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RESULTS FROM THE LSST SITE MONITORING

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RESUMEN

El LSST (Large Synoptic Survey Telescope) es un telescopio de 8.4 m de apertura con el que se va a llevar a cabo un monitoreo de todo el cielo en varias bandas de longitud de onda. En el 2006 se tomó la decisión de instalar este telescopio en El Peñon, que es una de las cumbres en la loma del Cerro Pachón. Desde el año 2003 hay un monitoreo de las condiciones meteorológicas en esta cumbre, y desde el 2006 también del *seeing*. Hacia fines del año 2009 se comenzó una campaña de comparación entre los sistemas DIMM de LSST y del sistema que fue usado en el *site testing* para el Thirty Meter Telescope (TMT). Aqui reportamos los resultados generales de las condiciones meteorológicas y en particular los resultados de turbulencia óptica en El Peñon. De la comparación de los sistemas DIMM de LSST y TMT se muestra –una vez más– que el telescopio usado para el monitoreo tiene un gran impacto en las mediciones. La comparación de los resultados de El Peñon con las mediciones tomadas en Cerro Tololo y Cerro Pachón muestran que no hay gran diferencia del nivel de turbulencia en altura sobre estos sitios.

ABSTRACT

The Large Synoptic Survey Telescope (LSST) is an 8.4 m telescope which will be dedicated to conduct an all-sky survey in several wavelength bands. In 2006, the El Peñon summit on the Cerro Pachon mountain ridge was selected to become the site hosting the LSST telescope. Since 2003 meteorological data have been collected on Peñon and since 2006 seeing measurements have also been obtained. Also, in late 2009 a campaign was started to compare the LSST DIMM monitor to the one used by the Thirty Meter Telescope (TMT) site testing project. Here we report on the overall results on meteorological conditions at Peñon, and in particular on the optical turbulence conditions. From the LSST-TMT seeing monitor comparison it will be shown that –again– the site monitoring telescope is impacting on the measured overall seeing. The Peñon results are also compared with measurements from Cerro Tololo and Cerro Pachón. It was found that high altitude turbulence does on average not greatly vary between those sites.

Key Words: atmospheric effects — instrumentation — site testing — telescopes

1. INTRODUCTION

After conducting more than 2 years of site evaluation at several locations (Sebag et al. 2006), the Large Synoptic Survey Telescope project (Krabbendam & Sweeney 2010) selected the mountain El Peñon (or El Penyon) in northern Chile as the location for this telescope facility. El Peñon (2656 m a.s.l.) is the southernmost summit of the Cerro Pachón ridge where already two astronomical observatories are present: The Gemini South Observatory and the SOAR facility. Figure 1 shows the view of the Pachón ridge from Cerro Tololo (2200 m a.s.l.), which is located approximately 15 km North-West of Cerro Pachón.

Site monitoring has been carried out on El Peñon since 2003, measuring a wide range of different atmospheric parameters. In § 2 the details of the instrumentation will be outlined and in § 3 a peculiarity of the meteorological conditions of the Cerro Pachón ridge will be shown. The finding of an artificial seeing bias in data obtained at Cerro Tololo (Els et al. 2009), triggered a comparison campaign of the LSST seeing monitor with one of the seeing monitors used during the site testing for the Thirty Meter Telescope (TMT, Schöck et al. 2009). Some results of that campaign between late 2009 and mid 2010 will be summarized in § 4.

2. LSST SITE MONITORING EQUIPMENT

The site monitoring on El Peñon began in July 2003 with the installation of an automatic weather station. This station recorded at approximately 2 m above ground the main atmospheric conditions, like air temperature, pressure, relative humidity, and wind speed and direction. In 2006 a Differential

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Fig. 1. View of the Cerro Pachón summit ridge as seen from Cerro Tololo. The existing telescope facilities are indicated. SOAR is located at the northern edge of the ridge, while Gemini South is located on the main Pachón summit. Photograph courtesy Tim Abbot (CTIO).

Image Motion Monitor (DIMM, Sarazin & Roddier 1990) was installed on an approximately 5 m tall tower to measure the total site seeing, followed in 2007 by the deployment of a 30 m tower equipped with four ultrasonic anemometers at 5, 12, 20 and 30 m above ground. To further assess the optical turbulence near the ground and in the low atmosphere (up to approximately 300 m) during 2008 microthermal probes were mounted on the tower in 2 m intervals and several campaigns were performed using the Lunar Scintillometer (LuSci, e.g., Tokovinin 2010) built by CTIO. Late 2009, the TMT-T1 site monitoring telescope was installed only few meters away from the LSST DIMM system. Figure 2 shows the setup. Initially used on Cerro Tolar since early 2003 for the TMT site testing (Schöck et al. 2009), T1 was transferred to Cerro Vizcachas in late 2007 where it was operational until early 2009 in the site testing framework for the E-ELT.

