The Galaxy—Halo Connection Across Cosmic History

石川　将吾 (NAOJ/CfCA)

第４回 銀河進化研究会, 2017年６月８日

Reference: Ishikawa et al. (2017), ApJ, 841, 8

Co-Investigators

Nobunari Kashikawa, Jun Toshikawa, Masayuki Tanaka, Takashi Hamana, Yuu Niino, Kohei Ichikawa, and Hisakazu Uchiyama

Introduction

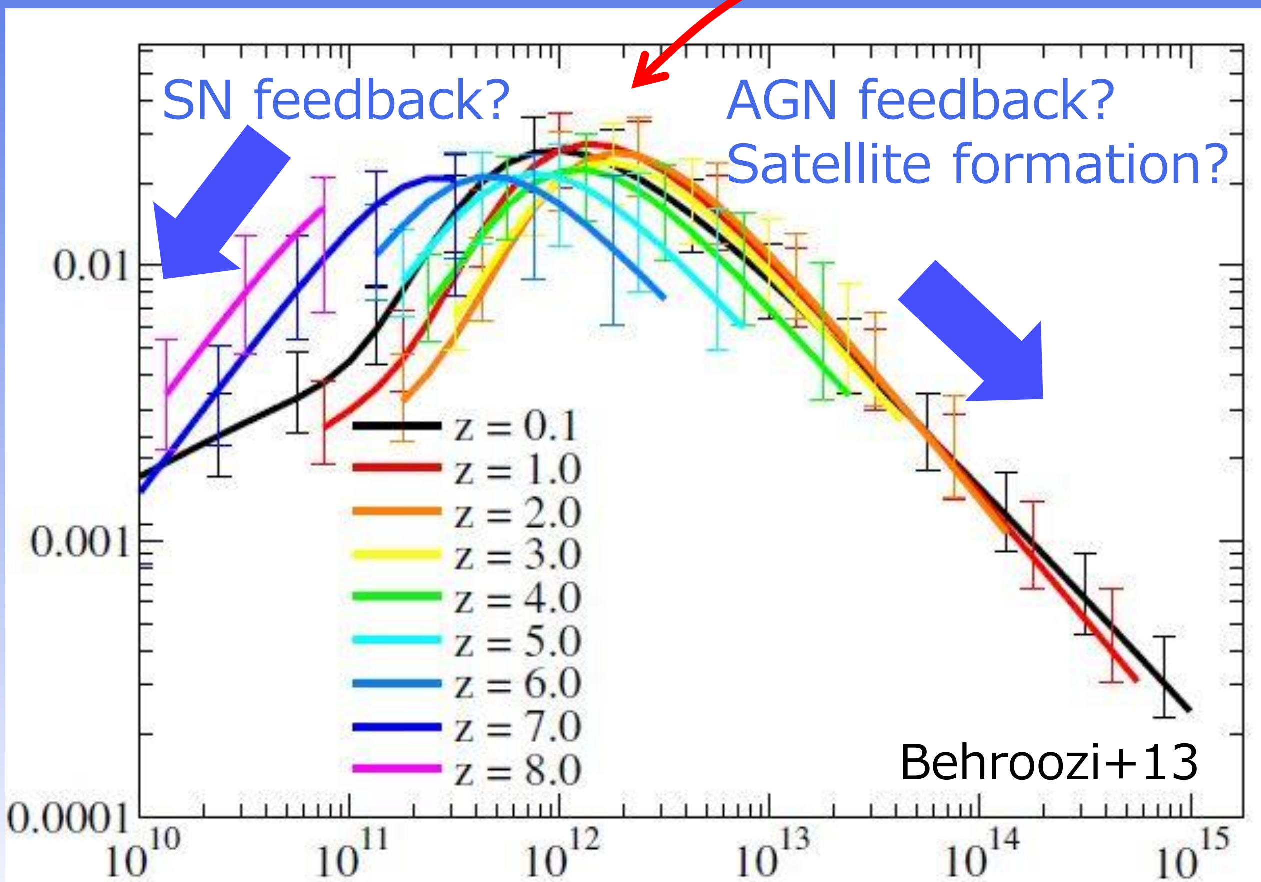
Introduction

Stellar-to-halo Mass Ratio (SHMR)

Star-formation efficiency as a function of DMH mass

~ Mstar/Mhalo

Pivot halo mass



SHMR (Mstar/Mhalo)

Dark Matter Halo Mass [Msun]

