Imperial College London

QUIJOTE views of our Galaxy

Mike Peel, on behalf of the QUIJOTE/TMS/GroundBIRD collaborations

NAM, 9 July 2025

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN
UNIÓN EUROPEA
Fondo Europeo de Desarrollo Regional "una manera de hacer Europa"
Ref. de la ayuda: ICTS-2019-03-IAC-12

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INSTITUTO DE ASTROFISICA DE CANARIAS IAC

IFCA Instituto de Física de Cantabria

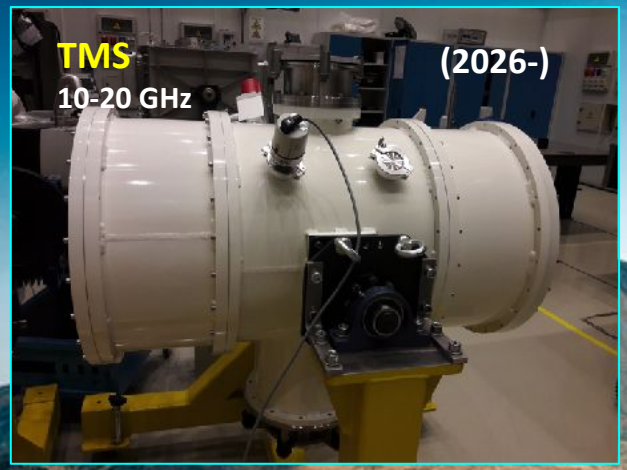
DICOM

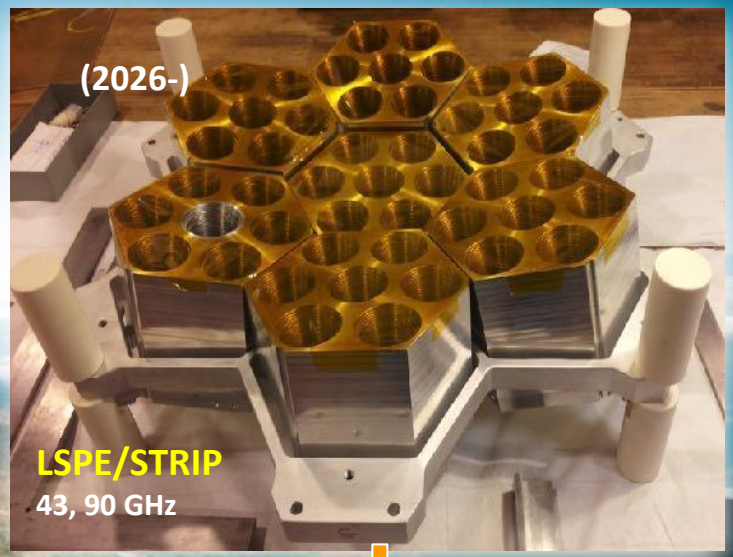
MANCHESTER 1824 The University of Manchester

