Subaru Super Deep Field (SSDF) using Adaptive Optics

Yosuke Minowa（NAOJ）

on behalf of Yoshii, Y. (IoA, Univ. of Tokyo; PI)

and SSDF team:

Kobayashi, N. (IoA, Univ. of Tokyo), Totani, T. (Kyoto Univ.), Takami, H., Takato, N. Hayano, Y., Iye, M. (NAOJ).

SSDF project: What?

Scientific motivation

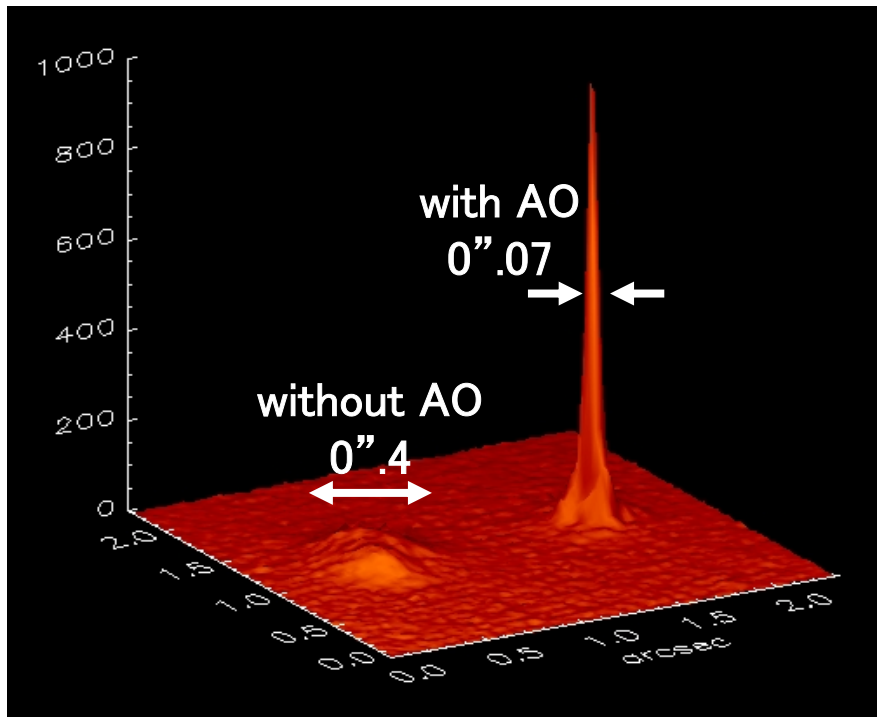
1. Study the galaxy population at the unprecedented faint end (K'=23-25mag) to find any new population which may explain the missing counterpart to the extragalactic background light.

