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Dome C: An exceptional site for solar observations

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Abstract. Dome C, on the Antarctica plateau, may be the best site on Earth for astronomy, thanks to outstanding image quality and very pure and cold atmosphere. This is of particular interest for solar physics, namely for very high-resolution studies of the solar surface and for magnetometry of the innermost solar corona. Here we review Dome C unique atmospheric properties and present two projects aimed at quantitatively qualify this site for solar observations.

Key words. Sun: site testing – Antarctica

1. Introduction

The Antarctica plateau is an extremely clean place: no animal or plant life, negligeable human activities. On this plateau, Dome C is the place of the french-italian Concordia permanent station. It is a high altitude (3220 m elevation), high latitude (75 S) and very cold (summer average of -35 C and winter average below -60 C) site and one of the quietest place on Earth regarding the mean wind speed. It could be the best site on Earth for ground based astronomical observations (Fossat, 2005). Its excellent summer seeing, very pure sky and the possibility of very long continuous observations, make Dome C extremely attractive for solar observations, namely very high resolution solar surface magnetometry and coronal magnetometry, the kind of observations required to improve our understanding on the solar activity and on its effects on the heliosphere. We will present results of daytime site testing at Dome C and discuss instruments aimed at quantitatively qualify this site for observations of the solar surface and corona.

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2. Daytime seeing at Dome C

The Antarctic plateau has unique atmospheric properties: most of the optical turbulence is located in the boundary layer, meaning that most of the seeing comes from this layer. At heights of 20 m to 200 m above ground, depending on plateau topography and wind speeds, the residual boundary layer seeing is below 0.1 arcsec 50% of the time (Swann and Gallée 2006).

High and flat locations, like Dome C have the thinnest boundary layer. Dome C summer site testing campaigns began in 2000-2001 and are performed every year for then resulting in a good determination of daytime turbulence (Aristidi et al. 2005a) while the first winterover started on February 2005. Seeing measurement performed at 8.5 meters above ground found, unexpectedly, better values during daytime than during nighttime (Agabi et al. 2006). Above the boundary level (typically 36 m thick at Dome C compared to 200 m thick at South pole) the free-atmosphere seeing is around 0.3 arcsec (Lawrence et al. 2004). The boundary level turns out to be more turbulent during wintertime than during summer time, due to a larger temperature gradient. During summertime, this gradient cancels several hours a day, free atmosphere seeing is then measured less than ten meters above ground. The 24 hours pattern in seeing variations, surprisingly similar from day to day all over the summer, is a consequence of the changes in the boundary layer temperature gradient over the same period of time (Fig. 1). This pattern demonstrates that about 5 hours of seeing of 0.5 arcsec (or r_0 large than 20 cm) or better are granted each day while r_0 is almost always larger than 10 cm. The parameter r_0 was introduced by Fried (1966), it is related to the seeing value, ε, by the relation:

$$\varepsilon = 0.98 \frac{\lambda}{r_0}$$

The best sites surveyed for the Advanced Technology Solar Telescope (ATST) (Keil et al. 2003) almost never provide, at 8 m above ground, r_0 larger than 20 cm, their average daytime r_0 being of the order of 5 cm (cf Fig. 4 and 5 of Socas-Navarro et al. 2005). For those classical sites, contrary to Dome C, daytime seeing is worse than nighttime seeing: the Sun warms up the ground, increasing turbulence above it.

3. Testing Dome C for solar astronomy

3.1. A 40 cm solar telescope for Dome C

G. Severino and his group plan to install a 40 cm aperture Ritchey-Chretien high optical quality telescope (diffraction limited at 400 nm) at Dome C to determine seeing values directly on solar images (Severino et al. 2002). This is the perfect way for Dome C characterisation from the point of vue of high spatial resolution solar observations. A 40 cm telescope is a lot too small to take full advantage of Dome C best seeing conditions. It will anyway allow to built histograms of solar images quality and determine the percentage of time this quality is limited by the telescope size.

