Stellar Mass Growth of Galaxies since z~3 in MODS

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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 investigated the SMF for passive and star-forming galaxies separately, and found that the strong evolution of ~M* galaxies is due to a rapid increase of the number of passive galaxies. We also studied star formation rates of galaxies as a function of stellar mass to investigate how star formation activities drive the evolution of the SMF in the important era.

MOIRCS Deep Survey

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

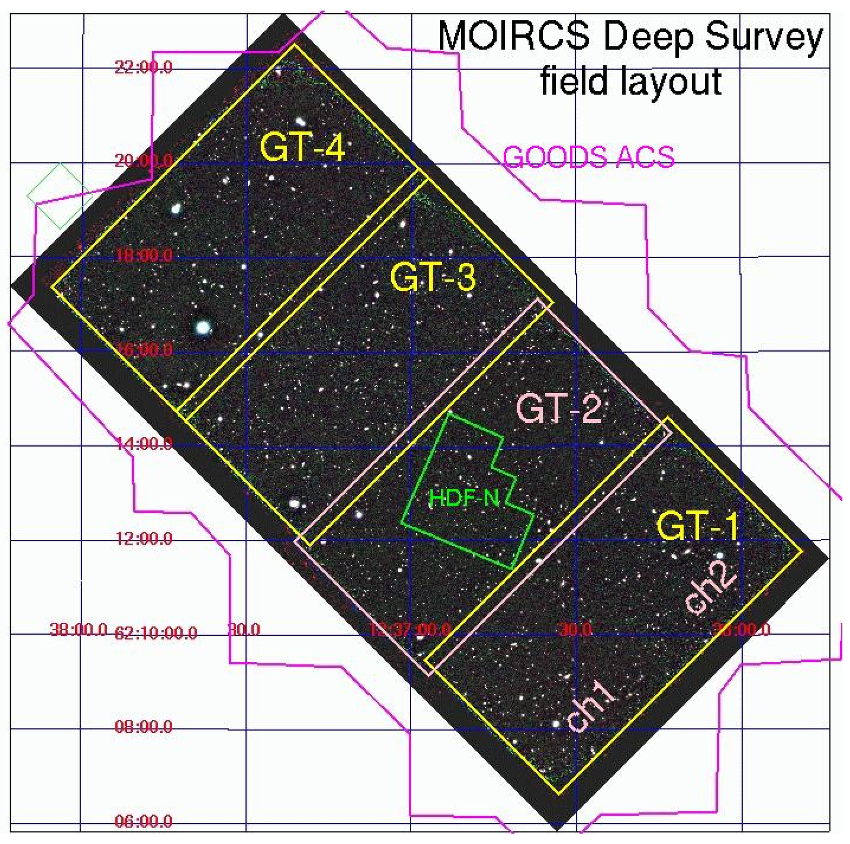
- Wide (GT-1,(2),3,4) ~103 arcmin^2

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

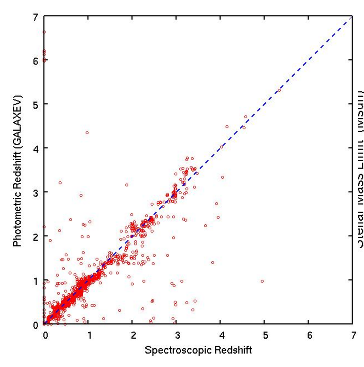
◆ Multi-band photometry
- KPNO/MOSAIC (*U* band)
- HST/ACS (*B*, *V*, *i*, *z* bands)
- Subaru/MOIRCS (*J*, *H*, *K* bands)
- Spitzer/IRAC (3.6, 4.5, 5.8 μm bands)

◆ SED fitting analysis

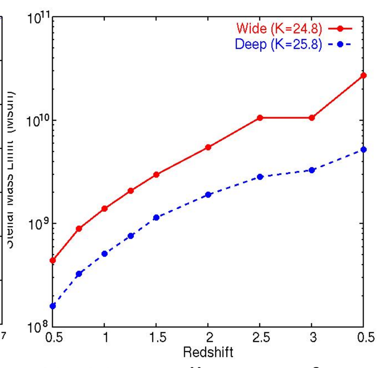
GALAXEV model (Bruzual & Charlot 2003)

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

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



Photometric redshift vs. spectroscopic redshift



Limiting stellar mass for the wide (solid) and deep (dashed) fields.

