The University of Tokyo Atacama Observatory 6.5m Telescope Project

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ABSTRACT

The University of Tokyo Atacama Observatory (TAO) is a project to construct a 6.5m infrared-optimized telescope at the summit of Co. Chajnantor, 5,640 m altitude, in northern Chile, promoted by Institute of Astronomy, University of Tokyo. Thanks to the high altitude and low water vapor, continuous window from 0.9 to 2.5μm as well as new windows at wavelength longer than 25μm appears. The site shows extremely low precipitable water vapor of 0.5mm (25 percentile), and fraction of usable night is more than 80%. Measured median seeing is 0”.69, which is comparable or better than major observatories over the world. Prior to the 6.5m telescope, a 1m pathfinder telescope called miniTAO is installed and started observations in 2009. Its successes of Paschen α imaging at 1.875 μm and mid-infrared observations at 30μm confirm promising capabilities of the site. The 6.5m telescope is now at a design phase, and two facility instruments are now being constructed, which are a near-infrared imager/multi-object spectrograph with a field of view of 9’.6 and a mid-infrared imager/spectrograph for observations in 2 to 38μm.

Keywords: TAO, telescope, infrared, Chile, Atacama, Co. Chajnantor, high altitude, remote observation

1. INTRODUCTION

Japanese astronomical community has entered a new era in this century. Since 1999 the 8.2m Subaru telescope has been in operation by National Astronomical Observatory Japan (NAOJ) and another large project, ALMA (Atacama Large Millimeter/submillimeter Array) is now under construction by NAOJ in collaboration with European, North-American, and Asian astronomical communities. In space, Japan Aerospace Exploration Agency has launched an X-ray observatory (Suzaku, July, 2005), an infrared surveyor (Akari, February, 2006), and a solar satellite (Hinode, September, 2006). Suzaku and Akari are carrying out observations of the whole sky, however, the southern-most celestial sky is inaccessible from the Subaru telescope. It is obvious that Japanese astronomers desire a new optical-infrared telescope with comparable performance to the Subaru telescope in the southern hemisphere.

Institute of Astronomy, University of Tokyo plans to build a telescope with 6.5m aperture at the world’s highest site, the summit of Co. Chajnantor with 5640m altitude in the northern Chile. This project is called University of Tokyo Atacama observatory (TAO)[1]. Using both the TAO and the Subaru telescopes, we can observe the most important areas for research in cosmology, galactic formation, and star/plant formation; the two galactic poles, the Magellanic clouds, the Galactic center, and the Orion star-forming regions as shown in Figure 1.

Figure 2 shows atmospheric transmittances at the TAO and other major observation sites simulated with ATRAN software[2]. Thanks to the extreme altitude and low perceptible water vapor (PWV) of the site, seamless spectroscopic observations can be made from the visible to the near infrared wavelength. In addition, the atmospheric window extends to 43 μm. This makes it possible to observe in a new wavelength range which has been inaccessible from the ground.

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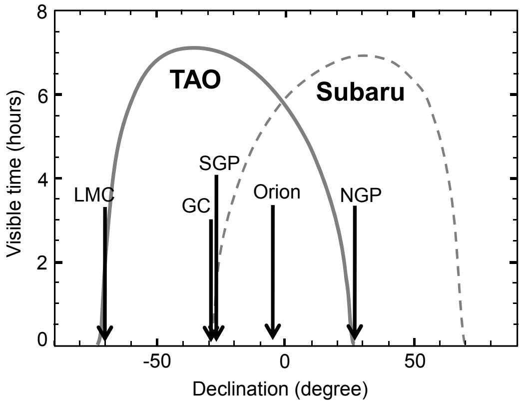

Figure 1. Comparison of accessibility for five important sky areas between the TAO and the Subaru telescopes. The vertical axis is time available for continuous observations with an airmass less than 1.5. The horizontal axis is declination of a target. The TAO 6.5m telescope build in Atacama, Chile where the latitude is around −20 degree, is capable to make intensive observations of the south galactic pole (SGP), the Galactic center (GC), the large and the small Magellanic clouds (LMC/SMC), and the Orion star-forming region.

