Title : will be set by the publisher
Editors : will be set by the publisher
EAS Publications Series, Vol. ?, 2004

MASS SEEING MEASUREMENTS FROM DOME C

M. C. B. Ashley[1], J. S. Lawrence[1], J. W. V. Storey[1] and A. Tokovinin[2]

Abstract. The astronomical seeing from the Antarctic high plateau site Dome C has been a matter of speculation for over a decade. During 2004 we made the first wintertime measurements of the seeing using a Multi Aperture Scintillation Sensor (MASS), a device that is well-suited for automated unattended operation. The mean seeing was found to be 0.27 arcseconds, and the seeing is better than 0.15 arcseconds for 25% of the time. These extraordinarily low levels of turbulence make Dome C a superb site for future optical and infrared telescopes.

1 Introduction

The first published predictions of exceptional seeing in Antarctica appear to be by Gillingham 1991 and 1993. However, the history goes back at least as far as 1970, when Arne Wyller wrote a letter to the National Science Foundation suggesting that the seeing might be good at the South Pole (see Indermuehle *et al.* 2004 for an interesting historical summary). Marks 2002 compared seeing measurements from the South Pole station with predictions at other high plateau sites.

The summertime seeing at Dome C has been measured during the 2002/3 and 2003/4 seasons by the University of Nice group consisting of E. Aristidi, A. Agabi, J. Vernin, M. Azouit, F. Martin, A. Ziad and E. Fossat. They saw periods of seeing as good as 0.2 arcseconds in bright sunshine, which is unprecedented for an observatory site. Balloon launches during summer have shown that the wind profiles as a function of height are consistent with superb seeing (Aristidi *et al.* 2004).

We set out to measure the seeing during wintertime, and to measure the contributions to the seeing from various layers in the atmosphere up to a height of 20 km.

Until Concordia Station at Dome C opens for winter operation (expected in 2005) it will remain very challenging to operate instruments over the winter-

---

[1] School of Physics, University of New South Wales, Sydney 2052, Australia
[2] Cerro Tololo Inter-American Observatory, La Serena, Chile

DOI: (will be inserted later)

time. The instruments need to be highly reliable, automated, and need no human interaction apart from what can be achieved with a slow communication link such as Iridium (see Ashley *et al.* 2004 for a discussion of robotic telescopes in Antarctica). Furthermore, there is no electrical power or heat available, so experimenters need to provide this themselves. Fortunately, we had previously developed the Automated Astronomical Site-Testing International Observatory (AASTINO) (Lawrence *et al.* 2003; Lawrence *et al.* 2004a) which generates its own heat and electricity using Stirling engines powered by jet-fuel. The AASTINO operated successfully at Dome C for 143 days following station close in 2004.

Astronomical seeing is a difficult quantity to measure with a simple automated instrument. While it can be measured using a Differential Image Motion Monitor (DIMM), this requires a moderate-sized telescope (> 25 cm) and a precision mount capable of arcsecond stability. The DIMM must be at ambient temperature, since any local turbulence from heating will affect the results. A DIMM is sensitive to the total integrated seeing, and give no information on the altitude dependence of the turbulence, which is crucial for deriving related parameters such as the isoplanatic angle, coherence time, and the expected performance of adaptive optics. The altitude information can be obtained using SCIDAR (SCIntillation Detection And Ranging) and SLODAR (SLOpe Detection And Ranging) instruments, but these also require moderate-sized telescopes, even larger than those necessary for a DIMM. Sonic radars (SODARs) do give height-resolved measurements of the turbulence, and are very suitable for automation, but are limited to about 1 km in range. Tower-based microthermal sensors are able to measure the turbulence very close to the ground, and can be carried aloft in balloons to measure the entire atmosphere; however, these techniques are difficult to automate: the sensors tend to ice-up and launching balloons without human intervention in wintertime would be very challenging.

2 The Multi-Aperture Scintillation Sensor

Fortunately, an ideal instrument for our purposes was the MASS developed by Andrei Tokovinin and his colleagues Victor Kornilov, Andrei Zaitsev, Ol'ga Vozyakova, Nicolai Shatsky and Sergei Potanin from the Sternberg Astronomical Institute of the Moscow University. MASS observes the shadow-bands at ground-level that result when light from a single star passes through the atmosphere—these are the same shadow-bands that are seen during a solar eclipse immediately prior to and after totality. The MASS operation is somewhat analogous to determining the amplitude of the waves on the surface of a swimming pool by looking at the patterns of dark and light on the bottom of the pool caused by sunlight.

MASS has several key advantages: it needs only a small telescope (85 mm aperture), it requires only modest pointing accuracy (1 arcminute), it is insensitive to turbulence close to the instrument (the instrument can therefore be heated without concern about the affect on the seeing), and it gives height-resolved turbulence profiles (in six bands from 0.5 to 20 km). A disadvantage to MASS is that, being insensitive to the 0-500 m ground layer, it needs to be supplemented with, e.g., a SODAR, to determine the overall integrated seeing. Since the AASTINO was already fitted with a SODAR, and had operated successfully during 2003 (Travouillon *et al.* 2003), this was not a problem for us.

The detailed design and operation of the MASS instrument has been well-documented in the literature (Kornilov *et al.* 2003; Tokovinin 2002). The MASS has been well-characterized against alternative methods of measuring the seeing (Tokovinin *et al.* 2003a; Tokovinin *et al.* 2003b).

3 The siderostat mount

Apart from the MASS itself, the other key component in our seeing instrument was a mount capable of acquiring and tracking bright stars to a precision of about one arcminute. For the greatest reliability and simplicity we chose a gimbal-mounted siderostat mirror (see Figure 1). To find a star we drove the gimbal to the expected location, and then performed a spiral search until the star was detected by MASS. A final "half-power peak-up" centered the star precisely, and we then tracked using feedback from a CCD camera (visible at the upper left corner of the UNSW crest in Figure 1). All of this was fully-automated and controlled by a computer running the Linux operating system. For further information see Lawrence *et al.* 2004b.

