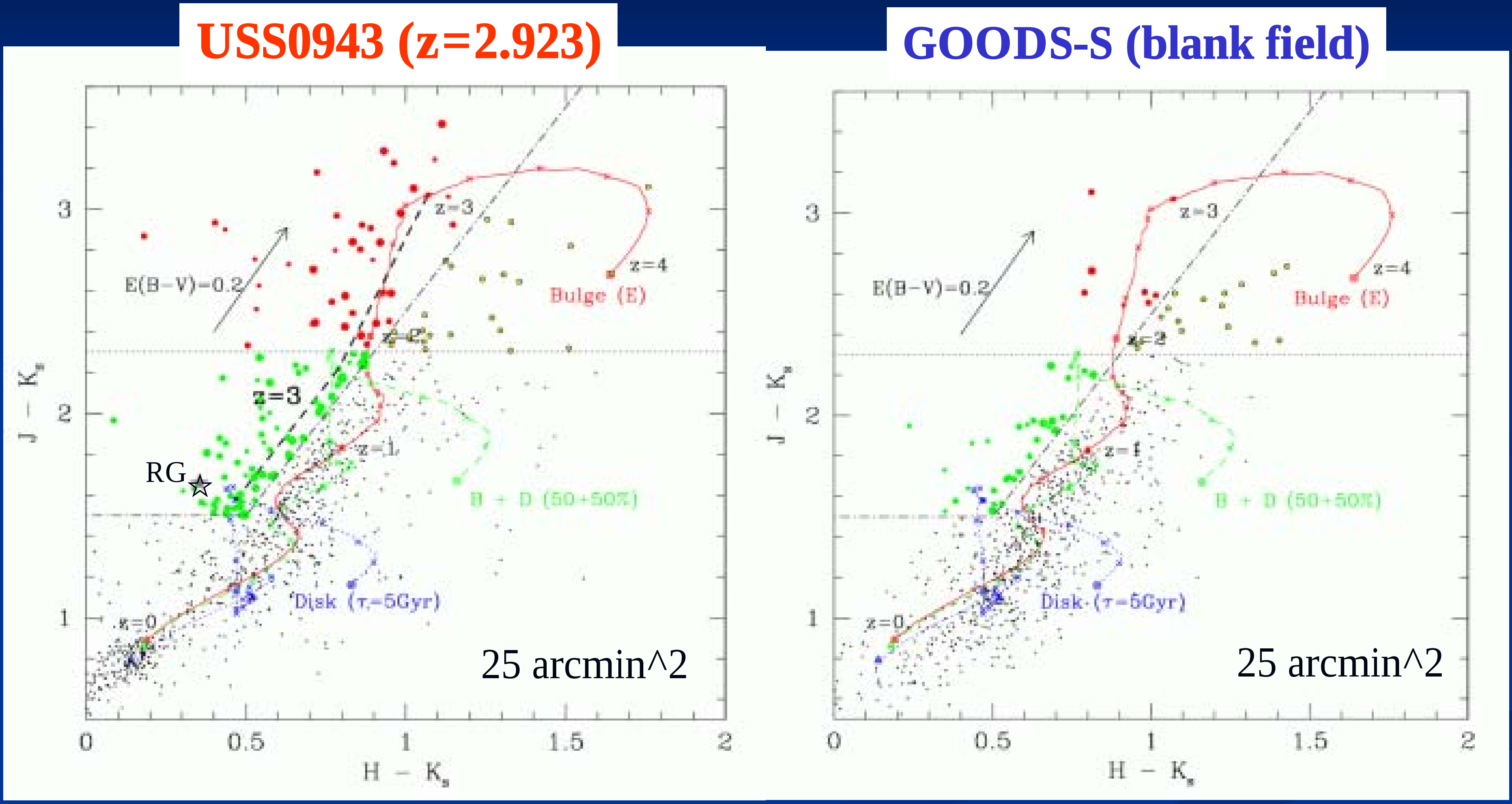
passive/dusty +

star-forming gals at 2<z<3

J-K>2.3 -- r-JHK

J-K<2.3 -- b-JHK

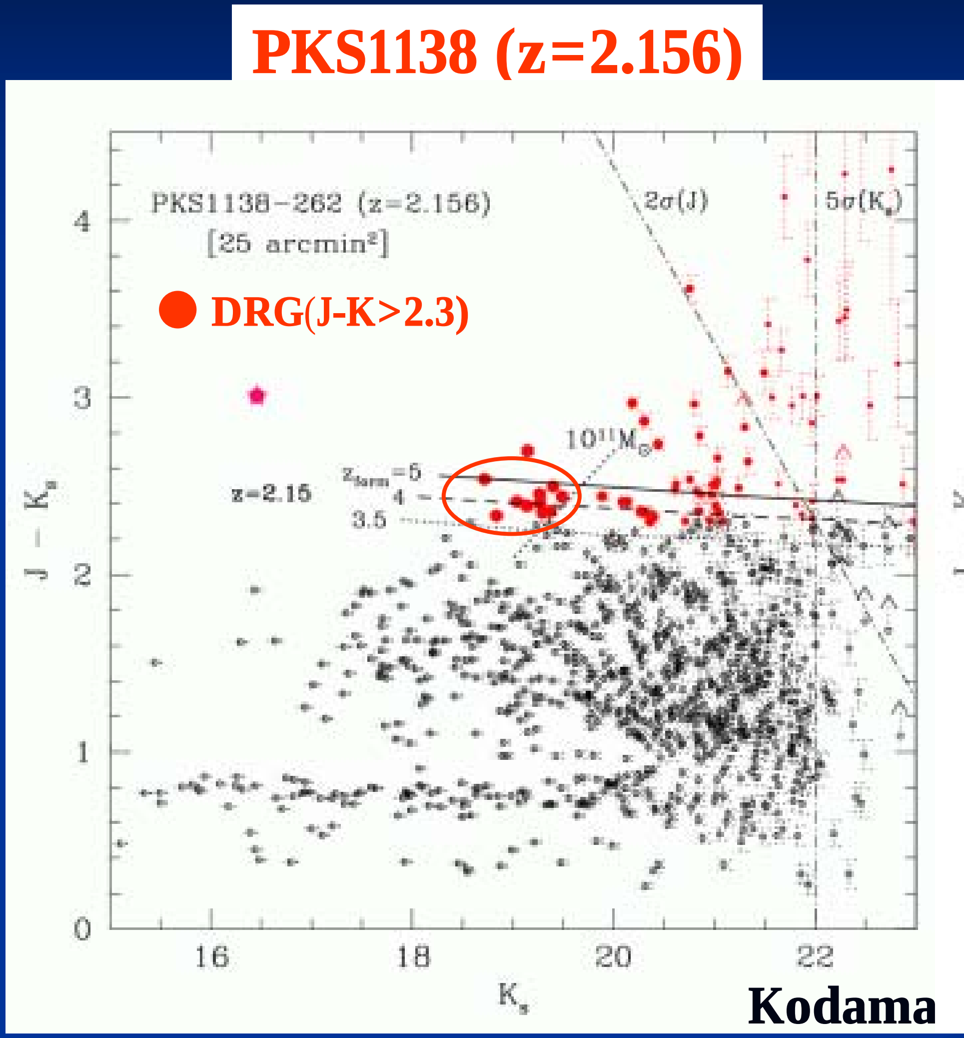
# JHK diagram (0943@z=2.923)

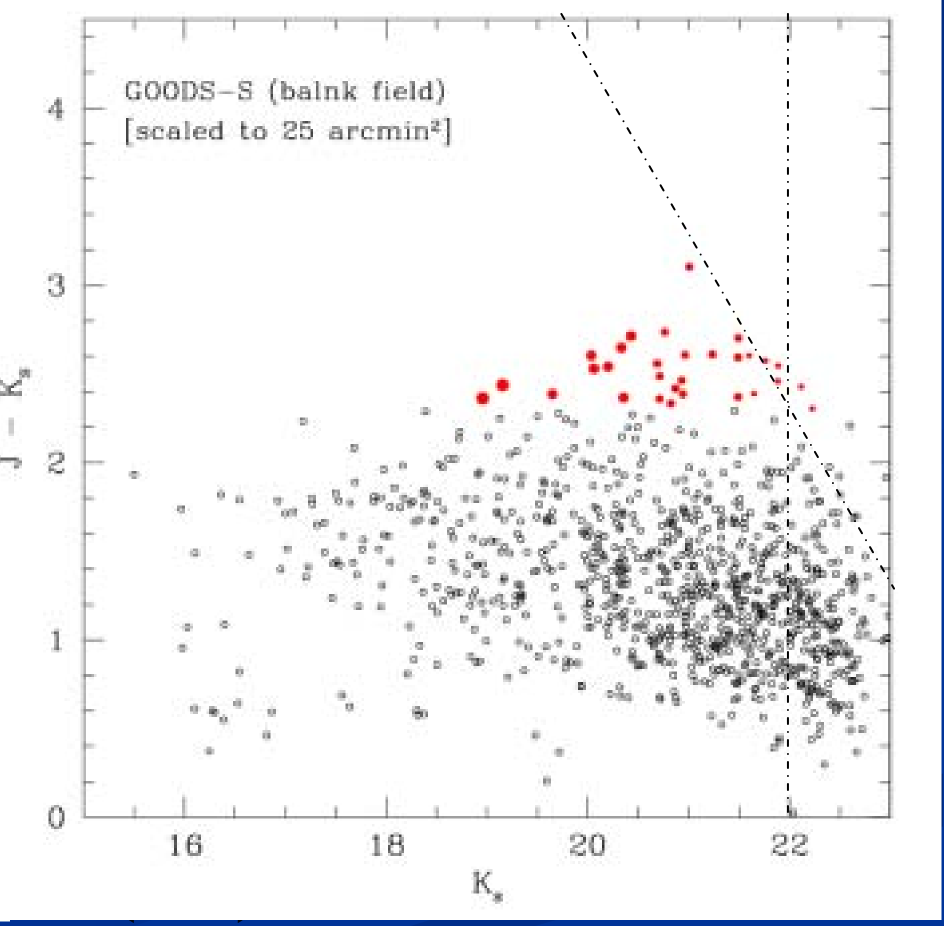



Excesses of both r-JHK and b-JHK are clearly seen (factor>2.5).

**Kodama et al. (2006)**

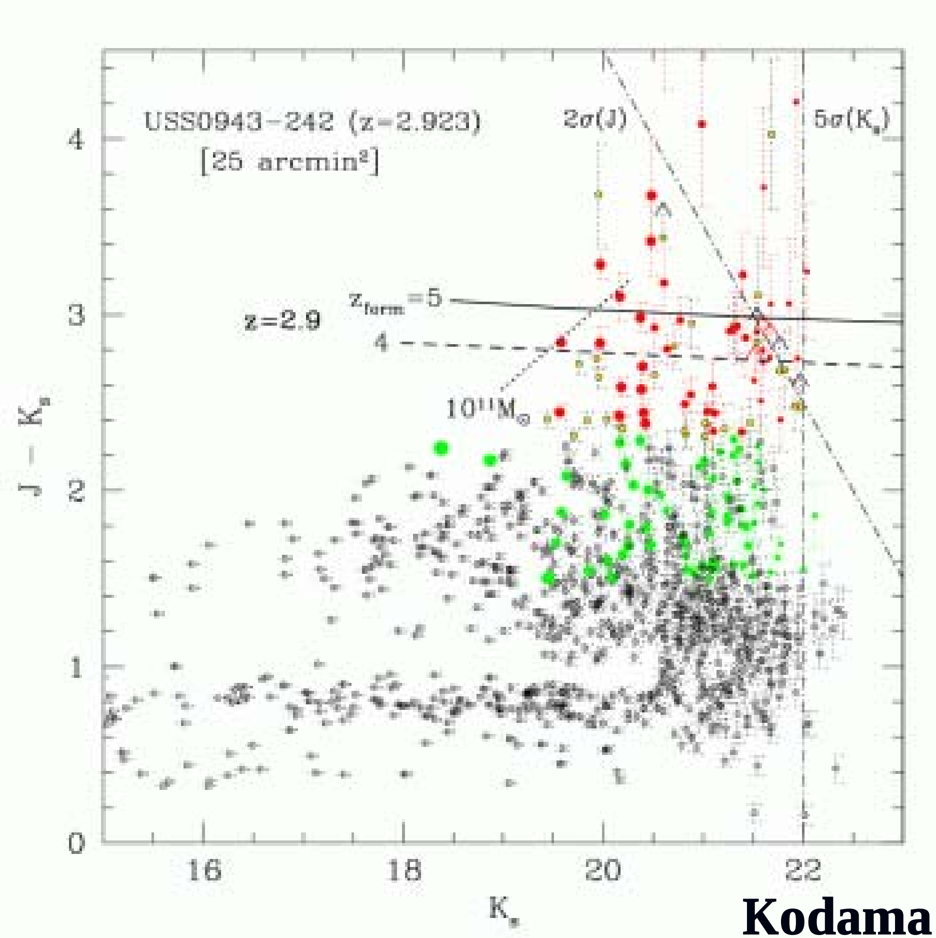
# Colour-Magnitude (1138@z=2.156)

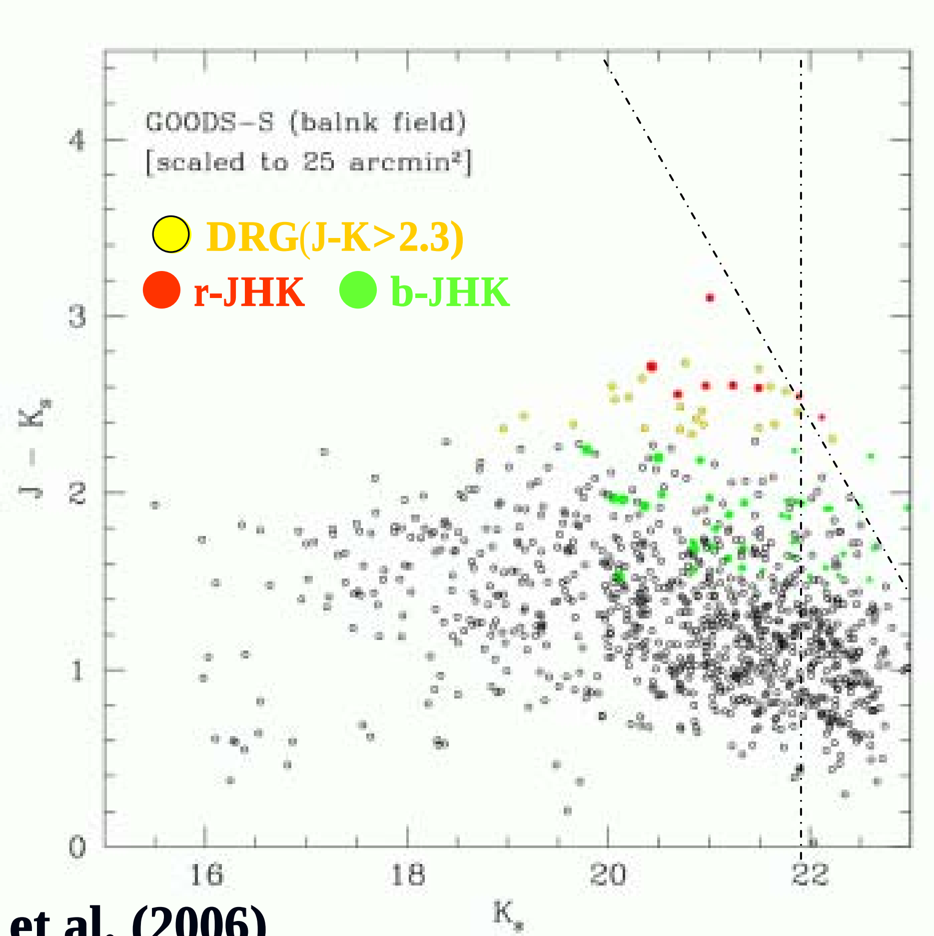



Well-visible red sequence consistent with passive evolution formed at z~4-5.
They are very massive (>10^11Msun) !

# Colour-Magnitude (0943@z=2.923)



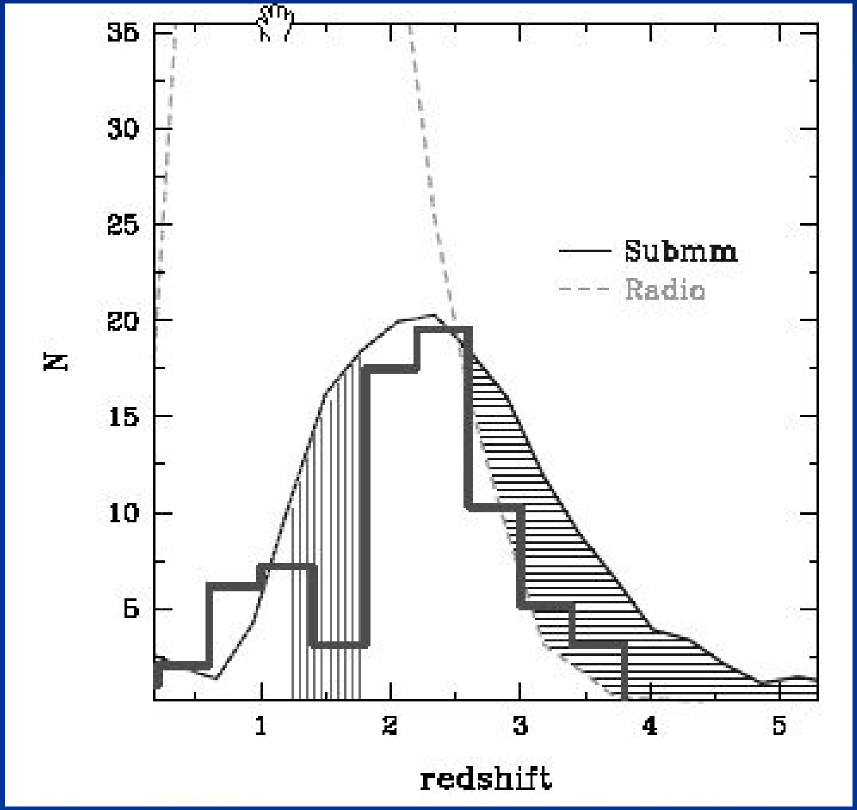




**Kodama et al. (2006)**

Clear excess of red galaxies consistent with passive evolution formed at z>4, but few massive ones (>10^11Msun) ! → not assembled yet !?

