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Special Session 7 Astronomy in Antartica

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Abstract. The high, dry and stable climatic conditions on top of the Antarctic plateau offer exceptional conditions for a wide range of observational astronomy, from optical to millimetre wavelengths. This is principally on account of the greatly reduced thermal backgrounds, the improved atmospheric transmission and the supurb seeing, in comparison with conditions at temperate latitude sites. The polar plateaus in the Arctic may also offer excellent conditions for astronomy, though these have yet to be quantified. We briefly review the history of astronomy in Antarctica and outline some of the activities now taking place on the polar plateaus, and plans for the future.

Keywords. Antarctica, site testing, infrared, optical, millimetre, neutrinos, meteorites

1. A brief history of antarctic astronomy

Antarctica is the highest, driest and coldest continent, facets which all offer gains for observational astronomy. The field goes back as far as 1912 with the discovery of the 'Adelie Land Meteorite' during Douglas Mawson's Australasian Antarctic Expedition (see Indermuehle, Burton & Maddison 2005). It was to be another 60 years, however, before this investigation advanced further, with the discovery in Antarctica, by Japanese scientists, of a number of different meteorites in close proximity – an event which could not have happenned by chance (Nagata 1975). More meteorites have since been discovered on the continent than the rest of the world put together, a result of the favourable conditions for their collection.

Cosmic ray detectors were installed in the Australian base of Mawson in 1955 and the US base of McMurdo during the International Geophysical Year of 1957, and are now widespread around the continent, taking advantage of the high geomagnetic latitude to detect lower energy particles than reach the ground at mid-latitudes.

The modern era in Antarctic astronomy began in 1979 with measurement of solar oscillations using an 8 cm optical telescope at the South Pole by a team led by Martin Pomerantz (see Grec *et al.* 1980). The field began in earnest with the establishment in 1991 of the Center for Astrophysical Research in Antarctica (CARA) at the South Pole, led by Al Harper. Experiments were begun in infrared, sub-millimetre and CMBR astronomy, together with an extensive site testing program to quantify the conditions for observation. Particularly successful were the sub-mm observations pursued with the 1.7 m AST/RO telescope (resulting in nearly 50 refereed publications; see Stark *et al.* 2001), and a series of increasingly precise measurements of fluctuations in the cosmic microwave background (e.g., the first measurement of its polarization – Kovac *et al.* 2002).

An extensive bibliography of publications relating to Astronomy in Antarctica can be found at the JACARA website `<www.phys.unsw.edu.au/jacara>`. Papers by Burton

(2004), Ashley *et al.* (2004), and Storey (2005) provide further background on conducting astronomy in Antarctica and some of the current activities taking place.

2. The South Pole

The South Pole suffers from a turbulent boundary layer, approximately 200 m thick, driven by the katabatic wind flowing off the summit of the Antarctic plateau (i.e., from Dome A). The seeing at ice level is thus modest, and so optical and infrared observations have not been pursued there beyond using modest-sized telescopes (e.g., the 60 cm SPIREX; see Rathborne & Burton 2005 for a review), where the diffraction limit is comparable to the seeing. Nevertheless, extremely deep thermal IR images have been obtained. For instance, it was only in 2004 that the 8 m VLT achieved deeper (ground-based) images at 3.5 μm than those obtained with SPIREX in 1998 of the 30 Doradus star forming complex in the LMC (see Maercker & Burton 2005).

Conditions for millimetre astronomy are, however, supurb, as they are for neutrino detection (making use of the vast quantities of pure ice to track the Cerenkov radiation following extremely rare interactions with nuclei). Astronomy at the South Pole is today dominated by two experiments being built to exploit these conditions. These are the 10 m South Pole Telescope (SPT, Ruhl *et al.* 2004), designed to measure the SZ-efect towards galaxy clusters in the sub-millimetre, and IceCube, a 1 km^3 neutrino *telescope*, designed to locate neutrino sources in the northern skies (Ahrens *et al.* 2004). A new station has been constructed at Pole by the US in order to meet the required infrastructure needs.

3. Dome C

Concordia Station, at the 3,200 m Dome C (one of the ‘summits’ along the ridge of the Antarctic plateau), is the newest scientific station on the continent. Run jointly by France and Italy, the Station’s first ‘winter’ occurred in 2005. Already the median visual seeing, above an $\sim$30 m thick boundary layer, has been shown to be $\sim 0.''25$, and to fall below $0''.1$ on occassion (Lawrence *et al.* 2004; Agabi *et al.* 2006). Amongst the gains that have been quantified for optical and infrared astronomy are an isoplanatic angle 2–3 times smaller than at good temperate sites, coherence times 2–3 times longer, IR sky backgrounds 20–100 times lower, image sizes 2–4 times smaller (when using the same size telescope), and scintillation noise 3–4 times smaller.

An 80 cm prototype mid-infrared telescope (IRAIT) is shortly to be commissioned at Dome C (Tosti *et al.* 2006), in order to provide a first demonstration of the science potential, as well as to conduct a range of science programs. This may be followed by the 2.4 m optical/IR PILOT (Storey 2006; Burton *et al.* 2005). PILOT would be large enough to have comparable IR sensitivities as temperate latitude 8 m-class telescopes (on account of the low background), but be able to obtain high angular resolution (on account of the supurb seeing) over wide fields of view.

Beyond this, there are several possible options for telescopes under active discussion. These include optical/IR interferometers (API, Swain *et al.* 2003; and KEOPS, Vakili *et al.* 2005), as well as large (8 m++) telescopes (e.g., LAPCAT, Storey *et al.* 2006; and GMTA, Angel *et al.* 2004). Whether these are built at Dome C, or eleswhere, will depend on when other high plateau sites are opened for astronomy.

4. Dome A and Dome F

There are other sites along the summit ridge of the Antarctic plateau that will provide comparable conditions to Dome C, and possibly be superior in some respects. These are the highest point, the 4,200 m Dome A, and the 'northern' end of the summit ridge, the 3,800 m Dome F. Dome F is already the site of a Japanese ice-core drilling station ('Fuji') and has wintered over, though no measurements have yet been made of the astronomical site conditions. Dome A ('Argus') was visited for the first time by humans in January 2005 on a Chinese traverse, and is the subject of expeditions for the International Polar Year of 2007–08. Compared to Dome C, the most significant gain may be the lower water vapour content of the atmosphere, opening up windows in the terahertz regime, and possibly a slightly lower IR background (colder) and thinner boundary layer (even lower katabatic winds).

5. The Arctic

The polar plateaus of the Arctic also offer some promise for observational astronomy, though no site testing has yet been carried out. In particular, the summit ridge of the Greenland icecap (including the 3,200 m Summit Station) and northern Ellesmere Island in the North-West territories of Canada (reaching 2,600 m) warrant investigation. While not as cold or as dry as the Antarctic plateau, conditions should still be favourable for infrared and sub-millimetre astronomy. However it is possible that higher winds (storms?) and greater cloud cover may limit their use for astronomy?

Acknowledgements

The Antarctic astronomy program at UNSW could not have been developed without the support of a great many colleagues from around the world. I particularly wish to thank John Storey, Michael Ashley & Jon Lawrence at UNSW, without whose trojan efforts over the past decade the program would be but a shadow of what is has now become.

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Ten years from the Antarctic Sub-millimeter Telescope and Remote Observatory

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1. The telescope

Beginning with the winter season of 1995 and for the next ten years, the Antarctic Sub-mm Telescope and Remote Observatory (AST/RO, Stark *et al.* 1997; Stark *et al.* 2001; `<http://www.cfa.harvard.edu/ASTRO/>`), a 1.7 m diameter, offset Gregorian telescope located at an altitude of 2847 m at the Amundsen-Scott South Pole Station collected sub-mm and Terahertz data in the 1.3 mm to 200 μm wavelength bands. From its location just a few hundred meters away from the geophysical South Pole, AST/RO was the first sub-mm telescope to over-winter on the polar plateau, a location uniquely suited to high quality sub-mm observations due its very low humidity, high atmospheric stability and thin troposphere (Chamberlin *et al.* 1997).

While there are a number of scientists around the world still making use of AST/RO data, the telescope itself was regrettably decommissioned in December 2005. This was due in part to the slow drifting of snow at the South Pole which caused the snow level surrounding the building to slowly rise over time. In Fig. 1, you can compare two photos of the telescope building taken a few years after construction and then again from a similar vantage point in late 2005. In the background can also be seen one of the other grand changes to the landscape during this ten year time-span, the construction of the new Amundsen-Scott South Pole Station to replace the iconic dome.

2. Observing highlights

Over the past ten years scientific results using AST/RO data have appeared in nearly fifty peer-reviewed articles, seven Ph.D. theses, and numerous conference proceedings. For the full list see the AST/RO web site. While the full details of all of AST/RO's results are far too numerous to list here, I would like to highlight just a few.

