The FMOS-COSMOS survey: Measurement of galaxy density field and clustering properties at z~1.6

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Introduction:
Galaxy evolution revealed by Subaru/FMOS

How are galaxies built up with cosmic time?
- Star-formation activity
- Environmental effects
- Roles of AGNs and SMBHs

Subaru/FMOS is very unique NIR instrument:
• Wide field-of-view (30’ diams.)
• High multiplex (400 fibers)
  ➡ Powerful for mapping general galaxy populations and for catching rare objects
• Near-IR window & high-resolution
  ➡ Suitable for Hα emission from high-z (z>1)
The FMOS-COSMOS survey

PI: John Silverman (Kavli IPMU)

A large spec. survey designed to detect Hα emission line from star-forming galaxies (sBzK, SED-selected) with $M_\star \gtrsim 10^{10} M_\odot$ and $z \sim 1.6$.

- **accurate SFR from Hα**
  - less affected by extinction
  - most well-defined indicator at $z=0$
  - Kashino+13; Rodighiero+14

- **ISM conditions from key lines**
  - Hα, Hβ, [NII], [OIII]
  - Metallicity / Ionization (BPT diag.)
  - Yabe+12,14; Zahid+14ab
  - Kartaltepe+, submitted

- **the local density field**
  - general SF population by spec-z beyond $z \sim 1$
  - small scales traced by multiple exp.

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Star-forming main sequence

Stellar mass [$M_\odot$]

Kashino, Silverman+13
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Mass-metallicity relation

SDSS $z=0$
FMOS $z=1.6$
Zahid, DK, Silverman+14
The FMOS-COSMOS survey

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- **the local density field** • general SF population

- by spec-z beyond z~1

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**Fig. 3.— The BPT diagram, [OIII]/Hβ versus [NII]/Hα, for two optically selected galaxy samples at high redshift with near-infrared spectroscopy at z~1.5 (green, from the high resolution FMOS program; Silverman et al. 2014) and z~2.2 (gray, from MOSFIRE; Steidel et al. 2014) in comparison to our infrared selected sample at z~1.5 (red). Over-plotted are the AGN classification lines at z=0, z=1.5, and z=2.2 from Kewley et al. (2006, 2013) and the contours of the full SDSS sample at low redshift. Note the offset between the infrared and optically selected samples.**

**References:**

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![BPT diagram](image-url)

Fig. 3.— The BPT diagram, $\log([\text{OIII}]/H\beta)$ versus $\log([\text{NII}]/H\alpha)$, for two optically selected galaxy samples at high redshift with near-infrared spectroscopy at $z \llap{\sim} 1.5$ (green, from the high resolution FMOS program; Silverman et al. 2014) and $z \llap{\sim} 2.2$ (gray, from MOSFIRE; Steidel et al. 2014) in comparison to our infrared selected sample at $z \llap{\sim} 1.5$ (red). Over-plotted are the AGN classification lines at $z=0$, $z=1.5$, and $z=2.2$ from Kewley et al. (2006, 2013) and the contours of the full SDSS sample at low redshift. Note the offset between the infrared and optically selected samples.
The FMOS-COSMOS survey

Completed observations | S12A-S14A

- **H-long | Hα + [NII] — 14 nights**
  Japan time (Intensive; PI JDS)
  +UH time (Sanders, Zahid)
  4-5 hour integration per pointing

- **J-long | Hβ + [OIII] — 7 nights**
  UH-time (PI: D. Sanders)

Additional nights | S15A-S15B

- New intensive program: 9 nights
- UH time: 6 nights (S15A)
  - H- & J-long gratings
  - Covering the whole COSMOS field!
  - Rare key populations
    — Massive galaxies & AGNs
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The FMOS-COSMOS survey
Redshift measurements

Observed galaxies: 2232
Emission line detections: 1145
(sBzK/SED-selected)

- zFlag ≥ 1: Single line w/ SN > 1.5, 101
- zFlag ≥ 2: Single line w/ SN > 3, 224
- zFlag ≥ 3: Single line w/ SN > 5, 150
- zFlag ≥ 4: SN > 5 + additional line, 510

