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INTERCALIBRATION OF THE SAN PEDRO MÁRTIR AND CTIO DIMM UNITS

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RESUMEN

Comparamos mediciones simultáneas de *seeing* obtenidas durante 14 noches con los monitores de movimiento diferencial de imagen (DIMM) usados en el Observatorio Astronómico Nacional en San Pedro Mártir (SPD) y en Cerro Tololo Inter-American Observatory (RoD). Para el conjunto de datos, compuesto de 1581 mediciones cuasi-simultáneas, encontramos que la media y la mediana de las diferencias de *seeing* RoD-SPD son $+0.004 \pm 0.138''$ y $+0.010''$, respectivamente. También descubrimos que la mediana de las diferencias de *seeing* RoD-SPD es $+0.041''$ cuando el *seeing* es inferior a $1''$; $-0.032''$ cuando está entre $1''$, y $1.5''$ y $-0.292''$ cuando es superior a $1.5''$. Dado que el *seeing* es usualmente menor que $1''$, concluimos que las mediciones hechas con unidades tipo SPD deben incrementarse entre $0.01''$ y $0.04''$ al ser comparadas con unidades tipo RoD. Esta corrección es mucho menor que la dispersión natural de medidas de *seeing* que ocurren a lo largo de cualquier noche, y tiene sentido hacerla sólo si las condiciones operativas en ambos sitios son prácticamente las mismas.

ABSTRACT

We compare simultaneous seeing measurements produced by the differential image motion monitor (DIMM) units used at the Observatorio Astronómico Nacional at San Pedro Mártir (SPD) and at Cerro Tololo Inter-American Observatory (RoD), for a total of 14 nights. For the data set, made of 1581 nearly-synchronous measurements, we find that the mean and median RoD-SPD seeing differences are $+0.004 \pm 0.138''$ and $+0.010''$ respectively. We also find that the median of the RoD-SPD seeing measurements is $+0.041''$ when seeing is less than $1''$, $-0.032''$ when it is between $1''$ and $1.5''$, and $-0.292''$ when it is larger than $1.5''$. Since seeing is usually smaller than $1''$, we conclude that measurements obtained with SPD-like units should be increased by $0.01''$ to $0.04''$ when comparisons are made with sites using RoD-like units. This correction is much smaller than the natural dispersion of seeing measurements along any night, and it makes sense only when operational conditions in both sites are practically the same.

Key Words: **SITE TESTING**

1. INTRODUCTION

Seeing is one of the most important parameters when determining site quality for astronomical observations. Most professional observatories have measured this quantity in long-term campaigns, some do it on a permanent basis. Seeing has been measured in Mexico's Observatorio Astronómico Nacional at San Pedro Mártir (SPM) since 1968 (Echevarría et al. 1998; Conan et al. 2002; Echevarría 2003). The two longest-running seeing testing campaigns at SPM produced very similar values for the median yearly seeing, *i.e.* close to $0.6''$, even though different instruments and reduction techniques, the Steward Site Testing Telescope and the Carnegie Seeing Monitor, were used (Echevarría et al. 1998).

Thus, in terms of seeing, it would appear that SPM is one of the best among all sites where this quantity has been measured. But, though there is an abundant amount of seeing data from a large number of places, comparisons are rarely accepted without suspicion. There is, quite understandably, a general belief that those doing the comparison are biased in favor of the site that feeds them. But comparisons are also questioned on more objective grounds, namely, that the instrumentation and reduction technique that is being used differs from one site to the other.

Over the past two decades the differential image motion monitor (DIMM) has established itself as the instrument of choice to measure seeing. It has been discussed comprehensibly in a number of papers (e.g. Martin 1987; Sarazin & Roddier 1990; Vernin & Muñoz-Tuñón 1995; Tokovinin 2002), and is now being regularly used in many observatories. A DIMM unit was first used at SPM in May 2000 during 23 nights by Sánchez et al. (2003), who got a median seeing value of 0.84″. Later on, Michel et al. (2003a) used this instrument to measure seeing at SPM between August 18, 2000 and October 14, 2002 (a total of 90 nights). The median seeing reported by these authors (0.59″) is very similar to the one found previously using the Steward Site Testing Telescope and the Carnegie Seeing Monitor (Echevarría et al. 1998). This DIMM unit (henceforth SPD) is a replica of the DA/IAC DIMM described by Vernin & Muñoz-Tuñón (1995).