- First detection of C I emission in the Magellanic Clouds (Bolatto *et al.* 2000a)
- First detection of C I in absorption (Staguhn *et al.* 1997)
- Surveys of C I and CO $J = 7 \rightarrow 6$, CO $J = 4 \rightarrow 3$, and CO $J = 2 \rightarrow 1$ emission from
    - ○ The H II region/molecular cloud complex NGC 6334 (Kim & Narayanan 2006)
    - ○ The inner few degrees of the Milky Way (Martin *et al.* 2004)
    - ○ Nine strips across the Galactic plane (Lane, in prep.)
    - ○ The Carina spiral arm region around η Carinae (Zhang *et al.* 2001)
    - ○ N 159 / N 160 region in the LMC (Bolatto *et al.* 2000b)
    - ○ Lupus Clouds as part of the Spitzer Legacy Program 'Cores to Disks' (Tothill, in prep.)
- Maps in the [N II] 205 μm line of G287.57−0.59 using SPIFI
- Numerous PhD theses
    - ○ Staguhn (1996), U. Cologne – Galactic Center
    - ○ Ingalls (1999), Boston U. – High Latitude Clouds
    - ○ Bolatto (2001), Boston U. – Magellanic Clouds

Figure 1. On the left is a picture taken of AST/RO in the late 1990's, a few years after its construction. For contrast, another picture of AST/RO taken in late 2005 during decommissioning is shown on the right. You can clearly see how the snow level has risen around the building over the course of the decade due to drifting in the Dark Sector at the South Pole.

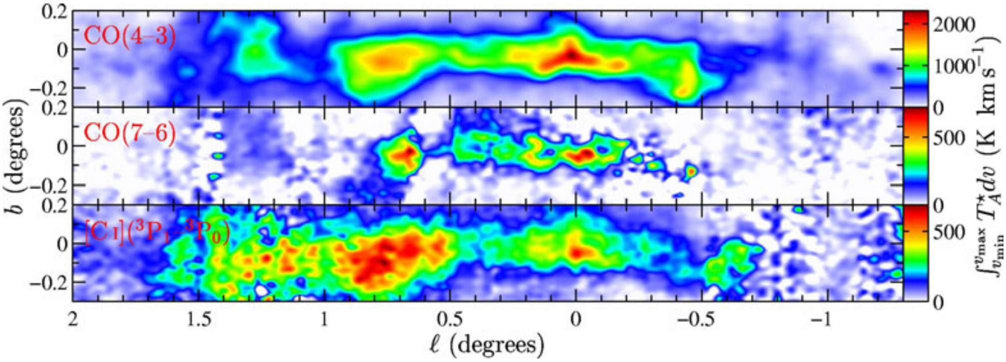

Figure 2. The three panels show spatial-spatial (ℓ, b) integrated intensity maps for the three transitions observed with AST/RO in the Galactic Center region. Transitions are identified at left on each panel. The emission is integrated over all velocities where data are available. All have been smoothed to the same $2'$ resolution.

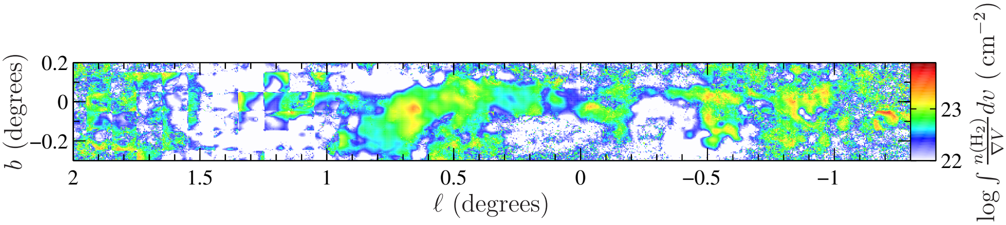

Figure 3. This figure shows one of the most exciting results of AST/RO's Galactic Center Survey. We used a Large Velocity Gradient (LVG) analysis to calculate quantities like the column density (shown here) for every point in our (ℓ, b) map. This independent estimate of column density is then available for a wide range of scientific studies. For electronic versions of results from this region as published in Martin *et al.* (2004), contact the author.

- Huang (2001), Boston U. – Southern H II Regions
- Kulesa (2002), U. Arizona – Dark Interstellar Clouds
- Groppi (2003), U. Arizona – Star Forming Regions

3. Galactic Center survey

While each of the highlights listed above is equally impressive, I would like to focus in on one to serve as an example for what AST/RO has been capable of.

To understand the strongly excited gas near the center of our own galaxy, detailed surveys in a variety of higher excitation states are required. To aid in this effort, AST/RO completed a fully sampled survey of CO(7-6), CO(4-3), [CI]($^3P_2$-$^3P_1$), and [CI]($^3P_1$-$^3P_0$) in a three square degree region around the Galactic Center (Martin *et al.* 2004) as shown in Fig. 2. In addition to this inner region, AST/RO has recently completed a survey area around Clump 1 and 2, thus covering the bulk of strongly excited gas near the center of the galaxy.

To collect this dataset required nearly a million distinct telescope pointings over many square degrees of the sky. To handle a sub-mm dataset of this size required the development of new automated observational methodologies, reduction techniques, and visualizations not to mention a substantial amount of observing time. Fortunately AST/RO was designed from the start as a survey instrument with a beam-size of 103–109″ at 461–92 GHz and 58″ at 807 GHz. So while covering a few square degrees was still a sizable proposition, we could reasonably contemplate making the multiple passes necessary to acquire data with the uniform signal-to-noise ratio required.

One of the interesting features of this data set is that by using the wide range of emission lines available to AST/RO, we can accurately estimate the kinetic temperature and density over a wide region of the survey using a Large Velocity Gradient (LVG) technique as shown in Fig. 3.

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While there are many people to whom thanks is due (see the AST/RO website for the full list), none of the work described here would have been possible without the tireless efforts of the winter-over scientists who spent a full year stationed at the South Pole with the telescope taking the data and maintaining the instrument. AST/RO is supported by NSF grant number ANT-0126090

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The IceCube neutrino observatory: latest results on the search for point sources and status of IceCube construction

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Abstract. The AMANDA neutrino telescope, prototype instrument of the IceCube neutrino observatory at South Pole, has collected data since 2000 in its final configuration. A period of 1001 days of livetime between 2000 and 2004 has been analysed in order to find evidence of a neutrino signal coming from point-like sources such as *microquasars*, *active galactic nuclei*, *supernovae remnants* or *gamma ray bursts*. A sensitivity to fluxes of $\nu_\mu + \bar{\nu}_\mu + \nu_\tau + \bar{\nu}_\tau$ of $d\Phi/dE = 1.0 \cdot 10^{-10} (E/\mathrm{TeV})^{-2} \cdot \mathrm{TeV}^{-1} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ was reached in the energy range between 1.6 TeV and 1.6 PeV. No significant excess over the background has been found so far. Flux upper limits infered from this study can constrain certain neutrino emission models of X-ray binaries. IceCube will have a substantially higher sensitivity. Currently at 10 % of its final extension, it will comprise 4800 optical sensors deployed along 80 strings by early 2011, instrumenting one cubic kilometre volume of ice and $1\,\mathrm{km}^2$ at the surface.

Keywords. Neutrinos, cosmic rays, point sources, gamma rays

1. Introduction

High energy neutrinos constitute highly valuable astronomical messengers. Unlike photons or protons, they can travel cosmic distances without being absorbed or deflected from their initial direction of propagation and deliver unaltered information related to the site of their emission. The Universe being transparent to photons only up to modest energies of order 1 TeV, neutrinos thus can be the indispensable partners of "conventional" astronomy to probe the most violent astrophysical objects.

Another major potential of neutrino astronomy resides in the fact that neutrinos could help us to understand the origin of cosmic rays. Indeed, these are thought to be accelerated in the expanding shocks of supernovae remnants, active galactic nuclei, gamma ray bursts or microquasars. In the vicinity of these extremely energetic sources, cosmic rays have the opportunity to interact with local hadronic matter or radiation fields giving rise to a flux of neutrinos and gamma rays (respectively by decay of charged or uncharged pions):

$$\begin{aligned} p + (p \; or \; \gamma) \rightarrow \pi^0 \; &\rightarrow \gamma\gamma \\ \rightarrow \pi^\pm &\rightarrow \nu_e \, \nu_\mu \rightarrow \nu_e \, \nu_\mu \, \nu_\tau \text{ (after oscillations)} \end{aligned}$$

The discovery of neutrino point sources would thus unambiguously reveal the sites of cosmic ray acceleration in the Universe.

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† `<http://icecube.wisc.edu/science/publications/vulcano2006.html>`

Table 1. Flux upper limits for the sources in the catalog of potential neutrino emitters. From left to right are given the source name, its sky position, the number of observed and expected events, the upper limit on the contribution from signal events at 90 % confidence level μ_{90} and the expected number of events from muon neutrino s_{ν_μ} and tau neutrino interaction s_{ν_τ} for a differential flux of $d\Phi/dE = 10^{-11}$ TeV^{-1}cm^{-2}s$^{-1}(E/\mathrm{TeV})^{-2}$. In the last three columns, upper limits are presented on the differential flux $d\Phi/dE = \Phi_0^{\nu}(E/\mathrm{TeV})^{-2}$ of muon neutrinos, tau neutrinos and both channels combined in units of 10^{-11} TeV^{-1}cm^{-2}s^{-1}.

