The QUIJOTE CMB Experiment

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on behalf of the QUIJOTE Collaboration

The QUIJOTE Collaboration

Q-U-I JOint TEnerife CMB Experiment

The QUIJOTE Experiment

- **Site**: Teide Observatory (altitude 2400 m, 28.3º N, 16.5 W)
- **Frequencies**: 11, 13, 17, 19, 30 and 40 GHz.
- **Angular resolution**: 0.92º to 0.26º
- **Sky coverage**: -32º < Dec. < 88º (fsky=0.65).

- **2 telescopes and 3 instruments:**
  - Two telescopes installed (2012 and 2014)
  - Multi-Frequency Instrument (MFI) with 4 polarimeters at 10-20 GHz. In operation since Nov 2012
  - Second Instrument (TGI) with 31 polarimeters @ 30 GHz. First light in May 2016
  - Third instrument (FGI) at 42 GHz (31 polarimeters).
  - TGI and FGI in joint comissioning phase

- **Observing strategy**: Deep observations in selected areas plus wide survey

Scientific goals

- To provide polarization maps at 6 frequencies in the range 10 - 40 GHz with sufficient sensitivity to correct foreground emission (synchrotron and AME) and to constrain the imprint of B-modes down to r=0.05

- Observational strategy
  - Wide survery

    Covering 20,000 deg^2

    ≈ 15 μK/(beam 1 deg) with the MFI @ 11, 13, 17 and 19 GHz

  - Deep cosmological survey

    It will cover around 3,000 deg^2 in three separated fields. The scientific goal is to reach r=0.05 after 3 years of operations of the TGI+FGI

    10 μK/(beam 1^o) after 1 year with the MFI @ 11, 13, 17 and 19 GHz

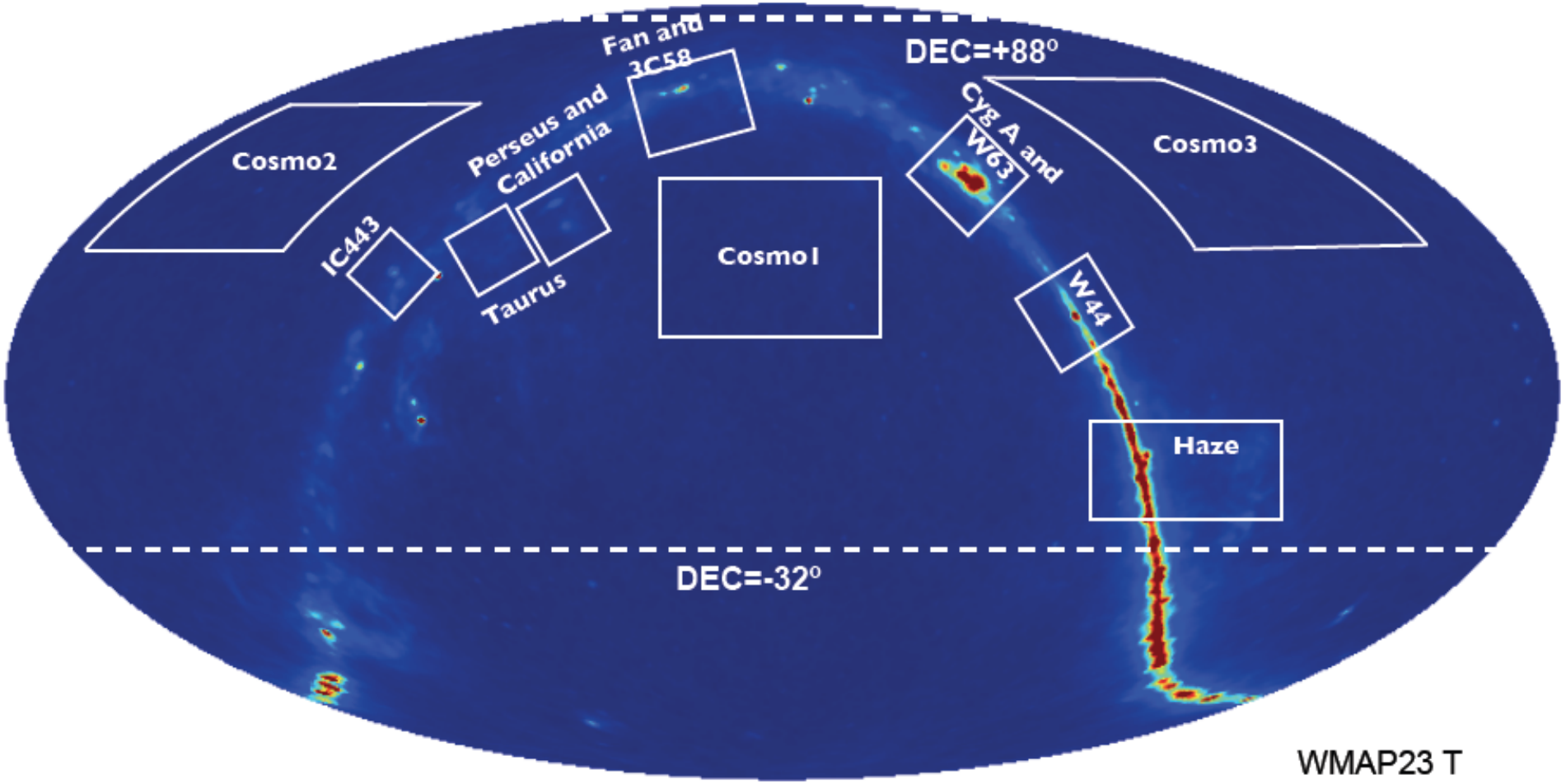
    ≈ 1 μK/(beam 1^o) after 1 year with the TGI and FGI @ 30 and 40 GHz

