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Determination of the Intrinsic Site Seeing for the Hobby-Eberly Telescope

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ABSTRACT

A long term program to quantify the intrinsic site seeing at McDonald Observatory, using two differential image motion monitors (DIMMs) has been initiated on Mt. Fowlkes where the Hobby-Eberly Telescope (HET) is located. Raw DIMM data are corrected to the zenith and to a uniform 10msec integration time. Nightly median seeing measurements (FWHM) along with the max/min range are presented for 186 nights over the 13 month period between July 2001 and July 2002. A definite seasonal effect is present in the dataset with the median seeing in the spring-summer-fall months (0.93±0.18 arcsec) being significantly better than the winter months (1.24±0.33 arcsec). The measured seeing was better than 0.70 arcsec about 9% of the time. Since the DIMM units were operated at ground level these data are not quite lower limits to the site seeing performance. Even so, the seeing of this West Texas continental site at 6,650ft (2,027m) elevation in the Davis Mountains is superior to what has been assumed in the past, based on less direct seeing measurements.

Future plans are described for moving a DIMM telescope to a tower mounted, semi-automated observatory to sample the site seeing at an elevation above the ground similar to the HET mirror. Analysis remains to be carried out to determine the frequency distributions for the Mt. Fowlkes site seeing as a function time of night and meteorological conditions.

Keywords: Site seeing, atmospheric turbulence, dome seeing, DIMMs, Hobby-Eberly Telescope

1. INTRODUCTION

During the summer of 2001 McDonald Observatory began a concentrated effort to quantify the intrinsic site seeing on

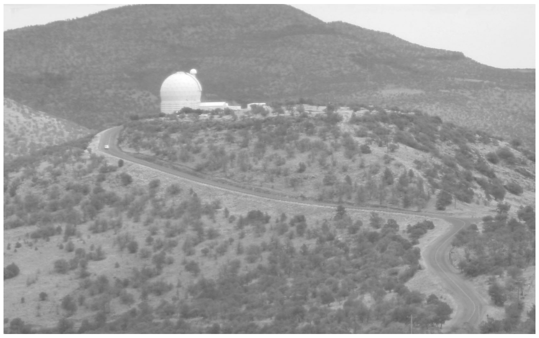

Figure 1: View of the HET on Mt Fowlkes from the southwest.

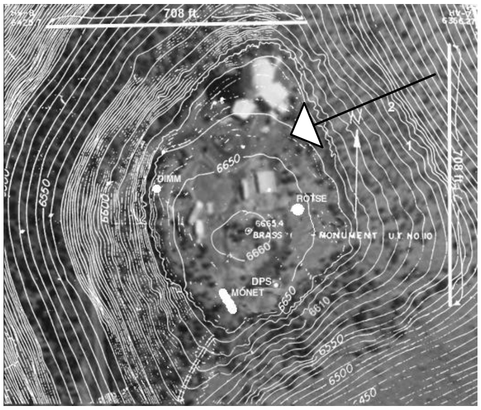

Figure 2: Aerial photo of HET superimposed on topographic map of Mt. Fowlkes. The ← marks the site of the DMM “pen”

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Mt. Fowlkes where the Hobby-Eberly Telescope (HET) was installed in the late 1990's. Mt. Fowlkes at an elevation of 6,650ft (2027m) (shown in Figs. 1 and 2) rises approximately 500ft (150m) above the local terrain and has a flat top area about 180m x 150m. Initial site surveys by Smith and Barker[1] were done on Mt. Fowlkes using acoustic sounders in the late 1980's and early 1990's. These studies were supplemented by visual double star measurements just before the HET site was selected. Averaged over a 210 day period in 1990-91 the site seeing was 0.4±0.3 or 1.0±0.7 (FWHM) arcsec, depending on different calibrations of acoustic backscatter for the Mt. Fowlkes Echosonde™. The Echosonde™ backscatter sampled only the boundary layer (some 10 to 1000m above the HET site). Mt. Fowlkes has good exposure to the prevailing winds which come from the SE to NW. After considering all effects such as wind exposure, seeing, and ease of construction, the northern site on Mt. Fowlkes was deemed the superior site.

The ultimate goal of our DIMM installation is to provide real time input to the HET queue scheduling decision tree during science operations. Armed with current seeing trends, the resident astronomer can make more informed choices between science programs and selections from the suite of HET spectroscopic instrumentation. During the past year DIMM measurements have defined a baseline for the evaluation of various aspects of the HET Completion Project[2], the new dome ventilation system[3], mirror alignment system[4], and our continuing efforts to remove heat sources from the dome and mirror environments. In this paper we will be referring to FWHM values at the zenith. The HET is a 10-meter class segmented telescope, which is fixed in elevation at 35º from the zenith. Thus, the HET always is observing at an airmass of 1.22. The reported zenith DIMM seeing values (FWHM) need to be scaled by a linear factor of $1.13 = (\cos(35^\circ))^{-5/3}$ for comparison with seeing (FWHM) measured on HET images.

