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Seeing Measurements with a Differential Image Motion Monitor

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Concept of the DIMM

Seeing is possibly the most important parameter describing a ground-based astronomical observatory. Under conditions of good seeing, an aberration-free telescope will produce sharp and bright images. The astronomer can then explore the universe to greater depths than otherwise possible.

In recent years, a considerable amount of theoretical and experimental seeing studies have been conducted. The action of the earth's atmosphere on the quality of astronomical observations is now understood in quite some detail, and it has also become possible to measure the prevailing seeing, without the use of large and very expensive telescopes. This is obviously of great interest in the search for new observatory sites.

One particular instrument which can simulate seeing conditions at larger telescopes is called the Differential Image Motion Monitor, or DIMM. Its concept goes back at least to 1960, when it was used for qualitative seeing studies [1]. Later, F. Roddier [2] has shown its potential for quantitative measurements. This prompted ESO to use DIMM in the search for the site for the Very Large Telescope.

The detector unit of DIMM houses an intensified CCD and is attached to an alt-alt mounted, 350-mm aperture Cassegrain telescope. All essential functions are computer controlled, and tracking is assisted by an autoguider. The instrument is placed in open air on a 5 m high tower. Typically, the telescope follows a bright star for a couple of hours, while the star crosses the meridian.

The full aperture of the instrument is used for self-calibration, while, in its regular mode of operation, the entrance is restricted to two circular holes. These are 4 cm diameter, and spaced 20 cm, centre to centre. Under perfect conditions, light arrives as a plane wave, forming two images at fixed positions. The presence of turbulence in the earth's atmosphere causes the arrival direction to differ slightly between the two holes. The two spots on the detector will then shift relative to each other. Their time-averaged motion is proportional to the astronomical seeing. In principle, the scaling factor is defined by the system parameters, and does not depend on any empirically determined value. To demonstrate that this is really the case, we decided to compare the DIMM with standard seeing measurements at big telescopes. Such have been conducted on a regular basis for several years, using imaging CCD cameras [5]. In order to allow a comparison as realistic as possible, it was necessary to mount the DIMM inside a dome. For the presently described tests, May 26 to 28, 1988, it was mounted on the exterior of the 2.2-m telescope's mirror cell.

Measurement in Parallel with the 2.2-m Telescope

In spite of the fact that the instruments were observing in parallel, at least two effects tend to complicate the comparison. A relatively small effect is due to turbulence within the 2.2-m mirror cell. This is not measured by the DIMM, since it used its own optics. The size of the error is difficult to quantify. We believe it is comparable to the measurement accuracy (0.1″), or smaller.

A more severe effect is due to optical aberrations in the 2.2-m. In order to quantify this, we refer to the last optical tests, which were conducted in December 1987. A set of Shack-Hartmann plates show that the main error is due to astigmatism, decentring coma being negligible and spherical aberration absent. At best focus, 80% of the energy is concentrated within a diameter of 0.45″. For seeing ~ 1″, this corresponds to a quadratic contribution of 0.35″ in terms of FWHM. To allow also for the mirror-seeing problem, we have

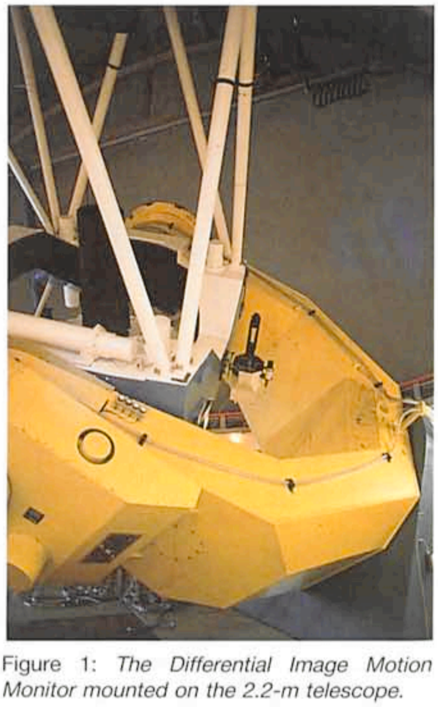

Figure 1: *The Differential Image Motion Monitor mounted on the 2.2-m telescope.*

