Seeing Environment at a 5640m Altitude of Co. Chajnantor in Northern Chile

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ABSTRACT

We have carried out a campaign to monitor seeing at a 5640m altitude on the summit of Co. Chajnantor at Atacama, for the 6.5m telescope TAO project planned by the University of Tokyo. The seeing conditions were measured at 0.5μm using a DIMM (Differential Image Motion Monitor) during 8 nights in November 2006 and April 2007. In April, the measurement was done on a 2m-tower to suppress effect of ground-layer turbulence. The best night showed median seeing of $0.''38$, while the total median seeing is $0.''69$. This is comparable or even better than most of the major observatories. Together with the high transparency in infrared wavelength owing to the extremely high altitude of 5640m and its accessibility, the summit of Co. Chajnantor is one of the best site for infrared astronomy on the Earth.

Keywords: seeing, DIMM, site evaluation, Atacama, Co. Chajnantor

1. INTRODUCTION

University of Tokyo is currently planning to construct a 6.5m telescope optimized to the near to mid-infrared wavelength in the northern part of Chile, called "University of Tokyo Atacama Observatory (TAO)" project (PI: Yuzuru Yoshii).[1]

The site selection started with the analysis of the satellite data in collaboration with CTIO.[2] In this study, 14 candidate sites and existing observatories in the northern Chile were selected and their cloud coverage and perceptive water vapor (PWV) were evaluated. From view of the infrared observations, PWV is one of the most important factor because the water vapor in the atmosphere creates a number of absorption bands, especially in the mid-infrared wavelength. From this point of view, we have selected Co. Chajnantor, a isolated peak at the Chajnantor plateau (ALMA site) in northern Chile, which is one of the highest peak of 5640m among the candidates. Its median PWV is less than 1mm, and the 1st quartile value is as low as 0.5mm, which is half the value at Mauna Kea, Hawaii.

The seeing measurement campaign at Co. Chajnantor has started in 2002. Because there was no access road to the summit of Co. Chajnantor in the beginning, all the measurements were carried out either at the plateau or at nearby peaks. While the seeing is not good at the Chajnantor plateau,[3] it becomes good as $0.''4 - 0.''7$ when we go up the nearby peaks.[4]

As the road construction to the summit completed in May 2006 which enables us to access the summit on vehicles, we have started the seeing observation campaign. In this presentation, we report the result of all the seeing measurement activities at the summit since then.

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Aperture diameter	74 mm ϕ
Aperture separation	205 mm (diagonal pair)
Number of apertures	4
Pixel scale	$0.''67$/pix $\times$ $0.''63$/pix
Effective wavelength	5500Å
Limiting magnitude	$\sim$ 1.5 mag (1 ms exposure)

Table 1. Specification of the UT-DIMM

2. UPDATED UNIVERSITY OF TOKYO DIMM (UT-DIMM)

2.1 System Overview

The seeing measurement has been carried out using the differential image motion monitor (DIMM), having been developed at the University of Tokyo. This system is called "UT-DIMM", and has been updated since 2004 when reported in Ref. 3. We describe the current system below. Table 1 summarizes the specifications, and Figure 1 shows the overall layout of the system.

2.2 Telescope and CCD

The base telescope is LX-200GPS, a 12-inch Schmidt-Cassegrain telescope manufactured by Meade Co. It is modified to have four apertures, with a wedge-prism in each of them to split a stellar image onto a CCD.

The telescope is controlled from a PC via RS-232C interface. This enables us to :

- Carry out a auto-guiding observation using current position of the star on the CCD.
- Obtain the azimuth/altitude information. The altitude direction is especially important, using which the elevation correction of the seeing is carried out.

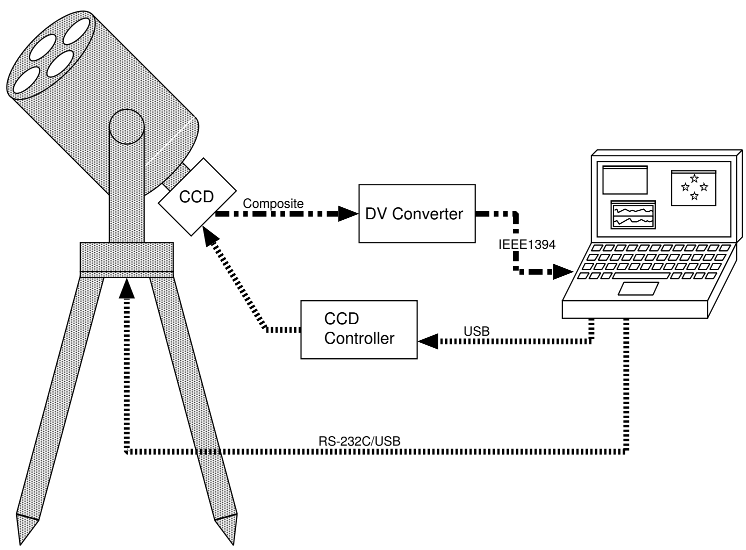

Figure 1. System overview of the updated UT-DIMM.

