QUBIC Argentina

History

In 2016 the QUBIC collaboration inquired about the possibility to install the QUBIC observatory in Argentina. ITEDA made the proposal to install it near San Antonio de los Cobres (SAC) in the Argentinian Andes Mountains which was accepted by the collaboration. At that moment, the QUBIC Argentina working groups were born. When Argentina joined the QUBIC collaboration it was decided that Argentina would be in charge of:

- The development of the infrastructure of the observation site with energy provision.
- The development and construction of a shelter for the instrument.
- The development and fabrication of a three-ax observation mount.
- The provision of laboratory space for the assembly and integration of the instrument.

Since then, there has been an intense interchange of information and joint development activities. Eight members of QUBIC Argentina have been sent for extended periods of time to the partner laboratories in order to receive training, participate in technical meetings and assist in development activities.

Since the fabrication of the required amount of bolometers needed help, the Department for Micro- and Nanotechnology of CNEA Buenos Aires joined the collaboration and began to transfer and adapt the microfabrication processes to match the possibilities of their microfabrication facilities with the objective of fabrication of bolometric sensors.

Status

Currently there are **50 persons** (not all FTE) from Argentina working for QUBIC. QUBIC Argentina has been able to receive funding in the amount of **820 kUSD** from local authorities.

QUBIC Argentina has worked hard to comply with its responsibilities and will be prepared to receive the instrument in early 2021 according to the project schedule.

Argentinian Board of Directors: Alberto Etchegoyen (Chair), Beatriz E. García, Diego Harari, Gustavo E. Romero

This document reports on the status of the work being performed in Argentina.

Argentinian Project Management: Christian Kristukat (PM), Clara Duca (deputy PM)

The project administration is performed by *Fundación Ahuekna Investigación y Desarrollo Tecnológico.* Management: Ruben Denza, Alberto Etchegoyen. Accounting, International Trade and Transportation are performed by: Martín Calderón, Romina Campana, Sabrina Coller, Diego Ferrazza, Anibal Gattone, Eliana Tesoro, Javier Yturre.

The first QUBIC component delivered to Argentina was the groundshield, received in January 2020. The shipment of the instrument and all other sub-components is currently being prepared. Transportation costs from Paris to Salta will be paid by the Argentinian collaboration.

WP1: Site development

Lead: Beatriz García, ITEDA, Mendoza
Work group members: Fernando Farfán, Antonio Grasso, Santiago Grasso, Luciano Herrera, Facundo Lazarte, Alexis Mancilla, Javier Maya, Guillermo Sandlak, and Martín Varayud

The objective of WP1 is the development of the observation site:
- build an access road to the site (done)
- build a shelter for the instrument (engineering finished, building permit issued, materials bought)
- install a communication system (specification finished)
- install a power generator (specification finished).

Figure 1: Rendering of the shelter with the opened dome, the groundshield and the instrument in its center (left). Access road to the QUBIC site (right).

Detailed description

Shelter

The shelter for QUBIC will be located on the south side of the site, at 40 meters from the communication tower (figure 2), which will also carry the calibration source and a lightning rod. The concrete base of the building has a size of 12 × 9m, split into two parts: a heavy central part as support for the mount of the instrument and a platform surrounding the central part on which the metal structure of the building will be mounted. The division into two parts will help to decouple vibrations of the building (due to wind load) form the instrument. The excavation for the base has already been done (figure 3) by personnel from CNEA Córdoba.

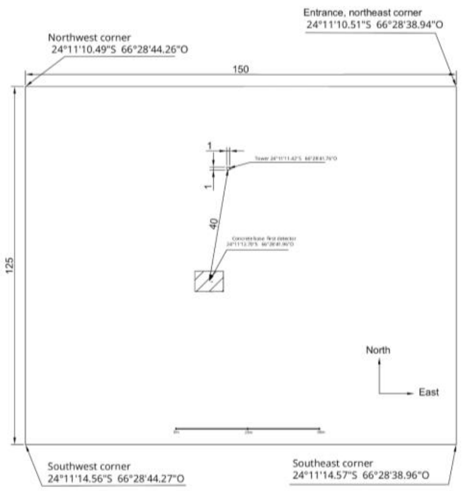


Figure 2: QUBIC site layout.

Figure 3: Site preparation for the base for the shelter.

The shelter was designed as a metal structure based on standard steel profiles (figure 4). In order to simplify the assembly of the shelter at the site, the structural elements (of dimensions as large as a truck may carry), will be pre-fabricated in CNEA Córdoba. At the site the elements will be assembled and joined with bolts so that no or just only few soldering will be required. The walls and roof will be made of thermally insulated metal sheet panels.

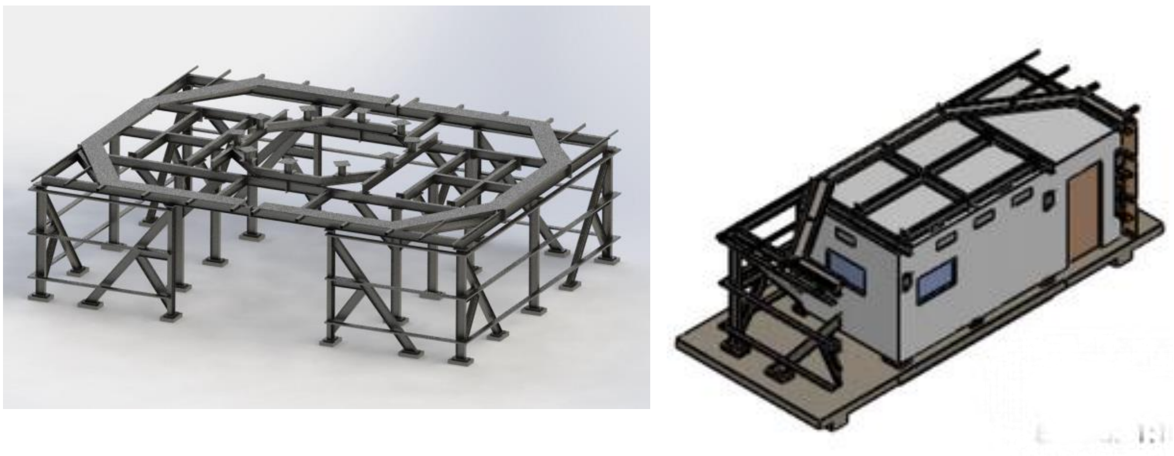


Figure 4: Steel structure of the shelter and control cubicle inside the shelter.

Dome

The design of the dome is based on the dome of the LIDAR receivers of the Pierre Auger Observatory. The dome is divided into two parts consisting of four rigid elements each, pivoting on the same axis (figure 5). Each half of the dome has an approximate weight of 2200 kg.

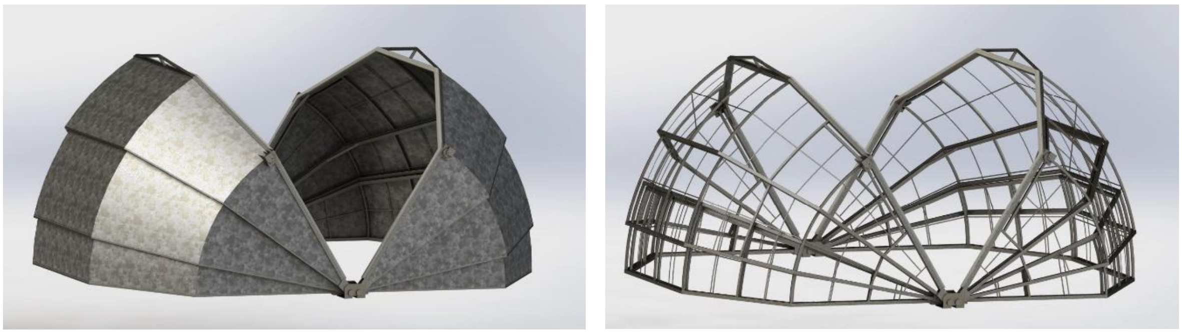


Figure 5: Construction details of the steel skeleton and the covering of the dome.

