The University of Tokyo Atacama 1.0-m Telescope

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ABSTRACT

The current status of the University of Tokyo Atacama 1.0m telescope project being constructed at the summit of Co. Chajnantor (5,640m) in Atacama, Chile, will be presented. This is an optical/infrared telescope at the world's highest site. A precipitable water vapor (PWV) amount of 0.4 to 1.3 mm at the summit, much lower than that of 0.9 to 2.8 mm at Mauna Kea, Hawaii. provides excellent atmospheric transmission from the near- to the mid-infrared wavelength. Seeing and weather conditions are confirmed to be suitable for infrared observations at the summit. The telescope is an f/12 Ritchey-Chrétien type with a field of view of 10 arcmin. The telescope is installed in a 6-m dome and controlled from an operation room in a container separated from the dome. The operation room will be directly connected to a base support facility in San Pedro de Atacama by a wireless LAN and a satellite link. A power generator and solar panels are equipped for a main and a back-up power supply, respectively. The ANIR near-infrared camera and the MAX38 mid-infrared camera are equipped on the Cassegrain focus. This telescope will start operation at the beginning of 2009, and will be operated remotely from the base facility in the near future.

Keywords: telescope, near infrared, mid infrared, Atacama, high altitude, remote observation, Co. Chajnantor

1. INTRODUCTION

The University of Tokyo is currently planning to construct a 6.5m telescope optimized to the near to the mid-infrared wavelength at the summit of Co. Chajnantor (5,640 m) in Atacama, Chile, called the University of Tokyo Atacama Observatory (TAO) project (PI: Yuzuru Yoshii) [1]. The University of Tokyo Atacama 1.0m telescope is a prior project of the 6.5m telescope and will start operation at the beginning of 2009. This is an optical/infrared telescope at the world's highest site, and will be operated remotely from the base facility in the near future. Infrared observations with low background and high sensitivity through newly opened atmospheric windows are expected.

In Section 2, the site of Co. Chajnantor and summit facilities will be described. The 1.0m telescope and control system will be described in detail in Section 3.

2. SITE

2.1 Location of Co. Chajnantor

The Atacama Desert is one of the driest regions on Earth, located in northern Chile. On the eastern side of the desert, plateaus over 5,000m altitude extend, and they are the best site for radio astronomy on Earth. Seeking for stable and high-transparent atmospheric environment, several radio telescopes, such as the Atacama Submillimeter Telescope Experiment (ASTE) and the NANTEN-2 at the Pampa La Bola plateau and the Atacama Pathfinder Experiment (APEX) and the Cosmic Background Imager (CBI) at the Chajnantor plateau are now being operated. Moreover, the Atacama

Large Millimeter/Submillimeter Array (ALMA), the world's largest millimeter/submillimeter interferometer, is now under construction at the Chajnantor plateau.

Cerro (Co.) Chajnantor is a peak lying between the Pampa La Bola plateau and the Chajnantor plateau (Figure 1). The summit is located at (S22°59′, W67°44′) with an altitude of 5,640m. The site has been chosen based on satellite data analyzed in collaboration with CTIO[2]. The precipitable water vapor (PWV) is 0.4 to 1.3 mm at Co. Chajnantor, much lower than that at the Mauna Kea observatory of 0.9 to 2.8 mm.

