ULTIMATE-Subaru: Comparisons with Space Missions

I. Iwata (Subaru Telescope)
2011/08/25
2013/05/28 small revisions
2013/06/04 include JWST/NIRISS
2016/06/16 revisions
Space Missions in Near-Future
JWST

• 6.5m Deployable Mirror, Passive Cooling at S-E L2
• Four Science Instruments:
  • MIRI: Mid-IR (5 - 28μm)
  • NIRSpec
  • NIRCam
  • NIRISS
JWST MIRI

- Imaging 5 - 28.3μm, FoV 1.25’ x 1.88’
- Coronagraph
- R=1,000 - 3,000 Spec
JWST NIRCam

- Two Channels, both 2.2’ x 4.4’
  - Short: 0.5 - 2.3 μm, 32 mas (8 H2RGs)
  - Long: 2.5 - 5.0 μm, 64 mas (2 H2RGs)
- Coronagraphic High Contrast Imaging
- Slitless Grism Spectroscopy R~180
NIRCam Filters
JWST NIRSpec

- 3.6’ x 3.4’ FOV
- Micro-Shutter Assembly: 0.2” x 0.46” Micro-Shutters
- Fixed Slits: 0.4”x3.8”, 0.2”x3.3”, 1.6”x1.6”
- IFU: 3”x3” FOV, 30 Slices, 0.1”(dispersion) x 3” (spatial)
- R = 100, 1000, 2700
- 2 x H2RG
JWST NIRISS (Near-IR Imager and Slitless Spectrograph)

- [http://www.stsci.edu/jwst/instruments/niriss](http://www.stsci.edu/jwst/instruments/niriss)
- 1x H2RG 5.3\(\mu\)m cutoff, 0.065”/pix, 2.2’ x 2.2’ FoV
- Wide-Field Slitless Spectroscopy: 1.0-2.5\(\mu\)m, R\(\sim\)150 optimized for \(z>10\) LAEs
- Single-Object Slitless Spectroscopy: R\(\sim\)700 (0.6-2.5\(\mu\)m) using cross-disperser optimized for transiting exoplanets
- Aperture Masking Interferometry: 3.8-4.8\(\mu\)m
- Imaging: 0.9-5.0\(\mu\)m
## WFIRST-AFTA

### WFIRST-2.4 Design Reference Mission Capabilities

<table>
<thead>
<tr>
<th>Imaging Capability</th>
<th>0.281 deg²</th>
<th>0.11 arcsec/pix</th>
<th>0.6 – 2.0 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filters</td>
<td>Z087</td>
<td>Y106</td>
<td>J129</td>
</tr>
<tr>
<td></td>
<td>H158</td>
<td>F184</td>
<td>W149</td>
</tr>
<tr>
<td>Wavelength (μm)</td>
<td>0.760-0.977</td>
<td>0.927-1.192</td>
<td>1.131-1.454</td>
</tr>
<tr>
<td></td>
<td>1.380-1.774</td>
<td>1.683-2.000</td>
<td>0.927-2.000</td>
</tr>
<tr>
<td>PSF EE50 (arcsec)</td>
<td>0.11</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>0.12</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>Spectroscopic</td>
<td>Grism (0.281 deg²)</td>
<td>IFU (3.00 x 3.15 arcsec)</td>
<td></td>
</tr>
<tr>
<td>Capability</td>
<td>1.35 – 1.95 μm, R = 550-800</td>
<td>0.6 – 2.0 μm, R = ~100</td>
<td></td>
</tr>
</tbody>
</table>

### Baseline Survey Characteristics

<table>
<thead>
<tr>
<th>Survey</th>
<th>Bandpass</th>
<th>Area (deg²)</th>
<th>Depth</th>
<th>Duration</th>
<th>Cadence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exoplanet Microlensing</td>
<td>Z, W</td>
<td>2.81</td>
<td>n/a</td>
<td>6 x 72 days</td>
<td>W: 15 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Z: 12 hrs</td>
</tr>
<tr>
<td>HLS Imaging</td>
<td>Y, J, H, F184</td>
<td>2000</td>
<td>Y = 26.7, J = 26.9</td>
<td>1.3 years</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H = 26.7, F184 = 26.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HLS Spectroscopy</td>
<td>1.35 – 1.95 μm</td>
<td>2000</td>
<td>0.5x10⁻¹⁶ erg/s/cm² @ 1.65 μm</td>
<td>0.6 years</td>
<td>n/a</td>
</tr>
<tr>
<td>SN Survey</td>
<td>Wide</td>
<td>27.44</td>
<td>Y = 27.1, J = 27.5</td>
<td>0.5 years (in a 2-yr interval)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>8.96</td>
<td>J = 27.6, H = 28.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deep</td>
<td>5.04</td>
<td>J = 29.3, H = 29.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFU Spec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Guest Observer Capabilities

1.4 years of the 5 year prime mission

<table>
<thead>
<tr>
<th>Z087</th>
<th>Y106</th>
<th>J129</th>
<th>H158</th>
<th>F184</th>
<th>W149</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.15</td>
<td>27.13</td>
<td>27.14</td>
<td>27.12</td>
<td>26.15</td>
<td>27.67</td>
</tr>
</tbody>
</table>
WISH: Wide-field Imaging Surveyor for High-redshift