  - Other Galactic regions

    Covering few hundred deg^2 . To understand radio foregrounds

    ≈ 30-40 μK/(beam 1^o) with the MFI @ 11, 13, 17 and 19 GHz

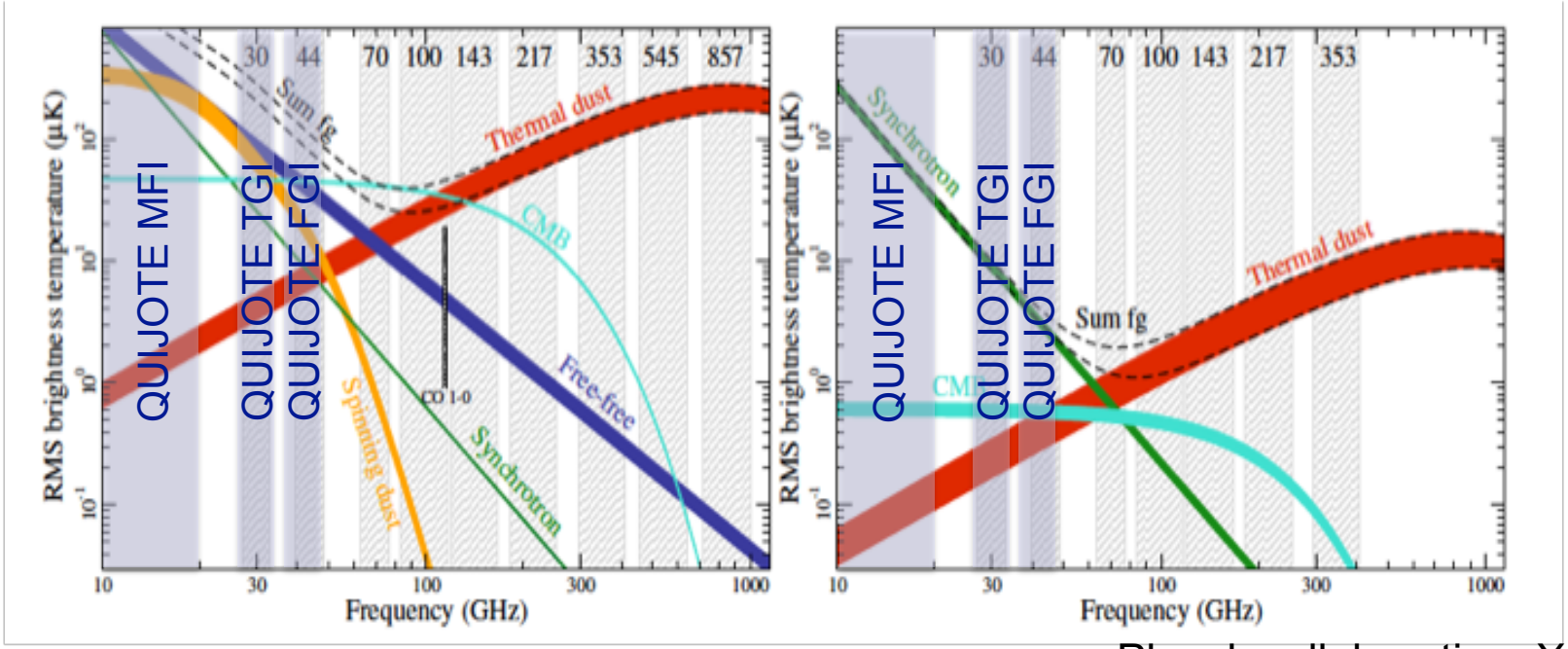
QUIJOTE cosmological and Galactic fields



Observation time: 21.000 hours (2.4 years)

Science with MFI

- The MFI maps provides a unique frequency range (10-20 GHz) to characterise the polarization properties of radio foregrounds:
  - Synchrotron emission: should dominate the emission at the MFI frequencies. WMAP 23 GHz shows it to be polarised at ~5-15%, depending on the Galactic latitude
  - Anomalous microwave emission: little known about its polarisation. Polarization fraction could be at the level < 1-2%

