QUBIC in Argentina

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Resumen / QUBIC (*Q&U Bolometric Interferometer for Cosmology*) es un proyecto de cosmología experimental para medir los modos B en la polarización de la radiación cósmica de fondo, reliquia fósil que revela las propiedades del Universo 380.000 años después de la era de Planck. El descubrimiento de la radiación cósmica de fondo en 1964 y la medición de pequeñas anisotropías en su temperatura en 1992 representaron significativos avances en nuestra comprensión del Universo. El siguiente desafío es medir con suficiente precisión la polarización de la radiación cósmica de fondo, ya que la detección de modos B revelaría la presencia de ondas gravitacionales primordiales, producidas en las primeras etapas de la Era de Panck, y permitiría poner a prueba las teorías de inflación, que postulan una expansión exponencial extremadamente rápida durante los primeros 10^{-33} segundos del Universo. El modo B, sin embargo, está asociado con una señal extremadamente débil y requiere de experimentos e instrumentos complejos para su medición. La colaboración QUBIC ha desarrollado el concepto de interferometría bolométrica, que busca reunir a la sensibilidad de los detectores bolométricos con el control de los efectos sistemáticos permitido por interferometría. QUBIC es una colaboración internacional en la que participan varias universidades y laboratorios en Francia, Italia, Reino Unido y EEUU. Recientemente, Argentina ha presentado como sitio candidato para la instalación de este experimento a Alto Chorrillo (Salta) cerca del sitio LLAMA. En esta presentación describiremos los objetivos científicos y las características de este experimento, y detallaremos el proceso a través del cual la Colaboracion Internacional QUBIC decidió la instalación en la Argentina del primer módulo y cuáles son los desafios para nuestro país en este proyecto.

Abstract / QUBIC (Q&U Bolometric Interferometer for Cosmology) is an experimental cosmology project to measure the B modes in the polarization of the cosmic background radiation (CBR), the fossil relic that reveals the properties at the Universe 380,000 years after the Planck Era. Discovery of the CBR in 1964 and measurement of tiny temperature anisotropies in 1992 were major breakthroughs in our understanding of the Universe. The next challenge is to measure the polarization of the CBR accurately enough to detect B modes that would reveal the existence of primordial gravitational waves produced in the first stages of the Planck Era and probe inflation theory, that assumes an accelerated expansion during the first 10^{-33} seconds. The B mode signal is however extremely weak and its measurement requires complex instruments. The QUBIC collaboration has developed the concept of interferometric bolometry, that brings together the sensitivity of bolometric detectors with the control of systematic effects provided by interferometry. QUBIC is an international collaboration involving several universities and laboratories in France, Italy, United Kingdom and USA. Recently, Argentina has suggested Alto Chorrillo (Salta), as candidate site for the installation of the experiment, next to the LLAMA site. Here we describe the scientific objectives and the main features of the experiment and we detail the process through which the international collaboration decided to install in Argentina its first module as well as the challenges for our country in this project.

Keywords / cosmology: cosmic background radiation, observations, inflation

1. Introduction and scientific motivation

The Cosmic Background Radiation (CBR) are the oldest photons that permeate the Universe. They provide a window to explore its conditions when their temperature was about 1000 times larger than their present 2.72 K. At that time, 380,000 years after the Big-Bang, electrons and protons combined into neutral atoms, and thus the CBR decoupled from matter. Slight primordial inhomogeneities in the matter density distribution that acted as seeds for the formation of galaxies and other large scale structures in the universe manifest themselves today as small anisotropies in the CBR temperature. They were measured for the first time in 1992 (Smoot et al., 1992). Subsequent experiments have measured with increasing precision the angular structure in the CBR temperature anisotropies, and determined the parameters of the standard cosmological model with high precision (Planck Collaboration et al., 2016).

The CBR was predicted to be linearly polarized (Rees, 1968) soon after its discovery by Penzias and Wilson (Penzias & Wilson, 1965). The polarization is induced by anisotropic Thomson dispersion right before the CBR decouples from matter. This small effect was experimentally verified for the first time by the

Degree Angular Scale Interferometer (DASI), located in the South Pole, in 2002 (Kovac et al., 2002).

