ULTIMATE-Subaru: Next panoramic strategy of Subaru in near-infrared

Yosuke Minowa
(Subaru Telescope)

ULTIMATE-Subaru working group
Yusei Koyama, Ikuru Iwata, Takashi Hattori, Christophe Clergeon, Ichi Tanaka, Naruhisa Takato, Nobuo Arimoto (Subaru), Tadayuki Kodama, Yutaka Hayano, Shin Oya, Hideki Takami (NAOJ), Masayuki Akiyama, Tatsuhiro Watanabe (Tohoku) Kentaro Motohara (Univ. of Tokyo)
Subaru’s Wide-Field Strategy toward 2020s

1. Very wide-field optical imager  
   SupCam → HSC (2013)

2. Wide-field multi-object spectrograph  
   FOCAS, FMOS → PFS (2019)

3. Wide-field near-infrared imager and multi-object spectrograph  
   IRCS, MOIRCS → ULTIMATE-Subaru (2023)

Extend Subaru’s survey capability to near-infrared
What is ULTIMATE-Subaru?

Ground-Layer Adaptive Optics ×

Wide-Field near-infrared instrument

GLAO performance simulation at Subaru

☆ On-sky performance verification with RAVEN (Oya et al. 2014)

- Uniform seeing improvement over ~20 arcmin FoV
- FWHM < 0.2 at K-band

Wider FoV and better image quality than VLT GLAO
(Seeing 0.8 → GLAO 0.4 at K, FoV~7.5)
Ground-Layer AO+Wide-Field NIR instruments

(1) Adaptive Secondary Mirror
(2) Laser Guide Star system
TOPICA fiber laser (589nm) × 2
Generate 4 laser guide stars

(3) Wavefront Sensors
Cs. Focus (FoV~20 arcmin)
Ns. Focus (FoV~6 arcmin)

(4) Wide-field NIR instruments
New wide-field imager (WFI) at Cs.
Reuse MOIRCS at Ns. IR
(Optional) Fiber-bundle multi-IFU at Cs.
proposed by AAO, Australia
ULTIMATE Wide Field Imager (WFI)

Baseline Specification

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Coverage</td>
<td>0.8-2.5 µm</td>
</tr>
<tr>
<td>Plate scale</td>
<td>0”/1/pixel</td>
</tr>
<tr>
<td>FoV</td>
<td>14’x14’</td>
</tr>
<tr>
<td>Filter</td>
<td>YJHK/MB/NB (+tunable filter)</td>
</tr>
<tr>
<td>Detectors</td>
<td>4 x H4RG</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt; 40%</td>
</tr>
</tbody>
</table>

K-band Sensitivity improvement
- 0.8-1.0 mag (PSF)
- 0.5 mag (galaxies with Re~2kpc)

3~4 times more sensitive (or faster)
ULTIMATE-WFI: Uniqueness

Widest FoV among NIR facilities in 2020s available at $\lambda > 2.0 \mu m$

- Subaru/MOIRCS (4’ x 7’)
- VLT/HAWK-I (7.5’ x 7.5’)
- Subaru/IRCS (1’x1’)
- HST/WFC3 (2.0’x2.3’)
- JWST/NIRCAM (2 x 2.2’ x 2.2’)
- ULTIMATE-Subaru (14’x14’)

[Diagram showing various telescopes and their fields of view with Subaru/Ultimate showing the largest FoV]
ULTIMATE-WFI: Key Science Case

Wide-field, high-resolution narrow-band imaging survey

1. Complete census of galaxy evolution
   - Hα/[[OIII]] emission line survey at z=2-3 down to $10^9 \, M_{\odot}$ in stellar mass.
   - Stellar build-up history
   - Quenching mechanism
   - Mass and environmental dependency

2. Exploring very high-z galaxies
   - Lyα emission line survey at $z=8, 9, 10\ldots$
   - History of cosmic re-ionization
   - Sensitivity of ULTIMATE-WFI in J-band NB is comparable to the JWST NIRCAM NB imaging.
ULTIMATE-WFI: Key Science Case

Mapping star-formation in galaxies at z=2-3 with Hα/[OIII] emission line with GLAO+NB imaging in K-band

Preliminary results from GANBA-Subaru

IRCS+AO188 NB+K images of star-forming galaxies at z~2 in FWHM~0”.2 resolution.