Numerical simulation predicts z=0-8

Star-formation is suppressed at the massive/less-massive end

DMH masses with peak SHMR (pivot halo masses) are almost unchanged

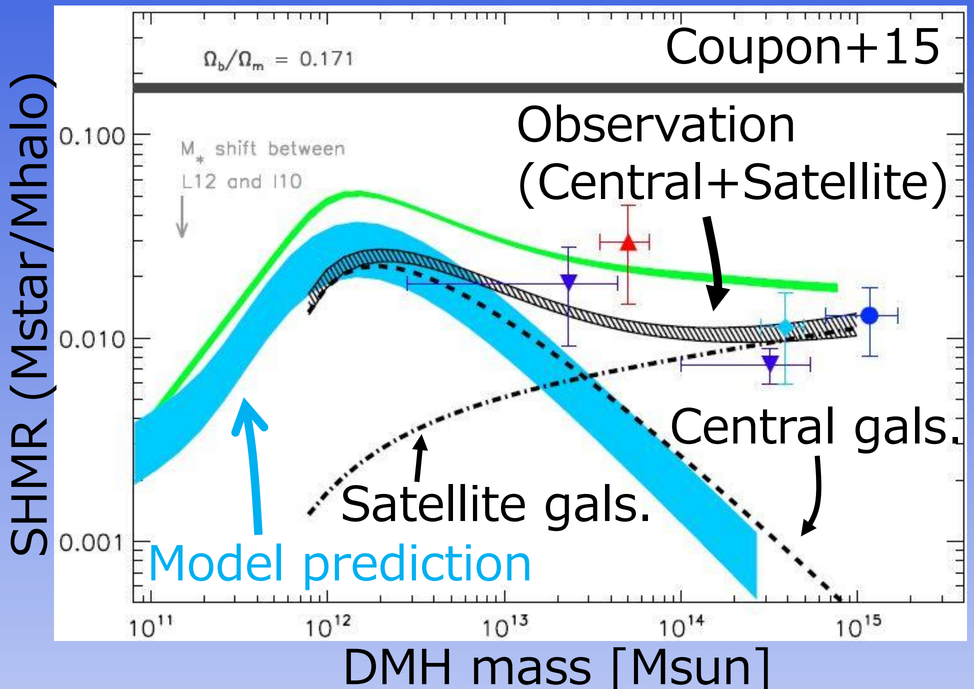
Introduction

Stellar-to-halo Mass Ratio (SHMR)

Why High-z?

SHMR is well constrained in low-z Universe

- Pivot halo mass is consistent with the model
- Massive end becomes flat due to satellite galaxies



...But SHMR at high-z have not been well studies!

- DMH mass estimation in high-z is difficult

  Large number of high-z galaxy samples are required

- Galaxy stellar mass estimation in high-z is difficult

  Deep (and wide) multi-wavelength imaging data are required

Stellar Mass Estimation

Imaging Data

Construct large LBG samples at z~3, 4, 5

Optical data: CFHT Legacy Survey Deep Field

Optical 5-band survey (u, g, r, i, z-band)

Deep imaging data（i<27.3mag, 3sigma, AB)

Wide survey area (1.0 deg x 4 fields)

Selected LBG samples

z~3: 63,563　z~4: 47,760　z~5: 9,477

NIR data: WIRCam Deep Survey

NIR 3-band survey (J, H, K-band)

Covered ~half area of the CFHTLS

Deep imaging data（K<24.5mag, 3sigma, AB)

→ SED fitting

Stellar Mass Estimation

Consistency of Stellar Masses

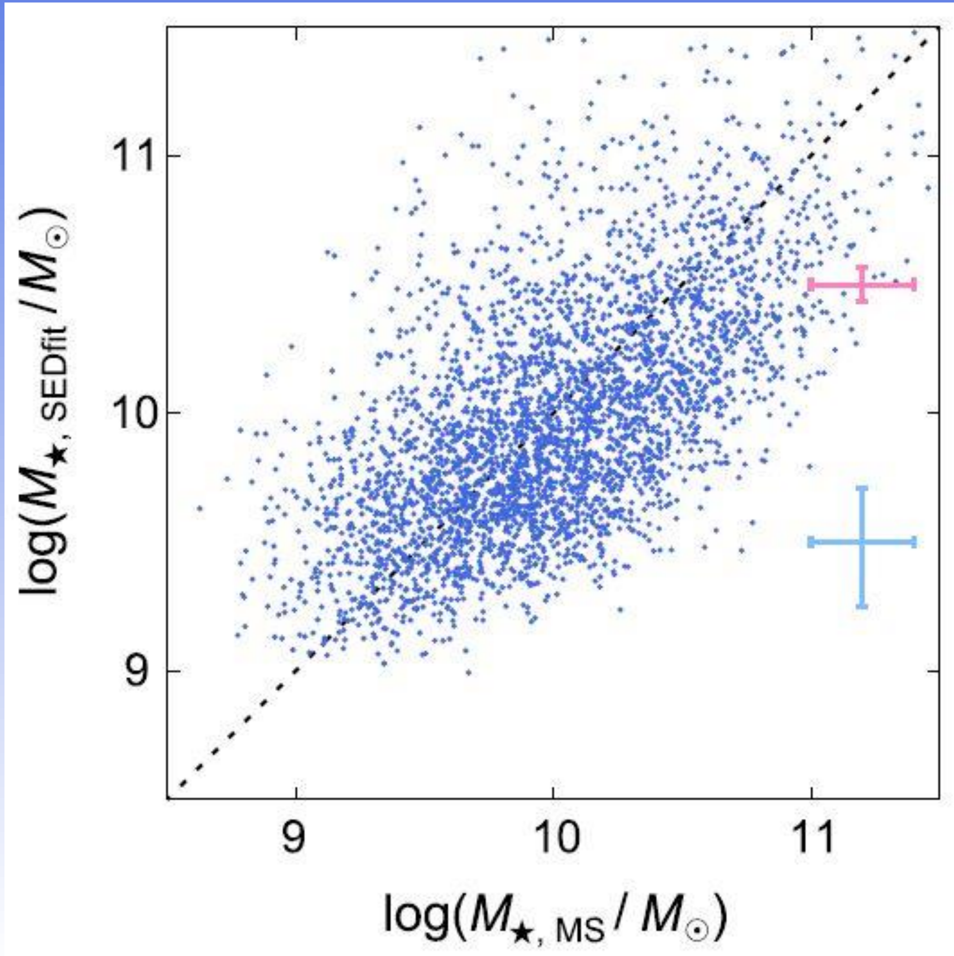
We estimate stellar masses of LBGs in two ways

