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Design and status of a near-infrared multi-object spectrograph for the TAO 6.5-m Telescope

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1. TAO Project & NIR Astronomy

The University of Tokyo Atacama Observatory (**TAO**) is a project to construct a 6.5m infrared-optimized telescope at the summit of Co. Chajnantor (5,640m altitude) in Atacama Desert, Chile (PI: Yuzuru Yoshii)[1,2]. Thanks to the dry climate and high altitude[3,4] at the TAO site, high atmospheric transmittance is expected in near-infrared (NIR) wavelengths (Figure 1), which is suitable for redshift surveys of distant astronomical objects (galaxies, galaxy clusters, and so on).

A NIR spectrograph for the TAO 6.5m telescope, **SWIMS** (**S**imultaneous-color **W**ide-field **I**nfrared **M**ulti-object **S**pectrograph), has capabilities of wide-field imaging and multi-object spectroscopy (MOS) for a wide spectral range from 0.9-2.5 μm at a time using a dichroic mirror placed in the collimated beam. Taking advantages of the site, SWIMS enables us to obtain various redshifted spectral features (emission lines and continuum breaks) simultaneously under same observational conditions (weather, telescope, and the instrument), as shown in Figure 2.

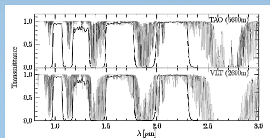


Figure 1. Atmospheric transmittances in NIR wavelengths at the TAO site (Co. Chajnantor, 5,600m alt., PWV=0.5mm) and the VLT site (Co. Paranal, 2,600m alt., PWV=6.0mm) calculated using ATRAN software (Lord, S.D. 1992, NASA).
*PWV: Precipitable Water Vapor

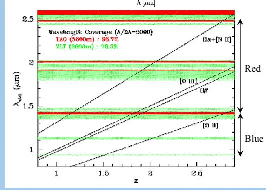


Figure2. Observed-frame wavelength of optical emission lines as a function of redshift. Red and green hatched regions represent wavelength ranges with low atmospheric transmittance (<50%) at the TAO site and the VLT site, respectively. Solid lines show the wavelength of Hα (λ_{rest} = 6563Å), [OIII] (λ_{rest} = 4959, 5007Å), Hβ (λ_{rest} = 4861Å), and [OII] (λ_{rest} = 3727Å). Wavelength coverages of SWIMS are also shown with arrows on the right.

2. Specification of SWIMS

The most remarkable feature of SWIMS is NIR two-band **simultaneous** (imaging or MOS) observations (0.9-1.4 and 1.4-2.5 μm) using a dichroic mirror.

- We are planning to carry out commissioning and early science observations on the Subaru Telescope at Hawaii before the construction of the TAO 6.5m telescope.
  → Part of the initial design of the instrument is optimized for the Subaru.

The full FoV at the Nasmyth focus of the TAO 6.5m telescope (ϕ9'.6) is covered by four HAWAII-2RG arrays with 0".13 pixel^{-1} sampling. During the commissioning phase on the Subaru, two arrays are installed on each channel, which covers 6'.8 x 3'.4 with 0".10 pixel^{-1}.

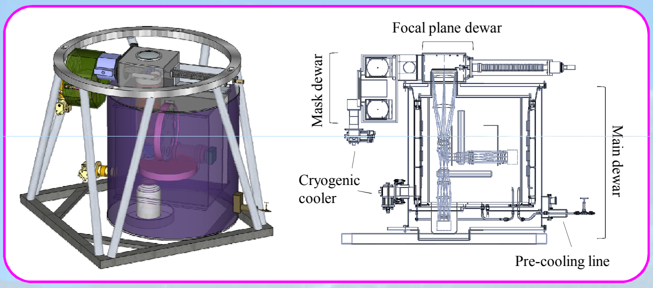


Figure 3. 3D (*left*) and 2D cross-sectional (*right*) schematics of SWIMS. Dimension and weight of SWIMS are ~2x2x2 m³ and 2t.

Table1. Specifications of SWIMS.

	TAO 6.5m (Nasmyth)	Subaru 8.2m (Cassegrain)
Observation Modes	Imaging and Multi-Object Spectroscopy (MOS)	
Field of View	8'.8 × 4'.4 (ϕ9'.6[a])	6'.8 × 3'.4
Pixel Scale	0".13 pixel^{-1}	0".10 pixel^{-1}
Wavelength Coverage	0.9–1.4 μm (*blue* channel) and 1.4–2.5 μm (*red* channel)	
Detector	2048 × 2048 pixel HAWAII-2RG	
Filters[b]	Y (1.02 μm), J (1.25 μm), H (1.64 μm), K_s (2.15 μm)	
Spectral Resolution	$\lambda/\Delta\lambda \sim 1000$	
Slit mask Capacity	20 masks	
MOS Multiplicity	~ 30 objects per mask	
Estimated Total Throughput	Imaging: 31%, Spectroscopy: 20%	
Estimated Limiting Magnitudes (in AB)[c]		
Imaging (1hr, S/N=5):	Y=25.0 mag, J=24.2 mag, H=23.5 mag, K_s=23.8 mag,	Y=25.3 mag, J=24.5 mag, H=23.7 mag, K_s=24.0 mag,
Spectroscopy (1hr, S/N=5, R=1000):	Y=23.3 mag, J=22.4 mag, H=22.2 mag, K_s=21.9 mag,	Y=23.6 mag, J=22.7 mag, H=22.5 mag, K_s=22.2mag,

[a]The full field of view at the Cassegrain focus of the TAO 6.5-meter telescope is covered with four detector arrays (4096 × 4096 pixels).
[b]Narrow-band filters are under consideration.
[c]Magnitudes for TAO are estimated from those for Subaru by only considering the difference of the telescope diameter between TAO (6.5m) and Subaru (8.2m).