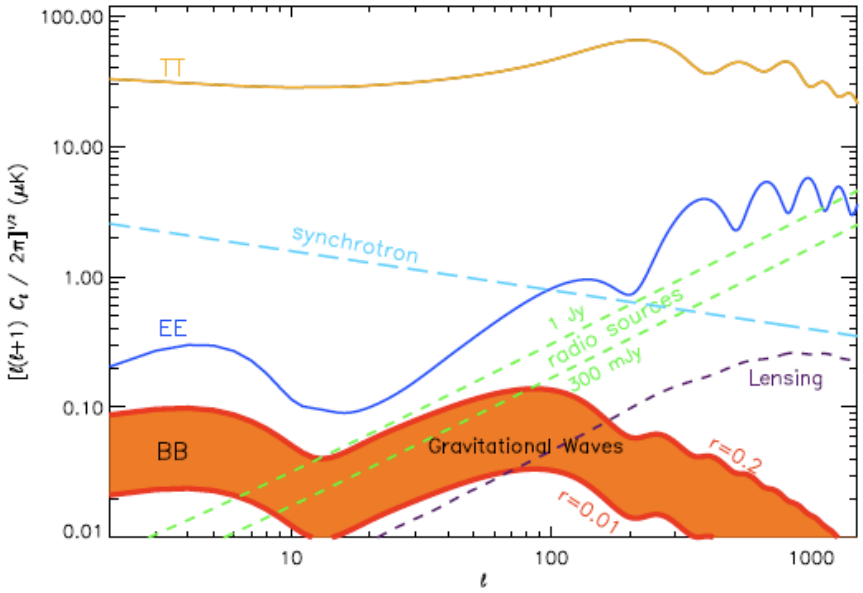


Planck collaboration X (2015)

Science with MFI

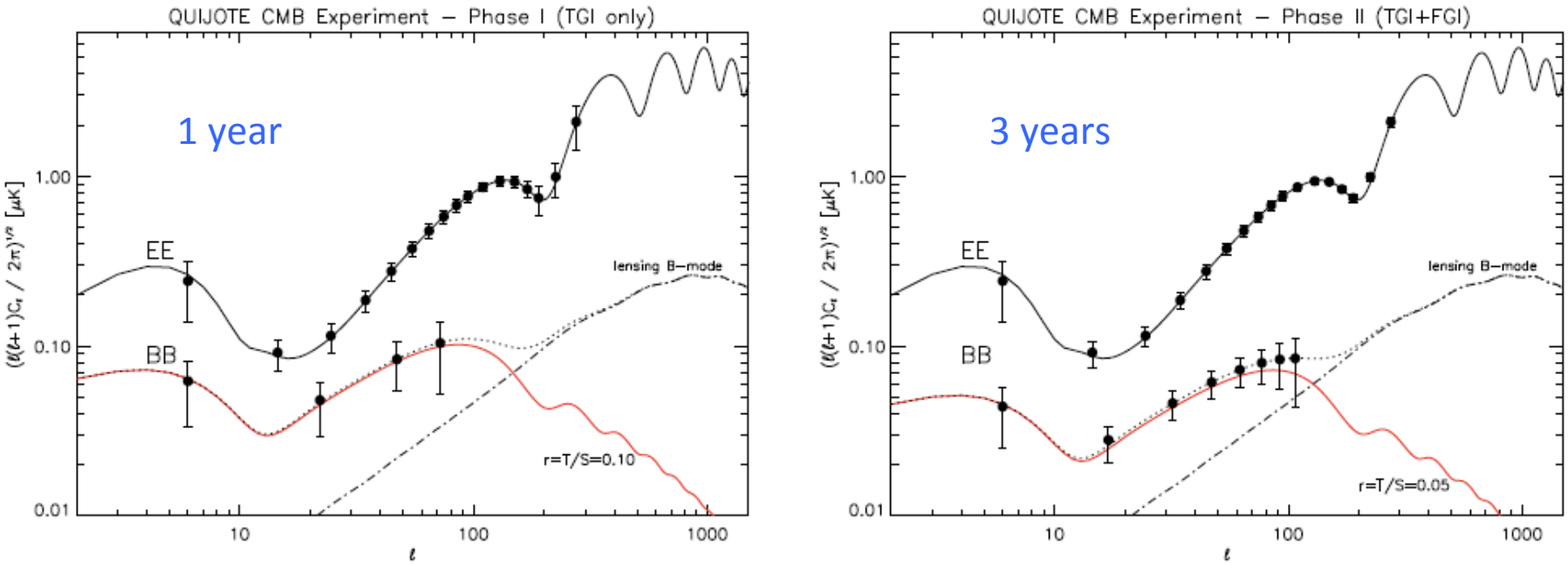
- MFI maps will be used to clean the 30 GHz and 40 GHz maps obtained with the 2nd (TGI) and 3rd (FGI) QUIJOTE instruments.

