QUBIC:

Exploring the primordial universe with QUBIC, the Q&U Bolometric Interferometer for Cosmology

Today eight articles prepared by the QUBIC collaboration will appear on a special issue of the "Journal of Cosmology and Astroparticle Physics". They describe in detail the current configuration of the experiment and the results obtained from the calibration tests. QUBIC is an experiment conceived to explore the physics of the newborn universe, an infinitesimal fraction of a second after the Big Bang. It will achieve its goals by observing the cosmic microwave background, the first light in the universe, in particular by measuring one of its polarized components, the so-called "B-modes". QUBIC is a totally new type of telescope based on the concept of "bolometric interferometry". It will observe the sky from the end of 2022 from its observing site located in Argentina at 5000 m, close to San Antonio de Los Cobres. Following its development and the integration in Europe the instrument arrived at Salta, in Argentina, in July 2021. The tests have confirmed that the instrument is operating as expected.

Scientific context

Despite the impressive progress in cosmology, that is to say in our understanding of the Universe, made over the last few decades several profound questions remain: What is dark matter? What is dark energy? What happened in the first moments of the Universe? QUBIC tries to answer this last question.

The theory of cosmological inflation was proposed in the 1980s to explain the flatness and extreme homogeneity of space-time. More interesting still, inflation provides a physical mechanism for producing primordial density fluctuations in the universe, the seeds that later gave rise to large-scale structure (galaxy clusters, galaxies, stellar structures). Inflation is a period during which the primeval Universe underwent an extremely rapid expansion that lasted for less than one thousandth of a billionth of a billionth of a billionth of a second (10^{-35}s). It was during this rapid expansion phase that density fluctuations formed, which would later give birth to structures in the universe (stars, galaxies, galaxy clusters).

Even though all observations to date are compatible with the theory of inflation, we still do not have direct proof that it actually occurred. It is precisely this proof that QUBIC is searching for. If Inflation took place, calculations show that it should have left tiny traces in the form of primordial gravitational waves, which would themselves leave their imprint on the cosmic microwave background in the form of a certain type of polarisation of the radiation, called B-modes, that no other primordial mechanism could produce. If primordial B-modes are detected it will be direct

proof of the phase of inflation, a major result in cosmology with profound consequences for particle physics. The study of the B-mode pattern will enable the study of fundamental physics at energies that will be impossible to achieve in particle accelerators for centuries to come.

The search for the B-modes presents a considerable challenge for astrophysicists. The expected signal is extremely weak and its detection requires ultra-sensitive detectors and an exceptionally precise telescope. The signal is also affected by the presence of non-primordial B-modes (especially those produced by dust in our own galaxy) which must be removed. The topic of B-mode polarisation is at the heart of modern cosmology and the Grüber prize in Cosmology was this year awarded to three physicists for their theoretical work on this question, one of whom, Matías Zaldarriaga is Argentinian and is a close collaborator with QUBIC.

QUBIC

QUBIC is an instrument that was specifically designed to detect the B-mode polarization and is the result of a collaboration between 130 researchers and engineers in France, Italy, Argentina, the United Kingdom and Ireland. In particular, the instrument has been integrated in France at the APC laboratories (Paris) during 2018, and tested in 2019-2020. The Italian collaboration includes research groups at Sapienza Università di Roma, Università degli Studi di Milano, Università di Milano Bicocca, Università di Roma Tor Vergata and corresponding sections of Istituto Nazionale di Fisica Nucleare, with funding from Programma Nazionale Ricerche in Antartide and INFN.

The Italian contribution has been key for the instrument development. The cryostat, designed and built by Sapienza Università di Roma (INFN Roma-1 section), is able to cool the detectors and all the optical system to temperatures close to absolute zero. The same team has also realized the cryo-mechanical system that rotates the optical components enabling polarization measurements. The advanced corrugated antennas that receive the sky photons have been developed by the University of Milan (INFN Milano section), while the University of Milano Bicocca developed the optical system focussing the radiation onto the detectors and a shutter system allowing the so-called “self-calibration” of the interferometer. The University of Roma Tor Vergata (INFN Roma-2 section) contributes to the development of the complex data analysis software.