4 Testing MASS before deployment

With a hard deadline of 1 Jan 2004 to ship the instrument to Antarctica, MASS was ready for commissioning with two weeks to spare. Testing on the sky was performed on the roof of our laboratory in Sydney during rare patches of clear weather. The alignment of the instrument, and the accuracy of the tracking software, was confirmed by tracking Venus during the day. Nighttime tests allowed us to confirm that MASS itself was working, and to commission the spiral-search and peak-up software. Precision dowels allowed us to disassemble the instrument for shipping in the knowledge that it would go back together with sufficient precision to need no adjustment.

5 Commissioning at Dome C

Commissioning the instrument at Dome C during summertime, when the sun was continuously above the horizon, was a challenge in itself. Fortunately, it was just possible to see stars during the day in the MASS eyepiece (similar in difficulty to seeing Venus during the day with the naked eye). By carefully aligning the gimbal, measuring the nine angles that determine the relationship of the MASS aperture to the sky, and setting the clock on the computer accurately, there was a star visible in the eyepiece on the first attempt (i.e., the blind pointing accuracy was 0.15°). We were able to observe several stars over a 24 hour period, and this enabled us to produce a computer pointing model which was accurate to within

Fig. 1. The MASS instrument, telescope and siderostat, as installed in the AASTINO, February 2004

0.03°. In early February 2004 the Concordia station closed for the winter, and our only contact with the experiment since has been through an Iridium phone.

6 Results

We observed bright, single, stars that were close to the zenith (so that they were visible through the window in the AASTINO). We choose Alpha Carina (Canopus), Beta Carina (Miaplacidus), Beta Crucis (Mimosa), and Alpha Triangulum Australae (Atria), and obtained six weeks of data from March to May 2004. The data we obtained show a mean seeing of 0.27 arcseconds, better than 0.15 arcseconds for 25% of the time, and with a lowest recorded seeing of 0.07 arcseconds (Lawrence *et al.* 2004c). The cumulative histogram of the seeing distribution shows a similar shape to that observed from Mauna Kea, but shifted to lower seeing values by a factor of about 2.5.

7 Future plans

We plan to obtain a longer time-series of data with the same instrument during 2005, and to measure the 0–30 m turbulence profile using a new instrument being built by Tony Travouillon. Concordia Station will likely be wintering, which will allow simultaneous measurements from both a DIMM and balloons.

It is also necessary to obtain a long times-series of data on the cloud cover at Dome C—preliminary indications (Ashley *et al.* 2003) have shown 74% clear weather, and are promising.

In the medium term we are pursuing an international collaboration to build a 2 m optical/IR telescope called PILOT (Pathfinder for an International Large Optical Telescope) at Dome C. This telescope will develop the technologies and techniques required to successfully exploit the potential of the site, and to allow the serious consideration of larger telescopes, 8 m and beyond.

8 Acknowledgements

We wish to thank A. Moore (Anglo-Australian Observatory), T. Travouillon (UNSW) and C. Bonner (UNSW) for contributions during the Dome C deployments; M. Swain (JPL), J. Lloyd (Caltech), and J. Everett (UNSW) for intellectual input into the Dome C MASS project; S. Kenyon (UNSW) for assistance with data analysis; V. Kornilov and N. Shatsky (Moscow University) for software support of MASS.

The AASTINO project is supported by the Australian Research Council, the Australian Antarctic Division, the French and Italian Antarctic research programs and the US National Science Foundation.

References

Aristidi, E. *et al.* 2004, A&A, in press

Ashley, M. C. B., Burton, M. G., Calisse, P. G., Phillips, A., and Storey, J. W. V. 2003, Highlights of Astronomy, ASP Conf. Series, volume 13, Eds. O. Engvold & M. Burton, in press

Ashley, M. C. B., Burton, M. G., Lawrence, J. S., and Storey, J. W. V. 2004, Astron. Nachr., No. 6–8, 619

Gillingham, P. R. 1991, Proc. Astron. Soc. Aust., 9, 55

Gillingham, P. R. 1993, ANARE research notes 88, 290

Indermuehle, B. T., Burton, M. G., and Maddison, S. T. 1994, Proc. Astron. Soc. Aust., in press

Kornilov, V. *et al.* 2003, Proc. SPIE 4839, 837

Lawrence, J. S., Ashley, M. C. B., Burton, M. G., Calisse, P. G., Dempsey, J. T., Everett, J. R., Maher, O., Storey, J. W. V., and Travouillon, T. 2003, Mem. S.A. It., 2, 217

Lawrence, J. S., Ashley, M. C. B. and Storey, J. W. V. 2004a, J. Electronic Electrical Eng. Aust., submitted

Lawrence, J. S., Ashley, M. C. B., Lloyd, J. P., Tokovinin, A., Swain, M., Kenyon, S., and Storey, J. W. V. 2004b, Proc. SPIE, 5490, in press

Lawrence, J., Ashley, M. C. B., Tokovinin, A., and Travouillon, T. 2004c, Nature, 431, 278

Marks, R. D. 2002, A&A, 385, 328

Tokovinin, A., Baumont, S. and Vasquez, J. 2003a, MNRAS, 340, 52

Tokovinin, A., Kornilov, V., Shatsky, N. and Voziakova, O. 2003b, MNRAS 343, 891

Tokovinin, A. 2002, Appl. Opt., 41, 957

Travouillon, T. *et al.* 2003, Astronomy and Astrophysics Research at the Concordia Station 2, 13