- Radio-sources: low contribution at degree scales, but potentially relevant for B-modes science ⇨ follow-up observations with VLA to correct for polarised sources selected from PLANCK maps. Observations in different epochs are being performed to study variability



30 GHz

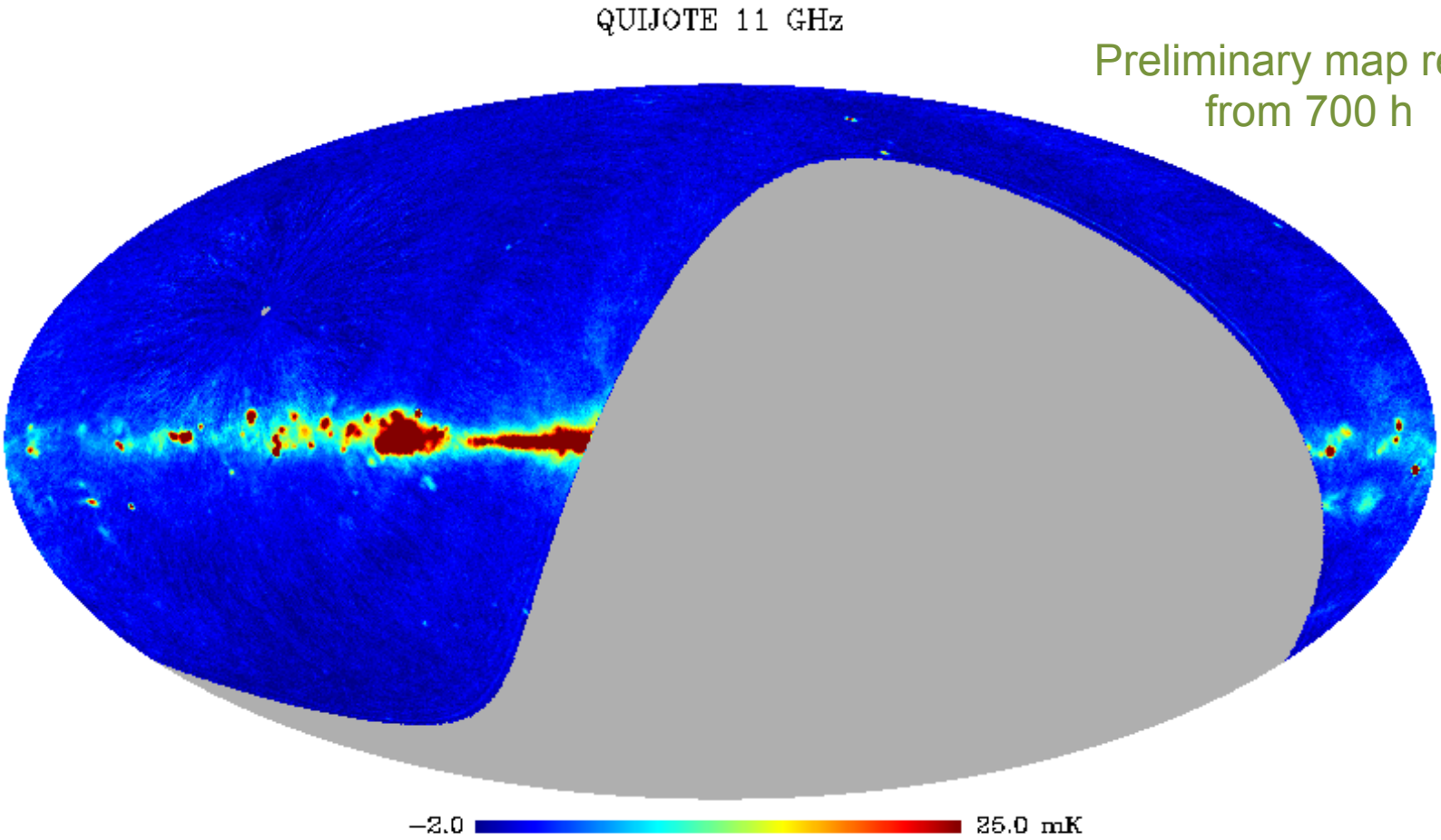
Science with QUIJOTE second (TGI) and third (FGI) instruments



Left: Example of the QUIJOTE scientific goal after 1 year (effective) observing time, and a sky coverage of 3,000 deg^2. The red line corresponds to r = 0.1.
Right: 3 years of effective operations with the TGI plus 2 years of effective operation of FGI. The red line now corresponds to r = 0.05.