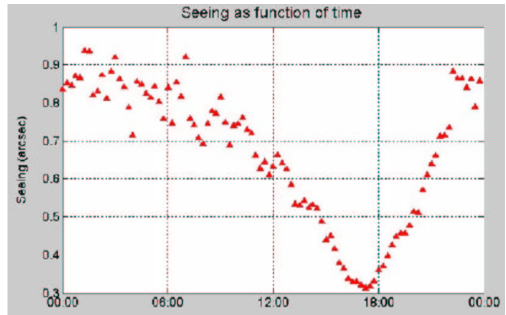

Fig. 1. Seeing *versus* local time, averaged over the 2.5 months summer 2003-2004 campaign, from Aristidi et al. 2005b.

Observations continuity allowed by this high latitude site will be exploited for helio-seimologic observations aimed at studying the physical connection between the small scale events and the global resonant oscillations of the Sun.

3.2. A Sky Brightness Monitor (SBM)

SBMs (Fig.2) were developed at the Institute for Astronomy of the University of Hawaii (Lin and Penn 2004) for the ATST site survey project. The ATST is a project of a 4 meter aperture telescope with low scattered light capabilities for the observations of the solar photosphere and corona. SBMs are compact and robust small externally occulted coronagraphs designed for sky brightness measurements at 4 to 8 solar radii distance and in four bandpasses centered at 450, 530, 890 and 940 nm. Six SBMs were built for the 6 surveyed sites. Halekala (Maui, Hawaii) was found to be the best site for coronal studies,

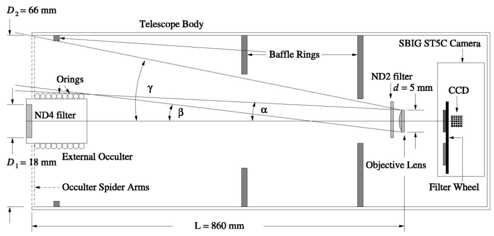

Fig. 2. Diagram of the SBM, from Lin and Penn 2004

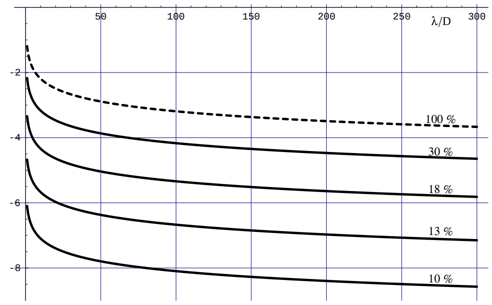

Fig. 3. Diffracted light level, in units of solar disc intensity, versus limb distance, in units of λ/D. The y-axis is in logarithmic scale. It is indicated on each curve the througput of the apodized aperture, in per cent of the clear aperture (curve in dashed line). For a 50 cm aperture telescope at λ = 0.5 μm, 300 λ/D = 60 arcsec. A Lyot type coronagraph limits the diffracted light level using a pupil diaphragm. its througput is about 50 %.

providing the darkest skies near to the Sun, (Penn et al. 2004). It was selected as the ATST site. National Solar Observatory (NSO) kindly lended to us, to test Dome C for coronagraphy, one of the SBMs made available by the end of the ATST site survey. We are in the process of preparing it for use at Dome C, during the 2007-2008 summer, in the conditions of a very cold (-20 to -50 C) and isolated site. This will allow direct comparisons of Dome C with Kaleakala. Thanks to its four spectral bandpasses, SMB will also provide quantitative informations on Dome C aerosols level, expected to be very low in this extremely clean place.

4. Conclusion

Solar observations are only possible at Dome C part of the year. However, our understanding of small scale solar structure mainly improves, as far as ground based telescopes are concerned, from use of the moments of best seeing. So, this limitation is not a problem as far as very high spatial resolution is concerned. To really take advantage of Dome C best seeing conditions, a two meters aperture telescope is at least required. Such a telescope could be designed for stellar studies during wintertime for a better efficiency of this investment. A 50 cm size coronagraph installed at Dome C would allow, thanks to superb seeing and sky purity conditions, to perform magnetometry in the innermost corona and to take the best advantage of apodization methods (Aime 2007) reducing by several orders of magnitude the light diffracted by the objective (Fig. 3) which otherwise overwhelms the faint chromosphere and the corona more than one arc minute above limb. An apodized coronagraph does not requires a Lyot stop, neither a Lyot diaphram. Magnetometry of the corona below 30 arcsec from the limb as well as magnetometry of the emission chromosphere off limb without the problem of a large amount of parasitic light, are likely possible only in Dome C conditions whatever groundbased or spacebased observations are considered.

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