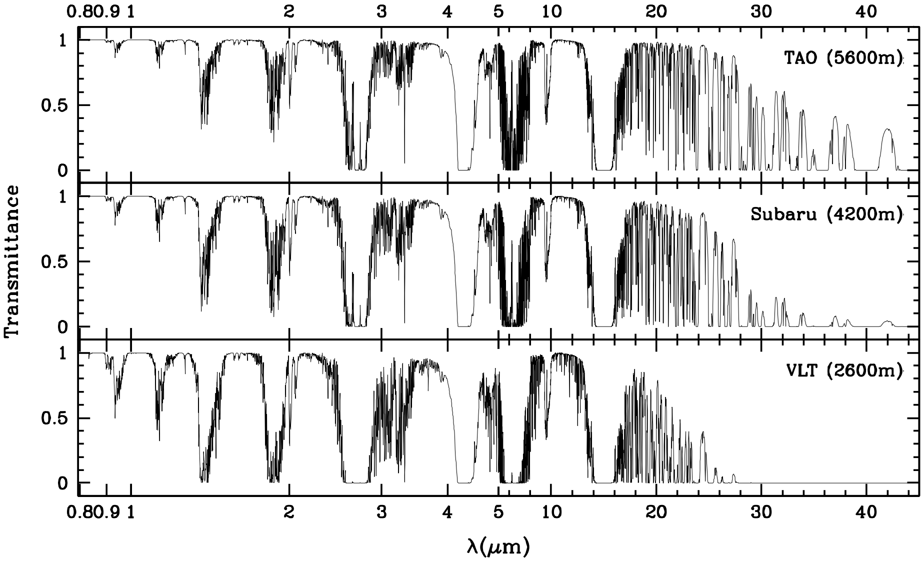

Figure 2. Comparison of atmospheric transmittances between the TAO and other major observation sites. from 0.8 to 45 μm. (Top) The TAO site (Co. Chajnantor): 5,600m, 498 hPa, PWV=0.5 mm, (middle) the Subaru site (Mauna Kea): 4,200m, 600 hPa, PWV=1.0 mm, and (bottom) the VLT site (Paranal): 2,600 m, 737 hPa, PWV=6.0 mm.

The science objective has a broad range of spectrum, from observational cosmology, galaxy formation/evolution, to star/planet formation. Infrared imaging and spectroscopy is necessary to reveal stellar mass, morphology and chemical evolution histories of galaxies and clusters of galaxies. Accurate dark energy measurements with distant SNe, baryon acoustic oscillation, and gravitational lenses are also among the key topics. Both the large aperture of the TAO telescope and low water vapor at the TAO site enable us to resolve formation mechanism of stars and planets through high-spatial-resolution mid-infrared observations. Monitoring observations of dust emission from circumstellar disks and shells in the mid-infrared will provide a new aspect to understand formation of Jovian and terrestrial planets.

In this paper, we present an overview of the TAO project including site characteristics, telescope, instrumentation, and support facilities.

2. TELESCOPE AND INSTRUMENTS

2.1 Telescope

A preliminary design study of the 6.5m telescope structure was carried out by European Industrial Engineering S.r.l in partnership with Ansaldo Camozzi. The current design of the telescope is shown in Figure 3 and its physical and optical specifications are summarized in Table 1. The telescope is designed by referring to the 6.5m Magellan telescope and the optics is modified so that we can share instruments between the TAO and the Subaru telescopes. The Cassegrain interface is designed to be same as that of Subaru as well. The telescope has three foci, with a mid-infrared instrument installed at the Cassegrain focus, and near infrared and optical instruments are installed at the Nasmyth foci.

We adopt a borosilicate honeycomb primary mirror with F ratio of 1.25. The mirror is supported by 104 pneumatic actuators for active optics correction. A conventional secondary mirror is used for early phase operation, which is expected to be replaced with an adaptive secondary mirror now under study. The mirrors and the actuator system can be manufactured by the Steward Observatory / Mirror Laboratory , University of Arizona.