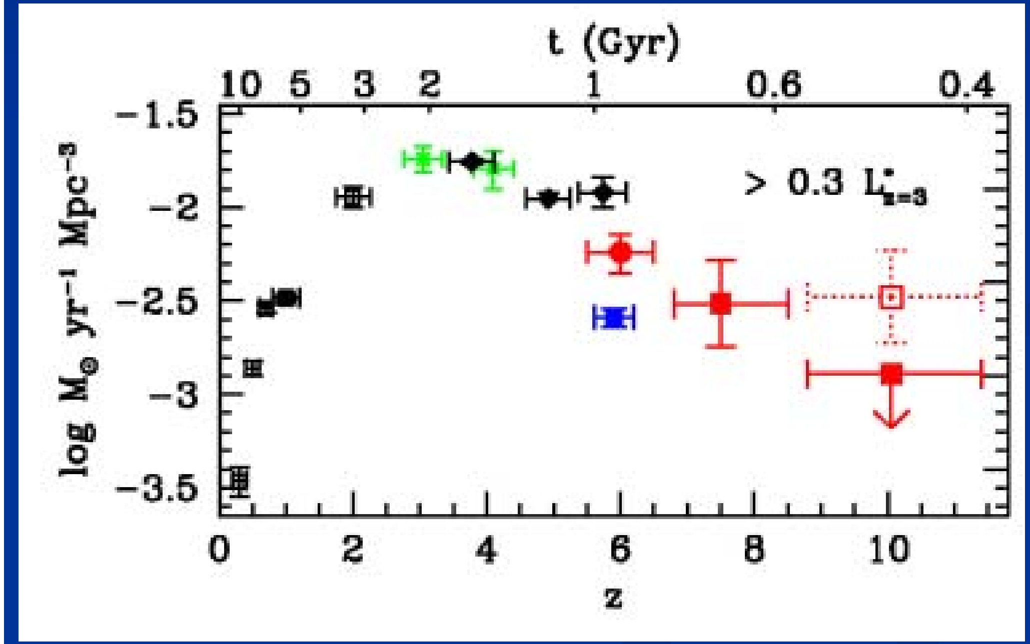
# What's the era of 2 < z < 3 ?

**SCUBA sources peak at z~2.4**




Chapman et al. (2005)

**Cosmic SFR peaks at z~3**

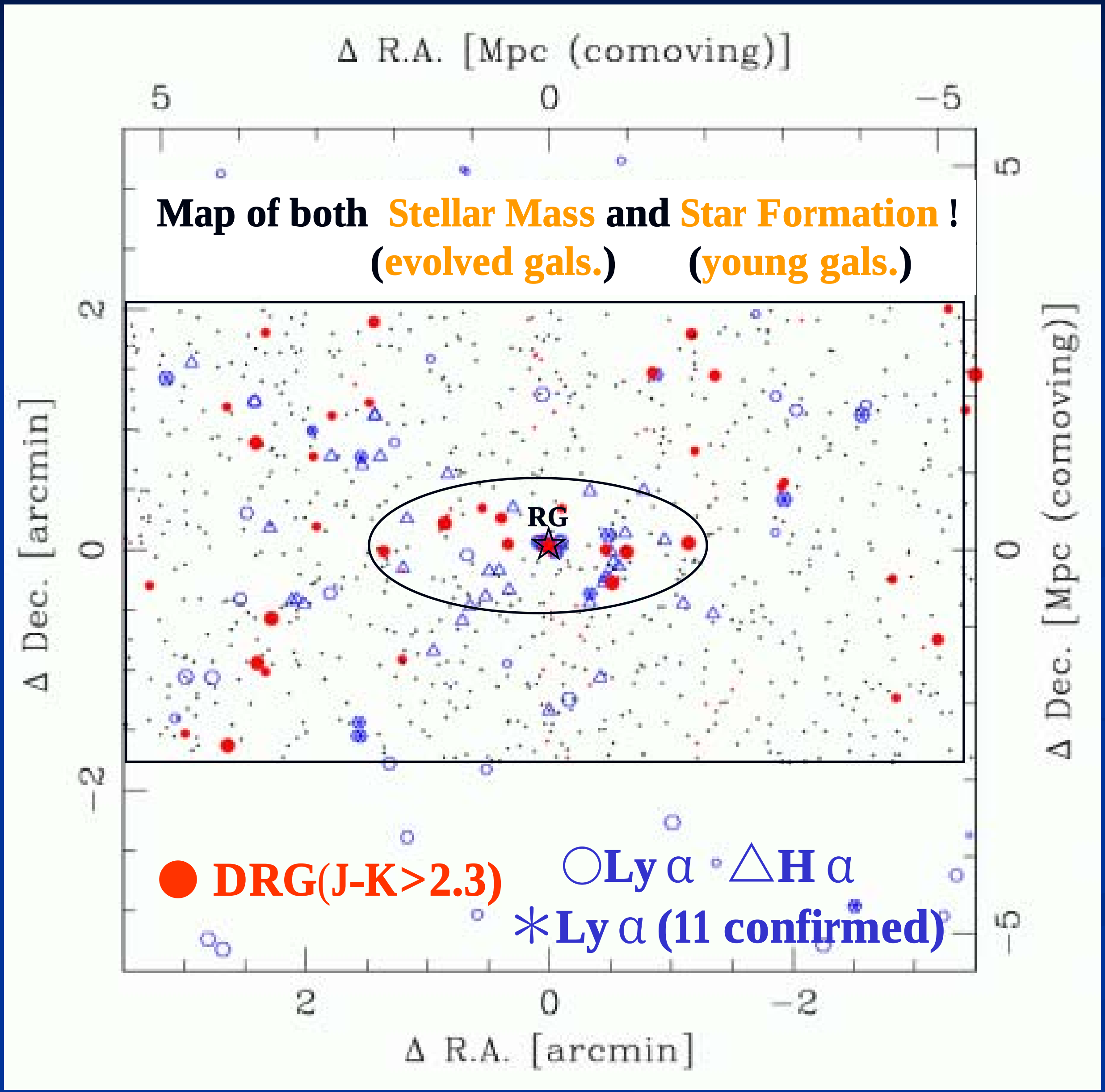



Bouwens et al. (2005)

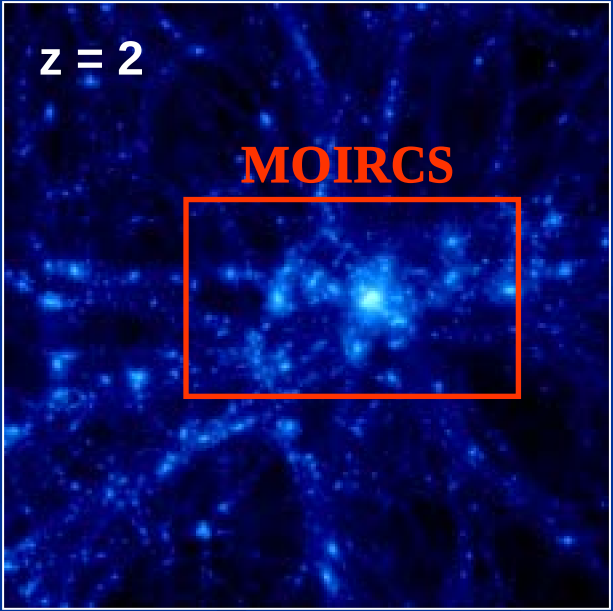
⊿t(2<z<3)

**100 Msun/yr × 1 Gyr = 10^11 Msun**

# 2-D Structure of PKS1138 (z=2.156)




simulation

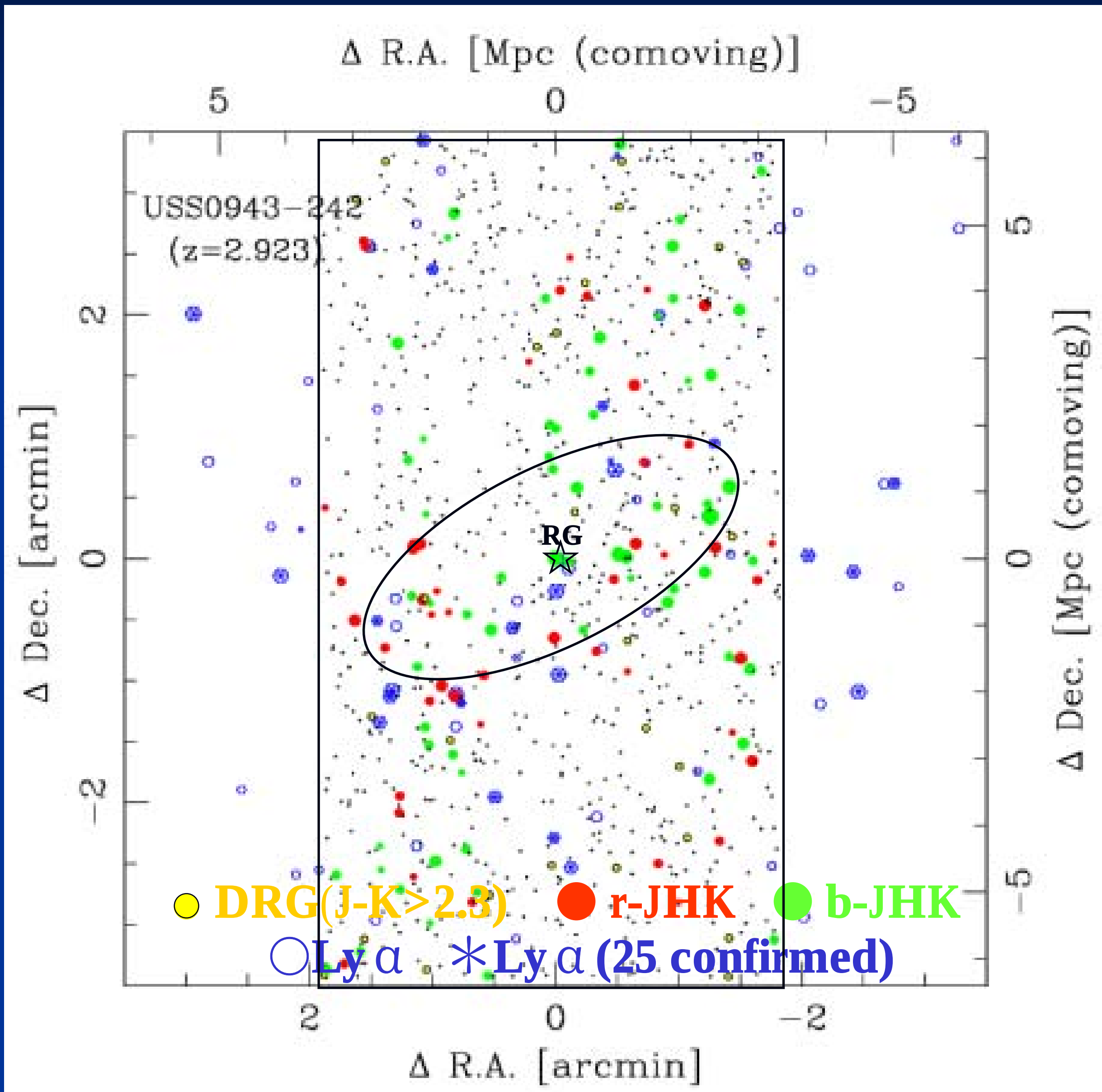



see also

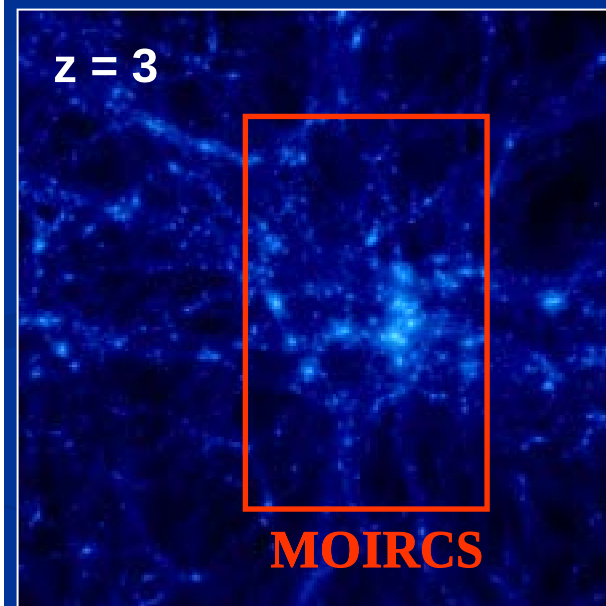
Kurk et al. (2004)

Croft et al. (2005)

# 2-D Structure of USS0943 (z=2.923)

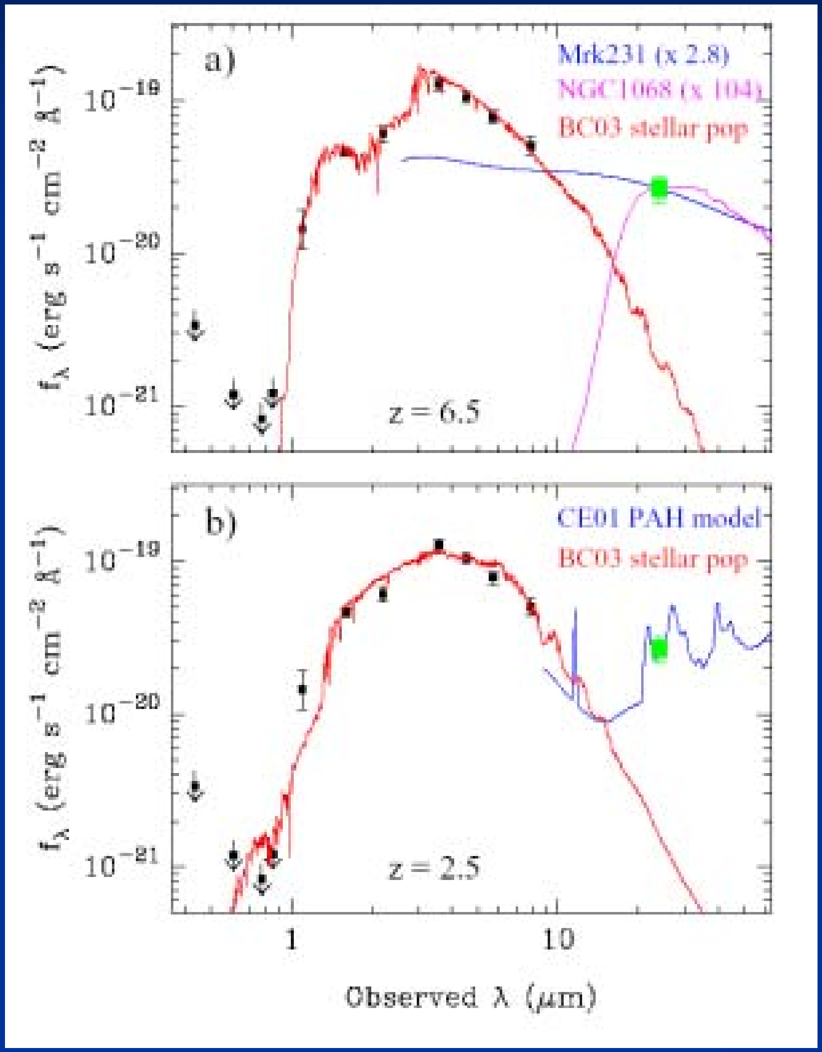


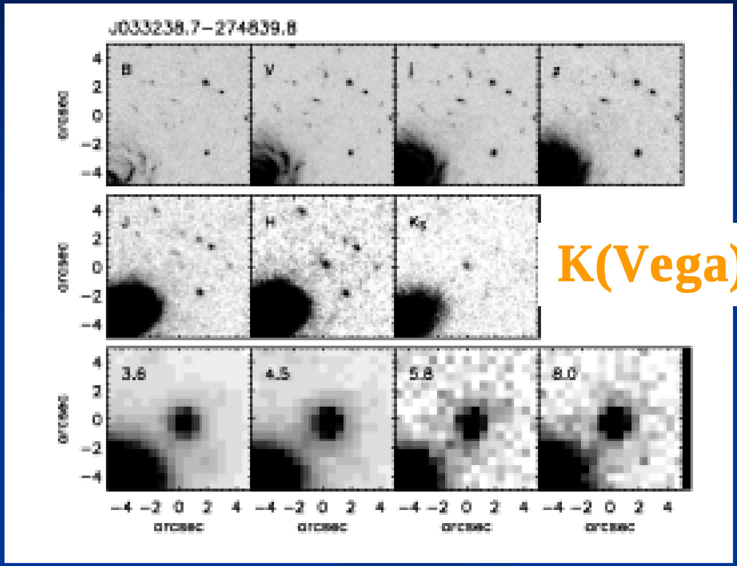

simulation



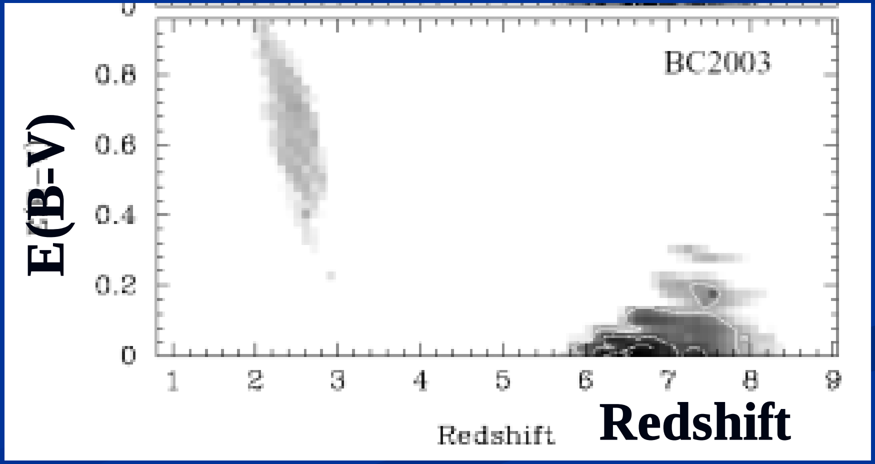
# A Post-Starburst Galaxy at z~6.5 ?

