Evolution of the stellar mass function of galaxies to z~3 in MOIRCS Deep Survey

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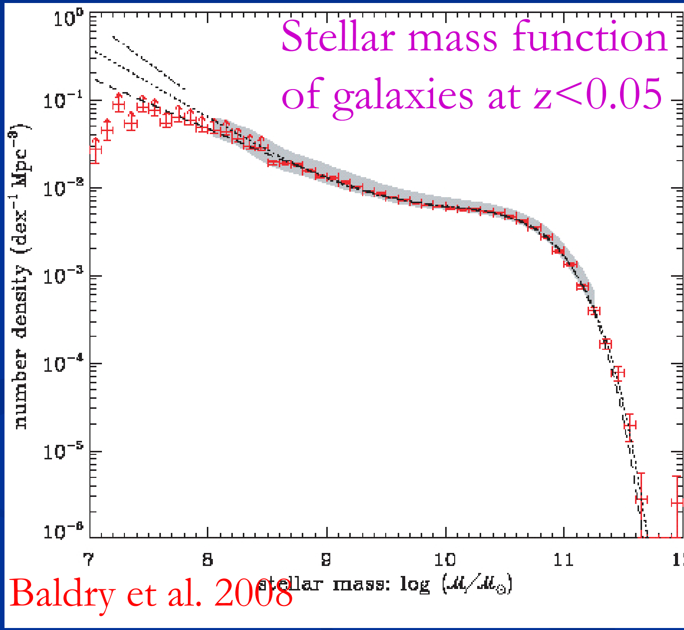
This talk

- MOIRCS Deep Survey (MODS)

Deep NIR imaging survey with Subaru and MOIRCS in the GOODS-North region.

  - Search for z>7 galaxies
  - **<u>Evolution of stellar mass function</u>**
  - Evolution of clustering properties
  - Star formation/AGN and stellar mass



- Evolution of stellar mass function

✓ Evolution of integrated stellar mass density
→ when stars formed

✓ **<u>Evolution of stellar mass function</u>**

➡ How stellar mass assembly of galaxies proceeded in different mass ranges.

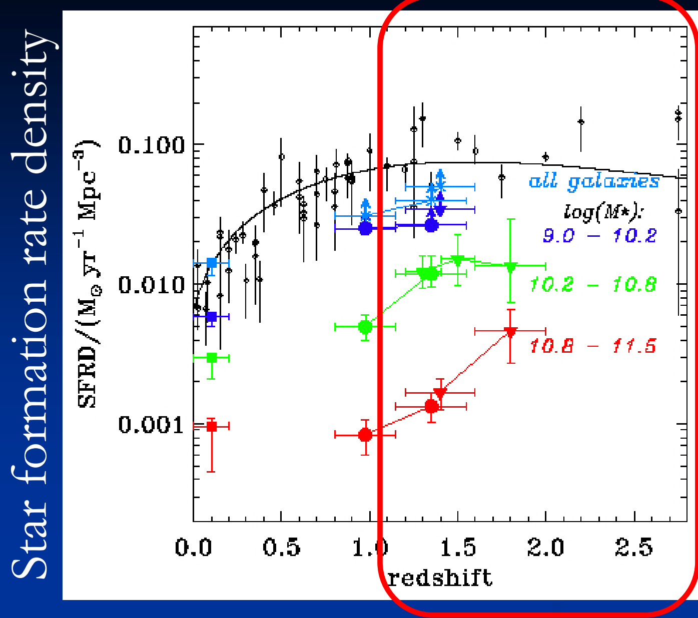
<u>We used MOIRCS Deep Survey data to investigate the evolution of the stellar mass function over the wide range of mass back to z~3.</u>

z=1~3: Important era

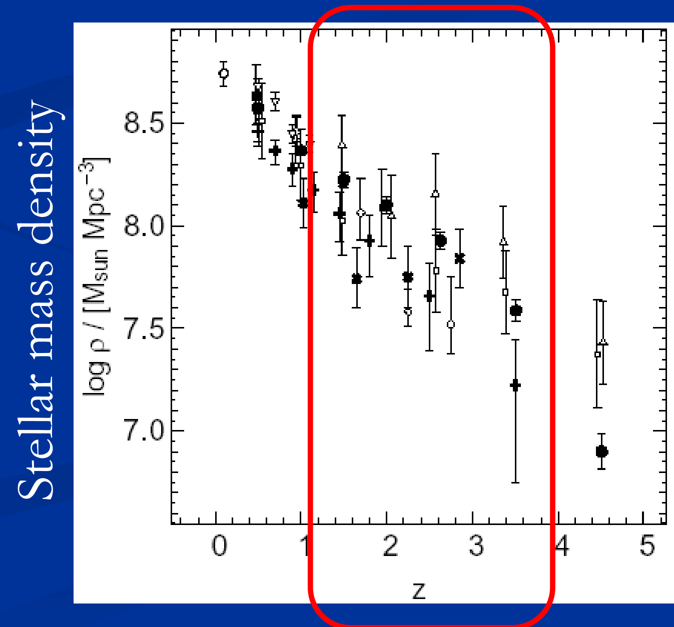
- Peak of star formation/AGN activities
- Active star formation in massive galaxies
- Strong evolution of stellar mass density
- Formation of Hubble sequence

Very important epoch in the histories of star formation and mass assembly of galaxies

How galaxies formed and evolved?