Source name	RA[h]	Dec[°]	$\mathrm{N_{obs}/N_{bg}}$	μ_{90}	s_{ν_μ} / s_{ν_τ}	$\boldsymbol{\Phi_0^{\nu_\mu}}$	$\Phi_0^{\nu_\tau}$	$\boldsymbol{\Phi_0^{\nu_\mu+\nu_\tau}}$
TeV Blazars								
Markarian 421	11.1	38.2	6 / 7.37	4.1	0.97 / 0.15	**4.2**	27.8	**7.4**
1ES 1426+428	14.5	42.7	5 / 5.52	4.8	0.90 / 0.13	**5.4**	36.6	**9.4**
Markarian 501	16.9	39.8	8 / 6.39	7.9	0.93 / 0.14	**8.5**	57.2	**14.7**
1ES 1959+650	20.0	65.1	5 / 4.77	5.6	0.71 / 0.11	**7.8**	52.2	**13.5**
1ES 2344+514	23.8	51.7	4 / 6.18	3.1	0.89 / 0.15	**3.5**	20.9	**5.9**
GeV Blazars								
QSO 0219+428	2.4	42.9	5 / 5.52	4.9	0.89 / 0.13	**5.5**	37.6	**9.6**
QSO 0528+134	5.5	13.4	4 / 6.08	3.2	1.06 / 0.14	**3.0**	22.8	**5.3**
QSO 0954+556	9.9	55.0	2 / 6.26	1.4	0.91 / 0.15	**1.6**	9.2	**2.7**
3C273	12.5	2.1	8 / 4.72	9.6	0.96 / 0.10	**10.0**	94.3	**18.0**
other AGN								
NGC 1275	3.3	41.5	4 / 6.75	2.7	0.95 / 0.14	**2.9**	19.7	**5.0**
M87	12.5	12.4	6 / 6.08	5.3	1.07 / 0.14	**4.9**	38.6	**8.7**
Microquasars & Neutron star binaries								
LSI +61 303	2.7	61.2	5 / 4.81	5.6	0.75 / 0.13	**7.4**	44.0	**12.6**
SS433	19.2	5.0	4 / 6.14	3.1	1.16 / 0.13	**2.7**	23.6	**4.8**
Cygnus X-1	20.0	35.2	8 / 7.01	7.3	0.95 / 0.15	**7.7**	48.4	**13.2**
Cygnus X-3	20.5	41.0	7 / 6.48	6.4	0.95 / 0.14	**6.8**	46.7	**11.8**
Supernova Remnants & Pulsars								
Crab Nebula	5.6	22.0	10 / 6.74	10.1	0.98 / 0.15	**10.2**	68.9	**17.8**
Geminga	6.6	17.9	3 / 6.23	2.0	1.01 / 0.14	**2.0**	14.0	**3.5**
PSR 1951+32	19.9	3.3	4 / 6.72	2.7	0.94 / 0.14	**2.9**	19.0	**5.0**
Cassiopeia A	23.4	58.8	5 / 6.00	4.4	0.86 / 0.13	**5.1**	33.2	**8.9**
Unidentified high energy gamma-ray sources								
3EG J0450+1105	4.8	11.4	8 / 5.94	8.4	1.08 / 0.14	**7.8**	61.6	**13.8**
TeV J2032+4131	20.5	41.5	7 / 6.75	6.1	0.95 / 0.14	**6.4**	43.8	**11.2**

2. Different strategies to search for extraterrestrial neutrinos

Completed in 2000, AMANDA has demonstrated the capability to detect neutrinos and determine their direction of origin (Andres *et al.* 2000). Five years of data have been accumulated between 2000 and 2004, corresponding to a livetime of 1001 days. After applying the reduction procedure aimed to reject the atmospheric muon background (Ahrens *et al.* 2004a), a sample of 4282 candidate neutrinos was selected in the northern hemisphere.

In a first step, a search for neutrinos was done by looking for excesses of events with respect to background coming from selected potential sources. Table 1 shows the different candidate sources reviewed as well as the number of observed and expected events. All the observations are compatible with the atmospheric neutrino background hypothesis. The highest excess found corresponds to the direction of 3C 273 with eight observed events compared to an average of 4.72 expected background (1.2 σ).

A complete survey of the northern hemisphere neutrino sky was then achieved by means of a grid search (Ackermann 2006). The highest significance (3.74 σ) obtained is located at $\alpha = 12.6$ h and $\delta = 4°$. However, the probability to observe this or a higher

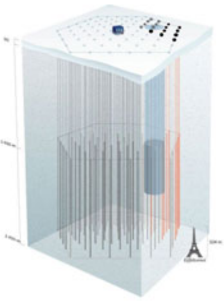

Figure 1. Representation of the IceCube neutrino observatory in its final extension. AMANDA is shown as a darker cylinder.

excess from a random fluctuation of the background, taking into account the trial factor, is 69 %. There is thus no claim of discovery.

As no evidence of a neutrino signal was found in the previous analyses, upper limits on the neutrino flux were determined (cf. Table 1) and compared to specific theoretical predictions. In the case of SS 433, the limit infered in this analysis excludes 0.4 times the corresponding flux predicted in Distefano *et al.* (2002). The upper limit for Cygnus X-3 and the predicted flux in Bednarek (2005) are of the same order of magnitude. However, the upper limits obtained for pulsar wind nebulae and AGN's are at least one order of magnitude above predictions, except for the most optimistic case of neutrino production in the jets of *EGRET* blazars predicted by Neronov & Semikoz (2002) and Neronov *et al.* (2002).

Finally, in order to further increase the sensitivity to particular AGN classes, a stacking analysis was developed: the cumulative signal coming from several AGN's of the same class was evaluated and compared to the corresponding background level (Achterberg *et al.* 2006a). No particular excess was found but the limits could be significantly improved.

3. IceCube status and prospects

The deployment of the IceCube neutrino observatory has started at South Pole during the austral summer 2004–05 (Achterberg *et al.* 2006b). IceCube is currently composed of 9 strings deployed in the ice and 16 IceTop surface cosmic ray air shower detector units (cf. Fig. 1). The strings consist of 60 optical sensors each deployed at a depth between 1450 m and 2450 m. Once completed in early 2011, one cubic kilometre volume of ice will be instrumented with 80 strings (4800 optical modules) and an array of one square kilometre will be covered by IceTop stations at the surface (320 optical modules). The 604 deployed sensors consist of 25 cm diameter photomultipliers and associated electronics, housed in a transparent pressure vessel. The first data taken with the 9 string array (about 140 events/second) are consistent with expectations based on detailed computer simulations.

According to initial potential performance studies (Ahrens *et al.* 2004b), the angular resolution of IceCube will be better than 1° for muon energies above 1 TeV and the effective area for muon detection will exceed 1 km^2 above 10 TeV. It is expected that the limit on an E^{-2} flux of diffuse neutrinos will be about thirty times smaller than the limit reached during a similar period of observation with AMANDA.

First tests show that the deployed hardware meets its performance goals (Achterberg *et al.* 2006b). IceCube is already producing physics data and will rapidly reach an unprecedented sensitivity to sources of extra-terrestrial neutrinos in the next few years.

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Site testing at Dome C: history and present status

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1. Introduction

The idea of starting an astronomical site testing in Antarctica began during a congress organized by French Académie des Sciences, in 1992, and entitled 'Recherches polaires-Une Stratégie pour l'an 2000'. At this time, one of us (Vernin 1994) gave a proposal for an astronomical site testing in Antarctica. This proposal was rapidly followed by a meeting between Al Harper (from 'Center for Astrophysical Research in Antarctica', Chicago), Peter Gillingham (from the Anglo Australian Observatory, Australia) and Jean Vernin (from Nice University) at Lake Geneva, Wisconsin, in 1993. It was decided to investigate what was the astronomical quality of South Pole station, each institute bringing its own participation: CARA, the South Pole infrastructure, University of New South Wales, a PhD student and Nice University its expertise and instruments.

On September 7th, Mike Dopita and John Storey presented a proposal to Roger Gendrin (former head of Institut Polaire, Michel Glass (former IFRTP head) and Jean Vernin. Later, following the project of a French-Italian base to be setup at Dôme C, we presented the first France-Italian-Australian proposal for Astrophysics at Dôme C, Paris, November 11th 1994.

2. South Pole site testing 1994–1995

The first astronomical site testing at South Pole took place from April to August 1994. We investigated the surface layer, attaching many sets of microthermal probes at various altitude on a mast (Marks *et al.* 1996) and next year we launched 15 balloons instrumented with microthermal probes to assess the optical turbulence vertical profile (Marks *et al.* 1999). From this two year campaign, it appeared clearly that almost all the optical turbulence was concentrated within the first 200 m of the surface layer. The overall seeing was $1''.86$, but only $0''.37$ when excluding those first 200 m.

From Fig. 1 (*middle*) one can see the huge injection of kinetic energy in the surface layer. This kinetic energy is mixing parcels of air with very large variation in potential temperature (refractive index) giving rise to huge optical turbulence (*bottom*).

It was thus clear that katabatic winds were inducing this important wind shear and that one had better to investigate antarctic sites where no katabatic winds were expected. Indeed, at South Pole, even if the terrain seems quite flat, there remains still some slope from Dôme A and Dôme C, which triggers such a flow.

