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COCHISE

Cosmological Observations at Concordia with High-sensitivity Instrument for Source Extraction

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Abstract. The Antarctic Plateau is considered the best site for astronomical observations in the submillimetric and millimetric wavelength range. Our team already performed three observing campaigns at Dome C, using telescopes up to 1.5 meters, thus confirming this result. The Antarctic Plateau, with the combination of low water vapor content, stable atmosphere, low temperature and low wind speed, offers the best conditions for ground-based observations in the most unexplored wavelength range. In the following we describe an experiment performed at Dome Concordia with the aim of measuring the atmospheric stability. The main results, the frequency and the angular scale dependence of the atmospheric noise show that Dome C has excellent conditions for millimetric observations. We also present a project which is aimed to build a 3 m class, multipurpose telescope for astronomical observations in the millimetric and submillimetric range. This facility will use state-of-the-art detector technology and eventually will be remotely controlled for unattended operations.

Key words. atmospheric effects – site testing

1. Introduction

Ground-based astrophysical observations at millimetric wavelengths can be severely constrained by atmospheric noise. Experiments at these wavelengths are affected by fluctuations in atmospheric emission and absorption, mainly due to the water vapor content. These problems occur at ground-based sites and, to a lesser extent, from balloon-borne platforms. Because satellite missions are very expensive, it is important to select the best sites for ground-based observations, for planned and future projects of large telescopes and long integration observations. Antarctica appears to have the best observing conditions in the world at

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millimeter wavelengths, due to its dryness and atmospheric stability.

A candidate site is the Dome Concordia Italian-French base, located on the high Antarctic Plateau at Latitude 75^o 06' 25" S and Longitude 123^o 20' 44" E. We performed atmospheric measurements at this site in 1995, with a 37 cm telescope, in 1996 (APACHE96, see Dall'Oglio et al. 1996, Valenziano et al. 1997, 1998) and in 1999. Here we present a description of the last experiment, performed in January 1999 in collaboration with P. Timbie and L. Piccirillo, and the analysis of the data. The main results, the frequency and the angular scale dependence of the atmospheric noise show that Dome C has good conditions for millimetric observations.

Recent balloon experiments (BOOMERanG, MAXIMA) and near-future space missions (ESA/Planck) will open new windows in our understanding of the origin of the Universe. High sensitivity and high resolution maps in the submillimetric require careful consideration of the contamination from the foreground emission of local sources (Solar system, Milky Way) and extragalactic objects (radio sources, AGNs, etc) and from cold dust emission.

The main goal of the project we propose is to map the anisotropies and the polarization of the cosmic background radiation at small angular scales in a significative portion of the southern sky with observations from the high Antarctic plateau (Dome C) and from O.A.S.I. Observatory at Terra Nova Bay (Dall'Oglio et al. 1992). Important topics are:

Cosmology: cosmological research includes dust emission, point source contamination and Sunyaev-Zeld'ovich effect;

Extragalactic Astrophysics: FIR-luminous galaxies, Extreme Gigahertz Peaked Spectrum sources (GPS), quasars and BL LAC objects, variable sources, burst and flaring sources;

Galactic Astrophysics: dust properties in the galactic plane and galactic objects.

2. Our previous observations

The Antarctic Plateau provides unique opportunities for science because it is the coldest, driest, highest, and most isolated region on Earth. The average elevation is more than 2000 m with an equivalent pressure of a higher site because of the reduced thickness of the atmosphere at the Poles.

In this area the average Precipitable Water Vapor (PWV) content is less than 0.5 mm during summertime and the median wind speed is reported to be 2.1 m/s (Valenziano & Dall'Oglio 1999). These conditions produce an average atmospheric transmission at millimetric wavelengths greater than 90% (Hidas 2000). Moreover, the geographical position of Dome C, in the highest part of the Antarctic Plateau, is at the border of the Antarctic wind circulation pattern. Therefore, a laminar flow is present due to settling of the cold air and exceptionally stable atmospheric conditions are expected, especially during the Antarctic winter.