Juneau et al. 2005



Elsner et al. 2007

Importance of NIR data

✓z~1-2

Rest-NIR luminosity

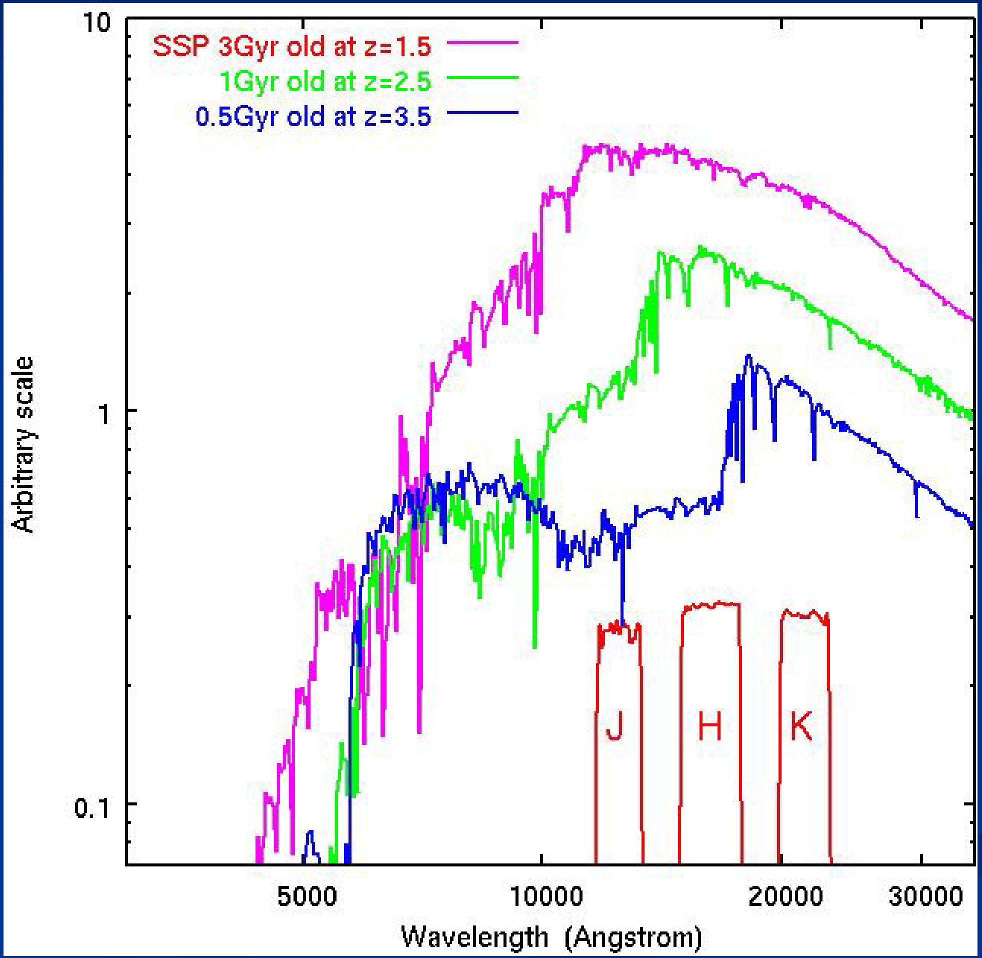
➡ Stellar Mass

✓z~2-4

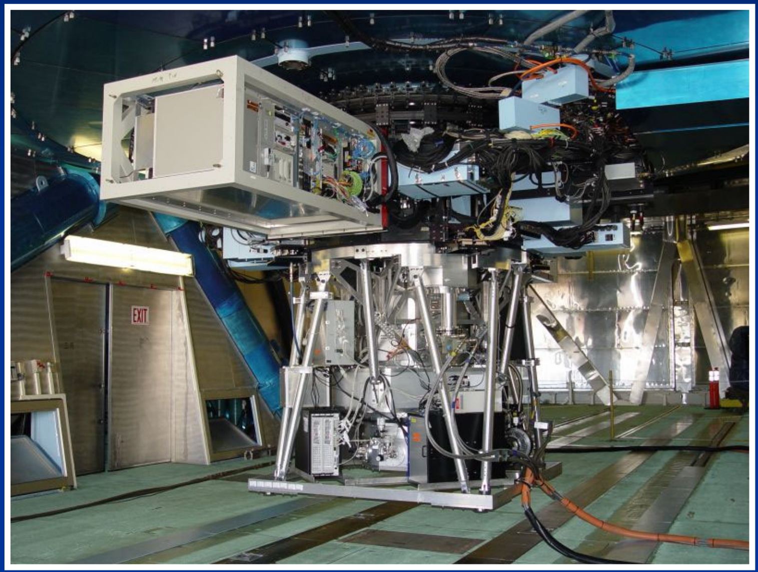
Balmer/4000 Å break

➡ Stellar age
M/L ratio

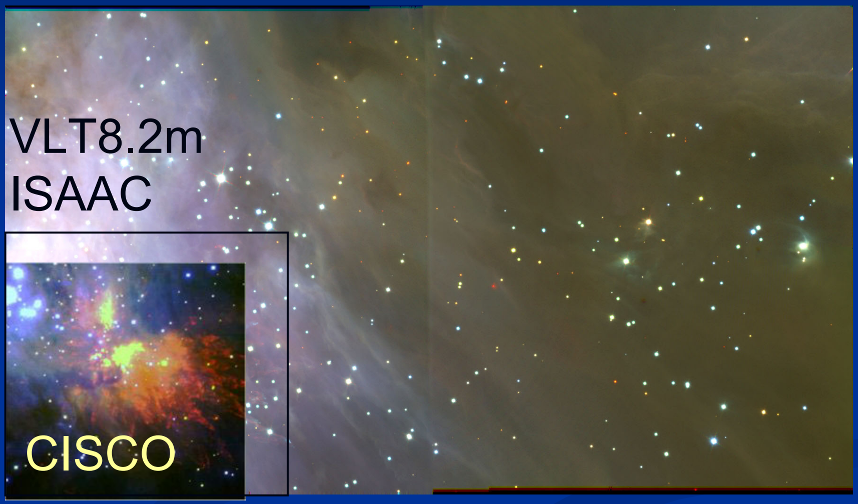
History of Star formation
Mass assembly



MOIRCS



4×7 arcmin^2



Multi-Object InfraRed Camera and Spectrograph

Near-infrared (0.9~2.5 μ m)

- large telescope
- wide F.O.V.
- high image quality

→ We can construct large NIR-selected sample to faint (low-mass) limit

MOIRCS Deep Survey (MODS)
in GOODS-North Region

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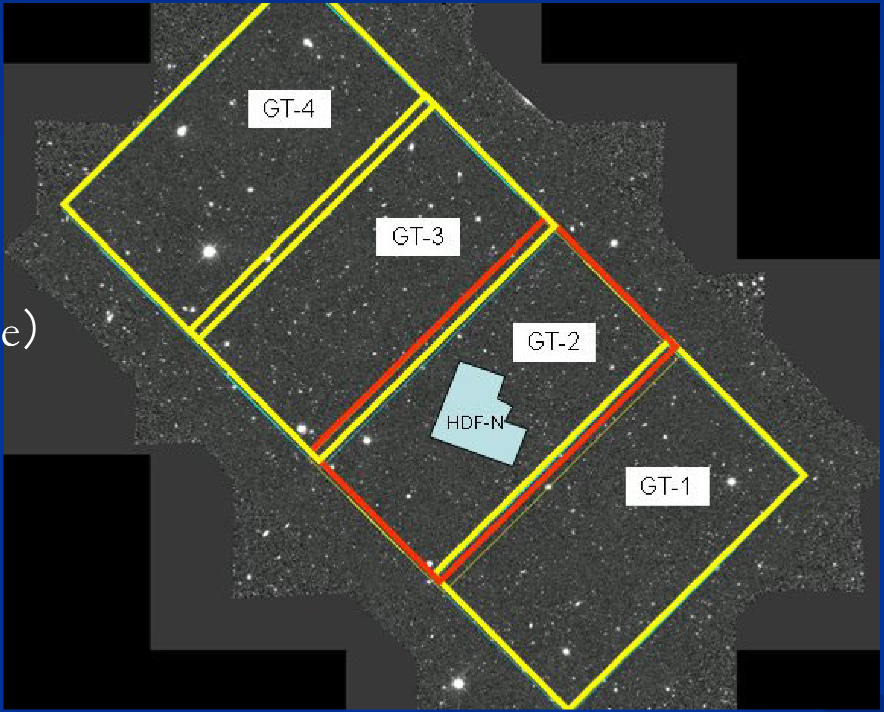


GOODS-North
JHKs-bands deep imaging

MODS data (S06A~S08A)

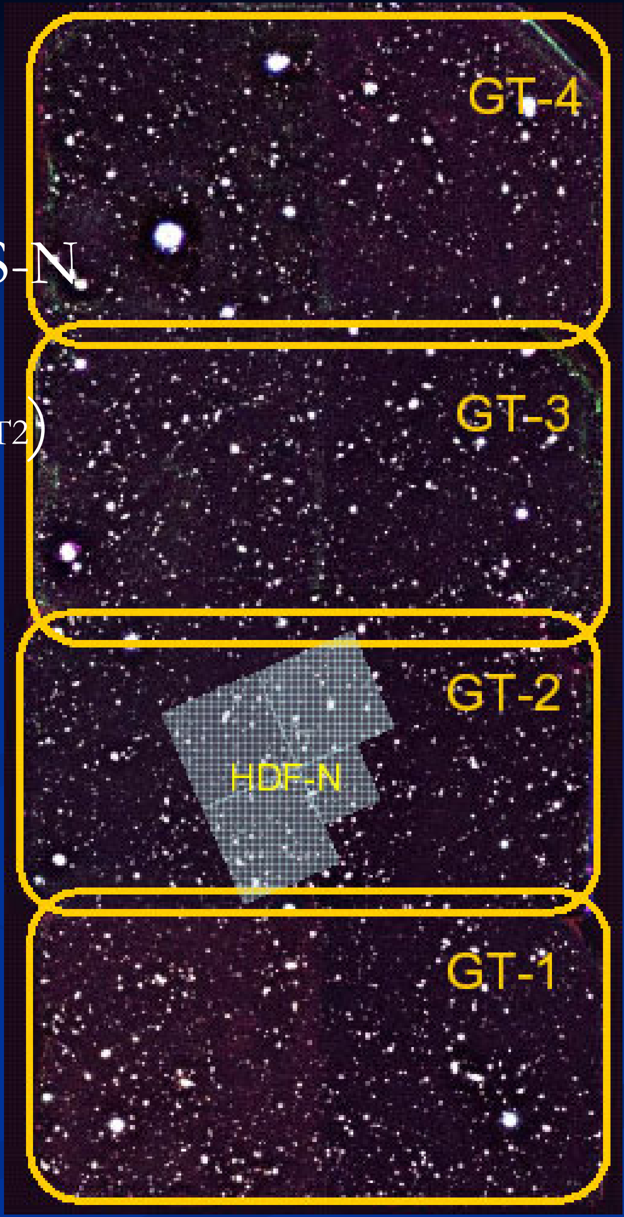
4 pointings of MOIRCS cover 70% of GOODS-N

✓ GT-1, 3, 4 (wide, ~103 $arcmin^2$ including GT2)

