Mem. S.A.It. Suppl. Vol. 2, 146

Memorie della
Supplementi

First daytime seeing monitoring at Dome C

E. Aristidi, A. Agabi, J. Vernin, M. Azouit, F. Martin, A. Ziad, and E. Fossat

Laboratoire Universitaire d'Astrophysique de Nice, Université de Nice Sophia Antipolis, Parc Valrose, F-06108 Nice Cedex 2
e-mail: aristidi@unice.fr

Abstract. The first astronomical seeing monitoring has been made with a DIMM instrument at the Antarctic plateau site of Dome C in December, 2002 on the bright star Canopus (α Eri) during the daytime. In these far from optimal conditions, a median seeing of 1.2 arcsec as been obtained, with extended periods better than 1 arc-sec and 12 percent of the time better tan 0.75 arcsec.

Key words. Site Testing

1. Introduction

A site-testing program (part of the Concordiastro project) has been initiated 3 years ago at Dome C. The goal is to monitor, during the polar night, the atmospheric turbulence expected to be very weak. The first DIMM instrument (Sarazin and Roddier, 1990) has been tested for this purpose during the summer season 2002/2003. The exceptional transparency of the Antarctic sky made possible to measure the seeing on a bright star at any time of the day, even with the Sun being at an elevation angle of 38°.

2. Instrumentation

The differential image motion monitor (DIMM) measures the differential motion of two stellar images at the focus of a small telescope. A mask with two sub-apertures is located at the entrance pupil. A prism is added on one of the sub-apertures, so that two images of the same star are observed at the focus. The differential motion of these two images is related to the Fried parameter. Our DIMM is based upon the instrumental concept described by Vernin and Munoz (1995). The instrumental set up was as follows:

- Celestron 11 telescope (28 cm aperture, 2.8 m focus) on an Astrophysics 1200 equatorial mount
- 6 cm diameter sub-apertures separated by 20 cm. The mask was placed at the top of the telescope, 5 cm above the Schmidt entrance corrective window
- A glass prism of dimension 7cm × 7cm with a deviation angle of 30 arcsec fixed on one of the sub-apertures, the other is left open
- A digital CCD camera, operating in the visible (300 – 1000 nm) is at the telescope focus. The pixel size of 10 μm is consistent with the spatial sampling of the Airy Disc of the sub-apertures.

Send offprint requests to: E. Aristidi

The camera is placed inside a thermostated box, ensuring a temperature never colder than $-20°$C. Digital image signal was then transported by a 10 m cable to a PCI controler board inside a laboratory tent.

Nearly one month of seeing measurements was performed at Dome C, from Dec 6, 2002 to January 2, 2003. The first days of the campaign were devoted to the precise polar alignment of the telescope mount. As the Sun was present 24 hours per day, we did the alignment by using the Bigourdan method on sunspots, Venus and Mercury. At local noon, with the Sun around 35° above horizon, stars of magnitude 1 were still observable with a reasonable contrast. We selected Canopus (α Eri, $V = -0.9$) for the seeing measurements.

3. Data processing

The main difficulty in daytime stellar observations is the sky background level. After different trials, an exposure time of 10 ms has finally been selected. It led to a background level of the order of 10 to 15% of the star image maximum intensity.

A software was developed to perform real time data processing. Each sort exposure frame was thresholded to eliminate the background, then the two stellar images were easily detected and their photocenter coordinates computed by means of a simple barycenter formula.

Every two minutes, the variances of longitudinal (parallel to the aperture alignment) and transverse distances between the two stars were computed on about 1000 individual images. Statistical error on the variance was $\delta\sigma^2/\sigma^2 \simeq 5\%$ (Sarazin and Roddier, 1990). These variances are obtained in unit of pixel square and require a calibration of the pixel size. That was done by imaging the double star Alpha Centauri, which angular separation $\rho = 12$ arcsec has been estimated from the orbit of Heinz (1960).