Polarization of the CBR can also be induced by gravitational waves (Polnarev, 1985; Crittenden et al., 1993; Harari & Zaldarriaga, 1993) and its measurement could provide a test of the predictions of inflationary cosmological models and determine the energy scale at which inflation took place in the early Universe. Temperature T anisotropies and those in the Stokes parameters Q and U can be characterized by an expansion in spherical harmonics (with spin 2 in the case of polarization) as follows:

$$\begin{aligned} T &= \sum_{lm} a^T_{lm} Y_{lm} \\ (Q \pm iU) &= \sum_{lm} a^{(\pm 2)}_{lm} Y^{(\pm 2)}_{lm} \ . \end{aligned} \tag{1}$$

An alternative description in terms of E and B modes reveals the dynamics of the electrons that induced polarization at the time of decoupling: B modes measure their vorticity. The coefficients for the E and B modes are given by the linear combinations (Seljak & Zaldarriaga, 1997; Kamionkowski et al., 1997)

$$\begin{aligned} a^E_{lm} &= -(a^{(+2)}_{lm} + a^{(-2)}_{lm})/2 \\ a^B_{lm} &= -(a^{(+2)}_{lm} - a^{(-2)}_{lm})/2i \ . \end{aligned} \tag{2}$$

E modes are parity invariant, while B modes change sign under a parity transformation. Scalar fluctuations at first order generate E modes only, while tensor fluctuations can produce both. The footprints of gravitational waves in the polarization of the CBR are more evident than those imprinted upon its temperature anisotropy. Weak gravitational lensing effects can turn E modes into B modes (Zaldarriaga & Seljak, 1998), an effect that has already been observed at angular scales smaller than few arcmin (Hanson et al., 2013; The Polarbear Collaboration, 2014). This indirect contribution can be disentangled from the B modes produced by gravitational waves through its different dependence on the angular scale.

The relative intensity between the tensor and scalar fluctuations predicted by inflation is typically characterized by the dimensionless quantity r :

$$r = \frac{\langle h^2 \rangle}{\langle (\delta\rho/\rho)^2 \rangle} \ , \tag{3}$$

where h is the amplitude of the gravitational waves and $\delta\rho/\rho$ are the relative density fluctuations. In first approximation $r = 8M^2_{\mathrm{Planck}}(V'/V)^2$, where $M_{\mathrm{Planck}} \approx 10^{19}$ GeV is Planck's mass, and V' is the derivative of the potential $V(\phi)$ driving inflation. This implies in addition a consistency relation between r and the spectral index of the fluctuations. Measurement of r would reveal the energy scale at which inflation takes place.

Two years ago the BICEP2 experiment, located just next to where DASI measured E modes for the first time in 2002, made the first detection of B modes in the sky at degree angular scales (Bicep2 Collaboration, 2014), with an instrument operating at 150 GHz and scanning a region of the sky in which the galactic contamination was expected to be negligible, compatible with a value $r = 0.2$. Subsequent analysis, in particular using data from the Planck satellite at several other frequencies, revealed (BICEP2/Keck and Planck Collaborations et al., 2015) that a substantial fraction (if not all) of the signal measured by BICEP2 is due to polarized emmisssion by galactic dust. The search for primordial B modes in the CBR is still a major challenge, pursued by several experimental efforts.

2. The instrument

QUBIC is a novel kind of instrument (QUBIC Collaboration, 2011, 2016), that combines the background-limited sensitivity of Transition-Edge-Sensors (TES) and the control of systematics allowed by the observation of interference fringe patterns. It will operate at two different frequencies to help disentangle polarized foregrounds from primordial B mode polarization. Originally planned to be installed in the Concordia station in Antartica, the collaboration has decided in April 2016 to set up its first module in Alto Chorrillos, Salta.

The QUBIC instrument (see Fig. 1) is composed by a cryostat cooled down to 4K using pulse-tubes. The cryostat is open to the sky with a 45 cm diameter window made of high-density polyethylene. After the window, filters ensure a low thermal load inside the cryostat and a rotating Half-Wave-Plate modulates the polarization. Then, a polarizing grid selects one of the two polarization angles w.r.t the instrument. An array of 400 corrugated horns selects the baselines observed by QUBIC, and are immediately followed by back-horns re-emitting the signal inside the cryostat towards a telescope that combines on the focal plane the images of each of the secondary horns in order to form interference fringes. Before the focal plane, a dichroic plate splits the signal into its 150 and 220 GHz components that are each imaged on a focal plane equipped with 1024 TES from which 992 are exposed to the sky radiation (blind ones are used for systematics studies) cooled down to 320 mK and read using a multiplexed cryogenic readout system based on SQUIDs and SiGe ASIC operating at 4K. Interferometry offers an improved control of instrumental systematics through the observation of interference fringes that can be calibrated individually, thanks to electromagnetic switches between the primary and secondary horns. The use of bolometric detectors allows to reach a sensitivity comparable to that of an imager with the same number of receivers.