- Main sequence of star-forming galaxies
- SED fitting technique

Stellar mass shows nearly a one-to-one correspondence

We adopt the MS relation to use

- all of the selected LBGs
- faint LBGs



Dark Matter Halo Mass Estimation

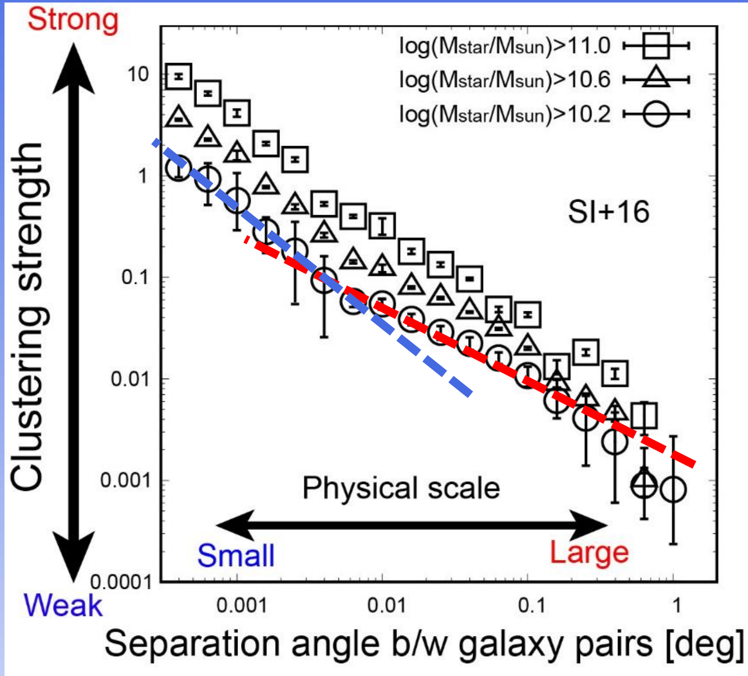
Angular Correlation Function

Statistical measurement of the galaxy clustering

Angular correlation function (ACF)

$$\omega(\theta) \approx <DD> / <RR>$$

<DD>: the number of galaxy pairs
<RR>: the number of random pairs
with separation angle θ

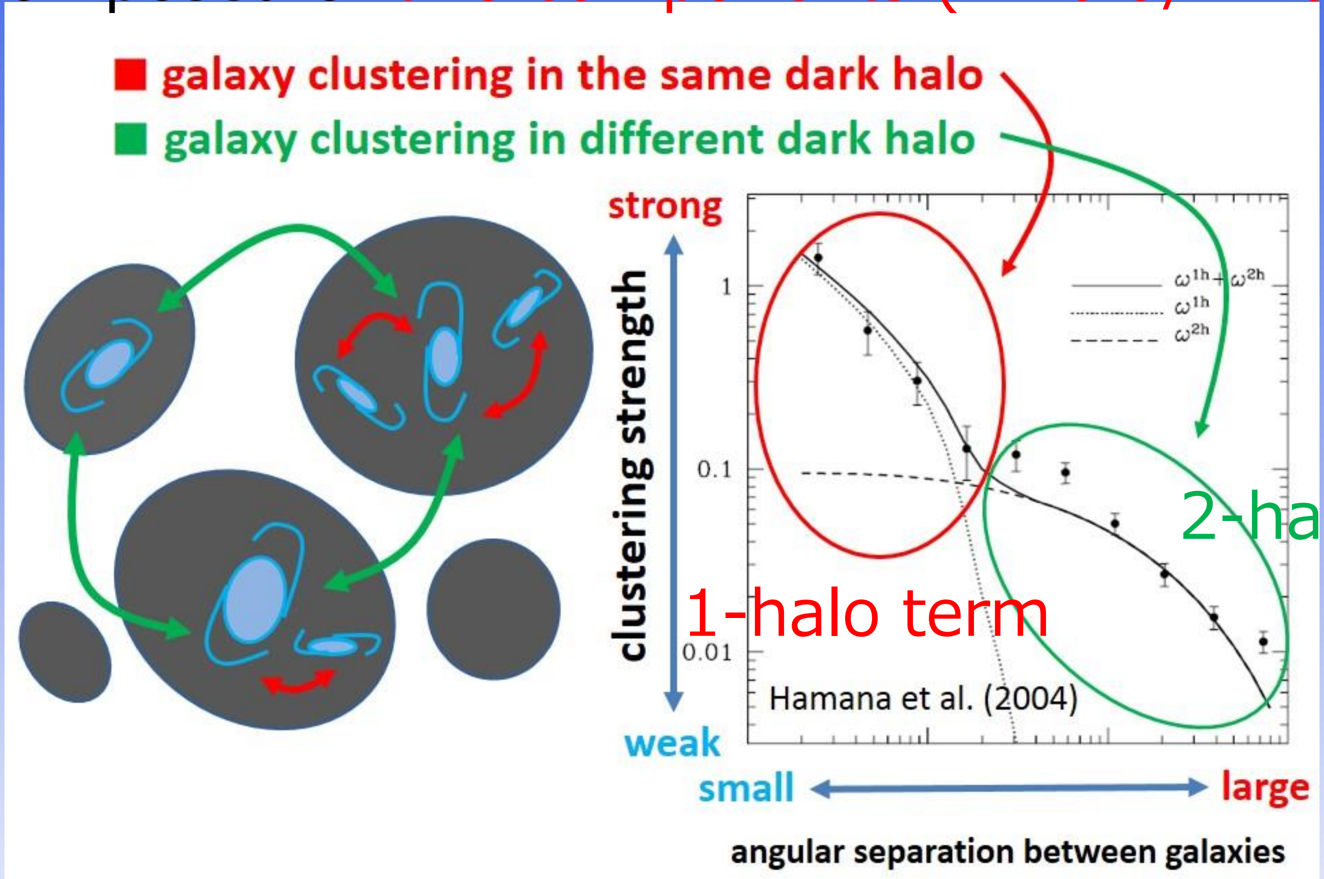


Strong galaxy clustering -> larger values of w(θ)

Large number of galaxy samples are required to measure ACFs with good S/N...