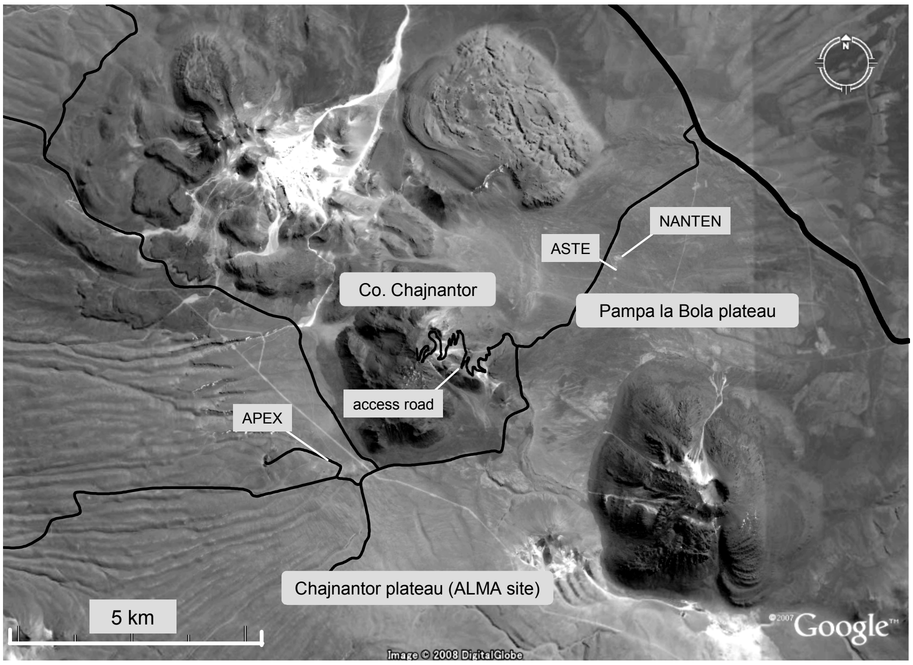

Figure 1. Map of the Chajnantor region. Up side is north. Co. Chajnantor lies between the Pampa La Bola plateau and the Chajnantor plateau. The access road to the summit is constructed on the east face, and the entrance is located at 5,150 m altitude on the opposite side of the ALMA site.

2.2 Atmospheric Environment

Figure 2 shows the atmospheric transmittance calculated with PWV=0.5 at 5,600m altitude (a model for Co. Chajnantor) and PWV=6.0mm at 2,600m altitude (for Co. Paranal) using ATRAN modeling software (Lord, S.D. 1992, NASA Technical Memorandum 103957). It can be seen that:

- ✓ New atmospheric windows beyond the wavelength of 30μm appear.
- ✓ The absorption bands in the near-infrared wavelength at 0.8 to 2.5μm almost disappear.

We also have been evaluating seeing and weather condition at the summit of Co. Chajnantor. Seeing measurement campaign has been carried out for 8 nights during 2006 to 2007[3] at the optical wavelength (0.5 μm). The best night shows median seeing of 0.38 arcsec, while the total median seeing is 0.69 arcsec. This is comparable or even better than most of the major observatories. Weather and cloud4 at the summit is also monitored for more than a year, showing that fraction of clear nights is over 90 % except winter season, maximum speed of wind 35 m sec-1, and minimum temperature about -10°C. These results demonstrate that the summit of Co. Chajnantor is one of the best sites for the infrared astronomy on Earth.

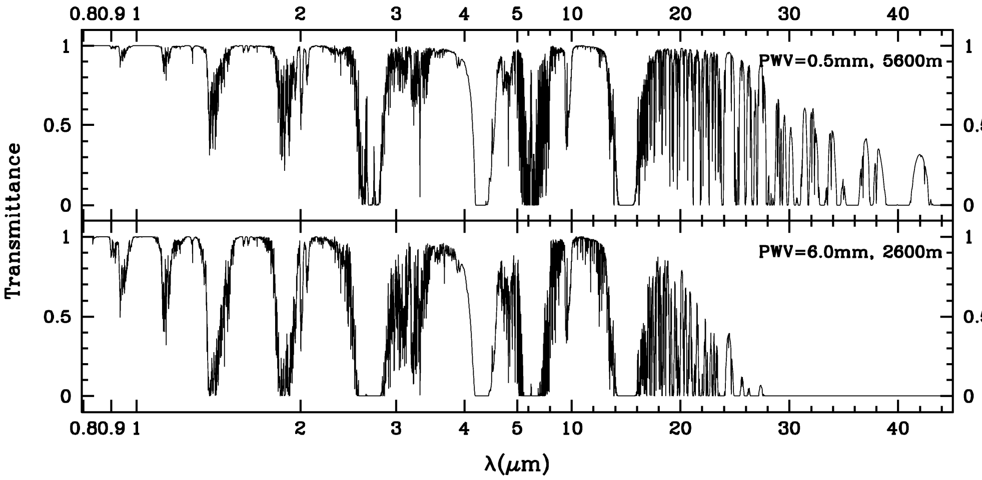

Figure 2. Comparison of atmospheric transmittances at 5,600m altitude (a model for Co. Chajnantor) and 2,600m (for Co. Paranal). At the summit of Co. Chajnantor, new atmospheric windows beyond the wavelength of 30μm appear, and the absorption bands in the near-infrared wavelength at 0.8 to 2.5μm almost disappear.