The actuation mechanism of the dome follows the idea of the LIDAR: a system of pulleys and wire ropes was proposed (figure 6). It will have a gear motor for each of the two half-domes for opening and closing. The motor-reducer assembly consists of one motor and two reducers that will be joined by means of a rubber coupling, favoring maintenance and repair. In case of a power cut the mechanical link can be undone and the dome may be operated manually using a crank.

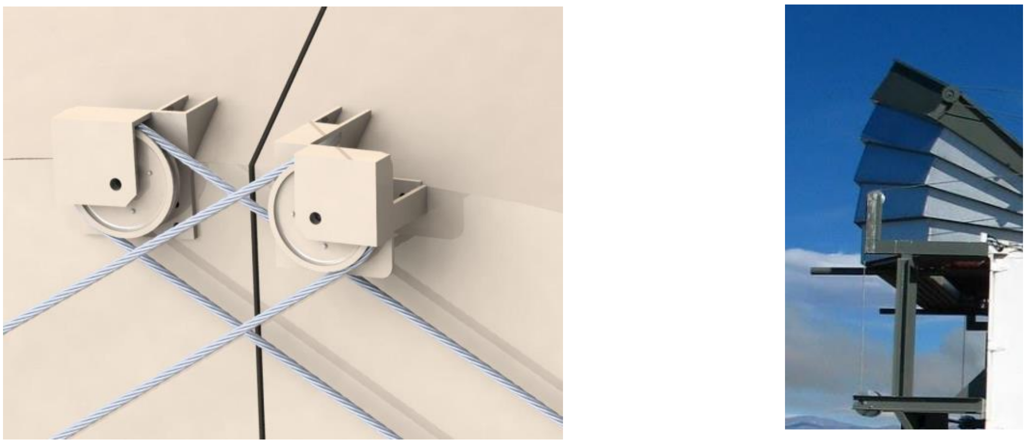


Figure 6: Pulley system for the actuation of the dome (left) and picture of the mechanism of the LIDAR dome (right).

All these designs were performed by ITeDA-Mendoza and reviewed by from Gerencia de Desarrollo Tecnológico y Proyectos Especiales-CNEA Buenos Aires

Weather monitoring system

It is foreseen to implement a weather monitoring and forecast system, since it will be necessary to close the dome to protect the instrument from adverse weather conditions. The initial proposal consists in the installation of three weather stations with different capabilities with the main station at the shelter, consisting in:

- Humidity, temperature, pressure, rain and wind sensors.
- Five cameras, to inspect the site conditions and cloud coverage.
- Lightning sensor (under research).

and two secondary and simpler weather stations towards the north-west and the south-east of the shelter with:

- Wind and rain sensors.
- Lightning sensor.
-

The layout of this proposal is presented in figure 7. All stations, including those of the shelter, will be powered by photovoltaic systems thus rendering them independent. A data processing system is being developed that will monitor the meteorological conditions at the different stations making the information available remotely, so that it can be decided whether to close or open the dome. As for the cameras, they will have the function of allowing the (remote) operator to evaluate the conditions in terms of clouds, rain, etc. and decide whether operation is possible or not.

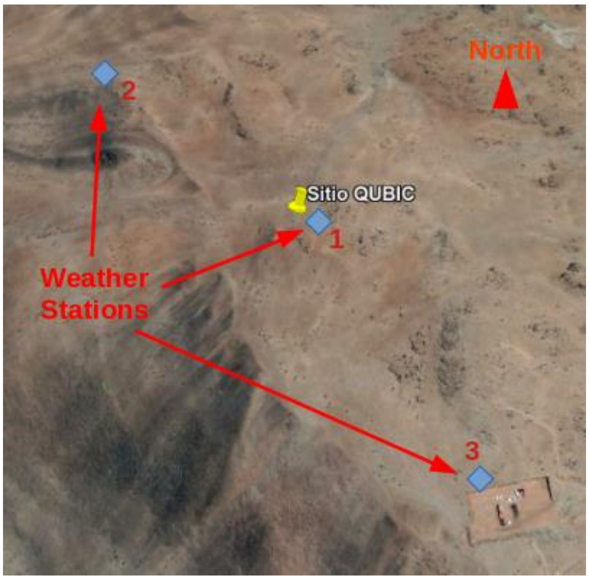


Figure 7. Scheme of the distribution of weather stations.

Power

During the initial phase of observation at the site, energy will be provided by diesel electro generators. Two generators of identical performance with transfer panels will be installed. It is foreseen that the generators operate alternately so that maintenance can be performed without having to cut the power to the Observatory. The installation will have remote diagnostics and possibly remote control capabilities. A fuel tank with a capacity for continuous operation of at least two weeks will be installed next to the power generators.

It has been decided to build a gas-powered power plant in a joint effort with other projects (for the moment LLAMA, others may follow).

Communication tower

A tower (figure 8) will be constructed north to the shelter that will host the communication system, a lightning rod, and the calibration source. The range of protection of the lightning rod on the tower is not sufficient to cover the whole QUBIC site. Additional rods will have to be attached to the shelter to increase the protection area.

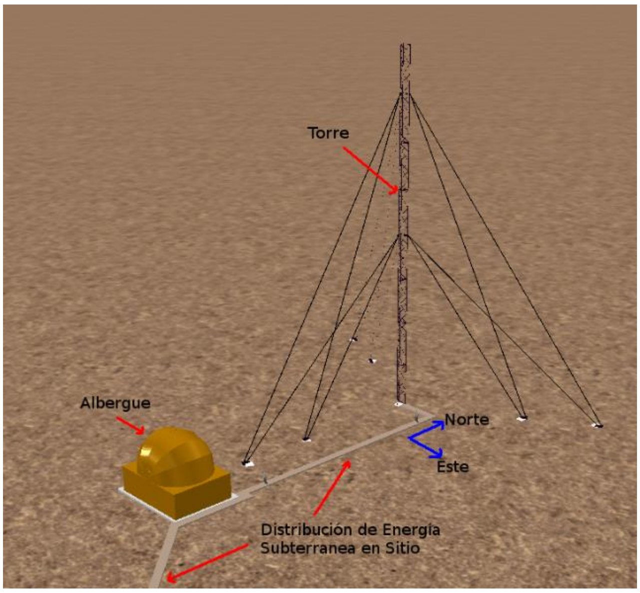


Figure 8: Communication tower towards the north of the shelter.

For the communication (5 Mbps symmetric as required by the project) two alternatives are being discussed:

- A commercial radio link as offered by local communication providers.
- A radio link to an intermediate place in SAC which is in direct view from the tower and a second fiber-optics link to a connection point to the national high speed science fiber network already available in SAC.

The second alternative is favored.

Safety plan

A safety plan for the QUBIC Observatory is being worked taking into account the potential risks of working in rough climatic conditions and at 4800m above sea level. A designated site manager, Eng. Fernando Farfán, will be in charge of site security.

Status

- The access road to the site and the preparation for the construction of the concrete base of the shelter have been finished.

- The majority of the material for the construction of the shelter and equipment needed to accomplish that task has been bought and delivered to CNEA Córdoba (figure 9) where the pre-fabrication will start as soon as the sanitary situation caused by COVID-19 allows it.
- The design of the shelter has been reviewed and approved by an external consultant. The project has been presented to the city administration of SAC and the building permit has been issued.
- A provider for the construction of the communication tower is currently being selected.
- Quotes for the generators and the fuel tank are being received.

Figure 9: Left: unloading of steel material for the shelter. Right: new soldering equipment for the pre-fabrication of the shelter.