Wide survey

- 8,500 hrs on a region of 20,000 deg^2 in the northern sky.
- Still on-going (will reach ~10000 hrs).
- Goal: ~15 μK/beam in polarization



Preliminary map resulting from 700 h

Wide survey

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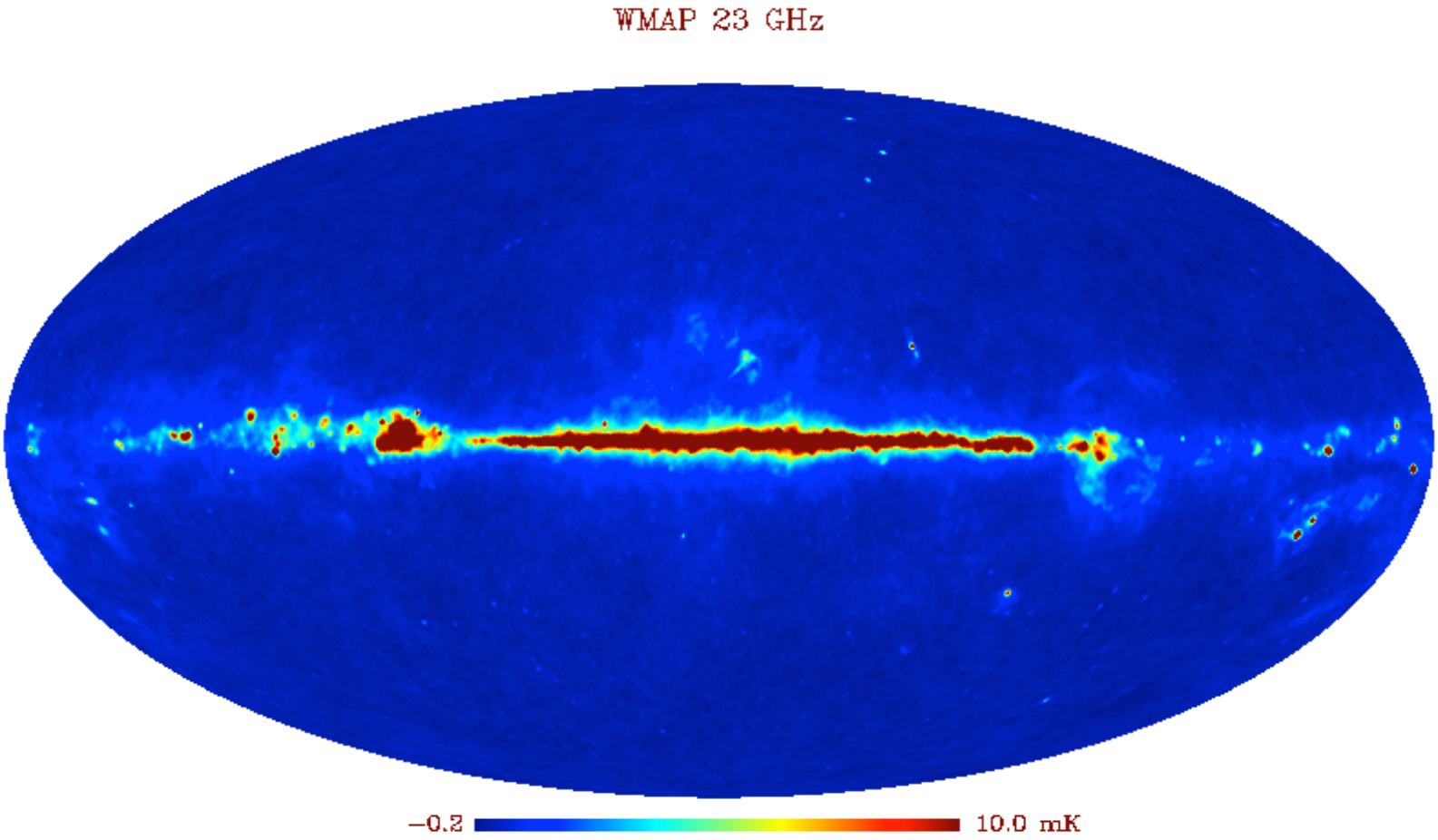
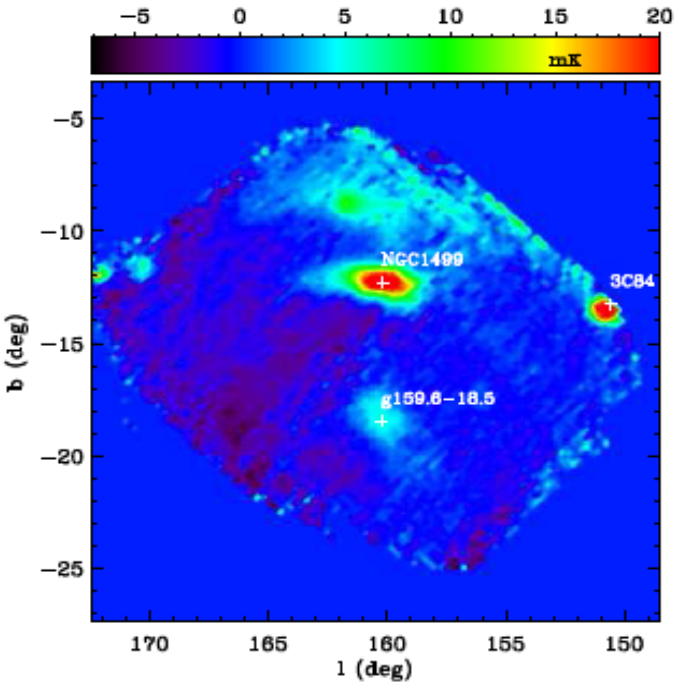


