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## COCHISE: Cosmological Observations from Concordia, Antarctica

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COCHISE is a 2.6 meter millimetric telescope devoted to cosmological observations. It is located near the Concordia Station, on the high Antarctic plateau, probably the best site in the world for (sub)millimetric observations. At present time, COCHISE is the largest telescope installed at Concordia: besides the scientific expectations, it is of great interest as a pathfinder for future Antarctic telescopes. The main characteristics of the telescope will be presented, including the scientific goals and the technical aspects related to the use of such an instrument at the extreme conditions of the Antarctic environment. Key aspects of the atmospheric transmission will be also discussed, by showing the preliminary results of site testing experiments.

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### I. SCIENTIFIC CONTEXT

Observations at (sub)millimeter wavelengths are extremely important since they provide many useful information about different astrophysical problems, such as cosmological studies, early stages of stellar evolution, properties of cold interstellar medium, infrared galaxies, cosmic structures at high redshift and so on. We are particularly interested in the study of the so-called Sunyaev-Zeldovich Effect (SZE). This is the process by which the photons of the Cosmic Microwave Background (CMB) radiation undergo inverse Compton effect on the high energy electrons contained in clusters of galaxies. This effect changes the spectral shape of the CMB by increasing on average the energy of the photons (see for example Carlstrom et al. [1]). SZE surveys can be used to extract values of the main cosmological parameters. The main features of the SZE are found in the wavelength range between  $850\ \mu\text{m}$  and  $2\ \text{mm}$ , hence the exact comprehension of this effect requires the observation of clusters of galaxies in this wavelength range in order to constraint the theory and retrieve physical parameters.

### II. THE SITE

A major problem when performing ground-based millimetric observations is the presence of water vapor in the atmosphere. Indeed, in this

wavelength range water vapor shows absorption bands that attenuate the intensity of the incoming signal. Since the vertical distribution of water vapor in the atmosphere has a typical scale height of 3 Km, a site located at high altitude is required to perform (sub)millimetric observations. Preliminary site testing measurements have revealed that from this point of view the Antarctic plateau (and Dome C in particular) is one of the best site in the world; similar atmospheric conditions are found only in the Chilean desert. In Figure 1, a typical atmospheric transmission curve for the Dome C site is reported as a function of wavelength between 100 and 2000 GHz (from Schneider et al. [2]). The exact shape of the curve depends on the local vertical profiles of pressure and temperature, and strongly on the integrated amount of water vapor on the column. This quantity is called *precipitable water vapor* (*pwv*): it is the height (measured in millimetre) of the column of liquid water that would be on the ground if all the vapor on the vertical is condensed. As evident from Figure 1, the amount of *pwv* is critical in particular for the window at  $200\ \mu\text{m}$ , that is very interesting for cosmologists. The Dome C site seems to allow the observations at this wavelength. In that site, during the last few years Italy and French have realized a common scientific station called Concordia: it is located at 3200 meter above sea level, at 1200 km from the coast (Lat.  $75^\circ\text{S}$ , Long.  $123^\circ\text{E}$ ); typical temperatures vary during the year from  $-35^\circ\text{C}$  to  $-80^\circ\text{C}$ . The Station

is completely isolated from the rest of the world for almost 10 months each year, from February to November. The location and the prohibitive working conditions, both for people and for instrumentation, make the site logistically difficult. Anyway, there are many advantages, from astronomical point of view, that made this site of extreme interest. First of all, the atmosphere is dry, hence the millimetric transmission is exceptionally good. Then, the atmospheric temperature is very low, hence the sky emissivity is at minimum. Moreover, the atmosphere is basically stable, with laminar wind motion and very low turbulence levels. Due to the lack of natural or human obstacles, the horizon is completely available for observations. The site is very far from human or natural activities, that means that the air is free from aerosol particles and pollution. The latitude of the site makes a large part of the sky observable without interruption for an indefinite time. Finally, the duration of the polar night, the distance from other continents and the lack of significant human activities make Antarctica an ideal site for astronomical observations.