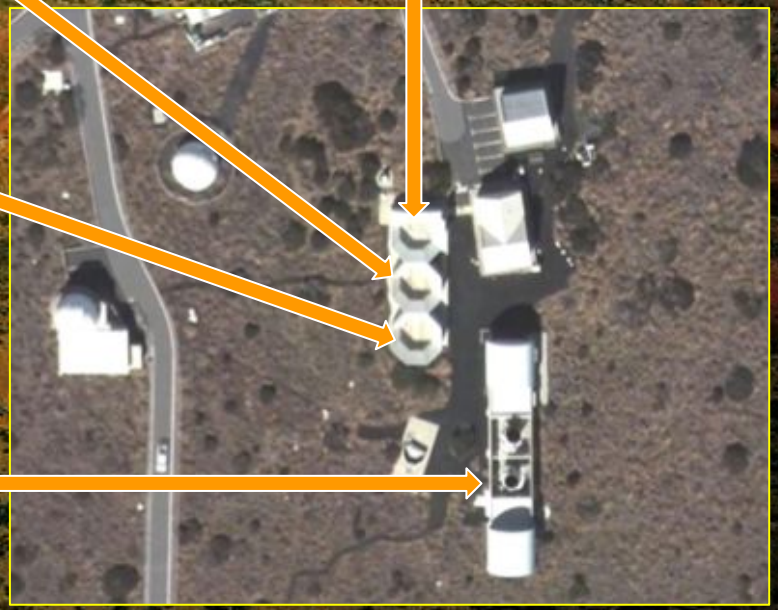
UNIVERSITY OF CAMBRIDGE

idom

Teide Observatory
CMBLab



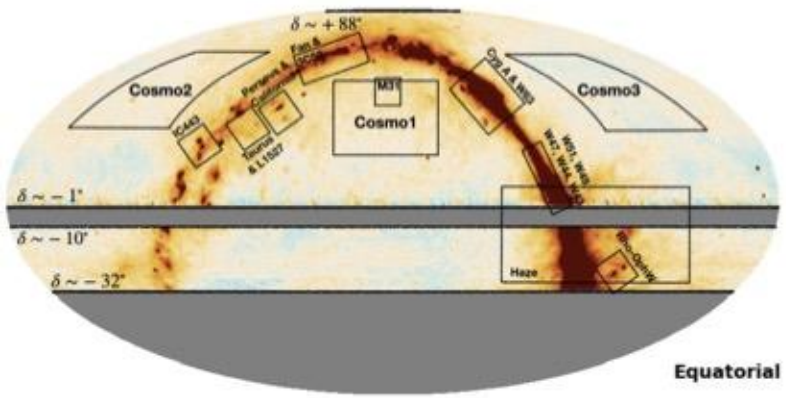




QUIJOTE coverage

Complementary with:
- C-BASS (5GHz)
- WMAP (23+GHz)
- Planck (28+GHz)
- GroundBIRD (150, 220GHz)

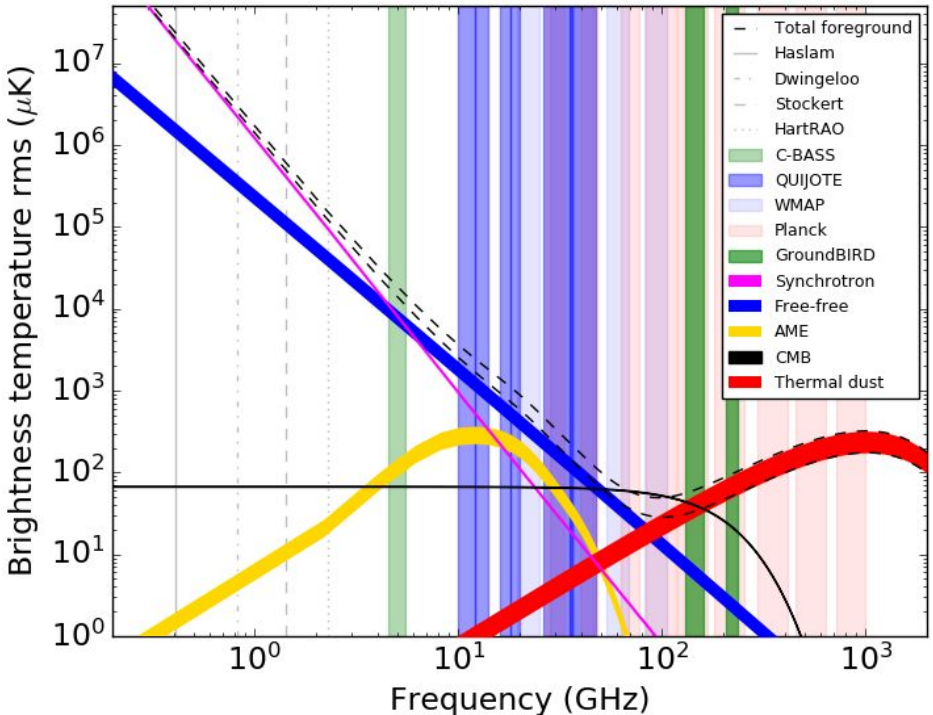
Northern hemisphere observations
- Wide survey (~10,800h)
- Galactic regions (~4,800h)
- Cosmology fields (~6,500h)

