Evolution of Galaxy Stellar Mass Function since z~3

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Abstract

We present results on the evolution of the galaxy stellar mass function (SMF) at z~1-3 from MOIRCS Deep Survey, which is a deep NIR imaging survey with Subaru/MOIRCS in the GOODS-North region. The deep NIR data allow us to construct a nearly stellar mass-limited sample down to $\sim10^{9.5}$-$10^{10}\,M_\odot$ even at z~3. We found that the low-mass slope of the SMF becomes steeper with redshift and that the evolution of the number density of ~M* ($\sim10^{11}\,M_\odot$) galaxies is stronger than low-mass (10^{9}-$10^{10}\,M_\odot$) galaxies at z>1. We also found that the low-mass slope of the SMF for quiescent galaxies is significantly flatter than that of star-forming galaxies at 0.5<z<2.5. The evolution of the number density of quiescent galaxies is stronger than star-forming ones, which causes the rapid increase of ~M* galaxies relative to low-mass galaxies.

MOIRCS Deep Survey

Deep *JHKs*-bands imaging survey with Subaru/MOIRCS in GOODS-North

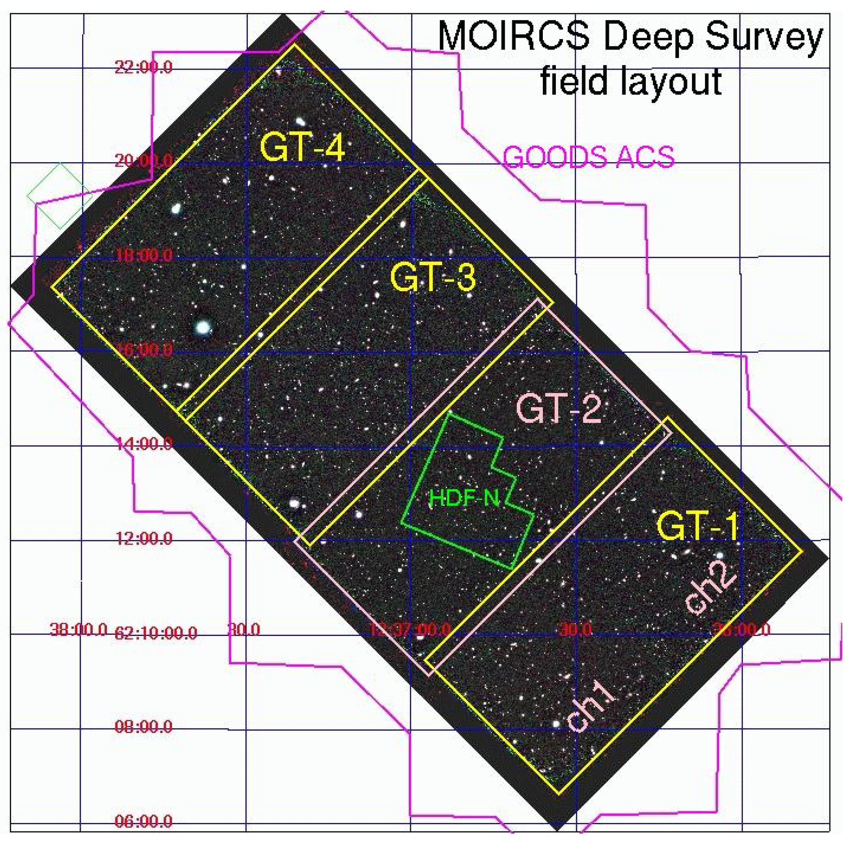
- Wide (GT-1,(2),3,4) ~103 arcmin^2

band	5σ limit (AB)	exp. time (hour)
J	25.2	6.3-9.1
H	24.5	2.5-4.3
Ks	25.0	8.3-10.7

- Deep (GT-2) ~28 arcmin^2

band	5σ limit (AB)	exp. time (hour)
J	26.1	28.2
H	25.3	5.7
Ks	25.9	28.0

Reduced images and catalogs are publicly available at http://www.astr.tohoku.ac.jp/MODS/



- ✓ 4 pointings of MOIRCS cover ~70% of the GOODS-N region.