Fried parameter was then computed from longitudinal (σ_l^2) and transversal (σ_t^2) variances using Eq. 5 and 8 of Tokovinin (2002). The wavelength is $\lambda = 500$ nm. The two estimations of r_0 are expected to give similar values ; all measurements for which $\left|1 - r_0^{(t)}/r_0^{(l)}\right| > 0.1$ were rejected. The seeing is then calculated and compensated from the zenith angle effect by the standard formula $\epsilon^{(t|l)} = 0.98 \cos z^{-3/5} \lambda / r_0^{(t|l)}$

The zenithal angle z of Canopus at Dome C ranges between 22° and 52°, the minimum height being between 11 and 12 pm local time (UT+8) during the observing month. At such a large value of z, the compensation formula in $\cos z^{-3/5}$ may be a little bit inaccurate.

Another point to be taken into account in the seeing estimation is the exposure time τ. The seeing must be ideally given for instantaneous images, and the finite exposure time is responsible for a blurring of the images that artificially improves the measured seeing. This effect has been extensively investigated in the past. Proposed solutions are to use a double exposure time (τ and 2τ) and to apply a compensation formula (Tokovinin, 2002) or to make an exponential fit (Ziad et al, 2000). The acquisition software did not offer this possibility in last December, so the published seeings are computed for the value $\tau = 10$ ms. However we were able to record a few image sets with a sampling rate of 40 frames per sec. By averaging successive images by pairs, we could articially increase the exposure time and apply the compensation formula. We found a correction factor of the order of 5%, comparable with the statistical error.

4. Results

During the first week (December 6th–13th), the telescope was at ground level, its mount just standing on the snow surface. Then a wooden platform was erected and starting on Dec 16, the data have been collected from the top of this platform, 7 meters above the snow level, thus avoiding the always possible surface layer turbulence.

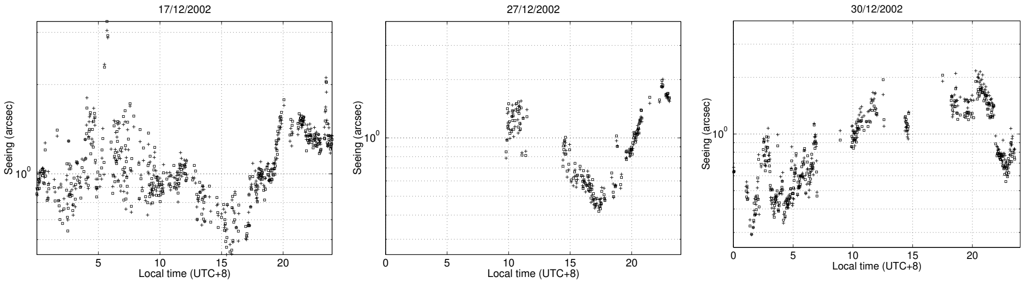

Fig. 1. Seeing measurements as a function of time for December 17, 27 and 30. Transversal seeing is plotted with '+', longitudinal with squares. Logarithmic scale has been used to emphasize good seeing values.

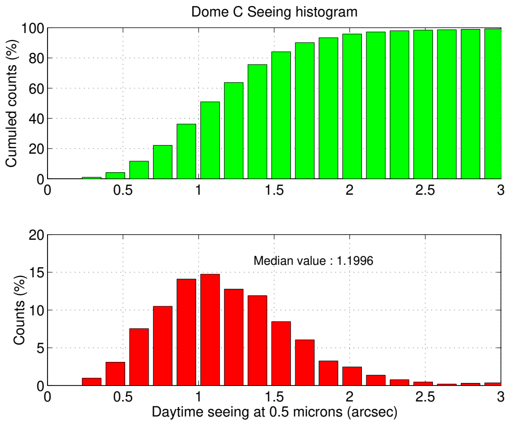

Fig. 2. Normalized histograms of seeing for an exposure time of 10 ms. Transversal and longitudinal values have been averaged.

A total amount of 3650 2-minute seeing values have been estimated. Figure 1 shows a sample of the seeing time series for three particular days. Thanks to the presence of two observers, several long time series have been made possible, for instance the star has been observed almost without stop during 48 hours between the 16th and the 18th of December.

The histogram of seeing values (averaged between transversal and longitudinal) is plotted on Figure 2. The median of all 3650 individual values is 1.2 arcsec, with about 30% of the values below 1 arcsec. This is quite exceptional in daytime, were the seeing, usually estimated on the solar limb, is of the order of 2 arcsec (Irbah et al., 1994). This is in particular far better than the South Pole seeing, estimated at *night time* (usually better than daytime) at 1.73 arcsec (Travouillon et al., 2003).