Fig. 1. Telescope at Dome C. The Cassegrain telescope points toward the large flat mirror, which il tilted at 45° to steer the beam toward the Zenith.

The main goal of the experiment was to monitor the atmospheric noise from the sky around the Zenith, close to the South Celestial Pole. The experiment was based on a 146.6 cm diameter on-axis Cassegrain telescope, with a 32.5 cm diameter fixed secondary mirror (see figure 1).

The telescope pointed horizontally at a large flat chopping mirror which steered the beam in the sky. The mirror was pointed with two electrical actuators that allowed the beam to execute arbitrarily complex scan patterns on the sky. The detector system defines the throughput $A\Omega = 0.24$ $cm^2 sr$, constant at all wavelengths, resulting in a frequency-independent FWHM beamwidth of $\sim$10 arcmin. A cylindrical aluminum shield surrounded the telescope itself to shield the secondary and primary mirrors from thermal radiation from the ground. Since the sun is always above the horizon at Dome C in January, the experiment was surrounded by a solar shield (Valenziano et al. 1997).

The detectors used for this experiment were monolithic silicon bolometers (see Downey et al. 1984), cooled to a temperature $T \sim$330 mK with a miniature ^{3}He sorption cooler (described in Dall'Oglio et al. 1997). The bolometers operated at wavelengths of 3.1, 2.2, 1.3 and 1.1 mm.

From Dome C all the common calibration sources (mainly planets) transit at very low elevation. While we did observe the Moon and Venus, atmospheric absorption (and emission) make the calibration of our experiment very difficult. For this reason we decided to rely on laboratory calibrations, which can be determined very accurately. We perfomed these calibrations in two different ways. First, a variable temperature blackbody source was installed inside the cryostat in front of the 4.2 K input horn. The temperature of the blackbody was changed from 8 K to about 30 K. At each temperature, a set of load curves of the bolometers were recorded and the corresponding calibration factors in Volt/K have been determined. Second, we used blackbody targets external to the cryostat and cooled to by either liquid oxygen or liquid nitrogen to calibrate under higher loading conditions. The two methods are consistent to within a few percent. Note, however, that these calibrations do not include the optical efficiency of the full telescope. We have assumed an optical efficiency of 0.9 for the telescope and degraded the sensitivity of the photometer by 10% in each of the channels. Their intrinsic noise, under sky loading, ranges from 0.8 to 6 $mK/\sqrt{Hz}$ at 20 Hz.

Using the versatility of the steerable mirror, we decided to sweep the beam through elliptical paths on the sky to probe the sky noise over a wide range of angular scales. The angular dimensions of the two axes of the observed ellipse are $\sim 3.8^o$ and $\sim 1.8^o$. The flat mirror is rotated around the Zenith position at 0.3 Hz.

The detector signals were amplified by 4 separate low-noise AC-coupled amplifiers, with a bandpass of about 30 Hz. The data acquisition system sampled the actuator reference signals and the 4 channels of the photometer at a frequency of 100 Hz, allowing a reliable synchronization.

3. Results

The analysis was divided in two steps: first we studied the frequency dependence of the noise by computing the power spectrum of the data and then we estimated the dependence on angular scale. In both steps we found the typical noise of a cloudy day and of a good observing day. We found that in the good observing day atmospheric noise is less than or comparable to the intrinsic noise of our detectors at all wavelengths.

3.1. Frequency Dependence of Noise

In figure 2 we show the power spectrum of our data from a typical cloudy day and a clear day. In all cases the effect of a high pass filter at $\sim$0.1 Hz is visible. Data from the clear day show 1/f noise, which we believe arises mainly from our detector system. The atmospheric noise in the cloudy data appears to have a roughly flat power spectrum in all frequency channels, with little channel-to-channel correlation. This is an interesting indication of the good observing conditions at Dome C.