Sample selection & Analysis

◆ *Ks*-band selected sample
- *K*<24.8 in the wide field
- *K*<25.8 in the deep field

◆ Multi-band photometry
- KPNO/MOSAIC (*U* band)
- HST/ACS (*B*, *V*, *i*, *z* bands)
- Subaru/MOIRCS (*J*, *H*, *K* bands)
- Spitzer/IRAC (3.6, 4.5, 5.8 μm bands)

◆ SED fitting analysis

GALAXEV model (Bruzual & Charlot 2003)

SFR ∝ exp (-age/τ)
Salpeter IMF
Calzetti extinction law

→
- Photometric redshift
- Stellar *M/L* ratio (→ stellar mass)

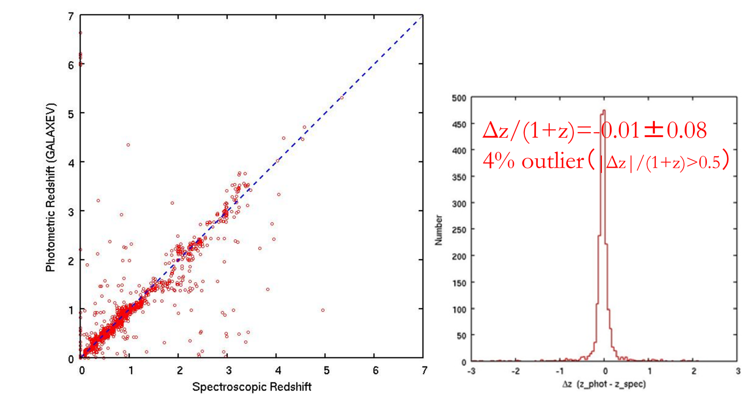
◆ Limiting stellar mass

K-band magnitude-limited sample

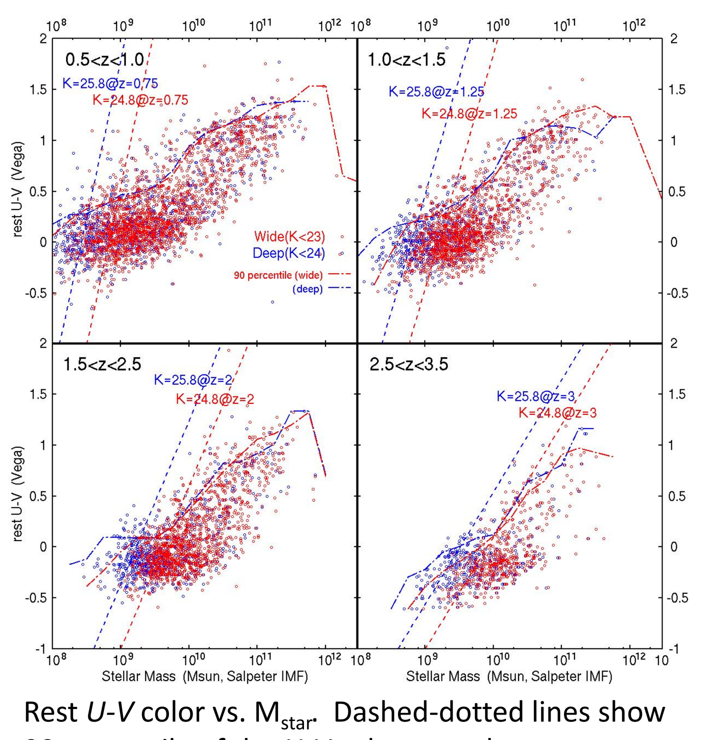
↓ rest-frame *U-V* color distribution at each-z → M/L ratio distribution as a function of mass

Stellar mass limit as a function of redshift

90% of galaxies with the limiting mass are detected at *K*<24.8 (*K*<25.8 for the deep field)



