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The QUIJOTE experiment: project overview and first results

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Abstract

QUIJOTE (Q-U-I JOint TEnerife) is a new polarimeter aimed to characterize the polarization of the Cosmic Microwave Background and other Galactic and extragalactic signals at medium and large angular scales in the frequency range 10–40 GHz. The multi-frequency (10–20 GHz) instrument, mounted on the first QUIJOTE telescope, saw first light on November 2012 from the Teide Observatory (2400 m a.s.l). During 2014 the second telescope has been installed at this observatory. A second instrument at 30 GHz will be ready for commissioning at this telescope during summer 2015, and a third additional instrument at 40 GHz is now being developed. These instruments will have nominal sensitivities to detect the B-mode polarization due to the primordial gravitational-wave component if the tensor-to-scalar ratio is larger than $r = 0.05$.

1 Introduction

The study of the Cosmic Microwave Background (CMB) temperature anisotropies by missions like *WMAP* [1] or *Planck* [11], and previous ground-based and balloon-borne experiments, have allowed the determination of cosmological parameters to unprecedented accuracy. While the addition of E-mode polarization data have allowed to tighten further these constraints, the detection of the B-mode polarization could potentially provide a confirmation of the existence of primordial gravitational waves created by inflation, the epoch of exponential expansion in the primordial Universe [8, 14]. Recently, the first primordial B-mode detection was claimed in data from the BICEP2 experiment at 150 GHz, with a level of the tensor-to-scalar ratio $r = 0.20^{+0.07}_{-0.05}$ [2]. However, data from the *Planck* satellite have shown that the level of polarized dust emission in the region of the sky covered by BICEP2 could form a significant component of the measured signal [12]. It is well recognised that any unambiguous detection of the B-mode anisotropy requires a detailed assessment of the level of foreground contamination and ideally confirmation by independent experiments operating at different frequencies. The QUIJOTE (Q-U-I JOint TEnerife) experiment [13, 9], thanks to its wide frequency coverage (10-40 GHz), will provide the characterization of the polarization of the synchrotron and anomalous microwave emission (AME), and of the B-mode signal down to a sensitivity of $r = 0.05$. Updated information of the project can be found in `http://www.iac.es/project/cmb/quijote`.

2 Project baseline

The QUIJOTE experiment is a scientific collaboration between the Instituto de Astrofísica de Canarias, the Instituto de Física de Cantabria, the IDOM company, and the universities of Cantabria, Manchester and Cambridge. The project consists of two telescopes and three instruments covering the frequency range $10-40$ GHz, with an angular resolution of $\sim 1^{\circ}$, and located at the Teide observatory (2400 m) in Tenerife (Spain). This site provides excellent atmospheric conditions for CMB observations, as demonstrated by many previous experiments. Data obtained with the first QUIJOTE experiment throughout one year shows

Figure 1: Left: QT1 (background) and QT2 (front) inside the enclosure, at the Teide observatory. Right: MFI, during integration tests (December, 2011).

that the zenith atmosphere temperature is on average ~ 2 K at 11 GHz and $\sim 4--6$ K at 19 GHz, while the PWV column density is typically between 2 and 4 mm.

The first QUIJOTE telescope (QT1) is currently fitted with the multi-frequency instrument (MFI), which has four frequency bands centred in 11, 13, 17 and 19 GHz, respectively. It saw first light on November 2012, and ever since is performing routine observations of different fields. Some results obtained with this experiment will be presented in Section 3. The second QUIJOTE telescope (QT2) was installed at the observatory on July 2014. This telescope will be fitted with the thirty-gigahertz instrument (TGI), consisting in 31 polarimeters at 30 GHz and which will start commissioning on April 2015. A third set of detectors, the forty-gigahertz instrument (FGI) is being constructed at the time of writing (January 2015). Figure 1 shows photos of QT1, QT2 and the MFI.