## Mobasher et al. (2005)




K(Vega)=22



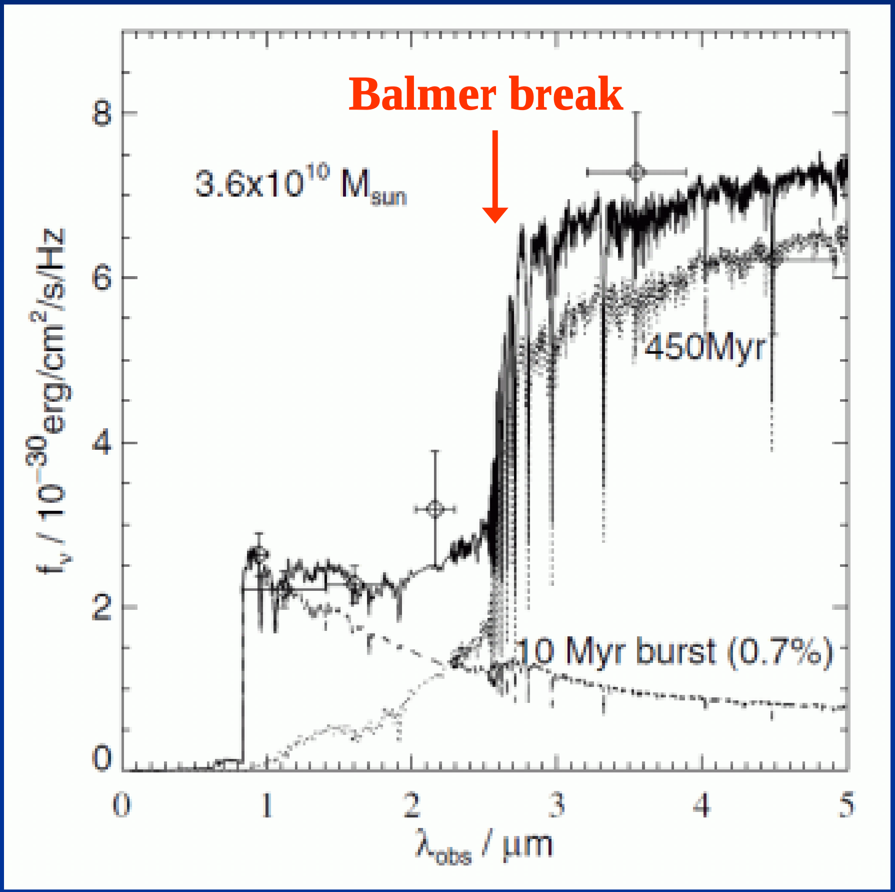

**Redshift**

**Mstar = 6 × 10^11 Msun ！**

13~18 massive galaxies at z>5 have also been found.
（<M*>=2x10^11Msun）

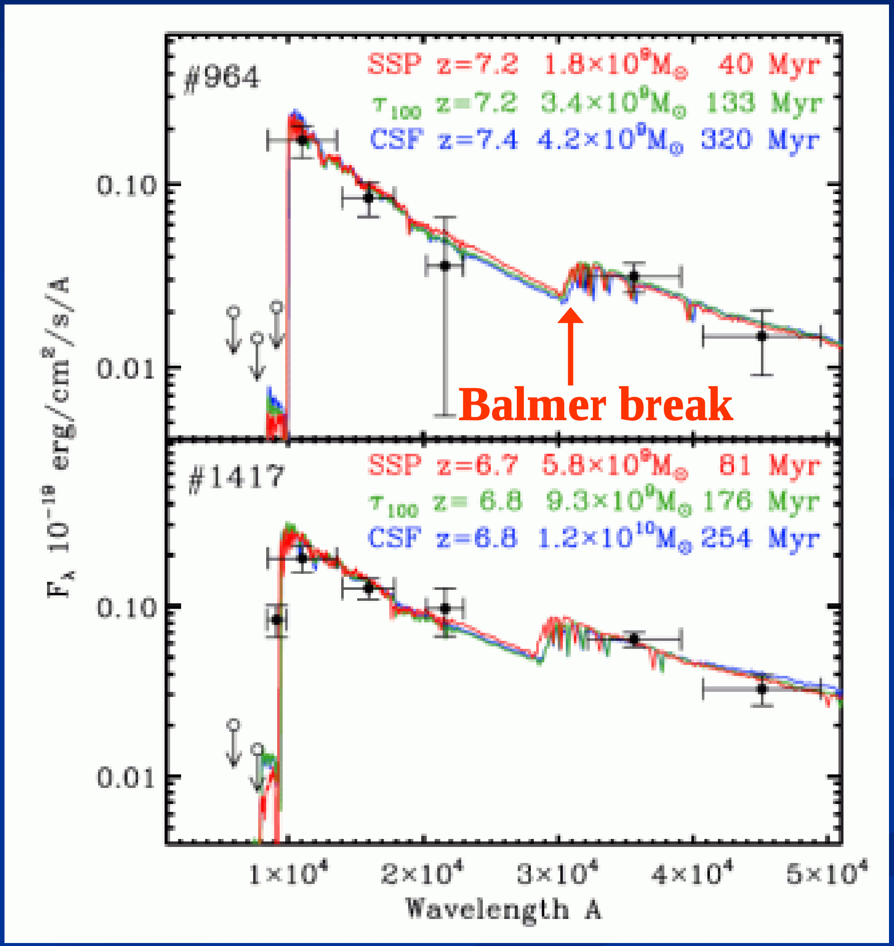
# Stellar mass of galaxies at frontier redshifts

1-4 x 10^10 Msun




z=6 (i'-drop), Eyles et al. (2005)

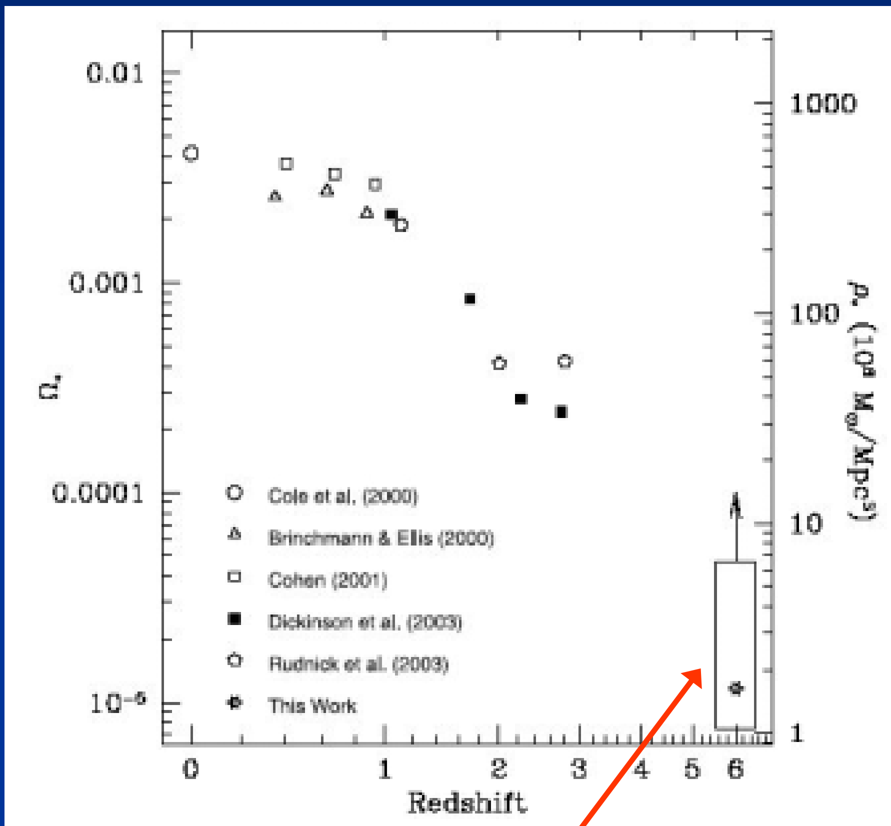
10^9 ~ 10^10 Msun

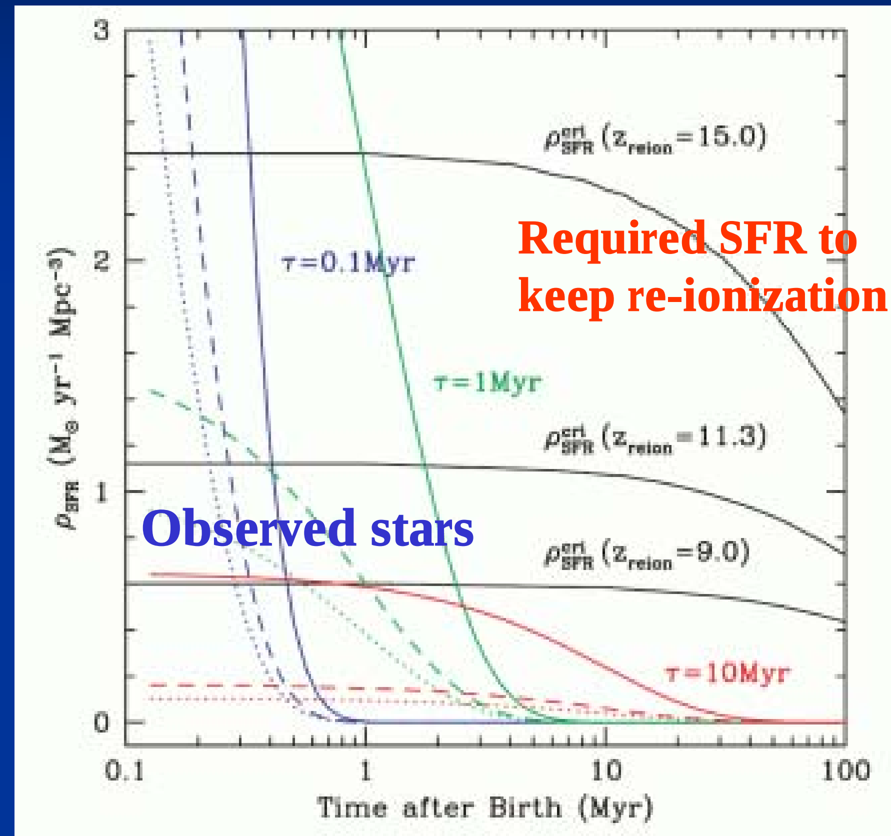



z=7 (z'-drop), Labbe et al. (2006)

Break features require relatively old stars formed in the re-ionization era (zf~10).

# Lack of re-ionization sources?




**53 i'-band dropouts in GOODS.**

10^9~10^10 Msun

>1% of stellar mass in local Universe is locked in stars at z~6.

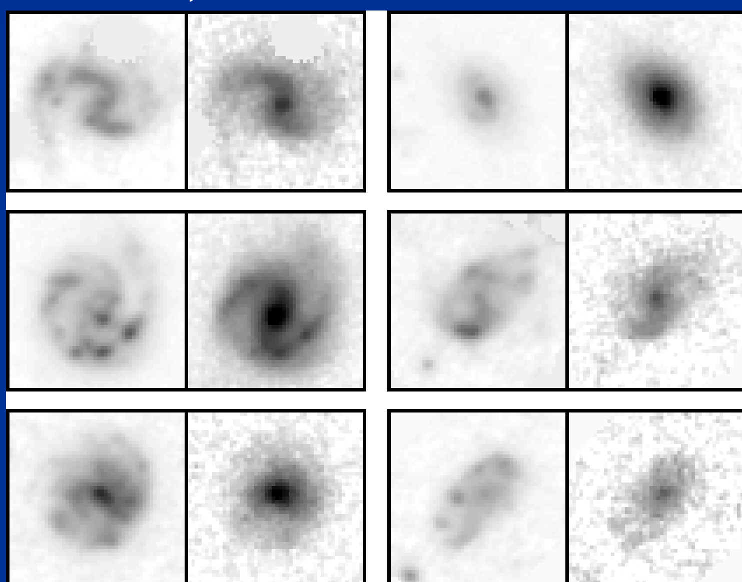
Massive galaxies at z~6 cannot sustain re-ionization → Contribution from dwarfs!

**Yan et al. (2006)**

# Morphology first appeared between z=1 and 2?

z ~ 1 (8Gyr ago)