2.3 Access Road to the Summit of Co. Chajnantor

We constructed an access road between the summit and an existing road on the Pampa La Bola plateau in 2006. It is unpaved and has a length of about 5.6km with an altitude difference of about 500 m. The width is currently 4 m, which will be expanded for the construction of the 6.5 m telescope in the future. The access road is constructed on the downwind side, the east face, of Co. Chajnantor to prevent the road to be closed due to snow.

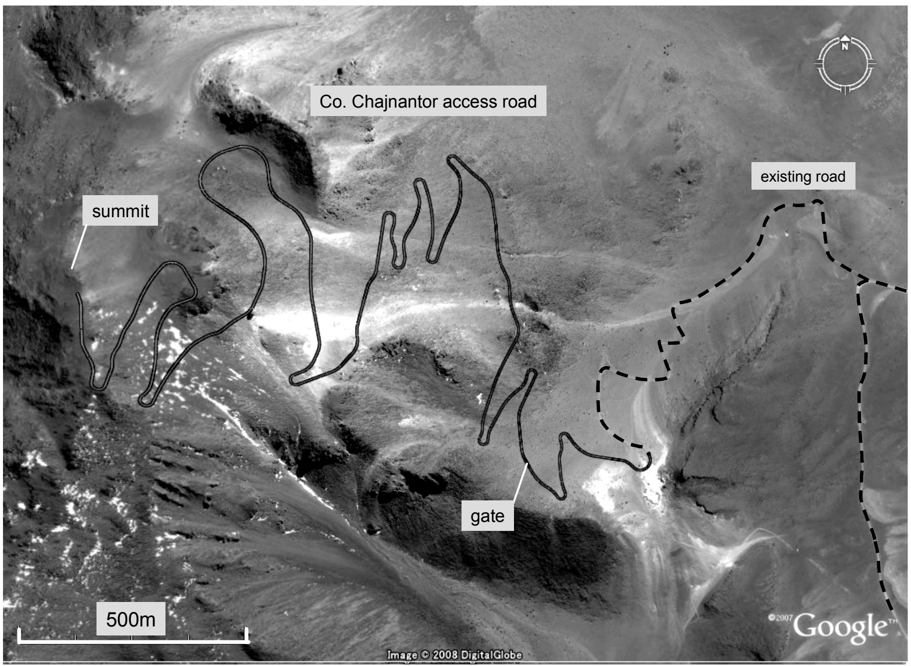

Figure 3. Map of the access road to the summit of Co. Chajnantor. Solid line shows the route of the access road, and dashed line shows an existing road. Up side is north.

2.4 Summit facilities

Summit facilities will be constructed at a level of 5,640m as shown in Figure 4. A telescope dome with 6m diameter is installed on the southwest ridge of the summit, the windward side, to obtain better seeing[3, 4]. A container 8m long is placed for operation at the summit, and two containers 6m long are installed for a storage and a power generator. Network and power are supplied to the containers and the dome using cables under the ground. The telescope is controlled from the operation room. An engine generator of 100kVA capacity and a solar system of 1.1kW capacity are used as main and backup power supplies, respectively. The solar system supplies power to a minimum portion of the network system, monitoring cameras, and weather monitor systems, when the generator does not work. The network at the summit is directly connected to a base support facility in San Pedro de Atacama by wireless LAN and satellite link as described in Section 3.3. Antennas for the wireless LAN and the satellite link are placed on the containers.

Schematics of the 6.0m dome are shown in Figure 5. The primary mirror of the telescope is installed at a height of 3.5m from the ground. The dome has a ventilating room equipped with air filters to keep out dust. Observation instruments are carried in to the Cassegrain floor from an entrance at the second floor. The building foundation is constructed with precast concrete segments to shorten the work period at the summit.

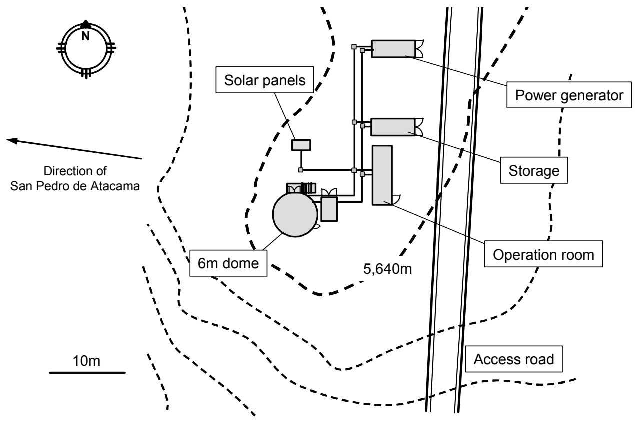

Figure 4. Layout of the summit facilities. The contour step is 1.0m. Up side is north. The telescope dome is placed on the southwest ridge of the summit, the windward side, to obtain better seeing.

