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SITE CHARACTERISTICS OF THE SUMMIT OF CERRO CHAJNANTOR AT THE 5640 M ALTITUDE

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RESUMEN

El Instituto de Astronomía de la Universidad de Tokio está promoviendo el proyecto TAO (University of Tokyo Atacama Observatory; Yoshii et al. 2010) para construir un telescopio infrarrojo en la cima de Cerro Chajnantor (altitud 5640 m) en el desierto de Atacama en el Norte de Chile. Para la evaluación de las características del sitio, primero se realizó el monitoreo del tiempo atmosférico, la emisividad de nubes y el seeing durante 2006–2007. La fracción despejada fue alta (>80%) y la mediana del seeing en la banda V fue de tan solo $0\farcs69$. Un telescopio explorador de 1 m llamado miniTAO fue instalado y comenzó a observar en 2009. Con éste se han obtenido imágenes satisfactorias de Paα de hidrógeno 1.875 μm como también imágenes de 30–40 μm por primera vez desde un telescopio en tierra. Estos resultados demuestran que la cima de Cerro Chajnantor es uno de los mejores sitios para la astronomía infrarroja en la Tierra.

ABSTRACT

Institute of Astronomy, University of Tokyo is promoting a project called TAO (University of Tokyo Atacama Observatory; Yoshii et al. 2010) to construct a 6.5 m infrared telescope on the summit of Cerro Chajnantor (5640 m altitude) at Atacama desert in northern Chile. For the evaluation of the site characteristics, we first conducted weather and cloud emissivity monitoring and seeing measurement in 2006–2007. The clear fraction was high as >80% and the median seeing in the V-band low as $0\farcs69$. A 1 m pathfinder telescope called miniTAO was installed and started observation in 2009. We have successfully obtained 1.875 μm hydrogen Paα images as well as 30–40 μm images for the first time from a ground-based telescope. These results demonstrate that the summit of Cerro Chajnantor is one of the best site for the infrared astronomy on the Earth.

Key Words: atmospheric effects — site testing

1. TAO PROJECT

Astronomers have been climbing up to higher altitude to get rid of water vapor in the Earth atmosphere and to pursue better atmospheric transmittance in the infrared. Now, Institute of Astronomy, University of Tokyo is promoting a project to construct a observatory at the summit of Cerro Chajnantor in northern Chile and to install a 6.5 m infrared-optimized telescope there, which is called TAO project (Yoshii et al. 2010). This is the world's highest astronomical observatory, and thanks to the high altitude of 5640 m with the dry climate of Atacama desert, perceptible water vapor (PWV) is expected to be low as <1 mm. This results in a continuous atmospheric window in the near-infrared (0.9–2.5 μm), and new windows in the mid-infrared (20–40 μm), as shown in Figure 1.

2. SITE STUDIES AT THE SUMMIT OF CERRO CHAJNANTOR

Site studies in northern Chile started in 1999 using the GOES-8 satellite infrared imaging data, which was carried out in collaboration with NOAO and ESO (Erasmus & van Staden 2001). From this survey, we have selected Cerro Chajnantor as our primary candidate site, which has high clear fraction (70% photometric and 78% spectroscopic) and very low PWV (25%-tile <0.5 mm).

Cerro Chajnantor is a hill with a height of ∼600 m located in the northern edge of Chajnantor plateau, and it takes only 1 hour to drive to its bottom from the nearest village of San Pedro de Atacama. As no road up to the summit existed, we first climbed up the hill on foot in 2002, to confirm the

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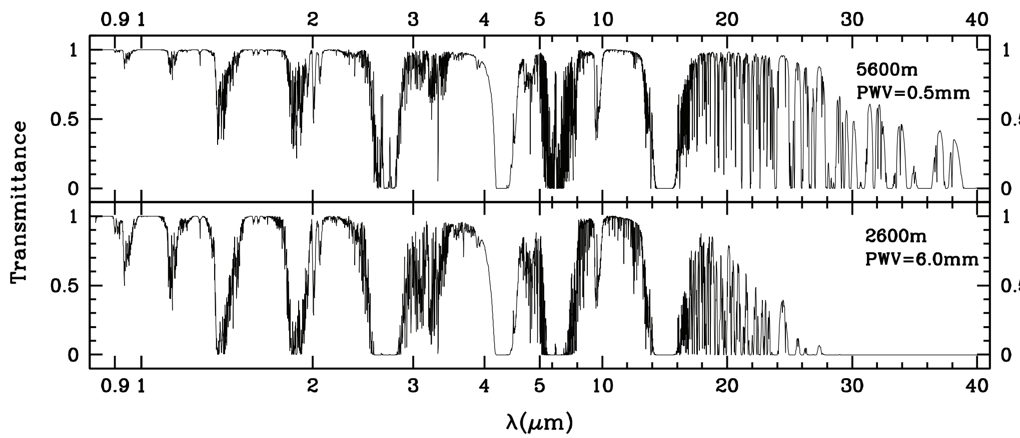

Fig. 1. Atmospheric transmittance curves in the near- to mid-infrared wavelength at the summit of Cerro Chajnantor (top) and at a typical observatory in Chile (bottom).

condition of the summit. Next, we constructed a new access road to the summit with 5.7 km length and 4 m width and started on-site weather and cloud monitoring in 2006 (Miyata et al. 2008a). In addition, we have carried out several campaign observations of seeing using DIMM system (Motohara et al. 2008a). The one-year monitoring provided several important informations.