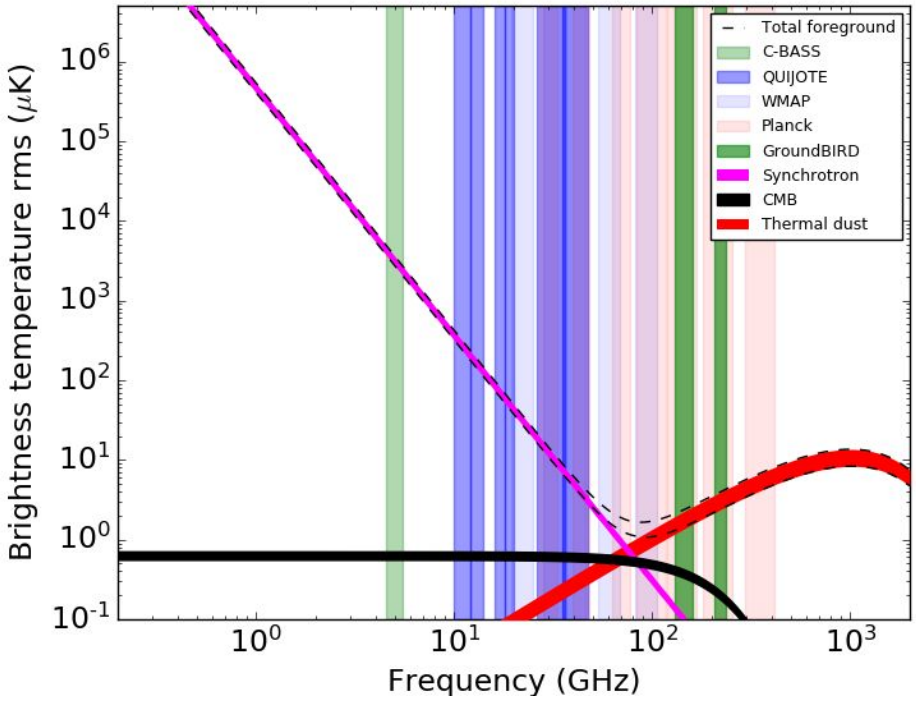


QUIJOTE covers:

Intensity:
- AME peak
- Free-free
- Synchrotron
- CMB

Polarisation:
- Synchrotron
- CMB





The QUIJOTE experiment

(Q-U-I JOint Tenerife Experiment, http://research.iac.es/project/quijote)

QT-1 and QT-2: Crossed-Dragone telescopes, 2.25m primary, 1.9m secondary.

QT-1. Instruments: MFI, MFI2.
11, 13, 17, 19 GHz. Δv=2GHz.
FWHM=0.93º-0.62º
MFI: 2012-18.
MFI2: 2023-

QT-2. Instruments: TGI & FGI
30 and 40 GHz. Δv =10GHz
FWHM=0.37º-0.28º
Commissioning 2018.
Observations re-started 2021.

NGI: 90GHz camera.
500 detectors (KIDs).

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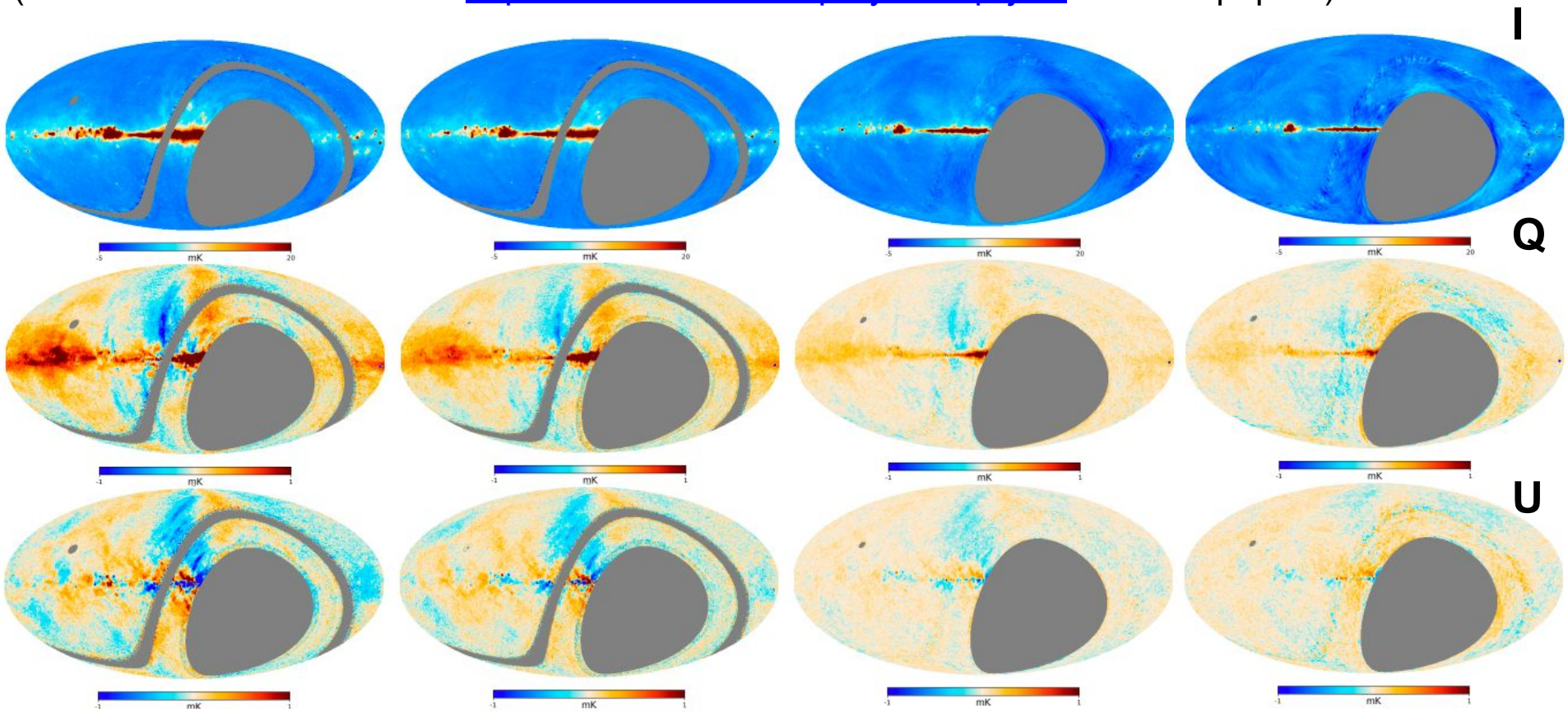
Wide survey with the QUIJOTE MFI (10-20 GHz)