3. Optics

The SWIMS optics is currently optimized for the Subaru Telescope (Figure 4 and Table 2).

A dichroic mirror is placed in the collimated beam for simultaneous-color observations. All of the components are placed on a optical bench (1400 x 920mm), and cooled down below 90K. Expected performances are shown in Figure 5. Good image qualities are achieved, and image distortions are negligible across the FoV.

Collimator Unit:

- Currently optimized for the Subaru Telescope
- Re-optimized by replacing the first three lenses when mounted on the TAO
- Field lens : ϕ216mm, CaF_2

Camera Units:

- Two channels: optimized for λ=0.9-1.5 μm (*blue*) and λ=1.4-2.5 μm (*red*)

Detectors:

- HAWAII-2RG array with 2.5 μm cutoff
- SIDECAR ASICs for readout
- Two arrays cover 6'.8 x 3'.4 with 0".10 pixel^{-1}

Figure 4. Optical design of SWIMS.

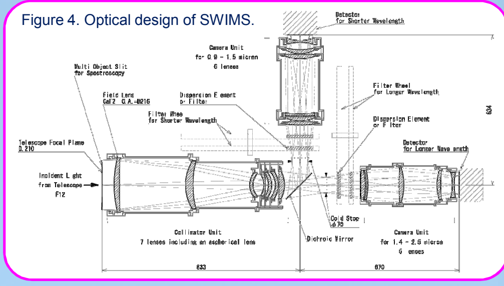


Table2. Specifications of the optics.

	Blue channel	*Red* channel
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	6 spherical lenses	7 spherical lenses
Image Quality (RMS Spot size)	< 1.3 pixel (< 1.2 pixel on TAO)	< 1.2 pixel (< 1.0 pixel on TAO)
Image Distortion	< 1% across the field of view	
Pupil Size	70 mm in diameter	
Overall Length	~ 1600 mm	
Operation Temperature	90 ±10 K	

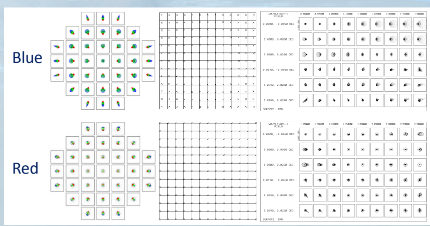


Figure 5. *Left*: Spot diagrams for 6'.6 x 6'.6 FoV of the imaging mode. Red, green, blue spots correspond to λ = (0.9, 1.25, 1.50) μm, and (1.4, 1.8, 2.4) μm for the *blue* and *red* channels, respectively. The box is 5.4 pixels (0".53) on a side. *Middle*: Distortion maps for 6'.6 x 6'.6 FoV of the imaging mode (exaggerated by a factor of 50). *Right*: spot diagrams of the spectroscopy mode. The box is 5.4 pixels (0".53) on a side.

4. Multi-Object Slit unit

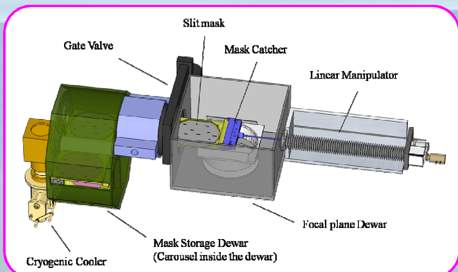
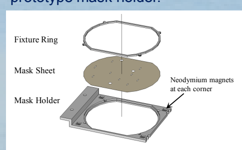
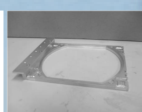


Figure 6. 3D schematic view of the MOS unit.

Figure 7. *Left*: A schematic drawing of the slit mask. A mask is made of aluminum sheet, and its shape is a combination of a circle with 210mm in diameter and a rectangle with 150mm x 210mm. *Right*: A prototype mask holder.





The design of the MOS unit of SWIMS is based on MOIRCS[5,6] on the Subaru Telescope,

- Mask storage dewar
  - ✓ 20 slit masks are stored in a carousel
  - ✓ GM cryo-cooler equipped.
- Robotic mask catcher

and refined to be operative at the Nasmyth focus of the TAO 6.5m telescope.

- **Neodymium magnets** are used to hold a slit mask on the focal plane as well as to stock the mask at the carousel.
- A slit mask holder is designed to hold a **cylindrically curved mask sheet** to compensate for the curved focal plane of the telescopes, especially for the TAO 6.5m telescope.

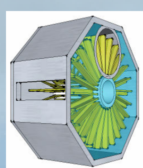


Figure 8. Mask storage dewar and Carousel.

5. Schedule

By July 2010	Detailed designs of optics, mechanics and MOS to be completed.
2011	Dewar, MOS and detectors to be delivered.
2012	Installation and assembly of the components to be completed.
2013	Transported to Subaru, and First Light.

References

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