Simulating Observations of z~2 galaxies with GLAO

Yosuke Minowa, Ikuru Iwata
(Subaru telescope)

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Motivation

• What is the most unique capability of the GLAO instrument?

• GLAO will start observation from somewhere around 2020
  → It is important to think about the uniqueness of the Subaru GLAO comparing to TMT and any other space based telescope.

• Evaluate the competitiveness of GLAO imager, MOS spec., and IFU spec.

• Case study for z~2 galaxies by simulating the actual observations.
Science requirement: Sensitivity

SINFONI spectroscopic survey of $z \sim 2$ star forming galaxies (Forster Schreiber+09)

• Can we detect $\text{H}\alpha$ emission line corresponds to $\text{SFR} \sim 1-10 \, M_{\odot}/\text{yr}$ to study $< 10^{10}M_{\odot}$ galaxies?

(Newman+13)
Science requirement: Spatial Resolution

• Can we spatially resolve ~1kpc scale star-forming clumps at z~2?
• Can we reconstruct morphological parameters of z~2 galaxies?
Simulating GLAO observation of z~2 galaxies

- z~2 galaxy sample selection
  - HST/WFC3 H-band (F160W) image of z~2 galaxies
    - Highest resolution image currently available
  - Data from CANDELS (Koekemoer et al. 2011) GOODS-S survey whose survey area (~120arcmin^2) is comparable to the GLAO instrument
  - Selected K_{AB}<23.9 BzK galaxies from MUSYC (Cardamone et al. 2010) catalog
    - z=2.1-2.6 star-forming BzK with spec-z: 40
      --- K-band imaging/spectroscopy
    - z=1.3-1.7 passive-BzK with phot-z: 6
      --- H,K-band imaging/spectroscopy
GLAO galaxy simulation recipe

1. Extracted galaxy morphological parameters
   --- Sersic profile fit: Effective radius Re, Sersic index N, Axis ratio, and Position angle

   ※ Simple convolution of the WFC3 image may not reproduce well the GLAO image since WFC3 spatial resolution (FWHM~0”.18) is worse than the best GLAO resolution (FWHM~0”.15).

2. Construct the model galaxy image from the morphological parameters without any PSF convolution.

3. Convolve the model galaxy image with the GLAO PSF

4. Add noise corresponds to 5 hrs integration
   We used 5hrs integration time and 5sigma S/N for all simulation, so as to evaluate the limitation in just 1 night observation.
Star-forming BzK at $z=2.1$-$2.6$ (Model)

Modeling sBzK galaxies based on GOODS-S WFC3 image (CANDELS)

Comparison with $z\sim2$ sBzK sample at GOODS-N (Yuma et al. 2011)

Sersic profile

$$\Sigma(r) = \Sigma_0 \exp \left\{ -b_n \left[ \left( \frac{r}{r_e} \right)^{1/n} \right] \right\}$$
GLAO PSF
(from Oya-san’s talk)

We used the center PSF at the moderate seeing condition to simulate the observation of $z \sim 2$ galaxies.

Seeing condition:
- Bad (75%): 0''.56@K
- Moderate (50%): 0.44@K
- Good (25%): 0''.35@K
PSF for each target field

- Subaru Deep Field (Dec =+27.5deg) → Apr, z=15deg
- COSMOS (Dec=+2.2deg) → Feb, z=15deg
- SXDF/UDS (Dec=-5.2deg) → Oct, z=30deg
### Summary of the PSF used in this simulation

<table>
<thead>
<tr>
<th></th>
<th>COSMOS</th>
<th>SDF</th>
<th>SXDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zenith angle</td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Month</td>
<td>Feb.</td>
<td>Apr</td>
<td>Oct</td>
</tr>
<tr>
<td>FWHM(Seeing)@K</td>
<td>0”.48</td>
<td>0”.46</td>
<td>0”.48</td>
</tr>
<tr>
<td>FWHM(GLAO)@K</td>
<td>0”.23</td>
<td>0”.18</td>
<td>0”.22</td>
</tr>
</tbody>
</table>
Simulated Observations

• Wide Field NIR imaging
  – Broad-band (BB) imaging
  – Narrow-band (NB) imaging

• Multi-Object Slit (MOS) spectroscopy
  – Emission line
  – Continuum

• Multi-IFU spectroscopy
  – Emission line
Imager

Baseline Specification

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>0.8μm – 2.5μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate Scale</td>
<td>0.10&quot;</td>
</tr>
<tr>
<td>FoV</td>
<td>13.6' x 13.6'</td>
</tr>
<tr>
<td>Detectors</td>
<td>4 Teledyne H4RGs (4 x 4096 x 4096 pixels)</td>
</tr>
<tr>
<td>Filters</td>
<td>Broad-band and Narrow-band filters</td>
</tr>
</tbody>
</table>