- Space Telescope Mission with 1.5m Diameter Aperture
- Wide-Field Near-Infrared Camera (0.9 - 5 μm)
- (Passively) Cooled Mission with Sun - Earth L2 Orbit

- Depth - deeper than images with any ground-based telescopes
- Width - 100 square degrees in deepest images, >1,000 deg² in shallower surveys

http://wishmission.org
FLARE

- to be proposed for ESA M5
- 2m-class Wide-field NIR imager up to 5μm + IFU
## Euclid and WFIRST

<table>
<thead>
<tr>
<th></th>
<th>Euclid</th>
<th>WFIRST-AFTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mirror</strong></td>
<td>1.2m</td>
<td>2.4m</td>
</tr>
<tr>
<td><strong>FoV</strong></td>
<td>0.5 deg$^2$</td>
<td>0.3 deg$^2$</td>
</tr>
<tr>
<td><strong>Visual Imager</strong></td>
<td>Rlz</td>
<td>↓</td>
</tr>
<tr>
<td><strong>NIR Imager</strong></td>
<td>YJH</td>
<td>0.7-2.0 μm</td>
</tr>
<tr>
<td><strong>Lim. Mag.</strong></td>
<td>24AB</td>
<td>26.7AB</td>
</tr>
<tr>
<td><strong>Survey Area</strong></td>
<td>20,000 deg$^2$</td>
<td>2,200 deg$^2$ (HLS)</td>
</tr>
<tr>
<td><strong>Primary Science</strong></td>
<td>Dark Energy</td>
<td>DE, Exoplanet, GO</td>
</tr>
<tr>
<td><strong>Expected Operations</strong></td>
<td>2020- (6 years)</td>
<td>2024? (5 years)</td>
</tr>
</tbody>
</table>
Imaging Sensitivity
Imaging: Sensitivity for Point Sources

Point Source Imaging 1e4 sec

![Graph showing sensitivity for point sources at different wavelengths. The graph displays data points for MOIRCS, Subaru-GLAO, WISH, TMT-IRIS, and JWST-NIRCam.]
Imaging: Sensitivities for Extended Sources

0.5" Extended Source Imaging 1e4 sec

Wavelength (μm)
Imaging: Sensitivity and Field-of-View

Point Source, $10^4$ sec

![Graph showing sensitivity and field-of-view for various imaging systems.](image)

- TMT/IRIS
- JWST/NIRCam
- MOIRCS
- HAWK-I
- VISTA
- Subaru-GLAO
- WISH

Lim. Mag. (5σ) vs. FoV / Shot (arcmin²)
Imaging: Sensitivity and Field-of-View

0.5" Extended Source, $10^4$ sec

Lim. Mag. (5σ) vs. FoV / Shot (arcmin$^2$)

- TMT/IRIS
- WFC3/IR (F160W)
- MOIRCS
- HAWK-I
- Subaru-GLAO
- VISTA
- JWST/NIRCam
- WISH
JWST fills in the opaque windows
ULTIMATE fills in JWST gaps

Possible ULTIMATE filterset = black outline, JWST/NIRCam = color filters
Spectroscopic Sensitivity
Spectroscopy: Continuum Sensitivity (Point Sources)

Continuum Limits for 1 hour

J-band

S/N=10 Lim. Mag. (AB)

Spectral Resolution

MOIRCS
Subaru-GLAO
JWST-NIRSpec
TMT-IRIS
Spectroscopy: Continuum Sensitivity (Point Sources)

Continuum Limits for 1 hour

H-band

S/N=10 Lim. Mag. (AB)

10 100 1000 10^4

Spectral Resolution

MOIRCS

Subaru-GLAO

JWST-NIRSpec

TMT-IRIS

10 20 22 24 26

S/N=10 Lim. Mag. (AB)
Spectroscopy: Continuum Sensitivity (Point Sources)

Continuum Limits for 1 hour

K-band

S/N=10 Lim. Mag. (AB)

Spectral Resolution

MOIRCS

Subaru-GLAO

JWST-NIRSpec

TMT-IRIS
Spectroscopy: Sensitivity for Emission Lines

1 hours, ~0.25” extended source

Lyα at z=12
Spectroscopy: Sensitivity for Emission Lines

1 hours, ~0.25" extended source

Hα at z=2.3

WFIRST:
~1e-16 erg/s/cm² (up to 2μm, z~1.9)
Summary

- Imaging: Space Missions have significant advantages
  - Narrow-band imaging capability is more suited for ground-based telescopes
- Spectroscopy:
  - Sensitivity gain can be as much as ~2x with GLAO
  - For extended sources difference between ground-based and space telescopes becomes smaller.
  - The most sensitive observations will be realized by TMT.
  - Reducing Read-out Noise is important.
Niches for ULTIMATE-Subaru

• Imaging:
  • JWST: More sensitive but limited in FoV and set of filters
  • WFIRST: up to 2μm, Broad-band filter only
  • → K-band and NB/MB filters

• Spectroscopy:
  • JWST: More sensitive but limited in FoV
  • WFIRST: More efficient but limited in sensitivity
  • → Multi-object (Integral-field) Spectroscopy
  • High spectral resolution >4,000?