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

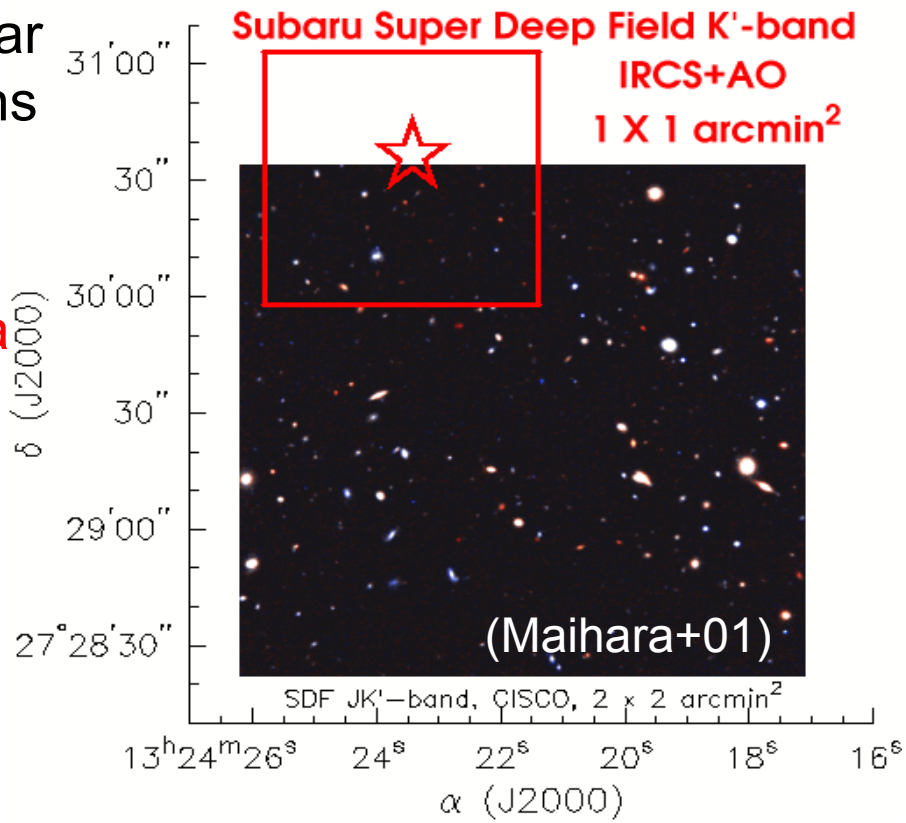


AO is best suited for the deep imaging study of high-z galaxies which requires both high-sensitivity and high-resolution.

SSDF project: Where?

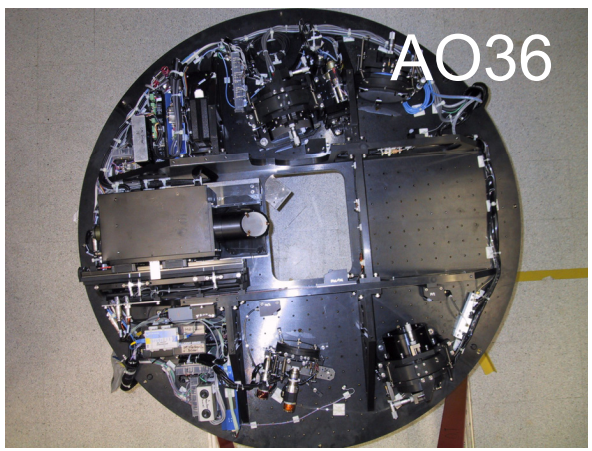
- Target field: a part of “Subaru Deep Field” (SDF)
  - Originally selected to locate near a bright star for AO observations (Maihara+01).
  - Optical~NIR deep imaging data are publicly available.
    - Enable the SED fitting of detected galaxies.

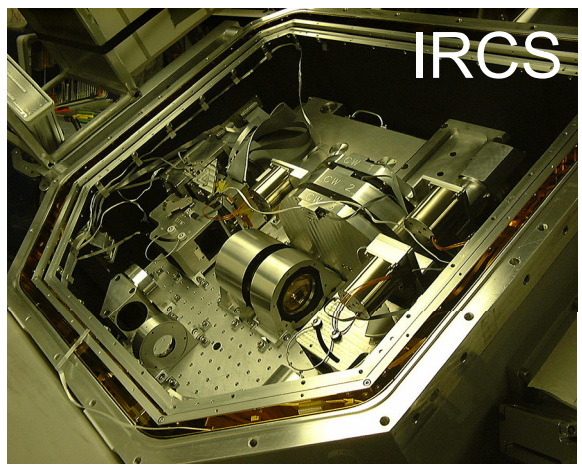
      → phot-z, rest-frame color, stellar mass…



Observations

- AO36+IRCS at Cassegrain
  - K'-band (2.12um) imaging with 58mas mode
  - providing 1x1 arcmin^2 FOV





To achieve unprecedented faint-end, we concentrated on K'-band imaging of this 1arcmin^2 field, rather than wide-field or multi-color imaging.