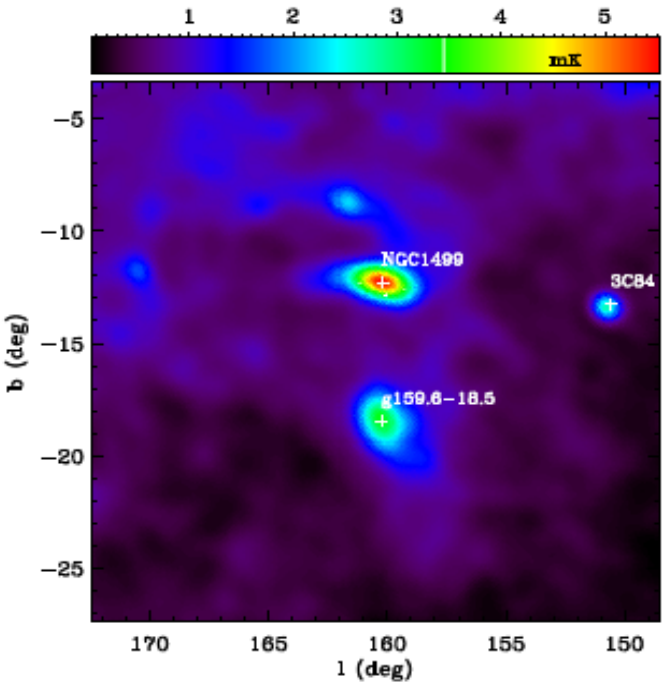
Perseus molecular complex

- Large observation program (~200 hours, 12/2012 to 04/2013), on an area covering ~250 deg^2 around the Perseus molecular complex.
- One of the brightest AME regions on the sky
- Final map sensitivity of ≈30 μK/beam