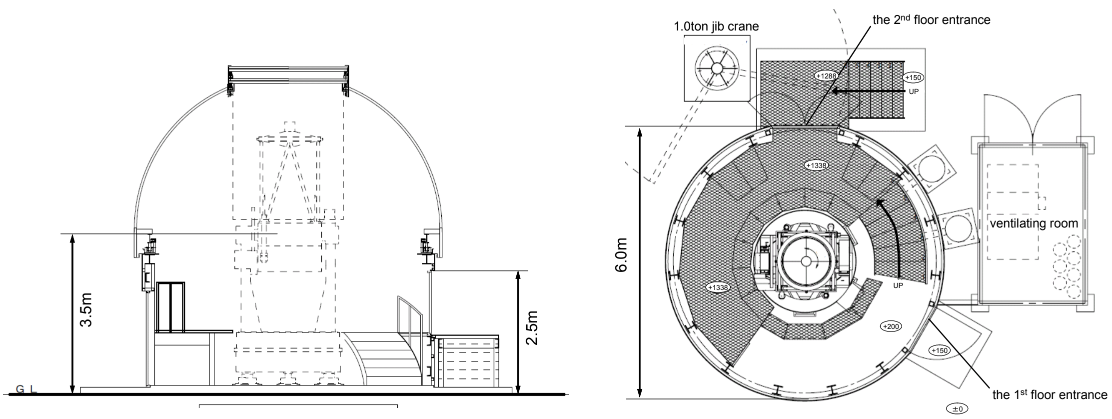

Figure 5. Schematics of the 6.0-m dome. (left) Cross-sectional elevation view from the first floor entrance. (right) Cross-sectional plane view. Up side is north. The 6m dome and the summit facilities are constructed by Kokusai Kogyo Co. Ltd and Nishimura Co., Ltd.

2.5 Base Support Facility

A base support facility will be constructed in San Pedro de Atacama. This building has experimental laboratories, office rooms, and accommodations for observers. The 1.0m telescope is operated remotely from the base support facility via a wireless LAN bridge and a satellite communication.

2.6 Problems at high altitude

The atmospheric pressure at the summit is only a half of that of sea level. This leads to a variety of medical problems such as acute mountain sickness and more serious symptoms. We have made a safety regulation for operation at the summit to ensure the safety and to keep our health. In accordance with the regulation, we carry out health checkups several times a day at the summit and before and after the works at the base support facility, and inhale oxygen with a portable oxygen system manufactured by CAIRE, Inc., which consists of a liquid oxygen reservoir Liberator 45 and portable tanks SPIRIT 600. This system allows us to work for about 4 to 6 hours at the summit.

The low air pressure affects equipments as well as a human body. It is particularly serious for a hard disk drive, which relies on air pressure to support the head at a proper flying height. Therefore, solid state disk drives are adopted as main data storages of all the equipments at the summit. The low air pressure leads to a lack of heat dissipation for the equipments, too. A radiator with substantial capacity should be equipped to prevent from thermal damage. As UV rays damage jackets of cables and then causes electric short, the cables exposed by the sunlight should be protected by tubes with resistance to UV rays.

Usual operations and observations will be carried out remotely from the base facility at San Pedro de Atacama. It reduces risk for medical conditions and improves efficiency of the work and the operation at the summit.

Figure 6. Portable oxygen system. Oxygen is inhaled from the potable tank refueled at the base support facility.

3. TELESCOPE

3.1 Optics

The telescope optics is a standard Ritchey-Chrétien type reflector with a clear aperture of 1042 mm. It is optimized for infrared observations and an oversized primary mirror (diameter 1060mm) is employed. The f-numbers of the primary mirror and the telescope are 2.5 and 12.0, respectively. Table 1 is a summary of the telescope optics.