Dark Matter Halo Mass Estimation
Halo Occupation Distribution

ACF is composed of two components (1-halo/2-halo term)



Predict ACFs assuming the relation b/w galaxies and DMHs

➡ Halo Occupation Distribution (HOD) model

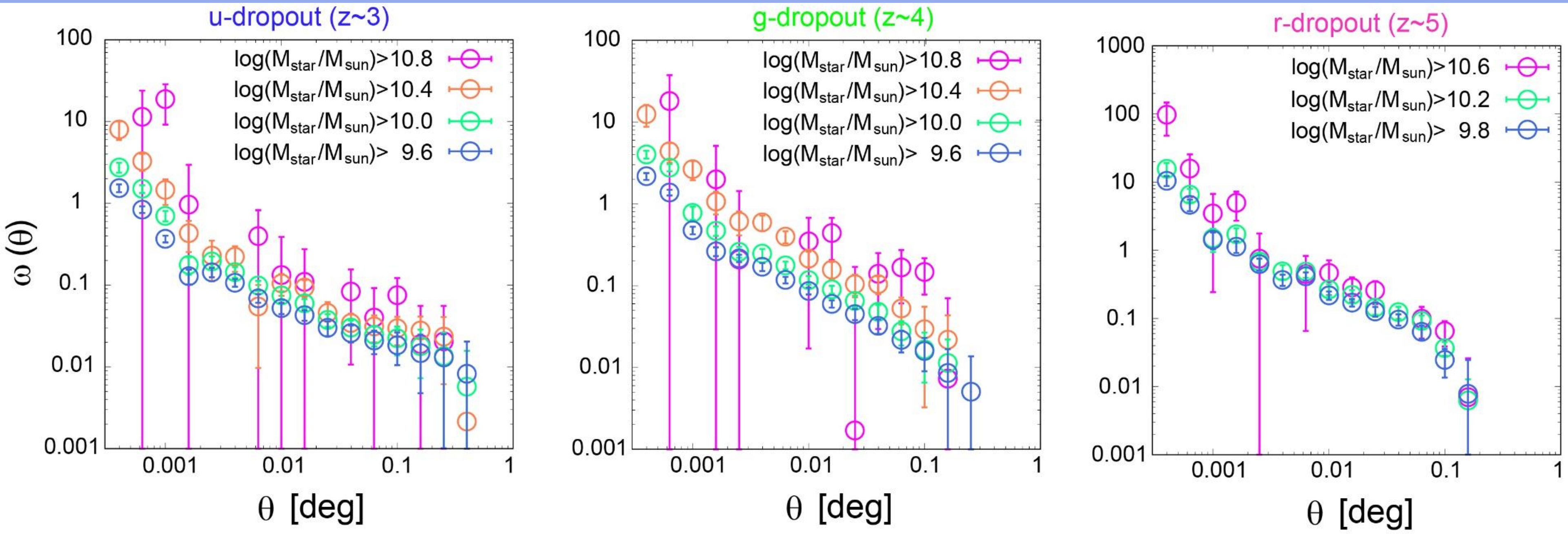
Results and discussion

- Clustering/HOD analyses
- Dark matter halo mass
- Satellite fraction
- Stellar-to-halo mass ratio

Results and Discussion
Clustering Analyses

We compute ACFs at z=3, 4, 5 as a function of galaxy stellar mass

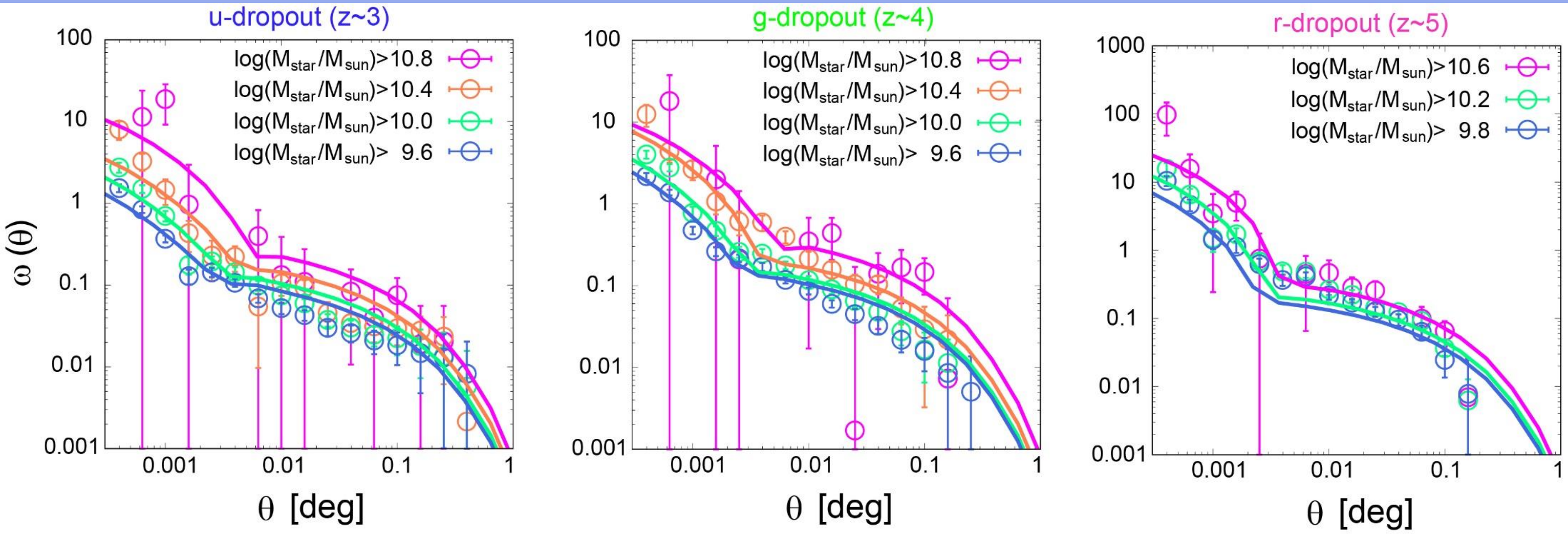
- Massive galaxies show the strong clustering
- High-z galaxies show the strong clustering at fixed a stellar mass