Thus, DIMM is now the standard technique used to measure seeing, providing a common base to compare results. But DIMM's are not identical clones, and there are pending issues that must be addressed before making a reliable comparison between any two sites using this instrument, such as differences in the specific instrumental setup and in data processing. This was well understood by the Thirty Meter Telescope (TMT) project site testing team, which has been carrying out long-term simultaneous seeing observations with the same instruments in a number of promising sites. It is expected that this will lead to the best possible site identification in atmospheric terms. One of the sites where the TMT group is conducting this research is SPM. Interested in knowing how their instrumentation compares with previous setups, TMT brought a NOAO RoboDIMM unit (henceforth RoD) to SPM, and with both units side-by-side (RoD and theirs) obtained simultaneous seeing measurements for an extended period of time.

The presence of these instruments was an opportunity to put previous seeing results at SPM in perspective. Thus, we also had SPD and RoD sitting side-by-side, producing simultaneous seeing measurements for a statistically significant number of nights. This will lead to more reliable seeing measurement comparisons between SPM and those sites using RoboDIMM-like units.

This paper is organized as follows: an overview of SPD and RoD is presented in § 2, the intrinsic instrumental error of SPD is discussed in § 3, seeing results from RoD and SPD are compared in § 4 and conclusions are given in § 5.

2. AN OVERVIEW OF SPD AND ROD

In astronomy, seeing is usually defined as the full width half maximum (FWHM) of a long exposure stellar image taken at the focus of a large telescope. In a perfect telescope, where image quality is only degraded by natural atmospheric turbulence, seeing is related to Fried's parameter, r_0, through the following equation (Hufnagel & Stanley 1964; Martin 1987)

$$FWHM = 0.976\frac{\lambda}{r_0} , \quad (1)$$

where λ is the imaging wavelength. Notice that this formula gives the radius of the first null of the Airy disk from a telescope with diameter $D = 1.25\ r_0$.

On the order hand, atmospheric turbulence will move the image position in short-time exposures. The variance of image position (σ) produced by atmospheric turbulence in a telescope with aperture diameter D has the following dependence on Fried's parameter (Fried 1965; Tokovinin 2002)

$$\sigma^2 = K\lambda^2 {r_0}^{-5/3} D^{-1/3} , \quad (2)$$

where K is a constant. Thus, Fried's parameter can be determined measuring image motion variance with a small telescope. Seeing is then calculated from equation (1). It is usually given at $\lambda = 500$ nm.

Since the telescope is not rigid, the image will also move due to guiding, drive and gear defects, mechanical stresses, wind shaking, dome effects, etc., adding an extra term to the image position variance. It is difficult to separate variance induced by turbulence from that induced by the telescope. In consequence, use is made of differential instead of absolute image motion. This is done with a differential image motion monitor system, or DIMM, which consists of two same-sized apertures on a common mount. Telescope induced image motion is canceled out taking the difference of the positions of images produced by each aperture. This does not cancel changes induced by turbulence, since these are slightly different for each aperture: the wavefront has been "corrugated" by atmospheric turbulence and the angle-of-arrival (or tilt) of the wavefront is not uniform (Sarazin &

Roddier 1990; Tokovinin 2002). Differential image motion variance depends on the ratio of aperture separation d to aperture size D, on the direction it is measured (parallel or perpendicular to the line joining the two apertures) and on the way image centers are defined (the so-called tilt, Tokovinin 2002). All these are included in the constant, K (different in each direction).