In Table 1 we show the nominal characteristics of the three QUIJOTE experiments. The noise equivalent power for each frequency band is computed as:

$$\mathrm{NEP}_{\mathrm{MFI}} = \frac{T_{\mathrm{sys}}}{\sqrt{\Delta\nu}} \quad , \quad \mathrm{NEP}_{\mathrm{TGI,FGI}} = \sqrt{2}\frac{T_{\mathrm{sys}}}{\sqrt{\Delta\nu N_{\mathrm{chan}}}} \quad , \tag{1}$$

where T_{sys} stands for the total system temperature, $\Delta\nu$ is the bandwidth and N_{chan} the number of channels (computed here as the number of horns times the number of output channels per horn). The NEPs are different for MFI compared to TGI and FGI because of their different strategies for measuring the polarization. In the MFI it involves differentiating pairs of channels, whereas the TGI and the FGI will make use of electronic modulation providing an instantaneous measurement of Q and U for each channel. The MFI parameters measured using real observations are in good agreement with the nominal parameters shown in Table 1. In particular, the measured Q and U NEPs are in the range $644--792$ μK $s^{1/2}$ for different frequency channels. In total intensity I, where the instrument knee frequencies are worse ($f_{\mathrm{k}} \sim 0.1$–1 Hz for Q and U and $f_{\mathrm{k}} \sim 10$–100 Hz for I) the instantaneous sensitivities are typically a factor ~ 2.5 worse.

Specific experimental details about the telescopes and instrument can be found in previous proceedings [5, 6, 7], and will be presented in extended papers that are in preparation.

Table 1: Nominal characteristics of the three QUIJOTE instruments: MFI, TGI and FGI. Sensitivities are referred to Stokes Q and U parameters.

	MFI				TGI	FGI
Nominal frequency [GHz]	11	13	17	19	30	40
Bandwidth [GHz]	2	2	2	2	10	12
Number of horns	2	2	2	2	31	31
Channels per horn	4	4	4	4	4	4
Beam FWHM (°)	0.92	0.92	0.60	0.60	0.37	0.28
$T_{\rm sys}$ [K]	25	25	25	25	35	45
NEP [μK $s^{1/2}$]	559	559	559	559	44	52
Sensitivity [Jy $s^{1/2}$]	0.61	0.85	0.62	0.77	0.06	0.07

3 Science cases and first results

3.1 Core science

The QUIJOTE project is envisaged to achieve two primary scientific goals: to detect the B-mode signal from primordial gravitational waves down to a sensitivity $r = 0.5$; and to determine the polarization properties of the synchrotron and anomalous microwave emissions from our Galaxy at low frequencies (10–40 GHz). To meet these goals we will perform two polarization surveys:

i) a wide Galactic survey. It covers around $20,000$ deg^2 and after 6 months of observations with each instrument it will have a final sensitivity of ~ 25 μK beam^{-1} at 11, 13, 17 and 19 GHz (MFI), ~ 4 μK beam^{-1} at 30 GHz (TGI) and ~ 6 μK beam^{-1} at 40 GHz (FGI). Currently we have finished this survey with the MFI, accumulating 7 months of data;

ii) a deep "cosmological" survey. It will encompass around $3,000$ deg^2 . Here we shall obtain a sensitivity of ~ 5 μK beam^{-1} after 2 years of observations with the MFI (11–19 GHz), and ~ 1 μK beam^{-1} with the TGI (30 GHz) and with the FGI (40 GHz).

According to these nominal sensitivities, QUIJOTE will provide one of the most sensitive measurements of the polarization of the synchrotron and anomalous microwave emissions in the frequency rage 10–20 GHz. This is essential as the B-mode signal is known to be subdominant over the Galactic synchrotron in our frequency range. Using the MFI maps from the deep survey we will be able to correct the TGI (30 GHz) and FGI (40 GHz) maps from these emissions, leaving residual signals below the instrumental noise sensitivities. According to the forecasted sensitivities in the deep cosmological survey, we have shown in a previous publication[13] that after 1 year of effective observing time over $3,000$ deg^2 with the TGI we could reach a sensitivity on the tensor-to-scalar ratio of $r = 0.1$ (at the 95% C.L.). The combination of 3 years of effective time with the TGI and 2 years with the FGI (we can observe simultaneously with the two instruments because we have two telescopes) would allow to reach $r = 0.05$.