Results and Discussion
Clustering Analyses

We compute ACFs at z=3, 4, 5 as a function of galaxy stellar mass

- Massive galaxies show the strong clustering
- High-z galaxies show the strong clustering at fixed a stellar mass
- the HOD model well represents observed ACFs

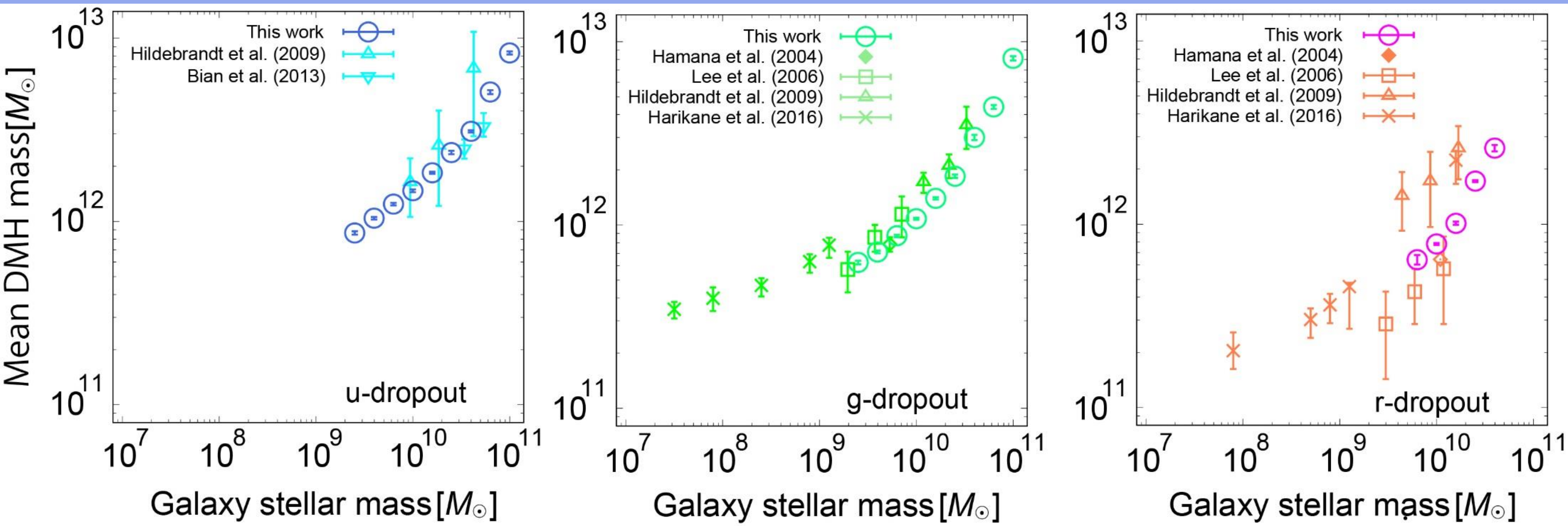


Results and Discussion

Dark Matter Halo Mass

DMH masses as a function of galaxy stellar mass

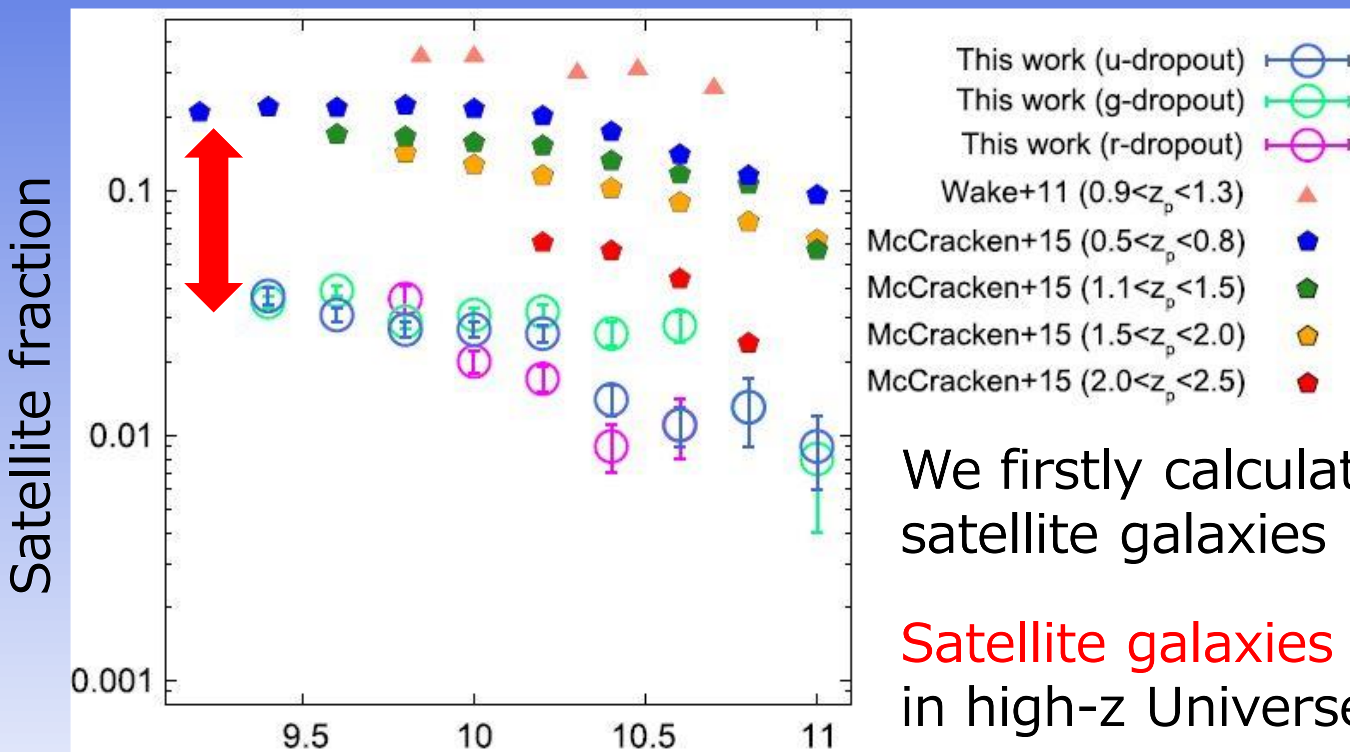
- We derive DMH masses with wide stellar mass range and small errors