Quijote 11 GHz



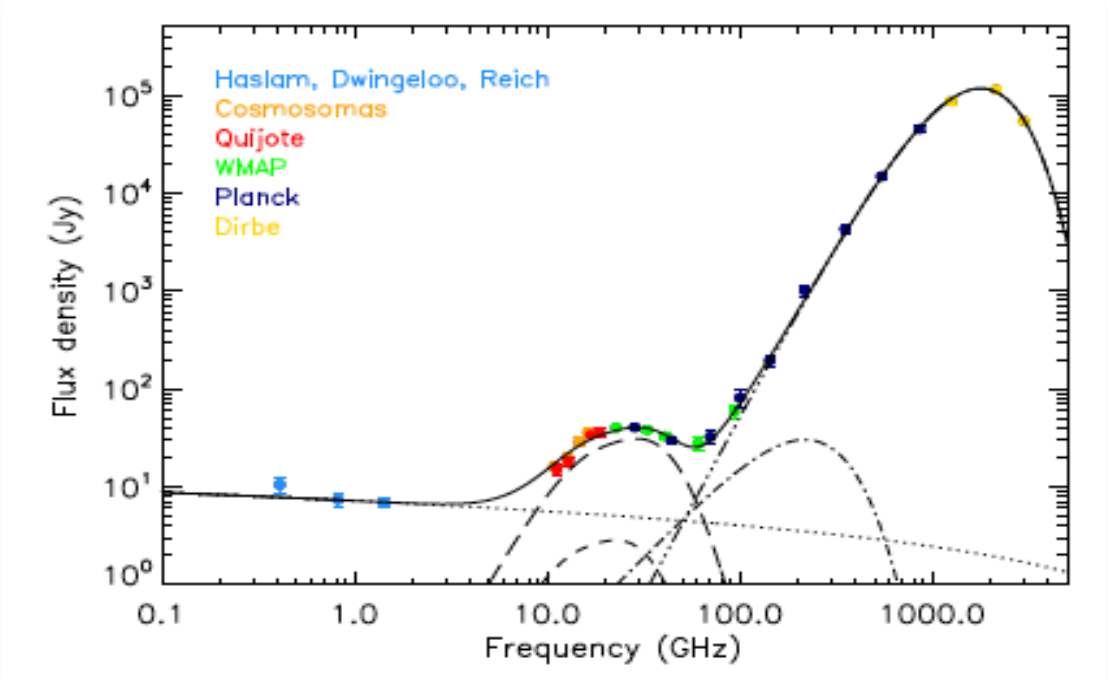
WMAP 23 GHz



Génova-Santos et al. (2015), MNRAS, 452, 4169

Perseus molecular complex

SED modelling on G159.6-18.5 in intensity



- AME (spinning dust) shows up at intermediate frequencies
- Most precise spinning dust spectrum to date (13 independent data points in the relevant range)
- No polarisation detection.
- $\Pi < 6.3\%$ at 12GHz and $< 2.8\%$ at 18GHz (95% C.L.)
- Stronger upper limits have been derived for other regions: W43, W44 and W47 (Génova-Santos et al. 2017)

QUIJOTE: plans

- Upgrade of MFI
  - Increasing sensitivity by a factor ~ 1.7
  - Ready in 2 years (already funded)
- Extension of QUIJOTE to the South Hemisphere
  - In collaboration with Wits University (South Africa)
  - A prototype of an MFI pixel to be constructed (already funded)
  - To be installed and tested at the 7.6m telescope at HartRAO ~ in 1.5 years
  - Plan to install a complete replica of QUIJOTE if the observations with the prototype are successful (not funded yet)

RADIOFOREGROUNDS Project

http://www.radioforegrounds.eu

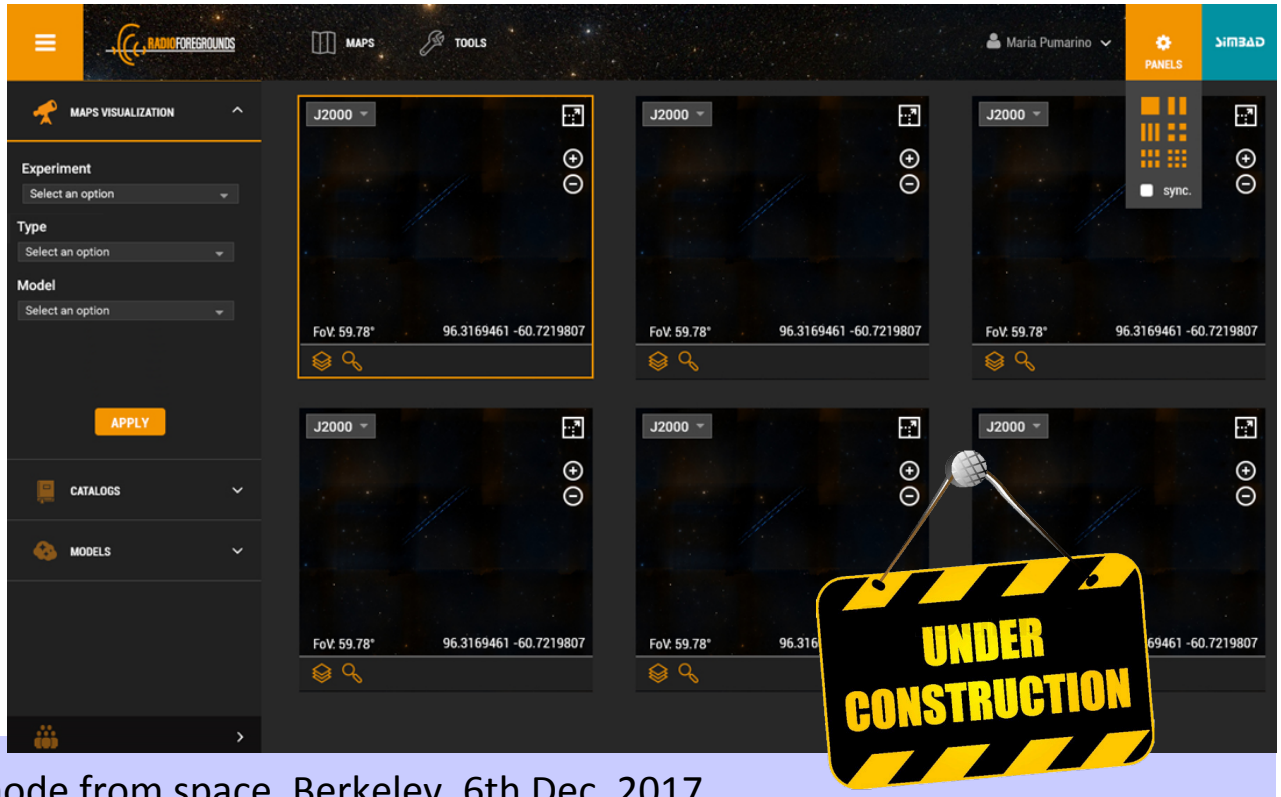
H2020-COMPET-2015. Grant agreement **687312:**
Ultimate modelling of Radio Foregrounds (RADIOFOREGROUNDS).
3-year grant 2016-18 (IAC; UC; Cambridge; Manchester; SISSA; Grenoble; TREELOGIC).