Sample size

	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

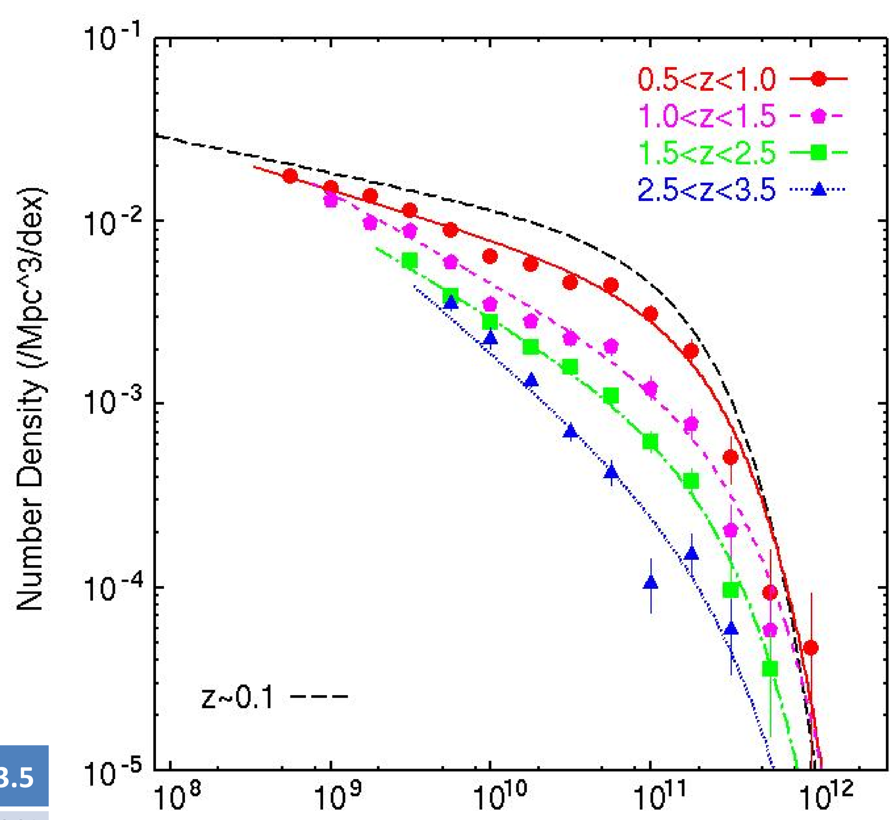
* objects with *K*=24.8-25.8 in the deep field only

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.