Reduction of thermal emission from the telescope structure is crucial for infrared observations. The inner area of the Cassegrain hole is the most critical source of the thermal emission. Therefore, a center cone is placed on the secondary mirror to obscure a virtual image of the Cassegrain hole. Spider arms of the secondary mirror are other bothersome sources. Emissions from the spider arms and surrounding warm structures reflected on surfaces of the spider arms come in to the Cassegrain focus through the secondary and the primary mirrors. They are not so prominent but their illuminating pattern varies with rotation of the Cassegrain instrument, causing irregular pattern of the background which cannot be subtracted in the mid-infrared wavelength. To reduce them, spider cover mirrors facing the primary mirror are attached on the bottom face of the spider arms (see Figure 7). They are adjusted for the ray from the Cassegrain focus to be reflected by the cover mirror and the primary mirror, and to escape to the sky.

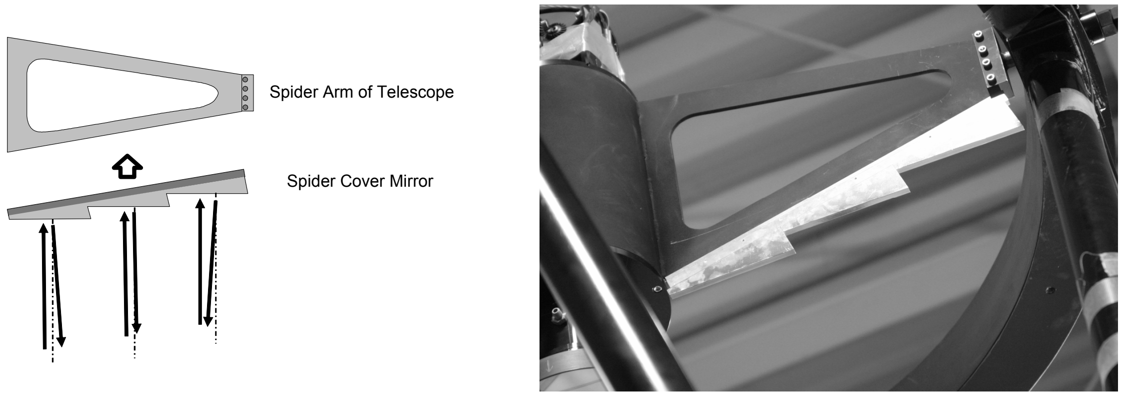

Figure 7. (*left*) Schematics of spider cover mirrors. All the mirrors are placed almost parallel to the primary mirror, but practically the cover mirrors near the secondary mirror are pointed slightly (1deg) outside and the mirrors near the top-ring slightly inside to reduce confusion of the emissions from the Cassegrain hole and the outside of the primary mirror, respectively. (*right*) Photograph of the spider cover mirrors installed at the spider arms.

Table 1. Optical specifications of the Atacama 1.0-meter telescope

Telescope	Type	Cassegrain/RC
Primary	Clear Aperture	1042.4 mm
	Physical size	1060.0 mm
	F-number	2.5
Secondary	Size	222.88 mm
	Radius of curvature	-1407.673 mm
Final F-number		12.0
Back focus		650.0 mm
Field of view		ϕ 10 arcmin
Plate scale		16.644 arcsec/mm

3.2 Mechanics

The structure of the telescope, which is rather conventional, is designed and fabricated by Nishimura Co. Ltd. The primary mirror is housed in a mirror cell, attached to the center section structure, while the secondary mirror and its drive structure is supported by four spider arms and held by a top ring, which is also connected to the center section by truss structure. The center section is then supported by a fork structure standing on an azimuth rotation disk. This rotation disk is held by a base disk. Only the Cassegrain focus with an instrument rotator is available, which makes the size of the telescope compact.

Mechanics of the telescope is designed with durability and stability of performances in the severe environments at the summit. As bearings, an R-guide with 1m radius, model HCR45A+60/1000R fabricated by THK, is used for the azimuth rotation axis and angular contact ball bearings, model #7940 by NTN, for the elevation axis. The R-guide is installed on the base disk mentioned above with an accuracy of circularity less than ±10μm, and a levelness of less than ±20μm between the both edges. For angle detection, angle encoders, model ERA180C and ROD780 by Heidenhain Co., are used for the azimuth and the elevation axes, respectively, providing resolution of 0.03arcsec/pulse. Both axes are driven by friction drives with servo motors, model DD-DM1A-200 by Yokogawa Electric Co, with torque of 200Nm and resolution of 4×10^8 pulse/rotation. Table 2 shows the specifications of the telescope structure. The pointing of the telescope is thus controlled to track the encoder values within an accuracy of 0.1arcsec r.m.s. Servo motors, model J3 by Mitsubishi Electric Co., are used to drive the secondary mirror support and the instrument rotator.

