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Design and development of SWIMS: a near-infrared multi-object spectrograph for the University of Tokyo Atacama Observatory

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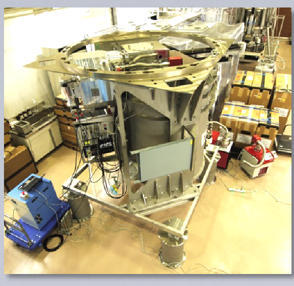
What is SWIMS ?

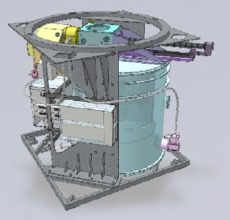
SWIMS, **S**imultaneous-color **W**ide-field **I**nfrared **M**ulti-object **S**pectrograph, is a near-infrared (NIR, λ = 0.9–2.5 μm) instrument for the University of Tokyo Atacama Observatory (**TAO**[1], P.I.: Yuzuru Yoshii) 6.5-m infrared telescope which is planned to be constructed at the world's highest astronomical site, the summit of Co. Chajnantor (5,640 m or18,500 ft altitude) at Atacama Desert in northern Chile.

By placing a dichroic mirror into the collimated beam, SWIMS is capable of wide-field two-color imaging and multi-object spectroscopy (MOS) using cooled multi-slit masks with low-to-medium spectral resolutions. The high IR transmittance at the site (Figure 3)[2–4] allows us to obtain almost continuous spectra covering the entire NIR spectral range (0.9–2.5 μm) in a single exposure.

In parallel, two developments are also in progress: a more flexible MOS using micro-shutter arrays as an alternative to the current slit mask, and a cooled, wide-field (14" x 10") integral field spectroscopy unit (IFU; refer to Ozaki et al. in this conference[5]) as a new observation mode.

Note that part of the final designs described here is currently optimized for installation on the Subaru Telescope for performance verification and early science observations prior to the construction of the TAO 6.5-m telescope in Chile.





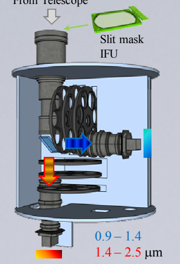
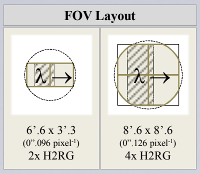


Figure 1. 3D schematics of SWIMS.

Figure 2. Layouts of the FOV. The entire NIR spectra can be obtained for slits placed in the hatched area.



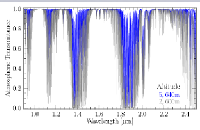


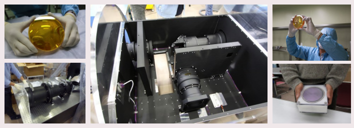
Figure 3. Atmospheric transmittances in the NIR wavelengths at the TAO site (*blue*, 5,640m) and the VLT site (*black*, 2,600m) simulated using ATRAN atmospheric model (Lord 1992)[6]

Specifications of SWIMS		
	TAO 6.5m	**Subaru 8.2m**
Observation Mode	"Two-color" Imaging and Multi-Object Spectroscopy (MOS)	
Dimensions, weight	2.0 x 2.0 x 2.0 m^3 , < 2.5 tons	
Wavelength Coverage	0.9–1.4 μm (blue arm) and 1.4–2.5 μm (red arm)	
Detector	HAWAII-2RG[a] (four arrays per arm) (two arrays currently procured for each arm)	
Field of View (FOV) Imaging / Spectroscopy[c]	8'.6 x 4'.3 (ϕ9'.6)[b] / 3'.7 x 4'.3 (3'.7 x 8'.6)[b]	6'.6 x 3'.3 / 2'.8 x 3'.3
Pixel Scale	0".126 pixel^{-1}	0".096 pixel^{-1}
Filters (broad-band and narrow-band)	*Y*, *J*, *H*, K_s and *N*129, *N*133, *N*1875, *N*195	
Spectral Resolution (0".5 slit width)	Blue: λ/Δλ ~ 700–1,000; Red: λ/Δλ ~ 500–900	
MOS Multiplicity	~ 20 masks (excluding long slit masks), ~ 30 objects/mask	
Expected Total Throughput	Imaging: 31%; Spectroscopy: 20%	
Expected Limiting Magnitudes (in AB)[d] Imaging (1hr, S/N=5) / Spectroscopy (1hr, S/N=5, R=1,000)	*Y*=25.0, *J*=24.2, *H*=23.4, K_s=23.7 / *Y*=23.3, *J*=22.4, *H*=22.2, K_s=21.9	*Y*=25.3, *J*=24.5, *H*=23.7, K_s=24.0 / *Y*=23.6, *J*=22.7, *H*=22.5, K_s=22.2