	5σ limit (Vega)	exposure (hr)
J	24.2	8.0
H	23.1	3.3
K	23.1	9.6

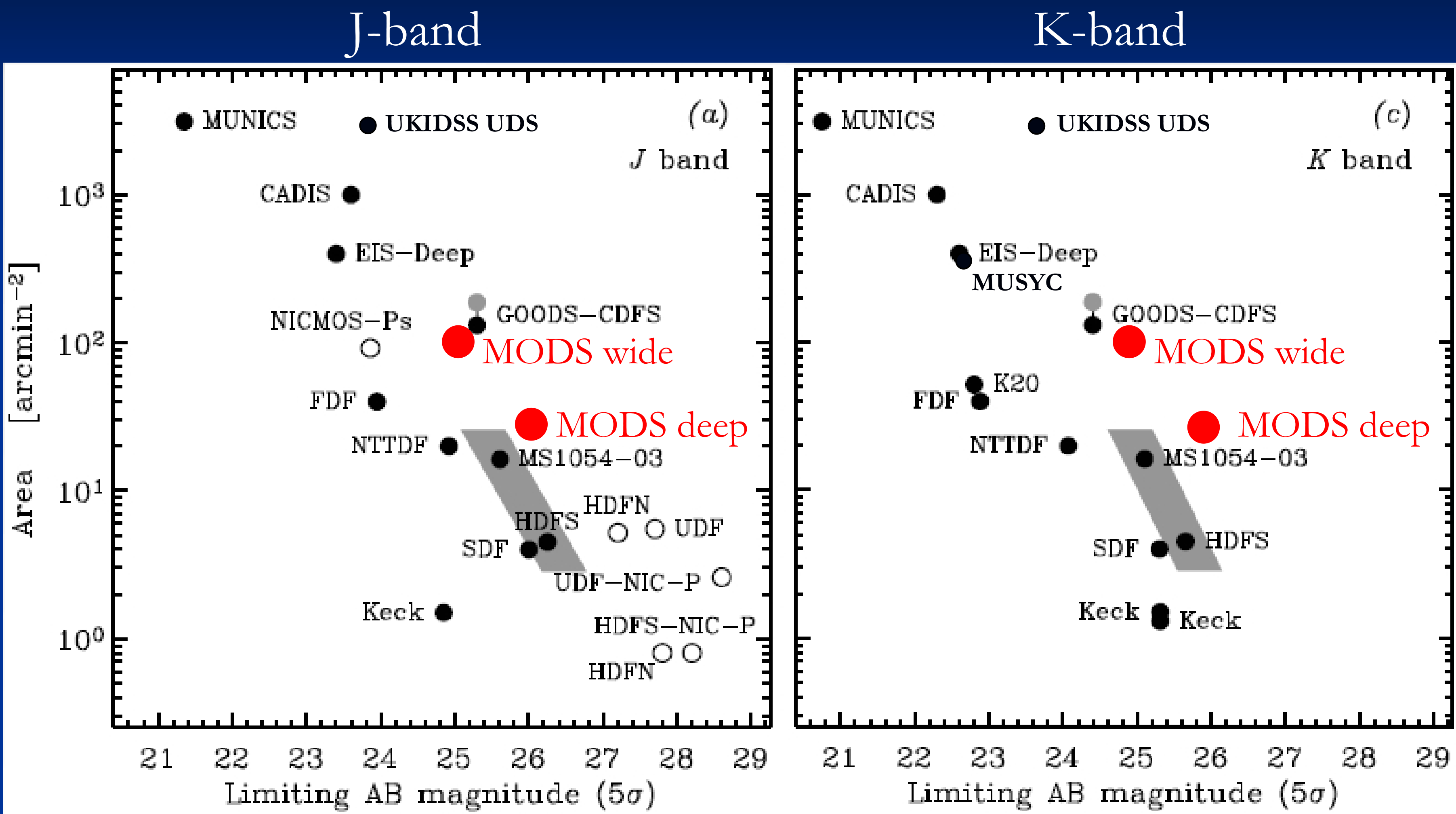
✓ GT-2 (deep, ~28 $arcmin^2$)

	5σ limit (Vega)	exposure (hr)
J	25.1	28.2
H	23.7	6.7
K	24.1	28.0



JHK 3color image

Comparison with other NIR surveys



Forster-Schreiber et al. 2006

very deep --- detect low-mass (10^9-$10^{10}M_{\odot}$) galaxies even at z~2-3

wide area --- measure the number density evolution with high accuracy

analysis

- Source detection in the K-band image
- Multi-band photometry
  - U（KPNO）、BViz（HST）、JHK（MOIRCS）、3.6,4.5,5.8 μ m（Spitzer）
- Redshift determination（spec-z, photo-z）
  - distance → luminosity、rest-frame SED
- Multi broad-band SED fitting
  - fitting multi-band photometry with SED models → stellar M/L ratio
  - L and M/L → stellar mass
- Estimate stellar mass function in each redshift bin
  - Vmax method
  - Sandage Tammann & Yahil method (maximum likelihood)

Sample

- Wide (103arcmin^2)

  6381objects with K_{Vega}<23mag

- Deep (28arcmin^2)

  3161 objects with K_{Vega}<24mag

total 7563 objects (with 2098 spectroscopic redshifts)

We investigated the evolution of stellar mass function over 0.5<z<3.5.

Number of objects (spec-z)

	0.5<z<1.0	1.0<z<1.5	1.5<z<2.5	2.5<z<3.5
Wide	~2000(859)	~1300(353)	~1300(209)	~500(95)
Deep	~900(311)	~600(105)	~700(75)	~350(57)

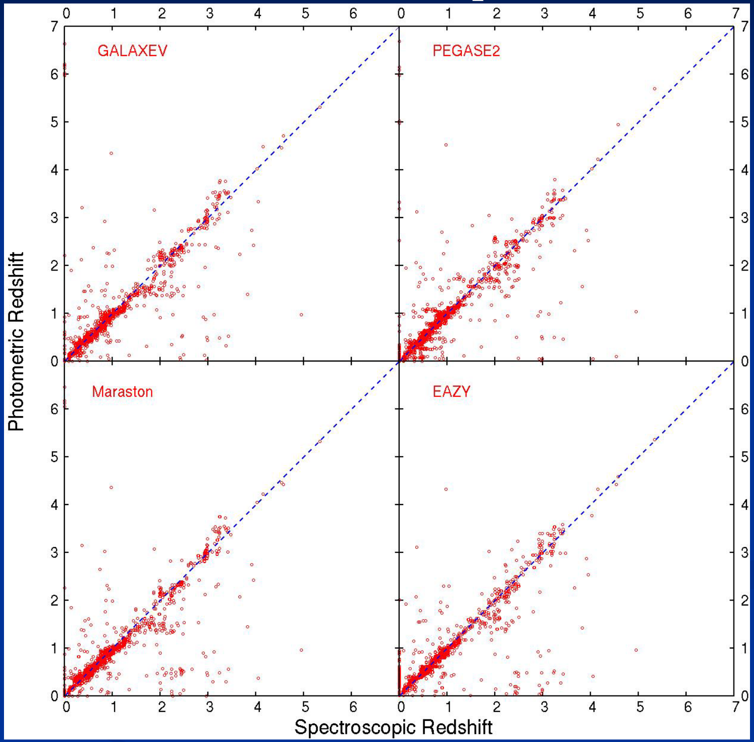
Photometric redshift

- model template
  - ✓ GALAXEV
  - ✓ PEGASE2
  - ✓ Maraston 2005

Different SED models

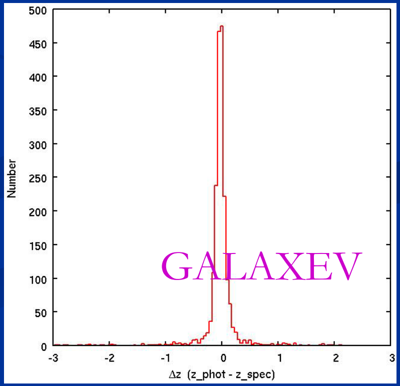
Check for systematic effects on { Photo-z, M/L ratio }

Photo-z vs spec-z



- ✓ EAZY (Brammer et al. 2008)
  - •Public photo-z code
  - •Independent check for photo-z

EAZY uses templates based on the principal components ⇨ Estimate of M/L ratio
- GALAXEV
- PEGASE2
- Maraston



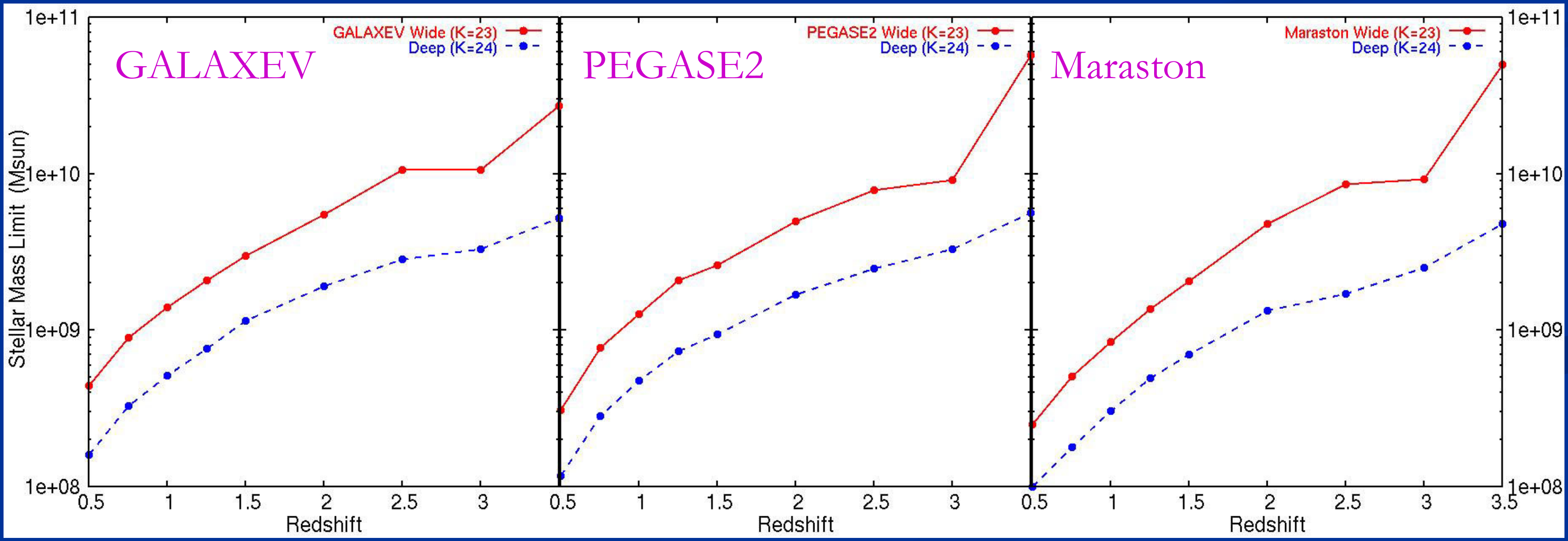
stellar mass limit

K-band magnitude limited sample

rest-frame U-V color distribution at each redshift → M/L ratio distribution as a function of mass