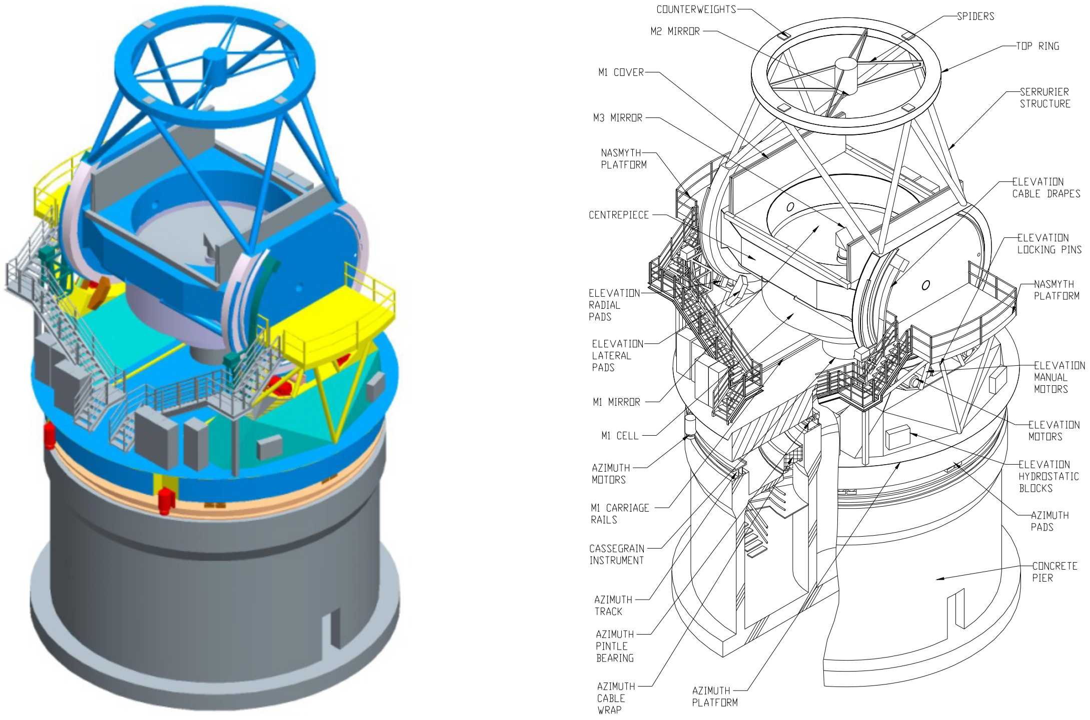

Figure 3. Design of the 6.5m telescope

Table 1. Specifications of the 6.5m telescope

Telescope Type		Cassegrain / Ritchey-Chretien
Primary	Clear Aperture	> 6,480 mm
	Physical size	6,500 mm
	F-number	1.25
Secondary	Size	897 mm
	Radius of curvature	2,657 mm
Final F-number		12.2 (same as the Subaru telescope)
Foci		Cassegrain and two Nasmyth
Back focus		4,000 mm
Field of view		ϕ 25’
Plate scale		2”.7475 /mm
Cassegrain focus		
	Max. loading capacity	2,000 kg
	Max. dimension of an instrument	2,000 mm × 2,000 mm × 2,000 mm

2.2 Instrumentation

Two first generation facility instruments of the 6.5m telescope are an imager/multi-object spectrograph in the near-infrared and an imaging-spectrograph in the mid-infrared, which are already funded by the Japanese government and are constructed. The development of these instruments will be completed by 2013, and they are planned to be commissioned at the Subaru telescope in advance to operations with the 6.5m telescope.

2.2.1 The Near Infrared Camera and MOS Spectrograph

The near-infrared instrument is called SWIMS[3] (Simultaneous-color Wide-field Infrared Multi-object Spectrograph), covering a wavelength range of 0.9 to 2.5μm with a field-of-view (FoV) of 9’.6 in diameter. The FoV is covered by 4096 × 4096 pixels with a pixel scale of 0”.12/pixel. It will be installed at the Nasmyth focus of the 6.5m telescope. For both imaging and spectroscopy, wavelength ranges of 0.9-1.4μm (called blue channel) and 1.5-2.5μm (red channel) are observed simultaneously by a dichroic mirror placed in the collimated beam. It will enable us not only to carry out multi-band observations efficiently, but also to obtain 0.9-2.5μm spectra simultaneously under the same condition. Such capability is highly efficient for redshift surveys of distant galaxies, as well as for follow-ups of rapidly time variable events such as Gamma-ray bursts. The multi-object spectroscopy (MOS) mode uses cooled multi-slit masks with maximum 30 objects, and achieves a spectral resolution of R~500-1000. Eight HAWAII2-RG array detectors will be used in total, with four arrays covering the focal plane of each channel. However, only two arrays for each channel (four in total) are procured at the moment and four more will be added after the construction of the 6.5m telescope.