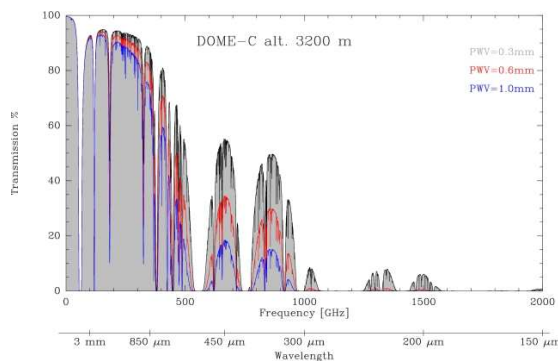


FIG. 1: The plot shows the atmospheric transmission in percent for values of  $pwv=0.3\text{mm}$  (grey),  $0.6\text{mm}$  (red), and  $1\text{mm}$  (blue) against frequency/wavelength for a frequency range 0-2000 GHz transmission (Schneider et al. [2] <http://transmissioncurves.free.fr>).

### III. THE COCHISE TELESCOPE

For the reasons exposed so far, Concordia has been chosen to install astronomical instrumentation. COCHISE is a Cassegrain 2.6m millimetric telescope, with a wobbling secondary mirror, a field of view of few arcminutes. A detailed description can be found in Sabbatini

et al. 2009 (submitted). The COCHISE telescope is very similar to the OASI one (Infrared and Submillimetric Antarctic Observatory), installed at the Italian Mario Zucchelli Station by the same Group and described in dall'Oglio et al. [3]; the work performed at the OASI telescope provided to the Group a deep experience in the working conditions at Antarctic sites. Images of OASI and COCHISE are shown in Figure 2. The main scientific objective of COCHISE is the SZE, even though also very interesting galactic observations devoted to study the presence of cold dust can be performed with this instrument, as the ones carried out from OASI telescope (Sabbatini et al. [4]). Moreover, in the perspective of very big telescopes to be installed at Concordia in the future (see for instance Minier et al. [5]), COCHISE will provide further site testing measurements, and the possibility to study and solve the technological aspects related to the use of a telescope at the Antarctic conditions.



FIG. 2: A view of the OASI telescope (top) located at the Italian Mario Zucchelli Station on the coast, and the COCHISE telescope (bottom) located at the Italian and French Concordia Station, on the Antarctic plateau. Also the laboratory tent is visible on the astrophysical platform.

The telescope is located on the astrophysical platform, about 400 meters far from the Station; the laboratory tent used for maintenance

is hosted on the same platform. The installation of COCHISE has been accomplished during two summer campaigns. Up to now, COCHISE has not performed astrophysical observations yet, while it has been used for preliminary operations and technological developments. Indeed, particular attention has to be posed on some technical aspects, in order to adapt the telescope at the harsh Antarctic environment. For example, it is mandatory to take into account the strong thermal variations (temperature at Concordia can change of more than  $20^{\circ}\text{C}$  in few hours) that cause differential contractions on the materials; it has to be avoided the sinking into the ice of the structures. The electronics must be properly heated and insulated; the functioning of all the parts (mechanics and electronics) has to be tested at various temperatures. Cables and connectors must be suitable for operations at  $-80^{\circ}\text{C}$ .

During the preliminary operations, a cryogenic photometer has been used in order to arrange the optics, including the alignment and the focus. The photometer requires the use of liquid Helium and  $^3\text{He}$  refrigerators (Graziani et al. [6], Pizzo et al. [7]) in order to keep the detectors at their operating temperature, about 0.3 K for the bolometers used. In the next future, the liquid Helium will be substituted by the use of a cryocooler, more suitable to the difficult conditions of the Antarctic environment.

One of the major problem in the functioning of a telescope on the high Antarctic plateau during the winter is the formation of frost, due to the condensation of the water vapor, and the accumulation of snow. An experimental defrosting system has been designed and realized for COCHISE by the CEA-Saclay team, within an international collaboration under the responsibility of Gilles Durand. The goal of this system is to keep the primary mirror free from frost during winter. The system consists of three subsystems based on the three main thermodynamical processes: conduction, convection, irradiation. For what concern the conduction, the primary mirror is heated from the rear with heating cables properly insulated, to force frost sublimation (see the left side of Figure 3). The convection has been applied by means of a blowing system that provides dry, cold air at the edges of the primary mirror, directed toward the center. The irradiation includes infrared lamps located all around the primary mirror pointing in a direction transverse to the beam (see the right side of Figure 3). The different subsystems can be used independently or in combination and all

the system is controlled by remote; the primary mirror is monitored by a webcam that takes regularly images. This system has been tested during the whole year in order to find the good configuration to keep the surfaces clean; as a first preliminary result, the combined use of heating and blowing has been found very interesting. It has been found that keeping the mirror for few hours at a temperature of few degrees higher than the air one can remove the frost formation (see Figure 4). The heating also assures a slippery surface that allows the removal of snow by the mechanical action of the blowing system.