3. Summer-winter Dôme C site testing

Site testing operations began at Dôme C in 1995 during the stay of one of us (JV). Operations started again during summers 2000 to 2004 during which many DIMM measurements were performed (Aristidi *et al.* 2003, 2005). One of the main conclusion is that

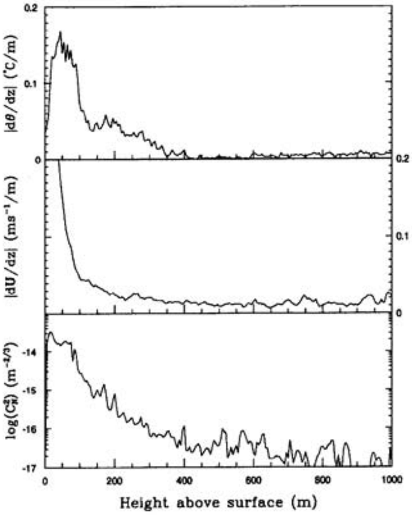

Figure 1. From *top* to *bottom*: vertical profile of the vertical gradient of the potential tempearature, the gradient of the wind velocity and the $C_N^2(h)$ within the first km above ice, as observed at South Pole. The same behavior is observed at Dôme C with less intensity and over a 30 m thick surface layer.

the median seeing is $0''.54$ and that every day during a 4 hr period the seeing is better that $0''.5$ arcsec. For solar as well as IR astronomy (in bands were sky background from the sun is not annoying) Dôme C seems one of the best place in the world.

In 2005, AstroConcordia station was first open for winterover. One of us (AA), setup two DIMMs and launched successfully about 40 balloons (Azouit & Vernin 2005) instrumented for $C_N^2(h)$ and $\mathbf{V}$(h) profiles. Again, it became obvious that most of the turbulence was generated within the surface layer (Agabi *et al.* 2006), as it was found at South Pole, but, the depth of the SL is 30 m instead of 200 m and the optical turbulence is much less. This site is much better since almost all the large telescope have their mirror at such an altitude. For smaller telescopes, stiff platform might be envisaged in order to operate above the SL.

In 2006, a second winterover took place with the installation of two new instruments: the Generalized Seeing Monitor (GSM) and the Single Star Scidar (SSS). From the first instrument the outer scale of the wavefront of the light seems to be smaller than everywhere in the world, i.e., 10 m. The SSS worked all along the whole polar night during about 400 hours, giving thousands of $C_N^2(h)$ and $\mathbf{V}$(h) profiles.

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Single Star Scidar first light from Dôme C

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1. Introduction

In the recent years, a lot of instruments have been put into operation during the polar summer at Dôme C., Then, during the first polar night when the Astro-Concordia sation was open for the first time during winter, about 40 balloons (Azouit & Vernin (2005)) instrumented to measure optical turbulence profiles and 2 Differencial Image Motion Monitors (DIMM) were setup. The main results from this first important campaign are found in Agabi *et al.* (2006). It appears from this first night time observations that almost all the optical turbulence was concentrated in the first 30 m above the ice. At an elevation of 8.5 m above the ice the seeing is about $1''.4$, while above an elevation of 30 m the seeing drops down to $0''.36$. This last figure is coherent with the estimation from Lawrence *et al.* (2004) if one takes into account that they were not sensitive to the first 30 m., which corresponds to the turbulent surface layer.

For the second winter, we decided to implement the so-called Single Star Scidar (for SSS see Habib *et al.* 2005, 2006) in order to assess continuously the vertical profiles of both the optical turbulence and the wind speed. Indeed, a balloon gives a cut of the atmosphere with a very good vertical resolution but it traverses optical turbulent layers in few seconds. The SSS technique is able to retreive both $C_N^2(h)$ and $\mathbf{V}$(h) vertical profiles from the groud up to 25–30 km each 15 s, during hours. At Dôme C, and tracking Canopus bright star, it becomes possible to monitor $C_N^2(h)$ and $\mathbf{V}$(h) during days almost continuously.

2. First light

During spring 2005 began the construction of the Antarctic SSS which was sent to Dôme C during the fall of the same year. Then the instrument was setup on top of a 8.5 m high plateform (see Fig. 1) by one of the authors (MC) with the precious help of E. Aristidi, and, on February 4th, we got the first light from this 40 cm telescope (see `<http://www-luan.unice.fr/CHADID/chadid-aristidi.htm>`).

Then, night time measurements where performed by E. Aristidi during the whole winter, from March to August. Thousands of profiles were obtained during almost 400 hr of observations. From this huge set of measurements, only a small part have been processed yet in our laboratory, since only few minutes of observations can be sent by e-mail per day.

3. First profiles

To imagine what will be the installation of a large telescope at Dôme C, and what will be the consequences of an interaction between such a building and the optical turbulence concentrated in the surface layer, it was of major importance to have the detailed structure of both $C_N^2(h)$ and $\mathbf{V}$(h) profiles. But the vertical resolution of the SSS is around one km. Thus we decided to leave the Simulated Annealing method to reconstruct four

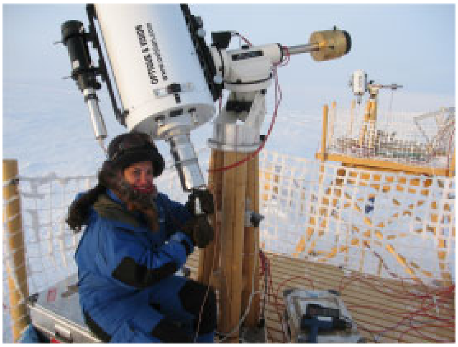

Figure 1. Installation of the Single Star Scidar on a 8.5 m high plateform at Dôme C during summer 2005.

arbitrary layers at ice level, and the other layers distributed every 1 km. Of course, SSS is not able to distinguish between the altitude of the first four layers, but we assumed that the wind speed is increasing from the bottom to the top of the surface layer, and thus it became possible to sort the four first layers with increasing speed.

As we already know that most of the optical turbulence is concentrated within the first 30 m, and that we are very interested in the $C_N^2(h)$ and $\mathbf{V}$(h) profiles within those 30 m, we left the SA algorithm to reconstruct four layers within the SL. In Fig. 2 one can see the rapid decrease of the optical turbulence intensity and the rapid increase of the wind speed. The seeing deduced from the optical turbulence profile is $0''.56$, very close to the $0''.6$-$0''.7$ measured by the DIMM at the same time.

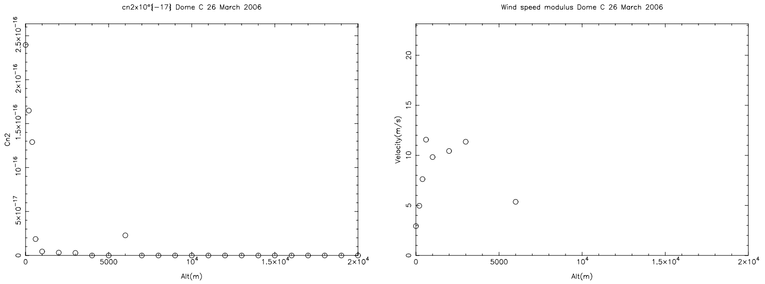

Figure 2. *Left*: Optical turbulence profile. Rapid decrease of the C_N^2 in the surface layer and a layer at 6 km. *Right*: Wind speed rapidly increases from 3 to 13 ms^{-1} in the SL.

4. Conclusion

The Antarctica Single Star Scidar was installed at Dôme C during January–February 2006 and ran almost continuously from March to August giving thousands $C_N^2(h)$ and $\mathbf{V}$(h) profiles. This will help to have a better knowldge of the optical turbulence within the surface layer as well as the free atmosphere.

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Optical sky brightness at Dome C, Antarctica

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1. Introduction

Dome C, Antarctica is a prime site for astronomical observations in terms of climate, wind speeds, turbulence, and infrared and terahertz sky backgrounds (for example, see Aristidi *et al.* 2005; Storey *et al.* 2005). However, at present little is known about the optical sky brightness and atmospheric extinction. Using a variety of modelling techniques, together with data from the South Pole, the brightness of the night sky at Dome C is estimated in Kenyon & Storey (2006) including the contributions from scattered sunlight, moonlight, aurorae, airglow, zodiacal light, integrated starlight, diffuse Galactic light and artificial sources. The results are compared to Mauna Kea, Hawaii. We summarise the main conclusions.

2. Discussion

The high latitude of Dome C has an impact on the number of formal astronomical dark hours that the site experiences. Although Dome C has less total dark time than sites closer to the equator, when cloud-cover is taken into account Dome C may have a comparable number of cloud-free dark hours to Mauna Kea. The atmosphere at Dome C is very clear and this should lead to reduced sky brightness contributions from scattered sunlight and moonlight, and should reduce the atmospheric extinction in the optical. At Dome C the Moon never rises higher than between about 33° and 43°, depending on the 18 yr lunar nodal cycle. Modelling shows that moonlight is expected to contribute less at Dome C than at Mauna Kea because of the lower elevation angles. Dome C is close to the centre of the annular auroral region in the southern hemisphere. Aurora will generally be no higher than 7° above the horizon and further than about 1,200 km away. Aurorae are expected to have a minor impact in the optical. Zodiacal light is expected to be less at Dome C than at Mauna Kea because the ecliptic plane is always close to the horizon. Airglow emissions at Dome C are thought to be about the same brightness as those at temperate sites. Integrated starlight is anticipated to be negligible because of the excellent seeing and low atmospheric extinction at Dome C. Diffuse Galactic light may be brighter at Dome C than Mauna Kea because the Galactic plane is always close to the zenith, however this contribution is not large when compared to other sources of sky brightness. Sky brightening by artificial light sources should be non-existent at Dome C, if proper planning is put into place.