Figure 2. UT-DIMM set up at the summit of Co. Chajnantor.

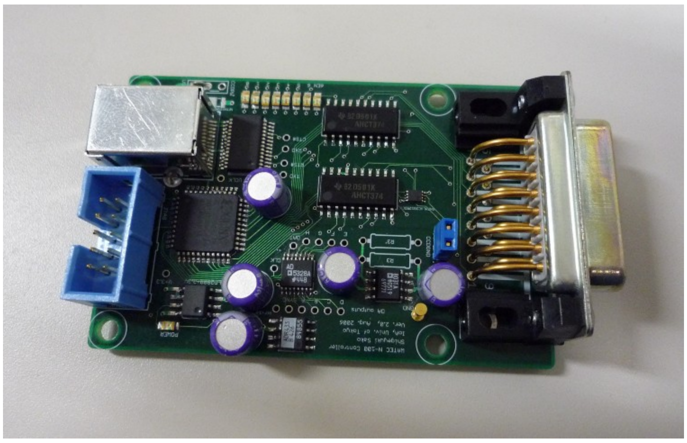

Figure 3. (Top) The CCD controller board.

Figure 4. (Right) The data acquisition system of UT-DIMM. The car batter is placed at the middle of the box, while the DC-AC inverter is seen left to it. The DV converter is the small box lower to the inverter, and the Laptop PC is layed at the top.

The CCD camera is a low-noise, video-rate model WAT-100N manufactured by Watec Co. Ltd. To control the CCD camera, we have developed a remote controller board to replace the hand-held controller (Figure 3). This board is based on a FPGA chip, and connected to the PC via USB interface. The shutter speed, gain, and gamma correction can be controlled remotely from the control PC via USB interface.

2.3 Data Acquisition System

The video output from the CCD is converted to DV stream by a DV converter box model ADVC-55 manufactured by Canopus Co. Ltd., and send to the Laptop PC via IEEE-1394 interface. One of the difficulties we encountered at the altitude of 5640m is that some of hard disk drives don't even spin up due to the low pressure, and that their reliability seem quite low. Instead of using hard disk drives, we decided to boot from a flash-memory based USB memory key.

2.3.1 Software System

Whole the software system is developed on Knoppix 5.0 Japanese Edition, a read-only system based on Debian Linux, which is modified to match our purpose. The advantage of Knoppix is that it consists of a single ISO image file and boot loader, which can be installed on any bootable devices, such as CD-ROMs, DVDs, USB memory keys, and so on. We have adopted a 2GB USB memory key for the device, and divided it into two partitions with 1GB each. Knoppix system is installed onto one partition, and the other partition is used for seeing monitor softwares and a data storage for acquired data. This is because the boot partition of Knoppix is set to read-only, and we cannot write any data on it.

2.3.2 Seeing Measurement

The DV stream from the converter is decoded using "libdv" library. A frame image is extracted on the main memory whenever a new frame is obtained, and stellar positions are measured in it. From the four stellar positions in the image, two diagonal pairs are chosen, and seeing value is calculated from the standard deviation of their relative position using the relation given by Ref. 5 every 120 frames. Because of the interlaced video output from the CCD, odd- and even-line images are offset by 1/60 sec. We therefore treat them as different images, and calculate the seeing independently.

As each pair of the stellar images returns two seeing values, that is, one obtained from transverse motion and the other from longitudinal, and two values from the interlaced odd- and even-line images are also available, we finally have 8 seeing values from a single dataset of 120 frames every 4 seconds in total. These values are found to match within 10% accuracy, so we average them and use as a single value hereafter.

All these calculation can be processed within frame rate (1/30 sec) of the video output using the Intel Pentium III 900MHz CPU.