Smoothed 1 deg maps

(Rubino-Martin et al. 2023)

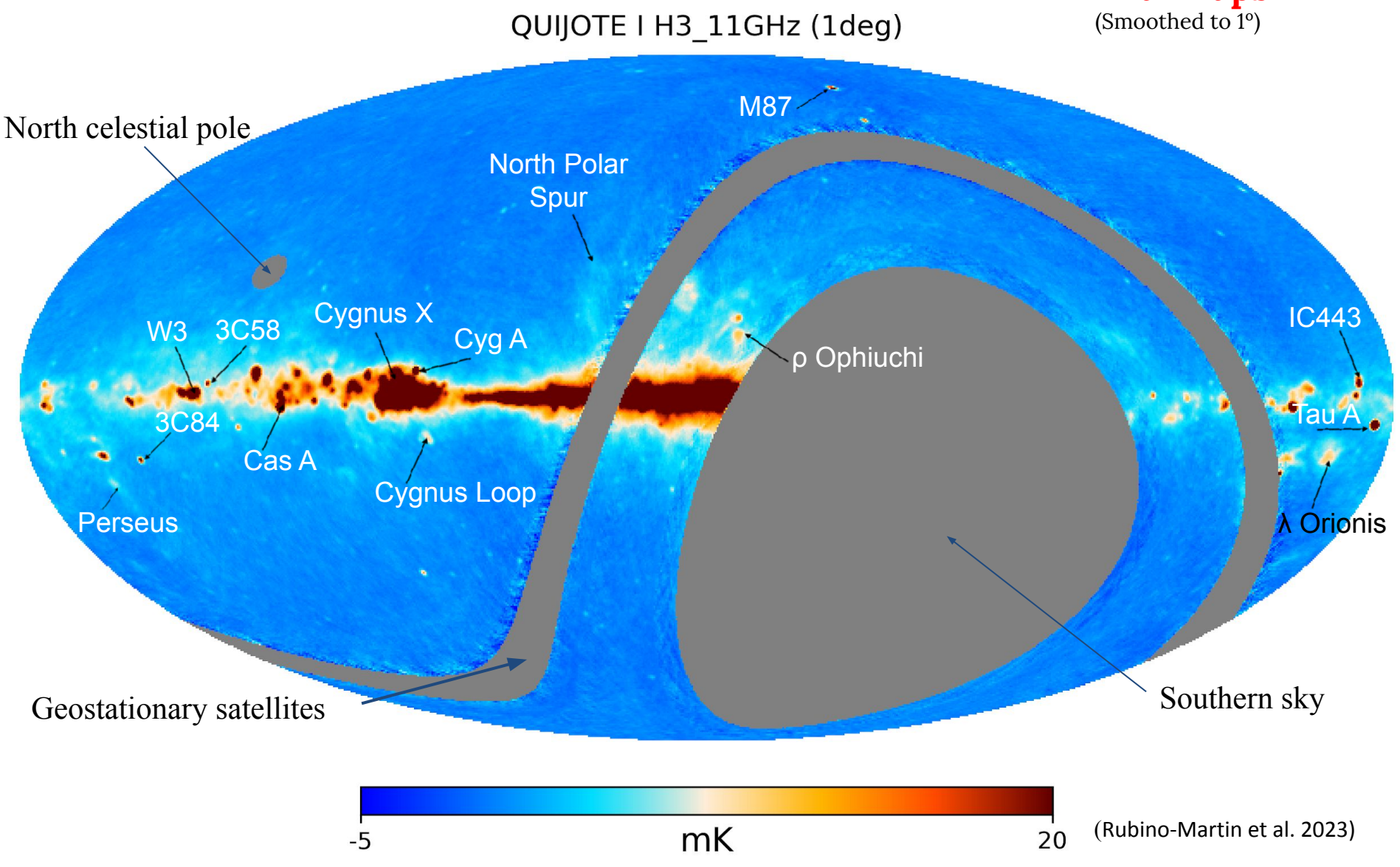
(Data release Jan 12th 2023: https://research.iac.es/proyecto/quijote. First six papers)



Approx. 29,000 deg^2. About 10,000 h of observations. Sensitivities in polarization (Q,U): ~35-40 μK/deg equivalent to 2.4 μK.arcmin @ 100GHz with β=-3.