We conclude that Dome C is a very promising site not only for infrared and terahertz astronomy, but for optical astronomy as well.

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Atmospheric scintillation at Dome C, Antarctica

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1. Introduction

Dome C, Antarctica is one of the most promising astronomical sites in the world (Fossat & Candidi 2003, and references therein). Dome C boasts low wind speeds, very cold temperatures and little precipitation. The atmospheric turbulence is very weak compared to temperate sites, leading to sub-arcsecond seeing conditions (Lawrence *et al.* 2004; Agabi *et al.* 2006).

A Multi-Aperture Scintillation Sensor (MASS) was operated at Dome C (123°21″ E, 75°06″ S, 3260 m) during the first two months of the 2004 Antarctic winter season. The MASS instrument measures the scintillation of a single star; from this information the vertical distribution of atmospheric turbulence is derived. These data have been analysed in terms of seeing (Lawrence *et al.* 2004) and scintillation (Kenyon *et al.* 2006), here we summarise the main conclusions of the second paper and look at the implications for photometry and astrometry. The results are compared to similar data from Cerro Tololo (70°48″ W, 30°09″ S, 2215 m) and Cerro Pachon (70°44″ W, 30°14″ S, 2738 m) in Chile.

2. Results

A comparison of the turbulence profiles measured above Dome C with those of the two Chilean sites shows that Dome C has significantly less turbulence in all layers except the lowest layer. The most striking result is that the turbulence measured in the highest layer above Dome C is negligible compared to the Chilean sites. It is this high-altitude turbulence that has the largest influence on the astrometric and photometric precision achievable at a particular site. Using average wind speed profiles, we assess the photometric noise produced by scintillation, and the atmospheric contribution to the error budget in narrow angle differential astrometry.

2.1. *Photometry*

High-precision photometry is important, for example, for the detection of extra-solar planets and for observations of objects with very fast intensity changes (e.g., asteroseismology). The calculation of the photometric precision from atmospheric turbulence profiles depends on the length of the integration time and the size of the telescope. For the case of a long integration time on a large diameter telescope the photometric precision is expressed as

$$\sigma_I = \left[10.7 \int h^2 C_n^2(h) V^{-1}(h) \mathrm{d}h\right]^{1/2} D^{-2/3} t^{-1/2}, \tag{2.1}$$

where h is the height above the site, C_n^2 is the refractive index structure constant, V is the wind speed, D is the telescope diameter and t is the integration time. Fig. 1 (*left*) shows the median photometric precision at each site as a function of telescope diameter

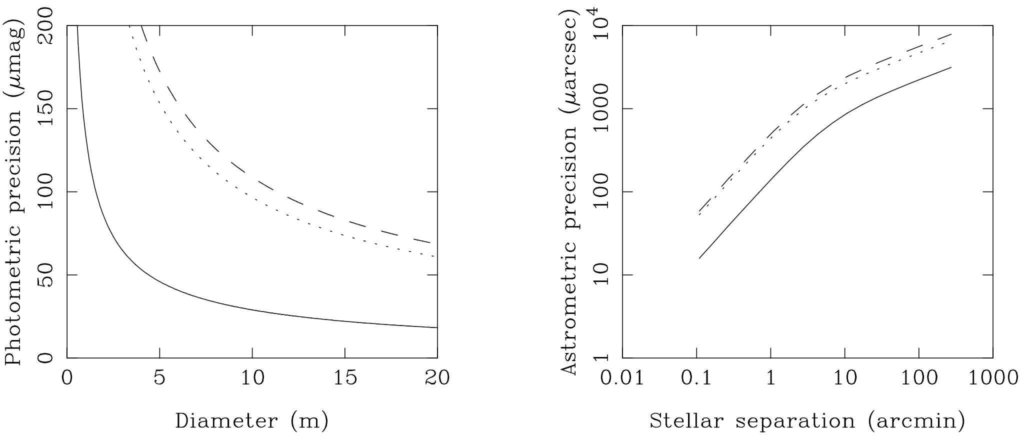

Figure 1. *Left*: the median photometric precision at Dome C (*solid line*), Cerro Tololo (*dashed line*) and Cerro Pachon (*dotted line*) as a function of telescope diameter, for a 60 s integration time. *Right*: the median astrometric precision at each site as a function of angular stellar separation, for a 1 hr integration time and 10 m baseline.

for a 60 s integration. Dome C offers a gain of about 3.6 in photometric precision over the two Chilean sites.

2.2. *Astrometry*

Long baseline interferometry can be used to achieve high precision very narrow angle differential astrometry, benefiting science programs such as extrasolar planet searches and the study of close multiple star systems. Uncertainties in astrometric precision arise from instrumental effects and atmospheric effects. The astrometric uncertainty caused by the atmosphere can be calculated for two regimes, narrow-angle and very narrow angle, using the equations from Shao & Colavita (1992).

$$\sigma_{atm} = \begin{cases} \theta^{1/3} t^{-1/2} \left[5.25 \int h^{2/3} C_n^2(h) V^{-1}(h) \mathrm{d}h\right]^{1/2} & \text{narrow angle, } \theta\overline{h} \gg B \\ \theta B^{-2/3} t^{-1/2} \left[5.25 \int h^{2} C_n^2(h) V^{-1}(h) \mathrm{d}h\right]^{1/2} & \text{very narrow angle, } \theta\overline{h} \ll B \end{cases} \tag{2.2}$$

where, B is the baseline length, θ is the angular separation between the two celestial objects and $\overline{h}$ is the turbulence weighted atmospheric height. Figure 1 (*right*) shows the median astrometric precision at each site as a function of angular separation for a 1 hr integration and a 10 m baseline. Dome C offers a significant advantage in achievable astrometric precision.

3. Conclusions

Although the data from Dome C cover a fairly limited time frame, they lend strong support to expectations that Dome C will offer significant advantages for photometric and astrometric studies. Dome C offers a potential gain of about 3.6 in both long integration photometric precision and narrow-angle astrometry precision when compared to two mid-latitude sites in Chile.

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AMICA – the infrared eye at Dome C

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1. Introduction

Amica (Antarctic Multiband Infrared Camera) is a dual-channel Infrared Imager (2-28 μm), that will be located at the Nasmyth focus of the IRAIT telescope at Dome C. Dome C base, on Antarctic plateau offers an unique chance for infrared astronomy. It has several advantages like temperature, pressure and site environment. Temperature, around −60°C (mean) allows a good atmospheric stability (good seeing and good windows transparency) a low atmospheric background and the reduction of instrumental background. Pressure (equivalent of 4000 m a.s.l.), implies low content of water vapors; this means higher transmission, broader and new astronomical windows. The site offers the possibility of very long observations (about 6 months winter night).

2. Science

Most of the scientific targets of the IRAIT-amica project have been selected to take profit of the environmental conditions described above. Indeed the first goal is the site testing and characterization of the Dome C sky, in the bands between 2 to 28 μm, followed by a survey in these bands. Once the above general goals will be achieved a variety of cool IR targest could be observed with IRAIT-amica. Among these: AGB stars in the Milky Way, star formation regions in our and nearby galaxies, Solar System bodies, supernova remnants, extragalactic point-like sources, etc. Last, but not least, the IRAIT-amica collaboration will allow the development of the first permanent astronomical observatory in the Dome C base, with the possibility of find and solve a lot of environmental problems of a quasi-space situation.

3. The instrument

Amica is a near-mid infrared camera, with a wavelength coverage between 2–28 μm. The camera has an all-reflective design (in order to reduce aberrations) and is composed by two off axis parabolas and two gold-coated plain mirrors. The wavelength coverage is done with two detectors: the SWA (Short Wavelength Array) that covers from 1 to 5.5 μm (InSb, 258×258 pixels, Raytheon), and the LWA (Long Wavelength Array) that covers from 7 to 28 μm (SiAs, 128×128 pixels, DRS Technologies). The instrument toggles between the LWA and the SWA by means of a folding mirror, before the detectors. The focal reduction of AMICA is 1:1.47 and the best sampling is at 3.42 μm for SWA and 8.54 μm for LWA. Plate scales are $0''.538$/pixel (SWA) and $1''.345$/pixel (LWA). The field of view is $2'.29 \times 2'.29$ for SWA and $2'.87 \times 2'.87$ for LWA. The entrance window is made of CdTe that guarantees and high transmission for all the 1–25 μm microns band. The first-light set of filters will be a standard set in order to calibrate the camera with existing standards (K, L, M, N_1, N_2, Q_1, and Q_2).

4. The cryostat

The internal temperature of the cryostat will be around 35 K except for the LWA detector that will be at 7 K. All internal components (mirrors, optical bench, mountings, filterwheel, etc.) will be in aluminum, in order to have an homotetic contraction during the cooling-down process. This allows to align the optical components at room temperature and maintain the alignment at any temperature, drastically reducing the number of regulations and the necessity of human operations during the functioning time. The cryocooler will be an ARS 2-stage with a power consumption of 3.5 kW. The choice of this element was a critical point: the power supply from the base is limited, and the low density of the atmosphere, causing limited convection, requires an increased capability of heat removal.