λ rest=3000 Å, 6500 Å

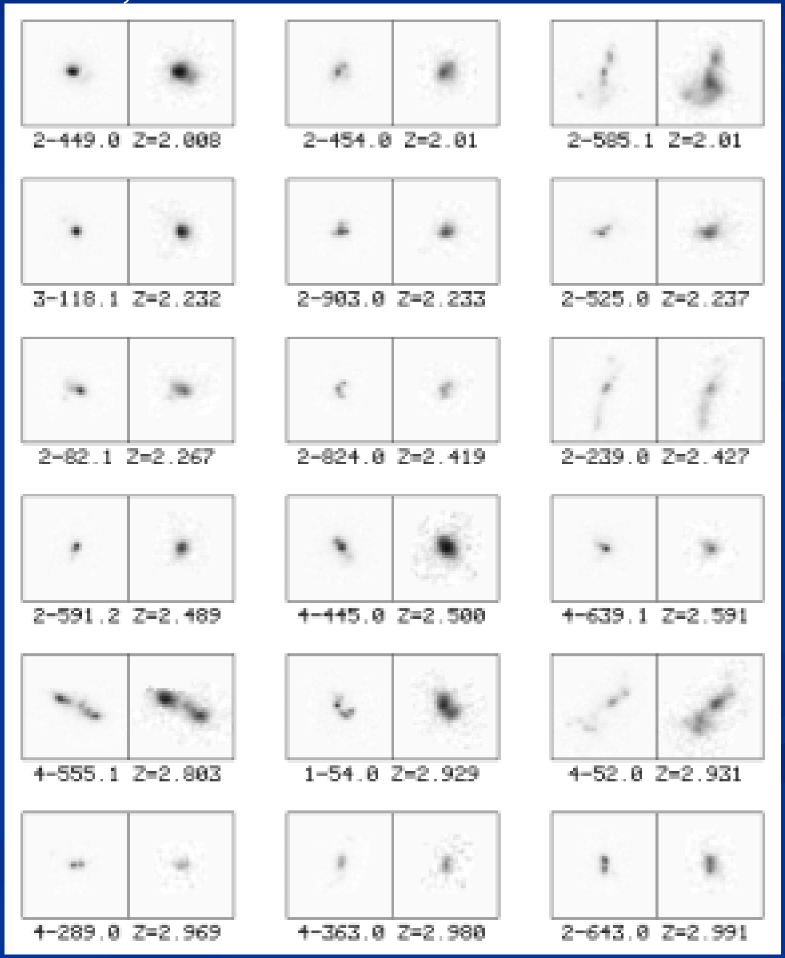


4 x4 arcsec^2 squares

Dickinson (2000), HDF-N

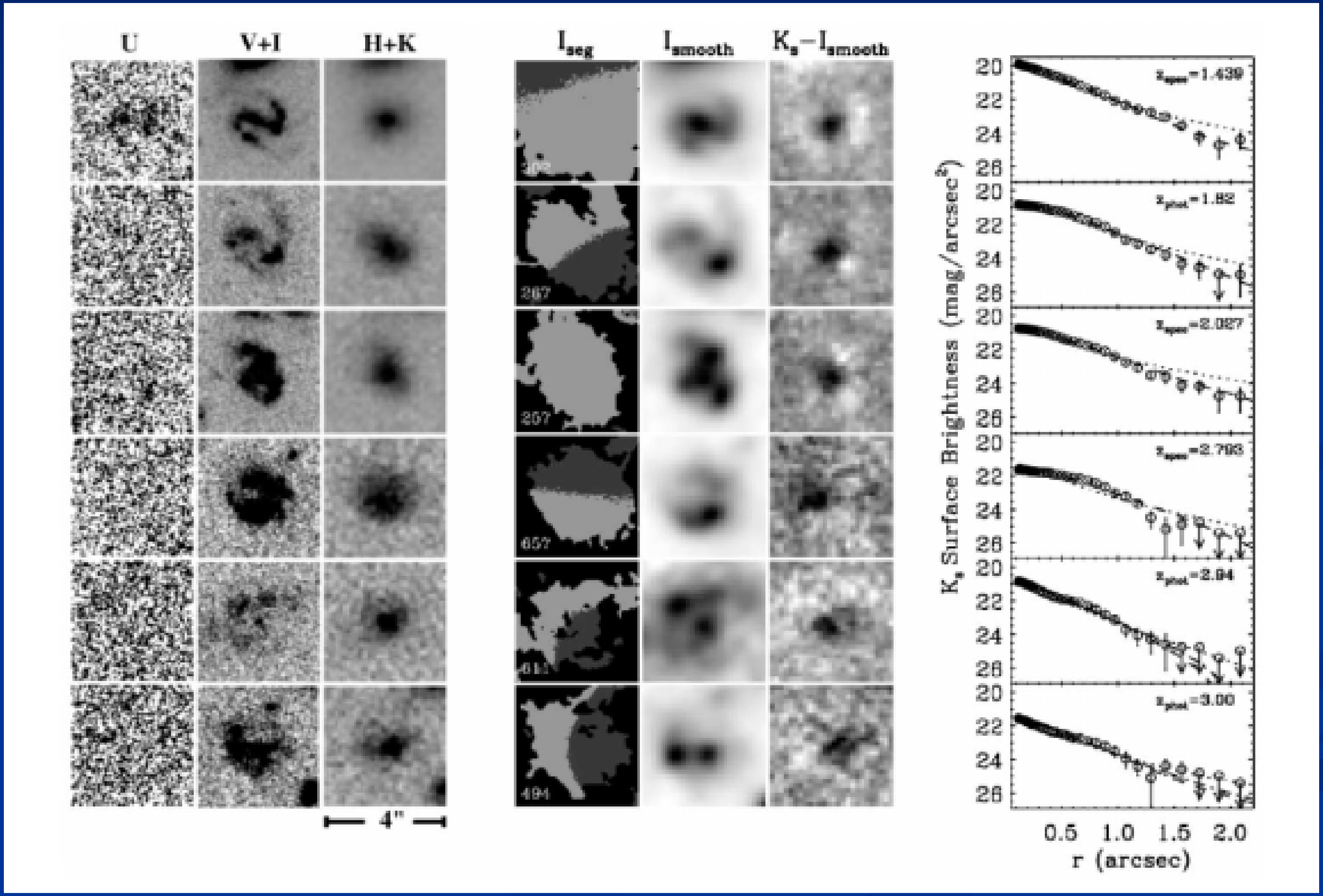
z ~ 2-3 (10~11Gyr ago) LBGs

λ rest=1700 Å, 4300 Å



# Large Disk Galaxies at 1.4<z<3

WFPC2(HST) + ISAAC (VLT) 102hr JHK imaging in HDFS

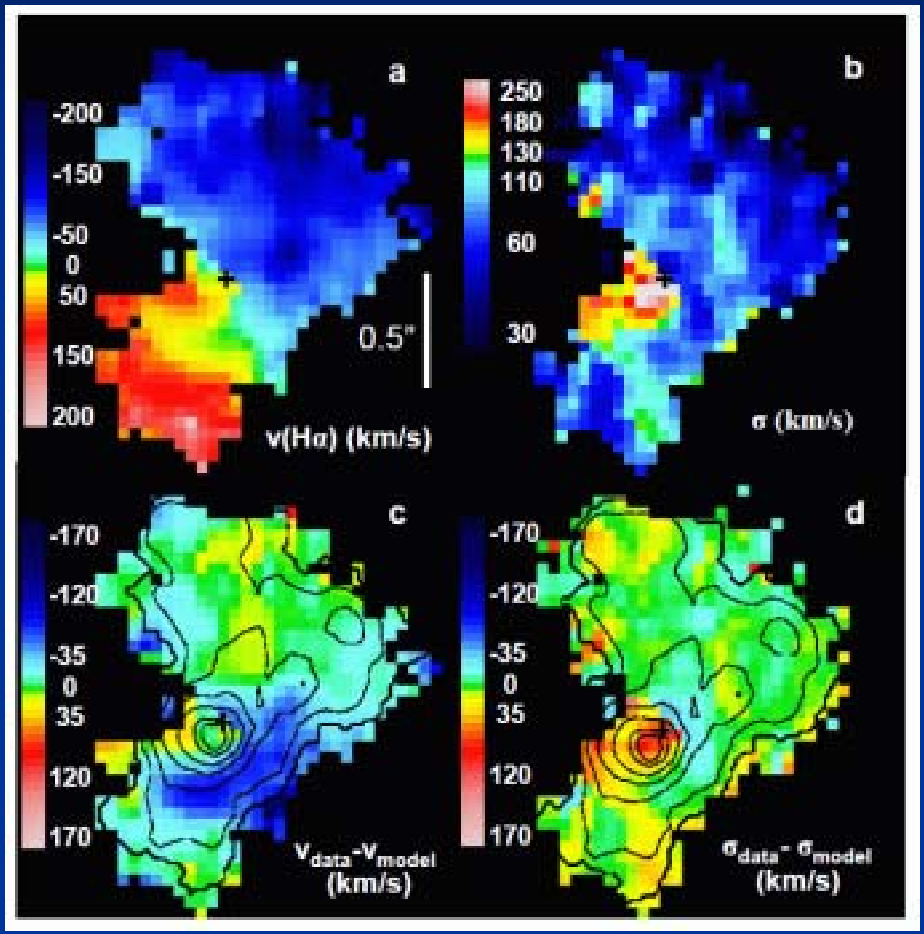


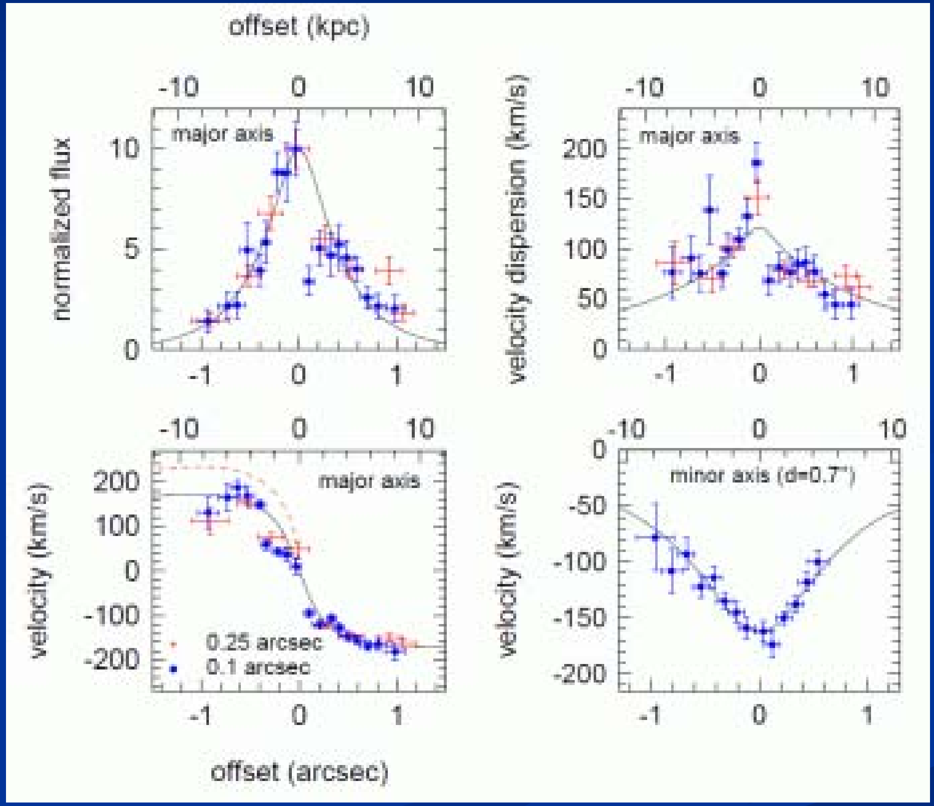

Re ～ 5--7.5 kpc !

Labbe et al. (2003)

# Rotation of a distant disk galaxy

IFU(SINFONI, VLT) + AO → 0.15” resolution (~1.2kpc@z=2.38)




z=2.38, Ks=19.2, Mdyn=1.13*10^11Msun (Vc=230km/s),

M*=7.7*10^10Msun, Re=4.5kpc , Mgas(Ha)=4.3*10^10Msun

**Genzel et al. (2006, Nature)** **See also Foerster-Schreiber et al. (2006)**

# Rotation of distant disk galaxies

IFU(SINFONI, VLT), 0.5” seeing (~4kpc@z=2)

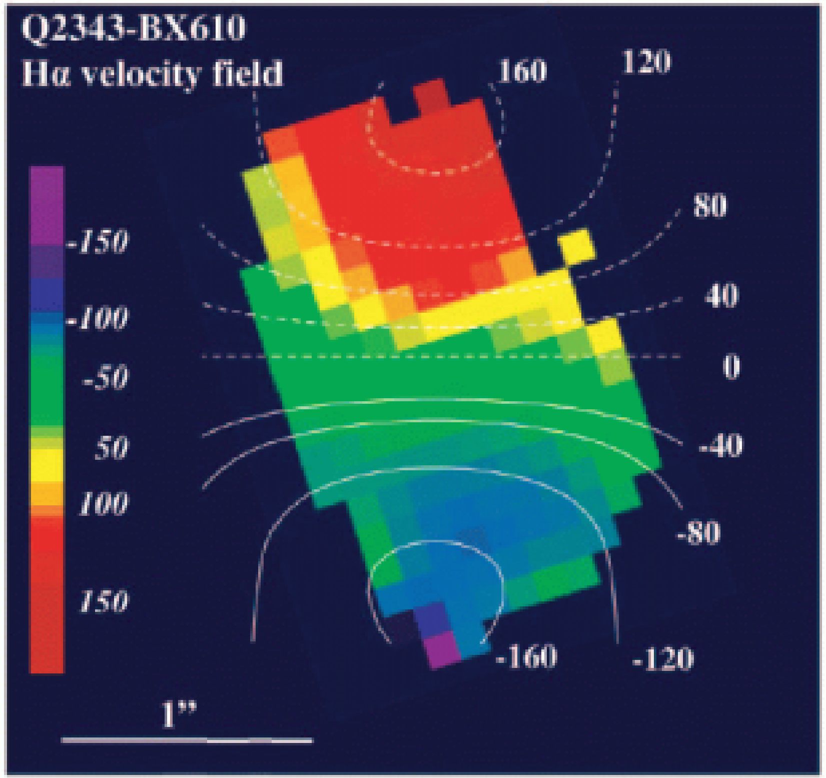
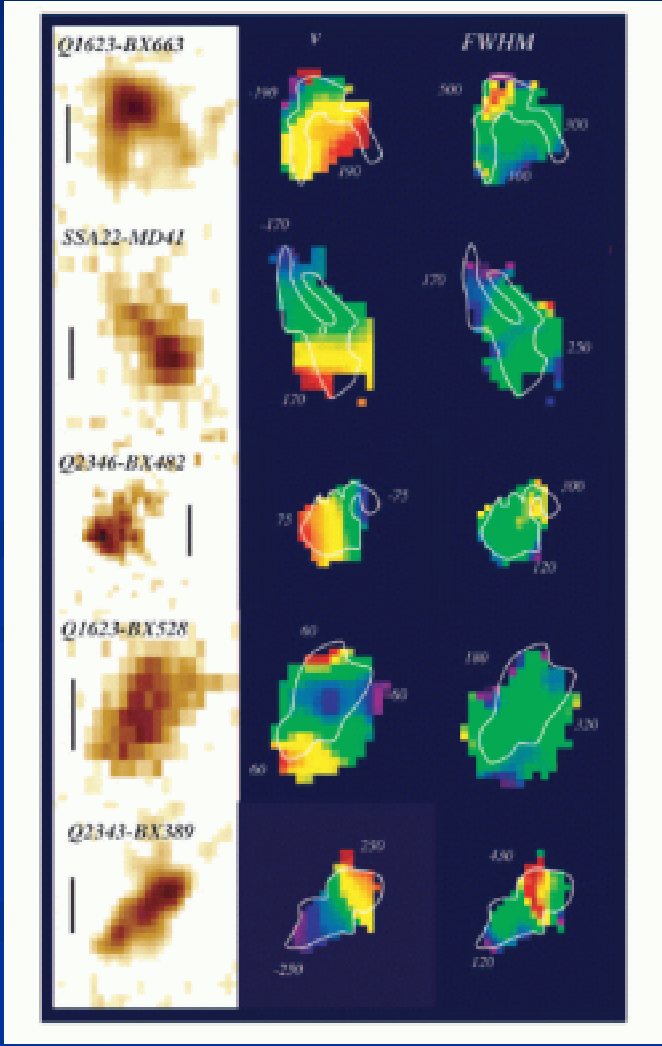



FIG. 5.— Two-dimensional Hα velocity field of Q2343-BX610. The velocity field derived from the observed Hα line emission is shown in colors, with a linear scaling increasing from purple to red. The superposed contours show the iso-velocity map from the best-fit rotating disk model, labeled with values relative to the systemic velocity in units of km $s^{-1}$ (see § 4.3).




**Foerster-Schreiber et al. (2006)**

## *"Fast Formation of Massive Galaxies"*

in all aspects:

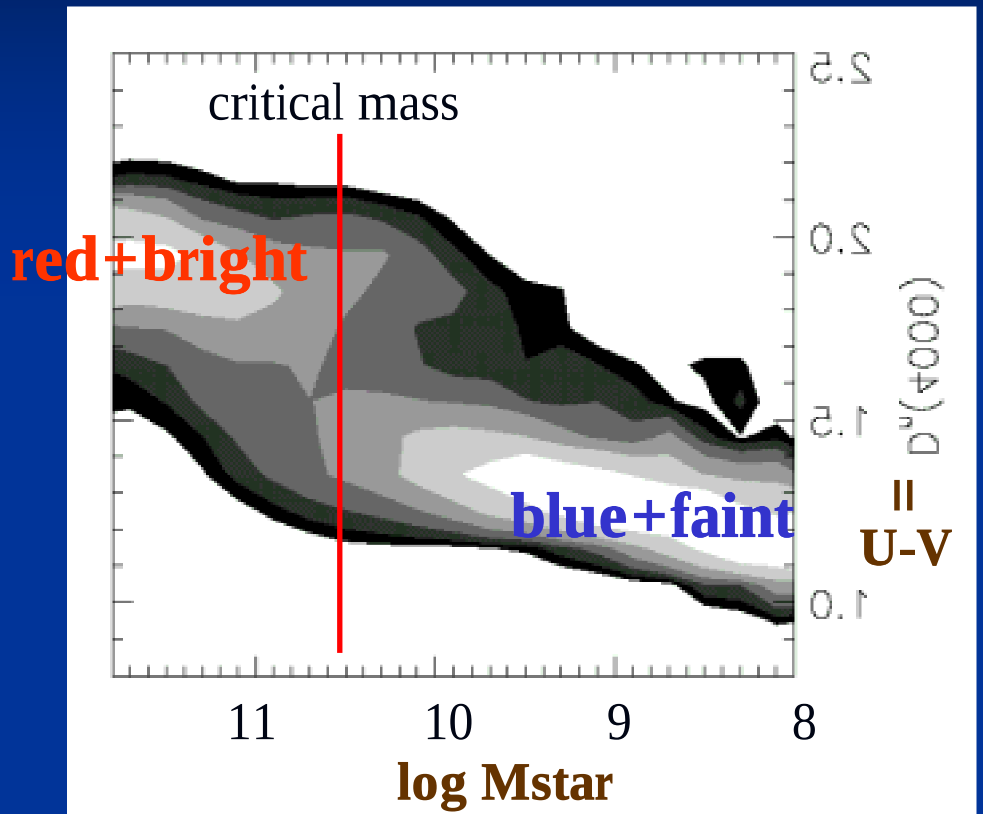
Star formation, Mass assembly, and Morphology.

- **What is the origin of down-sizing?**

  Is it consistent with the bottom-up picture ?