SWIMS will be installed in a container and attached to the Cassegrain focus during the commissioning observation at the Subaru telescope.

2.2.2 Mid-Infrared Camera and Spectrograph

The mid-infrared instrument[4] covers a wide wavelength range from 2 to 38μm with three detectors (Si:As, Si:Sb and InSb) and attached to the Cassegrain focus of the 6.5m telescope. Diffraction limited spatial resolution can be achieved at wavelengths longer than 7μm. Low-resolution spectroscopy can also be carried out with grisms. This instrument equips a newly invented “field stacker”, an optical system consisting of two movable pick-up mirrors and a triangle shaped mirror. It combines two discrete fields of a telescope into the camera’s field of view. It will enable us to apply differential photometry method and dramatically improve accuracy of relative photometry and thus feasibility of the monitoring observations.

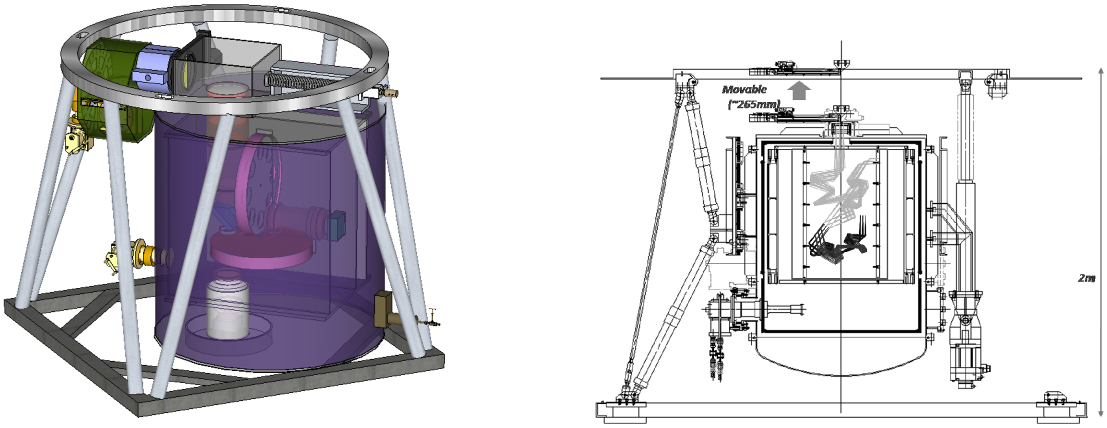

Figure 4. (Left) 3D sketch drawing of SWIMS installed into the Cassegrain container of the Subaru telescope. (Right) Drawing of TAOMIR chamber and the telescope interface.

3. SITE TESTING

3.1 Site Selection Process

Since 2001, we have made four assessments of weather conditions using satellite data, meteorological monitoring, seeing measurement, and monitoring cloud coverage in northern Chile. The fraction of photometric nights and the amount of perceptible water vapor (PWV) are estimated with the satellite data[5]. After a comparison with fourteen spots, we conclude that the Atacama area, especially the summit of Co. Chajnantor, is the best for the infrared astronomy. A robotic weather station is installed in a plateau in the Atacama area in 2001. Its data shows that the median of water vapor is less than 0.4 g/cm^3 in August and September, which means that the atmospheric transmittance is excellent in the infrared[6]. In 2003, we carried out a seeing monitor campaign observation using Differential Image Motion Monitor (DIMM) system at four locations in the Atacama plateau. Results of observations over three nights show that the seeing size is typically 0".6 and less than 0".4 under the best condition[7],[8]. The cloud-coverage above the summit of Co. Chajnantor was measured with an infrared cloud monitor from its foot on the northeast side. The measurement presents that the optical depth in the infrared is less than 0.05 during 94 % of the total nights in June. These data show that the summit of Co. Chajnantor is promising for the infrared astronomy.

3.2 The Summit of Co. Chajnantor

In order to carry out site studies at the summit of Chajnantor, a new road was constructed from a point at 5,075m altitude to the summit. The total length of the access road is 5.7 km and its effective width is 4 m. A route map and a photograph of the road are presented in Figure 5. The road construction was completed in May 2006, followed by meteorological monitoring, cloud monitoring, and seeing measurements at the summit. Instruments installed for the site evaluations at the summit are shown in Figure 6.