5. Electronic and housekeeping

Due to atmospheric conditions (temperature, pressure, etc.) we decided to keep only few elements at external temperature: the cryocooler head and the ‘remote’ unit. All the other subsystems will be placed in a temperature-controlled rack. Also for the electronic system we decided to divide the readout and control electronic in two subsections: the first is a ‘remote unit’ next to the telescope, with essential controls, the second is a ‘local unit’, inside the base. The software development has been designed as a modular structure, in order to drive both the telescope and the camera.

6. Testing subsystems

The AMICA team has designed and built ANTARES (ANTARctic Environment Simulator), a climatic chamber specifically designed to test each component before the delivery at Dome C of AMICA. ANTARES allows the test of small and medium size components with a pressure of 410 mbar, a temperature of −60°C and relative humidity of 6 %.

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Design and construction of the moving optical systems of IRAIT

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1. Introduction

The IRAIT (International Robotic Antarctic Infrared Telescope) project (Tosti *et al.* 2006) is based on a 80 cm aperture telescope to observe in the infrared range. It is due to start operations in spring 2008, several months after installation in Dome C (Antarctica). We describe the contributions made to such project by the Institute for Space Studies of Catalonia (IEEC) and the University of Granada, whose participation has been mainly focused in developing the moving optical system for the secondary (M2) and tertiary (M3) mirrors of the telescope. Moving parts of the optical system provide focusing and chopping capabilities, implemented in M2, and a rotation mechanism, implemented in M3, allow observation in either Nasmyth foci. The work package includes the design and construction of both mirrors, the mechanical supports, the electronics and the control software, all prepared to work at the low temperatures at Antarctica. A Spanish company, NTE, was contracted to carry out the design and manufacture. Tests at low temperature and integration in the telescope were finished during summer 2006, before sending the telescope to Antarctica, scheduled by the end of the same year.

2. Secondary mirror driver subsystem

The M2 Drive Subsystem is the system in charge of providing the following movements to the mirror: (1) Focus: movement of the mirror in Uz axis, (2) Chopping: tip-tilt mirror movement. Three main parts compose the assembly: (*a*) fixed subassembly; (*b*) mobile subassembly or focuser; and (*c*) chopper and M2 mirror subassembly. A number of parts are made of stainless steel in order to prevent corrosion or important dimensional variations caused by the coefficient of thermal expansion that could block the system, leaving it unusable at certain temperatures. Other materials are used: anodized aluminium, carbon fiber composite and Teflon.

(*a*) Fixed subassembly: holds the cryogenic motors and also contains the guiding system, the safety switches and the backward and forward actuator.

(*b*) Focuser: the focusing mechanism is realized by means of a linear actuator, manufactured by INA, which include a motor and a reduction stage (Pythron VSS32.200.1.2.UHVC and VPGL 32 i-50 UHVC units). The stroke of the actuator is 100 mm, and the screw pitch is 2 mm per revolution. Two limit switches prevent the actuator from getting over the limits. These guiding systems have been considered as the most appropriate due to its compactness, high load capacity and accuracy on corrosion resistance. The cryogenic motor supplies the mechanical power to move this assembly over a temperature range that goes from −270°C up to 30°C. The rotational movement of the motor is converted into a lineal movement through a roller screw. The roller screw is manufactured on a G1 ISO quality corrosion proof that assures the accuracy, repeatability and steadiness of the advancing movement. The kinematics mechanism has been dimensioned for not being back drivable. All mobile parts are lubricated with cryogenic grease with melting point of −90°C in order to avoid crystallization that would lead to a halt of the system.

(*c*) Chopper and mirror assembly: the chopper assembly is the mechanism that provides the tilting movement on the XY plane to the M2 mirror. The mechanism is designed to provide an angular oscillation from 0 to ± 4.6 mrad (equivalent to $5' \times 5'$ in the sky) over the specified temperature range. This device allows us to obtain a maximum chopping frequency of 25 Hz, compatible with the lower resonance frequency of the telescope top ring which was estimated to be about 80 Hz. Within the mobile parts there are the piezoactuators, manufactured by PiezoMechanik technology, that provide the displacement to activate the chopping movement. They have cryogenic capabilities and are close loop servo actuated. The sensors that supply the feedback are Eddy current. The reason of this choice instead of a capacitance sensor is that they are more suitable for adverse environment conditions, such as moisture presence or possible ice deposition on the sensor surface. The chopper subassembly is composed for the following parts: radial spring, piezo stacks, mirror support, M2 mirror, sensor position, tilting adjusting system.

3. Tertiary mirror driver subsystem

The M3 Drive Subsystem disposes of the following performances: (*i*) Locates the mirror in proper place to receive the light from M2 and send it to the cameras located at the Nasmyth focus. To obtain a correct position, two adjusting mechanisms have been implemented: Tilt Correction Mechanism, in base, and Mirror Position Mechanism, in mirror base; (*ii*) Allows mirror rotation in *z*-*z* axis from 0 to 180° with high accuracy; (*iii*) Allows fixation of the whole subsystem in the M3 Interface Area.

This subassembly can be divided in the next main parts and mechanisms:

(*a*) M3 Mirror: main element of the subsystem. It has an oval shape with a rear square interface to place and fix the element.

(*b*) Mirror position mechanism: mechanism in charge of adjusting the mirror orientation once the M3 Drive subsystem is assembled. It consists on a rear flexure, used to join the mirror and the tube, and one adjustment screw, used to modify the angle orientation.

(*c*) Tube: element in charge of providing stiffness to the subsystem. It is made of stainless steel and disposes of a lower flange to fix it to the rotating actuator and an upper flange to accommodate the mirror position mechanism. This upper flange is 45° inclined to direct the M2 light to the Nasmyth focus.

(*d*) Rotating actuator: it is used to allow z-z rotation and *z*-*z* adjustment of the subsystem is based on a Micos PRS-110 precision rotation stage modified for operation in a low-temperature environment (down to −80°C) The unit incorporates two electrical limit switches that will be set at the 0° and 180° positions. The repeatability of these switches (5 μm) provides an angular repeatability of $0^\circ.008$.

(e) Axial alignment mechanism: mechanism located below the rotating actuator and it is able to rectify misalignment in the mirror due to mechanical tolerances. This mechanism can tilt the tube in two axis thanks to a platform driven by three screws.

(f) Base: element in charge of the following issues: support all the subsystem with enough stiffness, fix all the assembly in the interface area, allow to plug and unplug the Rotating Actuator wires and connectors, allow to actuate the tilt correction mechanism, allow inner access for cleaning purposes. An Hex tool accommodation is placed in the base centre. It permits to drive the adjustment screw of the Mirror Position Mechanism in order to tilt the mirror.

Acknowledgements

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Multi-aperture interferometry at Concordia

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1. Introduction

The next generation (post-VLTI) of multi-telescope interferometric arrays operated in optical/infrared wavelengths should be kilometric, from 1 to 10 km. The Concordia station offers a unique opportunity to set such an interferometer in the best atmospheric conditions presently known on Earth.

2. KEOPS – the concept

The Dome C site astronomical qualities begin to be well bracketed. After several summers and now almost two winter-over site testing campaigns, it is clear that it is, for many astronomical parameters, the best, or one of the very best sites on Earth. Some of these parameters still demand additional investigation or more statistics. But the global quality has been proved to be enough out of range for attracting an ever increasing scientific community. French and Italian funding has started to be raised, so that beyond the site testing, real astronomical programmes are expected to be operated in 2008 (IRAIT from Italy and A-STEP from France).

On the longer term range, medium and far infrared imaging on one hand, and on the other hand Extremely High Resolution Imaging even in visible light are among the favorite targets in the prospect studies. Some are thinking of an Antarctic ELT, to be set above the 30-m turbulent surface boundary layer, others would prefer an multi mirror interferometer. Such an interferometer, that could be called an optical equivalent to the VLA in radio waves or ALMA in millimetric, can possibly be regarded as the next generation, post-VLTI, of large size optical interferometry.

Of course, optical long baseline imaging interferometry is extremely difficult, as the technical challenges go more or less as the inverse of the wavelength, and that means a factor 100 to 1000 for optical or near-IR as compared to the millimetric case of ALMA. However and to some extent, it can now be regarded as a mature observing technique. Several optical arrays are able to provide 2-D maps: NPOI in Arizona, COAST at Cambridge, UK, CHARA at Mount Wilson, California and of course the VLTI at Paranal, Chile. At the 2004 Liège International Astrophysical Colloquium devoted to the Science case for next generation optical/infrared interferometric facilities (the post-VLTI era), it was recognised by Pierre Lena that on one hand *"the next interferometer generation should operate at least from 1 to 12 μm and have kilometric baselines (1 to 10 km at most)"*, and on the other hand *"the Dome C site characteristics, as far as they are known today, appear to be of an entirely different class than any other ground-based site: in fact, this site classifies as an intermediate one between space and conventional ground.*

They appear especially favorable for interferometry (transparency, isoplanetism, stability of the atmosphere, area)".