The TMT-T1 system is equipped with a MASS-DIMM device (Kornilov et al. 2007), thus allowing to measure also the vertical turbulence profile by means of the Multi Aperture Scintillation Sensor MASS. This comparison campaign ended during the second half of 2010, and all equipment was removed from El Peñon in preparation of the excavation works for LSST which started in November 2010.

3. METEOROLOGICAL CONDITIONS

The measurements have shown that the wind direction is very stable coming primarily from 20° NNE direction. The median night wind speed is equal to 5.6 m/sec and the median night temperature is 10.3°C. In addition, we started to compare our meteorological measurements with the other monitoring stations located on the Pachón ridge, at SOAR and Gemini South. As an example, we show in Figure 3 the wind roses measured at SOAR and El Peñon over the course of four years. Interestingly, it turns out that the prevailing wind direction on El Peñon differs by close to 90° from the one measured at the SOAR station. Observations that the prevailing wind direction changes across the Pachón ridge had already been reported during the SOAR site testing (Baldwin 1999). Back then, a very similar shift in the prevailing wind direction had been observed between the SOAR and Gemini South locations. Taking the new El Peñon measurements into account, it appears that the SOAR location is somewhat outstanding in the sense that it sees winds almost exclusively from the North-West, whereas the southern areas of the ridge experience winds from the North-East (northern winds dominate also the wind rose of Cerro Tololo). This, however, needs confirmation as we have not analysed data collected by the Gemini South weather station during the same years.

Fig. 2. The Peñon site with the two site monitoring telescopes on their respective towers, and with their domes opened. To the left (South) the TMT-T1 site testing telescope, to the right (North) the LSST one. Photograph courtesy CTIO site team.

4. OPTICAL TURBULENCE DATA

The collected LSST DIMM data at El Peñon cover the years between January 2006 until October 2010. Those measurements result in a median DIMM seeing of 0.″84. This value is very similar

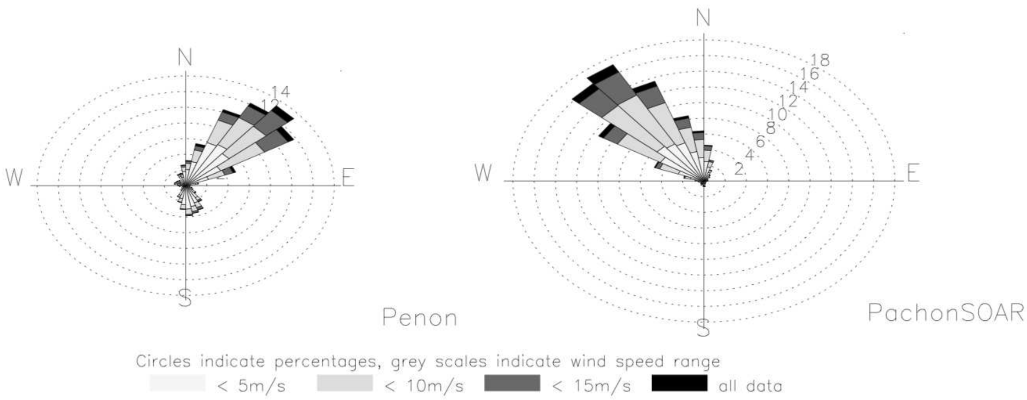

Fig. 3. Windroses measured between 2004 and 2008 at El Peñon (left) and SOAR (right). Circles are in 2% steps, while the grey scale indicate the different wind speeds.

to the median DIMM seeing of 0.″88 measured formerly at Cerro Tololo with the CTIO MASS-DIMM site monitor. Both the LSST DIMM and the CTIO MASS-DIMM were developed and operated in a similar fashion. Because a significant seeing bias was found from the detailed analysis of CTIO DIMM data with a TMT seeing monitor, the described comparison campaign of the LSST DIMM with a TMT MASS-DIMM system was pursued.

4.1. *Free atmosphere seeing*

The TMT-T1 MASS-DIMM system used for the comparison measured the total seeing as well as the seeing from approximately 500 m above the telescope to the top of the atmosphere. This MASS seeing ϵ_{MASS} is commonly referred to as *free atmosphere seeing*. A number of MASS-DIMM systems are operated at the other observatories and Table 1 summarizes the medians computed from the data recorded by the MASS systems on Pachón, Tololo and Peñon during the months of the comparison campaign. It can be seen that all three systems measure approximately 0.″4 as the average of the median ϵ_{MASS} at these sites. The spread between those sites is consistent with a MASS precision of 0.″05, similar to what had been reported by several other studies. It is, however, interesting to note that there is no large difference between ϵ_{MASS} at Peñon/Pachón and Tololo. This indicates that in the region of Tololo/Pachón the MASS recorded seeing is indeed a free-atmosphere seeing. A more detailed analysis, covering five years of MASS observations in this region will be provided in a forthcoming publication.