In the case of SPD the image center is thought to be the centroid of angle-of-arrival fluctuations (gravity or G tilt), and

$$K_{\|} = 0.358(1 - 0.541S^{-1/3}) \;, \tag{3}$$

and

$$K_{\perp} = 0.358(1 - 0.811S^{-1/3}) \;, \tag{4}$$

where $K_{\|}$ and $K_{\perp}$are the constants for the parallel and perpendicular motion variance ($\sigma_{\|}$ and $\sigma_{\perp}$) in equation (2) and $S = d/D$ (Sarazin & Roddier 1990; Vernin & Muñoz-Tuñón 1995). These equations are approximations that hold when $S \geq 2$.

In the case of RoD, the image center is considered to be the field location where aberration is minimal (Zernike or Z tilt). In this case (Tokovinin 2002)

$$K_{\|} = 0.364(1 - 0.532S^{-1/3} - 0.024S^{-7/3}) \;, \tag{5}$$

and

$$K_{\perp} = 0.364(1 - 0.798S^{-1/3} - 0.018S^{-7/3}) \;. \tag{6}$$

Tokovinin (2002) shows that differences between the approximate G-tilt constants and the accurate Z-tilt constants are minimal.

In practice, $\sigma_{\|}$ and $\sigma_{\perp}$ are generally different and do not produce the same value for r_0 and, consequently, seeing. In the case of SPD, a mean seeing value is thought to be reliable only when the difference between the parallel and perpendicular FWHM is not larger than 12%, which is the expected experimental error (Muñoz-Tuñón, Vernin, & Varela 1997). In the case of RoD, the data acceptance criterion is based on image quality, and the mean FWHM is considered valid only when the Strehl ratio is larger than 0.5 in both stellar images (Tokovinin 2004).

Some technical parameters of SPD and RoD are listed in Table 1. A more complete description of SPD can be found in Vernin & Muñoz-Tuñón (1995), Muñoz-Tuñón et al. (1997) and Michel et al. (2003a, 2003b). The RoD is described in Walker et al. (2003), Bustos, Tokovinin, & Schwarz (2004) and www.ctio.noao.edu/telescopes/dimm/dimm.html.

Exposure time in SPD is user defined. In all our experiments the exposure time was 5 ms. Since SPD uses an intensified CCD, a latent image is left on the phosphor screen after each exposure. According to instrument designers, this latent image is faint enough to do the next exposure 40 ms later. Each stellar image (shutter open) is followed by a dark frame (shutter closed). Variance is determined after 200 frames. A seeing value is returned approximately every 14 seconds. As discussed by Martin (1987), DIMM's are only sensitive to atmospheric fluctuations on scales comparable to the distance between the two apertures. These high-frequency fluctuations will be missed if the turbulent layer moves appreciably during an exposure, and position variance will be underestimated. Since SPD does not correct for this effect, known as exposure time bias, it will deliver a seeing that is smaller than the actual value (since variance is proportional to FWHM) when the wind speed at some turbulent layer exceeds $\sim$ 15 m/s. In the case of RoD, the instrument delivers interlaced exposures of 5 and 10 ms each in order to correct exposure time bias in the manner described by Tokovinin (2002) and Tokovinin et al. (2005). In RoD variance is determined after some 200 exposures, and a value for seeing is returned roughly every minute.

TABLE 1

SPD AND ROD TECHNICAL PARAMETERS

	SPD	RoD
Telescope	Celestron 8″	Meade 10″
Pupil diameter	60 mm	95 mm
Pupil separation	140 mm	150mm
Prism deviation angle	30″	75″
CCD format	576×550 pix	320×240pix
Pixel size	23×23 μm	10×10 μm
Plate scale	0.6″/pix	0.769″/pix
Intensified	Yes	No

An additional difference between SPD and RoD is the way centroids are determined. In both cases the centroid position C is found with

$$C = I_{tot}^{-1} \int xI(x,y)dxdy \;, \tag{7}$$

where $I(x,y)$ is the intensity at pixel (x,y) and I_{tot} is the total intensity within the region of integration. In SPD this region extends over pixels where $I(x,y)$ is larger than a predefined value or threshold, which is the CCD noise as given by the dark frame. In the case of RoD, this is a circular region within a certain radius from an approximately known center (such as

