Subaru Super Deep Field (SSDF) using Adaptive Optics

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SSDF project: What?

Scientific motivation

1. Study the galaxy population at the unprecedented faint end (K’=23-25mag) to find any new population which may explain the missing counterpart to the extragalactic background light.

2. Study the morphological evolution of field galaxies in rest-frame optical wavelengths to find the origin of Hubble sequence.

→ high-resolution deep imaging of distant galaxies
SSDF project: How?

- Deep imaging of high-z galaxies with AO.
  - Improve detection sensitivity.
    - Peak intensity: ~ 10-20 times higher
  - Improve spatial resolution
    - FWHM < 0”.1

AO is best suited for the deep imaging study of high-z galaxies which requires both high-sensitivity and high-resolution.
SSDF project: Where?

- Target field: a part of “Subaru Deep Field” (SDF)
  - Originally selected to locate near a bright star for AO observations (Maihara+01).
  - Optical~NIR deep imaging data are publicly available.
    - Enable the SED fitting of detected galaxies.
      - phot-z, rest-frame color, stellar mass…
Observations

- AO36+IRCS at Cassegrain
  - K’-band (2.12um) imaging with 58mas mode
  - providing 1x1 arcmin² FOV

To achieve unprecedented faint-end, we concentrated on K’-band imaging of this 1arcmin² field, rather than wide-field or multi-color imaging.
Summary of the observations

- **S02A-IP1 (10 nights)**
  - 5 nights on Apr. ’02: ×
    - No observation was carried out due to bad weather.
  - 2 half nights on May ’02 (directors discretionary time): △
    - We obtained 5.5hrs data and confirmed the expected sensitivity and resolution with AO (pilot observation).
    - However, contamination of thermal background from telescope severely hampers the detection of faint galaxies.
    - Stopped AO TT-mirror operation to avoid the background.
  - 5 nights on Mar. ’03: ○
    - almost successful with good condition (one night was lost due to mechanical trouble)

- **S03A-062 -- 3 nights on Apr. ’03: ○**
  - successful with good condition

Total 7 nights
Results

SSDF ($K'$-band)

- Integration time: **26.8 hours**
- Limiting mag: $K'_{\text{vega}} \sim 24.7$
  (5 $\sigma$, point-source)
  - More than 0.7 mag fainter than previous deep imaging observations.
- Spatial resolution: **FWHM~0''.18**
  - Sharper than HST NICMOS
- Detected Objects: **145 ($K'\leq24.7$)**

Deepest $K'$-band image ever obtained with higher spatial resolution than the HST.
K-band galaxy count

- Number counts in the faintest end.
  - Obtained down to K’~25
    (~M_V^*+2 at z~3)
    0.5 mag fainter than previous data
- Slope of galaxy count
  (α=dlogN/dm)
  - α ~ 0.15 (K’>22)
  - Flatter than the slope at K<22 (α ~0.28).

Unusual galaxy population is not necessary to explain the faint-end counts.
High-resolution K’-band image of distant galaxies

K’-band imaging with AO is a unique method to study spatially resolved morphology of z=2-3 galaxies in the rest-frame optical.
Morphological analysis

- Decomposition of the surface brightness profile of galaxies using the PSF convolved Sersic model.

\[
I(r) = I(0) \exp\left[-\kappa_n \left(\frac{r}{r_e}\right)^{1/n}\right]
\]

(n=1: exponential, n=4: de Vaucouleurs)

- Size (effective radius; re)
- Morphology (Sersic index; n)
  (magnitude, axis ratio, PA)

Size (re) and morphology (n) are derived for the galaxies down to \(K' \sim 23\) (~0.6L* at z~3).
Redshift vs. Physical size [kpc]

- PSF size in the SSDF is smaller than the measured effective radii of the observed galaxies.

Obtained the spatially resolved morphology of galaxies out to $z\sim3$ for the first time.
Luminosity-size relation at z<3

- Mock local M_B-r_e relation at z=1-3.
  - Late type (upper)
    Catalog of local low-SB galaxies.
    (Impey et al. 1996)
  - Early type (lower)
    Catalog of local elliptical galaxies.
    (Bender et al. 1992)
Luminosity-size relation at $z<3$

- Comparison between $z=0$ and $z=1-3$
  - (●: SSDF, ×: Local galaxies)

  - Late type (upper)
    - $z<3$
      - Little or no evolution
  - Early type (lower)
    - $z<2$
      - No evolution
        - (except for a object with large uncertainty in size.)
    - $2<z<3$
      - Decrease in size at a given luminosity
        - can be explained by passive luminosity evolution.

Suggesting no intrinsic size evolution between $z\sim3$ and present-day.
Comparison with other AO imaging studies of high-z galaxies.

- Similar deep imaging studies with AO were performed using VLT/NACO: wide field (~15arcmin^2), but shallow depth (K<22) survey. (Cresci et al. 2006, A&A, 458, 385; Huetras-Company et al. 2006, astro-ph/0611220)
  
  Results: morphological evolution at z<1 (similar to the results of HST/ACS,WFPC2)

- Kinematical studies of star forming galaxies at z=1-2 were performed using Keck/OSIRIS and VLT/SINFONI. (Genzel et al. 2006, Nature, 442, 786; Wright et al. 2006, astro-ph/0612199)
  
  Results: found a large and massive protodisk galaxies at z~2

- Our works (SSDF): deepest (K<24.7), but small FOV (1arcmin^2) survey.
  
  Results: faintest galaxy count, morphological studies at z<3.

- Our morphological studies at z<3 is very unique, although survey volume is not enough to make statistics.

- Further investigation and confirmation with LGSAO is critical to strengthen our findings.
Contribution to the Subaru community.

- The SSDF data is not very useful for the Subaru community…

- The strategies for analyzing AO imaging data, which we learned through the SSDF project, could be useful for coming era of LGSAO.
Summary

Subaru Super Deep Field using AO

- Deepest and highest-resolution $K'$-band image ever obtained ($K'<24.7$, FWHM~0\".18).
- Derived the “spatially resolved” and “rest-frame optical” morphology of galaxies down to $K'\sim23$ (~0.6$L^*$ at $z$~3).

Faintest number counts of galaxies down to $K'\sim25$
- Flatter slope (0.15) than the previous data at the faint-end

Luminosity-size relation out to $z$~3
- Suggesting little or no intrinsic size evolution of galaxies out to $z$~3

Typical field galaxies have evolved mildly since $z=3$?