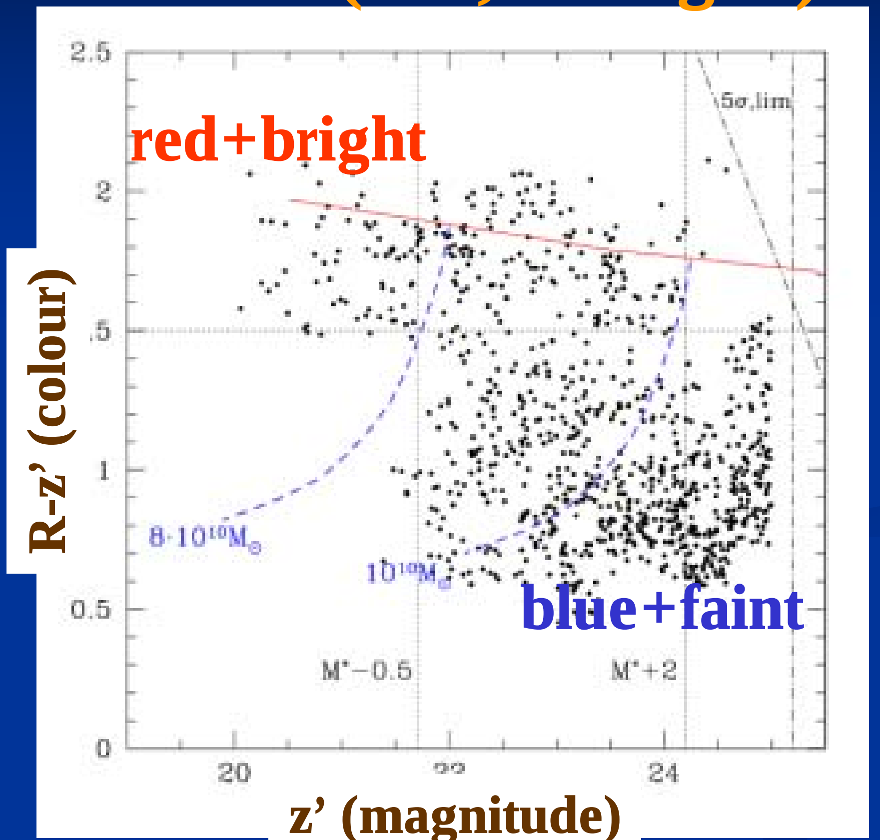
# Down-Sizing in Star Formation

**SDSS (z=0)**




Kauffmann et al. (2003)
see also Bell et al. (2004) for COMBO-17

**SXDS (z=1, 1.2deg^2)**

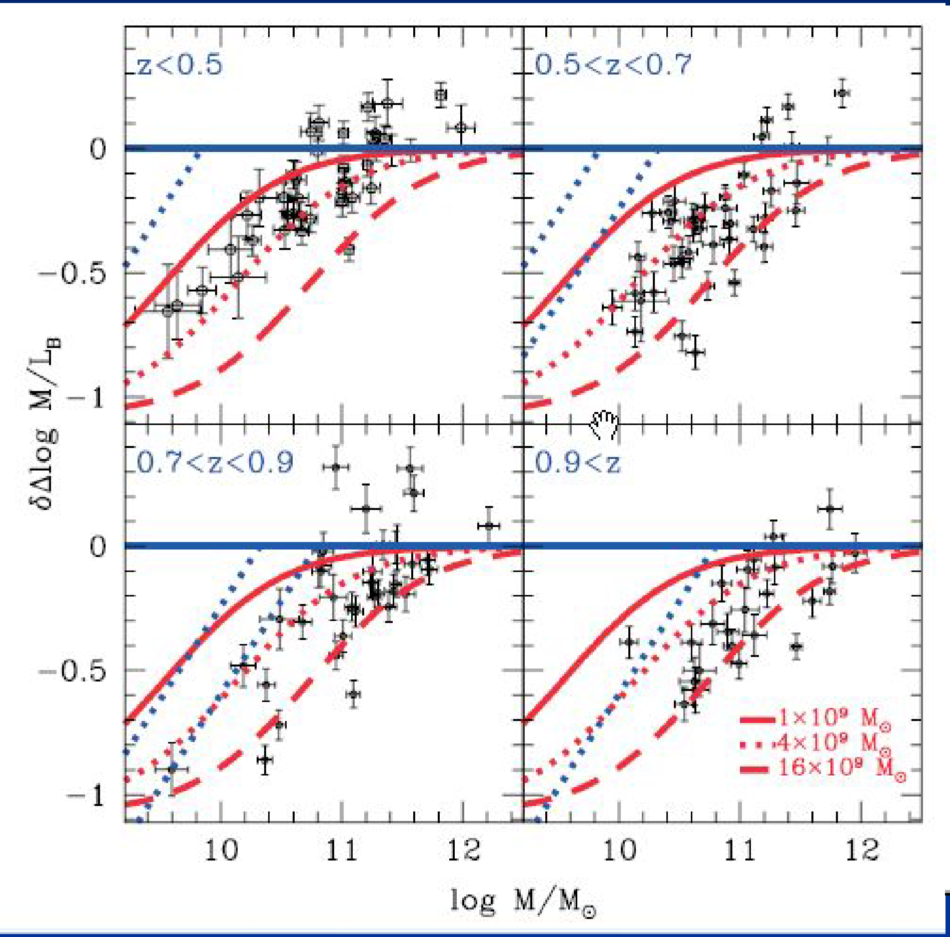



Kodama et al. (2004)
see also De Lucia et al. (2004) for EDisCS

Massive galaxies are old, while less massive galaxies are younger or have more extended star formation: → "**Down-sizing**"!

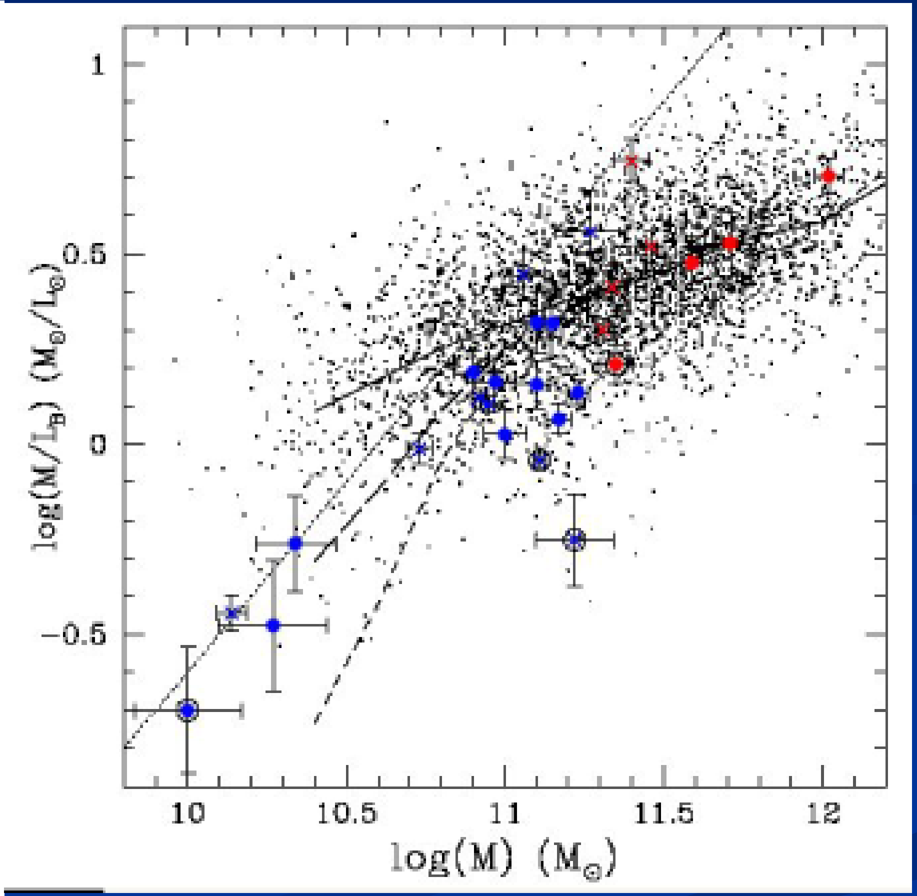
# Down-sizing seen in the FP to z~1

GOODS (141 field early-types)




Treu et al. (2005)

CDFS/1252 (27 field early-types)

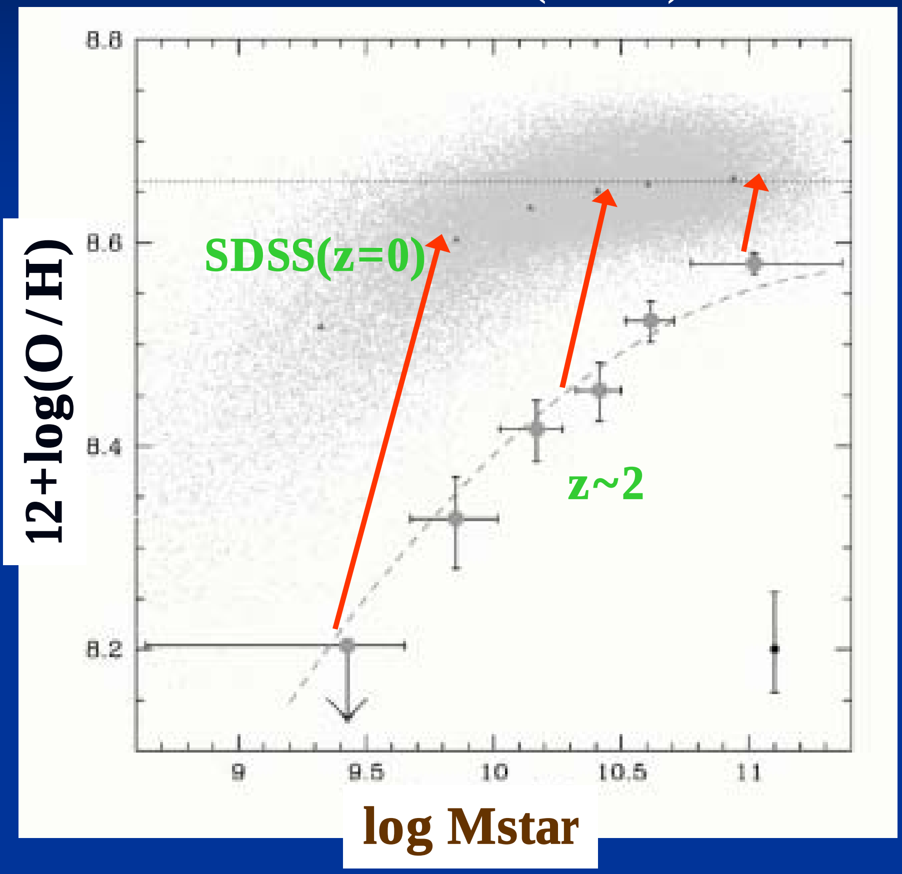



van der Wel et al. (2005)

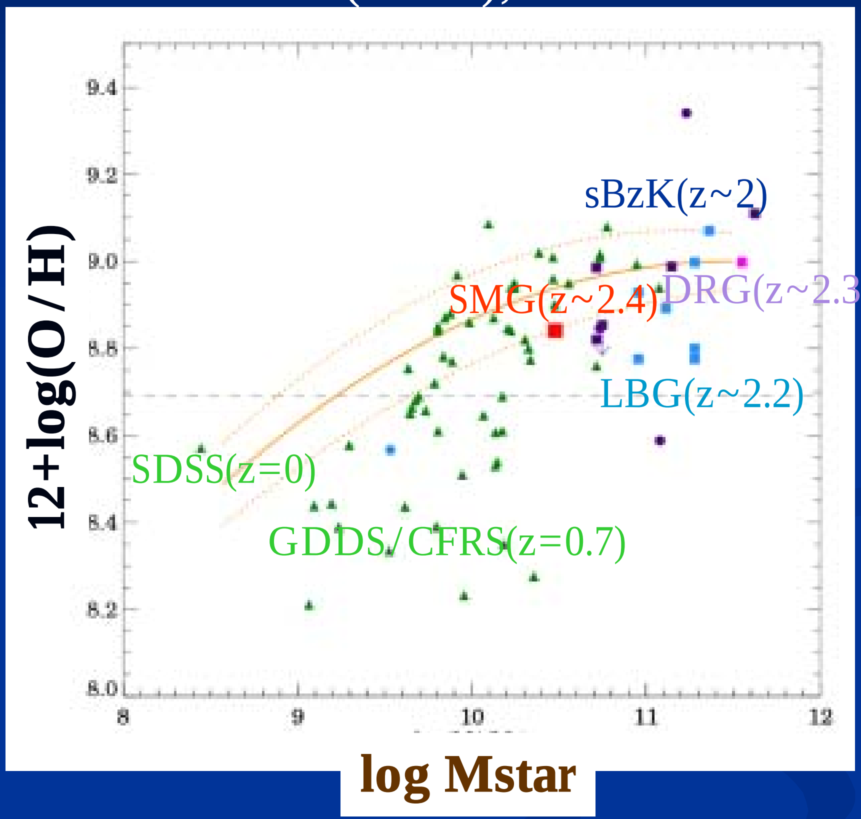
Less massive galaxies tend to have larger deviation in M/L ratio compared to local FP, suggesting their younger ages.

# Down-sizing seen in chemical evolution

Erb et al. (2006)




Onodera (2005), PhD thesis



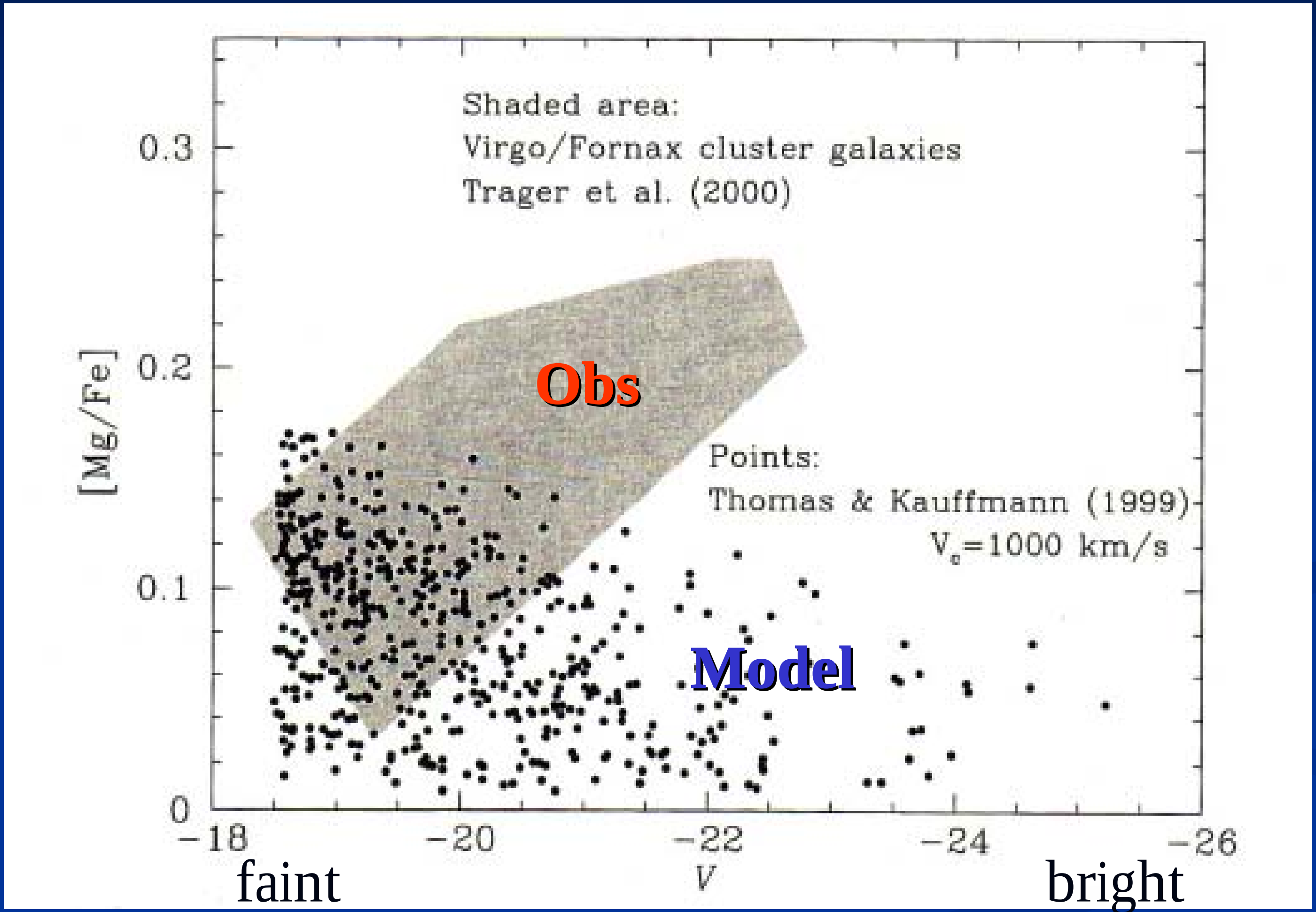

**[NII]/Hα → (O/H)**

Chemical Evolution

↕

Star Formation History

# Down-sizing seen in Mg/Fe ratio




Lower Mg/Fe ratio towards smaller ellipticals suggesting longer timescale of star formation.