2. DIMM OPERATIONS THEORY

Turbulent cells in the atmosphere cause image degradation commonly called seeing. According to the Kolmogorov theory, these turbulent cells come in various sizes. Thus, the turbulence-induced wavefront perturbations occur at various frequencies, mainly depending on the size of the cells and the wind speed. The Fried parameter, r_o is a measurement of the size of these turbulent cells, in particular r_o is the linear dimension over which the turbulence is coherent. Following the discussion presented by Vernin[5] and others, the angular diameter (FWHM in arcsec) of the seeing degraded image can be expressed in terms of the diffraction pattern produced by a region in the atmosphere

$$\mathrm{FWHM} = 0.98\,(\lambda/\ r_o) \tag{1}$$

where λ is the wavelength in µm and $r_o \ll D$ which is the diameter of the telescope. Other authors characterize r_o as the aberration strength of the atmospheric turbulence. Small values of r_o indicate strong turbulence which results in poor seeing conditions. Astronomical seeing consists of two components, (1) the blurring caused by random thermal or density distortions of the wavefront and (2) the image motion or erratic displacement of the image. The later type of image degradation is caused by tilting of the wavefronts. The FWHM values predicted by equation (1) are valid only if the telescope diameter is much greater than r_o but are much smaller than the outer scale of turbulence, L_o.

Measurement of the intrinsic astronomical seeing above a site requires the instrument be isolated from the other sources of image degradation, such as changes in focus, wind shake, telescope tracking errors, lack of exposure to the free air or the effect of the local thermal environment. Following the pioneering work by Roddier[6] in the 1980's several groups have developed similar differential imaging motion monitors or DIMMs which have been used at several sites worldwide to quantify and characterize the intrinsic site seeing[7,8,9]. The basic method consists of measuring the wavefront slope differences over two small pupils (D) separated by a fixed distance (d) in the focal plane. Differential image motion monitors use a prism to produce well-separated subimages of one and the same star. The turbulence-induced wavefront perturbations cause relative motion of the two subimages. Common mode motion, such as tracking errors and wind shake, affect each image in the same manner and do not produce relative image motion. Therefore the variation of the subimage separation is a better way of obtaining a quantitative estimate of the seeing. The relative motion of the dual star images which has been caused by local wavefront tilts can be expressed in terms of an absolute seeing scale according to the approximate formula[9]:

$$\mathrm{FWHM} = \lambda^{-1/5}\,[\sigma^2 \cos(\theta)]^{3/5} \tag{2}$$

where λ is the wavelength in µm, σ^2 is the variance of the differential image motion and θ is the zenith angle of the star being used. Actually the image motion can be measured in both the transverse and longitudinal directions when using a CCD for a detector. Our DIMM software provides both σ^2 values which can be displayed in real time. If there is a significant wind blowing across the beam, the σ^2 values are systematically separated indicating the need to use a shorter exposure time or stop recording data. Other misalignment and system failures provide separated transverse and longitudinal variances, a useful monitor of the data quality. Since all image motion with a frequency greater than the reciprocal of the exposure time is averaged out in a single frame, the DIMMs sample only a truncated power spectrum depending on the exposure time used.

Sarazin and Roddier[7] develop detailed expressions for the transverse and longitudinal variances which are dependent on the values of the aperture diameter (D) and the separation of the apertures (d). These expressions for the variances are only valid for $d \geq 2D$. The differential longitudinal image motion is in the direction of the wavefront tilt, whereas the differential transverse image motion is in the direction perpendicular to the tilt.

$$\sigma_l^2 = 2\lambda^2 r_o^{-5/3}[0.179\ D^{-1/3} - 0.0968\ d^{-1/3}] \tag{3}$$

$$\sigma_t^2 = 2\lambda^2 r_o^{-5/3}[0.179\ D^{-1/3} - 0.145\ d^{-1/3}] \tag{4}$$

With the measured variances from the DIMM software, we are able to solve for the FWHM values using equations (1,3,4). The values of FWHM are averaged and then corrected back to the zenith via equation (2).

In summary, these devices monitor the atmospheric effects on light by sampling wavefront perturbations along two separate optical paths. By measuring how different the slopes of the wavefronts are between the two images over short time intervals (10msec), one can determine how turbulent the atmosphere is at a given time. This information can readily be converted to a quantitative measure of the image quality of a point source, i.e. a measurement of the seeing (characterized by the FWHM).