The concept of KEOPS results from these statements. It emerges as an imaging array of optical diffraction limited telescopes of 1.5 to 2-m diameter in Dome C conditions. These telescopes are spread over three concentric rings of 200, 348 and 676 meter radii. Six or seven telescopes on the first ring, 12 or 13 on the second, 18 or 19 on the outer one. These numbers offer optimized u-v coverage to achieve a 1 mas resolution at 10 μm in order to resolve the angular distance between a star and its exo-Earth at a one kpc distance. KEOPS is an implicitly co-phased array operated in the so-called hypertelescope mode (Labeyrie *et al.* 2003), but using a more efficient nulling design named IRAN (Vakili *et al.* 2004). KEOPS has an equivalent collecting surface comparable to the Keck interferometer, but located in extreme cold, dry and excellent seeing conditions of the Antarctica plateau. It will challenge a 30 m-class ELT, and the number of available square kilometers on the polar plateau is essentially unlimited!

3. KEOPS – the science rationale

The bottom line of an interferometric instantaneous field of view is the Airy disc of individual telescopes. Considering the 1.5 to 2-m diameter proposed for KEOPS, one may expect a sub-mas resolution across a 1 arcsec field of view. Thus, unlike classical wide field telescopes, KEOPS offers Ultra High Spatial Resolution imaging with a reasonable wide field of 2000×2000 resolution elements (resels). The inefficient filling factor (less than 10^{-3}) could be compensated by Earth rotation synthesis for imaging compact objects which benefit from the long polar night of Antarctica. Beyond the search for exo-Earths, it could bring significant breakthroughs in the study of galactic and extra-galactic objects from the visible to the thermal infrared wavelenths inaccessible from any other ground based site. That could be stellar surface imaging, the central engines of YSO's, the cores of AGN, or even the ballet of stars rotating around the central black hole of galaxies as far as a few millions light-years. In fact the number of possible scientific scoops with such an instrument is nearly infinite.

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Antarctica – a case for 3D-spectroscopy

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1. Advantages of 3D-spectroscopy

DS or Integral-Field Spectroscopy (IFS) provides multiple spectra for each point of a 2-D field, rather than along a narrow, 1-D spectrograph slit only. Therefore, IFS does not require very accurate telescope pointing, nor do pre-assumptions about slit or aperture sizes have to be made. It avoids any 'slit-losses' due to seeing or atmospheric dispersion, which eliminates the need for any parallactic alignment or a dispersion compensator (see Fig. 1).

Integral-field units (IFUs) with 100 % fill factor (e.g., PMAS, Roth *et al.* 2005) can be used for accurate spectrophotometry (Kelz & Roth 2006). As all the information is gathered at the same time, 3D-spectroscopy is more efficient than any scanning technique and insensitive to variable instrumental and atmospheric conditions. The resulting data-cube (with coordinates in RA, Dec, and lambda) allows both a PSF-optimized extraction of single and combined spectra, as well as the re-construction of narrow- and broad-band images, without the need for filters. As the sky background around the target is recorded with better coverage than with slits, an improved background subtraction, in particular in crowded fields, is possible (Becker *et al.* 2004). Additional results from post-processing, such as differential images, abundance ratio maps, or velocity fields can be extracted with little effort from the data cube. Obviously, spectroscopy of any complex structures such as galaxies, mergers, nebulae, winds, or jets benefits from the 2-dimensional field-of-view. The various advantages of 3DS are discussed in Roth *et al.* (2004).

Certain IFUs, such as the PPak fiber bundle (Kelz *et al.* 2006), provide very high instrumental grasp, i.e., light collecting power. The availability of 2-D information allows spatial binning of spectra to improve the signal-to-noise, in particular for low surface brightness objects, even further. For projects where flux collection, rather than spatial resolution is an issue, binning the IFU spaxels has the same effect as increasing the aperture size of a telescope. In case the spatial position of the target is not known well enough (e.g., optical counterparts of X-ray sources, γ-ray bursts, or because the target is too faint to be visible at the acquisition system), the integral-field provides an increased error circle to ensure that the target is not missed altogether. If the location of spectral features is uncertain (e.g., because the redshift is unknown a priori), 3DS is the only technique that can reliable detect these. For extra-galactic or cosmological applications, the 3D-data cube corresponds to a volume in space, which otherwise can only be recorded with time-consuming scanning techniques using tunable filters (Bland-Hawthorn 2006).

2. Relevance for Antarctica

While the above advantages of 3DS are of general nature, some of them are particularly important at a remote location such as in Antarctica, where highly autonomous or robotic telescopes are required (Ashley *et al.* 2004). The case stated here is applicable to the optical/near-IR domain, i.e. to future spectroscopic instrumentation and related science cases as proposed for a PILOT-like telescope (Burton *et al.* 2005).

Given the environmental conditions in Antarctica (Storey *et al.* 2005), it is desirable to reduce the amount of movable components as a potential source of failure. 3DS completely

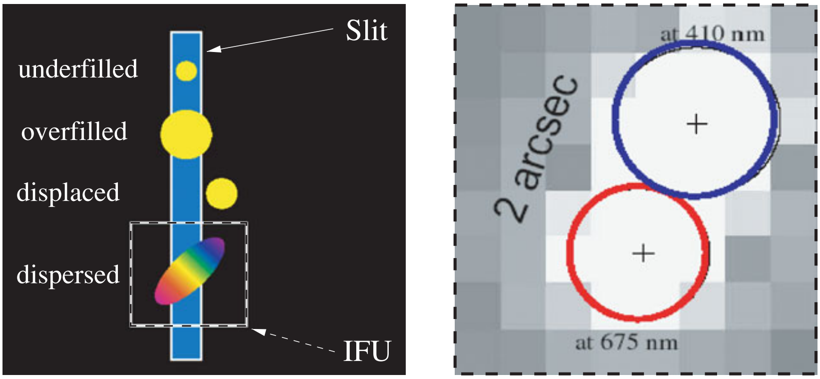

Figure 1. *Left*: Sketch of the common problems present in classical slit-spectroscopy. From top to bottom: under-filling and over-filling of the slit, mispointing, atmospheric dispersion and parallactic misalignment. *Right*: A re-constructed image of a star, observed with an integral–field-unit (IFU) at an air mass of 1.7. Despite a dispersion of $2''$ between 410 nm and 675 nm, the IFU records the entire flux, avoiding any slit-losses or chromatic errors.

avoids the need for a (rotatable) filter wheel, any slit width or angle adjustments or an ADC. If the IFU is fiber-coupled, the subsequent instrumentation can be mounted remotely from the telescope in a stable and climatized environment. This would imply that the telescope and fiber-link needs to be adapted to the Antarctic conditions, but not the spectrograph as such. The background subtraction, in particular for the OH-bands in the NIR, is improved by IFS. Furthermore, IFS may be operated with a nod-&-shuffle mode (Roth *et al.* 2002) or fiber Bragg gratings (Bland-Hawthorn 2006) may be used for future fiber-coupled instruments. The precision requirements for telescope pointing, target acquisition, guiding and tracking are less stringent for IFUs, which greatly relaxes the demands on the accuracy of drives, gears and motors for the telescope and reduces frequent re-calibrations due to any ice-drift.

In summary, the use of innovative IFUs eliminates much of the complexity, present in classical spectroscopy (Kelz 2004). It relaxes acquisition requirements and removes critical, movable parts from the system. This simplifies the instrumental design and minimizes potential sources of failure. 3DS allows a fast and reliable ‘point-and-expose’ observational approach, which is ideally suited for remote or robotic observations. At the same time, it offers multiplex and time-saving advantages for a broad range of scientific projects, ranging from stellar population studies to cosmology, that are proposed for a large telescope at Antarctica.

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CAMISTIC: THz/submm astronomy at Dome C in Antarctica

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1. Project context

Submillimetre (submm) astronomy is the prime technique to unveil the birth and early evolution of a broad range of astrophysical objects. It is a relatively new branch of observational astrophysics which focuses on studies of the cold Universe, i.e., objects radiating a significant – if not dominant – fraction of their energy at wavelengths ranging from $\sim 100\,\mu$m to ~ 1 mm. Submm continuum observations are particularly powerful to measure the luminosities, temperatures and masses of cold dust emitting objects. Examples of such objects include star-forming clouds in our Galaxy, prestellar cores and deeply embedded protostars, protoplanetary disks around young stars, as well as nearby starburst galaxies and dust-enshrouded high-redshift galaxies in the early Universe.

A major obstacle to carry out submm observations from ground is the atmosphere. Astronomical observations in the submm spectral bands can only be achieved from extremely cold, dry and stable sites (e.g., high altitude plateau, Antarctica) or from space (e.g., the *Herschel Space Observatory*) to overcome the atmosphere opacity and instability that are mainly due to water vapour absorption and fluctuation in the low atmosphere. Chile currently offers the best accessible (all-year long) sites on Earth, where the precipitable water vapour (PWV) content is often less than 1 mm. Chile hosts the best astronomical facilities such as ESO VLT, APEX and Chajnantor plateau will be the ALMA site.

At longer term, and particularly if global warming severely restricts the $200-350-450\,\mu$m windows on ESO sites, Antarctica conditions with less than 0.2 mm PWV, could offer an exciting alternative for THz/submm astronomy (Fig. 1). This is an attractive opportunity for the $200\,\mu$m windows, especially, which are normally explored with space telescopes (e.g., *Herschel*).