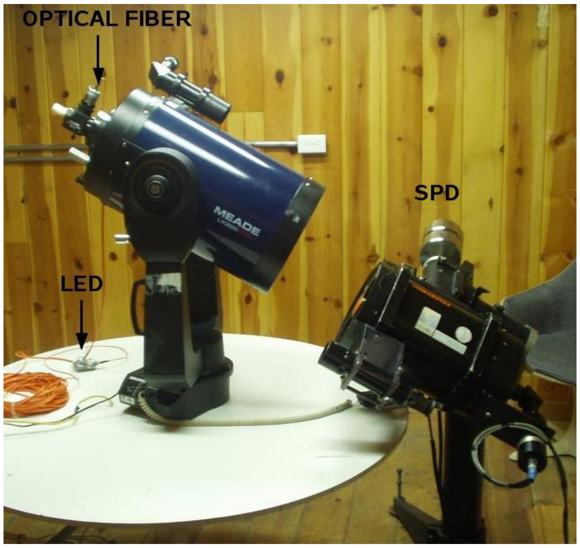

Fig. 1. Setup to determine the instrumental noise of SPD.

Fig. 2. Location of RoD (left) and SPD (right) when the systems were compared.

the brightest pixel). The first null of the Airy disk, at $1.22\lambda/D$ radians, is the selected radius. Differences between the thresholding and windowing methods are not large (Tokovinin 2002). Other aspects of these two instruments are comprehensibly discussed in Vernin & Muñoz-Tuñón (1995) and (Tokovinin 2002).

3. INSTRUMENTAL NOISE OF SPD

An artificial star was created to obtain the intrinsic instrumental noise of SPD. This star was produced with an auxiliary telescope, illuminated at the focal plane by a 125 μm optical fiber in contact to a LED operating at $\lambda = 660$ nm (see Figure 1). The intensifier gain was set to its normal operating conditions. The luminous flux of the LED was adjusted, through its operating current, to reflect in the instrument a flux from a star with $m_v \sim 2$; i.e., a maximum count close to 200. At this level of flux, the photon noise of the instrument gives a contribution of $\sim$0.026 arcsec for an exposure time of 5ms (see eq. 18 in Vernin & Muñoz-Tuñon 1995).

The setup produces 2 fixed spots from where the centroids were measured. Experiments were carried out with a 40×40 pixel window. Declination and right ascension motors were on. A sample of 200 frames at 5-ms integration time produces one centroid measurement. We selected the data points only when the difference between the parallel and perpendicular measurement was not larger than 12%. From the data, we got standard deviation values of 0.011 arcsec in both directions. Combining these values in quadrature, we obtained an intrinsic random noise of 0.032 arcsec. In this latter calculation we introduced a factor of 2 from the differential nature of the measurements. The instrumental noise of RoD is reported to be 0.03 arcsec (www.ctio.noao.edu/telescopes/dimm/dimm.html).

4. COMPARISON BETWEEN SPD AND ROD

Simultaneous seeing measurements from SPD and RoD were carried out during 14 nights. The systems were placed less than 3 meters apart and 1 meter above ground level (a concrete base) in a wind protected area. Thus, operating conditions were virtually identical (see Figure 2). Notice that RoD was attached to a tube that was anchored to the concrete base, whereas SPD rests on a structure with three unanchored supports. Bear in mind that this experimental setup may be adequate to compare the two instruments, but is far from the normal operational conditions of any DIMM unit measuring seeing at an astronomical site. Both instruments observed the same stars at all times. These stars were η Uma ($V = 1.86$), β Dra ($V = 2.79$), α Cep ($V = 2.44$) and δ Cas ($V = 2.68$). In the case of SPD, we used a 40×40 pixel window and measurements were accepted only when the difference between the parallel and perpendicular FWHM was not larger than 12%. The intensifier gain was adjusted in order to keep the maximum count as close as possible to 200. In the