WP2: Integration Laboratory

Lead: Diego Fracchia, ITEDA, Salta
Work group members: Fernando Farfán, Antonio Grasso, Santiago Grasso, Raúl H. Luterstein, Inés Torino, and Martín Varayud

The objective of WP2 is the construction and operation of a laboratory at CNEA RNO Salta City suitable for the integration and testing of all QUBIC components. In there, the instrument will be re-assembled and tested after its reception from France, the observation mount will be assembled and tested. Finally the instrument will be tested on the observation mount before disassembling and sending it to the observation site.

As no suitable space could be found in the existing buildings at CNEA RNO it was decided to build a new building to host the integration laboratory according to the requirements defined by the QUBIC collaboration (ATRIUM-132063). The construction started in 2018 and was finished in 2019 (figure 1). It comprises a large working area of 20m × 10m and 6m of height, a storage space, a workshop area, and sanitary facilities and in the second floor a conference room and office working space of 5mx10m. It has been both designed nd built entirely by personnel of CNEA Córdoba.

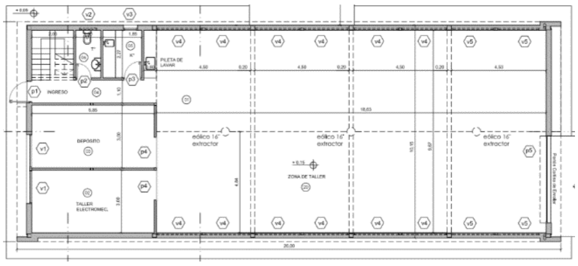


Figure 1: Architectural drawing, exterior and interior views of the building that hosts the integration laboratory.

The electric installation is designed to provide power to more than one instrument and mount at a time. It was necessary to extend the electric connection of the CNEA complex to the power grid of the local electricity company. Therefore, a new connection terminal has been built and the connection to the grid was applied for. Furniture for the conference and office space has been purchased.

The following pieces of equipment will be available when the integration phase starts:

- scaffolding, ladders, and safety harnesses: **purchased**
- hand pallet truck: **purchased**
- mobile bridge crane for 3tn and 5m of height: **purchased**
- mobile clean tent: **design finished, to be built by members of QUBIC**
- 20kW chiller: **specification done, waiting for commercial offers**
- tools for mechanic and electronic workshop: **waiting for commercial offers**
- signal generator, oscilloscope, low noise amplifier: **waiting for commercial offers**

Status

- The integration laboratory is finished
- Purchase process of equipment and tools started

WP3: Mount system

Lead: Pablo Ringegni, GEMA, Universidad de La Plata
Work group members: José Alberro, Néstor di Castillo, Lucía Perticaro, Hernán Medina, Luis Mariano Mundo, Adrían Riello, Diego Silva, and Carlos Varela.
Collaborators: Gustavo di Pasquale, Ismael Nuñez Pettinari, Luis Stella

The objective of WP3 is the development of a three-axis mount according to the scientific requirements of QUBIC (ATRIUM-97333). The most important requirements are:
Range of movement:

- azimuth +/- 200°
- elevation: 30°-70°
- instrument axis: +/- 15°

Pointing accuracy:

- 3 arcmin with respect to the positioning of the axes
- 15 arcsec pointing measurement accuracy

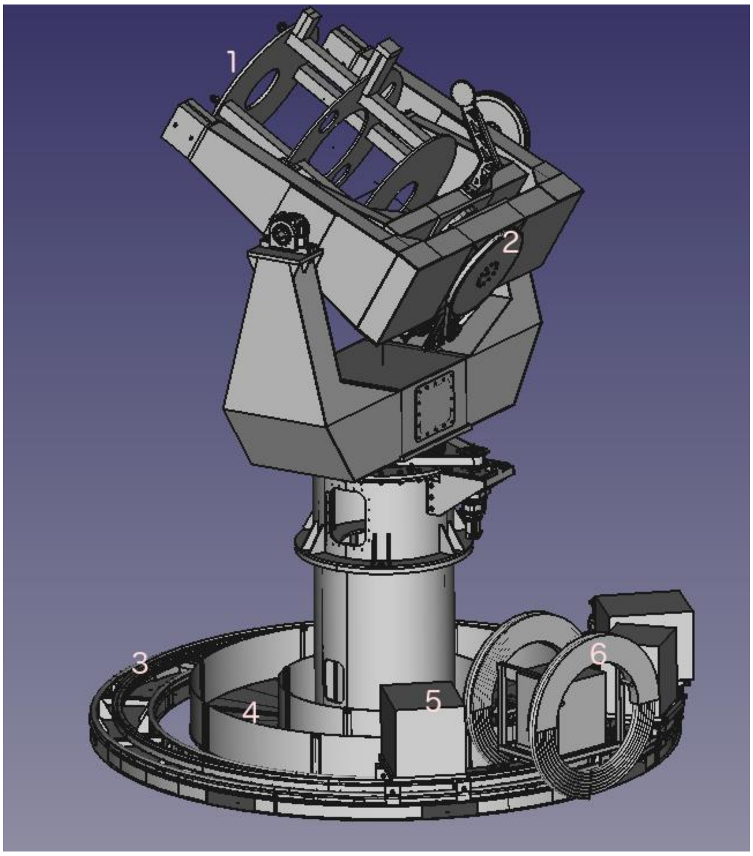
Detailed description

The mount system consists of:

- the mount: a three-axes gimbal mechanics sitting on a static pedestal
- the equipment carrier train which moves on circular rails surrounding the mount
- a rotational cable carrier which links the moving train to the fixed environment

A rendering of the complete system including a mechanical dummy of the cryostat is shown in figure 1.

The axes are driven by servo motors which are linked to the axes by means of toothed pulleys and belts. A fourth servomotor is mounted on one of the trolleys and drives the train. A mount motor control is being developed which takes care of the synchronous movement of the azimuth axis and the train and the independent positioning of elevation and instrument axis. A simple communication interface will allow for the easy integration with QUBIC Studio.



1) Dummy cryostat
2) Three-axes gimbal mechanics
3) Rails of the equipment carrier train
4) Rotational cable carrier
5) Trolley with electronics rack
6) He Compressor with support for the He hoses

Figure 1: The mount system

Several emergency stop push buttons will be placed in the shelter and monitored by the mount motor control in order to stop the movement of the motors immediately in case of an emergency.

The reason for placing the He compressors on the train is to avoid cyclic bending of the He hoses between compressors and the pulse tube valves. If the compressors follow the azimuth movement of the mount, the bending of the He hoses is limited to a tolerable range related to the movement in elevation only. Moreoverit is preferable to minimize the cable length between the QUBIC electronic equipment. For that reason the majority of the equipment is placed on the train, too.

The cable carrier is fixed at its inner end, close to the base of the mount, while the outer end is attached to the train and thus follows its movement within +/-200°. It is designed to host power and data cables and four water hoses which provide the cooling water for the two He compressors.

The assembly of the mount system will be done in the integration laboratory in Salta City once all components are available.

Status

- The design of the whole system has been performed by GEMA (Grupo de Ensayos Mecánicos Aplicados), UNLP and has been reviewed and approved by engineers from

Gerencia de Desarrollo Tecnológico y Proyectos Especiales, CNEA, Buenos Aires and ITeDA, Buenos Aires.

- The drawings (more than 60) and the technical documentation for the fabrication of the structural elements of the mount have been finished. The call for bids is being prepared. Estimated costs: 120 kUSD.
- The drawings of the equipment carrier train are almost finished (more than 100).
- All non-custom components have been selected (pulleys, belts, bearings, motors, and drivers) and the purchasing process has started.