Observations of submm continuum emission are usually carried out with bolometer detectors. Recently, two Research Departments at CEA (DSM/DAPNIA/SAp and DRT/LETI/LIR) developped filled bolometer arrays for the PACS submm/far-infrared imager on the *Herschel Space Observatory*, to be launched by ESA in 2007. The R&D was based on a unique and innovating technology that combines all silicon technology (resistive thermometers, absorbing grids, multiplexing) and monolithic fabrication. The bolometers are assembled on a mosaic 'CCD-like' array that provides full sampling of the focal plane with $\sim 2{,}000$ pixels that are arranged in units of 256 pixels. They are cooled down to 300 mK to optimise the sensitivity down to the physical limit imposed by the photon background noise. The PACS bolometer arrays have passed all the qualification tests (Billot *et al.* 2006). The newly started ArTéMiS project at CEA Saclay capitalises on this achievement by developing submm $(200-450\,\mu$m) bolometer arrays with $\sim 4{,}000$ pixels for ground-based telescopes. A prototype camera operating in the $450\,\mu$m

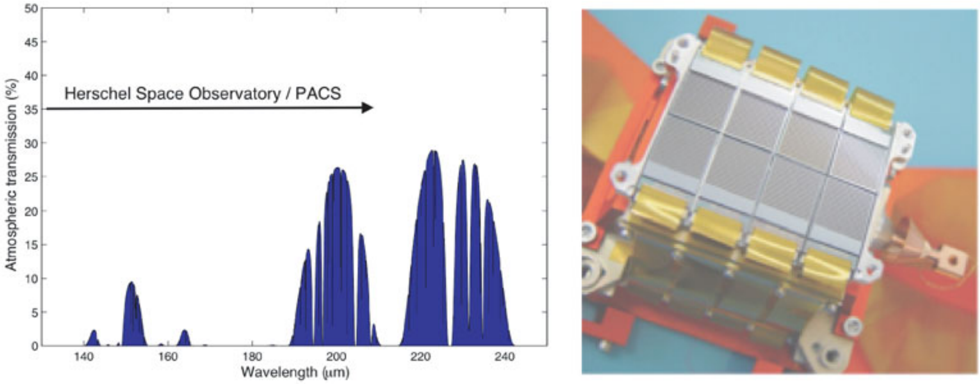

Figure 1. *Left*: Atmospheric transmission between 130 and 250 μm assuming a $\mathrm{PWV} = 0.2$ mm. *Right*: CEA bolometer array for *Herschel Space Observatory*-PACS.

atmospheric window has successfully been tested in March 2006 on the KOSMA telescope (Talvard *et al.* 2006).

In the future, placed on a 12-m single-dish telescope at Dome C, a bolometer camera with $\sim$10,000 pixels at $200-450\,\mu$m will be particularly powerful to undertake wide field surveys of star-forming complexes in our Galaxy as well as deep field surveys of dust-enshrouded high-redshift galaxies in the early Universe.

2. CAMISTIC objective

The CAMISTIC project aims to install a filled bolometer-array camera with 16×16 pixels on a small telescope (e.g., IRAIT) at Dom C and explore the 200 μm (i.e., THz) windows for ground-based observations. Many windows between 150 and 250 μm are reachable if PWV is below 0.2 mm (Fig. 1), which is an expected value at Dome C (cf. Vernin, this SpS 7). Opening these windows would be an important achievement as this part of the electromagnetic spectrum is usually observed by the mean of space telescopes. Ground-based submm telescopes will have the advantages to be potentially larger than space telescope and, therefore, allow observations with higher angular resolution.

CAMISTIC will be located at about 500 m from the base, with very reduced access. Autonomous and automated cryogenic devices specifically designed for the harsh conditions in Antarctica will therefore be needed. We plan to demonstrate the reliability of a novel cryogenic system with all static parts placed next to cryostat at outer temperature conditions and a warmed cabinet for compressors, motors and valves. Extensive tests in wintering condition will be performed before expedition.

CAMISTIC will be equipped with novel bolometer technology. The filled bolometer array with a monolithic grid of 256 pixels was designed by CEA for the far-IR/submm imager *Herschel Space Observatory*-PACS. It can operate in the $150-250\,\mu$m range with an adequate filter for each specific window.

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A test for the detection of vegetation on extrasolar planets: detection of vegetation in Earthshine spectrum and its diurnal variation

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Abstract. The search for life in extraterrestrial planets is to be tested first with the only planet known to shelter life. If the planet Earth is used as an example to search for a signature of life, the vegetation is one of its possible detectable signature, using the Vegetation Red Edge due to chlorophyll in the near infrared (0.725 μm). We focus on the test of the detectability of vegetation in the spectrum of Earth seen as a simple dot, using the reflection of the global Earth on the lunar surface, i.e., Earthshine. On the Antartic, the Earthshine can be seen during several hours in a day (not possible at our latitudes) and so variations due to different parts of Earth, that is to say oceans and continents facing the Moon could be detected.

Keywords. Earth, Moon, astrobiology, techniques : spectroscopy, vegetation red edge, biomarker, Earthshine, exolife

1. Introduction

It could be hoped that in few years (e.g., beyond 2015) we will search for detection of life in terrestrial extrasolar planets. Life on extrasolar planets will probably present unusual and unknown forms. However, as we know nothing about these forms of life, we look for indices of presence of life similar to the one we know on Earth. Firstly, we explore classical biosignatures like H_2O, CO_2, O_3 and O_2, but it is also interesting in visible wavelengths to search how vegetation can be distinguished on a planet seen from space.

2. Detection of vegetation

Vegetation spectrum presents an increase at 0.5 μm in the green range, which implies that plants are seen as green, but mostly a very sharp rise at 0.725 μm, known as the Vegetation Red Edge (VRE, Arnold *et al.* 2002), the signature of photosynthetic plants. The Vegetation Red Edge can be much more easily detected than the bump at 0.5 μm, and this signature corresponds hardly to other elements than chlorophyll. The search for vegetation on exoplanets should be tested with the only planet known to shelter life. Vegetation can be detected on the planet Earth from a spacecraft as done by Sagan *et al.* (1993) using the *Galileo* spacecraft but in that case, vegetation has been detected vertically, and obliquity, limb effects, nor cloud cover have been considered. Earth has to be observed as a whole like we see a extrasolar planet, i.e., as a point source. Presently, no distant spacecraft has the cability to take a spectrum of the whole Earth.

3. Earthshine

Another possibility is to use the Moon as a giant reflector and to observe ashen light or Earthshine. Earthshine can be seen on the dark part of the Moon during the first or the last days of the lunar cycle. This corresponds to a Earth light on the Moon. The light of the Sun arrives on Earth, is reflected by Earth, arrives on the Moon, is reflected by the Moon and comes back on Earth. The light coming from the different parts on Earth is blended and thus, as in the case of an exoplanet, seen integrated. Then: $[Earthshine\,Spectrum] = [Solar\,Spectrum] \times [Earth\,Albedo] \times [Moon\,Albedo]$ and transmitted three times through Earth atmosphere; and: $[Moonligh\,spectrum] = [Solar\,Spectrum] \times [Moon\,Albedo]$ and transmitted once through Earth atmosphere.

Arcichovsky V.M. (1912) suggested to look for chlorophyll absorption in the Earthshine spectrum, with the aim to calibrate chlorophyll in the spectrum of other planets, but at these times, Earthshine observations did not have sufficient spectral resolution (Tikhoff 1914; Danjon 1928). Earthshine shows Rayleigh scattering in the Earth atmosphere and allowes to predict that from space Earth is seen as blue. The red side of the Earth reflectance spectrum shows the presence of O_2 and H_2O absorption bands, while the blue side clearly shows the Huggins and Chappuis ozone (O_3) absorption bands.

4. Results obtained

The first detections of vegetation from the Earthshine spectrum were obtained by Arnold *et al.* (2002) at Haute-Provence, and by Woolf *et al.* (2002) at the Tucson. Observations made at ESO NTT (Hamdani *et al.* 2006) obtain a VRE lower than previous studies, which were near $8-10\%$ when Africa and Europe light the Moon (Arnold *et al.* 2002). The present results are from 3 to 4 % when Africa faces the Moon and 1.3% when the Pacific faces the Moon. Even with these lower values, VRE differs over Pacific Ocean *vs.* Africa, thus allowing detection of vegetation on Earth. These observations also show significant variations in Rayleigh scattering depending on cloud cover, implying that Earth as ‘pale blue dot’ can be almost white.

5. Importance of observations from Dome C, Antarctica

Observations of Earthshine can be done during the first and last days of the lunar cycle. From intermediate Earth’s latitudes, observations of the waxing Moon are possible in the evening, and of the waning Moon in the morning, in both cases twilight observations. Only at high latitudes it is possible to observe the Moon in the first or the last days of the cycle during several hours, sometimes even all the day long. This happens at Dome C (75°06′S, 123°21′E), about six times per year. During one observing run, continents and oceans successively face the Moon and the variations of the VRE corresponding to successive ‘landscapes’ of the planet Earth can be detected. A small telescope and low resolution spectrograph can be used to detect VRE in Earthshine spectra. Observations are carried out by one of us (E.A.) since March 2006.

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