Wide survey with the QUIJOTE MFI (10-20 GHz)

Final maps
(Smoothed to 1º)



(Rubino-Martin et al. 2023)

Wide survey with the QUIJOTE MFI (10-20 GHz)

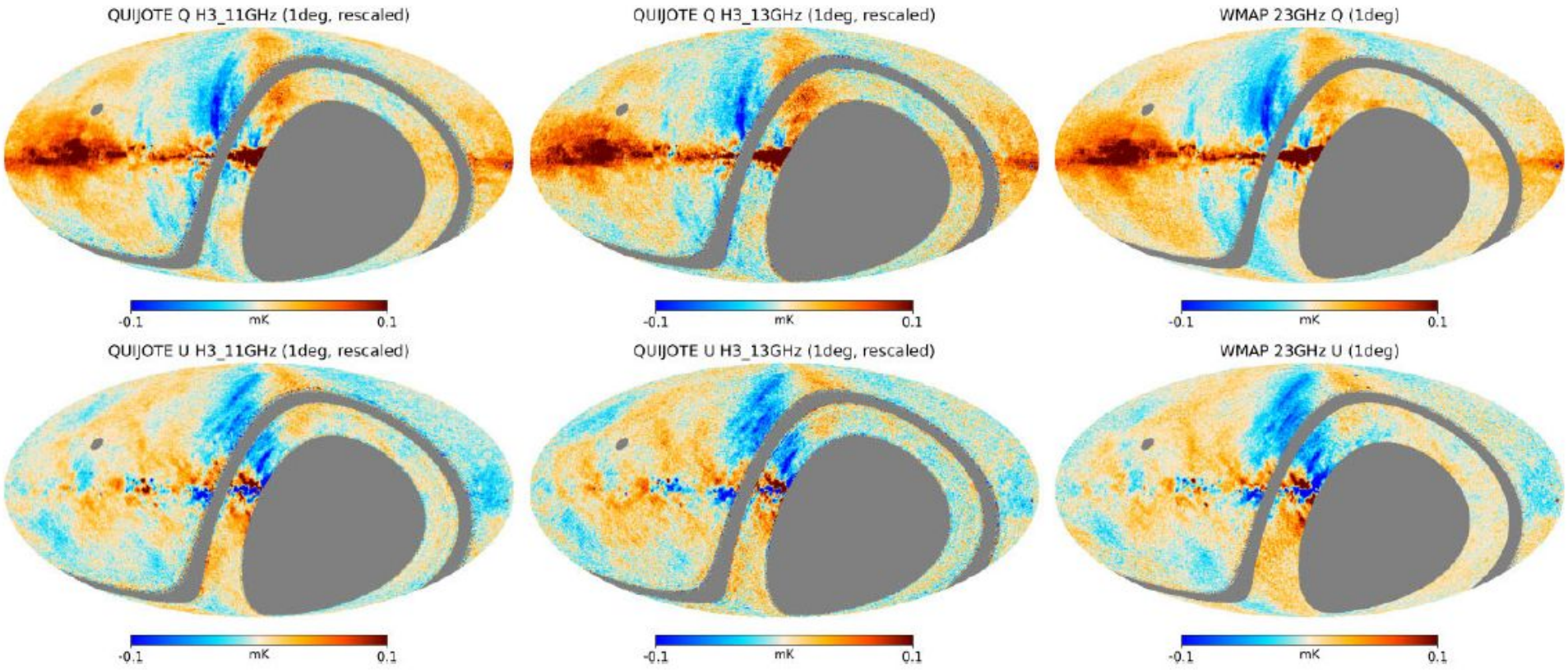
QUIJOTE

WMAP

11GHz

13GHz

23GHz

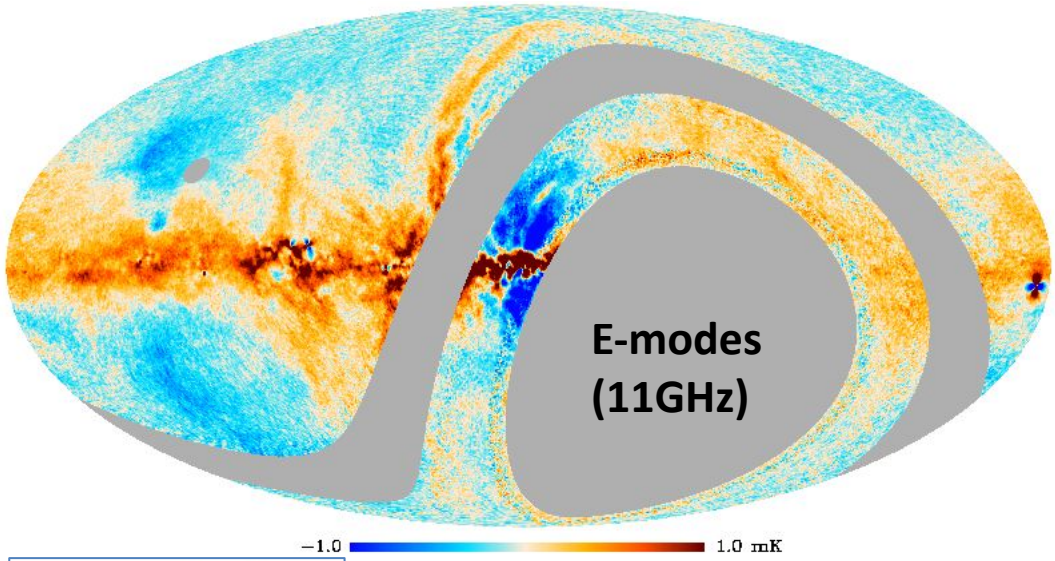


QUIJOTE maps scaled to 23 GHz using β=-3.1 (for synchrotron). Same colour scale in all maps!
For visualization purposes, the QUIJOTE mask is applied to WMAP 23GHz

(Rubino-Martin et al. 2023)

Wide survey with the QUIJOTE MFI (10-20GHz)