WP4: Microfabrication

Lead: Juan Bonaparte, DMNT, CNEA, Buenos Aires
Work group members: Clara Duca, Alejandro Fasciszewski, Diego Pérez, Diego Silva, Carlos Varela.
Collaborators: Mariano Gómez Berisso, Hernán Pastoriza, Christian Enss (Univ. Heidelberg-Germany), Sebastian Kempf (KIT-Germany), Marc Weber (KIT-Germany).

The objective of this WP is the fabrication of QUBIC sensors detectors according to both the design established by the International Collaboration and also to propose and test an upgrade with better performances and easier to manufacture. These sensors will be needed to complete the final instrument. They roughly consist of three components: i) absorber, ii) sensor layer, iii) readout system. The current detector technology of QUBIC is a Transition Edge Sensor (TES) featuring a superconducting sensor layer. The new type of detector which is being worked on alongside Heidelberg University and Karlsruhe Institute of Technology (KIT), Germany is a Magnetic Metallic Bolometer (MMB).

Since the facilities of the micro fabrication line at the DMNT (CNEA Buenos Aires) are different from that of France, the fabrication process had to be adapted to the possibilities of the laboratory. The main difference is the lack of a XeFl etch tool. The focus of the current phase is the development of a robust fabrication process for a strain-free absorber membrane. This membrane can either be used for TES or MMB sensors.

As a first step a single SiO_2 layer membrane was fabricated and released by an anisotropic reactive ion etch (RIE) process from the top of the substrate needed to open the grid followed by an isotropic etch step (fig. 1). The original QUBIC design uses SiN_x as membrane material. This material is etched by the same RIE process (chemicals) as plain silicon and thus is not suitable as hardmask for the anisotropic etch step nor as etch stop. The membrane was released everywhere but at the central part where the detector will be placed. The lateral extension of the central part is too large to be released by an isotropic etch process from the top-side. On the other hand it can be observed that the released areas of the membrane buckle. This is a result of the strain produced in the SiO_2 during cooldown of the substrate after the thermal oxidation step. To avoid the buckling a strain-compensated three-layer membrane was developed consisting of a SiN_x layer sandwiched between two SiO_2 layers. The first SiO_2 layer was fabricated by thermal oxidation the resting two layers by PECVD. Process parameters were found which allow for the fabrication of slightly tensile strained (<100MPa) membranes. Those membranes were used to develop a back-side etch process with the objective to release the membrane completely. Initially, the front-side etch processes were run, including an isotropic silicon etch step in order to underetch the grid laterally to some extent.

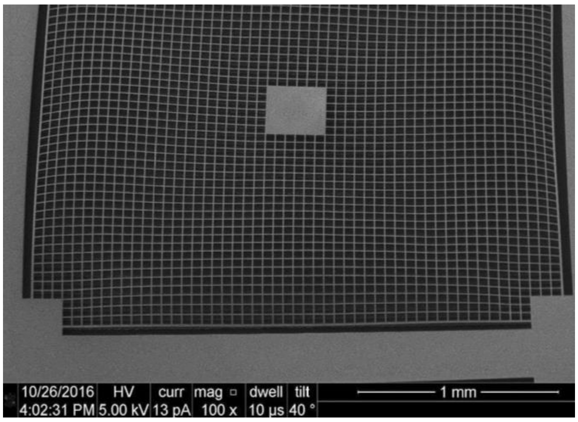


Figure 1: Released SiO_2 membrane by top-etch process (simplified version of the QUBIC design).

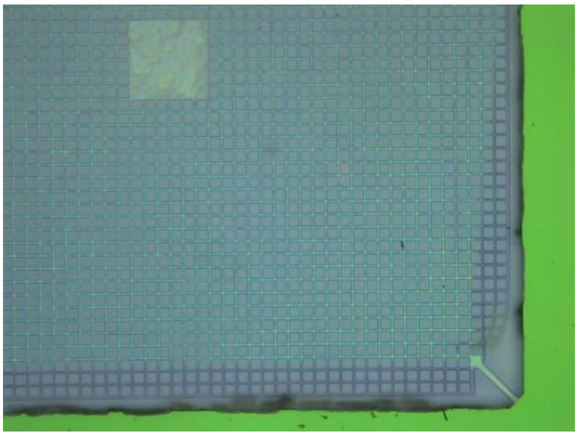


Figure 2: SiO_2-SiN_x-SiO_2 membrane with QUBIC design released by isotropic top etch through the membrane openings. A light bending at the borders is observed.

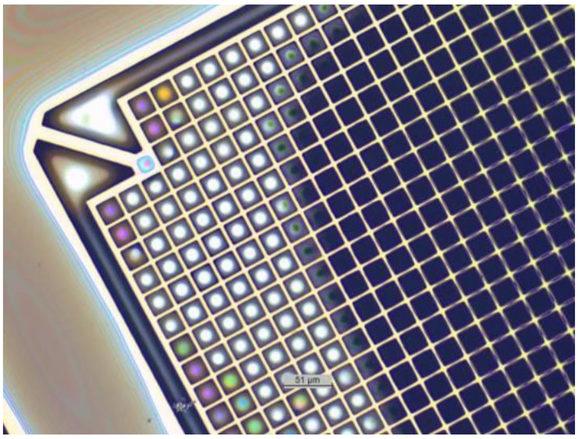


Figure 3: QUBIC membrane after back etch process. The dark areas of the membrane are not completely released.

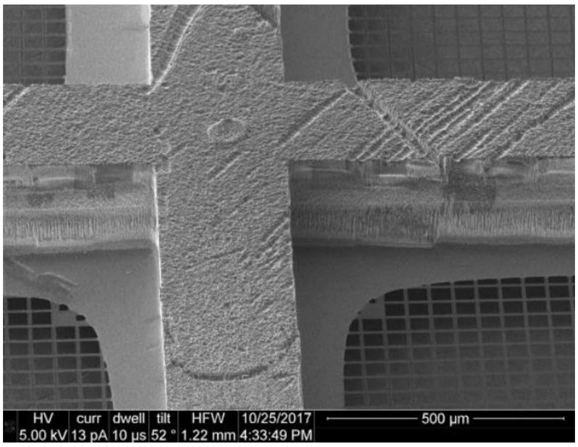


Figure 4: SEM image showing underetched zones near the edge of the membrane.

On the back-side, a 200nm aluminum layer was deposited which was structured using an aluminum etchant to form the back-side hard mask. The front-side of the substrate was glued to a carrier substrate with vacuum grease before starting the deep anisotropic etch (BOSCH) from the back-side. The back etch process has to traverse the whole thickness of the substrate and stop precisely at the membrane layer. Figures 2-4 show different images of the membrane after the back-etch process. Currently it is being worked on two issues: the typical process homogeneity of the deep etch process is about 1-2%. For a 500 um deep etch this results in inhomogeneities of 5-10 microns of thickness. Consequently parts of the membrane will be exposed to the process more than needed and are likely to be destroyed, while other areas will still be covered with silicon. The other issue is the detachment of the membrane from the carrier layer. During that process the membrane tends to break locally especially at places where it has been overetched.

A solution to the before mentioned problems may be the use of SOI substrates instead of plain silicon substrates as those have thick SiO_2 layer near the surface which acts as etch stop for the back etch. The remaining material between oxide layer and device layer is very thin and can be etched away with higher precision. On the other hand it is planned to use an improved carrier substrate with a shallow cavity in the area of the membrane so that there is no physical contact between the substrates in the delicate areas.

Status:

- A process has been developed to fabricate strain-free membranes.
- The front-side etch process has been developed.
- Two major issues have been identified with respect to the current back-side etch process needed to release the membrane, which will be addressed in the next development phase.
- Recently, an extra 70kUSD for the purchase of process consumables have been granted.