3. INSTRUMENTATION

Our DIMM telescopes were installed on fixed piers (Fig. 3) in a fenced "pen" just to the SE of the HET dome primarily for logistical reasons including ready access by the HET telescope operators for nightly setup and monitoring during the nighttime hours. Although the "pen" is within 200 feet of the HET complex (see arrow in Fig. 2), the telescopes have clear exposure to the prevailing winds except those from the NW to N directions. Our systems consist of matching 12-inch Meade LX200 telescopes with alt-az mountings. The dust cap also served as an aperture mask with two 5.7cm apertures separated by 19.4cm. A thin wedge prism was a mounted over one of the apertures, thus providing a secondary image of the star being observed. The aperture masks and rest of the telescope and instrumental setup is shown in Fig. 4. We are using the same software developed by Rest[9] to control matching SBIG (Model ST-237) CCD systems. Dell Latitude CX500 laptops running Windows 2000 provide the computer platform to run the data acquisition software. The laptop computers can be connected to the LAN for the HET facility. Using a virtual network connection (VNC) the telescope operators have access to a remote display of the DIMM data stream, so they can monitor seeing conditions in real time. Automatic focusing sleeves were installed early in 2002 to correct random focus drift by locking down the primary mirrors. Although Rest's software performs an auto focus routine when necessary, an additional benefit of the remote focus sleeve was to allow remote re-focusing by the HET telescope operators from the HET control console. The new computer controlled focus sleeves changed the plate scale from 0.501arcsec/pixel to 0.473arcsec/pixel which has been factored into the data acquisition software. Tests have been run comparing the systems with different exposure times from 10 to 100msec and for stars of different brightness and color. The overall agreement is very to close to the airmass and exposure time dependence presented by Rest[9] for almost identical systems that were installed and operated at Apache Point Observatory.

The software package produced 1 minute samples of the calculated variance of the transverse and longitudinal image motions. A lower limit of 100 exposures was required for each sample period. On occasion, during cloudy weather or windy conditions this lower limit was not achieved, thus no variances were recorded to disk. Under good conditions up to 250, 10msec images would be centroided and the variances in the centroids calculated. Real time displays of the

FWHM values assisted the operators in evaluating the current conditions. The data stream was recorded to disk on the laptop and transferred to archival storage the following afternoon.

The weather conditions are monitored with tower based systems both on Mt. Fowlkes and Mt. Locke where the other McDonald Observatory 2.7m, 2.1m, 0.91m, and 0.76m telescopes are site. The temperature, relative humidity, dew point, pressure, wind speed and wind direction sensors are sampled every second. These readings are averaged over a 5 minute periods with the averages and their standard deviations being displayed locally and stored to computer disk for archival retrieval. The particle count in two different size distributions is sampled by a dust monitor and these readings are stored every 5 minutes to disk. No significant differences are seen in the datasets, but the Mt. Locke station has been in operation much longer.

Figure 3: DIMM “pen” looking NE, note two apertures on dustcap of Meade telescope in foreground.

Figure 4 DIMM 2 with computer and CCD. Equipment cart used to transport system to DIMM “pen” each night.

4. OBSERVATIONAL DATASET

During the summer of months of 2001 the DIMMs were set up and run every night (weather permitting). Due to constraints on the staffing level at the HET and experience in the operation of the DIMMs, we did not set up the systems on nights when the weather conditions were marginal. When the wind was above 25-30 mph wind bounce caused the software enlarged the sample window to a size where readout time prevented the acquisition of 100 samples which was the lower limit to the number on samples required for a valid 1 minute data point. We also had problems with condensation on the wedge when the relative humidity was above 85%. Starting in January 2002 the DIMMs were setup and operated under the following general guidelines; wind < 20 mph, RH < 70%, clouds < 15% and temperature > 0ºC. In practice, we acquired data under poorer weather conditions than the guidelines. In summary, DIMM #1 operations have produced 83 nights of reduced data since May 2001. DIMM # 2 has produced 127 nights of reduced data since it came into operation in July 2001. The data sets have been edited for obviously bad samples, such as focus problems, airmasses greater than 2, mechanical and computer failures, transitions between stars and other setup errors. During the course of dual DIMM operations inside the HET dome, we noted that the outside DIMM gave biased results when pointing at Polaris. Further investigation showed that the outside DIMM was being affected when the wind was blowing over the HET dome. Consequently, we have avoided using Polaris for a target star. The effect of being down wind of the HET dome will be eliminated when we move our outside DIMM to a tower on the western edge of Mt. Fowlkes.

Each night's data stream was processed via an Excel spreadsheet to produce a plot of the FWHM in arcsec versus time (Fig. 5). For uniformity the seeing values have been reduced to the zenith and corrected to a standard exposure time of 10 milliseconds. Fig. 5 shows a several "seeing" events over the night with the gap at 8 hours UT being due to the change over to a new target star. As part of this daily reduction the mean, median, maximum and minimum were calculated for each night and DIMM. A histogram was constructed as shown in Fig. 6. Typically, the histograms were uni-modal and similar to the one presented in Fig. 6.

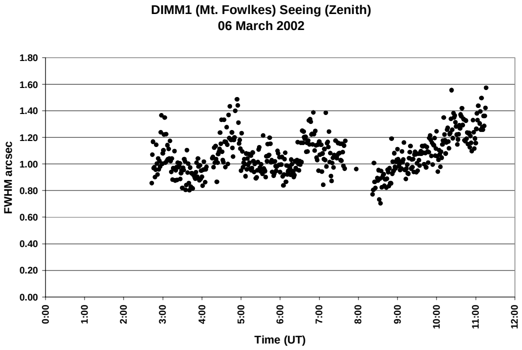

Figure 5: Sample DIMM data stream on March 6, 2002. Gaps occurred when changing between target stars.