ULTIMATE NB survey will provide >1000 of spatially-resolved Hα/[OIII] maps of SF galaxies at z=2-3 down to 10^9 M_{sun}
ULTIMATE-WFI: Key Science Case

ULTIMATE-K imaging survey

- Wide-field K-band (BB and MB) survey is still unique in the era of WFIRST
- Provide >1mag deeper and ~10 times wider survey data than UKIDSS.
- Synergy between WFIRST (JH) and ULTIMATE-K is powerful to detect galaxies at z=4-5 (especially for rare objects such as quiescent galaxies)
- LBG technique to detect z~15 galaxies?

Muzzin et al. (2013)
ULTIMATE-WFI: Preliminary Survey Plan

- Several NBs (in JHK), MB+BB (in K) imaging using ~300 nights to conduct survey for galaxies at $z=2-3$ in Hα/[OIII], $z=4-5$ in Balmer break, and $z>8$ in Lyα.
- 2 deg$^2$ survey in well-known deep field such as COSMOS/SXDF
- Assume J and H-band data will be taken by WFIRST
- If we concentrate only K-band (ULTIMATE-K), we can extend the survey field up to 20 deg$^2$

<table>
<thead>
<tr>
<th>Survey type</th>
<th>Filters</th>
<th>Exp. time per FoV [hrs] (including overheads)</th>
<th>Limit mag. (5σ, AB)</th>
<th>N. of nights</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB imaging</td>
<td>NB$_J \times 2$</td>
<td>8.0 (10.0)</td>
<td>27.0</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>NB$_H \times 2$</td>
<td>4.0 (5.0)</td>
<td>24.2</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>NB$_K \times 2$</td>
<td>4.0 (5.0)</td>
<td>24.1</td>
<td>32</td>
</tr>
<tr>
<td>MB imaging</td>
<td>$K_1$</td>
<td>10.0 (13.0)</td>
<td>26.1</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>$K_2$</td>
<td>10.0 (13.0)</td>
<td>26.1</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>$K_3$</td>
<td>10.0 (13.0)</td>
<td>26.1</td>
<td>42</td>
</tr>
<tr>
<td>BB imaging</td>
<td>$K$</td>
<td>9.0 (13.5)</td>
<td>26.7</td>
<td>45</td>
</tr>
<tr>
<td>Total time</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>299</td>
</tr>
</tbody>
</table>
ULTIMATE-MOIRCS (multi-object slit spectrograph)

- MOIRCS will be reused for the first-light instrument for GLAO
- Move to Nasmyth IR platform for better stability in spec. mode
- New Grism will be installed for better total efficiency
- With GLAO, MOIRCS can reach the sensitivity better than MOSFIRE
- Extension of PFS spectroscopic survey to z>2 with ULTIMATE

Baseline Specification

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<th>Specification</th>
<th>Value</th>
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<tr>
<td>Wavelength Coverage</td>
<td>0.8-2.5 μm</td>
</tr>
<tr>
<td>Plate scale</td>
<td>0&quot;.1/pixel</td>
</tr>
<tr>
<td>FoV</td>
<td>φ ~6’</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>R~3000 (0&quot;.2 slit)</td>
</tr>
<tr>
<td>No. of slits</td>
<td>40~60</td>
</tr>
<tr>
<td>Detectors</td>
<td>2 x H2RG</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt; 30%</td>
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Expected to be...
ULTIMATE-MIFS (Multi-IFU spectrograph)

AAO developed Concept of Fiber bundle multi-IFU system (Ellis, S et al. 2016)