Stellar mass limit as a function of redshift

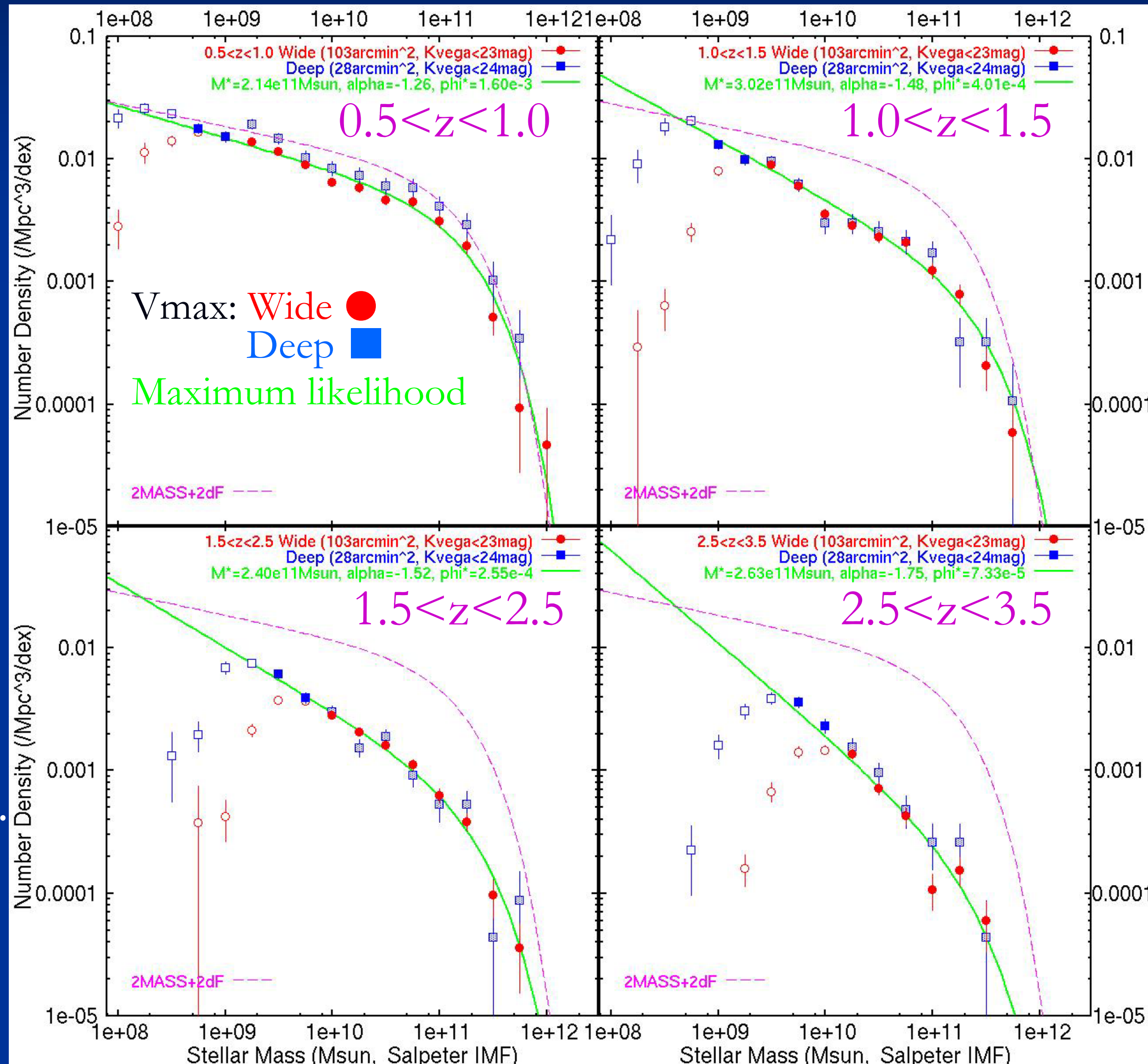
90% of objects with the limiting mass are detected at K<23(24 for deep)



results

Evolution of stellar mass function (GALAXEV SED template)

✓Number density of galaxies decreases with redshift.



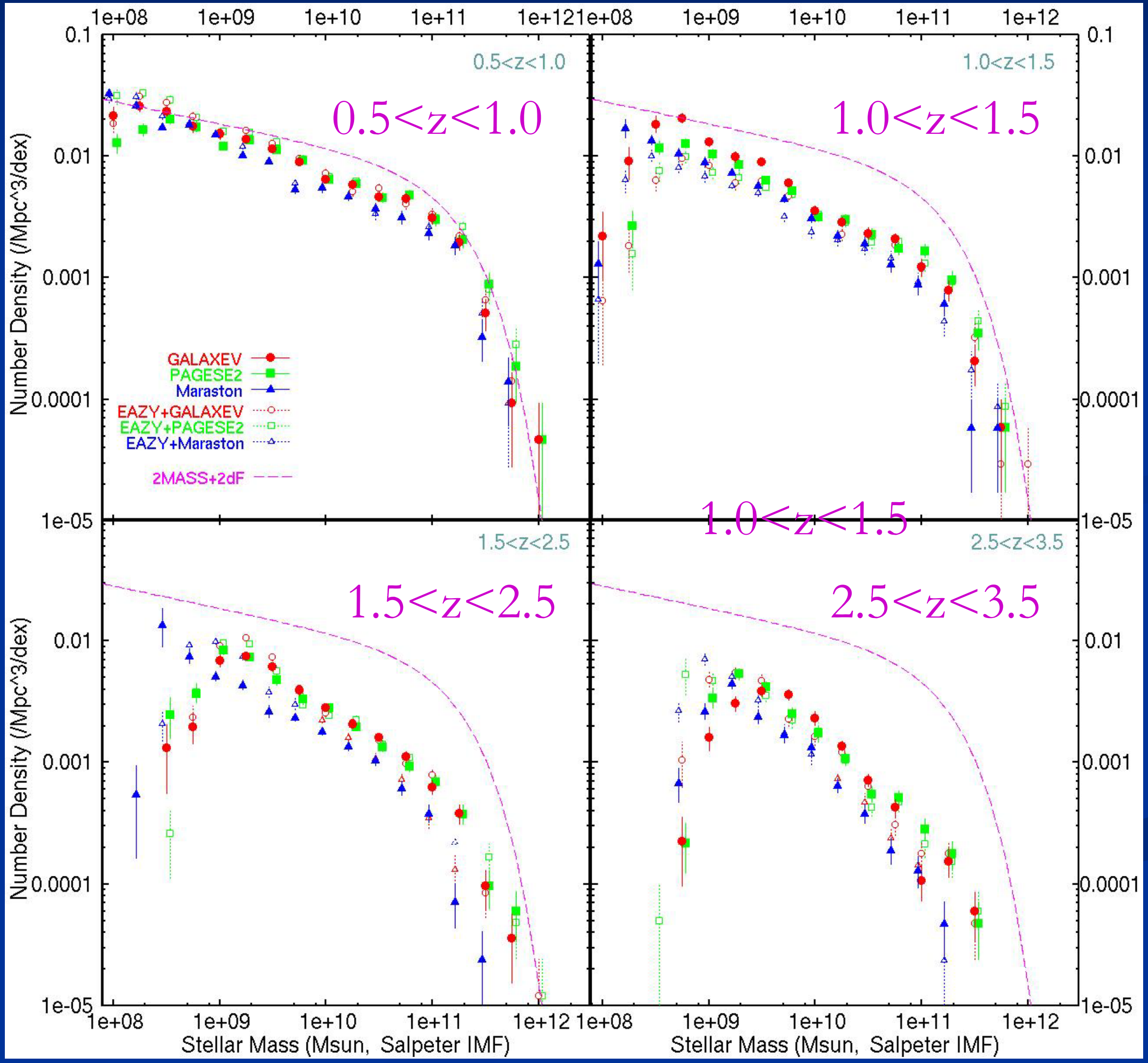
✓Strong evolution at ~M* (~10^{11}M◎)

✓Low-mass end slope becomes steeper with redshift.