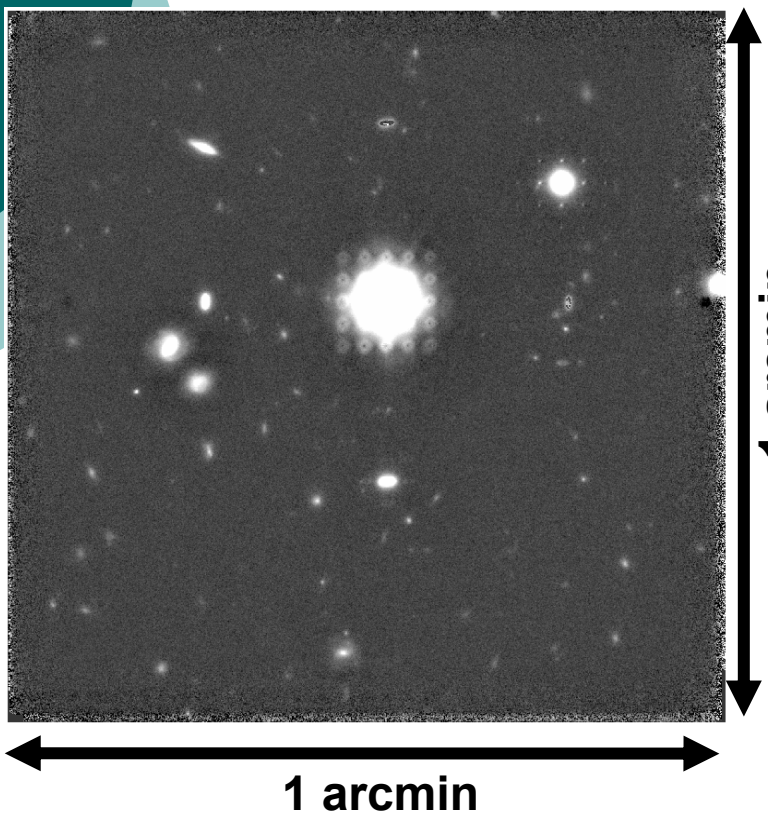
Summary of the observations

- 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

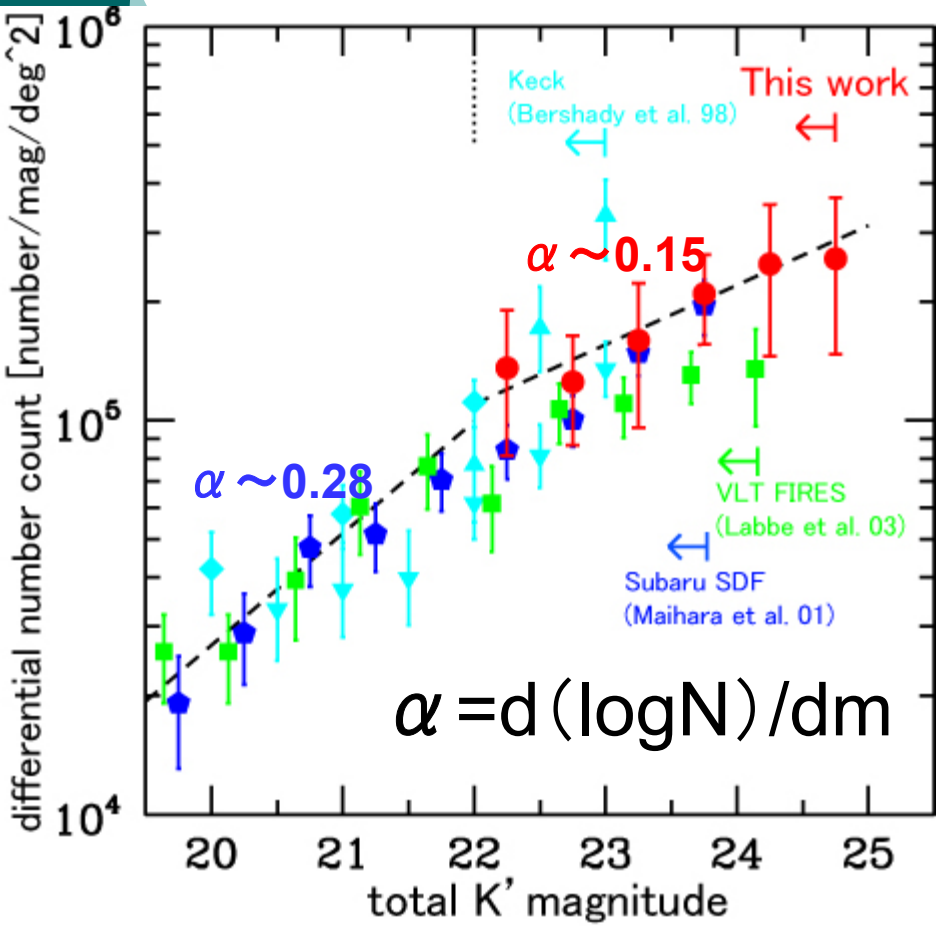
SSDF（K’-band）



- Integration time： **26.8 hours**
- Limiting mag： **K'_{vega} ~24.7**
  （5σ, 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’<24.7)**

Deepest K’-band image ever obtained with higher spatial resolution than the HST.