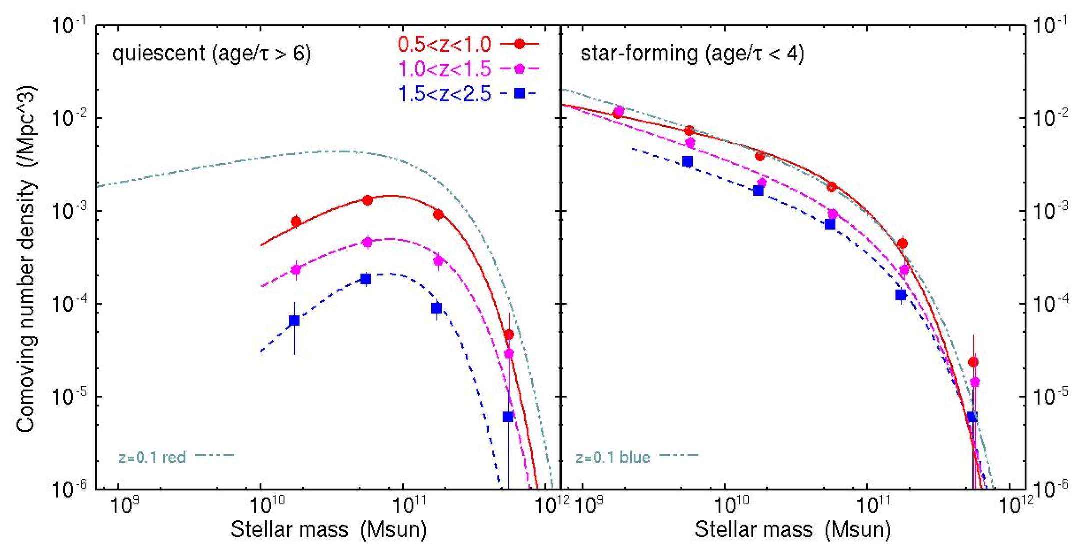
Quiescent & star-forming populations

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

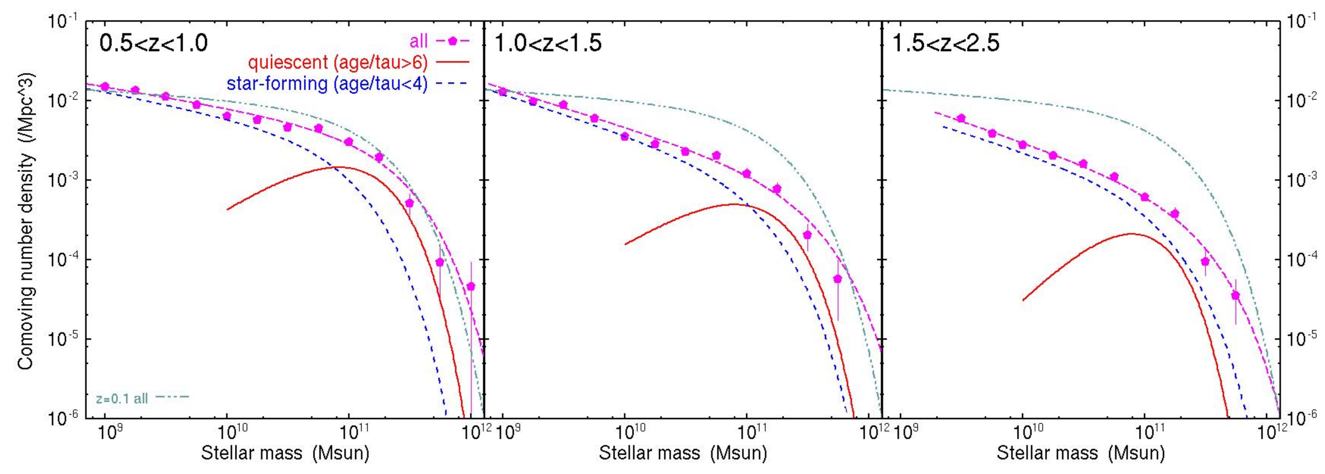
- ☐ age/τ > 6 → quiescent
- ☐ age/τ < 4 → star-forming

✓ 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.

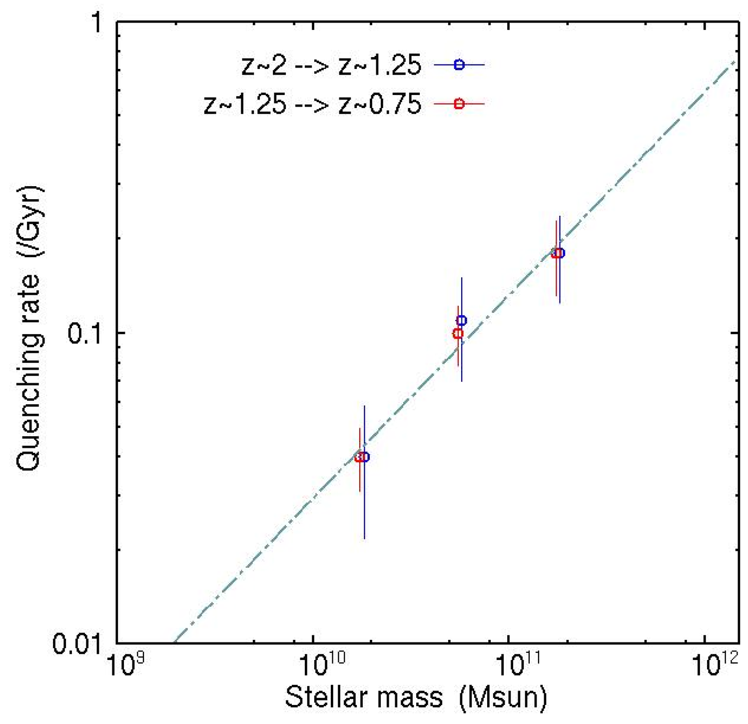


Contributions to the number density of galaxies from quiescent (long-dashed) and star-forming (short-dashed) populations as a function of stellar mass. The fraction of quiescent galaxies around $10^{11} M_\odot$ significantly increases from z~2 to z~0.75, while the quiescent fraction for low-mass galaxies 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.

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.

	$10^{10-10.5}M_\odot$	$10^{10.5-11}M_\odot$	$10^{11-11.5}M_\odot$
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.