Photometric redshift accuracy

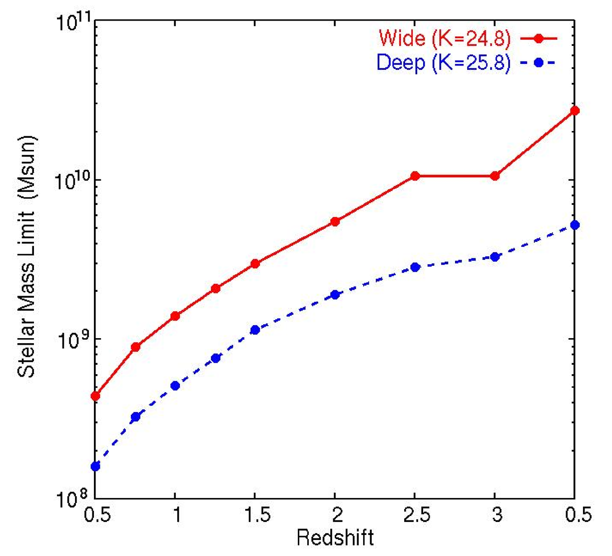


Rest *U-V* color vs. M_{star}. Dashed-dotted lines show 90 percentile of the *U-V* color at each mass. Dashed lines show maximum mass of galaxies with the limiting *K*-band magnitude at each *U-V* color. The limiting stellar mass is determined as a crossing point of the two lines.

Size of the stellar mass-limited sample

	0.5<z<1.0	1.0<z<1.5	1.5<z<2.5	2.5<z<3.5
wide	1592	1143	994	302
deep*	83	85	101	63
total	1675	1228	1095	365

* objects with *K*=24.8-25.8 in the deep field only



The resulting limiting stellar mass for the wide (solid) and deep (dashed) fields.

Related papers

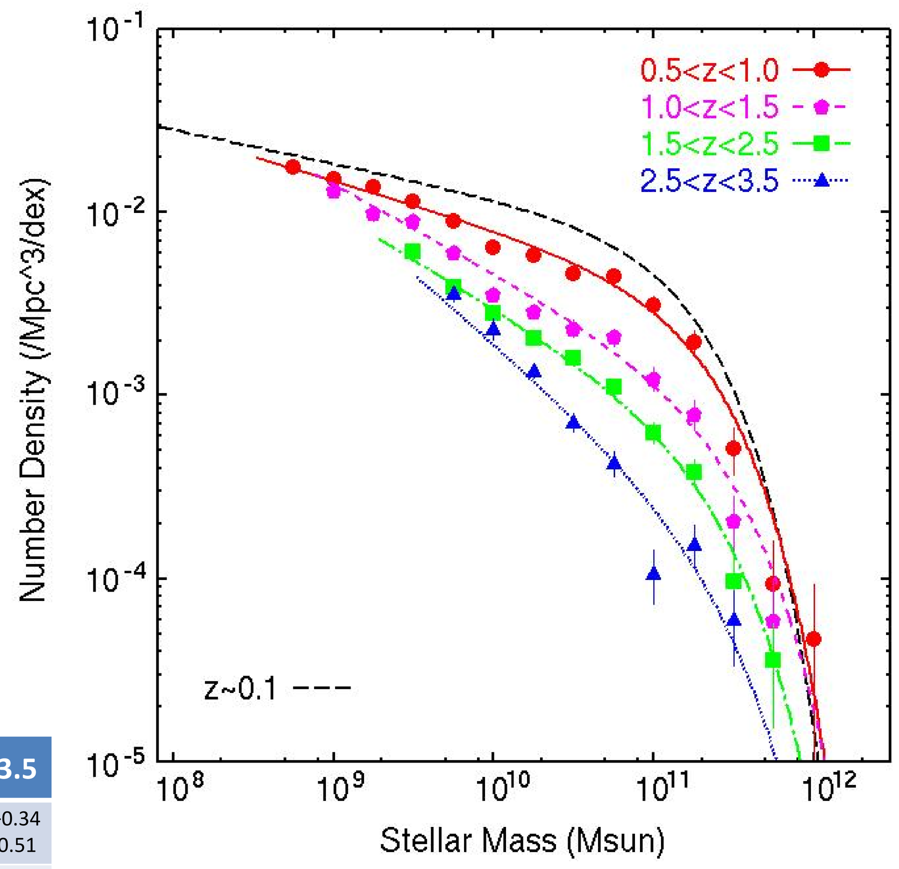
Kajisawa et al. 2009, ApJ, **702**, 1393
Kajisawa et al. 2011, PASJ, **63S**, 403
Kajisawa et al. 2010, ApJ, **723**, 129
Kajisawa et al. 2011, PASJ, **63S**, 379