WP5: QUBIC Electronics Upgrade

Lead: Alejandro Almela, ITEDA, Buenos Aires
Working group members: Juan Bonaparte, Manuel García Redondo, Juan Geria, Mariano Gómez Berisso, Silvina Gutierrez, Luciano Ferreyro, Matias Hampel, Manuel Platino, and Juan Salum,
Collaborators: Oliver Sander (KIT-Germany), Marc Weber (KIT-Germany), Sebastian Kempf (KIT-Germany)

The current QUBIC detection system is, as mentioned in WP4, based on TES (Transition-Edge Sensor) for which the electronics is already designed and working.

The objective of this WP is to study the feasibility of replacing, in future developments/upgrades, the TES sensors with MMB (*Metallic Magnetic Bolometer*) sensors in order to improve the instrument's sensitivity. For this goal, a multiplexing and reading system is being designed for the new QUBIC cryogenic detectors, and a contribution will be made to the reading techniques of this system.

This work is performed in collaboration with the Karlsruhe Institute of Technology (KIT) and the University of Heidelberg, Germany. Five PhD students are participating in this WP in the framework of a double degree PhD program between Argentina and Germany.

Focal plane and the cryogenic reading system for the second sensor's generation.

The detectors are composed of an absorber, designed to have a high stopping power for the particles to be detected, strongly coupled to a temperature sensor which has a weak thermal link to a heat bath.

New sensors are being designed for the bolometer thermometer. The MMB are paramagnetic sensors embedded in a controllable weak magnetic field which sets their point of operation. These sensors are temperature dependent, so a change in temperature, due to flux photon absorption for example, results in a change in the magnetization of the sensor. The latter is measured by the flow generated using an inductor coupled to a SQUID.

The absorption of a flux of energy P in a detector characterized by a thermal conductance G results in an increase of temperature $\Delta T = P/G$. Metallic magnetic Bolometers (MMB) use a paramagnetic material located in a weak magnetic field as a temperature sensor. The change of the detector temperature ΔT upon the absorption of energy leads to a change of the sensor magnetization M which generates a change of magnetic flux $\Delta\Phi$ in a pickup coil. This process can be summarized by:

$$\Delta\Phi \propto \partial M/\partial T \, \Delta T$$

A sketch of an MMB is shown in Figure 1. The paramagnetic sensor is placed in a small external magnetic field and has a weak thermal link to the thermal bath. The absorption of a particle increases the temperature and thus decreases the magnetization of the sensor. This is read out by a low noise, high bandwidth SQUID magnetometer. In addition, a second SQUID is used to pre-amplify the signal before being directed to room temperature SQUID-electronics.

The choice of sensor material is crucial. For the development of magnetic temperature sensors for cryogenic temperatures, different materials have to be considered. We are studying a metallic dilute alloy of Au:Er where the erbium concentration can vary from a few hundreds ppm up to more than one thousand ppm.

We propose the use of MMBs as highly sensitive and low-noise detectors. The goal is to study the physics and technology of an MMB sensor capable of being integrated within a FDM system to be used in B-modes CMB polarization detection.

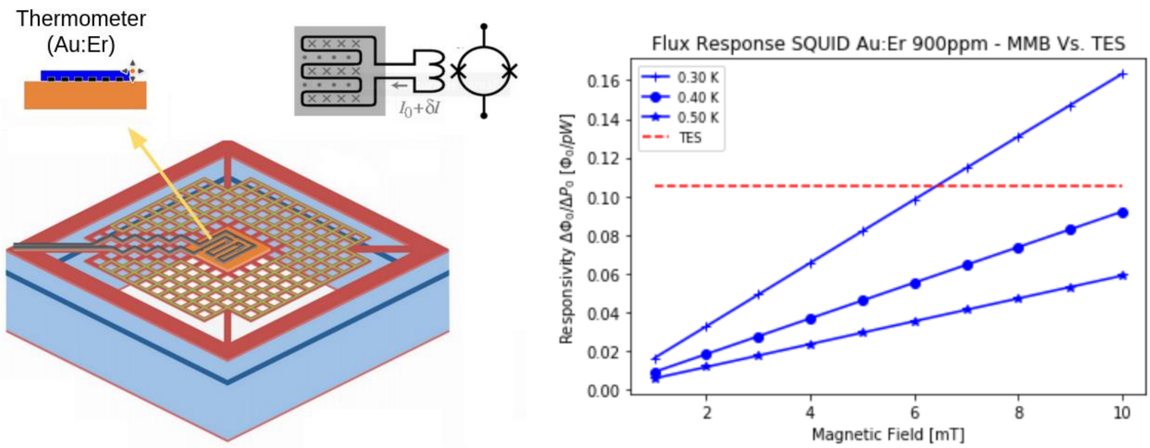


Fig. 1 Left: sketch of an MMB. The paramagnetic sensor is placed in a weak external magnetic field. The absorption of a particle increases the temperature and thus decreases the magnetization of the sensor. This change is read out by a low-noise high-bandwidth SQUID magnetometer. Right: A simulation of ∂M/∂T for different magnetic flux B for the blue lines and TES for the red line.

The microwave multiplexer for cryogenic metallic magnetic sensors for CMB.

A very promising technique that meets the requirements of large scale reading is an FDM multiplexing system based on SQUID and superconducting microwave resonators. Thus, it is possible to assign enough bandwidth per channel with a noise level that does not depend on the number of reading channels.

As already mentioned, hundreds of resonators can be read with only one transmission line, which is the great motivation for the development of this reading technique. A simple technique for generating a microwave frequency comb, as well as for determining the amplitude or phase of each transmitted carrier signal, is software defined radio (SDR).

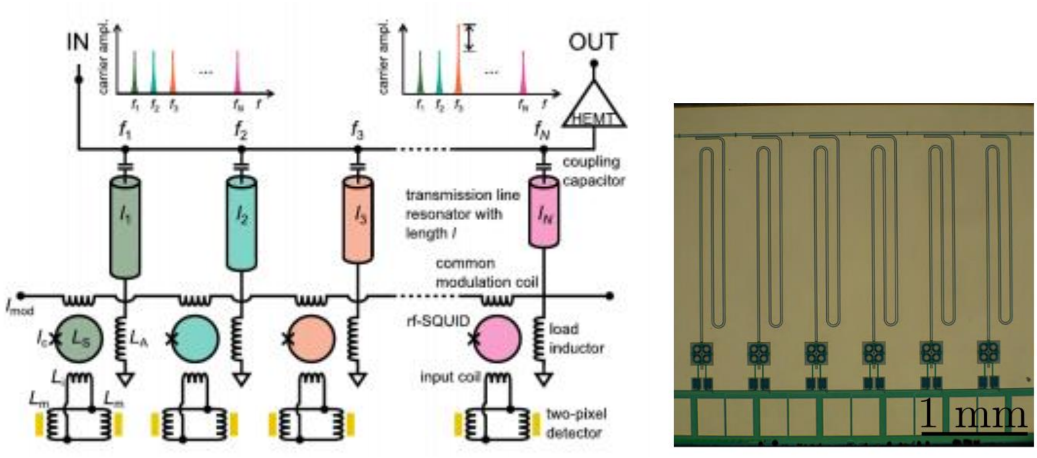


Figure 2: Left: schematic diagram of the circuit for 64 pixels which is read by an integrated microwave SQUID multiplexer. In this case, each detector consists of two coils connected to an MMC sensor. Both coils are connected in parallel with the input coil of the RF-SQUID by means of superconducting lines. The boxes show how the frequency combs are sent and received when the reading of µMUX based on amplitude is made and a detector event on channel 3 is assumed. Right: Close-up photo of resonators and SQUIDs of a µMUX made for ECHo.