This experiment is still in progress, with few changes that have been performed at the end of the first season of tests. The telescope has been left in tilted position to avoid snow accumulation and have a better understanding of the frost formation alone; the blowing system has been replaced by a compressed air system. The correlation with meteorological conditions will be better studied.

#### IV. INTRADAY MEASUREMENTS OF WATER VAPOR CONTENT AT DOME C

Although the Concordia site has been chosen for its extremely cold and dry air conditions, the water vapor content in the atmosphere can still great affect the incoming radiation. Therefore, routine measurements of  $p_{wv}$  are needed to evaluate its effects on transmission.

For that purpose, during the installation of COCHISE, measurements of  $p_{wv}$  have been performed by using a solar hygrometer, devoted to the intraday monitoring of the atmospheric transmission. This is a simple and robust instrument, accurate and reliable, designed to work at harsh conditions; it performs the simultaneous measurements of the solar radiation in two infrared spectral intervals chosen the first within an absorption band and the second in a transparency window. Since the solar spectrum is very well known in these bands, the ratio between the two measured values, appropriately calibrated, is directly related to the content of water vapor. The prototype of this instrument has been realized by Tomasi and Guzzi [8]. The same instrument has been already used in Antarctica by Valenziano et al. [9]; improvements have been adopted, including a better procedure of measurements, a more refined analysis of the radiosoundings and a more accurate calibration.

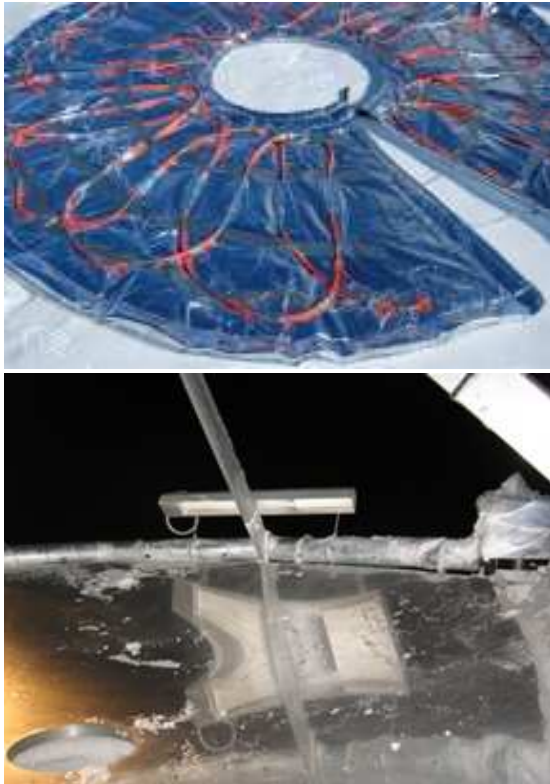


FIG. 3: The defrosting system. [Left] The preparation of the heating system: the heating cables have been uniformly distributed over an insulating cover and fixed on the rear of the primary mirror. [Right] A view of one of the infrared lamps located on the edge of the primary mirror; the lamp is installed on the tube of the blowing system and its position and inclination can be easily arranged.

The calibration of the solar hygrometer is attained by performing measurements at the same time of the radiosoundings that are daily launched at Concordia. The radiosoundings provide the vertical profiles of temperature  $T$ , dew point temperature  $T_d$ , pressure  $p$ , relative humidity  $RH$ , wind speed  $w_s$  and wind direction  $w_d$ . The data for the period of interest have been kindly provided by PNRA - Osservatorio Meteo Climatologico (<http://www.climantartide.it/>). The vertical profiles are used to evaluate the integrated columnar content of water vapor, after an accurate correction procedure needed to remove the systematic effects, as pointed out by the work of Tomasi et al. [10].