3.2 Non-core science

So far, we have invested a significant amount of time to observe different fields related with non-core since programmes. Some of these are:

i) Study of the polarization of the Anomalous Microwave Emission (AME). Currently there is very limited observational information about the level of polarization of the AME, and only upper limits, typically at $< 1\%$ [10], have been published. We have dedicated 149 hours to observe a 250 deg^2-region around the Perseus molecular complex, and have derived upper limits on the AME from G159.6-18.5 of $< 6.3\%$ and $< 2.8\%$ respectively at 12 and 18 GHz, a spectral range that had not been covered before in polarization [4]. We have new observations on G159.6-18.5, amounting to 450 hours, and over a smaller area of ~ 30 deg^2, which could potentially lead to upper limits better by a factor ~ 3.

ii) Study of the WMAP haze in polarization. This is a region with an excess of microwave emission in the region around the Galactic centre, initially found in WMAP data, and which was later discovered to have a γ-ray counterpart in Fermi data [3]. One appealing hypothesis is based on hard synchrotron radiation driven by relativistic electrons and positrons produced in the annihilations of one (or more) species of dark matter particles. This hypothesis can be tested by measuring the level of polarization of this emission. So far we have accumulated 406 hours of QUIJOTE data in a ~ 700 deg^2 region around the Galactic centre. In Figure 2 we show QUIJOTE maps at 11 and 13 GHz resulting from 97 hours of data, in comparison with WMAP maps at 23 GHz. A clear correlation can be seen between the polarized structures probed by QUIJOTE and WMAP.

iii) Fan region. The Fan region is one of the brightest features of the polarized radio continuum sky, located around $l = 140°$, $b = 6°$, and long thought to be due to local ($d < 500$ pc) synchrotron emission. This region is an interesting test-bench to assess the potentiality of QUIJOTE to recover diffuse polarized emission. At the time of writing we have accumulated 251 hours of data on a ~ 380 deg^2 region, covering not only the diffuse emission but the point-like emission from the 3C58 SNR.

iv) Study of SNRs. We are interested in the analysis of the spectral energy distributions of SNRs, in order to analyse possible curvatures of the synchrotron spectrum. The wide-survey, which covers the full northern sky, will have enough sensitivity to study different Galactic SNRs. A higher sensitivity is achieved in 3C58 in the Fan observations. We also observe, practically on a daily basis, Tau A, which is our primary calibrator. We have also collected 44 hours in IC443 and 75 hours in W63.

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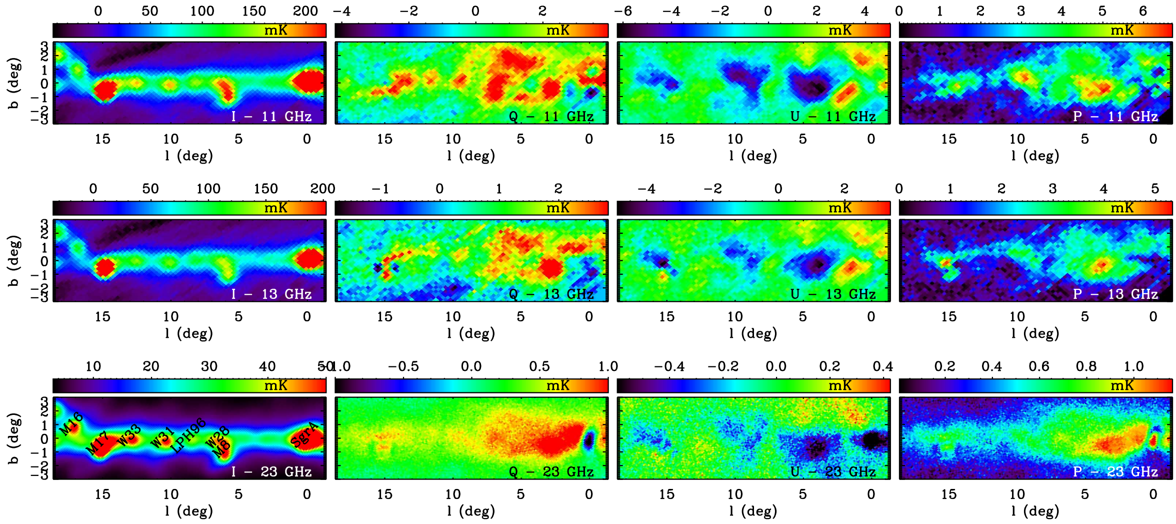

Figure 2: QUIJOTE and WMAP maps along the Galactic centre. We show QUIJOTE maps at 11 and 13 GHz and WMAP maps at 23 GHz. From left to right maps correspond respectively to total intensity Stokes I, Q and U and polarized intensity P. In the WMAP I map we indicate the names of some of the detected regions.

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