The complexities in cryogenic integration and wiring have driven efforts to develop cryogenic reading technologies with a high multiplexing factor, minimizing the reading noise of each channel. The easiest way to read large detector sets is to multiplex all the sensors into a single signal line. However, the linear scale of system complexity will raise the parasitic heat load to the cold stage of the cryostat, and the increased cooling power cost, with the number of detectors of QUBIC, makes this approach nearly impossible. This modern technique is currently being developed. Figure 3 shows a diagram of this type of multiplexing. The design in this diagram allows a better understanding of this work plan. In an ideal read multiplex system, the following features are desired:

- Scalability.
- Energy and time resolution independent of the number of sensors.
- Aggregated noise independent of the number of sensors.

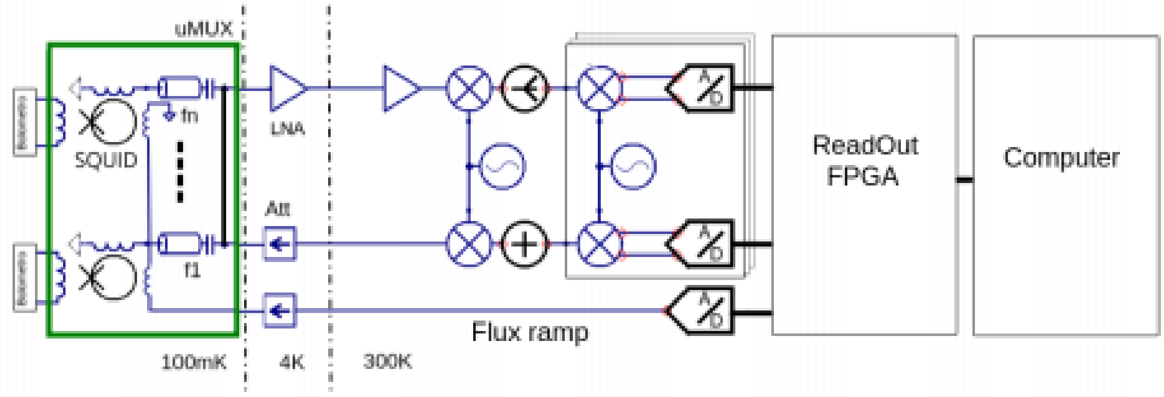


Figure 3: Diagram of the multiplexing and reading circuit proposed for the second stage of the Bolometric camera. The green box shows the μMUX. Inside, two resonators coupled to a transmission line are shown as an example. The SQUIDs vary the resonance frequency depending on the state of the sensors. Since these electronics work at temperatures close to 300 mK, it is necessary to use circuits that condition the intensity of the signal. In this case, attenuators and an LNA amplifier are shown. In order to know the state of each resonator, an RF circuit is used, with an SDR-like structure.

Read-out system of the multiplexer

A straight forward technique to generate the microwave frequency comb as well as to determine the amplitude or phase of each transmitted carrier signal is software defined radio (SDR). The frequency comb is created in the base band (several MHz) using two fast digital-to-analog converters (DACs).

The frequency comb is then upconverted into the frequency band of the SQUID multiplexer using an I/Q mixer to match the resonance frequencies of the resonators. Due to the very low intensity of this resulting signal, since it is desired to minimize the dissipation inside the cryostat, it is necessary to amplify it to be communicated to the outside of the chamber by means of a very low noise and consumption amplifier.

After injecting the frequency comb into the cryostat and passing the multiplexer, the modulated frequency comb is mixed into the base band again using an I/Q down-mixer. Both mixers are driven by the same local oscillator signal. The resulting in-phase and quadrature base band signals are digitized by two fast analog-to-digital converters (ADCs).

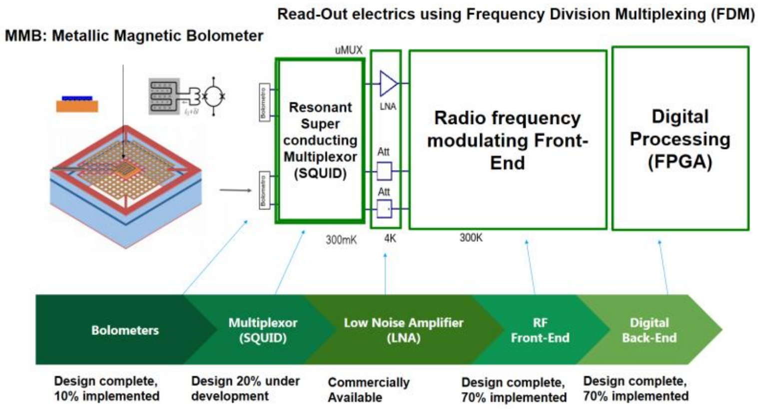
The subsequent signal processing, i.e. the separation of the frequency-comb into the different carrier signals, the determination of amplitude and phase of each carrier signal as well as the determination of the characteristic parameters of each detector signal, is then performed by using a field programmable gate array (FPGA).

Status (see figure below):

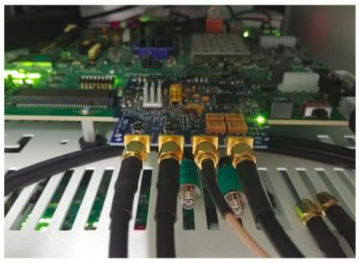
- Metallic Magnetic Bolometer:
    - Conceptual study by means of simulations of the responsivity, noise and temporal response of the sensor based on publications for the QUBIC design working temperature of 300 mK.
    - Design of the coupling system absorbers and SQUIDs.

- µMUX multiplexer:
  - Research of the characteristic parameters based on the design of the QUBIC sensors.
  - Study of the flow signal for the reading of SQUIDs.

- Readout system:
  - Design and implementation of the RF stage in collaboration with KIT, Germany.
  - Assembly of a digital system and programming for the generation and reading of the state of the multiplexer resonators.



Prototype Electronics



WP6: Data Analysis & Simulations

Lead: Claudia Scóccola, FCAG, UNLP
Work group members: Agustín Cobos Cerrutti, Beatriz García, Martín Gamboa-Lerena, and Daniel Supanitksy.

The main aim of WP6 is to contribute to the data analysis and simulations for the QUBIC experiment. Contributions to several important tasks of this front-end have been performed, which are still under research. Work is performed in close collaboration with the French and Italian groups, participating in all of the data analysis and calibration (international) telecoms.

The most important contributions are summarized below:

Contributions to the development of the end-to-end pipeline
Through the course of time and due to intense use, we were able to contribute to the improvement of the end-to-end simulation pipeline. This pipeline is able to simulate the TOD (Time Ordered Data) of the sky observed by QUBIC, and on a second stage, it is able to reconstruct maps at different frequencies. We have contributed to the generation of a user-friendly installation script and to many packages that are currently part of the pipeline.

Analysis of the angular resolution of the instrument
The angular resolution of QUBIC depends on the frequency. By doing end-to-end simulations of a point source, reconstructed with the full QUBIC pipeline, we computed the angular resolution at different sub-frequencies. We have obtained the expected results that the angular resolution improves with higher frequency. To carry-out this research, we needed to, firstly understand and handle the end-to-end pipeline (while helping to improve it), and secondly, we needed to develop a method to characterize the potential biases of these measurements, and correct for them.

Analysis of the spectral sensitivity function of the instrument
The synthesized beam for QUBIC has a primary peak, and multiple secondary peaks, whose positions depend on frequency. The peaks also have a given width. The frequency dependence allows for a separation in different sub-frequencies within the broad bands, at the map making level. However, given the intrinsic width of secondary peaks, when separating into different sub-bands, there is a superposition of winds (of the secondary peaks of monochromatic beams at different sub-frequencies) that results in a correlation between adjacent sub-bands. Therefore, there is an effective frequency point spread function (FPSF). We have made a numerical study to characterize this FPSF, by simulating the map produced by a monochromatic point source, reconstructed in different sub-bands. We moved the frequency of the source slowly, to characterize the FPSF, through the reconstruction of a source in the sub-frequency band it originally belongs to, and in the neighboring sub-frequency bands.