The square-root calibration curve usually adopted for this kind of instrument (Volz [11])



FIG. 4: Images taken by the webcam that monitors the primary mirror. The effect of the heating system is shown: on the left image the mirror appears opaque because it is covered by a layer of frost; after 12 hours of heating, at a set point temperature of few degrees higher than the air temperature, the mirror appears shiny: the frost has been removed.

is inappropriate for the Antarctic atmosphere, since it represents a strong water vapor absorption regime law, inadequate to the low content of water vapor usually measured in Antarctica. A more realistic analytical form for the hygrometric calibration curve has been proposed by Tomasi et al. [12], using radiative transfer codes to simulate the weak absorption by water vapor, taking into account the spectral near-IR curves of extraterrestrial solar irradiance, instrumental responsivity parameters, atmospheric transmittance and the field measurements taken at Concordia to determine empirically some shape parameters of the calibration curve.

The whole set of data of  $pwv$  is reported in Figure 5, plotted as a function Julian day, starting from December 2007. So far, this is the

largest dataset collected with this instrument, since more than 400 observations have been performed; they allow the evaluation on daily and seasonal fluctuations. In that figure, there are two evident gaps corresponding to the polar nights, when the solar hygrometer is not usable due to the elevation of the Sun. As preliminary results, the average lower values (and also the lower fluctuations) are present during September and October (JD around 400), that are the coldest months at Concordia, with typical temperature at  $-75^{\circ}\text{C}$ . Looking at the first block of data, a quick look reveals that February values (around the Julian Day 150) are sensibly lower than the previous ones, corresponding at the December-January period, showing a steep decrease. Very low values are also measured at the end of the winter season, October 2007 (corresponding in the plot to Julian Day about 380). A second peak is also evident, showing the increasing of water vapor content during summer period, when the humidity and the temperature are both higher. In any case, with few exceptions, the value is always less than 1 mm. It has to be underlined that this value constitutes an upper limit, since the measurements have been taken during the worst conditions: summer period and daytime, when the temperatures get higher and the Sun is always above the horizon. Also the dispersion of the values shows a trend with the period: we found lower fluctuations in the same period in which we have the lower values of  $pwv$ .

## V. CONCLUSIONS

There is an enormous interest in performing millimetric and sub-millimetric astronomical observations from Antarctica, since the site testing has revealed exceptional conditions, especially for the low water vapor content, that originates a very high atmospheric transmission. Therefore, it is of extreme interest the realization of cosmological observations at Concordia; that will be possible in the next future thanks to the COCHISE telescope, that will allow the exploitation of the spectral range between  $850\ \mu\text{m}$  and  $3\ \text{mm}$  of wavelength.

Besides the astronomical observations that will be carried out from COCHISE, the work performed is important also with respect to the technological issues related to the realization and running of this kind of structures in the Antarctic environment. In particular, the ap-

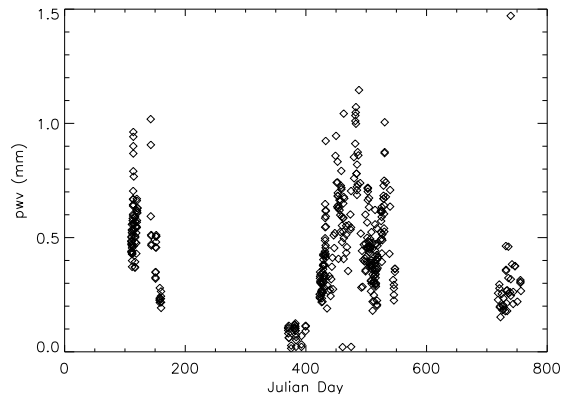


FIG. 5: Measurements of  $pwv$  in the period December 2007–November 2008. The two main groups of data corresponds to the two summer periods covered in this work, while the gap between them is due to the winter periods, where the Sun elevation is not enough to perform good measurements (or the Sun is above the horizon).

plication of the defrosting system on COCHISE has answered to many questions regarding the problem of frost formation on the structures and its removal. This work is of considerable importance for future large telescopes to be installed at Concordia.

The measurements realized with the solar hygrometer represent the first systematic monitoring of water vapor content and its daily and monthly fluctuations. The results from this work are particularly interesting for the astronomical community, since even a small advantage in transparency may constitute a critical issue in site selection for future instruments. Therefore a complete analysis to avoid bias and systematics is very delicate and it is still in progress.

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