Results with different SED templates

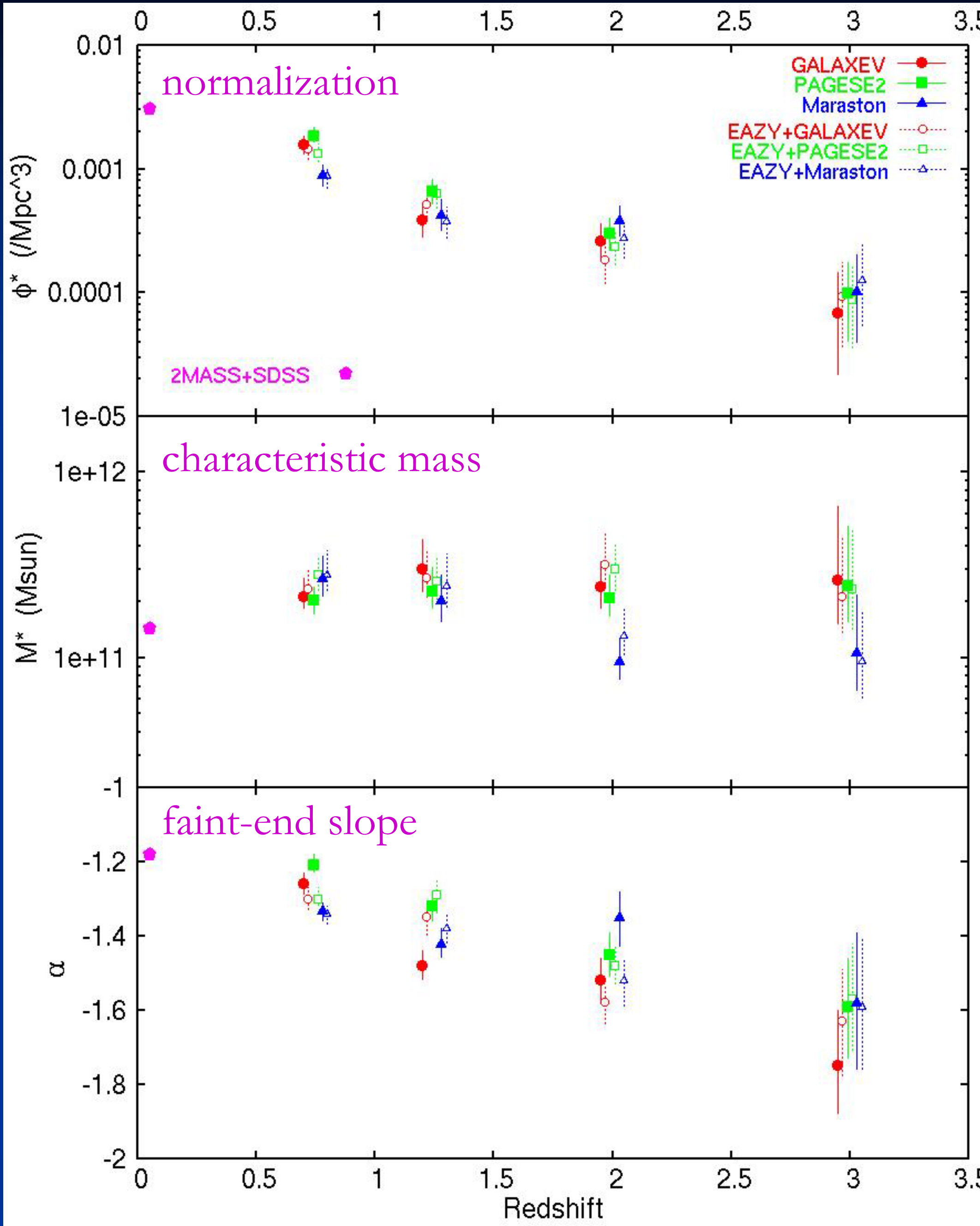
✓ Different SED models
→similar evolutionary trends

✓ Maraston model
smaller number density
at high mass and high-z

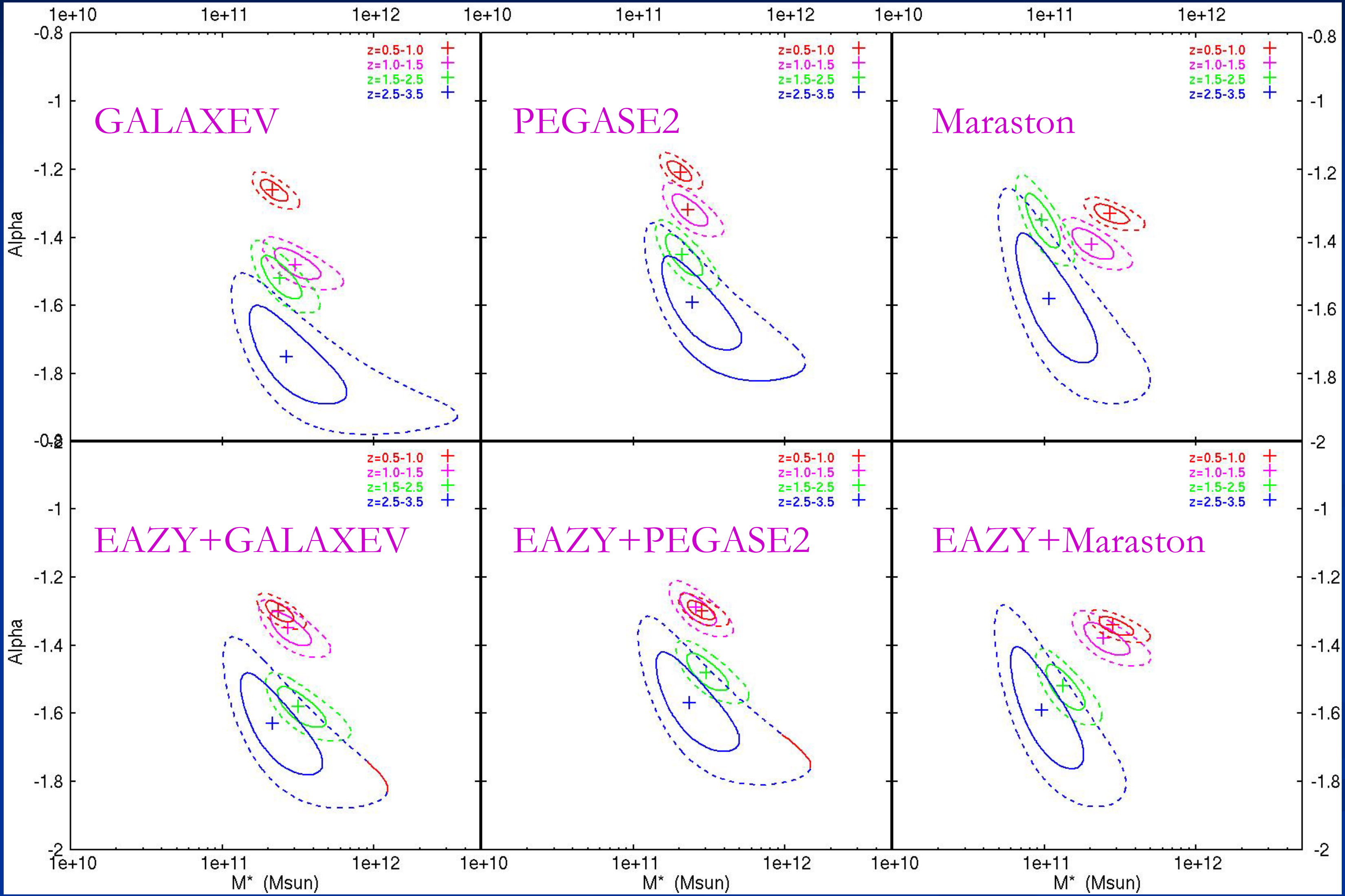


Evolution of Schechter parameters

- ✓ Normalization
  - gradually decreases with redshift
  - ~10% of the local value at z~2 and ~4% at z~3
- ✓ Characteristic mass
  - No significant evolution
  - decreases at z>2 in the case with Maraston model
- ✓ Low-mass end slope
  - becomes steeper with redshift
  - Some variance between the different SED models