- Typical wind speed is $\sim$10 m/s and a windy night with >20 m/s is rare.
- Clear fraction is 82%, showing good agreement with the satellite data analysis.
- Median seeing is $\sim 0\farcs69$ in the V-band, which is comparable or better than most of the best astronomical sites.

These results show that the summit of Cerro Chajnantor is one of the best astronomical sites, especially for infrared observations, on the Earth.

3. MINITAO 1.0 M TELESCOPE

Following the above results, we decided to construct a 1 m pathfinder telescope called miniTAO at the summit. The main purpose of the telescope is to carry out scientific observations to prove the above potential of the site, as well as to compile experiences to operate an observatory at the altitude of 5640 m. The telescope has a Ritchey-Chrétien optics with a Cassegrain focus, and final focal ratio is 12 (Sako et al. 2008a; Minezaki et al. 2010). Two science instruments are also developed; one is a near-infrared imager ANIR (Atacama NIR camera; Motohara et al. 2008b, 2010) covering the wavelength of 0.9–2.5 μm and the other is a mid-infrared imager/spectrograph MAX38 (Mid-infrared Astronomical eXplorer 38; Miyata et al. 2008b; Nakamura et al. 2010) covering 9–38 μm.

The installation of the telescope, dome, power generator, and observation containers are completed in March 2009, and we saw the engineering first light on March 22, 2009 using an optical CCD camera.

3.1. *NIR Observations and Results*

Main target of NIR observations is hydrogen Paα imaging at 1.8751 μm using narrow-band filters. Although Paα is the strongest hydrogen emission line in the near-infrared, the observation is difficult from the ground due to strong absorption features by water vapor in the Earth atmosphere. However, thanks to the low PWV, atmospheric transmittance exceeds 50% at 1.8751 μm at the summit of Cerro Chajnantor. ANIR is equipped with two narrow-band filters, $N1875$ and $N191$ for Paα imaging and for off-band imaging, respectively.

ANIR saw the first light in June 2009, and successfully obtained Paα narrow-band images of the Galactic center, Quintuplet, nearby LIRGs, and so forth for the first time from the ground (Figure 2; Motohara et al. 2010).

Figure 3 shows the relation between the effective atmospheric transmittance of the filters versus PWV measured at the APEX site at 5100 m, located in the Chajnantor plateau. The transmittances show good correlation against the PWV, and are systematically higher than the value expected from the PWV at the 5100 m altitude. Also, even if the PWV is larger than 1 mm, the transmittances stay at the same level as those with PWV<1 mm. These results suggest that most of the water vapor is deposited near the surface of the Chajnantor plateau, and the summit of Cerro Chajnantor is kept dry like "an island" in the sea of the water vapor.

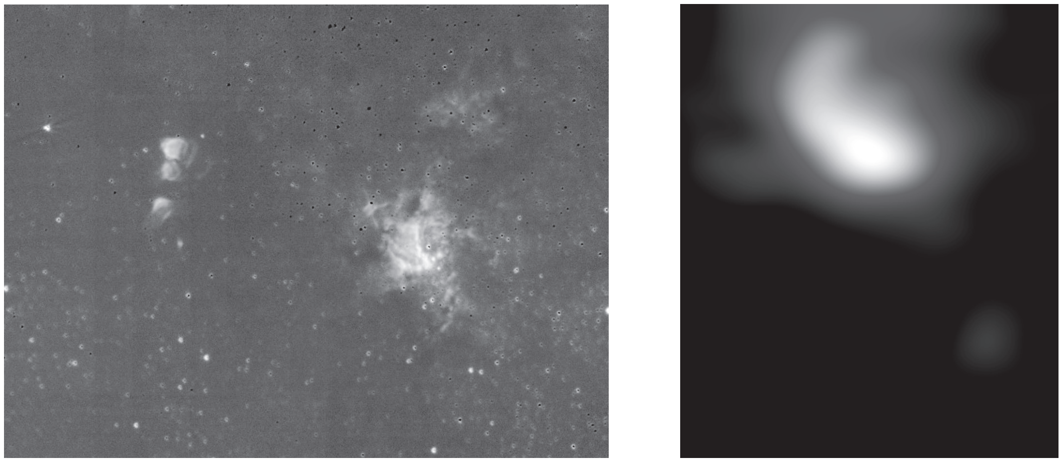

Fig. 2. Galactic center images in Paα by ANIR (left, $4'.7\times3'.5$), and in 31 μm by MAX38 (right, $40''\times40''$).