[a] 2048 x 2048 pixels, 18 μm/pixel, 2.5 μm cut-off.
[b] Field of view when covered with four HAWAII-2RGs (4096 x 4096 pixels).
[c] Field of view where the entire NIR (i.e., 0.9–2.5 μm) spectra can be obtained.
[d] Magnitudes for the case at the TAO are scaled from those at the Subaru by the difference of the telescope diameters.

Optical Design

(Collaboration with Optcraft)



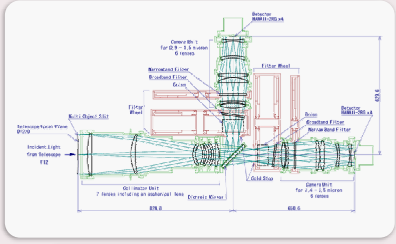


Figure 4. SWIMS Optical design optimized for the Subaru (the entrance window is not shown).

	Blue arm	**Red arm**
Optimized Wavelength	0.9–1.5 μm	1.4–2.5 μm
Collimator Unit (common)	7 lenses including an aspherical lens made of fused silica	
Camera Unit (f/4.8)	6 spherical lenses	6 spherical lenses
RMS Spot Size	< 1.3 pixel (< 1.2 pixel on TAO)	< 1.2 pixel (< 1.0 pixel on TAO)
Image Distortion	< 1% across the FOV	< 1% across the FOV
Pupil Size	ϕ70 mm	ϕ70 mm
Operation Temperature	< 70 K	< 70 K

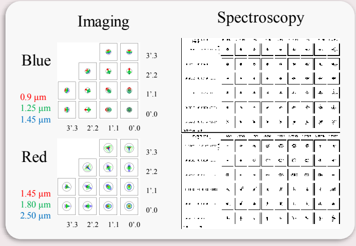
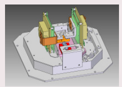
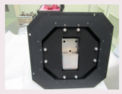
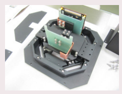


Figure 5. *Left*: Spot diagrams of the imaging mode. The box is 3 pixels (0".3) on a side. Circles corresponds to the Airy disk size at the longest wavelength for each arm. *Right*: Spot diagrams of the spectroscopy mode. The box is 4 pixels (0".4) on a side.

Optical Components:
- ☐ Entrance Window: a set of two Fused Silica lenses (ϕ254 mm + ϕ238 mm)
- ☐ Dichroic mirror: 165 x 125 x 25 mm^3. 95% reflectance at 0.9–1.36 μm and 95% transmittance at 1.4–2.5μm (fabricated by Asahi Spectra Co.)
- ☐ Filter/Grism Turrets: (i) 8 slots with ϕ120 mm for Grisms, (ii) 8 slots with ϕ120 mm for broad-band filters, (iii) 7 slots with ϕ125 mm for narrow-band filters.
  - ◆ Turrets (i) and (ii): placed into the collimated beam.
  - ◆ Turret (iii): placed into the converging beam to place filters orthogonal to the optical axis without having ghost images.
    → Minimizes band-shift effect of transmission wavelength depending on positions in the FOV. (A transparent plate with the same refractive index as the narrow-band filters is used for observations without narrow-band filters to keep the focus position on the detector.)