Thomas (2001) Ap&SS, 277, 209

# Down-sizing in star formation as a function of Time

**8,000 galaxies at 0.4<z<1.4 from DEEP2 Redshift Survey**

**0.40<z<0.70**

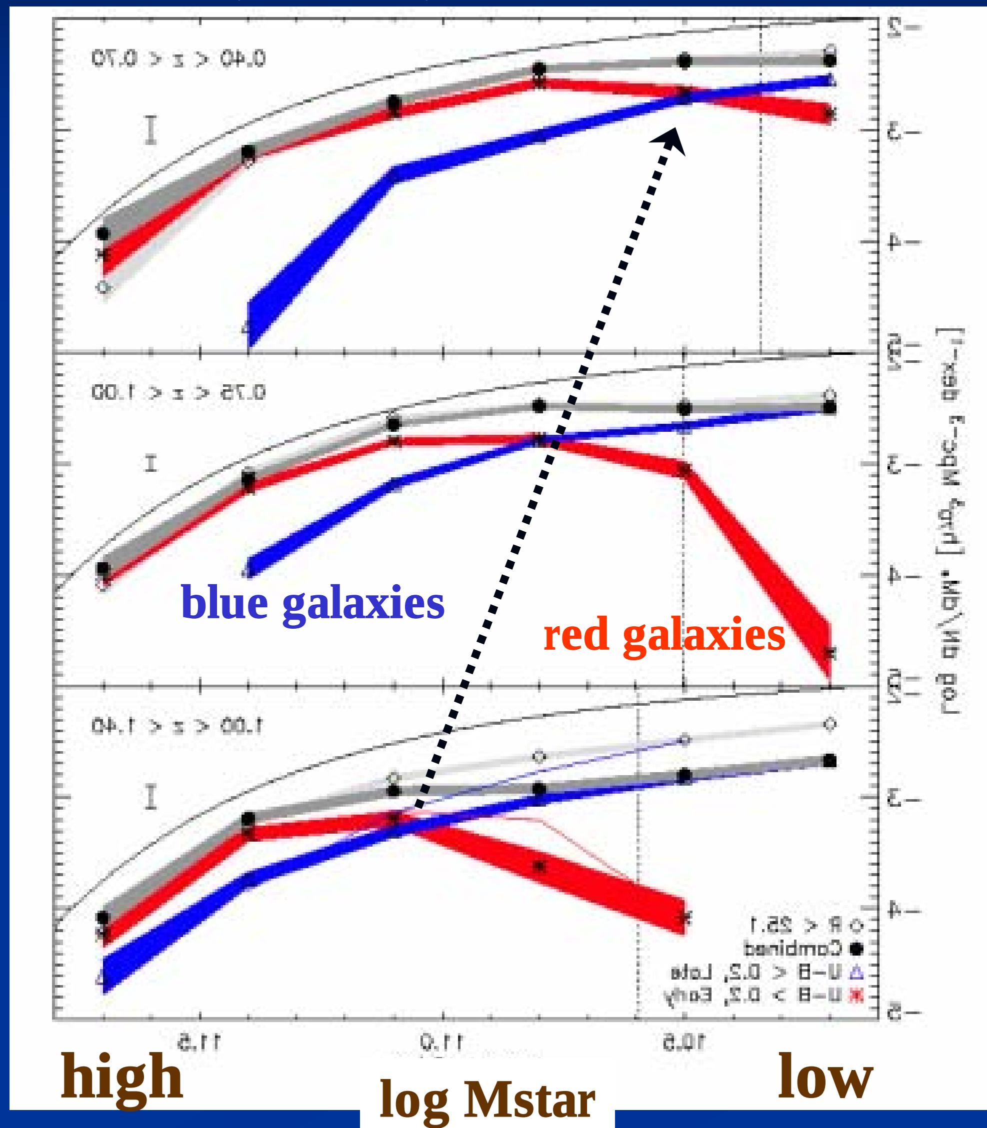
**4.3<t(Gyr)<6.3**

**0.75<z<1.00**

**6.5<t(Gyr)<7.7**

**1.00<z<1.40**

**7.7<t(Gyr)<8.4**

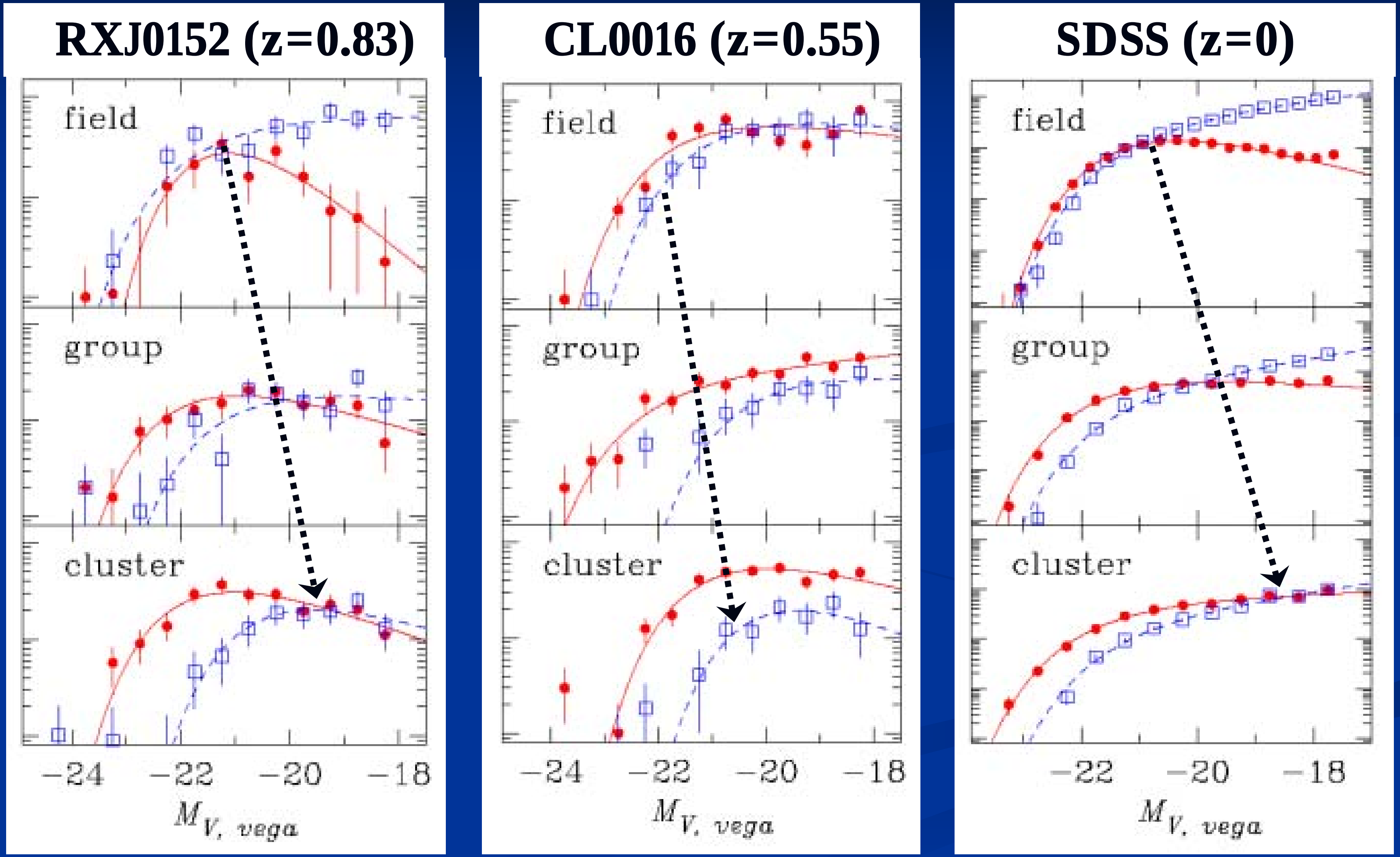



The critical mass that separate red/blue pops shifts to lower mass as time progresses!

**Bundy et al. (2006)**

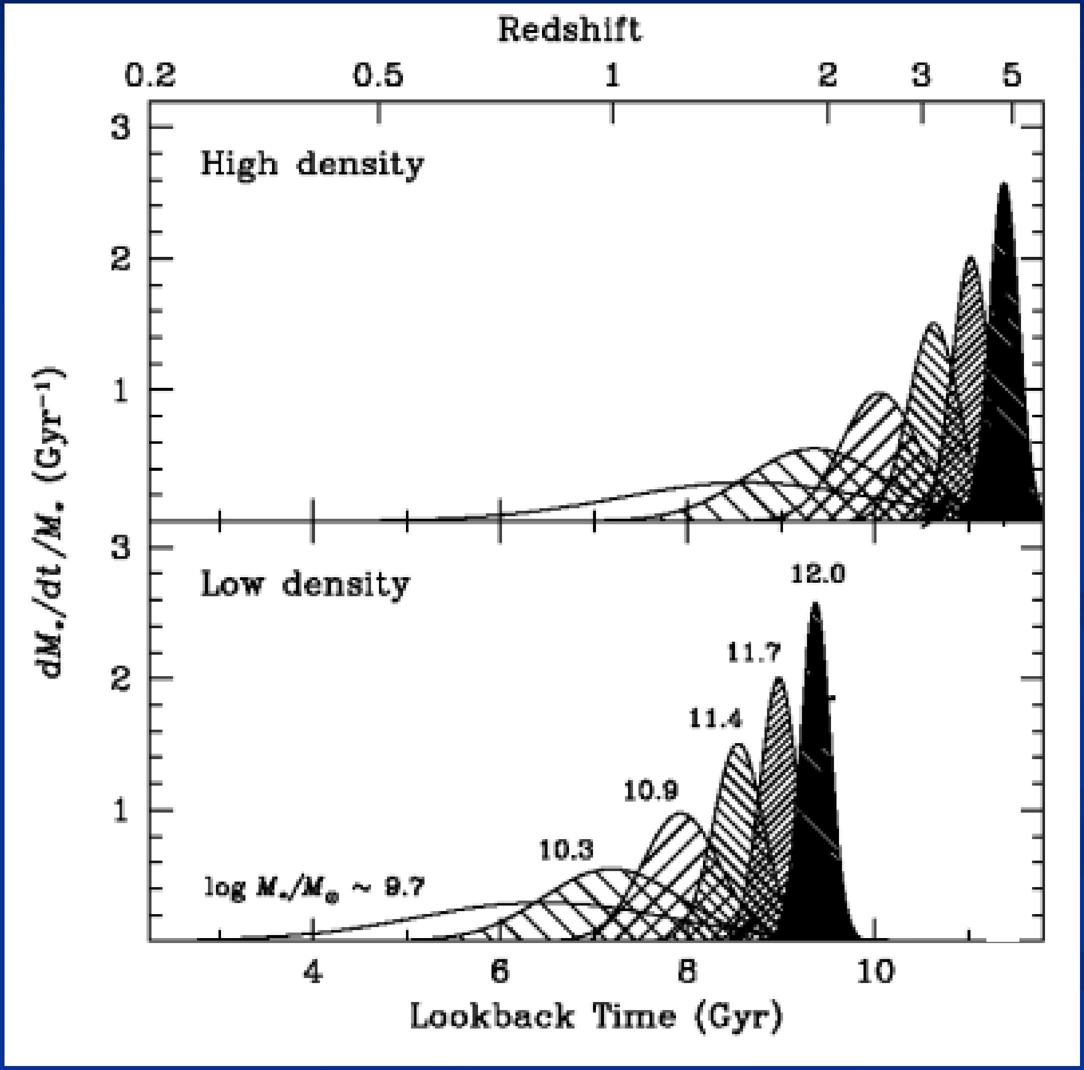
# Down-sizing as a function of Environment!

**red / blue galaxies**




Tanaka, TK, et al. (2005)

# Star Formation Histories of Galaxies vs. Mass and Environment



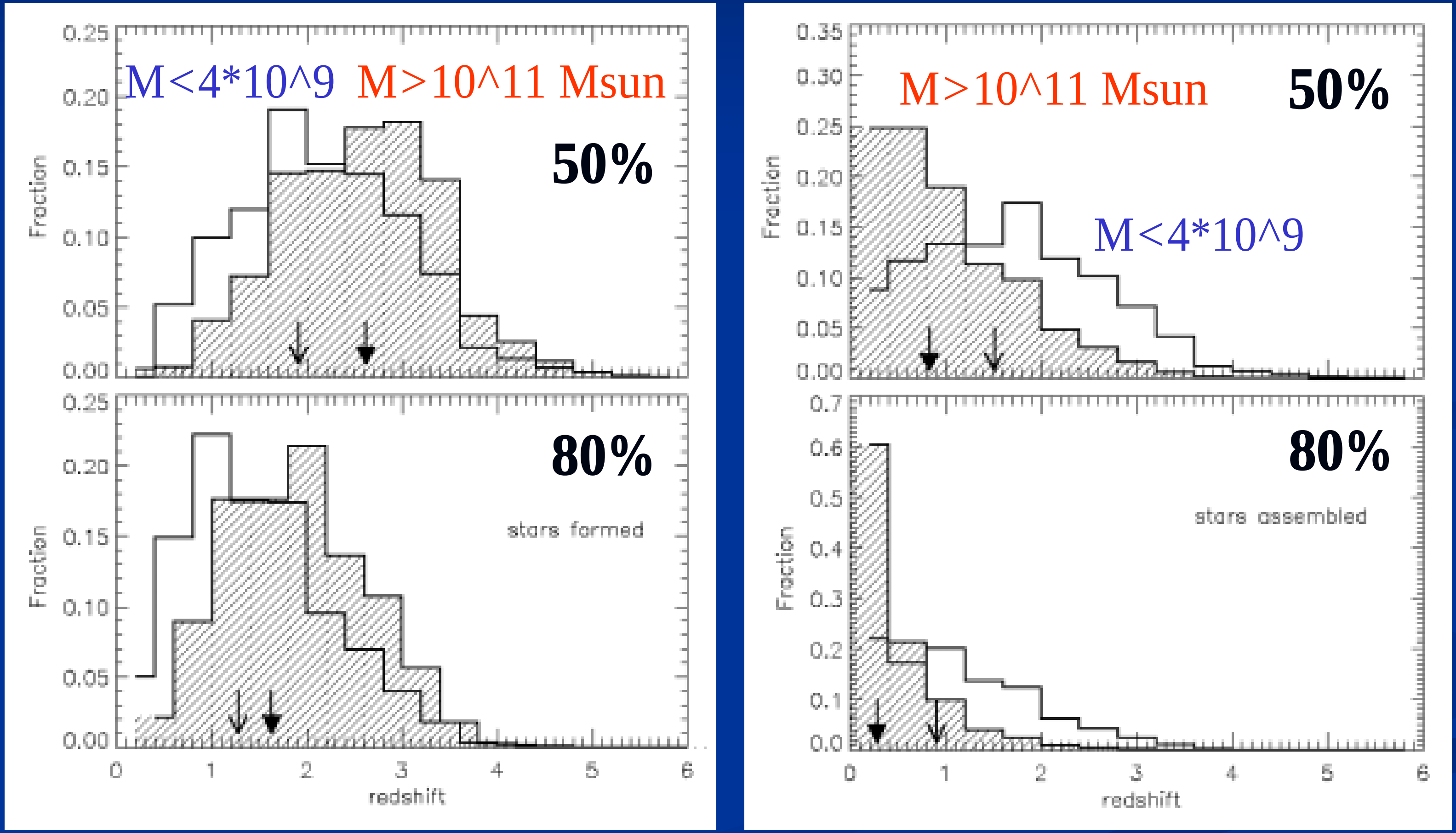

Thomas et al. (2005)

***high-mass/high-density → low-mass/low-density***

# Interpretation of Down-Sizing

Millennium simulation (N-body) + Munich semi-analytic model

**Star formation** | **Mass assembly**




**Massive (E) galaxies form stars earlier (intrinsic bias), but are assembled later than less massive galaxies.**

De Lucia et al. (2006)

# *“Slow/Delayed Formation of Low Mass Galaxies and in Low Density Regions”*

How can we extend star formation in such small systems where SN feedback can easily expel the gas?

Extremely low SF efficiency? Gas fall back? Interaction with host galaxies?

- **What is the sampling bias in high-z galaxies?**

What is the effects of dust ?

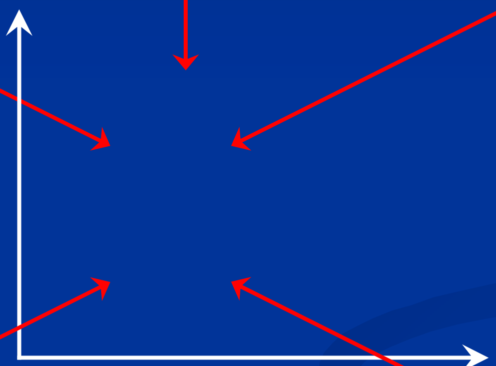
# *High-z Zoo*

**BzK**
**JHK**

**ERO**
**DRG**

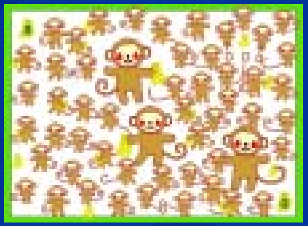
**SMG**

$$\mathrm{SSFR} = \frac{\mathrm{SFR}}{\mathrm{Mstar}}$$




**LAE**
**LAB**

**LBG**

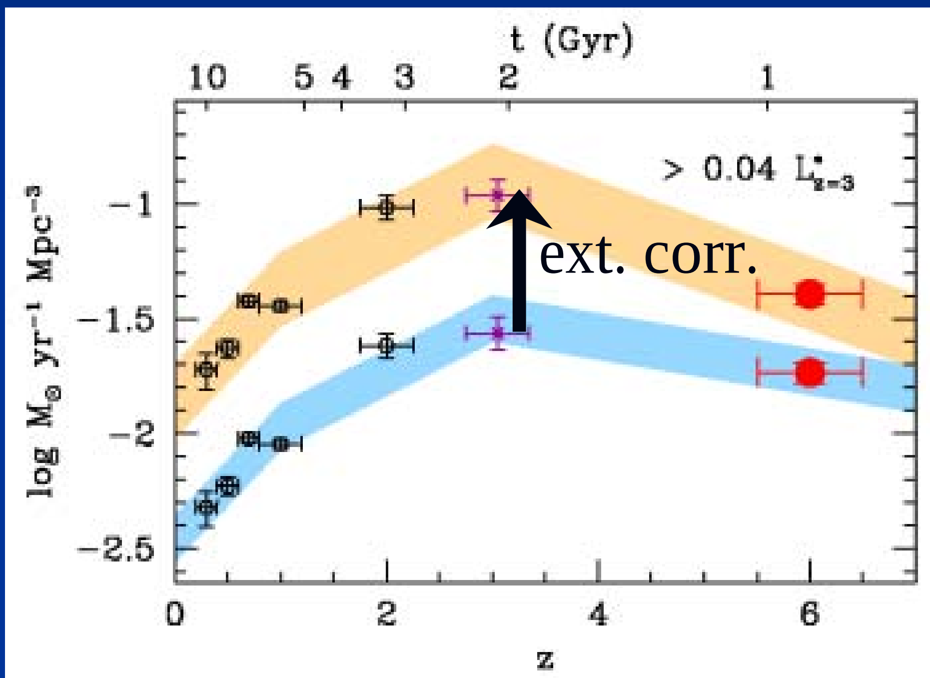


**Evolutionary state of each class of galaxies on a stellar-mass limited sample!**

SSFR ~ b (birth parameter) ~ f_gas (Schmidt law) = "evolutionary state"