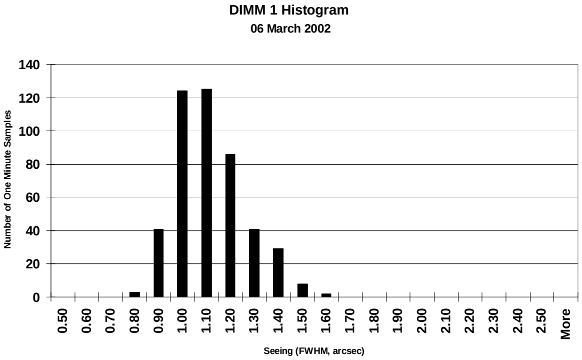

Figure 6: Sample nightly DIMM histogram for data stream shown in Fig. 5. Mean = 1.06, median = 1.04, max = 1.57, min = 0.70arcsec.

5. ANALYSIS

In the next four subsections we will discuss our DIMM data set which contains more than 54,400, one minute samples of the FWHM values obtained over a 13 month period from July 2001 to July 2002. Aspects of the calibration procedures, seasonal trends and summaries, seeing events and setting a baseline for dome seeing improvements will be addressed.

5.1 CALIBRATION

Our initial goal in the operation of the DIMMs at Mt. Fowlkes was to confirm that both DIMMs were producing the same values for the seeing and that those values corresponded to reality. A series of tests were carried out investigating

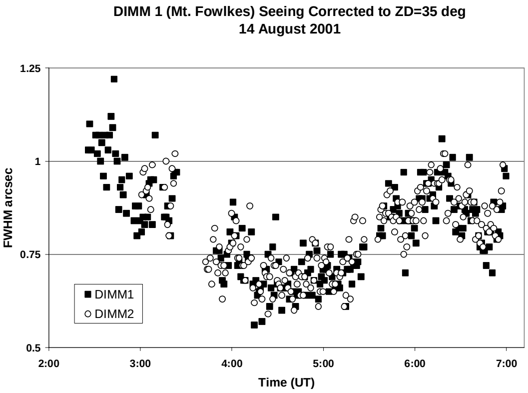

Figure 7: Simultaneous DIMM 1 and DIMM 2 measurements showing excellent tracking of the variable seeing on August 14, 2001. Note the expanded vertical scale.

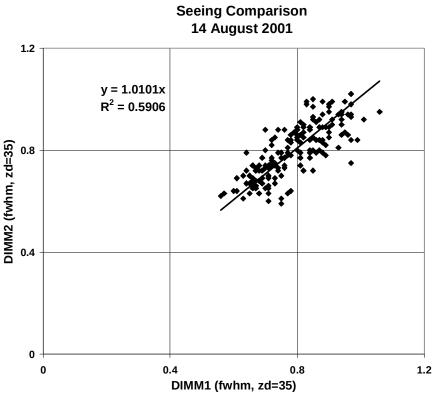

Figure 8: Correlation between simultaneous DIMM measurements shown in Fig. 7. The regression lines are fit through (0,0).

the dependence of the output on airmass, different color stars, dependence on exposure time, and other internal variables in the software, such as acquisition box size and the separation of the images. We confirmed the airmass dependence of the DIMM FWHM values on airmass measured by Rest[9] and others[5,7]. Simultaneous operation proved to be quite informative once the computer clocks were synched between the two systems to a few seconds. Fig. 7 shows a typical calibration run with both DIMMs observing the same star. The trends are the same although the minute to minute scatter in Fig. 8. On this particular night the 2 DIMMs agreed to about 1%. We carried out similar dual operations in October, November and March with similar fits between the two systems. Overall the two systems produce the same results to within 2-3%. We operated DIMM 1 as our standard reference from July until November 8, 2001 when we started using DIMM 2 as our reference. The DIMM 2 telescope and CCD system was more stable with respect to primary mirror mounting which meant fewer defocus problems and better pointing. We planned to move one of the DIMMs into the HET dome to quantify the dome seeing, so we chose to move around the less stable system which had to checked out for each setup anyway. The DIMM 2 computer system is faster and the VNC hardware which allows it to be on the LAN for the HET facility.

As part of the calibration procedure we carried out a series of observations where we observed the same star with both DIMMs, but kept the exposure time for DIMM 1 constant at 10msec while varying the exposure time for DIMM 2 between 10 and 100msec. Other DIMM users[5,8,9] have found that exposure times of 10msec or shorter are required to “freeze” the image motion, i.e. the exposure time of the images has to be sufficiently smaller than the time needed for the air cell to move across the line of sight for a given aperture telescope. If this is not the case then the seeing caused by the high part of the frequency power spectrum is not measured since high-frequency contributions to the differential image motion are averaged out over the exposure. Figure 9 is a rather busy figure as it combines different exposure time pairs on one plot. Only the 10, 50, 80, and 100msec data are shown, but slopes were also measured for 20, 30, 40, 60, 70, and 90msec exposures. Note that the slope of the linear regression curve for both DIMMs having the same 10msec exposure time is 0.966. As the exposure time for DIMM 2 increases to 100msec the slope decreases to 0.38. The reciprocals of these slopes are plotted in Fig. 10. A linear fit to the observed values yields a scale factor which can be used to convert a measured FWHM at any given exposure time to the FWHM measured at 10msec. Our scale factor agrees to with 15% of that determined by Rest[9] who’s observed reciprocal slopes also are plotted in Fig. 10. The correlation coefficient is much better for the APO data, primarily due to fact they had a significantly greater seeing range in their observations. Better fits could be obtained with Mt. Fowlkes data set that contained a larger range of seeing conditions. For example, the seeing range for the 100msec dataset was only 0.5 which did not allow much precision in the fitting of the slope. We carried out the calibration procedures demonstrated in Figs. 9 and 10 several times with results that scattered around the APO scaling factor determinations. We used a mean set of