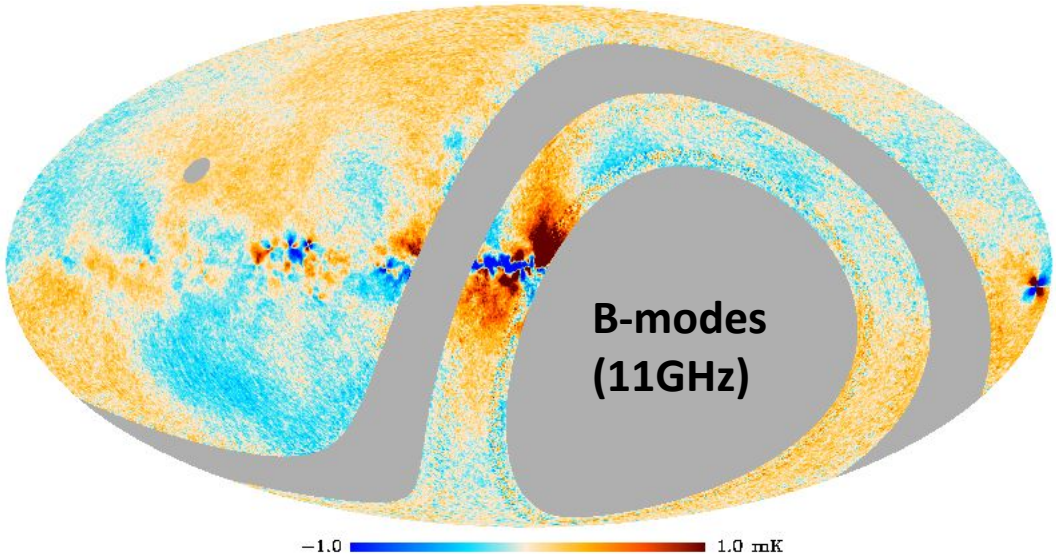
Synchrotron E-B modes and E/B ratio



- Most prominent polarized structures (Fan, NPS, loops) appear in the E-map.
- **EE/BB ratio is approx. 4 at large scales**. Consistent with Martire et al. 2022 (WMAP+Planck).
- Analysis at power spectrum level confirms this result (Vansyngel et al. in prep.)
- For thermal dust, the ratio was closer to 2 (BB/EE~0.5, Planck Collaboration XI 2018).
- We measure **EB and TB consistent with zero**. Positive TE at large angular scales.