Redshift vs Ha flux [cgs]
Ha flux vs SN

- zFlag = 1: Single line w/ SN > 1.5
- zFlag = 2: Single line w/ SN > 3
- zFlag = 3: Single line w/ SN > 5
- zFlag = 4: SN > 5 + additional line

Signal-to-Noise ratio
The FMOS-COSMOS survey

Redshift measurements

Observed galaxies: **2232**  ▶  Emission line detections: **1145**
(sBzK/SED-selected)

Comoving distance $[h^{-1}\text{Mpc}]$
Data & analysis:
Galaxy samples

Field
1.43<z<1.74 (~450 h⁻¹Mpc)
Area = 0.84 deg² (~50x50 h⁻¹Mpc)
Volume = 1.14 x10⁶ h⁻³Mpc³

Photometric sample: 22299
UltraVISTA catalog — K_AB < 24mag
Photo-z based on “LePhare”
(McCracken et al. 2011, Ilbert et al. 2013)

Spectroscopic sample: 665
FMOS: 573 galaxies with S/N>5
zCOSMOS-deep: 165 galaxies
PI S.Lilly (ETH) w/ a flag ≥ 3
(overlap 73)
Data & analysis:
Density measurements

Galaxy number counting:

Window function $W$ and smoothing kernel $R$

Cylinder window: the projected distances within some velocity interval (~1000 km/s).

Adaptive $R$ can provide a measurement with a larger dynamical range, commonly defined by the distance to the fixed $N$th nearest neighbor.

Combination of spec-z & photo-z samples:

Integral $P(z)$ within the cylinder.

$P(z)$ is modified based on the distribution of spectroscopic galaxies (The “ZADE” algorithm, detailed in Kovač et al. 2010)
Data & analysis: Clustering measurements

**Two-point correlation function** Peebles 1980

Landy & Szalay's (1983) estimator:

\[
\xi (r) = \frac{DD (r) - 2DR (r) + RR (r)}{RR (r)}
\]

**Projected correlation function**

minimize the effect of peculiar velocities of galaxies

\[
w_p (r_p) = \int_{-\infty}^{+\infty} \xi (r_p, \pi) d\pi = 2 \int_{0}^{\infty} \xi \left[ (r_p^2 + y^2)^{1/2} \right] dy
\]

In practice, a finite integral limit \(\pi_{\text{max}} (~40 \, \text{h}^{-1}\text{Mpc})\) is used.

**Bias & variance estimate**: Jackknife method
Results:
Measurement of the local density field

Redshift $1.43 < z < 1.74$

$log(1 + \delta_p)$

- 0.5-0.6
- 0.6-0.7
- 0.7-0.8
- 0.8-0.9
- 0.9-1.0
- >1.0

Preliminary
Two-point correlation function of spectroscopic sample

A anisotropy b/w $r_p$ and $\pi$ is clearly appears, which is possible evidence of “Finger-of-God” effect.
Results:
Galaxy clustering

Projected correlation function

\[ r_0 = 3.061 \pm 0.226 \, h^{-1}\text{Mpc} \]
\[ \gamma = 1.854 \pm 0.088 \]

Power-law fit

\[ r_0 = 3.06 \pm 0.23 \, h^{-1}\text{Mpc}; \, \gamma = 1.85 \pm 0.09 \]

Evolution of correlation length

Our measurement is consistent with other measurements based on a sample at similar stellar mass ranges \((\sim 10^{10.2} M_\odot)\).
Summary

From the first analyses based on 655 spec-z’s:

• The galaxy local density field has been measured, combining with the photometric sample.

• Two-pt. correlation function $\xi(r_p, \pi)$ and its projection $w_p(r_p)$ has been evaluated, which show a significant clustering signal.

• $\xi(r_p, \pi)$ shows a possible imprint of the “Finger-of-God” effect.

• The correlation length $r_0$ is consistent with previous studies.

On-going & Future

• Analysis has to be confirmed to be valid by Mock catalogs.

• Now we can start to study the environmental effects on the galaxy evolution.

• Statistics will be improved with the coming data in S15AB!