K-band galaxy count

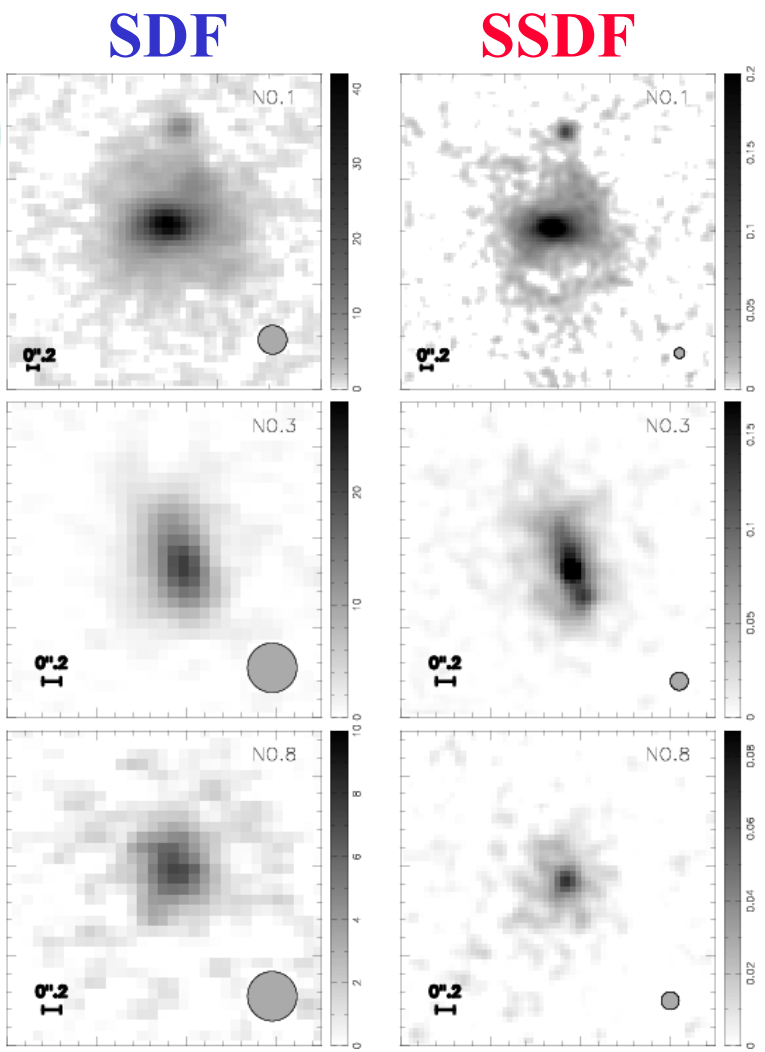


※Completeness>50%

- 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).