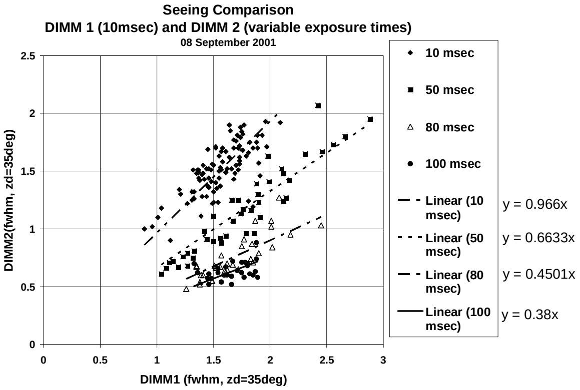

Figure 9: Simultaneous DIMM 1 and DIMM 2 measurements with DIMM 1 taking 10msec exposures and DIMM 2 taking 10 – 100msec exposures. Linear regression lines and solutions are shown for the data sets.

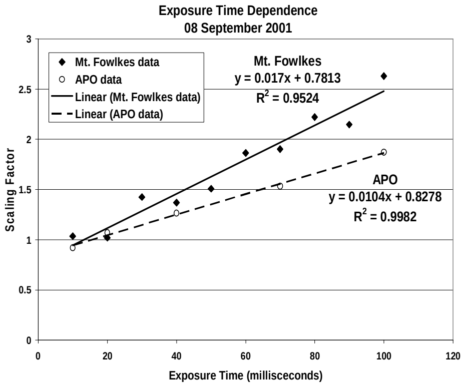

Figure 10: Determination of a scaling factor from the fit of the reciprocals of the slopes of the linear regression lines shown in Fig. 9

slopes to scale any of our DIMM data to an exposure time of 10msec. Most of our data was taken with a 10msec exposure, and thus no scaling was necessary.

One calibration or comparison remains to be carried out. The FWHM values as determined from DIMM exposures at 10msec need to be compared directly with FWHM values measured on CCD images taken with a 1m or larger telescope. This telescope needs to be in an environment which does not experience dome seeing or wind shake. Pedersen, et al.[10] has compared the ESO DIMM with the 2.2m telescope at ESO and found a correlation coefficient of 0.965. We had hoped to make the comparison directly with a HET segment, but have not been able to do so because of possible dome seeing effects within the HET dome and the difficultly of observing the same star with the HET and DIMM in the limited confines of the HET dome floor.

5.2 SUMMARY OF DATASET

Our acquired data set is summarized in the Fig. 11 and Table1. All of the seeing measurements (FWHM values) have been corrected to the same exposure time (10msec) and to the zenith. We have combined the 54,399 one minute samples of the FWHM into a single histogram. During the period from July 2001 to November 8, 2001 DIMM 1 was considered to be our reference or standard DIMM. For reasons described in Section 2, as of November 8, 2001 we defined DIMM 2 to be our reference system. The summary histogram presented in Fig. 11 is based on all samples taken by the DIMM defined as our standard regardless of which night they were obtained. The summary histogram shows that the reference DIMM experienced seeing of 0.7arcsec or less 8.7% of the time and it was 1.0 arcsec or less 51% of the sampled time period. A more meaningful display of the variation of the seeing values over the entire 13 months is given in Fig. 12 which is a plot of the nightly medians. These medians along with the corresponding max and min values for each night were determined from each individual dataset as demonstrated in Fig. 6. One can easily discern a seasonal variation which has worse seeing that is more variable during the winter months. From this display in Fig. 12 we can see that the minimum zenith seeing at Mt. Fowlkes is around 0.55arcsec.