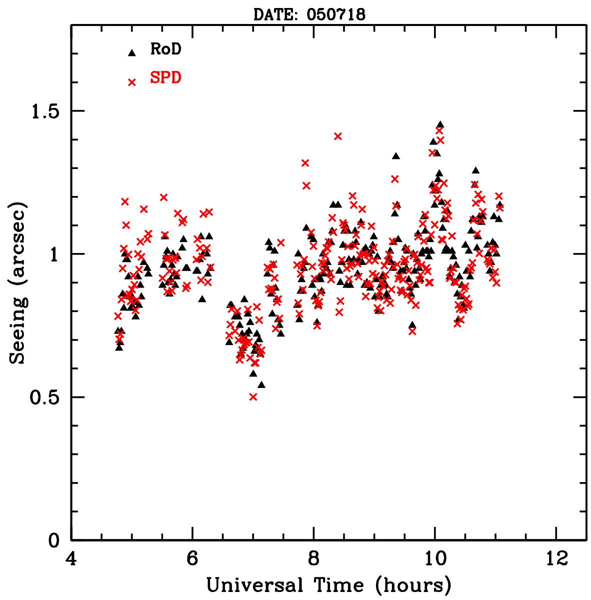

Fig. 3. Seeing measured with RoD and SPD on July 18, 2005.

TABLE 2

ROD AND SPD SEEING STATISTICS

Date	NP	RoD Avg	Med	NP	SPD Avg	Med
0621	111	0.855±0.179	0.820	329	0.873±0.225	0.803
0622	22	0.745±0.063	0.750	76	0.793±0.119	0.780
0716	236	1.076±0.194	1.090	745	1.040±0.243	1.036
0717	255	0.836±0.135	0.800	798	0.863±0.219	0.798
0718	251	0.936±0.145	0.940	768	0.946±0.179	0.937
0719	46	0.880±0.145	0.870	154	0.833±0.179	0.816
0720	19	0.810±0.054	0.800	53	0.783±0.119	0.770
0721	100	1.148±0.126	1.180	346	1.164±0.185	1.149
0817	55	1.150±0.105	1.140	205	1.211±0.159	1.197
0818	83	1.210±0.117	1.230	327	1.262±0.195	1.230
0826	59	1.202±0.100	1.180	198	1.176±0.165	1.178
0828	30	1.276±0.166	1.290	76	1.215±0.261	1.180
0829	204	0.933±0.198	0.870	642	0.899±0.302	0.805
0830	110	1.021±0.131	1.000	328	0.937±0.150	0.917

Note: The date format is mmdd, the year being 2005. NP stands for the number of data points. Avg and Med stand for the average and median night seeing in arcseconds.

case of RoD, measurements were accepted only when the Strehl ratio was larger than 0.5 in both images. Under these circumstances, the combined instrumental error is $0.044''$ ($0.032''$ for SPD and $0.030''$ for RoD). The group signing this paper performed all data acquisition and reduction for both instruments.

As an example, in Figure 3 we present seeing measurements from both instruments for a whole night. Nightly mean and median seeings measured by SPD and RoD are given in Table 2. The number of measurements for each night and instrument is also shown. As can be seen, data dispersions are substantially larger than differences in the mean and median seeing values, as well as the combined instrumental error ($0.044''$). For the entire 14 nights we find that the mean and median RoD-SPD differences are $+0.006{\pm}0.045''$ and $+0.026''$ respectively.

An additional and probably better method to establish differences between both instruments is to compare near-synchronous measurements. As mentioned before, SPD delivers a seeing measurement every 14 seconds, while RoD does so every minute. The time tag in the SPD data set is at the end of each measurement, whereas RoD has it at the beginning. Thus we compare an RoD measurement with the average of all SPD seeing measurements that were finished while the RoD experiment was in process. In Table 3 we present the mean and median night simultaneous seeing differences between this SPD average and the "simultaneous" RoD measurement. For the entire data set, consisting of 1581 nearly-synchronous measurements, we find that the mean and median simultaneous RoD-SPD seeing differences are $+0.004''{\pm}0.138''$ and $+0.010''$ respectively. Relative to the seeing value delivered by SPD, (RoD-SPD)/SPD, the mean and median differences are $+0.104{\pm}0.091$ and $+0.080$ (or roughly $+10$ and $+8$%)respectively. Thus, SPD delivers slightly smaller seeing measurements than RoD.