To minimize the external noise coming into the instruments caused by the driving motor of the telescope, the following measures have been carried out: (1) Line filters are inserted in the power lines of all the drivers, (2) choke coils and motor filters in the power lines between all the drivers and the motors, (3) and additional radio filters and power factor improving AC reactor are attached to the drivers for the J3 motors. The readout noise measurement during the pre-assembly by installing the real instruments on the Cassegrain focus, it is found that there is no additional noise caused by the telescope, even if we directly connect between the telescope and the instrument without any insulator. The measured readout noise for the ANIR near-infrared camera[5] is less than $10e^-$ r.m.s for a single correlated double sampling.

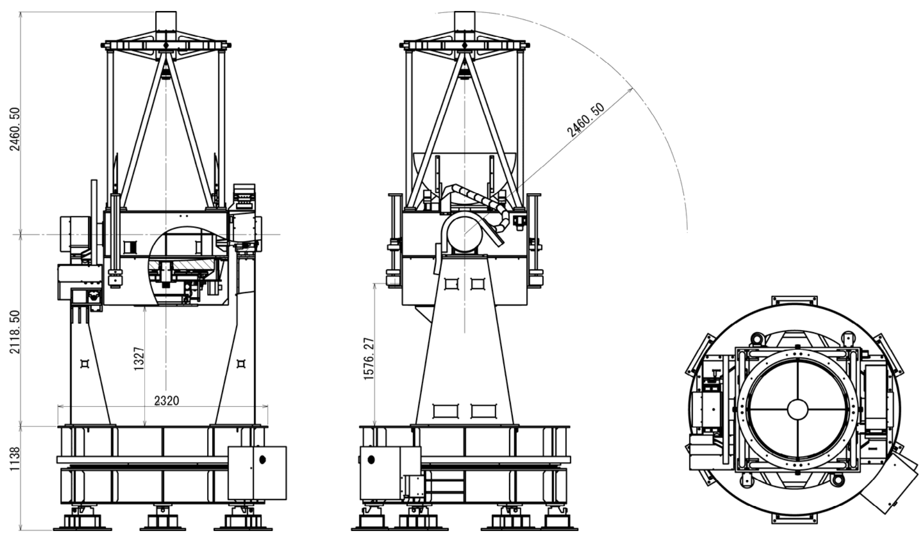

Figure 8. Schematics of the 1.0m telescope.

Table 2. Specifications of the telescope structure.

Rotation speed and range		
Azimuth	3 °/s	±270 °
Elevation	2 °/s	5 °~93 °
Instrument Rotator	3 °/s	±185 °
Focus range at the 2ndry mirror	±20 mm	
Pointing accuracy	1″.3 r.m.s.	
Max. loading capacity on the focus	300 kg	
Max. dimension of an instrument	ϕ1000 mm × 1150 mm	