The QUBIC concept is completely novel and it is the first ‘bolometric interferometer’, an instrument that combines the extreme sensitivity of bolometric detectors, cooled to -273°C, with the precision of interferometry. In addition, QUBIC offers the possibility of spectro-imaging, that is the simultaneous measurement of the colour of each pixel in an image, the only way of subtracting out the non-primordial B-modes. QUBIC will be installed on the plateau de La Puna in the north of Argentina, at an altitude of 5000 m and near the village of San Antonio de los Cobres in Salta Province. The instrument arrived at Salta in July 2021 and is undergoing tests in the integration hall that was built for QUBIC on the CNEA Regional Noroeste site. The tests have confirmed that the instrument arrived safely from France and is operating as expected. The infrastructure on the site is being completed (after a series of delays due to the pandemic) and the installation of the instrument on the observing site is planned for later in 2022.

Silvia Masi (Sapienza Università di Roma and INFN Roma-1 section), Italian QUBIC coordinator, underlines that “*QUBIC is an original and extremely complex instrument: for this reason it is necessary to publish as soon as possible all the hardware details and the new techniques to exploit its data. Furthermore, our calibration tests have allowed us to demonstrate in the laboratory the concept of bolometric interferometry applied to QUBIC. This is a key step before the forthcoming sky observations that will impact cosmology and fundamental physics.*” Aniello Mennella (University of Milan and INFN Milano section) adds: “*QUBIC will be deployed at the Alto Chorrillo site in a few months. The first measurements will demonstrate the novel method of bolometric interferometry not only in the laboratory but, for the first time, by observing astronomical sources. The instrument will be then upgraded with a larger number of detectors to be able to carry out cosmological measurements in about three years. It is still a long way to go and QUBIC plays its role as an approach that is original and complementary to all the others that are trying to measure this faint primordial signal*”. Mario Zannoni (University of Milano Bicocca and INFN Milano Bicocca section) reminds that “*The measurement of such an elusive signal will be considered free from systematic effects only if the results will be confirmed by various and different instruments. For this reason QUBIC, which is the only bolometric interferometer, is an irreplaceable asset in the quest for the B-modes and in the exploration of the first instants in the*

universe." Giancarlo De Gasperis (University of Roma Tor Vergata and INFN Roma-2 section): "*Its spectral imaging and self-calibration capabilities will allow QUBIC to produce data that will be original and complementary to those produced by competing experiments, and will offer data analysts a wide range of cross-checks and an unmatched robustness in the final results.*"

International context

QUBIC is in competition with a half dozen other instruments researching the primordial B-modes: BICEP/KECK, CLASS, SPIDER from the United States, Ali-CPT in China and the Japanese satellite project (with a significant European contribution) LiteBIRD (planned for 2033). All are variations on the classical telescope concept and don't offer what QUBIC can in terms of the measurement purity and spectral imaging that one gets from interferometry. The sensitivities of the instruments are comparable and, of course, the final B-mode discovery will have to be confirmed independently by various groups in order for it to make an impact on the scientific community and beyond.

Further reading

QUBIC web page: http://qubic.in2p3.fr/
Scientific papers:

- Special JCAP issue (Journal of Cosmology and Astroparticle Physics)

Contacts:

Jean-Christophe Hamilton, Spokesperson and Principal Investigator of QUBIC,
Research Director at APC (Paris) - CNRS-IN2P3 - hamilton@apc.in2p3.fr - tel: +33 6 88 01 06 75

In Italy:

Prof. Silvia Masi, coordinatrice Italiana
Dipartimento di Fisica di Sapienza Università di Roma e INFN sezione di Roma, tel. +39 06 49914271, silvia.masi@roma1.infn.it

Prof. Aniello Mennella
Dipartimento di Fisica, Università degli studi di Milano e INFN sezione di Milano, tel. +39 02 50317275, aniello.mennella@fisica.unimi.it

Prof. Mario Zannoni
Dipartimento di Fisica, Università degli studi di Milano Bicocca e INFN sezione di Milano Bicocca, tel. +39 02 64482379, mario.zannoni@mib.infn.it

Dr. Giancarlo De Gasperis
Dipartimento di Fisica, Università degli studi di Roma Tor Vergata e INFN sezione di Roma2, tel +39 06 72594091
giancarlo.degasperis@roma2.infn.it