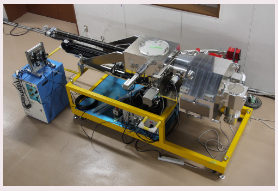


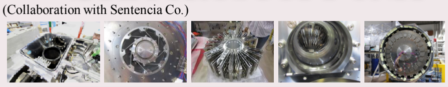
※The collimator unit will be replaced when being installed on the TAO.

Detector Configurations:
- ☐ HAWAII-2RG arrays and SICECAR ASICs: operated at 77 K
- ☐ JADE2 USB2.0 interface boards: placed at ambient temperature inside the cryostat
- ✓ Readout tests using a software provided by Teledyne are in progress at ambient temperature.

Multi-Object Spectroscopy Unit

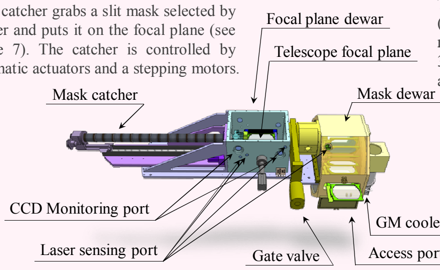
(Collaboration with Sentencia Co.)





Mask catcher grabs a slit mask selected by an user and puts it on the focal plane (see Figure 7). The catcher is controlled by pneumatic actuators and a stepping motors.

The slit mask is fixed accurately (< tens of micron expected) by neodymium magnets arranged in 3x3 grid at four corners (Figure 8) and alignment pins.



24 slit mask holders are stored in a carrousel under cryogenic temperature (< 100 K). Of them, one is for temperature monitoring, and other two for the retractable IFU. 20 slots at max. are available for users' MOS masks.

All exchanging motions are monitored by sensors. Compact CCDs are also equipped for visual inspection.

Slit masks are replaced through Access port without any influences to the main dewar (optics and detectors) by closing the gate valve.

Figure 6. 3D schematic view of the SWIMS MOS Unit (the entrance window and the window plate is not shown).

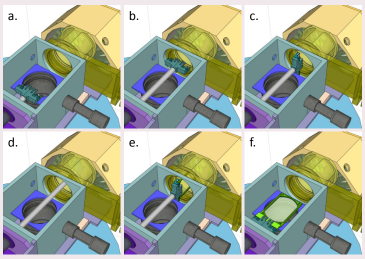


Figure 7. A mask exchanging sequence to set a slit mask on the focal plane.

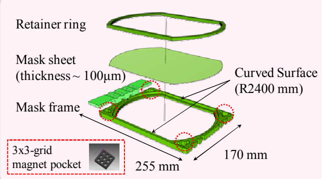
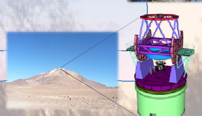


Figure 8. A schematic drawing of Slit mask holder. In order to obtain sharp spectra across the FOV, the slit mask holder is cylindrically curved along the field curvature of the telescope (R2400 mm for the Subaru and ~ R1250 mm for the TAO).

- ✓ Motion tests of the unit have been completed successfully under ambient and cryogenic temperature without any trouble.
- ✓ The reliability (e.g., stability, reproducibility) at various instrumental attitudes are being evaluated.

Schedule



2012	Unit testing of MOS unit and detector control Software development for MOS unit and detector control
2013	Installation, full assembly of the components and cryogenic tests
2014	Transportation to Hawaii First Light & Performance Verification on Subaru
2018	Transportation to Atacama, and First Light on TAO

References

1. Yoshii, Y., et al., "The University of Tokyo Atacama Observatory 6.5m Telescope project", Proc. SPIE 7733, 773308–773308–9 (2010).
2. Miyata, T., et al., "Site evaluations of the summit of Co. Chajnantor for infrared observations", Proc. SPIE 7012, 701243–701243–8 (2008).
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4. Miyata, T., et al., "Evaluations of new atmospheric windows at thirty micron wavelengths for astronomy", Proc. SPIE, in this conference (2012).
5. Ozaki, S., et al., "Development of an integral field unit for a near-infrared multi-object spectrograph SWIMS", Proc. SPIE, 8450-144 in this conference (2012).
6. Lord, S. D., NASA Technical Memorandum 103957 (1992).