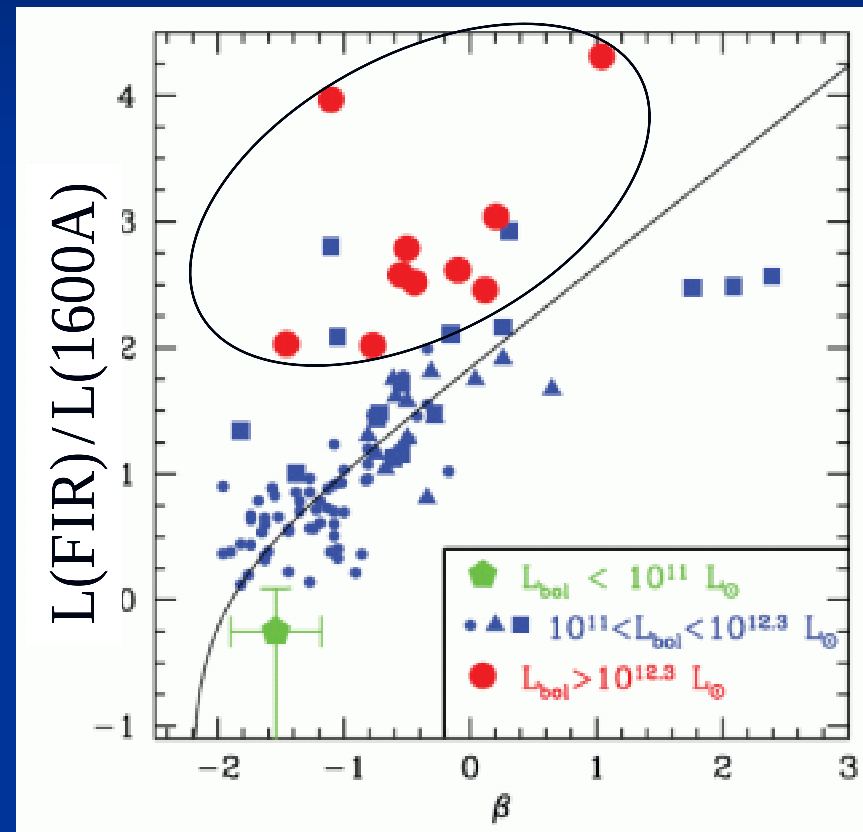
# Star formation is largely hidden in optical surveys!

Bouwens et al. (2005)




Uncertainty in cosmic star formation history is dominated by correction for dust extinction.

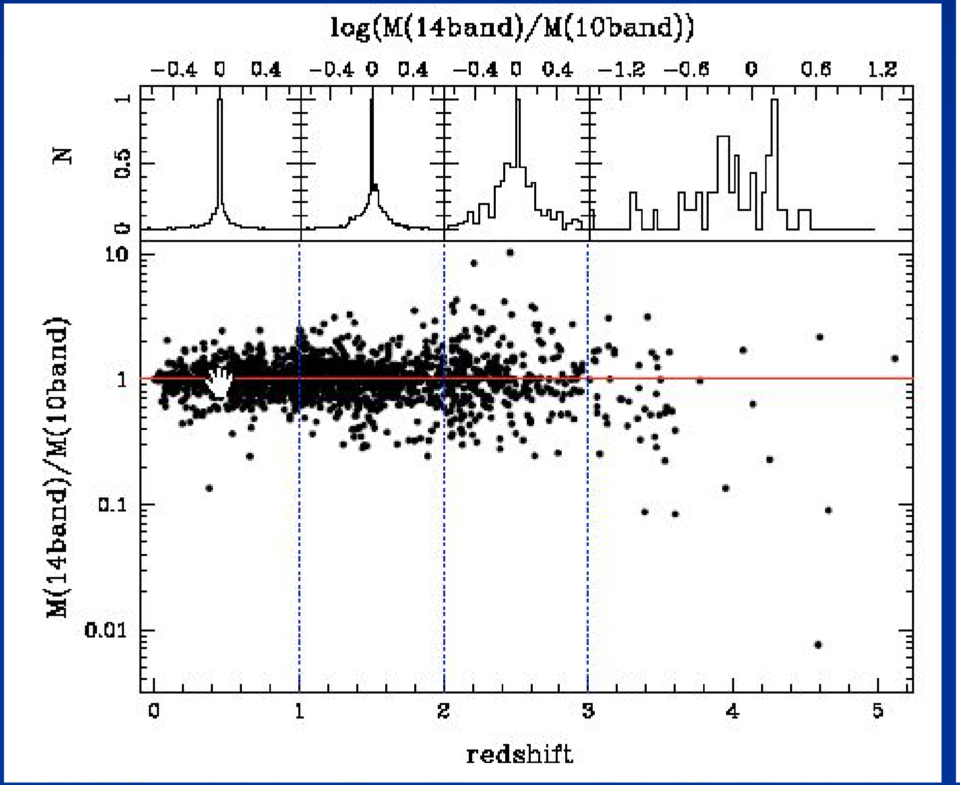
Reddy et al. (2006)

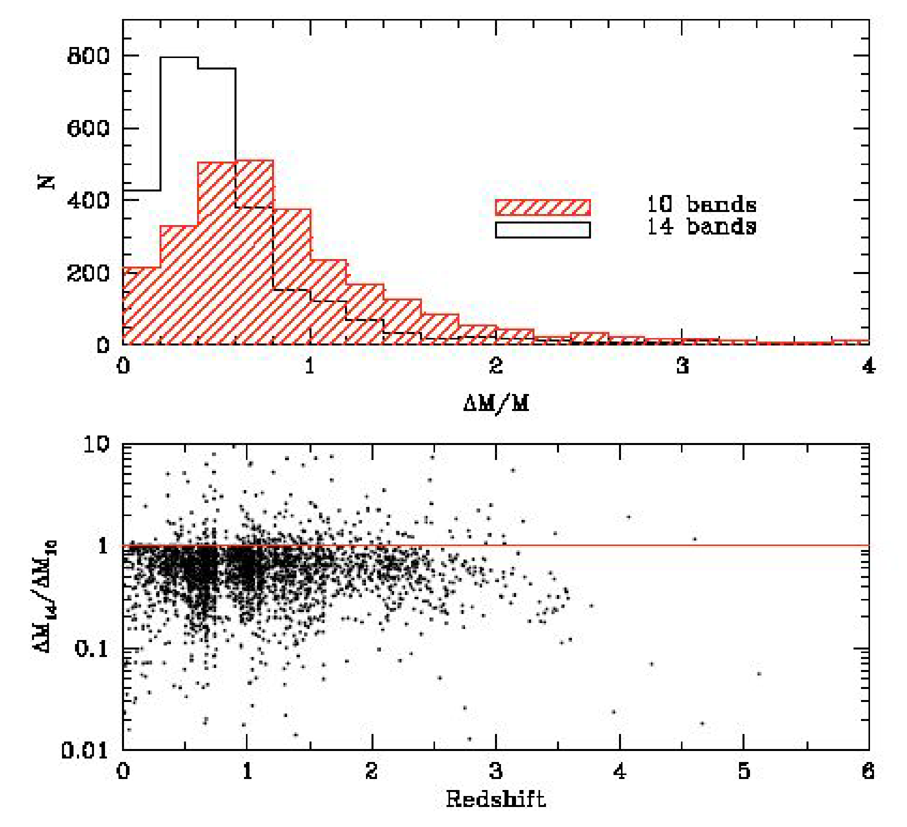



Even if you correct for extinction using UV spectral index, you still tend to under-estimate SFR for dusty galaxies.

# Improvement in estimates of stellar mass and photometric redshift with Spitzer bands

**M(with Spitzer) / M(without Spitzer)**

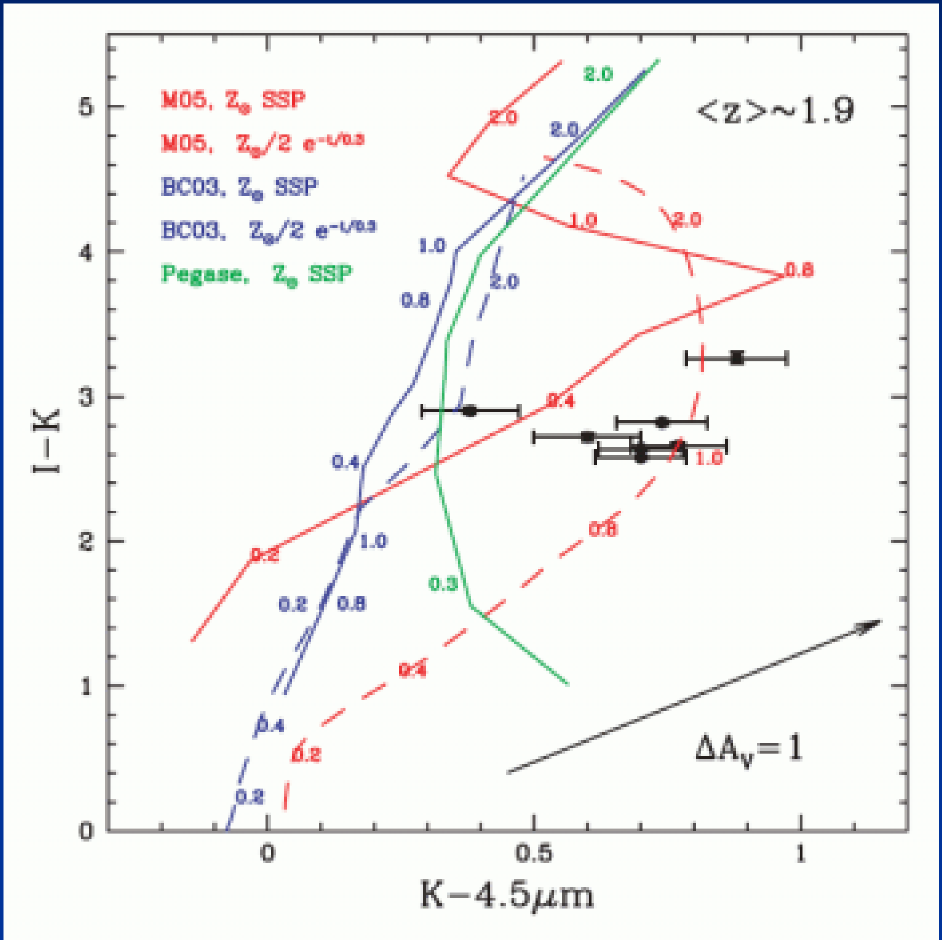


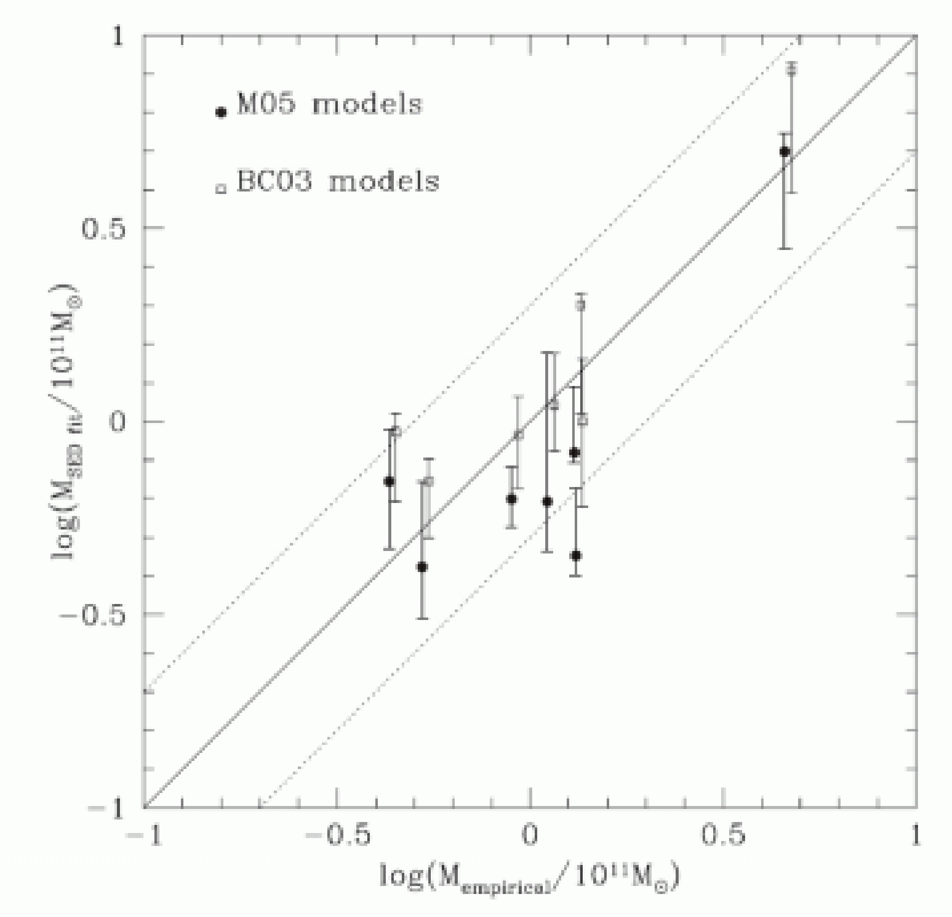




Fontana et al. (2006)

**Dramatic improvement in stellar mass estimates at z>2.**

# Model dependence in Mstars



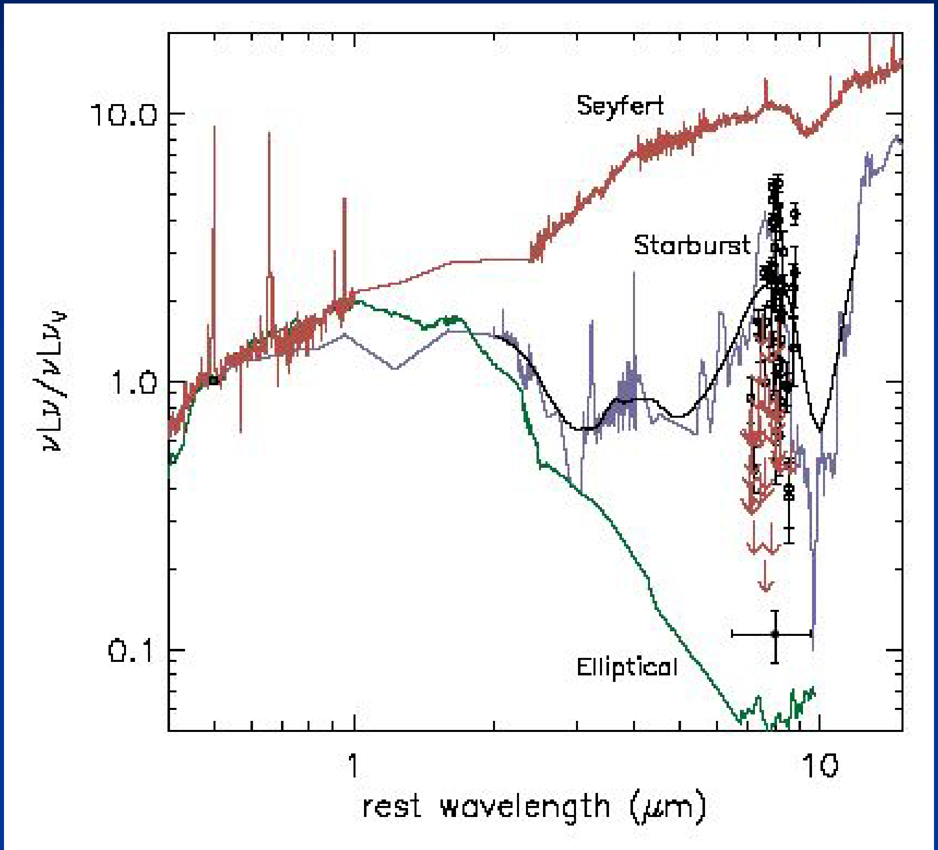

**TP-AGBs have significant contribution at rest-frame NIR at ~1Gyr.**

**Maraston et al. (2006)**

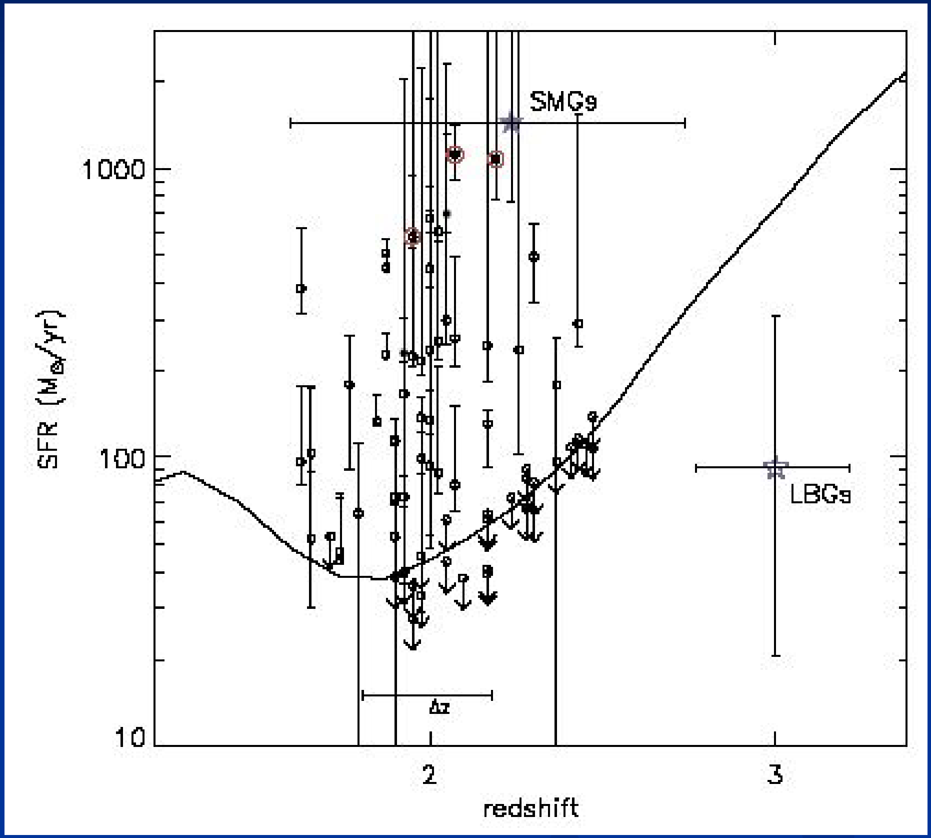
**BC03 model overestimates stellar mass by factor 1.6 compared to M05.**