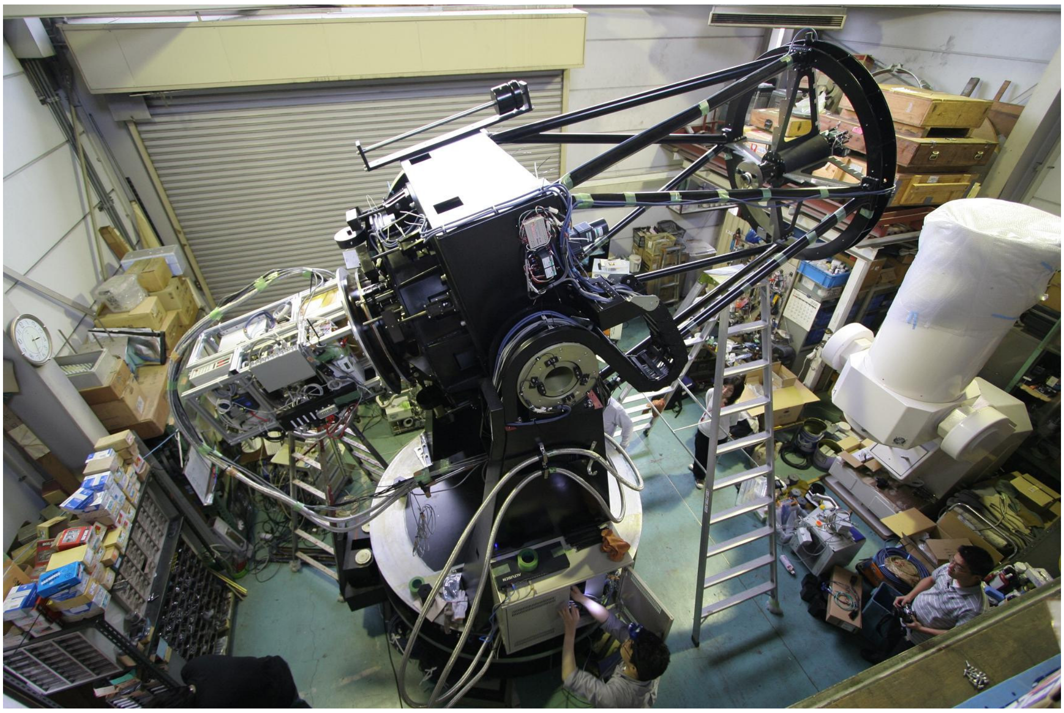

Figure 9. The 1.0m telescope pre-assembled in the factory at Kyoto, Japan. The MAX38 mid-infrared camera[6] is mounted on the Cassegrain focus.

3.3 Control system

The 1.0m telescope and the 6.0m dome are monitored and managed by a DOS based control PC in the operation room. Motor drivers and encoder boards for the telescope are operated by the control PC synchronized with GPS time. These devices are assembled in a 19-inch rack case except GPS antennas. A dome control unit consisting of motor drivers and programmable logic controllers (PLCs) drives the dome, and is managed by the control PC through a RS-485 interface. Status information of the telescope and the dome system is stored in a local disk drive of the control PC.

The telescope and the dome can be controlled via a handset unit placed in the dome or a Linux based server PC connected to the control PC with a RS-232C cable. Software running on the server PC translates commands from client PCs via TCP/IP into low-level commands and sends them to the control PC through the RS-232C interface. We access the server PC from the client PCs to control the telescope and the dome in normal operations.

Network system between the summit and the base support facility is designed by Ubiteq, Inc. The summit facility is linked with the base at San Pedro de Atacama, 48 km west from the summit, by a 2.4GHz wireless LAN bridge with an expected transfer rate of a few Mbps. A satellite communication with the INMARSAT/BGAN service, whose maximum data rate is 0.6 Mbps, is used as a backup line. All the equipments at the summit can be restarted remotely, being prepared for power failure or other kind of troubles. When the engine power generator does not work, a minimum portion of the summit network is supplied with power from the solar system to operate the weather monitor system and the monitoring cameras.

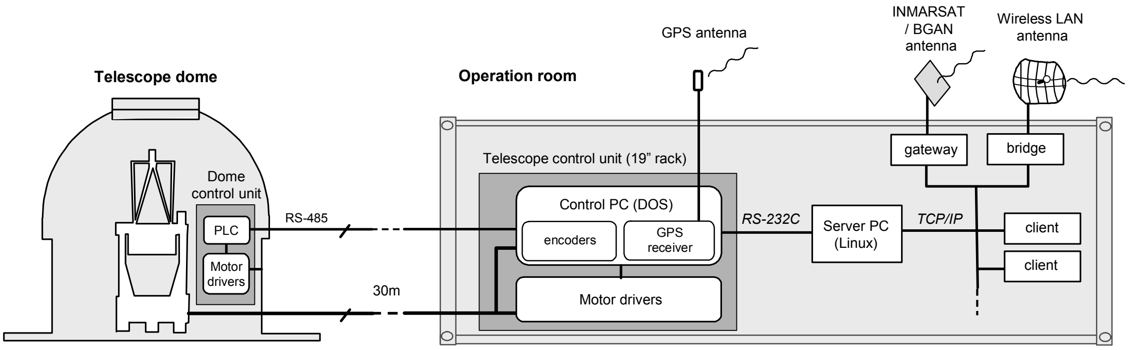

Figure 10. Diagram of control system for the 1.0m telescope. The 1.0m telescope and the 6.0m dome are managed with a DOS based control PC installed in the operation room. Users control the telescope and the dome via a Linux based server PC. The summit network is linked with the base support facility at San Pedro de Atacama by a wireless LAN bridge and a satellite communication.