Stellar mass function at 0.5<z<3.5

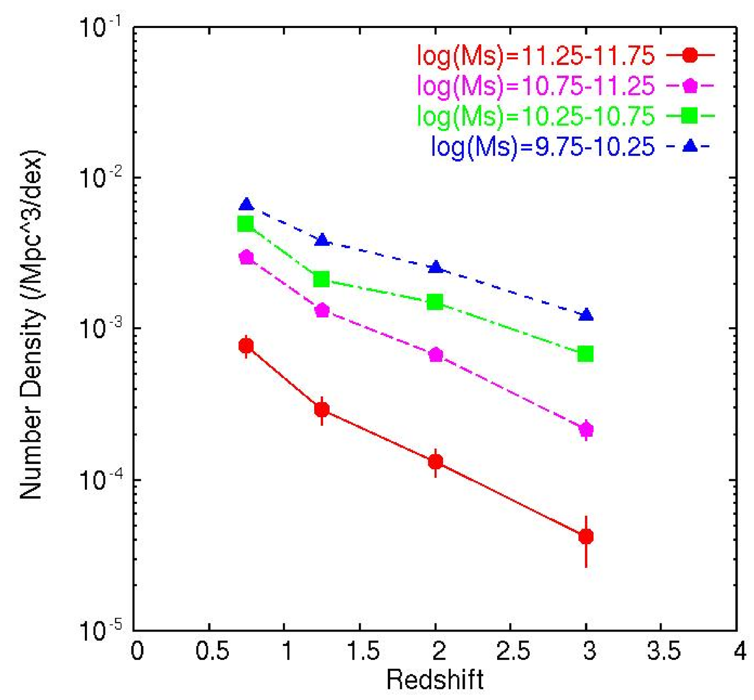
- ✓ Number density of galaxies over a wide range of stellar mass (normalization of the SMF) decreases with redshift.
- ✓ The strength of the evolution depends on stellar mass. The number density of galaxies with $M_{star}\sim10^{11}\,M_\odot$ evolves by more than an order of magnitude between z~0.75 and z~3, while galaxies with $M_{star}\sim10^{10}\,M_\odot$ evolve by a factor of ~5.
- ✓ The characteristic mass M* shows no significant evolution.
- ✓ There seems to be a upturn around $10^{10}\,M_\odot$ in the SMF.

The best-fit Schechter parameters

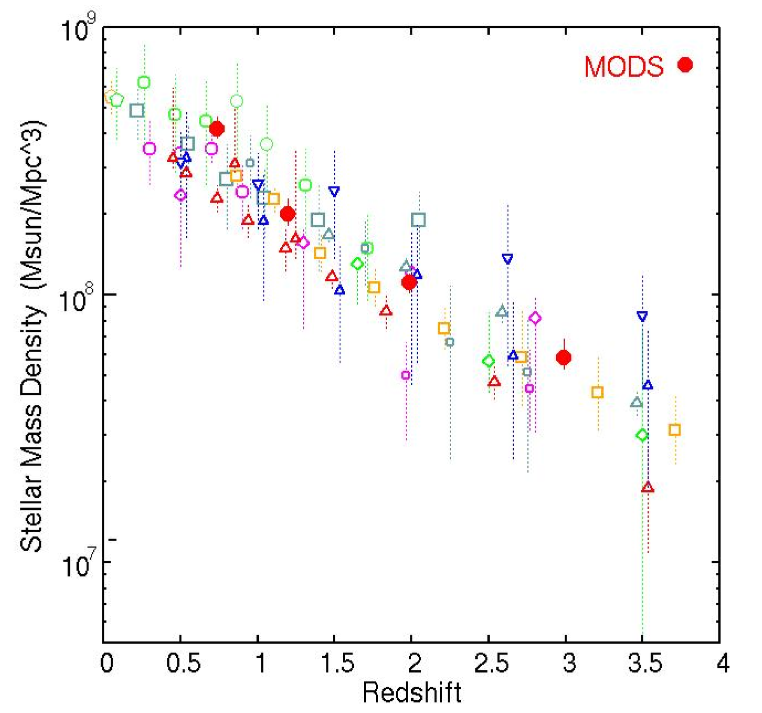
	0.5<z<1.0	1.0<z<1.5	1.5<z<2.5	2.5<z<3.5
log φ*	$-2.79^{+0.07}_{-0.08}$	$-3.40^{+0.13}_{-0.15}$	$-3.59^{+0.14}_{-0.16}$	$-4.14^{+0.34}_{-0.51}$
log M*	$11.33^{+0.10}_{-0.07}$	$11.48^{+0.16}_{-0.13}$	$11.38^{+0.14}_{-0.12}$	$11.42^{+0.40}_{-0.24}$
α	$-1.26^{+0.03}_{-0.03}$	$-1.48^{+0.04}_{-0.04}$	$-1.52^{+0.06}_{-0.06}$	$-1.75^{+0.15}_{-0.13}$