**→ CB07 models have now included TP-AGB.**

# 24 micron flux measures dusty SFR at z~2




SFR of 69 MIPS detected DRGs



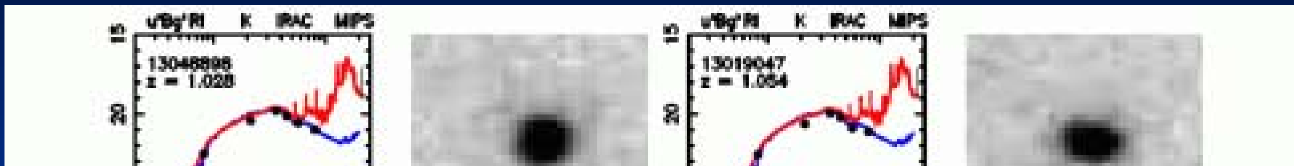

Webb et al. (2006)

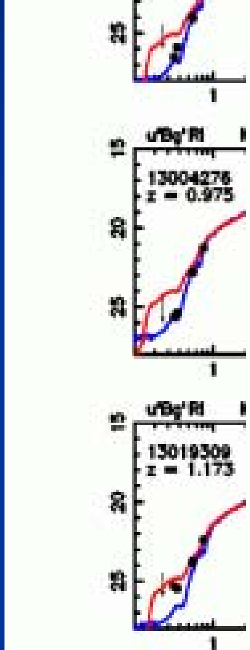
24μm samples PAH dust features (6.2-8.6um) from z~2 galaxies, which are good measures of dusty star formation rate (Chary & Elbaz 2001).

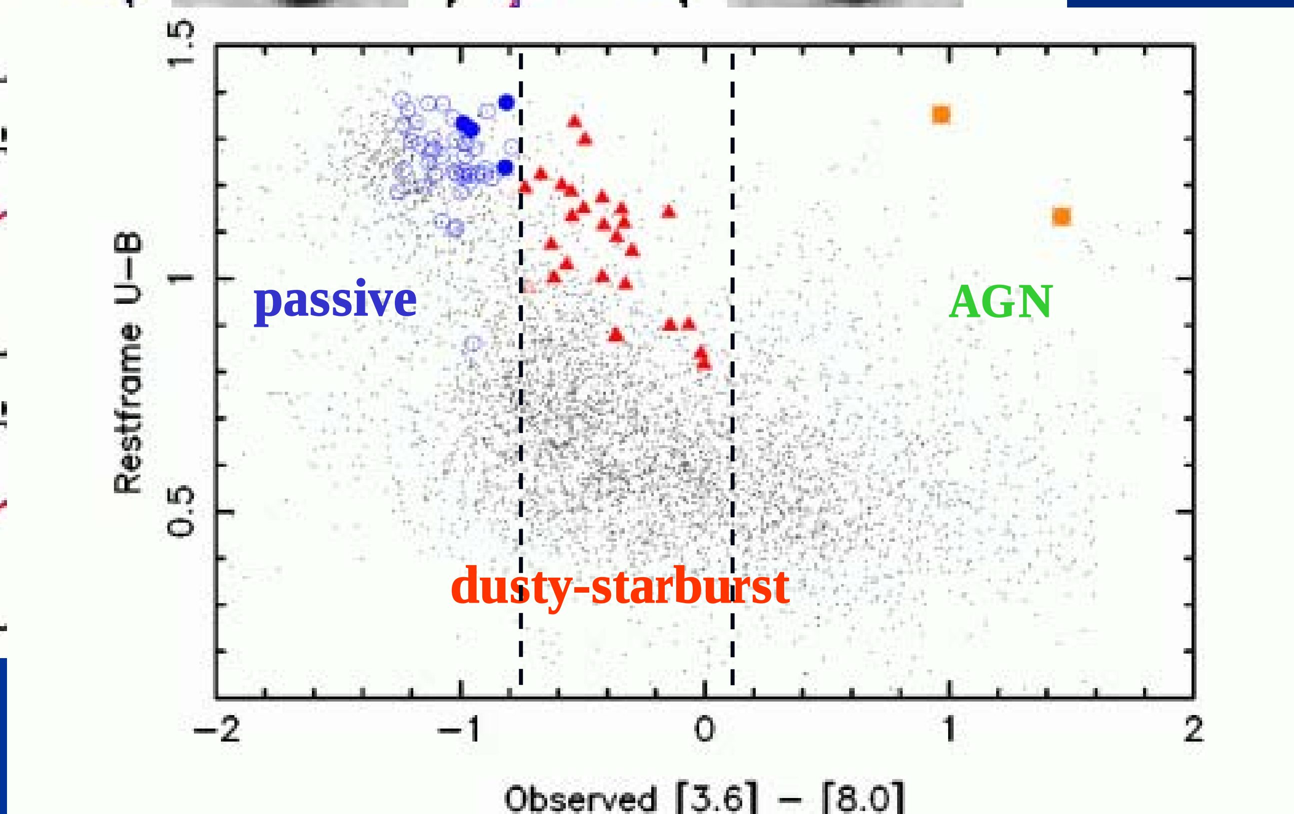
SFR=30~1000 Msun/yr (average 130Msun/yr). DRG contribute 20% of SFRD at z~2.

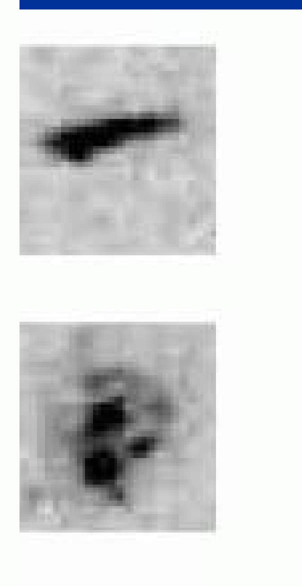
# Discrimination between Passive / Dusty / AGN

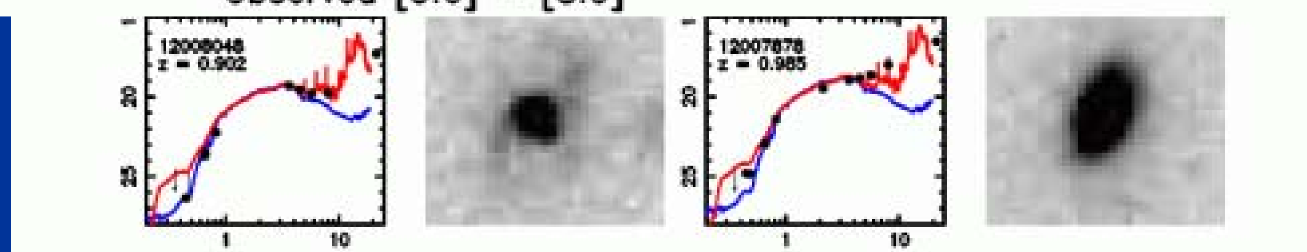
Wilson et al. (2006)



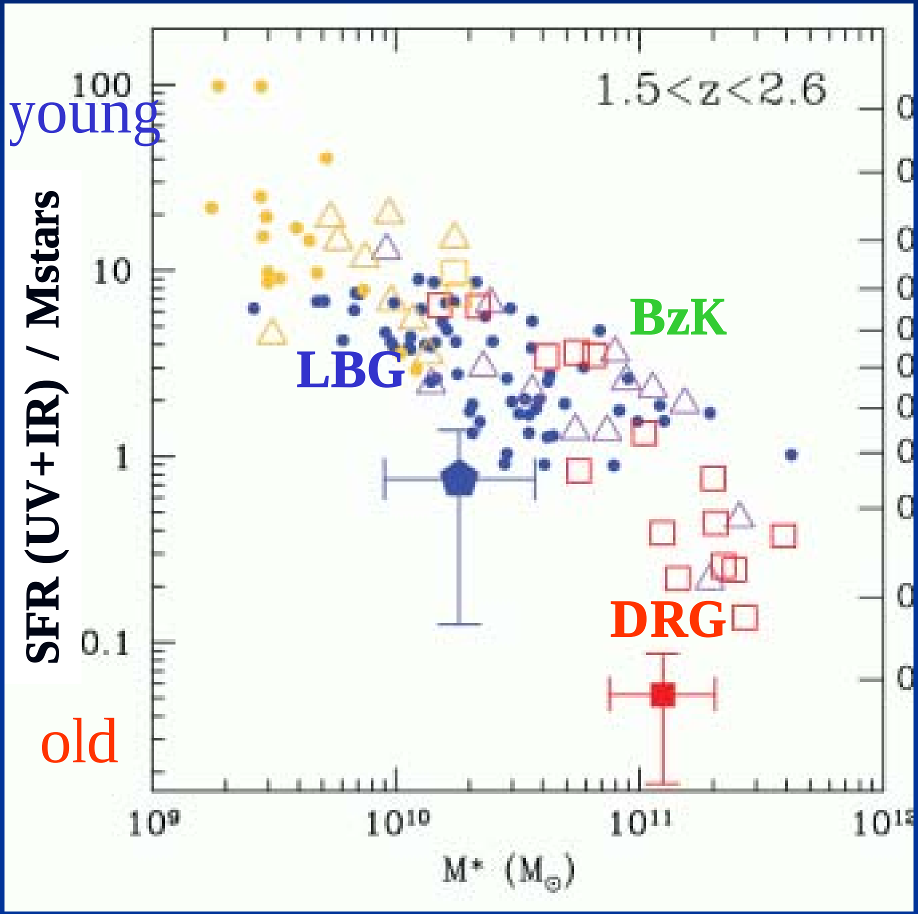



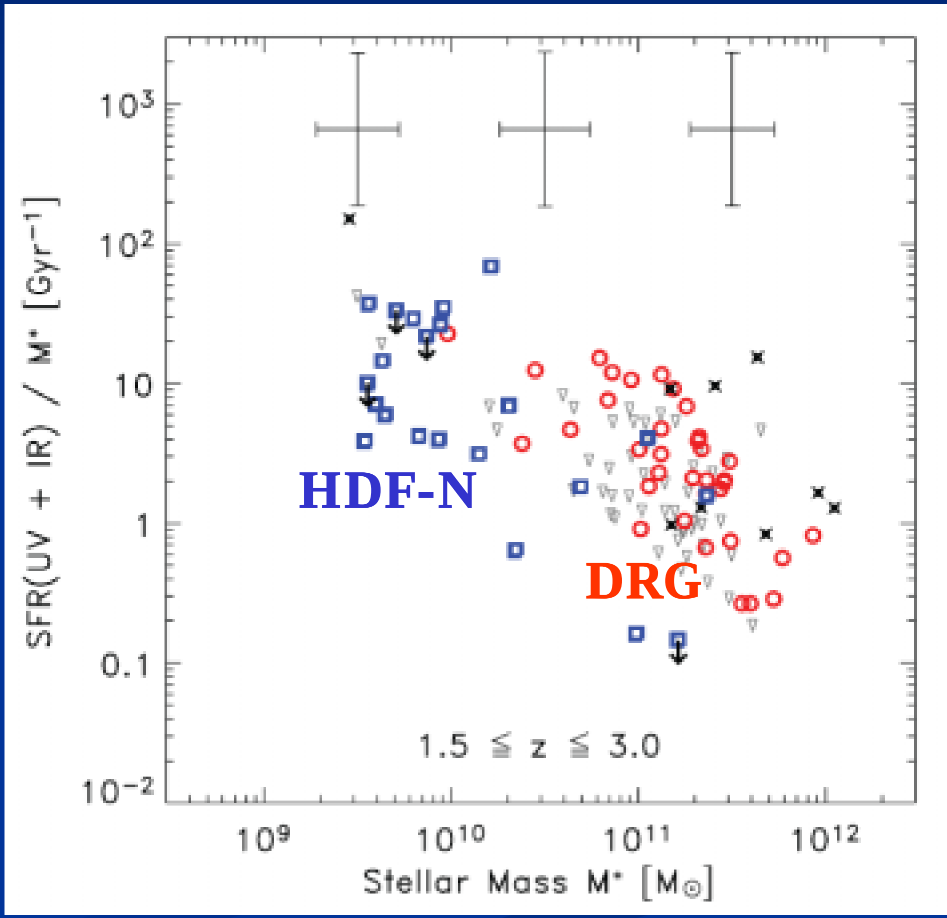



see also Stern+ (05), and Webb+ (06)

# Ultimate diagram to quantify galaxy evolution SSFR=SFR/M* versus M*



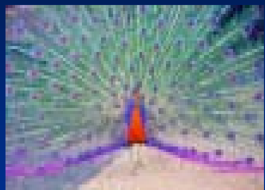

**Reddy et al. (2006)**




**Papovich et al. (2006)**

See also Erb et al. (2006) for H α based SSFR vs M*.

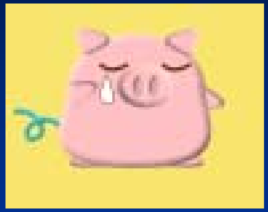
# ～ From “zoo” to “science museum” ～



**LAE**
**LAB**

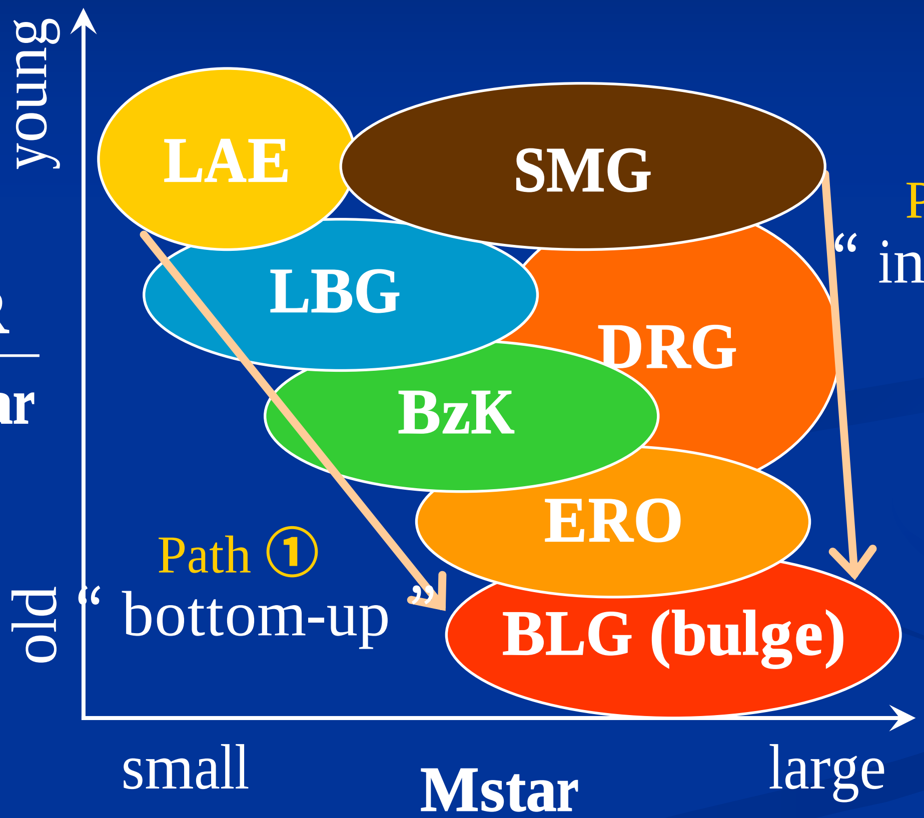
めだち系

**SMG**



きたな系

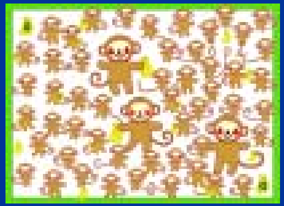
$$\mathrm{SSFR} = \frac{\mathrm{SFR}}{\mathrm{Mstar}}$$




**BzK**
**JHK**

ふてい系

うるさ系



**LBG**

いやし系

**ERO**
**DRG**