3.4 Instruments

The ANIR near-infrared camera[5] and the MAX38 mid-infrared camera[6] are equipped on the Cassegrain focus. The main aim of the ANIR camera is to carry out an imaging survey in Paschen α emission line (1.8751μm) taking advantages of 5,640m altitude. The MAX38 camera will carry out observations in the 30μm wavelength range through the newly opened atmospheric windows. The two instruments are designed to have similar weight (~160kg) and momentum on the Cassegrain focus in order to exchange them without readjusting a balance of the telescope.

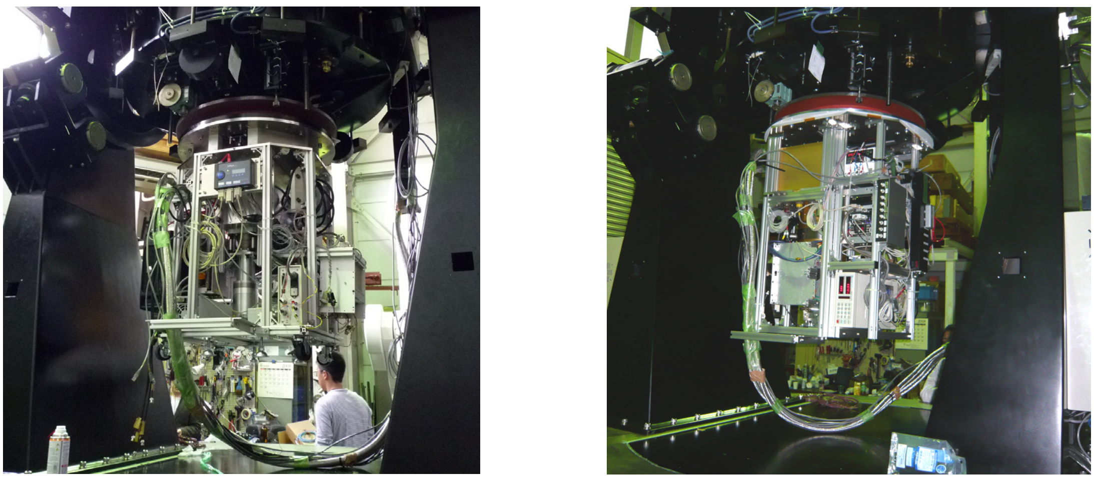

Figure 11. Photographs of the ANIR near-infrared camera (*left*) and the MAX38 mid-infrared camera (*right*) mounted on the Cassegrain focus of the 1.0m telescope.

4. SUMMARY

The University of Tokyo Atacama 1.0m telescope is being constructed at the summit of Co. Chajnantor (5,640m) in Atacama, Chile, and will be an optical/infrared telescope at the world's highest site. The low PWV of 0.4 to 1.3mm at Co. Chajnantor provides excellent atmospheric transmission from the near- to the mid-infrared wavelength. The median seeing of 0.69 arcsec and the fraction of clear nights over 90 % shows that the site is suitable for infrared observations. We constructed an access road with a length of about 5.6km to the summit of Co. Chajnantor in 2006. Summit facilities including the 1.0m telescope and a 6.0m dome will be constructed at a level of 5,640m. The telescope is an f/12 Ritchey-Chrétien type with a field of view of 10 arcmin and optimized for the infrared observations. The telescope and the dome are operated by a control system installed in an operation room at the summit. An engine power generator of 70kVA capacity and a solar system of a 1.1kW capacity are equipped for a main and a back-up power supply, respectively. In a near future, we will operate the telescope remotely from a base support facility at San Pedro de Atacama connected to the summit network by a wireless LAN and a satellite communication. The ANIR near-infrared camera and the MAX38 mid-infrared camera are equipped on the Cassegrain focus. This telescope will start operation at the beginning of 2009.

We thank all the workers at Monte Grade Co. at Calama, Chile for construction of the summit facilities and the access road, and Kokusai Kogyo Co., Ltd. for the arrangements of our activities in Chile. We are grateful to all of the members of Nishimura Co., Ltd for their supports in telescope tests. We also thank Nano-Optonics Research Institute for helpful support. This work has been supported by the Grant-in-Aid for Scientific Research (15253001, 17104002, and 20041003) from the JSPS. Part of this work has been also supported by NAOJ Research Grant for Universities. S. S. is financially supported by the JSPS (18-9936).

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