$$C_\ell^{XX} = A_{XX}\left(\frac{\ell}{80}\right)^{\alpha_{XX}} + c_{XX}$$

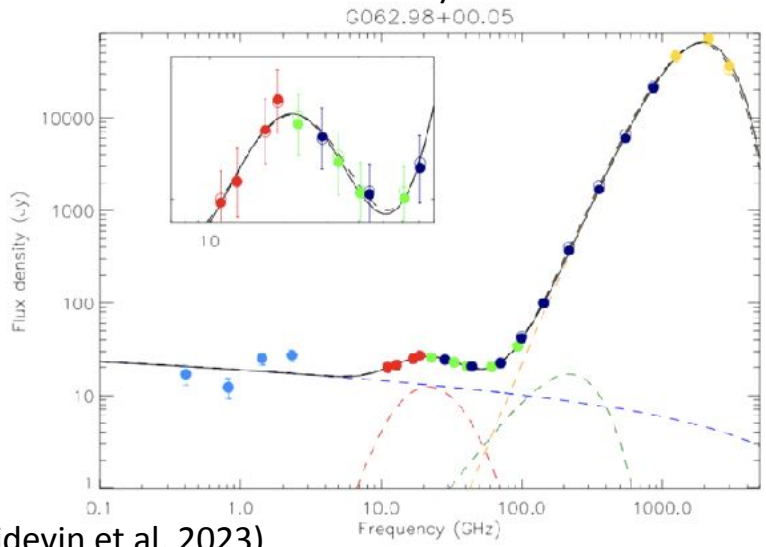
Mask	$\|b\| > 5°$	$\|b\| > 10°$	$\|b\| > 20°$
f_{sky}	0.38	0.34	0.27
	EE and BB fitted separately		
A_{EE} [μK^2]	1.52 ± 0.15	1.05 ± 0.18	0.81 ± 0.19
A_{BB} [μK^2]	0.52 ± 0.15	0.20 ± 0.12	0.18 ± 0.13
α_{EE}	−3.00 ± 0.16	−2.72 ± 0.26	−2.96 ± 0.36
α_{BB}	−3.08 ± 0.42	−3.13 ± 0.87	−3.12 ± 1.03
c_{EE} [μK^2]	0.07 ± 0.09	−0.13 ± 0.11	−0.09 ± 0.12
c_{BB} [μK^2]	0.10 ± 0.09	−0.06 ± 0.09	−0.09 ± 0.09
A_{BB}/A_{EE}	0.34 ± 0.10	0.19 ± 0.12	0.22 ± 0.18
	Joint EE and BB analysis		
A_{EE} [μK^2]	1.49 ± 0.12	0.97 ± 0.13	0.78 ± 0.14
α_{EE} ($=\alpha_{BB}$)	−3.04 ± 0.13	−2.83 ± 0.21	−3.03 ± 0.29
c_{EE} ($=c_{BB}$) [μK^2]	0.09 ± 0.06	−0.08 ± 0.06	−0.08 ± 0.07
A_{BB}/A_{EE}	0.36 ± 0.04	0.26 ± 0.07	0.26 ± 0.08



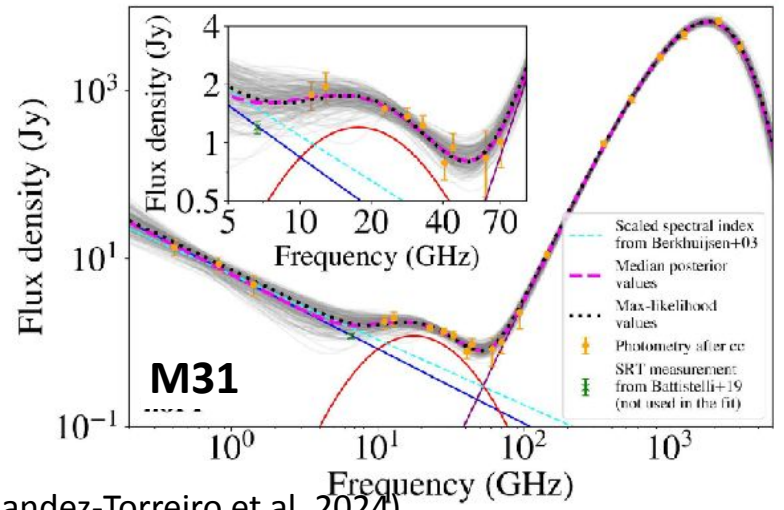
(Rubiño-Martin et al. 2023)

QUIJOTE-MFI results: modelling the Anomalous Microwave Emission

- **AME:** excess emission over free-free, dust and synchrotron in microwaves; spatially correlated with thermal dust. Origin unknown. Probably spinning dust grains. Polarization information is key.
- **QUIJOTE results in compact regions.**
  - **Tramonte et al. (2023)** AME detected in W49 (4.7σ) and W51 (4.0σ).
  - **Poidevin et al. (2023)**: Study of 56 compact AME sources (PIR XV 2014).
  - **Lopez-Caraballo et al. (2024):** CTB80, HB21, Cygnus Loop, CTA1, Tycho and HB9**.**
- **QUIJOTE results for AME diffuse emission in the Galactic plane (|b|<10º).**
  - **Fernandez-Torreiro et al. (2023).** Spatial variability of ν_{AME}. Correlation between AME emissivity – ISRF (G_0) confirmed.
- **Fernandez-Torreiro et al. (2024).** AME detected in M31 (3.5σ). Consistent with SRT (Battistelli+19).
- **Polarization constraints:**
  - Apparently unpolarized. Best upper limits in W44 (< 0.4% at 17GHz from QUIJOTE, and < 0.22% at 41GHz from WMAP). **Génova-Santos et al. (2017), Gonzalez-Gonzalez et al. (2025).**