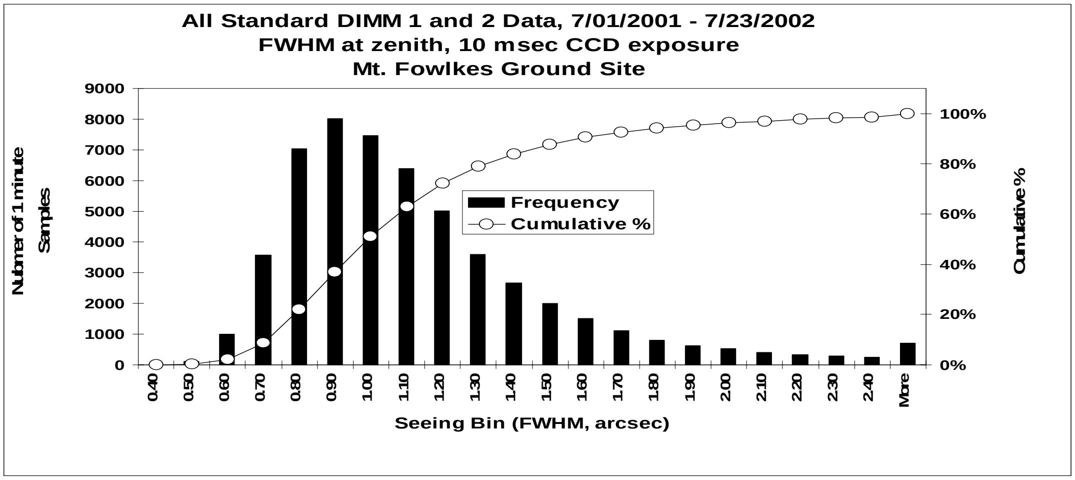

Figure 11: Histogram of All Data taken by either DIMM 1 or DIMM 2 when they were designated as the standard or reference DIMM for the night. The histogram is based on 54,399 one minute samples of the seeing at Mt. Fowlkes.

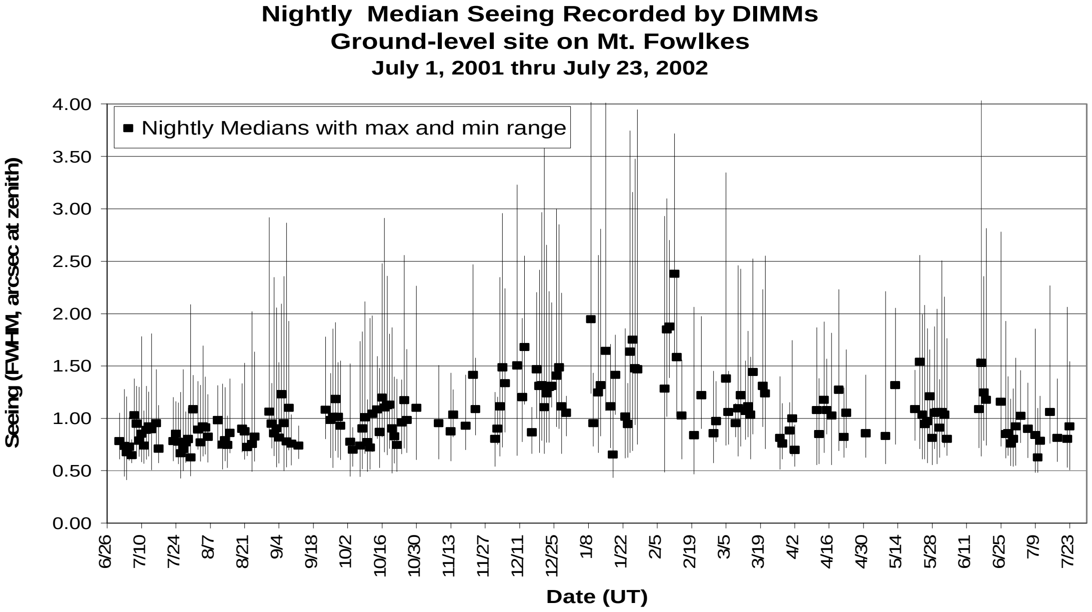

Figure 12: Nightly Medians for the period from July 2001 thru July 2002

TABLE 1: Monthly Means of the Nightly Seeing Medians

Month	Number of nights	Observation time (hrs)	Monthly Means of the Nightly Medians	Stdev of the Monthly Means
July 2001	24	59.0	0.81	±0.12
August 2001	16	59.5	0.85	0.09
September 2001	16	90.9	0.96	0.15
October 2001	21	154.8	0.95	0.16
November 2001	6	14	1.05	0.19
December 2001	18	97.8	1.25	0.23
January 2002	14	79.5	1.33	0.36
February 2002	9	47.2	1.44	0.52
March 2002	15	60.4	1.09	0.20
April 2002	10	45.9	1.01	0.17
May 2002	13	74.3	1.05	0.13
June 2002	12	56.2	1.03	0.23
July 2002	9	51.4	0.87	0.13
13 month period	186	890.9	1.03	0.28
Winter period	64	298.9	1.24	0.33
Summer period	122	592.0	0.93	0.18

The nightly median seeing values shown in Fig 12 can be grouped into monthly means as shown in Table 1. These means were calculated from the nightly median values for a given month. The standard deviation (stdev) of the monthly means was calculated from the dispersion in the nightly medians. The observation time was calculated from the number of one minute DIMM samples in month. The seasonal effect is even more apparent and can be statistically quantified. Although there are "good" nights in the winter months such on January 18, 2002 where the median seeing was 0.65 and less than 1.0arcsec for most of the night, the winter months of November, December, January, February and March are 0.2 to 0.4arcsec worse than the rest of the year. The doubling of the stdev for the winter months is also an indication of the periodic passage of cold fronts. In the summer months of July and August when the weather is dominated by periods of static high pressure, the seeing is statistically shows less variation night to night. Both of the conclusions have been part of the local astronomical "lore" at McDonald Observatory for many years, this DIMM study is the first to fully quantify the seasonal effect at the 0.1 arcsec level. Although the acoustic sounder studies in the late 1980s and early 1990s did show similar seasonal trends in the seeing FWHM values[1].