Contribution to the calibration of the synthesized beam in the lab
We have contributed to the characterization of the real synthesized beam in the lab, calibrating the image of the beam through the observation of monochromatic sources at different frequencies. Part of this work was done during a visit of Lic. Martín Gamboa-Lerena to the

APC, in April-May 2019. We contributed to the study of the variation in the distance between different peaks as a function of frequency and verified what was previously found in the simulations.

Study of the capabilities of the technological demonstrator (TD) to study the spectral properties of the dust in the galaxy

We have reconstructed the spectral behavior of the dust SED (spectral energy distribution) at the map level, from simulations of thermal dust, both at the galactic plane, and at the QUBIC sky patch. We have done this for the TD, and for the full instrument (FI), illustrating the capabilities of QUBIC to characterize the dust even in its TD (reduced) configuration.

Study of the noise and Covariance matrices

We are involved and very interested in the on-going study of the noise of the QUBIC experiment. We have contributed to the computation of a large sample of end-to-end simulations to recover maps from which to compute the noise, and study their properties. The angular power spectrum is then computed for those maps, and subsequently, the covariance matrices can be calculated. This was done for multiple configurations of the instrument parameters, including different numbers of reconstructed sub-frequencies within each frequency broadband. The properties of the noise in the maps thus found were used to feed in a fast simulator code that computes noise maps with the correct anti-correlation between sub-frequency maps, and proper spatial correlation within the map, which can also been seen in the angular power spectrum of the noise map.

Development of a component separation method (in progress)

The CMB signal is contaminated with galactic foregrounds, such as the emission of thermal dust at high frequencies, or the synchrotron emission at low frequencies. Contrary to the CMB which is independent of frequency, each foreground has a distinct spectral behavior. A good separation between the CMB signal and that of the foregrounds, using data at different frequencies, is of utmost importance to be able to disentangle the primordial B modes.

We have developed a likelihood package for the computation of a component separation method at the power spectra level, to simultaneously fit the CMB sky and the foregrounds, thus separating the CMB signal. We have used the Covariance matrices computed previously (described above), and analyzed the results when using a larger number of sub-bands. It is expected that the use of more sub-frequencies is suboptimal in terms of the noise, but at the same time, a clear benefit is expected from the spectral information that will allow to separate in a clear way the CMB signal from the foregrounds.

WP7: Outreach

Lead: Beatriz Garcia, ITeDA, Mendoza
Working group members: Mariel Cayla, Clara Duca, Silvina Pérez Alvarez, Facundo Lazarte, Raúl H. Luterstein, Alexis Mancilla, Javier Maya, and Claudia Scoccola,

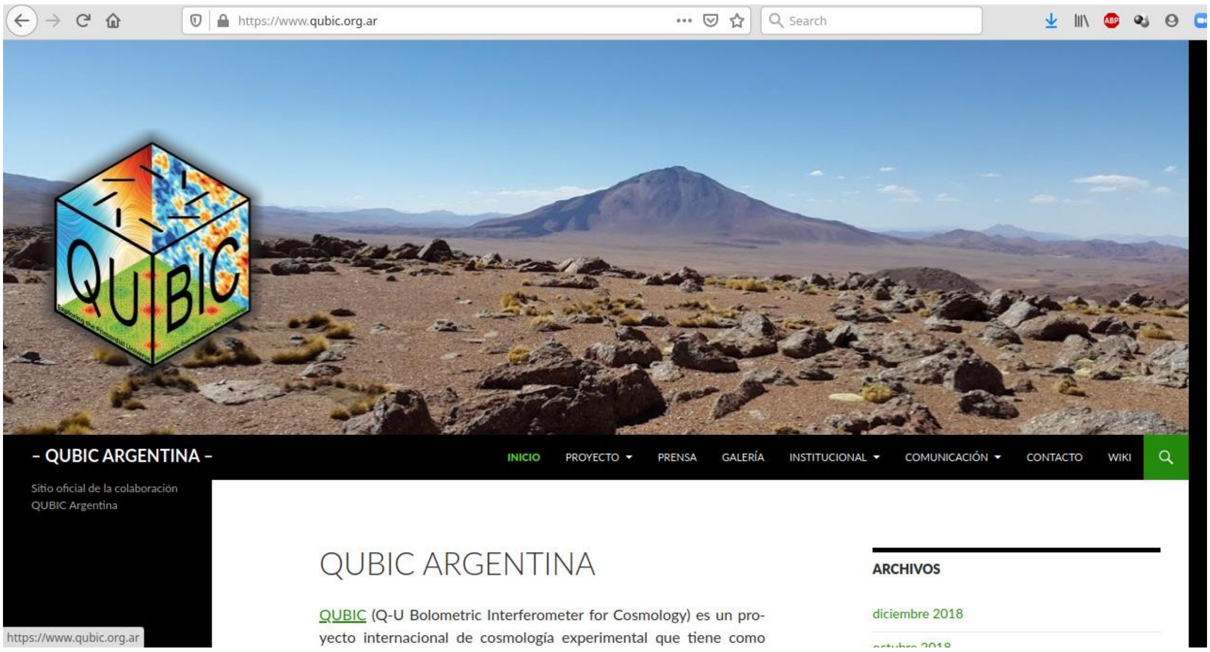
The following tasks have been performed or are in progress:

1. Teachers training courses in didactics of astronomy in Salta City and SAC. Pictures show the Network for Astronomy school education training course in SAC in 2018

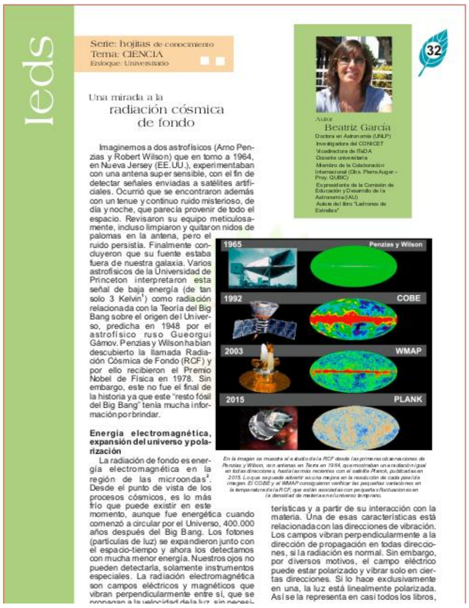
2. Workshops on positional astronomy and on light pollution in SAC


3. Design and construction of interactive modules and 3D models for the visitor center in SAC.

4. Design and maintenance of the website https://www.qubic.org.ar/



5. Publication of dissemination articles in “Ciencia Hoy” and “Hojitas del Conocimiento” (CNEA)



leds

Serie: hojitas de conocimiento
Tema: CIENCIA
Enfoque: Universitario

32

Una mirada a la
radiación cósmica de fondo

Autor
Beatriz García
Doctora en Astronomía (UNLP)
Investigadora del CONICET
Vicedirectora de ITeDA
Docente universitaria
Miembro de la Colaboración Internacional (Obs. Pierre Auger – Proy. QUBIC)
Expresidente de la Comisión de Educación y Desarrollo de la Astronomía (IAU)
Autora del libro "Ladrones de Estrellas"

Imaginemos a dos astrofísicos (Arno Penzias y Robert Wilson) que en torno a 1964, en Nueva Jersey (EE.UU.), experimentaban con una antena super sensible, con el fin de detectar señales enviadas a satélites artificiales. Ocurrió que se encontraron además con un tenue y continuo ruido misterioso, de día y noche, que parecía provenir de todo el espacio. Revisaron su equipo meticulosamente, incluso limpiaron y quitaron nidos de palomas en la antena, pero el ruido persistía. Finalmente concluyeron que su fuente estaba fuera de nuestra galaxia. Varios astrofísicos de la Universidad de Princeton interpretaron esta señal de baja energía (de tan solo 3 Kelvin[1]) como radiación relacionada con la Teoría del Big Bang sobre el origen del Universo, predicha en 1948 por el astrofísico ruso Gueorgui Gámov. Penzias y Wilson habían descubierto la llamada Radiación Cósmica de Fondo (RCF) y por ello recibieron el Premio Nobel de Física en 1978. Sin embargo, este no fue el final de la historia ya que este "resto fósil del Big Bang" tenía mucha información por brindar.