2.4 Operation at Co. Chajnantor

Because of the remoteness of the site, there are no grid power nor generator available on the site at the moment. Therefore, electrical power of AC 100V is supplied from a DC 12V car battery using a DC-AC inverter unit, which enable us to carry out a single observation for more than 12 hours. All the components including PC, DV converter, battery, DC-AC inverter unit and the others except the telescope is stored in a plastic box and placed under the telescope (see Fig. 2).

Actual measurements are carried out almost unmanned; The observer just set up the telescope at the beginning of the night, introduce the target star into the field of view, and run the software. The system will measure the seeing as long as the star is observable, and shut down the whole system just before the sunrise. In the next evening, observer exchange the USB memory key and the battery, and repeat the measurement again.

The typical exposure time is 0.5ms for a $\sim$1 mag star under normal condition, where the exposure-time effect is negligible.[6]

3. OBSERVATIONS

3.1 November, 2006

The first observation run was carried out at 4 nights of Nov. 9, 10, 12, and 13, 2006. The DIMM was installed $\sim$30m east of the western ridge of the leveled summit (Figure 5).

We have observed Achernar (α Eri, $V = 0.5$mag) with exposure time of 0.5ms.

The weather was moderately good except Nov 13, when thick cloud came in just after we have started observation (UT 24h), and only 1 hour of data was taken.

Figure 5. Two UT-DIMMs were set up at the summit of Co. Chajnantor for the simultaneous observations during the Apr. 2007 run, where one DIMM is set on the 2m tower to avoid the effect of the ground layer turbulence. The DIMM on the ground is installed at the same place as the run of Nov. 2007.

3.2 April, 2007

The second observation run was carried out at 4 nights of Apr. 17, 20, 22, and 23, 2007. This time, we have installed a 2m tower at the western ridge of the leveled summit to avoid the effect of ground layer turbulence. To evaluate the ground layer turbulence at the position of the previous run, another DIMM with same specifications was installed on the ground (Figure 5) and simultaneous observations was carried out for 3 nights of Apr 20, 22 and 23.

We have observed Hadar (β Cen, $V = 0.6$mag) with exposure time of 0.5ms.

The weather was moderately good except Apr 20, when cloud came in around UT 27h, and only 3 hours of data was taken for both DIMM at the tower and on the ground. In addition, we have encountered several troubles during this run and lost more data ; (1) On Apr 22, the entrance aperture of the DIMM at the tower was frosted due to high humidity and star was lost, which resulted in only 1 hour of data. (2) On Apr 23, the software of the DIMM on the ground was terminated with segmentation fault and only 2 hours of data was acquired.

4. RESULTS

Temporal variations of the seeing together with the weather information taken at the weather tower at the summit[7] is shown in Figure 6 and 7.

Typical wind pattern at the Chajnantor Plateau is that wind from the west is high at the beginning of the night, then, around 25h(UT), it gets lower and stabilized.[7] This results in bad seeing at the beginning of the night, and improvement toward the midnight as seen in Figure6

The temporal variation in Figure 7 demonstrates how the seeing improves by the tower; That is, in addition to the improvement of the average value, big “spikes” as large as $> 1''$ disappear.

75, 50, 25 and 10 percentile of the measured seeing is summarized in Table 2. It can be seen that the seeing values measured at the 2m tower is systematically better than those on the ground. Especially, the seeing on