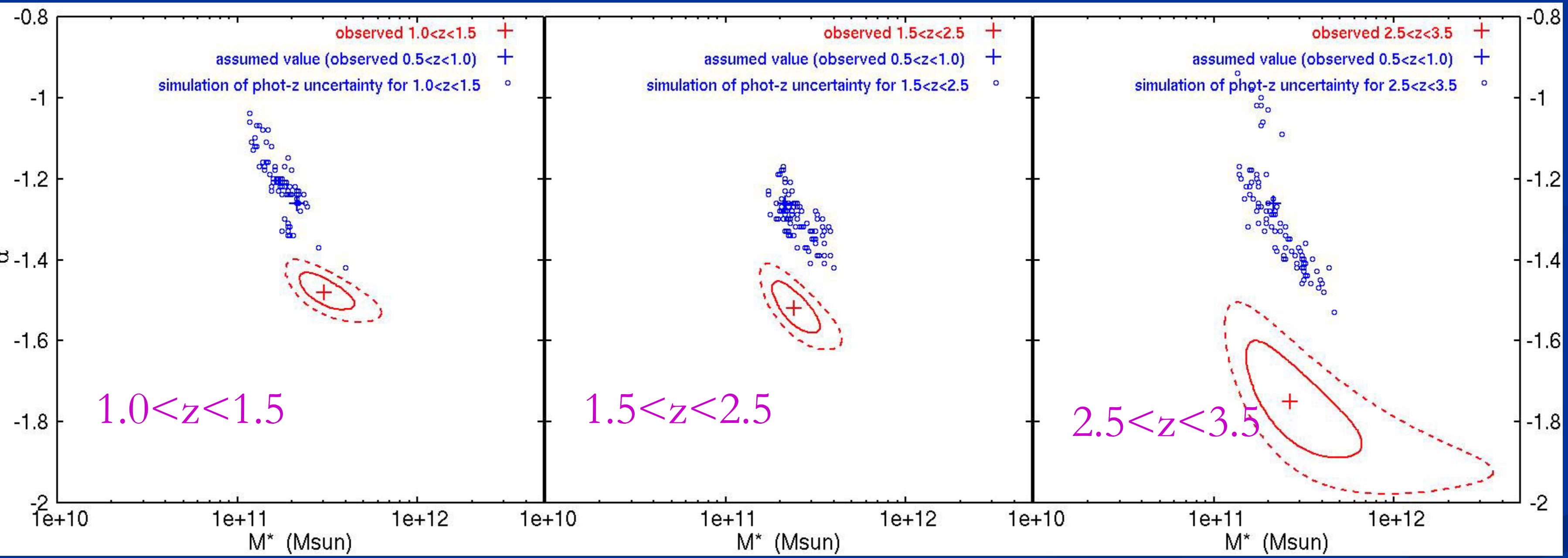
Evolution on M*- α plane



Significant steepening of α is seen.

Check for the effect of photo-z uncertainty

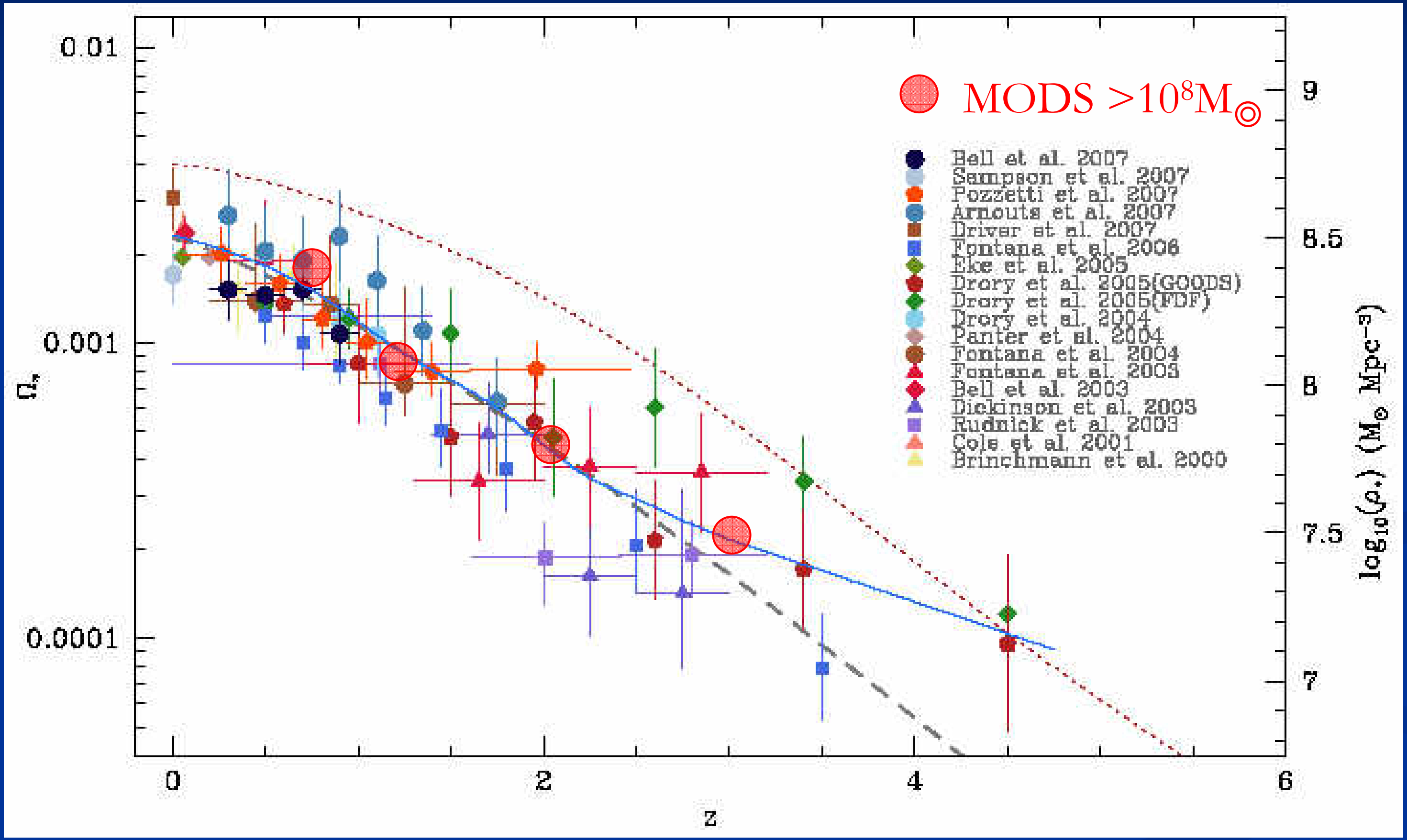
We performed simulations for the effect of the photometric redshift error on SMF in high-z bins, assuming no evolution of the shape of SMF (α and M* are fixed to those in 0.5<z<1.0 bin).



Although photometric uncertainty tends to make α steeper at high-redshift, the observed evolution of α is much stronger.

discussion

Evolution of stellar mass density



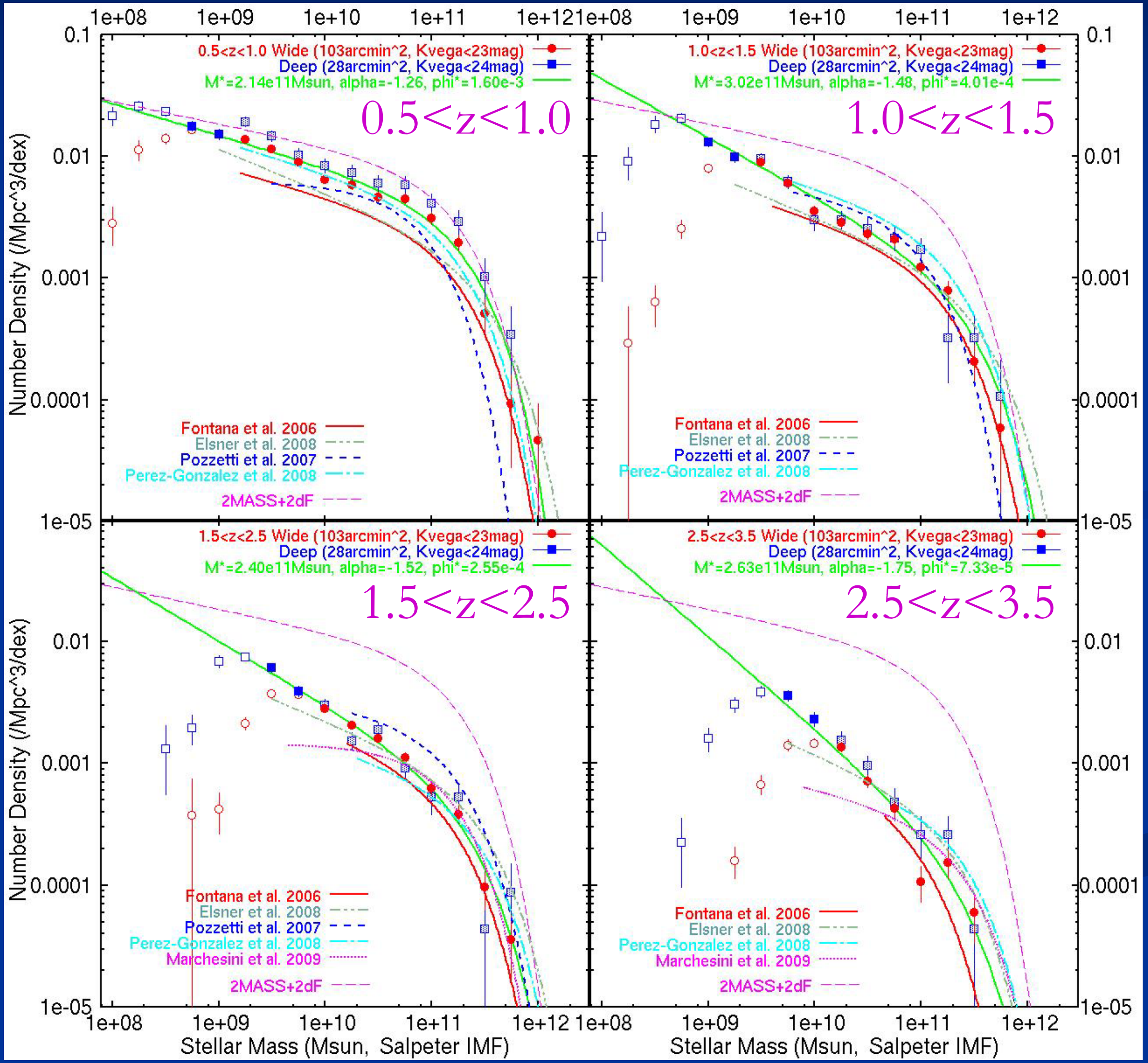
Average stellar mass density integrated down to $10^8 M_{\odot}$ decreases with redshift. The strength of evolution is consistent with those in other general fields.