By combining MFI QUIJOTE, Planck and other ancillary data, the project will provide:

- state-of-the-art legacy maps of the synchrotron and the anomalous microwave emission (AME) in the Northern sky
- a detailed characterization of the synchrotron spectral parameters
- a model of the large-scale properties of the Galactic magnetic field
- a detailed characterization of the AME, including its contribution in polarization
- To characterise the population of radio sources measured by Planck by adding unique information at 10-20 GHz
- specific (open source) software tools for data processing, data visualization and public information.

RADIOFOREGROUNDS Project

- Visualization tool for CMB data
- Prediction of foreground maps at a given frequency
- Point source catalogues
- Basic operations with maps
- Work with data base or upload user's maps



Impact of synchrotron

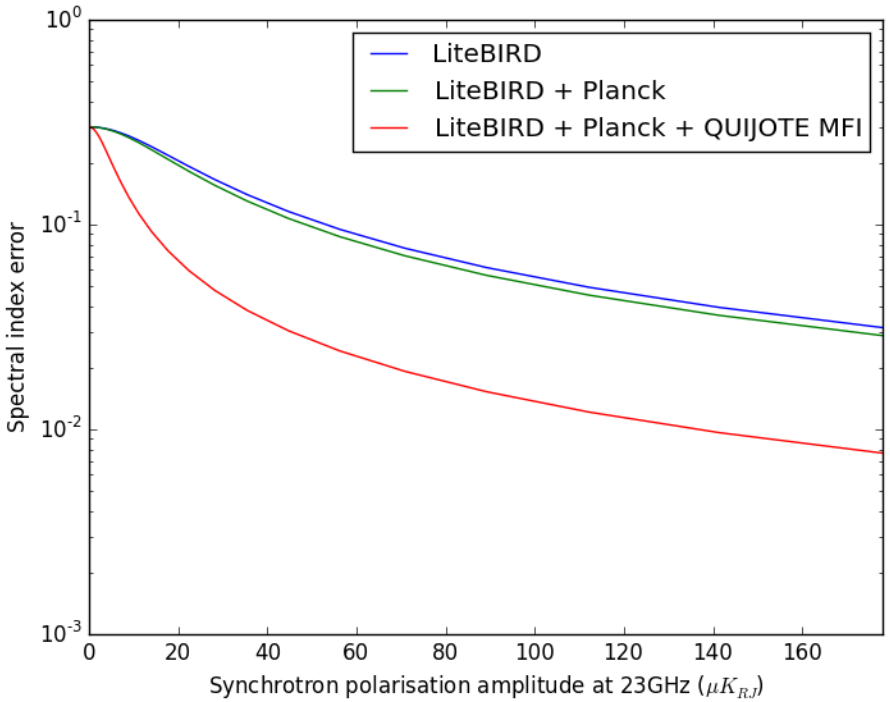
- Even in the cleanest ~1% region of the sky, synchrotron emission could be as large as r_{SYN}=0.005 @ 110 GHz [Krachmalnicoff et al. 2016], so it can not be ignored

- Error $\Delta\beta_s$~ 0.02 ⇒error $\Delta r \sim 10^{-3}$ when extrapolated from 23 to 145 GHz [see talk by M. Remazeilles]

- Low-frequency experiments (as e.g. QUIJOTE) are essential to monitor the synchrotron especially for spatially varying spectral indices [Errard et al. 2015]

Impact of synchrotron

The unique frequency range explored by QUIJOTE MFI (10-20 GHz) provides very useful and complementary information to the future sensitive experiments searching for cosmological B-modes (such as LiteBIRD)



B. Casaponsa et al.

- When adding QUIJOTE MFI [10-20 GHz], errors in the estimation of β_s significantly reduced with respect to using only LiteBIRD [40-400 GHz]
- These frequencies will be even more important if considering more complicated models for synchrotron
- Impact on reducing the level of residuals and the bias on r

Summary

- QUIJOTE is a polarization experiment designed with the aim of reaching the level of r=0.05 in the B-mode angular power spectrum and of characterising the foregrounds at low frequencies
- QUIJOTE is able to measure synchrotron and AME polarization in a frequency range not covered by other experiments so far [10-20] GHz. Excellent complement for future satellite experiments such as LiteBIRD, CORE, PICO and also for other sub-orbital experiments
- First results with MFI providing the best constraints on AME polarization at different regions of the sky already published
- TGI (30 GHz) and FGI (40 GHz) in joint commissioning phase
- Legacy polarization maps (10-40 GHz) and derived products will be publicly available.
- Plans to improve QUIJOTE: upgrade for MFI, extension to the South
- Technological development for the new generation of low-frequency instruments with larger number of detectors, based on an optical correlator (for direct image or interferometry)