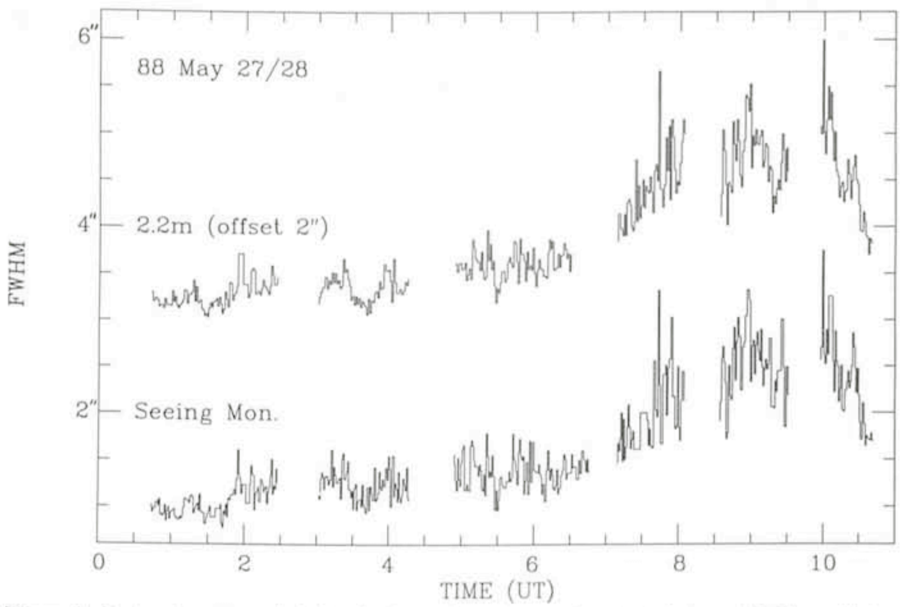

Figure 2: *During the second night of observation, the seeing started around 0.8", and later became worse. In this presentation the 2.2-m data have been rebinned to match the DIMM time slots, and corrected to a standard wavelength 560 nm.*

assigned 0.4" as the intrinsic image quality of the 2.2-m telescope.

During the nights of simultaneous seeing measurements, the 2.2-m CCD camera employed a detector with pixel size 0.365". At this resolution proper sampling is ensured. The optical filter was RG-9 and we have assumed that this corresponds to 800 nm effective wavelength. The integration time was 50 seconds, followed by 15 seconds dead-time. Standard software was used to fit Gaussian profiles to star-images. The seeing at full width, half maximum, was calculated in two orthogonal directions, S_x and S_y, and transformed to 560 nm wavelength. The astigmatism was noticed through slow drifts of the focus, caused by temperature changes of the telescope structure. To minimize the effect, we used the average, S, in the two directions. The rms error of a single determination of S is smaller than 0.1", as shown by an analysis of $S_x - S_y$.

The simultaneously acquired DIMM measurements lasted 1 minute each, and the statistical error was 6%. The conversion from differential image motion to equivalent seeing was also made at 560 nm. Note, however, that the DIMM results are independent of the detector's chromatic characteristics, since image motion is not a function of wavelength [3].

Figure 2 shows the results obtained during one of the test nights. The seeing ranged from 0.8" in the beginning, to more than 3". Periods without data correspond to change of star, combined with a careful refocussing of the 2.2-m. The 2.2-m data have been rebinned in time to correspond to the time-slots of the DIMM.

The direct comparison (using data from both nights) gives a best linear fit: $S_{2.2m} = 1.05 \times S_{DIMM} + 0.14$ arcseconds, with a correlation coefficient of 0.965. Following correction for the known aberrations of the 2.2-m telescope the relation (Figure 3) changes to $S_{2.2m} = 1.02 \times S_{DIMM} + 0.08$ arcseconds.

The difference from a one-to-one relation is more likely due to an undescribed problem in the 2.2-m data than to a systematic underevaluation on part of DIMM. Therefore we believe that the present comparison provides sufficient reassurance for the use of DIMM as a quantitative seeing measurement tool.

DIMM in Operation

The first DIMM unit has been in regular use since April 1987 when it was installed at Cerro Paranal, one of the candidate sites for the VLT. Over 40,000 individual seeing measurements are available from that place. A second system was recently built, and is now mounted at another candidate site, Cerro Vizcachas, a few km south-east of La Silla.

The hardware of both systems is prepared for automatization. This will be completed in the near future, whereafter seeing monitoring can be done on a permanent basis. As a by-product, we obtain quantitative data on the photometric quality of the sky.

We note that seeing monitors are not only of interest in the site-testing phase. Also remote controlled observations, and automated programme selection can benefit much from such information.

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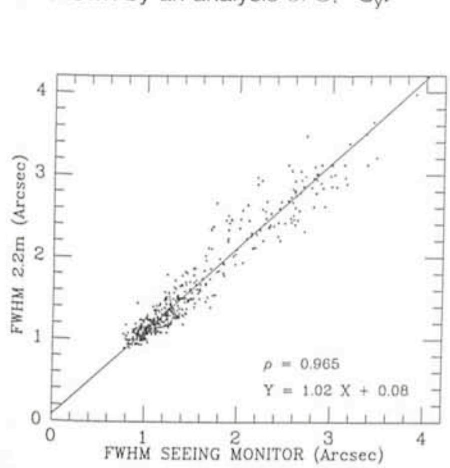

Figure 3: *Following a correction for image aberrations at the 2.2-m, the correlation between the two sets of data is acceptable.*

Visiting Astronomers

(October 1, 1988–April 1, 1989)

Observing time has now been allocated for Period 42 (October 1, 1988–April 1, 1989). As usual, the demand for telescope time was much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6-m Telescope

October 1988: Wampler, Guzzo/Collins/Heydon-Dumbleton, Soucail/Fort/Tyson/Turner, Mellier/Mathez/Soucail, Maccagni/Gioia/Maccacaro/Vettolani, Iovino/Shaver/Cristiani/Clowes, Danziger/Gilmozzi, Moorwood/Oliva, Danziger/Moorwood/Oliva, Danziger/Fosbury/Lucy/Wampler/Bouchet.

November 1988: Moeller/K. Rasmussen, Danziger/Cristiani/Guzzo, Barbieri/Clowes/