Comparison with other studies

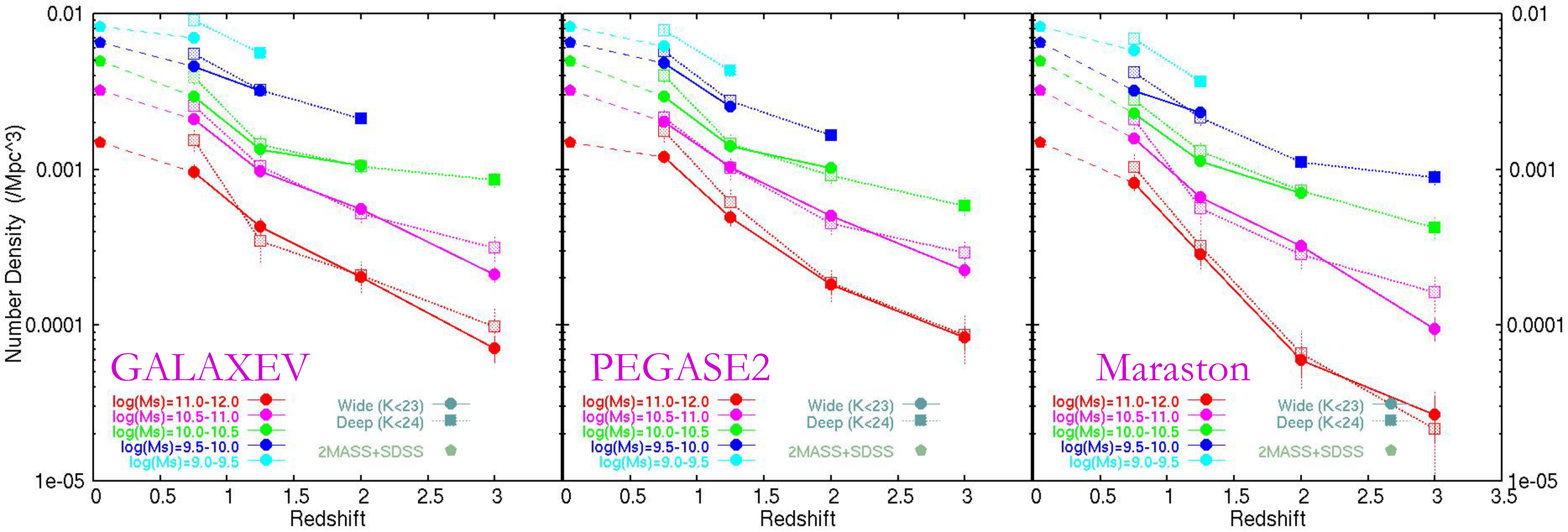
✓M* ~ 10 x M* ($10^{11-12}M_{\odot}$)
→consistent with other studies

✓ low-mass end ($10^{9-10}M_{\odot}$)
→slightly higher at high-z

- systematic uncertainty in the mass estimation
- incompleteness or fixing α in other shallower surveys

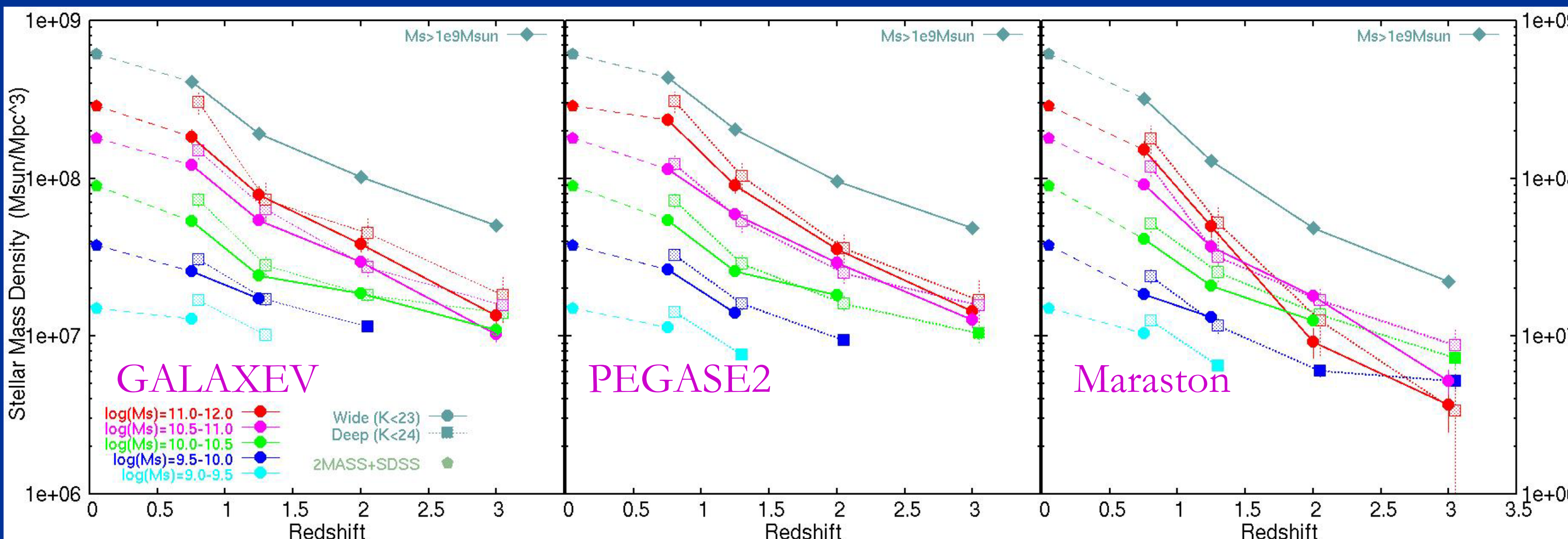


Mass-dependent number density evolution



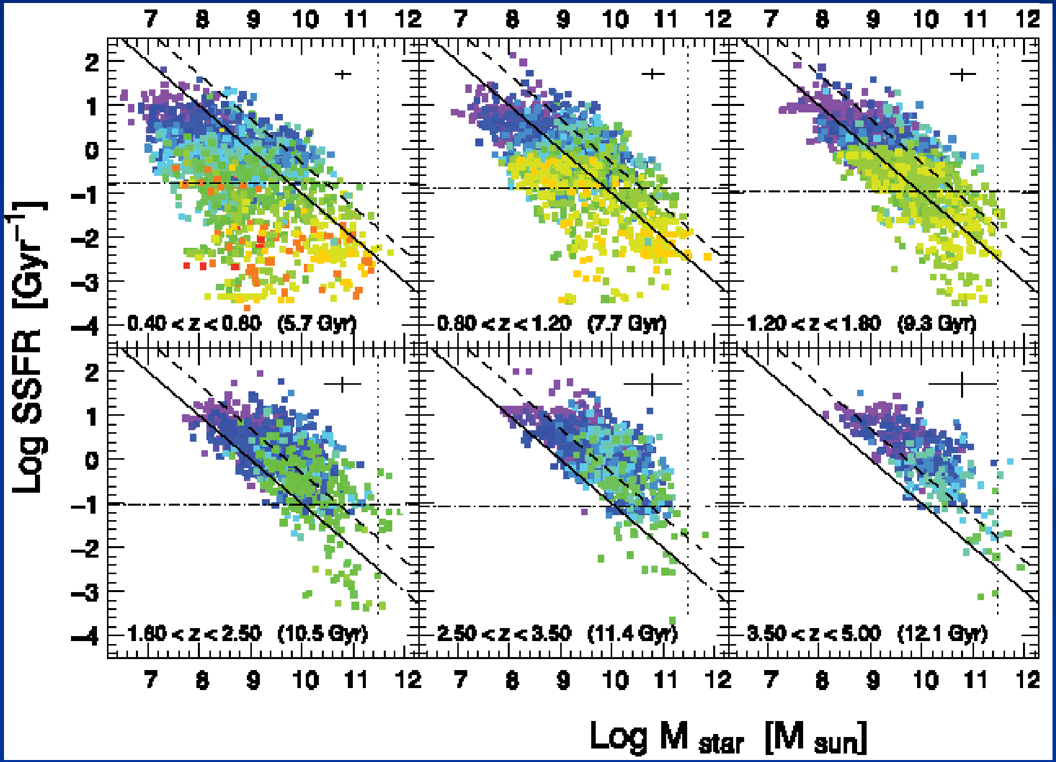
- Number density decreases with redshift
- ~M* galaxies show stronger evolution than low-mass (0.01~0.1M*) galaxies