- Wider than any NIR imager on 8m class telescopes
- The instrument throughput is assumed to be same as VLT/HAWK-I (~60%@JH, ~50%@K)
- Seeing performance is just same as VLT/HAWK-I
Broad-band imaging: Sensitivity

Star-forming galaxies at $z \sim 2$ (Ks-band)

Passively evolving galaxies at $z \sim 1.5$ (H-band)
Morphological study with GLAO as of 2011, 2012

FWHM~0”.2
BB imaging: Possibility for reconstructing the morphological parameters with GLAO imager
BB imaging: summary

• Simulated z~2 galaxy imaging in H, K-band with new GLAO PSF which takes into account the PSF difference according to the zenith angle and seasonal seeing change.

• The point source sensitivity gain against the normal seeing instruments (such as VLT/Hawk-I) is different for each field. (1.0 mag for SDF, 0.7 mag for COSMOS)

• The sensitivity gain for galaxies are almost same for all fields.
  – 0.3-0.6 mag for compact galaxies (<3kpc).
  – Hereafter, we used COSMOS PSF to simulate the observations of z~2 galaxies.

• The limiting mag. is more than 3 magnitude brighter than TMT or JWST (~30mag in K, Wright et al. 2010).
  – Broad band imaging cannot be competitive
  – Wide-field capability might be useful for finding rare objects like passively evolving galaxies.

• Morphological parameters (Re, N) can be reconstructed from the GLAO image for galaxies whose mass is larger than 10^{10} M_{\text{sun}}

• For lower mass galaxies 10^9 M_{\text{sun}}, we can reconstruct size (Re), but cannot reconstruct Sersic index.
Narrow-band imaging: Hα map

- Simulated Brγ-image of Hα emitters at z=2.3 with 5hrs integration
  - made from HST/WFC3 images of star-forming galaxies in SXDF (Tadaki+13)

\[
\log(M_*/M_{\odot}) \sim 10.8 \\
\text{SFR} \sim 300 \, M_{\odot}/yr
\]

\[
\log(M_*/M_{\odot}) \sim 11.2 \\
\text{SFR} \sim 230 \, M_{\odot}/yr
\]

\[
\log(M_*/M_{\odot}) \sim 8.9 \\
\text{SFR} \sim 90 \, M_{\odot}/yr
\]
NB imaging: Sensitivity for detecting Hα from z~2 galaxies
NB imaging: Summary

• Star-forming clumps in galaxies can be clearly resolved with GLAO NB imaging.

• GLAO can reach about 0.3-0.6 mag deeper than VLT/HAWK-I for compact galaxies (<3kpc)

• Brγ-imaging can reach Hα emitters with SFR < 10M sun/yr for compact galaxies with re < 3kpc.
  – Wide field NB-imaging can be a good sample provider for the IFU study with TMT

• JWST/NIRCAM (F212N) can reach about 1.8 mag deeper than GLAO NB image for galaxies with re~2kpc and more for point sources (from Iwata-san’s calculation).
  – More than 100hrs integration required to achieve similar depth as JWST/NIRCAM.
  – Legacy type survey could achieve this integration.
Multi-Object Slit Spectrograph

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<td>Filters</td>
<td>Broad-band and Narrow-band filters</td>
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<tr>
<td>MOS</td>
<td>Multi Slit Mask</td>
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<tr>
<td>λ Dispersion</td>
<td>~3000</td>
</tr>
</tbody>
</table>

- Keck/MOSFIRE type instrument with 13’x13’ FOV
  - Wider FOV than any existing MOS spectrograph on 8m class telescopes
- Assume similar throughput as Keck/MOSFIRE
  - the highest throughput ever achieved (30-40%@JHK)
  - Seeing performance is just same as Keck/MOSFIRE
- Slit width is assumed to be 0”.4 which is 2 times wider than GLAO PSF.
MOS Spec.: emission line sensitivity

- Emission line $5\sigma$ sensitivity for point source and extended source ($R_e \sim 1$ kpc or $\sim 0''.12$ and $N=1$) with 5hrs integration.
MOS Spec.: Emission line sensitivity

- S/N of Hα emission line flux which corresponds to SFR~ 1 $M_{\text{sun}}$/yr (assume $E(B-V)=0.2$) with 5hrs integration

(Point Source)  (Extended Source)
MOS spec.: Continuum Sensitivity

- Continuum 5 $\sigma$ sensitivity for point and extended source with 5hrs integration
MOS. Spec: Summary

- Emission line: GLAO can increase the S/N of emission lines by 2 times higher than MOSFIRE.