Evolution of the galaxy stellar mass function. For reference, the SMF of local galaxies of Cole et al. (2001) is also shown.



Mass-dependent evolution of the number density of galaxies. The evolution of galaxies with $M_{star}\sim10^{11}\,M_\odot$ is stronger than lower-mass galaxies.



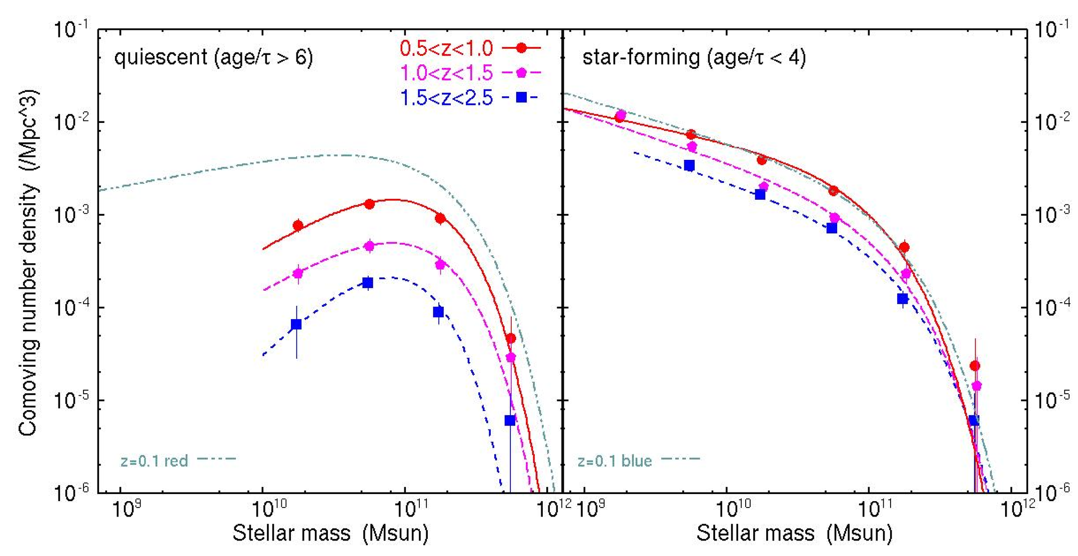
Evolution of stellar mass density integrated over 10^{8}-$10^{13}\,M_\odot$. Our results are consistent with other studies in general fields.