In Figure 4 we plot all RoD *vs.* SPD nearly-synchronous seeing measurements, along with a linear regression to the 1581 data points. The formula for this regression is

$$SPD = 0.95\ RoD + 0.05\ . \qquad (8)$$

The correlation coefficient is 0.81. This regression also shows that SPD delivers a smaller mean seeing value than RoD. A closer inspection of Figure 4 indicates that this is not so in all seeing ranges. It is quite clear that SPD usually yields a significantly larger seeing when the latter is greater than $\sim 1.3''$ to $1.4''$. To explore this further, we analyzed point-to-point differences in three seeing bands as given by SPD: seeing less than $1''$, between $1''$ and $1.5''$ and larger than $1.5''$. Results presented in Table 4 show that RoD tends to deliver a smaller value than SPD as seeing gets worse. The transition between the two smaller seeing bands is small. On the other hand, the quality of the data delivered by either one or both in-

TABLE 3

NIGHTLY NEAR-SYNCHRONOUS ROD-SPD SEEING DIFFERENCES

Date	NP	Δ Avg($''$)	Δ Med($''$)
0621	111	-0.023 ± 0.150	-0.018
0622	22	-0.072 ± 0.158	-0.013
0716	236	0.029 ± 0.122	0.029
0717	255	-0.028 ± 0.126	-0.005
0718	251	-0.005 ± 0.093	-0.003
0719	46	0.043 ± 0.062	0.050
0720	19	0.021 ± 0.062	0.033
0721	100	-0.025 ± 0.096	-0.021
0817	55	-0.060 ± 0.122	-0.048
0818	83	-0.039 ± 0.151	-0.038
0826	59	0.058 ± 0.198	0.047
0828	30	0.032 ± 0.197	0.030
0829	204	0.028 ± 0.169	0.055
0830	110	0.091 ± 0.123	0.081

Note: The date format is mmdd, the year being 2005. NP stands for the number of comparisons. ΔAvg and ΔMed are the mean and median seeing difference RoD-SPD in arc-seconds.

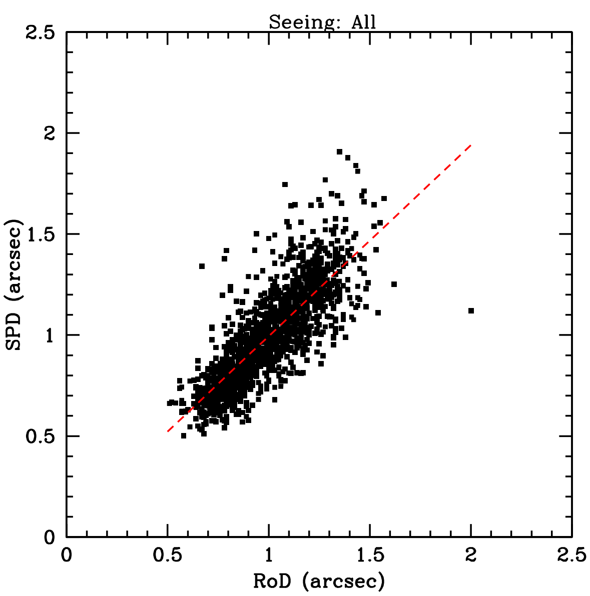

Fig. 4. RoD *vs.* SPD simultaneous seeing measurements. The dotted line is the linear regression to the 1581 data points (see Equation 8).

struments must be treated with great suspicion when seeing exceeds 1.5$''$, since the difference between the RoD and SPD seeings seems inordinately large. A possible explanation for this is that bad seeing is frequently associated to high velocity winds and wind gusts, which will also induce more mechanical vibrations in the more fragile system. As mentioned at the beginning of this section, the mechanical mount of SPD is less robust.