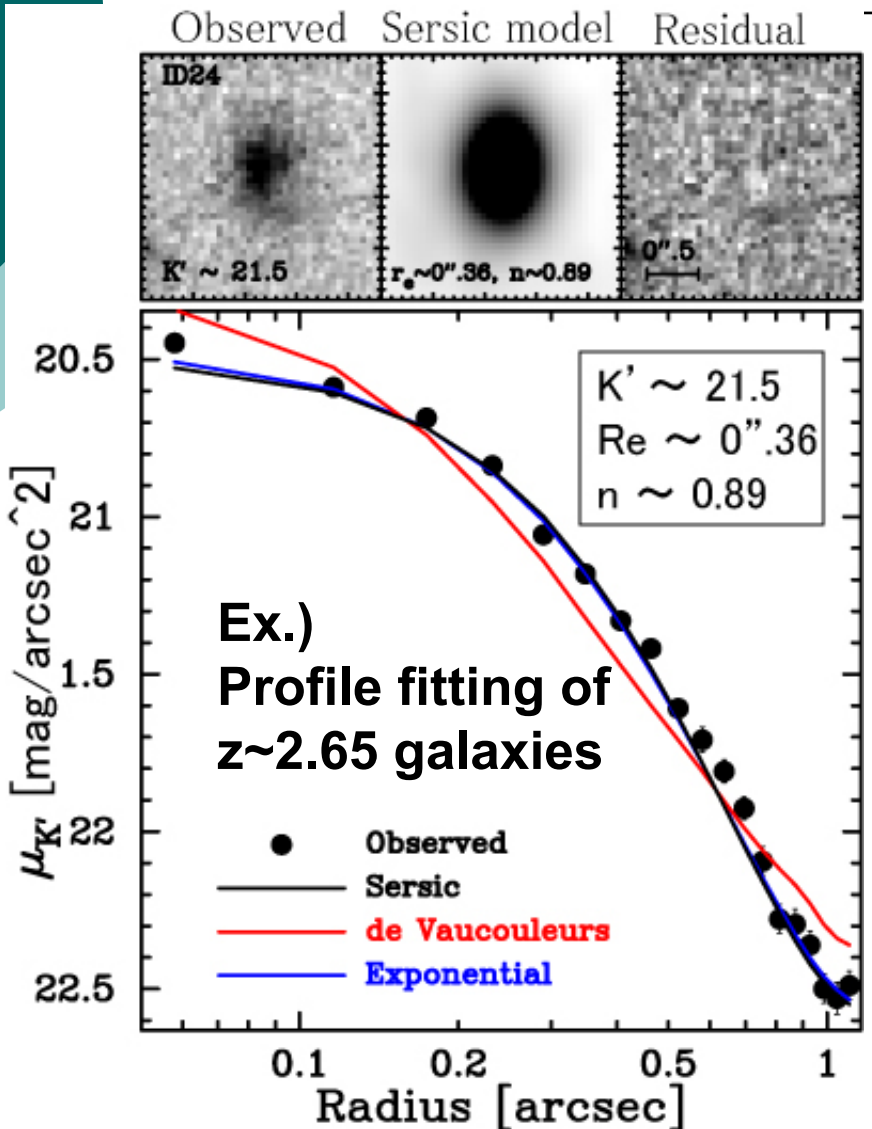
Unusual galaxy population is not necessary to explain the faint-end counts.

High-resolutin 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.

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

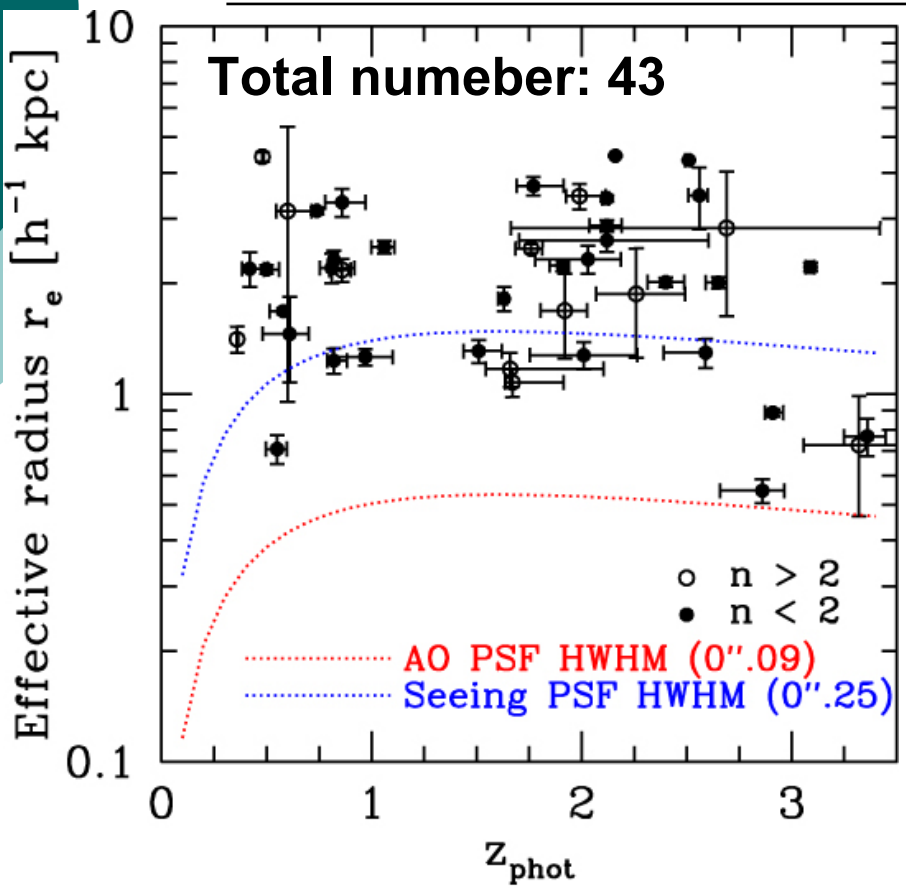
(n=1: exponential, n=4: de Vaucouleurs)