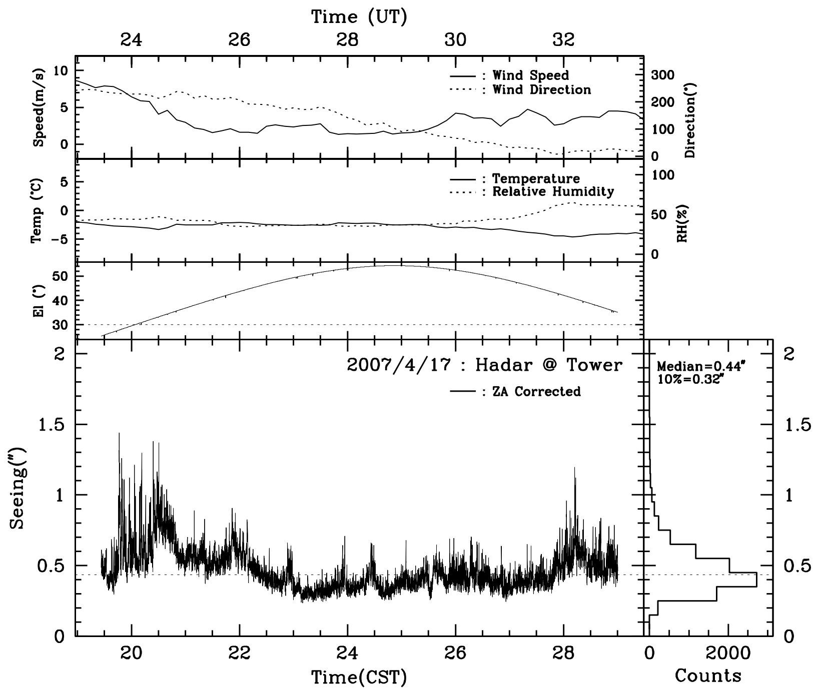

Figure 6. The seeing data taken at the 2m tower on Apr 17, 2007.

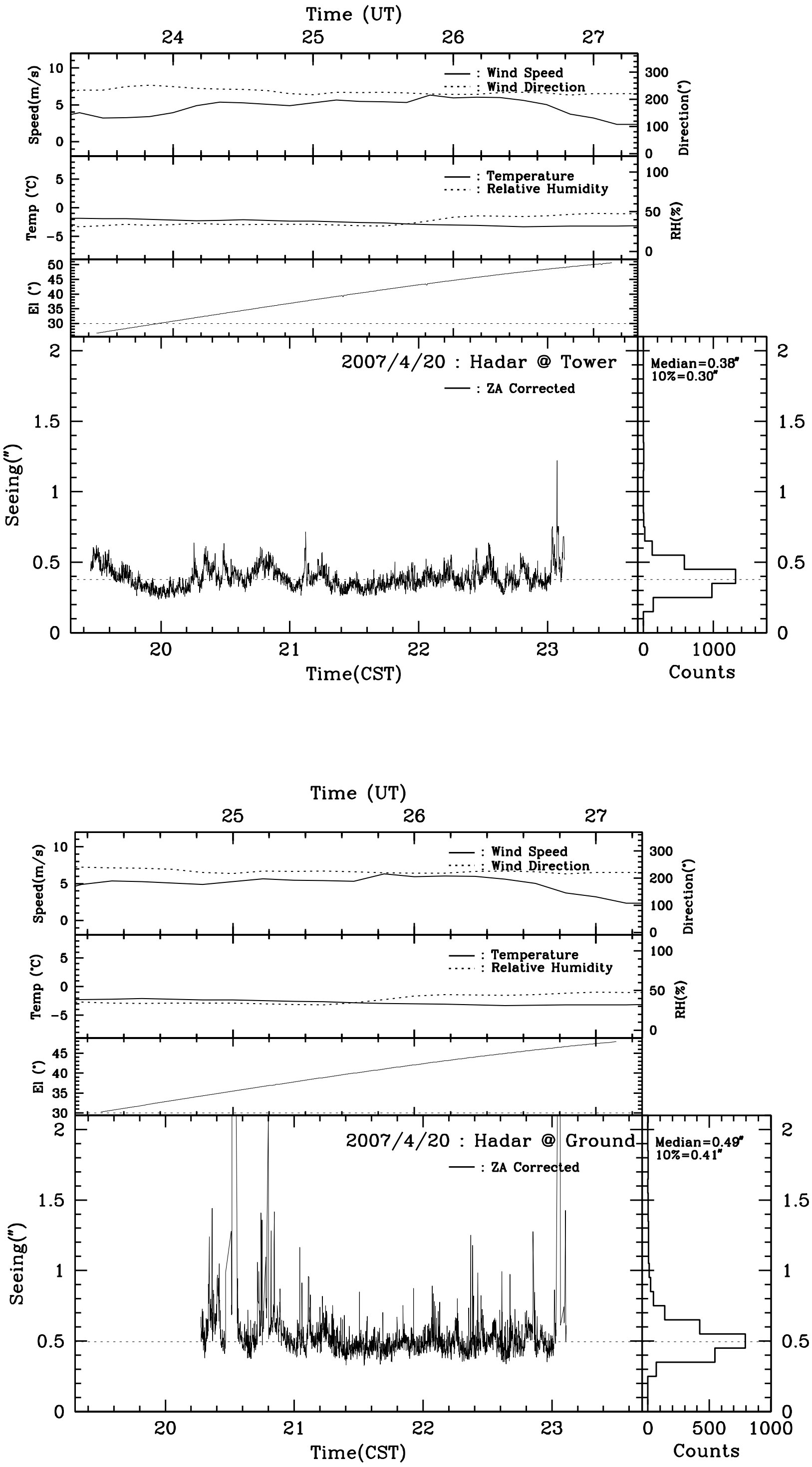

Figure 7. The seeing data taken at the 2m tower (top) and on the ground (bottom) on Apr 20, 2007. It can be clearly seen that the seeing at the tower is systematically better and has less bad "spikes".