The measured wind speed is on average ~10 m/s, while it becomes ~15 m/s in the afternoon to 9 PM during October to April[6]. It is rather high for an astronomical observatory site, but still acceptable. As for the cloud coverage, clear and usable fractions measured at the summit are 63 % and 19 %, respectively. This result is slightly better than that at Mauna Kea Observatory and Cerro Tololo Inter-American Observatory, which are considered to be the world's top-level sites.

Seeing is evaluated with the DIMM system placed on a 2m tower as shown in the right panel of Figure 6. The median seeing over 8 nights is 0□.69 with the best value of 0□.37 in the optical V-band[9], indicating that the seeing at the summit of Co. Chajnantor could be very good although the statistics is not very large.

To summarize the site studies, the summit of Co. Chajnantor is optimal for infrared observations with high clear fraction, good seeing, and acceptable wind speed.

Figure 5.(Left) Route map of the summit access road, where north is up. Solid line shows the route of the access road, and dashed line shows an existing road. (Right) Photograph of the summit access road. The effective width of the road is about 4 m.

Figure 6. (Left) The meteorological weather tower and a container installed at the summit. The cloud monitor and solar panels are placed on the container. (Right) The DIMM system on the 2m tower used to measure the seeing size.

3.3 The miniTAO 1m Telescope

In prior to the 6.5m telescope, a 1.0m pathfinder telescope called miniTAO was installed at the summit of Co. Chajnantor in 2009[10], [11]. The telescope and movable parts of its enclosure, 6m in diameter, were built in Japan by Nishimura Co., Kyoto and shipped to Chile in January 2009. The rest of the enclosure including a concrete base was constructed in Chile after careful environment studies. Three containers used as a control room, a warehouse, and a room for a power generator of 100 kVA are also installed at the summit. Photographs of the 1m telescope and the summit facilities are shown in Figure 7 and 8. On March 23th, 2009, we finally saw the engineering first light of the 1m telescope with an optical CCD camera. The telescope has a pointing accuracy of 1".8 r.m.s. and a Hartmann constant of 0".19 r.m.s., both are satisfactory for astronomical observations.

Figure 7. (Left) The 1m miniTAO telescope installed in its enclosure with the 6 m dome. (Right) A panoramic view of the observatory at the summit of Co. Chajnantor, showing the enclosure of the telescope and the three containers.

Figure 8. (Left) The 1m miniTAO telescope. (Middle and right) Images of the Galactic center taken at Paschen α (1.875 μm) with ANIR (middle), and at 30 μm with MAX38 (right) on the 1m telescope. The field of view of each image is 40” × 7”.

Two facility instruments, a near-infrared camera ANIR[12],[13], and a mid-infrared camera MAX38[14],[15], were developed at Institute of Astronomy, University of Tokyo.

ANIR is a simple near-infrared imager from 0.9 to 2.5μm and was commissioned in June 2009. The middle image of Figure 8 shows the Galactic center in hydrogen Paschen α line at 1.8751 μm[12]. Although the Paschen α is a very strong emission line from ionized hydrogen gas clouds, it is normally not easy to detect from the ground because the wavelength of the line is out of the atmospheric window. However, the wider atmospheric window at the summit of Co. Chajnantor allows us to observe it. Preliminary analysis of the ANIR Paschen α observations shows that PWV is less than 1mm for most of the nights, consistent with the analysis of the satellite data which predicts 0.8 mm in median. The median seeing is 0”.8. Considering that the diffraction limit image of a 1m telescope in the K band is about 0”.38 FWHM, the obtained seeing is remarkable. MAX38 started a commissioning run in November 2009. The right panel of Figure 8 shows an image of the Galactic center obtained at 30 μm. This is the world’s first 30 μm observation from the ground. Observations of both ANIR and MAX38 demonstrate that the summit of Co. Chajnantor is one of the best sites on Earth for the infrared astronomy. It is worth noting that we have verified it not only by the site monitoring instruments but by the real astronomical observations with the 1m telescope.

4. CONSTRUCTION PLANS

4.1 Time Schedule for Construction

The construction plan of TAO facilities is divided into three phases. The first phase for the site survey with small instruments was finished, and we are now getting into the second phase to evaluate the site and also to have experience of operation at the world's highest site with the 1m miniTAO telescope. The third phase is to install the 6.5m telescope while we continue the operation of the 1m telescope. The current timeline for the construction of the 6.5m telescope is shown in Table 2, where its first light is expected in 2016.