4.2. *DIMM seeing*

In the case of the former Tololo DIMM system an increase in the total seeing was found to be likely introduced by the disturbance of the airflow over the half closed dome structure. As the DIMM telescope was mounted on a relatively weak mount, it was found necessary to operate the system with a half-closed dome thus prevented wind shake. A comparable situation existed for the LSST DIMM telescope were the windward side of the dome was kept raised (see Figure 2). Observing simultaneously the same stars with the TMT-T1 and LSST DIMMs, and recording also wind speed and direction, it is possible to assess this suspected relationship. Figure 4 shows the result and again it is found that under northern winds the LSST DIMM seeing is up to 40% stronger than the TMT-T1 measured seeing. In terms of C_n^2 this corresponds to a 75% increase. Also during southern winds, there is still an approximately

TABLE 1

THE FREE ATMOSPHERE SEEING ϵ_{MASS} MEASURED BY THE MASS DEVICES PACHÓN, T1 ON PEÑON, AND T3 ON TOLOLO[a]

Percentile	ϵ_{MASS} [arcsec]		
	Peñon	Pachón	Tololo
10	0.24	0.16	0.23
25	0.32	0.24	0.30
50	0.44	0.34	0.40
75	0.60	0.50	0.57
90	0.82	0.73	0.82

[a]Based on 11690 individual profiles observed between December 2009 and May 2010 and taken within a maximum of 20 min time difference between those MASS systems and on the same stars.

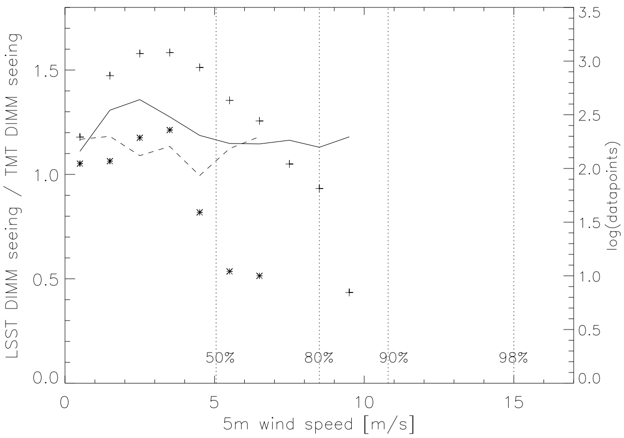

Fig. 4. Median ratios of DIMM seeing in wind speed bins measured by the TMT-T1 and LSST DIMMs. Solid line: under northern winds, dashed line: southern winds. Crosses mark the amount of data per bin under southern, asterisks under southern winds. The dotted lines indicate the probability for windspeeds.

10% seeing bias in the LSST DIMM measurements. Using the curves in Figure 4, the LSST DIMM measurements since 2007 for which also a wind speed and direction measurements were taken, could be adjusted. More than 90% of those DIMM data could be adjusted and the results are given in Table 2. Only data since the installation of the 30 m tower were assessed as during the comparison campaign only the anemometers on the tower were operational.

Again, we refer to a forthcoming publication on a more detailed investigation and discussion of the data obtained during the described campaign.

TABLE 2

DIMM SEEING MEASURED AT EL PEÑON BETWEEN JUNE 2007 AND MAY 2010[a]

Percentile	$\epsilon_{\mathrm{DIMM,adj}}$ [arcsec]	ϵ_{DIMM} [arcsec]
10	0.50	0.61
25	0.58	0.70
50	0.69	0.83
75	0.84	1.00
90	1.03	1.22

[a] ϵ_{DIMM} refers to the statistics of the initial DIMM measurements. $\epsilon_{\mathrm{DIMM,adj}}$ indicates the adjusted values (see text). Based on 125209 individual measurements.

5. CONCLUSIONS

The site monitoring of the El Peñon site showed that the DIMM median seeing at this site is approximately 0.″7 and is very similar to what is found at other locations in this region.

The median free atmosphere seeing above the Peñon-Pachón-Tololo region is 0.″4.

Again a non-negligible DIMM seeing bias, likely caused by the dome, was determined from the comparison of the LSST DIMM measurements with the TMT-T1 DIMM measurements. As designed, the DIMM instrument measures the total turbulence strength. Cost saving on the instruments and their supporting structures can compromise the collected data. Strict configuration control is a must, even for such 'easy' systems as site monitors.

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