	DIMM at ground				DIMM at 2m tower			
Date	75%	Median	25%	10%	75%	Median	25%	10%
2006/11/09	1.″042	0.″874	0.″748	0.″664				
11/10	1.″274	1.″101	0.″934	0.″796				
11/12	0.″755	0.″652	0.″562	0.″496				
11/13	1.″442	1.″159	0.″930	0.″814				
2007/04/17					0.″540	0.″436	0.″364	0.″322
04/20	0.″562	0.″494	0.″448	0.″411	0.″431	0.″377	0.″336	0.″303
04/22	0.″841	0.″709	0.″616	0.″554	0.″865	0.″794	0.″710	0.″634
04/23	1.″423	1.″228	1.″067	0.″905	0.″968	0.″822	0.″711	0.″636

Table 2. Nightly statistics of the measured seeing.

Apr 17 and 20, 2007 shows median values better than 0.″5, which suggest that excellent seeing can be expected at the summit of Co. Chajnantor.

5. EFFECT OF THE GROUND LAYER TURBULENCE

Figure 8 shows the correlation between the measured seeing at the 2m tower and on the ground, taken on Apr 20, 22, and 23, 2007, when the simultaneous measurements on the ground and at the tower were carried out.

It can be seen that:

- The correlation between the seeing at the tower and on the ground varies according to the median seeing.
- The best seeing values of the day improves $\sim 0.''1$ by the 2m tower.
- If the seeing is worse than the median value, it improves better by the 2m tower.

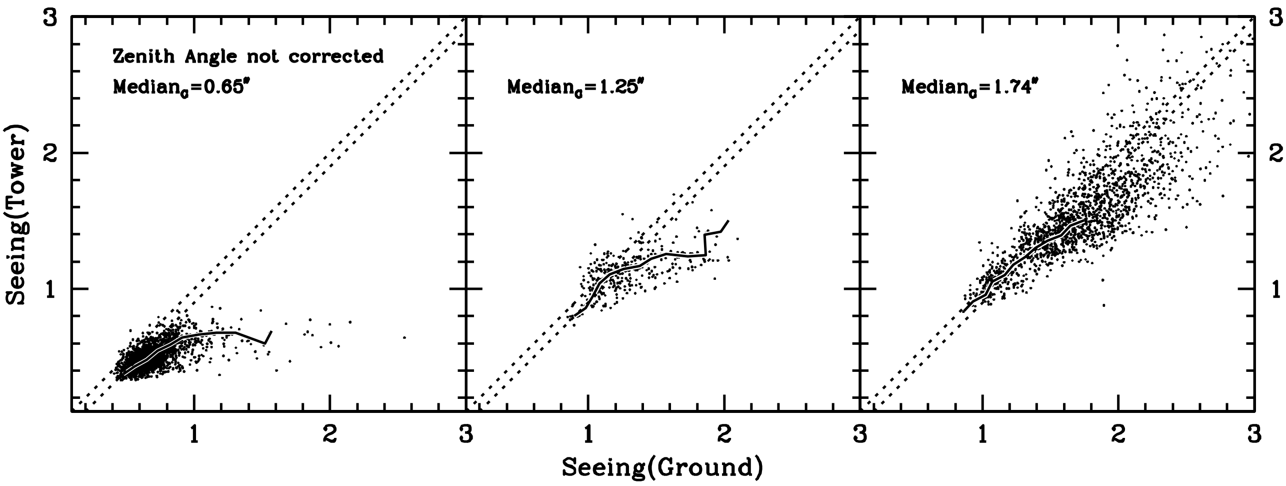

Figure 8. Correlation between the measured seeing at the 2m tower and on the ground on Apr 20, 22, and 23, 2007 from left to right. The values before the zenith angle correction are used. Thick lines shows the relation used for the tower-correction.