- Our DMH mass estimation is consistent with previous studies
- LBGs reside in DMHs with masses of 10^{12} M_{sun}



Results and Discussion

Satellite Fraction

We compute a fraction of satellite galaxies as a function of stellar mass



log(Mstar/Msun)

This work ($3<z<5$)

Literature ($0.9<z<2.5$)

We firstly calculate the fraction of satellite galaxies in high-z

Satellite galaxies are rarely formed in high-z Universe

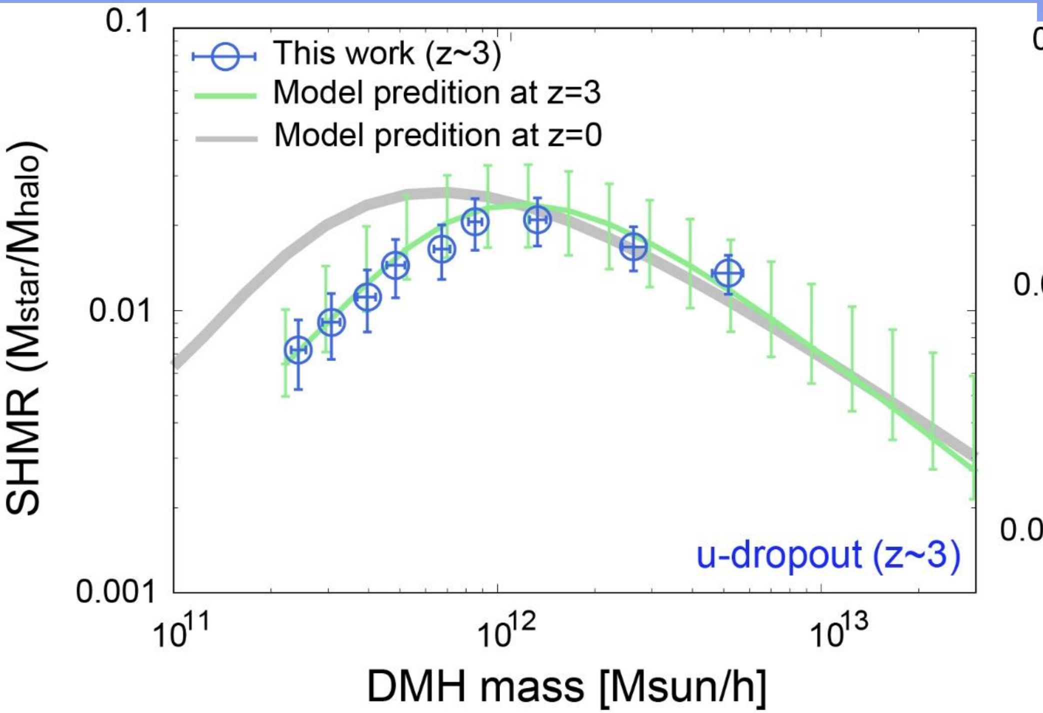
The number of satellite galaxy drastically evolves from z=3 to z=1