TABLE 4

NEAR-SYNCHRONOUS ROD-SPD SEEING DIFFERENCES IN THREE SPD SEEING BANDS

Seeing band	NP	Δ Avg($''$)	Δ Med($''$)
All	1581	$+0.004\pm0.138$	$+0.010$
$\leq 1''$	854	$+0.048\pm0.101$	$+0.041$
$1'' - 1.5''$	690	-0.032 ± 0.144	-0.033
$\geq 1.5''$	37	-0.310 ± 0.167	-0.292

Note: NP stands for the number of comparisons. ΔAvg and ΔMed stand for the mean and median simultaneous seeing difference RoD-SPD in arc-seconds.

In Figure 5 we plot histograms of the RoD and SPD seeing data. Data binning was 0.02$''$. It is clear from this figure that SPD generates a wider distribution of seeing measurements, that is, a larger proportion of good and bad seeing values. Indeed, the FWHM of the SPD histogram is $\simeq 0.62''$, as compared to $\simeq 0.52''$ for the RoD histogram. A histogram for the RoD-SPD seeing differences, with the same 0.02$''$ binning, is displayed in Figure 6. In this figure we also include a Gaussian fit to all data points, which is given by

$$\nu = 107.08\ e^{-35.19[(RoD-SPD)-0.002]^2}\ , \qquad (9)$$

where ν is the frequency and RoD-SPD is the seeing difference. The correlation coefficient for this fit is 0.987. The variance of the Gaussian distribution, $\sigma = 1/\sqrt{2\times 35.19} = 0.119''$, is very similar to the dispersion around the mean RoD-SPD difference (0.091$''$). In agreement with the two previous analyses of the data set, the Gaussian describing RoD-SPD is centered around zero. Finally, notice too that the Gaussian fit underestimates the frequency of large seeing differences, a feature that was found when inspecting the RoD *vs.* SPD plot shown in Figure 4.

DIMMs normally operate at a height of 6 m or more in order to diminish the effect of ground layer turbulence, that is, atmospheric turbulence up to a height of 15 m. Thus, in relation to normal operational conditions, ground layer turbulence is over-represented in our near-ground comparison between

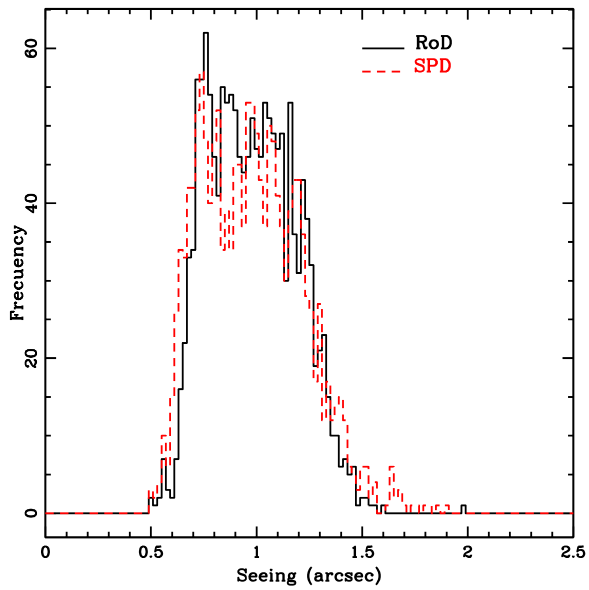

Fig. 5. Histograms for seeing measurements from RoD and SPD. Data binning is 0.02″.

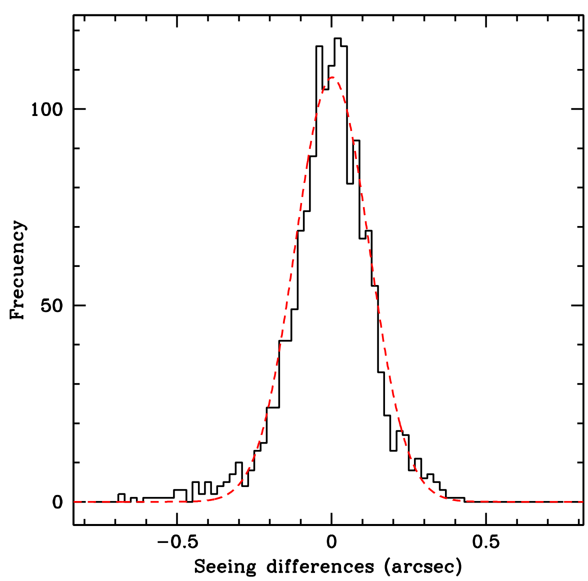

Fig. 6. Histogram for seeing difference RoD-SPD. Data binning is 0.02″. The dashed line represents the best Gaussian fit to the data.