Baseline Specification

<table>
<thead>
<tr>
<th>IFUs</th>
<th>Number of IFUs</th>
<th>8-13a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of elements per IFU</td>
<td>61 Hexagonally packed</td>
</tr>
<tr>
<td></td>
<td>Spatial sampling per element</td>
<td>0.15 arcsec</td>
</tr>
<tr>
<td></td>
<td>Total field of view per IFU</td>
<td>1.18 square arcsec</td>
</tr>
<tr>
<td></td>
<td>Total patrol area</td>
<td>φ ~ 15 arcminb</td>
</tr>
<tr>
<td></td>
<td>Minimum separation between IFUs</td>
<td>25 arcsec</td>
</tr>
</tbody>
</table>

Spectrograph (MOIRCS)

| Wavelength coverage | 0.9-1.8 μm |
| Spectral resolving power | 500-3000 |
| Dispersion | 1.6 A per pix (J), 2.1 A per pix (H) |
| Sampling | 2-5 pixels in FWHM |

Combined properties

| Total efficiency | 9% (J), 12% (H) |

Glazebrook’s talk

Observe kinematics of ~3000 galaxies at z=0.5-1.0

- quenching mechanism
- feedback process
- galaxy transformation (e.g. mergers)
Comparison with TMT/Space telescope in 2020s

<table>
<thead>
<tr>
<th></th>
<th>Imaging</th>
<th>MOS</th>
<th>M-IFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>JH</td>
<td>K</td>
<td>MB, NB</td>
<td>JHJK</td>
</tr>
</tbody>
</table>

Pointed observations

| Surveys        | WFIRST | ULTIMATE-WFI | WFIRST R~500 | PFS R~3000 | ULTIMATE-MOIRCS | ULTIMATE-MIFS |

We may still want to do JH survey over the area overlooked by WFIRST. (e.g., HSC/PFS survey fields where abundant targets are available for follow-up.)

AGNs are point sources and benefit from the sensitivity improvement with GLAO. Do we also gain from the better spatial resolution?

Broad-line AGNs are relatively sparse on the sky (~10 per 15' FoV at i < 24 mag).
ULTIMATE-Subaru Study Report 2016

- Science Case
  - High-z galaxies (Key Science)
  - Low-z galaxies
  - Galactic
- Adaptive Optics
  - Performance modeling
  - System modeling
  - Interface with telescope
- Instruments
  - Wide-Field imager
  - Multi-Object Slit spectrograph
  - Multi-Object IFU spectrograph
- Development Plan
  - Team organization
  - Budget
  - Timeline

ULTIMATE Subaru: Timeline

- **GLAO**: Concept Design, Prelim. Design, Detail Design, ASM Fabrication, Telescope Mod., AO experiment / Fibre Laser, WFS / GLAO development, CoDR for GLAO & WFI, PDR for GLAO & WFI, NAOJ investment for PFS, AIT / Eng w/MOIRCS, Science w/o GLAO, NAOJ investment for PFS, GLAO First Light with MOIRCS

- **WFI**: Concept Design, Prelim. Design, Detail Design, Fabrication, AIT

Prototyping key components using the existing AO188 system:
- WFS upgrade using modern detector system
- High-power fiber laser implementation to the telescope
- Real-time system test using GPU
Summary

- ULTIMATE-Subaru is a Subaru’s next generation facility instrument plan after PFS.

- ULTIMATE-Subaru will develop a ground-layer AO system and wide-field near-infrared imager, which provide ~14x14 arcmin $^2$ FoV with 0$''$.2 spatial resolution in K-band.

- Conceptual design of the GLAO and imager is ongoing, will be reviewed at the end of 2017. Expected first light of GLAO is 2023.

- Multi-Object fiber-bundle IFU spectrograph (M-IFS) is being planned in collaboration with Australia. Instrument concept is designed by AAO.

- Imaging survey using ~300 nights to map the galaxy evolution from z=1-8 is being planned.

- Not only high-z science, we are collecting various science cases such as local star-forming region, galactic archaeology, and near-by galaxies. Any input from cosmology?

- Any kind of participation in the ULTIMATE-Subaru project, Science case, Instrument development, is very welcome.