Over the 13 month period (186 nights) we calculate a mean value for the nightly median of 1.03±0.28. Limiting the calculation to those winter nights in November through March, we calculate a mean value of 1.24±0.33arcsec. Similarly the summer period consists of nights between March and October give a mean nightly median of 0.93±0.18arcsec.

5.3 SEEING EVENTS

The HET telescope operators carried out the setting up and monitoring of the DIMMS during the nights when they were deployed. Quite often they would note seeing events where the FWHM values would increase a few tenths of an arcsec and then settle back down. Figures 13 and 14 show examples of both variable and stable seeing nights, note the plots have the same vertical scale. Part of the next stage of our DIMM survey is to determine the metrological connection that is causing the seeing events. Shifts in the wind direction are likely candidates as they bring different volumes of boundary layer air into the telescope beams. The rising and falling of the boundary or inversion layer could also create variable seeing conditions.

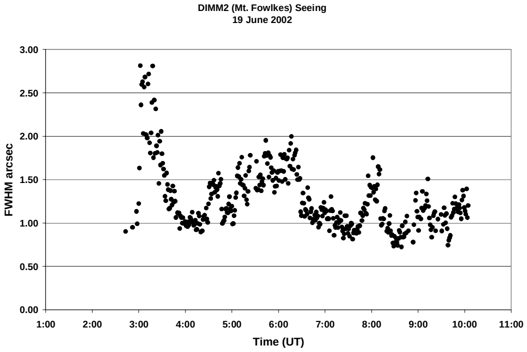

Figure 13: Sample of variable seeing.

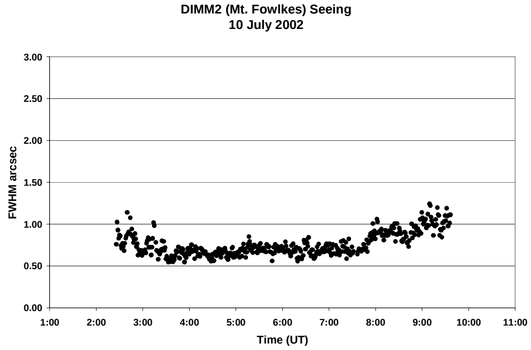

Figure 14: Sample of stable seeing.

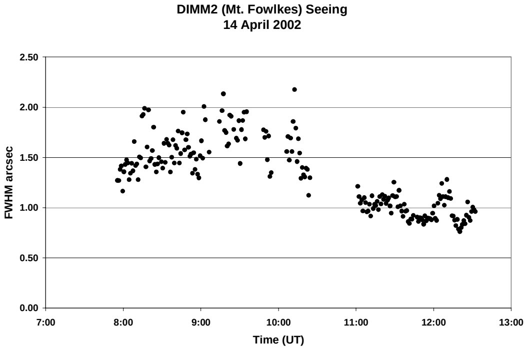

Figure 15: DIMM data of during the “neutral event” as seen in the microthermal run

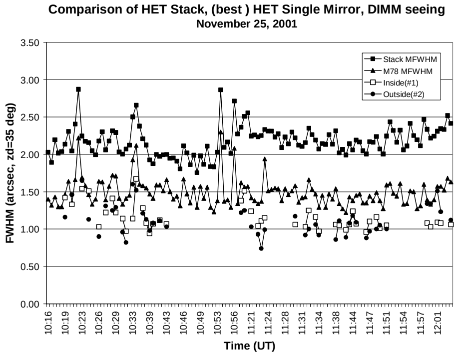

Figure 16: Comparison of Simultaneous HET stack, single mirror, and DIMM measurements of the seeing.

We may have a clue to one of the causes of seeing changes. During April we carried out a series of simultaneous DIMM and microthermal measurements. The University of New Mexico’s John McGraw loaned the microthermal system which had been used to survey potential telescope sites in western New Mexico[10]. Matched microthermal sensors were deployed at heights of 25m, 20m 15m and 6.6m directly above the DIMM site. The microthermal data will be discussed in a separate communication, but the microthermal activity completely ceased at the upper 3 sets of probes between

11:42UT and 12:00UT on April 14th. Simultaneous DIMM 2 data is show in Fig. 15 with a sudden decrease in the seeing to values less than one arcsec between 11:42 and 12:00UT, then increasing to 1.2arcsec or so. The progression of the decrease in microthermal activity in the upper 3 probe pairs indicate that an inversion layer settled down onto Mt. Fowlkes during this predawn period. This decrease maybe tied to the atmospheric "neutral event" which occurs when the radiation between the surface and the atmosphere is in a balanced state. The acoustic sounder data taken at McDonald Observatory in the 1980s and 1990s showed this minimum almost every twilight period.

5.4 DOME SEEING

The primary goal for making DIMM measurements is to provide a real time baseline for comparison with various attempts to improve the HET dome seeing environment. We have made major steps to improve the dome ventilation with the installation of 330º of louvers around the ring wall of the HET dome[3]. Plans are moving forward to install additional louvers in the 5/8 spherical dome as well. Several sources of heat have been or are being removed from the tracker and mirror environments.