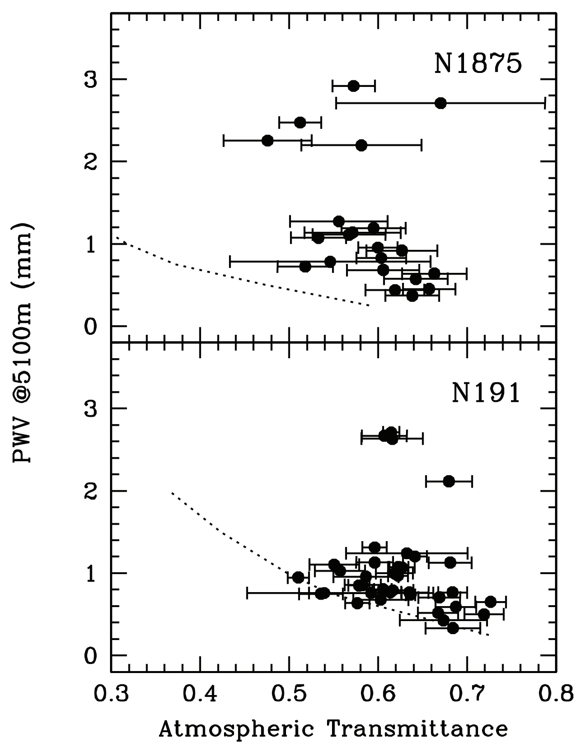

Fig. 3. Effective atmospheric transmittances at each filter band of $N1875$ and $N191$ versus PWV measured at APEX in the Chajnantor plateau (5100 m altitude). Each datapoint is calculated using the 2MASS stars in the image. Dashed lines show relation simulated by ATRAN atmospheric model software (Lord 1992).

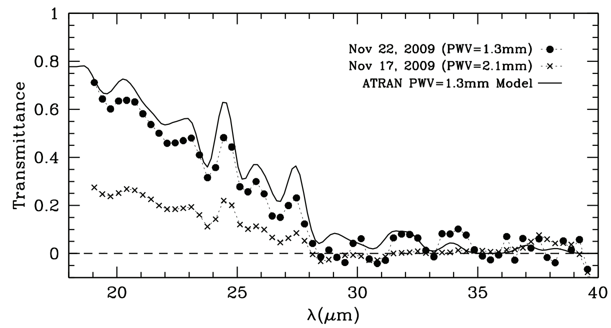

Fig. 4. Transmittances at 20–40 μ m measured by MAX38. Note that PWV is the value measured at APEX at 5100 m altitude. Solid line shows the simulated transmittance with PWV=1.3 mm by ATRAN software, which matches well with the real data.

3.2. *MIR Observations and Results*

MIR, especially at longer than 20 μm, benefits from the low PWV the most. The 20 μm window becomes more transparent and stable compared to other good observatories such as Mauna Kea at 4200 m altitude, and new windows at >30 μm appears. To observe these wavelength ranges, MAX38 is equipped with newly developed metal-mesh filters at 31 μm and 37 μm (Sako et al. 2008b) and a grism to evaluate the atmospheric windows.

MAX38 saw the first light in November 2009, and have successfully obtained images of the Galactic center, Jupiter, and so on in both 31 and 37 μm for the first time from the ground.

Figure 4 shows the obtained atmospheric transmittance using the grism spectroscopic mode. It shows that the atmospheric window at 31 μm exists when PWV=1.3 mm, but not when PWV=2.1 mm. This is consistent with the 31 μm imaging observations that a celestial object begins emerge in the image at PWV<1 mm.

4. SUMMARY AND FUTURE PLANS

We have been carrying out the site testing on the summit of Cerro Chajnantor at 5640 m altitude. One year monitoring shows clear fraction of $\sim$80% and median seeing of $\sim 0\farcs69$, which are comparable or better than major astronomical observatories in the world. Wind speed is $\sim$10 m/s typical, and enough low to operate a telescope there.

Following scientific observations with the newly installed miniTAO 1 m telescope successfully obtained NIR Paα images and MIR 31 μm and 38 μm images for the first time from a ground-based telescope. The measured transmittance in these wavelength confirms the result of the satellite data, that the typical PWV is less than 1 mm at the summit.

These results clearly show that the summit of Cerro Chajnantor is one of the best sites for the infrared astronomy on the Earth.

However, the operation of the 1 m telescope is a tough task, due to the low pressure and long driving time to the summit, and the observation is limited to $\sim$8 hour/day by observers' physical capacity. To solve this problem, we are now installing a 2.4 GHz wireless LAN system between the summit and a base facility at San Pedro de Atacama ($\sim$48 km distance). It adopts 1.1 m grid antenna with IEEE802.11b protocol, and throughput of more than 3 Mbps is expected. Installation of the system will improve the efficiency of the operation and opens way to more stable and easier observation.

Our next step is the construction of 6.5 m telescope, and the development of two instruments SWIMS (Konishi et al. 2010) and MIMIZUKU (Miyata et al. 2010) is now underway. In the current schedule, the first-light observation is expected to take place in 2017.

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