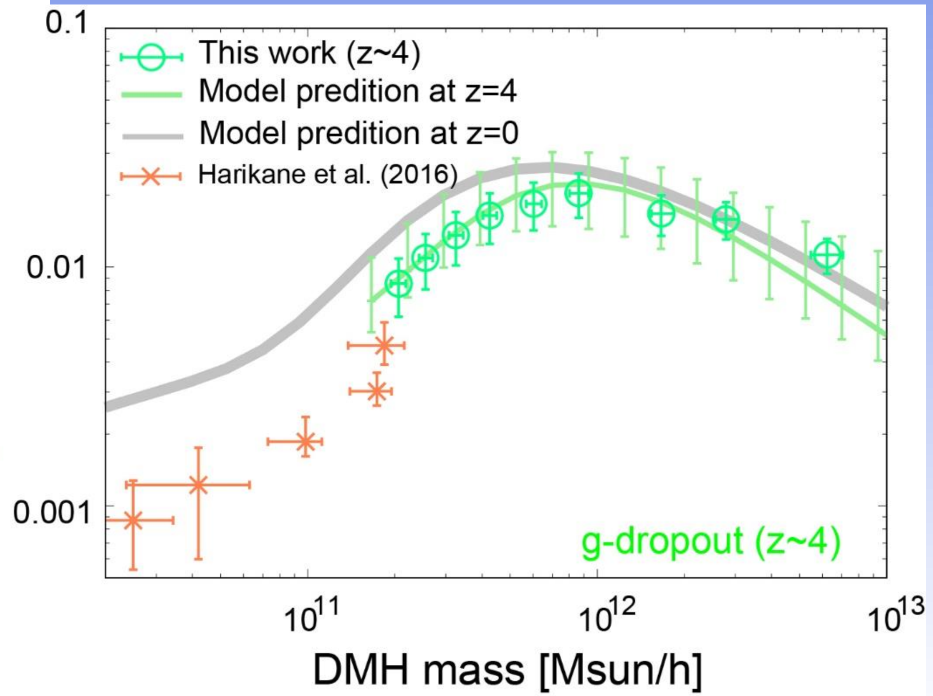
Results and Discussion

Stellar-to-halo Mass Ratio

Our stellar-to-halo mass ratios at z=3-5...

- are consistent with the model prediction (Behroozi+13)
- show significant evolution from z=0 (gray solid line)
- firstly capture pivot halo masses at z>3

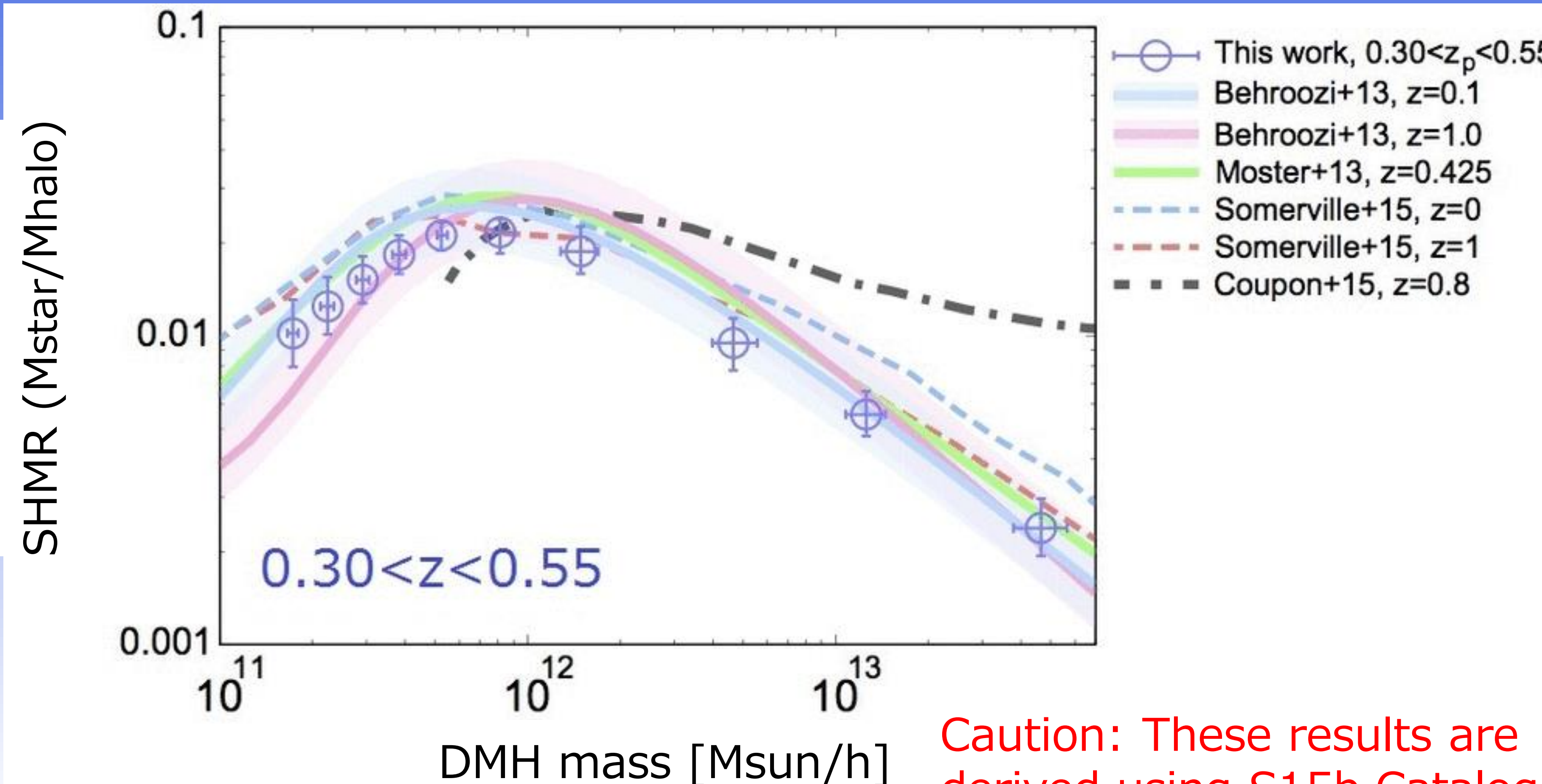




Results and Discussion

Stellar-to-halo Mass Ratio in Low-z

We also compute precise stellar-to-halo mass ratios at 0.3<z<1.4 using the excellent dataset of the HSC SSP