- SFR~1M$_{\text{sun}}$/yr can be detected with Ha emission line located between sky emission line.

- Provides better sensitivity than NB-imaging, which enables redshift confirmation of the Ha-emitter discovered by NB imaging.

- Although TMT can achieve 3 times better S/N than GLAO (based on Law et al. 2006), the MOS capability is still required to enable rapid follow-up of the target discovered by GLAO NB imaging.

- Continuum sensitivity is worse than K~23mag. Follow-up spectroscopy of z~2 passive galaxies discovered by BB imaging should be done by TMT.
Multi Object IFU

Baseline Specification

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Wavelength</td>
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<tr>
<td>Spatial Sampling</td>
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<tr>
<td>FoV per IFU</td>
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<tr>
<td>Number of IFUs</td>
<td>24 (TBD)</td>
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<tr>
<td>Detectors</td>
<td>3–4 H2RGs? (TBD)</td>
</tr>
<tr>
<td>Patrol Area</td>
<td>~ 13'</td>
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<tr>
<td>λ Dispersion</td>
<td>~3000</td>
</tr>
<tr>
<td>Imaging Capability</td>
<td>No</td>
</tr>
</tbody>
</table>

- VLT/KMOS type multi-IFU
- Throughput is assumed to be 80% of MOSFIRE due to the optical components for IFUs.
Multi-IFU: mock image

- Simulated IFU S/N map of Hα emitters at z~2.3
  – same objects as we used for NB imaging
SFR = 1 Msun/yr can be detected with S/N = 5 for galaxies Re = 1.4 kpc
Multi-IFU: Summary

• Star-forming cramps can be resolve with IFU.

• GLAO IFU spectrograph can be detected Hα emission line from z~2 galaxies corresponds to SFR~ 1Msun/yr, if size of galaxies is less than 2 kpc.

• TMT/IRIS can detect SFR~1Msun/yr from similar size galaxies with S/N>40 (Wright et al. 2010)

• To be competitive with TMT/IRIS, GLAO IFU should have multiplicity of targets with more than 64 pick-off arm.
  – Need to investigate if this number is technically possible.
Conclusion

Competitive  less competitive  Competitive?? (in Japanese微妙)

• Broad band imaging is not very competitive against the TMT/JWST, although >0.5mag gain can be obtained from the normal seeing instrument.

• NB imaging can reach the galaxies with SFR <10 Msun/yr, which can be good targets to follow-up with TMT IFU.

• Emission line sensitivity is only 3 times worse than TMT/IRIS, which could be competitive by combining with the GLAO NB imaging survey.

• Continuum sensitivity is less competitive as we can detect galaxies brighter than 23 mag in K-band.

• Multiple-IFU could be competitive against TMT/IRIS if we can have more than 60 pick-off arms, but it is better to invest TMT/IRMOS.

Any comment or request for the simulations of GLAO observations are welcome.
おまけ
Star-forming BzKs at $z=2.1-2.6$ (GLAO image)

- Assuming 5 hours integration in K-band under moderate seeing condition (0''.5)

MUSYC 34852: $z_{\text{spec}}=2.32$, $H=22.5$, $K=21.9$, $\log (M_*/M_{\text{sun}})=11.1$, $R_e=1.4[\text{kpc}]$, $N=1.7$
Passive BzKs at $z=1.3-1.7$ (Model)

Modeling pBzK galaxies from GOODS-S WFC3 image (CANDELS)

Comparison with the other $z \sim 2$ passive galaxies at HUDF (Cassata et al. 2010)

- Stellar mass ($M_*/M_{\odot}$)
- Effective radius $R_e$ (Kpc)

![Graph showing comparison of stellar mass versus effective radius for different samples.](image)
Passive BzKs at z=1.3-1.7 (GLAO image)

- Assuming 5 hours integration in H band under moderate seeing condition (0''.5)

MUSYC 37269: $z_{\text{phot}}=1.74$, H=22.4, K=21.7, $\log (M_*/M_{\odot})=11.1$, $R_e=1.1$[kpc], $N=1.7$
Impact of the LGS satellite closure
BB imaging: Morphological study

Sersic index ($n$)

Log(re) [kpc]

(Wuyts+2011)