Quiescent & star-forming populations

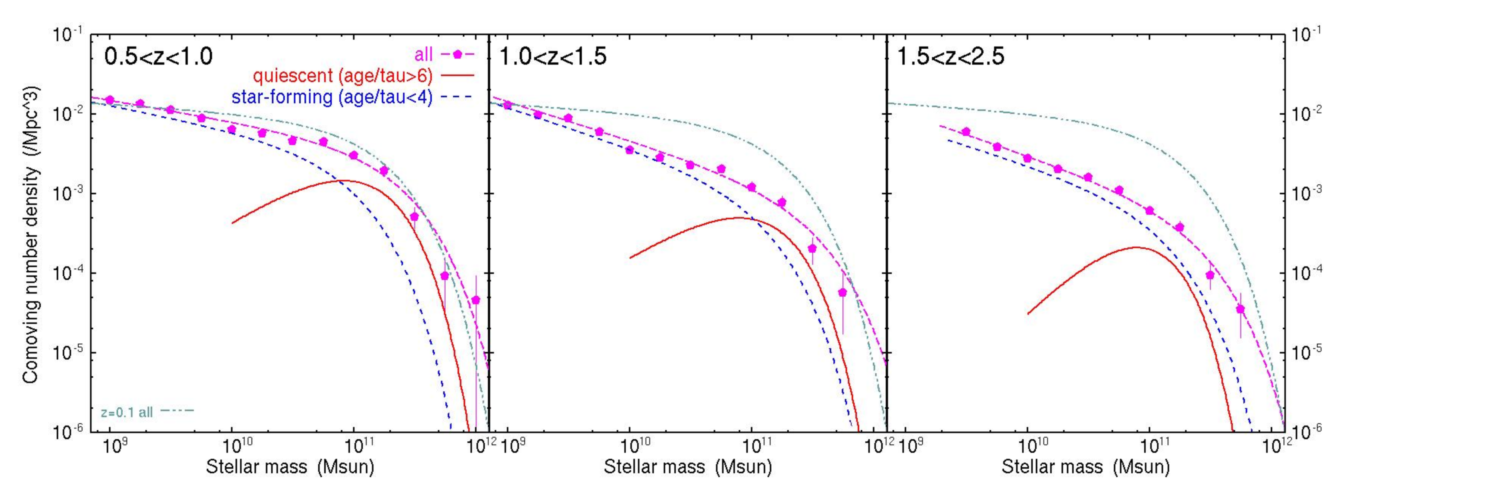
We divided the stellar mass-selected sample into quiescent and star-forming populations with the results of the SED fitting analysis.

- ☐ age/τ > 6 → quiescent
- ☐ age/τ < 4 → star-forming

- ✓ The low-mass slope of the SMF for quiescent galaxies is flatter than that for star-forming ones at 0.5<z<2.5.
- ✓ The strength of the number density evolution is different between the two populations. The number density for quiescent galaxies increases by a factor of ~10 from z~2 to z~0.75, while that for star-forming ones does by a factor of ~3.



Evolution of the SMF for quiescent (left) and star-forming (right) galaxies. The low-mass slope and the strength of the evolution are different between the quiescent and star-forming galaxies.



Contributions to the number density of galaxies from quiescent (long-dashed) and star-forming (short-dashed) populations as a function of stellar mass. The fraction of galaxies around $10^{11}\,M_\odot$ significantly increases from z~2 to z~0.75, while the quiescent fraction for low-mass galaxies remains small over the redshift range. The `dip' around $10^{10-10.5}\,M_\odot$ in the total SMF seems to be explained by the contribution of the quiescent population.

Discussion

The stronger number density evolution (a factor of ~10 between z~2 and z~0.75) and flatter low-mass slope (α > -1) of the SMF for quiescent galaxies → more rapid increase of ~M* galaxies with $\sim10^{11}\,M_\odot$ than lower-mass galaxies in the SMF.

If we assume that the increase of quiescent galaxies is caused by the cessation of star formation in some fraction of star-forming galaxies, a quenching of star formation is expected to occur preferentially in more massive galaxies at 0.5<z<2.5 in order to maintain the mass-dependence of the quiescent fraction.

Mass-dependent quenching rate

	$10^{10-10.5}M_\odot$	$10^{10.5-11}M_\odot$	$10^{11-11.5}M_\odot$
1.5<z<2.5 →1.0<z<1.5	7% (4% Gyr^{-1})	18% (11% Gyr^{-1})	29% (18% Gyr^{-1})
1.0<z<1.5 →0.5<z<1.0	10% (4% Gyr^{-1})	23% (10% Gyr^{-1})	41% (18% Gyr^{-1})

The fraction of newly emerging quiescent galaxies between the redshift bins relative to the star-forming population including newly increased galaxies at a given mass range.

As star-forming galaxies grow near to ~M*, star formation in these galaxies tends to cease.

→ Galaxies tend to accumulate around M* (if the stellar mass growth by mergers is not significant)
The number density of ~M* galaxies increases preferentially.