Caution: These results are derived using S15b Catalogue

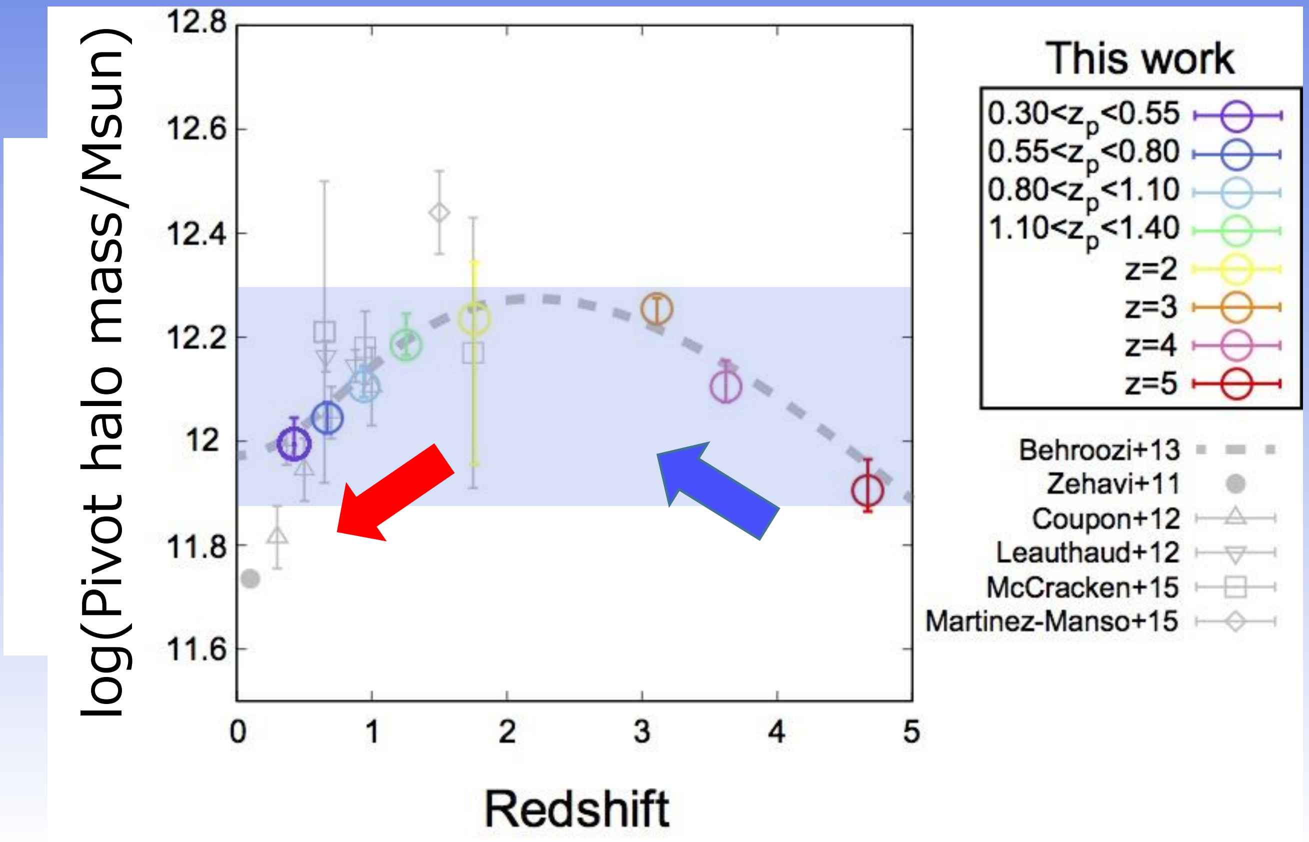
Results and Discussion

Redshift Evolution of Pivot Halo Mass

Pivot halo mass shows small increasing trend with cosmic time at z>3

At z<2, pivot halo mass decreases with decreasing redshift (downsizing)

Galaxies are efficiently formed within DMH with mass of 10^{12} M_{sun}



Highlights

- ✓ We construct large galaxy samples at z=3, 4, and 5, and carry out precise clustering analyses . Clustering strength monotonically increase with increasing galaxy stellar mass and redshift.

- ✓ LBGs are hosted in DMHs with masses of $10^{11.7\text{-}12.8}$ $h^{-1}M_{sun}$, which is consistent with results of previous studies. Our analyses show that satellite fraction of LBGs is less than 4%, indicating that satellite galaxies rarely form in high-z Universe.

- ✓ The observed SHMRs at z=3-5 are in good agreement with the model prediction.

- ✓ We find the pivot halo mass is almost unchanged around 10^{12} M_{sun} at $0<z<5$. Our study provides observationally evidence that galaxy formation is ubiquitously most efficient near a DMH mass of $M_h \sim 10^{12}$ M_{sun} over cosmic time.