- **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' ~ 23 (~0.6L* at z~3).

Redshift vs. Physical size [kpc]

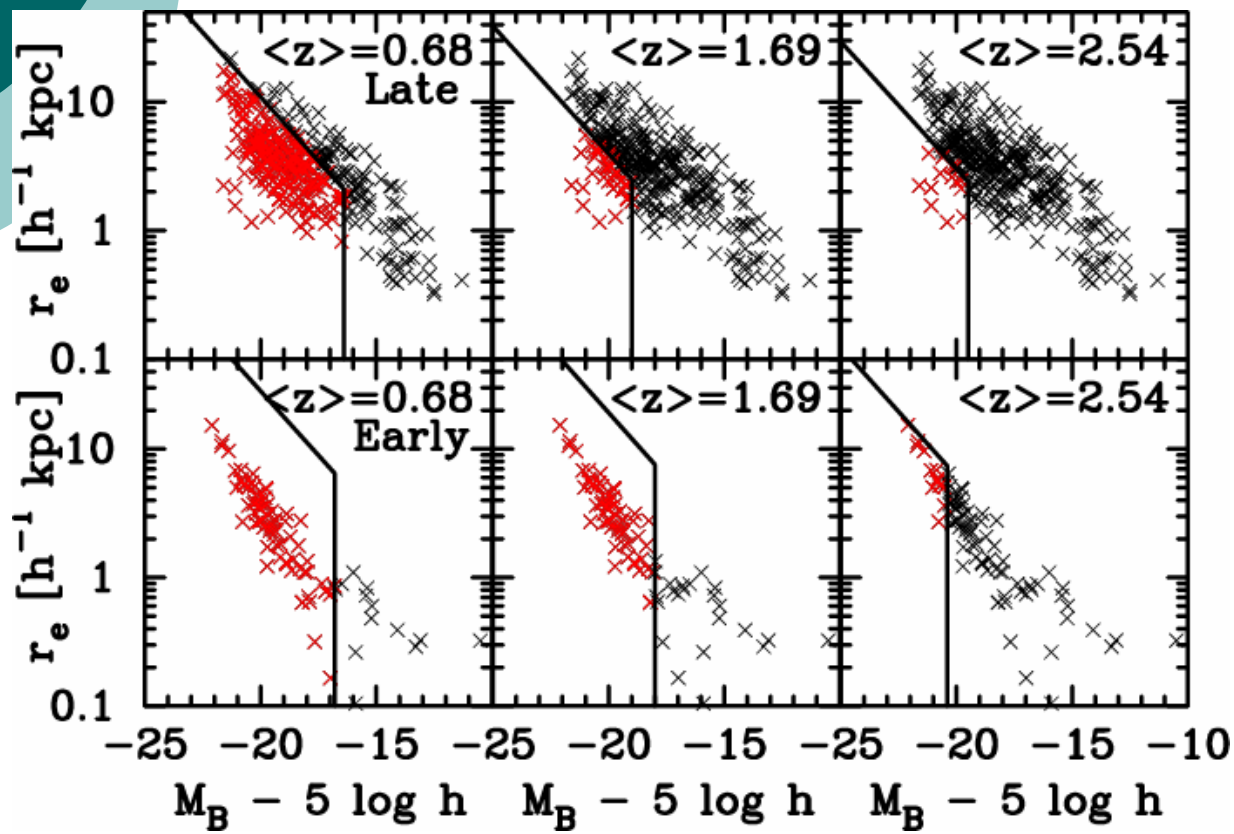


- PSF size in the SSDF is smaller than the measured effective radii of the observed galaxies.