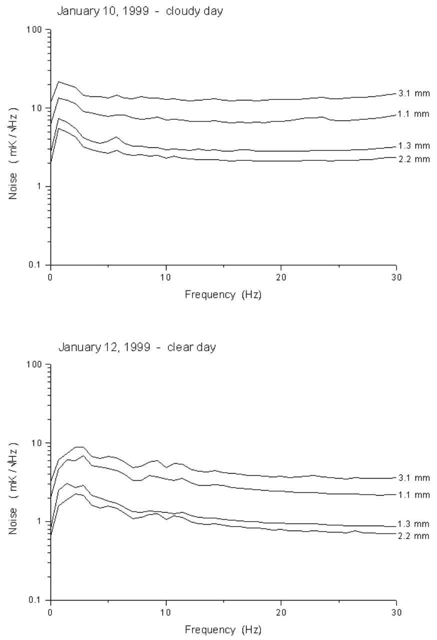

Fig. 2. Power Spectrum of a cloudy day and of a good observing day.

3.2. Angular Scale Dependence of Noise

In figure 3 we show the dependence of the noise on angular scale. Values in these graphics are calculated by dividing the ellipse in the sky into two semi-cycles on the longer axis, evaluating differences between the first point of the semi-cycle and the other ones and binning the data by angular separation. These results are not in agreement with those predicted by the Kolmogorov theory of fluid turbulence (Tatarskii 1961). According to that model, turbulent energy is injected into the atmosphere on large scales from processes such as convection and wind shear, and then cascades down through a series of eddies to smaller scale, until it is dissipated by viscous forces. If energy is conserved in the cascade then it is simple to show that the power spectrum of the fluctuations in a large 3-dimensional volume is proportional to $q^{-11/3}$, where q is the spatial wavenumber. This holds from the outer scale size, on which the energy is injected, to the inner scale size, on which it is dissipated. Tatarskii showed that this same power law applies to quantities that are passively entrained in the flow of air, such as the mass fraction of water vapor. However, this model does not take into account the variations of wind speed with height or any convective motions. In practice, these two effects could smear out the power dependence. Andreani et al. (1990) have measured the power spectrum of the atmospheric fluctuations at Terra Nova Bay at wavelengths between 350 μm and 2 mm. They measured a power index of -11/3.

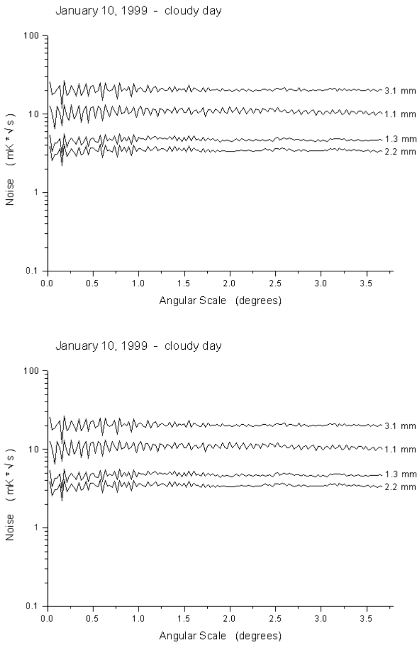

Fig. 3. Angular scale dependence of noise on a cloudy day and on a good observing day.

In fact from figure 3 it appears that atmospheric noise at Dome C has the same value for different angular scales until at least 3.8, suggesting that the tropospheric motions do not have any characteristic scale in this range. This is a very important result. It could mean that the thickness of the troposphere at this site is so low that the inner scale size appears from our ground-based measurements at a fairly large angular scale (Storey 1999, private communications). The clear day spectra in figure 3 do show some channel-to-channel correlation which could arise from some residual atmospheric emission.

4. Future plans: COCHISE

Pre-launch and follow-up ground based observations are included in the scientific programs of all the present and future space missions. Many ancillary observations can only be performed by ground-based observatory because of the possibility of dedicating long observing runs at a cost lower than a space mission. The proposed telescope will therefore complement observations of balloon-borne and satellite experiments in the millimetric range by allowing a careful understanding of foreground emission. The possibility of long-duration, deep observations of selected regions with dedicated observing schedules will make it possible to improve data quality of all the existing and future missions. It must be stressed that the proposing team is also partecipating to the ESA/Planck mission, which is scheduled to fly in 2007.