Date	75%	Median	25%	10%
2006/11/09	0.″983	0.″806	0.″684	0.″598
11/10	1.″107	1.″018	0.″839	0.″712
11/12	0.″739	0.″603	0.″504	0.″4 37
11/13	1.″096	1.″025	0.″841	0.″735
2007/04/22	0.″769	0.″633	0.″539	0.″476

Table 3. Nightly statistics of the measured seeing, calculated from the data after the correction for the ground layer turbulence up to 2m height.

From these plots, we have obtained relations between the seeing at the 2m tower and on the ground, which are indicated as a thick lines in Figure 8. Then, they are applied to the data taken on the ground to presume the seeing free of the ground layer turbulence up to 2m height. The nightly statistics of the corrected seeing is shown in Table 3. After the correction, seeing improves by 0.″05 – 0.″1.

6. OVERALL SEEING PROPERTIES AT THE SUMMIT OF CO. CHAJNANTOR

Figure 9 shows the histogram of the all data taken at the summit of Co. Chajnantor in a dotted line. If both the measurements at the 2m tower and on the ground exist, those taken at the tower is adopted. Next, all the data taken on the ground was converted to the "ground-layer-turbulence-free" value as explained in the previous section and the result is also shown in Figure 9 as a solid line.

The median values are 0.″75 without the correction, and 0.″69 with it. Table 4 compare these values with the other astronomical sites around the world. It is clear that Co. Chajnantor is one of the best sites for astronomical observations.

7. SUMMARY AND CONCLUSION

We have carried out seeing measurement observations at a 5640m altitude on the summit of the Co. Chajnantor for 8 nights in November 2006 and April 2007.

Updated UT-DIMMs were used for the observation, which are optimized to the site without power supply. The low pressure prevented us from using a hard disk drive, therefore we adopted a USB memory key with Knoppix-Linux within it.

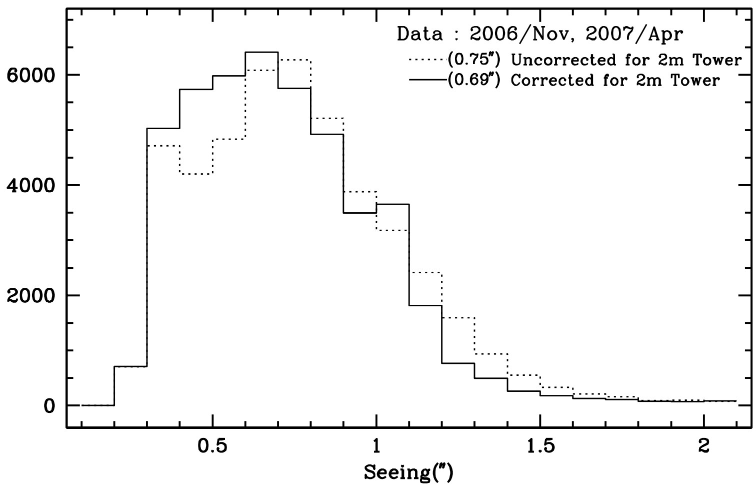

Figure 9. The histogram of the seeing taken at the summit of Co. Chajnantor. The dotted line shows the data without the correction of the 2m tower, while the solid line shows that corrected for the effect of the ground layer turbulence.

Site (Telescope)	Altitude	Seeing		
	(m)	(Median)	(25%)	(10%)
Peaks within Chajnantor Area				
Co. Chajnantor(This work)	5650	$0.''69$	$0.''51$	$0.''38$
Co. Toco[4]	5430	$0.''68$	$0.''50$	$0.''43$
Co. Chico[8]	5150	$0.''71$	$0.''55$	–
Existing Astronomical Observatories				
Las Campanas (Magellan)[9]	2300	$0.''63$	$0.''4$	–
Co. Pachon (Gemini-S)[9]	2710	$0.''75$	–	–
Co. Paranal (VLT)[9]	2640	$0.''82$	$0.''63$	–
La Silla (NTT)[9]	2350	$0.''87$	$0.''69$	–
La Palma (WHT)[9]	2330	$0.''69$	–	–
Mauna Kea (Subaru)*	4163	$0.''64$	–	–

Table 4. Summary of seeing at various astronomical sites.

To get rid of the ground layer turbulence, we have installed a 2m tower in the April run, resulted in excellent improvement in the measured seeing.

Overall value of of the seeing is $0.''69$, which is comparable or even better than most of the existing astronomical sites.

These results, together with the expected high transparency in the infrared wavelength and the good climate, suggest that the summit of Co. Chajnantor is one of the best site for the infrared astronomy on the Earth.

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