RoD and SPD. But, though ground layer turbulence is very important, it does not seems to dominate atmospheric seeing degradation. According to Sánchez et al.(2003), the contribution of the surface layer, from 2.3 to 15m, to the total optical turbulence has a mean value of 16% which corresponds to a degradation of 10% of the total seeing.

Fortunately, we can get an idea of the effect that height may have had in this comparison, since for a few nights seeing was also being measured by TMT. The TMT DIMM was located at the top of an 8 m tower at a site 200 m distant (SW, normally windward) from where we had SPD and RoD. The mean and median differences between TMT and SPD relative to the seeing value delivered by SPD, are roughly 4.5%.

5. CONCLUSIONS

(1) The instrumental noise of the SPD, obtained from values of the transversal and parallel centroid measurements of an artificial star, produced in a closed-doors and mechanically stable environment, was found to be 0.032″ when the SPD selection criterion was applied. This value is similar to the one reported for the RoD.

(2) Seeing measurements from SPD and RoD were compared for 14 nights between the months of June and August 2005. The two units were placed side-by-side, on a firm concrete floor in a wind protected area. Both telescopes, located roughly 1 meter above ground, monitored the same stars. Thus, the effect of ground layer turbulence is overrepresented, maybe by a factor of two, with respect to the usual operating conditions of DIMM's, which work at a height of 6 to 8 meters above ground.

(3) The mean and median RoD-SPD differences between the mean night seeing values produced by these instruments during our campaign, were $+0.006\pm0.045''$ and $+0.026''$ respectively. For the whole data set, consisting of 1581 nearly-synchronous measurements, we find that the mean and median RoD-SPD seeing differences are $+0.004\pm0.138''$ and $+0.019''$ respectively. A histogram of the RoD-SPD seeing differences can be represented with an excellent Gaussian fit centered at $+0.002''$, with a variance equal to $0.119''$.

(4) We find that the median of the RoD-SPD differences of nearly-synchronous measurements is $+0.041''$ when seeing is less than $1''$. This number changes sign and is equal to $-0.032''$ when seeing is between $1''$ and $1.5''$. The median difference is inordinately large ($-0.292''$) when seeing is at its worst (above $1.5''$). We suggest that this behavior is caused by the fact that SPD is mechanically less robust, hence more prone to vibrate in the presence of wind gusts or high wind speeds.

(5) Taking into account that seeing is usually under $1''$, all things being equal, seeing measurements made with SPD-like units should probably be increased by $\sim 0.01''$ to $0.04''$ when comparisons are

made with RoD-like DIMMs. Notice that these numbers are much smaller than the dispersion of seeing measurements produced during any one night.

(6) Reliable seeing comparisons between any two sites can be made once instruments are cross-calibrated and allowance is made for other factors that might affect observations. In the meantime, suspicions on the validity of seeing measurements at any one site will linger on.

This work was made possible thanks to the collaboration of the TMT site testing group and the continuous help and advice of those responsible for site testing at CTIO, Edison Bustos in particular. The support of the administrative and technical staff at SPM, in particular Antolín Córdova, is also gratefully acknowledged. Valuable observations made by Mauricio Tapia lead to many improvements in the paper. Above all, the quality of this paper was greatly benefited by many valuable suggestions and poignant criticisms made by an unknown referee. One of us (JB) acknowledges support from Conacyt project 400380-5-G36531-E and DGAPA-Universidad Nacional Autónoma de México project IN-102803.

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