Clustering Properties of Lyman-break galaxies at $z \sim 3$ based on SXDS and UKIDSS UDS

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Introduction
Galaxy Evolution
— Cold Dark Matter Model

Galaxies are born and evolve in Dark Haloes (DH).

To what dark haloes (given DH mass) do galaxies of a given SFR, Mstar, dust, …etc belong?

DH mass ⇔ Clustering strength

We study relation between properties of galaxies and DH mass based on clustering analysis of Lyman-break galaxies.

< Lyman-break galaxies>
- detected by spectral break at Lyman-limit redshifted into optical wavelengths
- young star-forming galaxies with strong UV continuum
- one of the most popular galaxy population at high redshift

$z \sim 3$
- the highest redshift where ground-based near-IR observation can scope rest-frame optical properties
Galaxy Evolution
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\[ \text{DH mass} \leftrightarrow \text{Clustering strength} \]

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(e.g., Giavalisco & Dickinson 2001; Lee et al. 2006)
Galaxy Evolution — Cold Dark Matter Model

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Mstar ⇔ rest-frame near-IR luminosity

SFR ⇔ rest-frame UV luminosity

(e.g., Giavalisco & Dickinson 2001; Lee et al. 2006)
Optical data: SXDS Project

A project to carry out a multi-wavelength survey for a very large area ($\sim 1^\circ$).

- **field**: Subaru XMM-Newton Deep Field (R.A., Dec) = (2h 18m, -5°)

- **optical imaging**: Subaru / Suprime-Cam

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<tr>
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<th>V</th>
<th>R</th>
<th>i'</th>
<th>z'</th>
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<td>limit mag. (mag.)</td>
<td>28.44</td>
<td>27.86</td>
<td>27.65</td>
<td>27.10</td>
<td>26.32</td>
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- **U-band**: only SXDF-S 26.97 (mag.)

- **survey area** (U – z'): 740 arcmin$^2$

Survey area of optical (Subaru/Suprime-Cam), And X-ray (XMM-Newton)
Optical data: SXDS Project

A project to carry out a multi-wavelength survey for a very large area (\(\sim 1^{\circ}\)).

- **field:** Subaru XMM-Newton Deep Field
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### Limit magnitudes

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- **U-band:** only SXDF-S
  26.97 (mag.)

- **survey area (U – z'):** 740 arcmin\(^2\)
Near-IR data: UKIDSS Ultra Deep Survey

A project to carry out a multi-wavelength survey for a very large area (~1°).

- field: Subaru XMM-Newton Deep Field
  (R.A., Dec) = (2h 18m, -5°)

- near-IR imaging:
  UKIRT / WFCAM

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<td>24.02</td>
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- survey area (U – z’, J, K): 561 arcmin²
z \sim 3 \text{ LBG Sample}
Detection of LBGs at $z \sim 3$

A typical spectrum of a young star-forming galaxy

Characterized by a large spectral break at Lyman $\alpha$ and Lyman limit.

Broad band

LBGs at $z \sim 3$ are selected by a set of U, V, and $z$ bands.
Selection by 2-color diagram

**Red lines:**
- Model spectrum of a young star-forming galaxies
  - $z = 2 - 3.5$

**Green, sky blue, blue lines:**
- Model spectrum of local elliptical, spiral, irregular galaxies
  - $z = 0 - 2$

**Asterisks:**
- Galactic stars

- HDF photometric redshift catalog
  - black : $z < 2.0$
  - blue : $2.0 < z < 2.5$
  - sky blue : $2.5 < z < 3.0$
  - green : $3.0 < z < 3.5$
  - pink : $3.5 < z < 4.0$
  - red : $4.0 < z$
Selection by 2-color diagram

- : all of the detected objects

\[ N = 795 \quad (z \leq 25.5) \]

J detected: 61
K detected: 144
completeness and contamination

completeness and contamination are estimated by Monte-Carlo simulation.

Detection/Selection rate is calculated by artistic galaxies of various mag. and redshift $p(m, z)$

HDF-N photo-z catalog is used as Local galaxy catalog.

boundary redshift $z_0 = 2.9$

$<z> = 3.3$
Clustering
clustering segregation with UV luminosity

- angular correlation function: $\omega(\theta)$
  $$\omega(\theta) = A_\omega \theta^{-\beta}$$

- redshift distributions of samples
  $\leftarrow N(z)$ by simulation

$\Rightarrow$ spacial correlation function $\xi(r)$
  $$\xi(r) = (r/r_0)^{-1.6}$$
  $r_0$: clustering strength

Angular correlation function

Spacial correlation function

Brighter galaxies in UV belong to DHs of larger mass
clustering segregation with optical luminosity

Rest-frame optical luminosity 
(K mag)

Rest-frame UV luminosity 
(z’ mag)

Angular correlation function

Spatial correlation function

bright

dark

dark

bright
clustering segregation with optical luminosity

1. Spacial correlation function
2. Angular correlation function

Rest-frame UV luminosity ($z'$ mag)
Rest-frame optical luminosity (K mag)

Bright
Dark
clustering segregation with optical luminosity

Rest-frame UV luminosity ($z'$ mag)

Rest-frame optical luminosity (K mag)

Spacial correlation function

Angular correlation function

Angular correlation function

$r_0$ [h⁻¹ Mpc]

$z'$ magnitude

$r_0$ [h⁻¹ Mpc]

$z'$ magnitude
Stellar mass, SFR \( \sim \) DH mass

- **Galaxies of large stellar mass**
  - DH mass: large
  - SFR: small
  - Bright rest-frame UV luminosity

- **Galaxies of small stellar mass**
  - DH mass: small
  - SFR: large
  - Dark rest-frame UV luminosity

A limit of SFR is determined by DH mass?
clustering segregation with dust extinction

E(B-V) $\leftarrow (R - z')$ can be used as an indicator:

\[
\begin{align*}
<R - z'> &= 0.16 \quad \Leftrightarrow \quad E(B-V) \sim 0.25 \\
<R - z'> &= 0.03 \quad \Leftrightarrow \quad E(B-V) \sim 0.15 \\
<R - z'> &= -0.12 \quad \Leftrightarrow \quad E(B-V) \sim 0.0
\end{align*}
\]

(assuming typical SED of LBGs at $z \sim 3$)

Galaxies with more dust extinction belong to DHs of larger mass.
Summary

We study clustering properties of LBGs at $z \sim 3$ in SXDS-S. (795 arcmin$^2$, $N = 23.0 < z' < 25.5$)

- Optical, UV luminosity and DH mass

- Galaxies with more dust extinction belong to DH of larger mass.