En la imagen se muestra el estudio de la RCF desde las primeras observaciones de Penzias y Wilson, con antenas en Tierra en 1964, que mostraban una radiación igual en todas direcciones, hasta las más recientes con el satélite Planck, publicadas en 2015. Lo que se puede advertir es una mejora en la resolución de cada pixel de la imagen. El COBE y el WMAP consiguieron verificar las pequeñas variaciones en la temperatura de la RCF, que están asociadas con pequeñas fluctuaciones en la densidad de materia en el universo temprano.

Energía electromagnética, expansión del universo y polarización

La radiación de fondo es energía electromagnética en la región de las microondas[2]. Desde el punto de vista de los procesos cósmicos, es lo más frío que puede existir en este momento, aunque fue energética cuando comenzó a circular por el Universo, 400.000 años después del Big Bang. Los fotones (partículas de luz) se expandieron junto con el espacio-tiempo y ahora los detectamos con mucha menor energía. Nuestros ojos no pueden detectarla, solamente instrumentos especiales. La radiación electromagnética son campos eléctricos y magnéticos que vibran perpendicularmente entre sí, que se

terísticas y a partir de su interacción con la materia. Una de esas características está relacionada con las direcciones de vibración. Los campos vibran perpendicularmente a la dirección de propagación en todas direcciones, si la radiación es normal. Sin embargo, por diversos motivos, el campo eléctrico puede estar polarizado y vibrar solo en ciertas direcciones. Si lo hace exclusivamente en una, la luz está linealmente polarizada. Así se la representa en casi todos los libros,

leds

Serie: hojitas de conocimiento
Tema: CIENCIA
Enfoque: Público en General

33

Una mirada al
Observatorio QUBIC
Investigando el comienzo del Universo

Autor
Beatriz García
Doctora en Astronomía (UNLP)
Investigadora del CONICET
Vicedirectora de ITeDA
Docente universitaria
Miembro de la Colaboración Internacional (Obs. Pierre Auger – Proy. QUBIC)
Expresidente de la Comisión de Educación y Desarrollo de la Astronomía (IAU)
Autora del libro "Ladrones de Estrellas"

Este proyecto internacional prevé la construcción de un observatorio en el norte argentino, con laboratorio y equipamiento de altísima tecnología. Su objetivo principal es, mediante la medición muy precisa de la radiación cósmica de fondo (RCF), investigar sobre los primeros instantes de existencia del Universo.

¿Qué es QUBIC?

QUBIC[1] es un proyecto internacional de vanguardia, destinado a detectar características especiales de la radiación cósmica de fondo, tal como contamos en la primera Hojita[2]. Las instalaciones del observatorio contarán con el instrumento sensor propuesto por la Colaboración QUBIC, que puede considerarse un telescopio, pero que no trabaja con luz visible, sino con radiación fuera de la región de energía que puede detectar nuestro ojo, en la región de las microondas. Este telescopio está encerrado en una carcasa cilíndrica o crióstato de 1,8 m de alto y 1,6 m de diámetro, que lo protege y mantiene a una temperatura muy baja (-269°C). Está abierto al cielo por medio de una ventana de 45 cm de diámetro de polietileno rígido, transparente a la radiación de microondas que se desea medir (150 y 220 GHz). Las señales se detectan mediante un conjunto de 1.024 fotodetectores, que conforman algo muy parecido a una cámara digital. Luego, a través de la aplicación de dos técnicas llamadas interferometría y bolometría, se analizan las características de la radiación registrada. Mantener el equipo a tan baja temperatura requiere disponer de un complejo sistema de refrigeración, especialmente diseñado para QUBIC.

Futuro laboratorio en donde se realizarán las pruebas cuando QUBIC llegue a Argentina (CNEA - Regional Noroeste y Regional Centro)

Un proyecto científico internacional

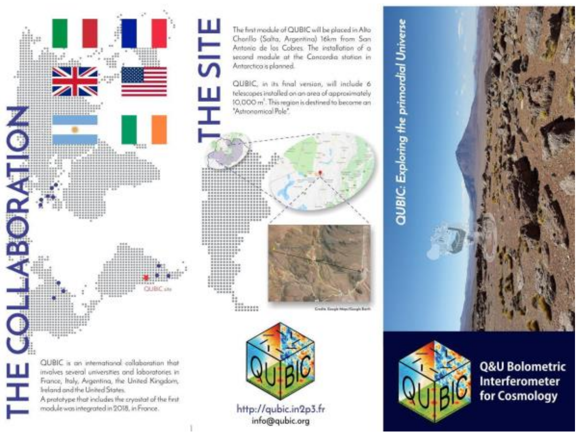
La colaboración internacional está integrada por Francia, Italia (países que son los

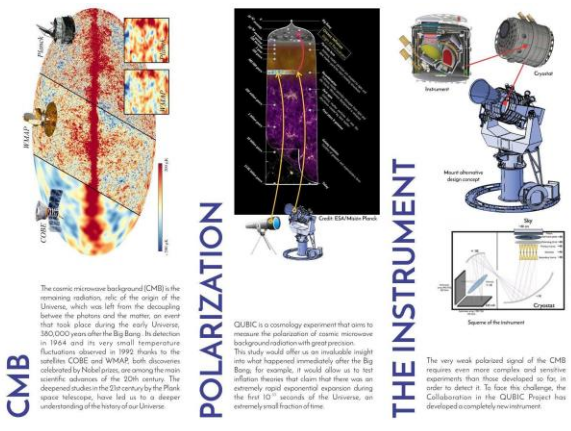
cuenta con el apoyo de investigadores de CNEA, IB, CONICET, UNSAM, UNLP e IAR. Cada país aporta al proyecto de diversas maneras; por ejemplo, Italia diseñó y fabricó el crióstato, Francia los sensores de luz y la electrónica de control, Reino Unido produjo la lámina polarizadora y Argentina está a cargo de la preparación del sitio donde se instalará el instrumento, del laboratorio en donde se los probará cuando llegue a Argentina, en la Regional Noroeste de la CNEA (Salta), antes de llevarlo a la montaña, del diseño, fabricación e instalación del albergue y el domo y finalmente, de la montura del telescopio. El proyecto ha involucrado hasta ahora más de 200 investigadores. El sitio elegido para su instalación está muy cerca de la localidad de San Antonio de los Cobres (Salta, Argentina), a una altura de 4.900 metros sobre el nivel del mar. El telescopio se comenzará a instalar a fines de 2019 y se estima comenzará a adquirir datos en 2020. Los descubrimientos asociados a este proyecto, las tecnologías que podemos desarrollar a partir de él y la formación de recursos humanos en nuestro país, podrían llevar a Argentina al primer nivel de investigación en el mundo. Si bien hay varios grupos de investigación que están intentando detectar el modo B de polarización de

6. Presentation of conferences related to the project for the general public (since March of 2020, online)

7. Presentations at national and international Congresses, Symposium and Workshops of general activity in QUBIC Collaboration (including presentations at IAU meetings)

8. QUBIC flyer in Spanish and English





9. Scientific tourism
Discussions are being held with the Ministry of Tourism of the Salta Province in order to organize scientific tourism in SAC possibly combined with trips on the “Tren a las Nubes” (https://trenalasnubes.com.ar/inicio-en/).