A technological demonstrator of the instrument, with one fourth of the total focal plane, will be assembled in early 2017 and will undergo first tests during this same year in France. It is expected that additional funding for the fabrication of the complete first module will be secured after this first step is completed. The first module is expected to reach a sensitivity $\sigma(r) = 0.01$ after two years of operation in Alto Chorrillos with an overall efficiency of 0.3 (see Fig. 2).

3. The site

The site chosen for the installation of QUBIC's first module is near the city of San Antonio de los Cobres, in the Salta Province. This site has coordinates 24°11′11.7"S; 66°28′40.8"W and an altitude of 4869m

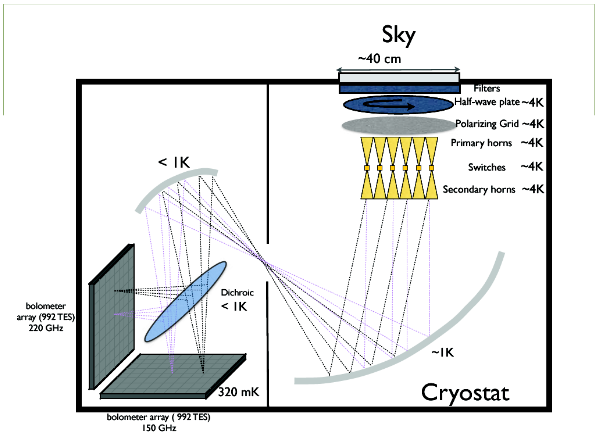

Figure 1: Scheme of the QUBIC instrument

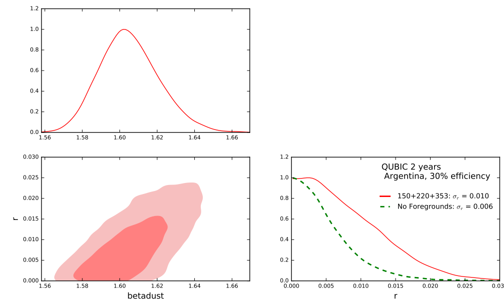

Figure 2: Expected forecast on dust spectral index and r for two years operation in Alto Chorrillos assuming 30% efficiency with Planck 353 GHz information added (red, solid line) and if no foreground were present (green, dashed line)

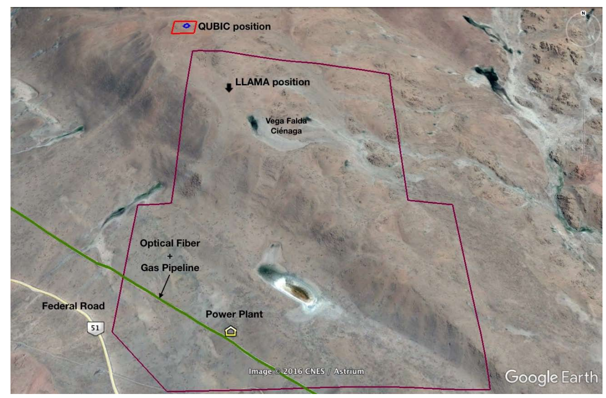

Figure 3: QUBIC site relative to LLAMA postion and available resources

a.s.l. It is located 180 km away from the Chajnantor site in Chile where other millimeter-wave experiments are located (ALMA, ACTPol, PolarBear) and offers similar atmospheric properties. It is next to the location of the Long Latin American Millimeter Array (LLAMA) Project, the joint initiative from Argentinian and Brazilian radio astronomers that is installing a 12 m antenna operating at millimeter and submillimeter wavelengths. The LLAMA project has conducted the site characterization studies, in particular related to atmospheric opacity. QUBIC could benefit from the LLAMA installation associated logistics. Fig. 3 depicts the site. The magenta polygon is the 400 hectares area allocated by the government of the Salta province to CONICET for the installation of LLAMA. In this figure we can also see the gas pipeline (green line) that will feed the gas generators for LLAMA and the Vega lagoon, from which the water needed for both instruments can be extracted.

Regarding the general atmospheric conditions, in addition to atmospheric opacity, temperature, humidity and wind speed have been monitored on site for several years. Except during the Bolivian Summer (December to March period) the values of these parameters are within the specifications for QUBIC's smooth operation. In order to confirm the values taken in the specific site and to monitor the atmospheric conditions during at least one year, a weather station has been installed in November 2016.

4. Argentinian participation in QUBIC

Researchers from different Argentinean institutions (CNEA,CONICET, UNLP, and UNSAM) are involved in QUBIC participating in the site development and instrument aspects (TES and MKIDS technology, bolometer mount, simulations). Additional information on some of the local activities and organization can be found at http://fisica.cab.cnea.gov.ar/particulas/html/qubic.

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