Several occurrences for long duration of weak turbulence are visible on Figure 1. For instance, the seeing was consistently better than 1 arcsec during 5 hours on Dec 17th, and again on Dec 27th.

In addition to seeing estimation, we made some post-processing on the few image sets (less than ten unfortunately) we recorded at a sampling rate of 40 frames per second. We computed the temporal autocorrelation function of the transverse and longitudinal motions of the spots at the focus of the DIMM. Figure 4 shows an example computed on one of these image sets with good seeing conditions (0.8 arcsec). These correlation functions exhibit an exponential behavior near the origin, with an average characteristic time $\tau_s \simeq 50$ ms. This quantity is the correlation time of the differential tilt of the wavefront. We are still working to connect it with the wavefront coherence time.

5. Discussion and conclusion

These measurements are the very first DIMM data obtained on the Antarctic plateau. They are also, to our knowledge, the first DIMM measurements ever made in

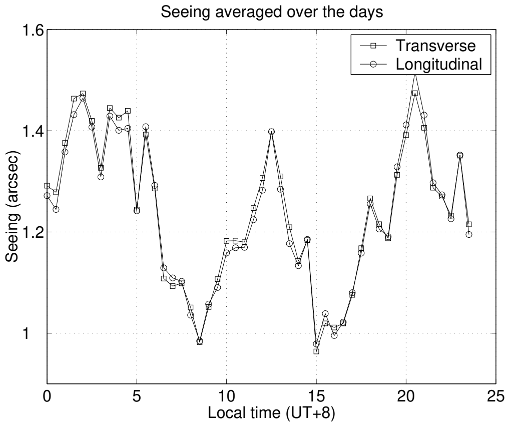

Fig. 3. Seeing as a function of local time, daily averaged.

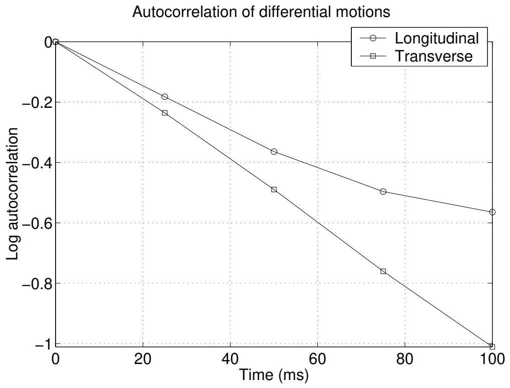

Fig. 4. Example of temporal autocorrelation function of the differential motion of the spots at the DIMM's focal plane. Corresponding data were collected on December 23, 0:04 local time where the seeing was 0.8 arcsec. The images are sampled at a rate of 40 frames per second, the exposure time was 5 ms. The characteristic time is here 100 ms (transverse seeing) and 150 ms (longitudinal seeing).

daytime. Although our measurements were made during daytime with the Sun always present between 5° and 35° above horizon, the seeing values can almost compare to those of other well known astronomical sites (Ziad et al, 2000) . The fact that the best seeing values, like 0.5 arcsec or better), have been generally obtained in mid local afternoon as shown in Figure 3 is extremely encouraging. Indeed, a discontinuity of the temperature gradient between 200 and 400 m has often been noted in the middle of the day, and disappears in the evening to be replaced by a standard surface inversion layer of 20 or 30 m. During the afternoon transition, there is a moment with an isothermal temperature profile. The generally excellent seeing obtained during this transition indicates that the contribution of all the rest of the atmosphere is indeed very small. At night with a telescope standing above the ground inversion layer, a really excellent seeing can then be expected almost continuously . We are now working at the improved seeing monitor, composed on 3 DIMMs based on the GSM concept (Ziad et al., 2000) allowing an analysis in 6 points of the wavefront. The objective is to perform a night-time monitoring of the turbulence parameters (seeing, coherence time, isoplanatic angle and outer scale) during the first winterover scheduled for 2005.

Acknowledgements. We wish to thank both Polar Insitutes,IPEV and ENEA, that made possible to have two observers on the site during this summer season, and all the Concordia staff at Dome C for their friendly and efficient help in setting up the Concordiastro platform.

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