Proposed instrument will take full advantage of the long-term experience of the Team in Antarctica and of the commonalities with other experiments in which the Team actively collaborates. The instrument our Team proposes to install at Concordia Station is a 2.6 m diameter Cassegrain submillimetric telescope very similar to the one already installed at Terra Nova Bay. Common elements between the two telescopes can be used to test new instrumentation at O.A.S.I. before being used at Dome C. It will be possible to accommodate detectors for observations of polarized radiation (of cosmological origin and from diffuse and point sources). The secondary mirror will be therefore supported by a cone of Styrofoam (almost transparent to millimetric radiation), according to an idea originally developed in our Team. The first detector that our Team proposes to install at the focal plane of this telescope is a multichannel single-pixel bolometric detector; to this purpose, we realized a ^{3}He refrigerator working below 300 mK starting from 4.2 K, without pumping on the main ^{4}He bath (Graziani et al., submitted), which offers the opportunity to eliminate the use of heavy, and limited life, cryogen liquids. Remote control of the system can also be developed in this simple configuration. The final goal is to take full advantage of the ultra-low temperature (100 mK) technology under development in our Team and to use a multichannel multipixel bolometric system. Detectors using HEMT technology, already under development for the Planck/LFI instrument (in which our Team is collaborating) will also be tested. Remote control operation of the telescope and of the instrumentation will also be studied and implemented.

5. Conclusions

The analysis of our data set obtained during 10 day of summer weather shows that in Dome C the atmospheric conditions are of good quality in terms of stability at millimeter wavelengths. We deduced 2 important results:

- in the good observing days atmospheric noise is less than or equal to the intrinsic noise of our detectors at all wavelengths;
- the atmospheric noise has the same value for different angular scales from 10' to 3.8^o and thus is not in agreement with a Kolmogorov model. It could mean that the tropospheric thickness at Dome C is so low that we are probing inside the inner scale of the turbulence for some angular degrees.

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References

Andreani, P., et al., 1990, Infrared Phys., 30, 479

Bally, J. 1989, Astrophysics in Antarctica, AIP Press-New York, 100

Burton, M.G., et al., 1994, PASA, 11, 127

Dall'Oglio, G., et al., 1988, Infrared Phys., 28, 155

Dall'Oglio, G., et al., 1992, Exp. Astr., 2, 275

Dall'Oglio, G., et al., 1996, PASA, 13, 44

Dall'Oglio, G., et al., 1997, Cryogenics, 37, 63

Downey, P.M., et al., 1984, Appl. Opt., 23, 6

Graziani, A., et al, 2003, Cryogenics, submitted

Halverson, N.W., et al., 1998, Proc. SPIE, 3357, 416

Hidas, M.G., et al., 2000, PASA, 17, 260

Houghton, J.T. 1977, ed. Cambridge University Press

Léna, P., et al, 1998, Springer

Melchiorri, B., et al., 1996, ApJ, 471, 52

Page, L.A., et al., 1990, ApJ, 355, L1

Storey, J.W.V., 1998, Proc. ASP Conference Series, 141, 313

Tatarskii, V.I., 1961, Dover - New York

Valenziano, L., et al., 1997, Proc. of Part. Phys. and Early Universe Conf., Cambridge (UK)

Valenziano, L., et al., 1998, Astronomical Society of Pacific '97 Conference, Astrophysics from Antarctica, Chicago 1997, Astron. Society of Pacific, Conference Series, vol. 141

Valenziano, L., Dall'Oglio, G., 1999, PASA, 16, 167

Waters, J.W., 1976, Methods of Experimental Physics - Astophysics, Academic Press, 12, 142

White, G.K., 1979, Clarendon Press, Oxford

Winston, R., 1970, J. of the Opt. Soc. of A., 60, 245