Contribution to stellar mass density in different mass ranges

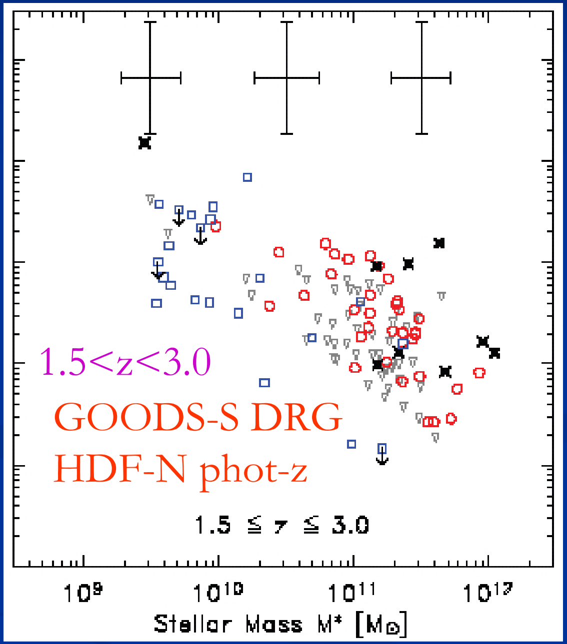


- Stellar mass density also decreases with redshift
- The contribution of low-mass galaxies increases with redshift

Specific star formation rate of low-mass galaxies



Feulner et al. 2005



Papovich et al. 2006

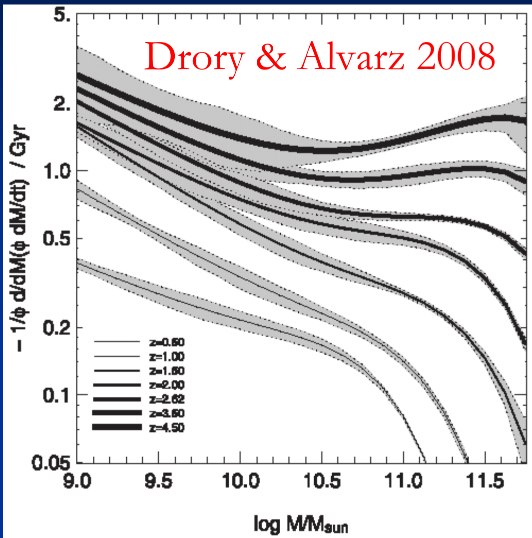
SFR/Ms of low-mass galaxies tends to be higher even at high redshift.

→ Low-mass galaxies are expected to have higher growth rate of stellar mass by star formation activities.

Evolution of low-mass end slope

✓ SSFR distribution

Relative change of number density expected from SFR

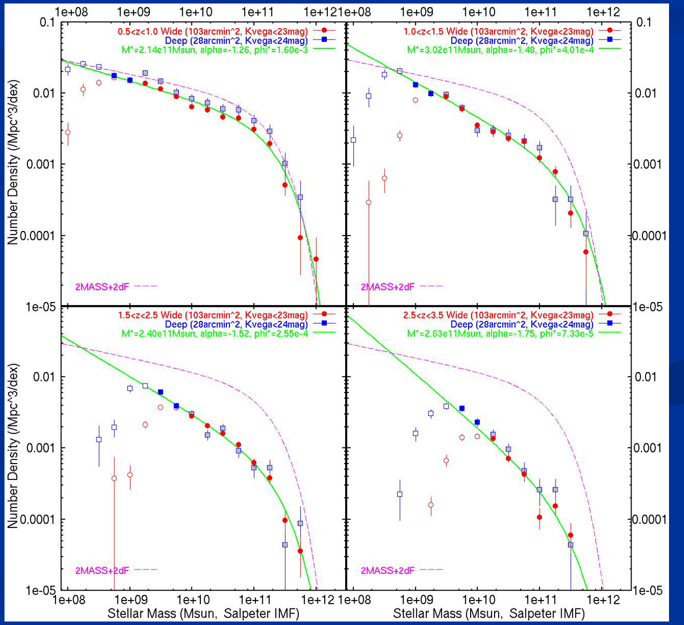


Mass growth rate of low-mass galaxies by star formation is higher than ~M* galaxies

➡ Low-mass slope is expected to become steeper **with time.**

- α becomes shallower with time.

Hierarchical merging → Mass function becomes flatter with time



Hierarchical merging flatten with time ⟺ Star formation steepen with time

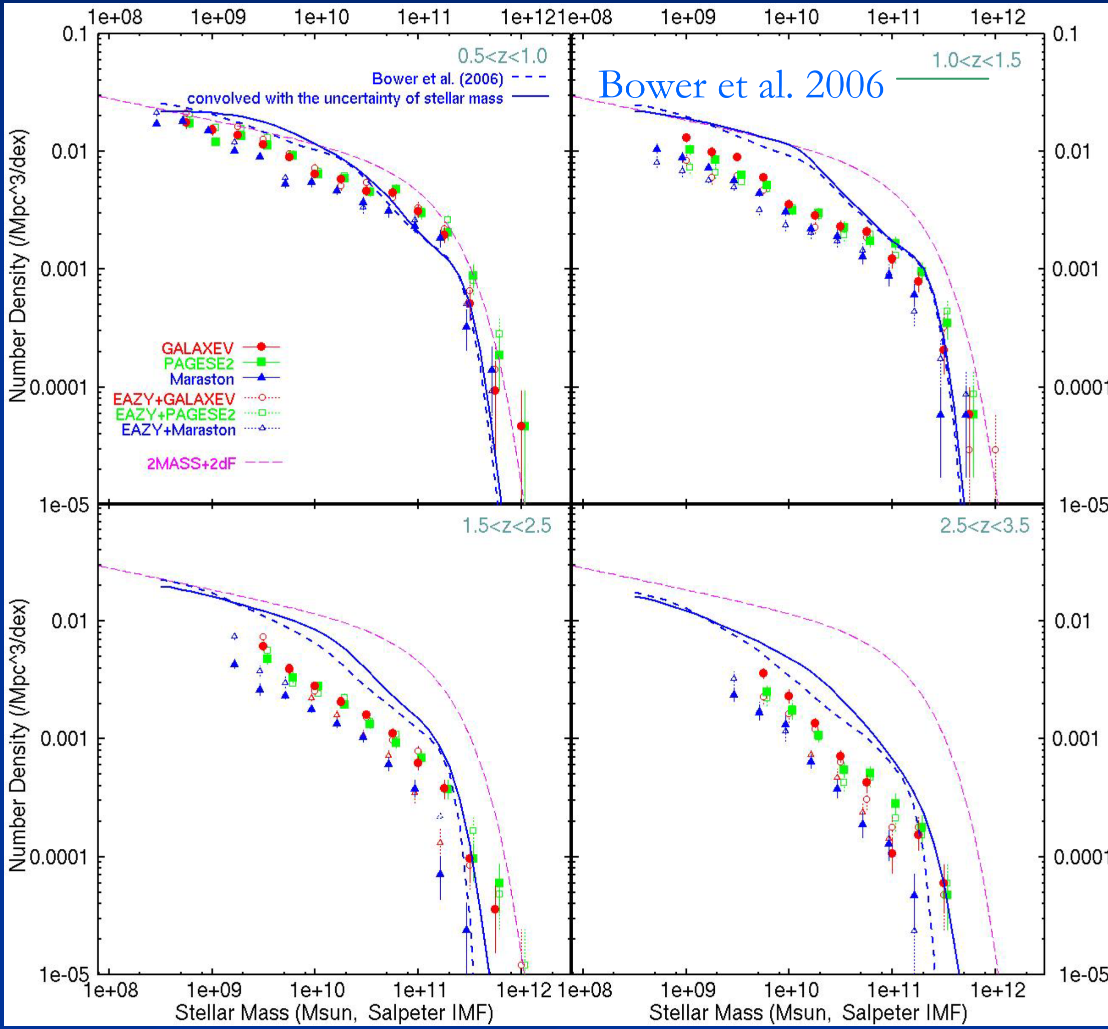
Evolution of low-mass slope

Hierarchical merging process played an important role for the stellar mass assembly of low-mass galaxies at high redshift.

Comparison with semi-analytic model

- ✓ Low-mass end slope
  - similar evolutionary trend
  - steeper SMF at high-z

- ✓ Normalization
- ✓ Detailed shape
  - significantly different from the models



Summary

- We used MODS data to investigate the evolution of the stellar mass function of galaxies down to $10^{9\sim10}\ M_{\odot}$ over $0.5<z<3.5$.
- Normalization of SMF and the integrated stellar mass density decrease with redshift.
  (~15% of the present value at z~2, ~7% at z~3)
- Evolution of number density of low-mass galaxies (0.01~0.1M*) is weaker than that of ~M* galaxies. Low-mass end slope becomes steeper with redshift.
- Evolution of low-mass end slope suggests that the hierarchical merging process was important for the stellar mass assembly of low-mass galaxies.

おわり