In November 2001 we attempted to set a baseline for the existing dome seeing effects. Simultaneous seeing measurements acquired by two separate DIMM units, one inside and another outside the dome. Images of eight of the single segments had been moved out of the stacked primary mirror array. The best single HET segment measurement of seeing is compared to the inside and outside DIMM data in Fig. 16. We found out that it was nearly impossible to properly sample the HET optical path (11m in diameter) with the DIMM telescope (0.3m) mounted anywhere inside the HET dome to obtain a valid comparison with the HET single segments. On this night the DIMMs indicated there was minimal dome seeing along the DIMM optical path as seen by the excellent agreement of the DIMM data points. However, the best single mirror image FWHM was still about 0.4arcsec worse than the DIMM measurements which maybe due to dome seeing in the HET optical path or we haven't ruled out a calibration offset between DIMM measurements of the FWHM and single mirror profile measurements of the FWHM of the image. The reasons for the 0.6arcsec stack offset and 0.5arcsec scatter in the eight single segments are addressed in companion papers on other aspects of the HET Completion project[2,3,4,11]. Currently, the telescope operators are carrying out experiments to isolate the operational parameters which provide the best dome seeing and the best on-sky image quality.

6. FUTURE WORK

Software needs to be developed to correlate the existing DIMM dataset with the observed meteorological conditions. Attempts to correlate FWHM values with meteorological conditions have been carried out on a few individual nights with seeing events without any significant correlations with wind speed or wind direction being noted.

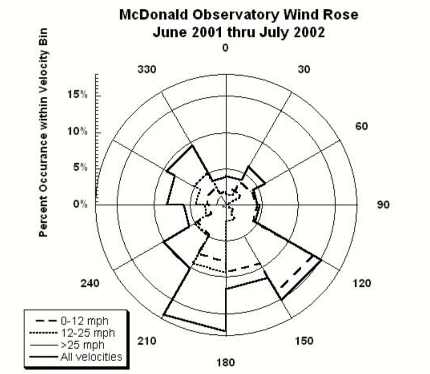

Figure 17: McDonald Observatory Windrose during the operational period for the DIMMs

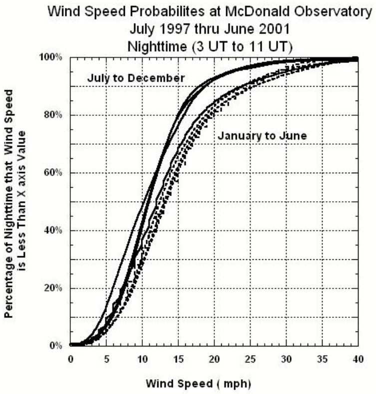

Figure 18: Wind Speed Probabilities

As we move into the 2nd year of DIMM operation, plans are being formalized to install one of the DIMMs on a tower 6-8 meters above the ground. The proposed site is noted on Fig. 2 as "DIMM" and is on the western edge of Mt. Fowlkes. This location will provide the best exposure to the prevailing winds from the S to the NW. The windrose for McDonald Observatory over the past several years is shown in Fig. 17. The wind speed is also a function of season at McDonald as seen in Fig. 18. During the summer months the wind is light (< 10 mph) and preferentially from the S-SE with the winter months having the higher velocity winds from the NW. The rest of the time the winds are from the SW and in the 10-20 mph range. While a tower mounted DIMM will be above the direct ground level turbulence it has experienced on the 2m piers (see Fig. 3), it may not be above the boundary layer on Mt. Fowlkes. However, we do expect the ground level contribution to the seeing integral to be at least 0.1 arcsec. One benefit of having the DIMM on a 5-7m tower is that the HET mirror is about 5-6m above the ground level with approximately the same wind exposure as the HET dome.

7. SUMMARY

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A DIMM samples the differential image motion of a single bright star between two separate optical paths through the atmosphere. This is accomplished with a 12inch telescope, which has a two-aperture mask on the front and a prism which displaces the light from one aperture to produce two well-separated subimages of one and the same star onto a single CCD camera. Wavefront perturbations caused by turbulence in the atmosphere produce the relative motion between the two subimages, but common mode motion, such as tracking errors and wind shakes, affect each image in the same manner and do not introduce relative image motion. Therefore the variation of the subimage separation is an excellent way of obtaining a quantitative estimate of the seeing. The operation and calibration of our DIMMs seems to be comparable to DIMM systems at other observatories such as Apache Point, CTIO, ING, and ESO.

Summarizing the 186 nights of DIMM data, we find that FWHM seeing on Mt. Fowlkes has a strong seasonal trend. The summer period (March to October) has mean median seeing at the zenith of 0.93±0.18. The mean median seeing for the winter period is 1.24±.0.33. The mean median seeing for the 13 month period of operation is 1.03±0.28arcsec.

We are planning to place one of our DIMMs on a 5-7m tower in the fall of 2002, so the intrinsic site seeing can be sampled without ground level effects. Getting above the ground level turbulence should reduce the recorded seeing by 0.1arcse or more.

8. ACKNOWLEDGEMENTS

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