A highest redshift submillimeter galaxy candidate discovered in the Subaru Deep Field

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In high-z, star-formation is hidden by dust

More hidden star formation @higher redshift (>70% at z~1)

Based on the comparison of lum. functions at FUV with GALEX & IR with IRAS/Spitzer

Submillimeter galaxy (SMGs)

SMGs are ULIRGs in the early universe. Typically they have $L_{IR} \sim 10^{12-13} L_{\odot}$ and SFR of $\sim 1000 M_{\odot} \text{yr}^{-1}$.

The first submm deep image in HDF. Map area was 8 arcmin$^2$. 7 SMGs were detected (Hughes+98).

JCMT 15m dish. Submillimeter telescope located at Mt. Mauna Kea.

The first submm bolometer camera, SCUBA(Holland+98). Obs $\lambda = 850 \mu m$. 37 pix.
800-1300 µm observations are good eyes for $z>4$ starburst

Blain et al., 2002, Physics Reports, 369, 111-176
Submillimeter galaxies play important role in formation of massive galaxies

SMGs are massive starburst galaxies in the early universe.

SMGs are thought to be progenitors of massive ellipticals in the local universe and even in the early universe.

ID: 217431

$z_{\text{spec}} = 1.4277 / z_{\text{phot}} = 1.246$

Yun+12

Onodera+10
A problem we face - Redshift distribution -

Only ~70% of SMGs have optical/NIR photo-z
Redshifts of the others are in mystery.

Because of
1. Difficulty of counterpart identifications for SMGs in high-z
2. Faintness at optical/NIR wavelength

![Graph showing comparison between opt/NIR spec-z and photo-z for AzTEC sources in SXDF.](image1)

![Graph showing optical/NIR photo-z distribution based on 221 AzTEC sources in SXDF.](image2)
The remaining 30% can be z>3-4 SMGs

30% consist of radio/24 μm faint sources, so it’s difficult to identifying counterparts for SMGs based on radio, 24μm position.

Faintness at radio, 24μm indicates that these SMGs can be located at z>3-4.

‘High-z tail’ of redshift distribution of SMGs is still in mystery.
z>5 SMGs have been confirmed in radio/24μm faint SMGs

Indeed, confirmed z>5 SMGs are faint at radio and 24 μm except lensed sources. There are a few reports of confirmation of z>5 SMGs.
How is redshift distribution of 24 μm and radio faint SMGs?

More SMGs may be located at higher redshift.
The key is study of multi-wavelength faint SMGs except submm/mm.
AzTEC/ASTE SMGs surveys

TAO/CCAT site
Mt. Chajnantor

ASTE telescope (Ezawa+08);
located at 4800 m altitude in
Chile and near the ALMA site.

AzTEC camera
(Wilson+08);
-144 pix
-λ=1100μm
SDF and SXDF are suitable field for studies of SMGs because deep and wide multi-wavelength data are required for studies of SMGs which have low surface number density.

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<tr>
<th>Waveband</th>
<th>SXDF</th>
<th>SDF</th>
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<tr>
<td>Optical</td>
<td>Suprime cam/Subaru</td>
<td>Suprime cam/Subaru</td>
</tr>
<tr>
<td>Near infrared</td>
<td>WFCAM/UKIRT (UKIDSS,UDS)</td>
<td>WFCAM/UKIRT (Motohara+ in prep)</td>
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<td>Mid infrared</td>
<td>IRAC, MIPS/Spitzer (SpUDS)</td>
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<td>FIR infrared Submm</td>
<td>PACS, SPIRE/Herschel (HerMES)</td>
<td>PACS, SPIRE/Herschel (H-ATLAS)</td>
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<tr>
<td>Radio</td>
<td>VLA (Arumgam+ in prep)</td>
<td>VLA (Ly+ in prep)</td>
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AzTEC/ASTE 1100 μm maps in SDF and SXDF

281 sources (≥3.5σ or 1.5 mJy)

SXDF

35 sources (≥3.5σ or 1.6 mJy)

SDF

In total, 316 SMGs are discovered in SDF and SXDF

int time~30 hrs

200 arcmin²

R.A. (degree)

int time~195 hrs

1200 arcmin²
A highest-z SMG candidate-SDF1100.001

SDF1100.001 is the brightest SMG discovered by AzTEC/ASTE in SDF

‘a’ and ‘b’ were not detected by K-band (3σ, 24.1 m_{AB}), and shorter wavelength. So SDF1100.001 can be K-band dropout due to z>5.

The IRAC color and faintness at λ <=2.2 μm of them indicate that they are plausible z>5 sources.
Submillimeter interferometric imaging

Figures are deleted!

The candidate ‘a’ and ‘b’ are detected on 1300 μm continuum image with S/N > 5.

Ikarashi+ in prep
IRCS w/ AO188 observation of SDF1100.001

Observations
- Instrument: IRCS w/ AO188(LGS)
- Filter and mode: K’-band, 52mas
- Date: 2012/06/06, the former half night
- Achieved PSF: 0’’.35 (FWHM)
- Sensitivity: 26.18 M_\text{AB} (2 \sigma)
- PI: Ikarashi

Purpose
- Constrain photo-z of SDF1100.001
- 4000Å comes between K’-band and IRAC 3.6 μm band if the targets are located at z>~6
Result: A major merger by SMG-SMG in very early universe?

Figures are deleted!
Future plan 1

Estimating photo-z using dust SED of SDF1100.001

We will estimate photo-z using radio/submm photometric data, in order to confirm their photo-z taking advantage of extinction free.

We are awarded ALMA cycle 1 time for SDF1100.001 with the highest priority (2012.1.01020.S: PI. Ikarashi).

In ALMA cycle 1 observations, we will observe SDF1100.001 at 1100, 880 and 450μm.
Future plan 2

Searches for more K-band faint SMGs

How large fraction are higher or z>5 SMGs?
Are their extreme optical/NIR faint SMGs, i.e., 3.6 μm dropouts?

We are awarded ALMA cycle 1 time for 30 AzTEC-SMGs in SXDF with the highest priority (2012.1.0326.S: PI. Ikarashi).

In ALMA cycle 1 observations, we will observe 30 AzTEC SMGs faint at Herschel/VLA band at 1100 μm in order to identify their optical/NIR counterparts.
Summary

✓ Submillimeter observation can detect ULIRGs even at z~10, and more than hundreds of SMGs have been detected.
✓ We selected SDF1100.001 as one of the best candidates of the highest-z SMG based on faintness at K-band and IRAC color.
✓ We conducted follow up deep imaging of SDF1100.001 at K’-band using IRCS w/ AO188. The observations achieved a PSF of 0”.35 (FWHM) and a sensitivity of 26.2 M$_{\odot}$ (2σ).
✓ SDF1100.001 can be a merging system at z>5 with a total SFR of ~3000 M$_{\odot}$/yr.
✓ Our proposal of SDF1100.001 for ALMA cycle1 has been approved. 450, 880 and 1100 μm deep imaging and photometry will be conducted.
✓ We also conduct ALMA imaging of 30 AzTEC sources with high angular resolution in order to find more K’-band faint, z>5 SMG candidates in ALMA cycle1.