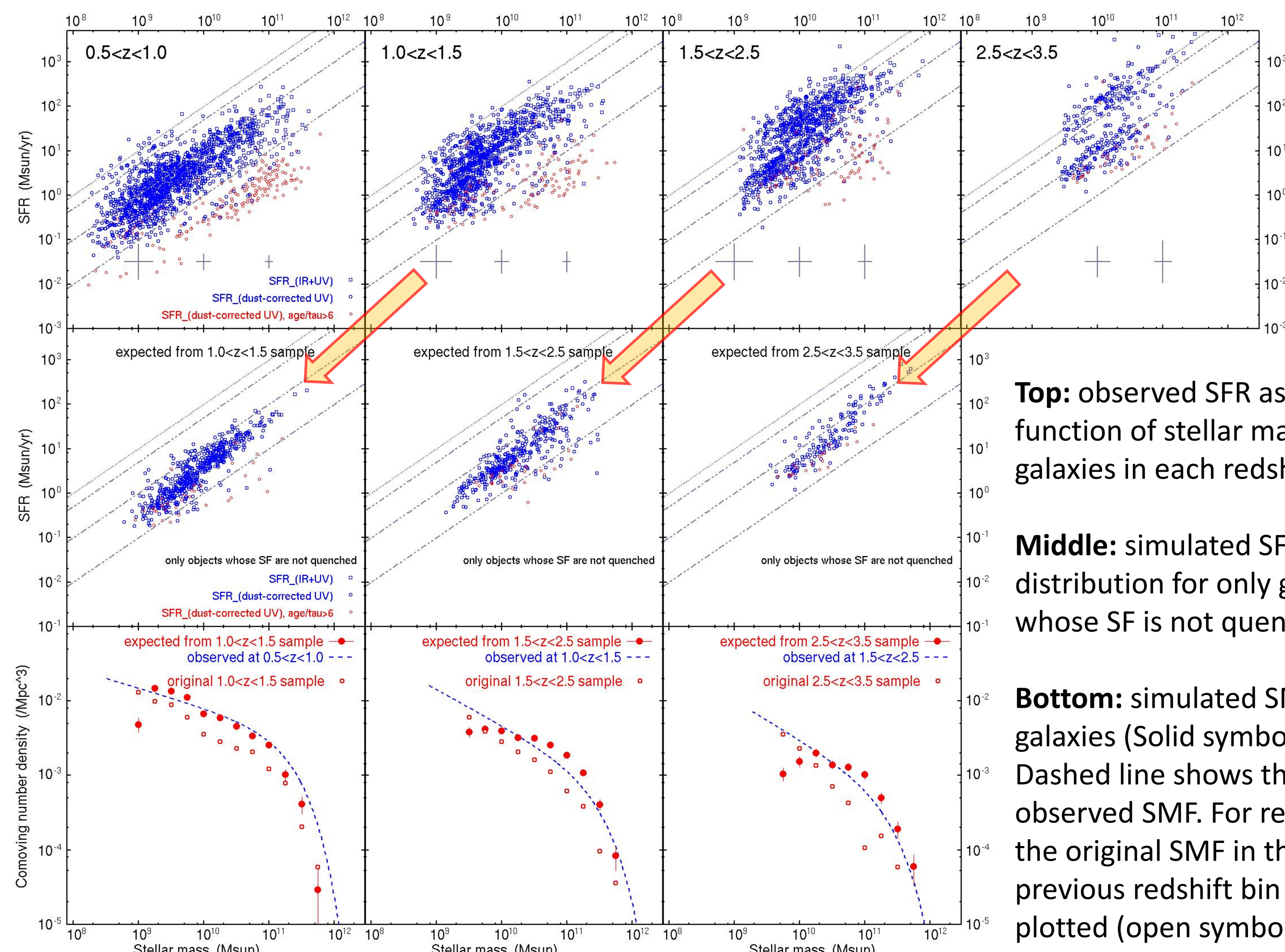
- Mass-dependent quenching rate
- No redshift evolution ??

Stellar mass growth by star formation

We estimated SFR for the sample galaxies from the rest-UV luminosity and Spitzer/MIPS 24μm flux , and simulated the stellar mass growth by star formation from a given redshift bin to the next redshift bin.

➤ Assumptions
- constant (observed) SFR between the redshift bins unless quenching occurs
- simple mass-dependent quenching rate (dashed-dotted line in the above figure)

➤ Monte Carlo simulation
- A redshift within the next redshift bin is randomly selected for each galaxy.
- We calculated stellar mass growth every 100Myr, and stellar mass is randomly occurred at the above quenching rate for stellar mass in each time step.



Top: observed SFR as a function of stellar mass for all galaxies in each redshift bin

Middle: simulated SFR-M_{star} distribution for only galaxies whose SF is not quenched

Bottom: simulated SMF for all galaxies (Solid symbols). Dashed line shows the observed SMF. For reference, the original SMF in the previous redshift bin is also plotted (open symbols).

- Quenching prevents over-production of very massive galaxies. But the number of ~M* galaxies is slightly over-predicted.
  → over-estimate star formation or quenching is more efficient??
- Simulated SFRs at a given mass tend to be systematically lower than observed.
  → additional high-SSFR population (newly formed or additional starburst) is needed?
  → stellar mass growth by star formation (constant SFR) is over-estimated?