Obtained the spatially resolved morphology of galaxies out to z~3 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)

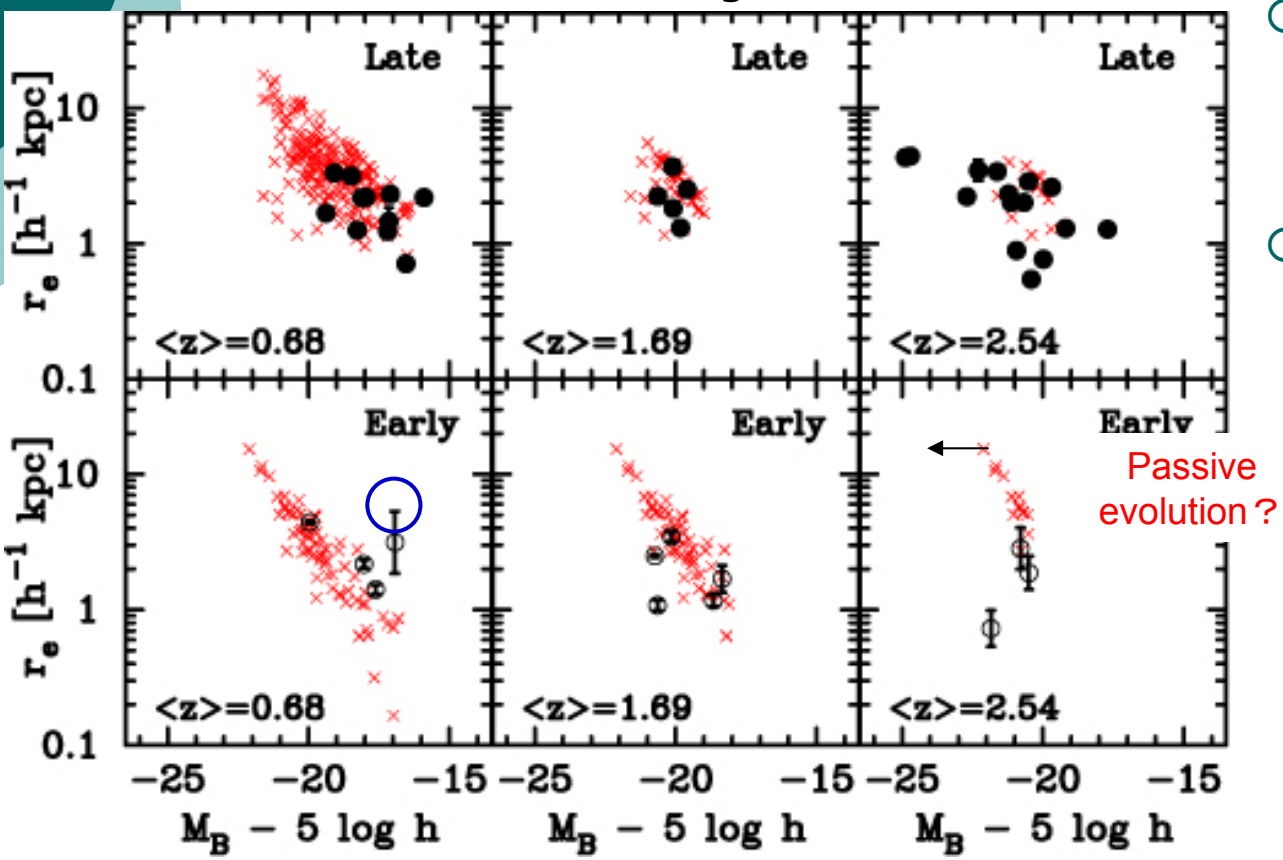
- Early type (lower)

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)



Passive evolution？

- 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~3 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 (1arcmin2) 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.
  - See Minowa et al. 2005 (ApJ, 629, 29) and 2007 in prep. (or Minowa PhD thesis) for details.

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' ~ 23 (~0.6L* at z~3).

Faintest number counts of galaxies down to K'~25

- **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?