Table 2. Timeline for construction of the TAO 6.5m telescope

Items	2009	2010	2011	2012	2013	2014	2015	2016
1. Site Studies and 1-m telescope								
Site Studies at the summit	▨							
1-m telescope installation	▨	▨						
1-m telescope operation	▨	▨	▨	▨	▨	▨	▨	▨
2. 6.5-m telescope								
Detailed design		▨	▨					
Primary			▨	▨	▨	▨	▨	
Enclosure, telescope structure				▨	▨			
Road and ground activities				▨	▨			
Enclosure installation					▨			
6.5-m telescope installation					▨	▨	▨	
6.5-m telescope operation							▨	▨

4.2 Support Facilities

The summit plan for the 6.5m telescope with the support facilities, in addition to the 1m miniTAO telescope, is shown in Figure 9. The 1m telescope is located at south-west of the summit while the 6.5m telescope and support buildings will be at the middle. The highest place of Co. Chajnantor at the north east corner is preserved permanently. The area higher than 5,630 m is used for these facilities, and necessary leveling of the ground is made. Since wind direction is usually from the west, we decided to install the 6.5m telescope at the west side of the summit area so that the effect of ground layer turbulence may become smaller.

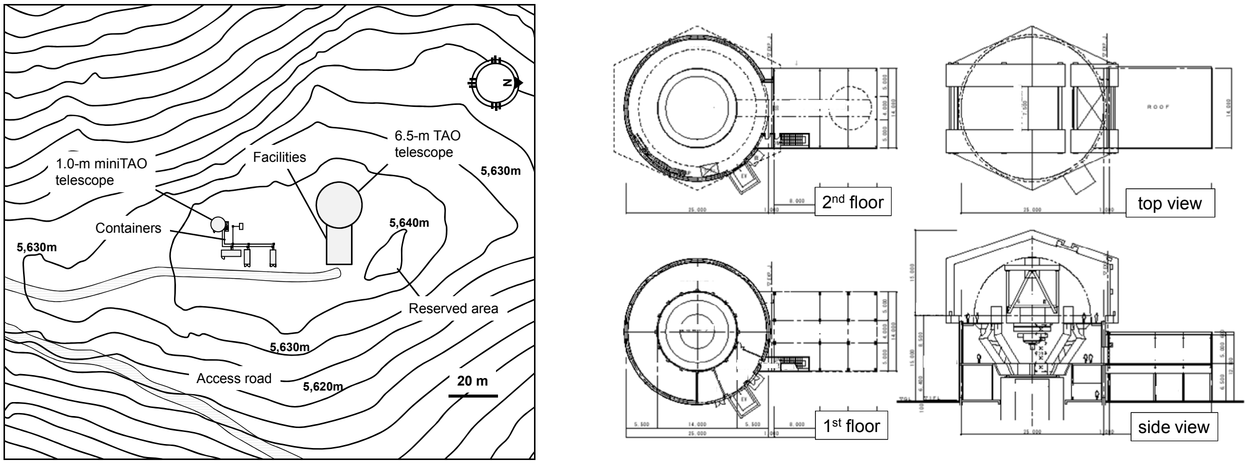

Figure 9. (Left) Summit layout plan for the TAO facilities, where north is right. The 6.5m telescope and its support buildings will be built at the middle. The 1m miniTAO telescope is at the south west corner, and its support facilities are between the two telescopes. The highest place at the north east corner is preserved permanently. (Right) Current design of the enclosure and the support building of the 6.5m telescope.

The current design of the enclosure of the 6.5m telescope is shown in the right panel of Figure 9, of which the diameter is 25 to 30 m. The support building will be annexed to the enclosure. Necessary equipments such as power generators (200 to 300 kVA × 2) and a mirror coating facility will be installed in the support building. Electric power as well as fiber cables for network connection may eventually be supplied through power cables from the downhill. Still, the power generators at the summit is necessary as backups. In order to transport the primary mirror and other large parts of the 6.5m telescope and the enclosure to the summit, the width of the summit access road should be expanded.

The conditions at the summit of Co. Chajnantor are extremely harsh for normal human activities. The oxygen partial pressure there is below 50 % of that at the sea level. Therefore, the telescope and the instruments should be automated as extensively as possible to be remotely operated. The base facility for the remote operation is planned to be constructed at the nearby city of San Pedro de Atacama.

5. ACKNOWLEDGMENTS

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