(Poidevin et al. 2023)

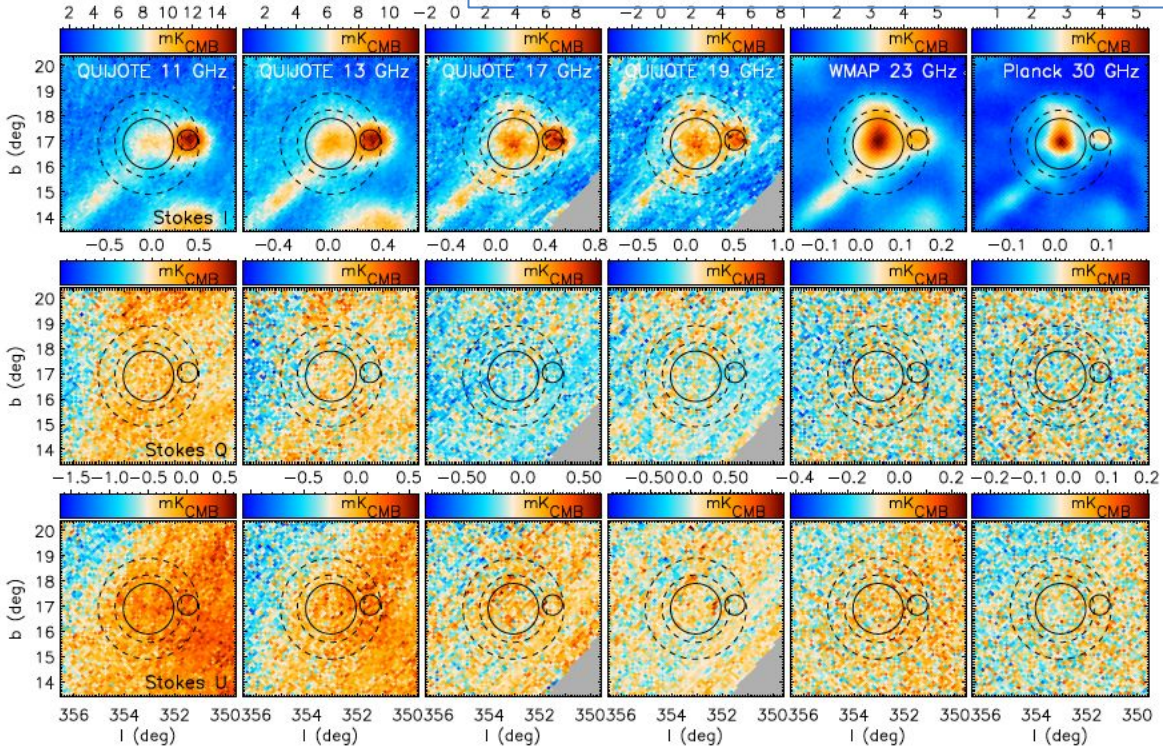


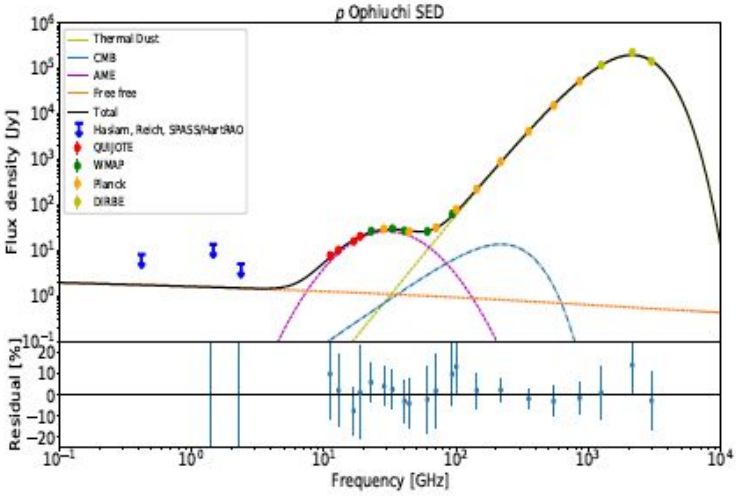
(Fernandez-Torreiro et al. 2024)

QUIJOTE-MFI wide survey results XVIII: AME polarization

- **QUIJOTE-MFI** wide survey data plus additional 1800 hours of dedicated raster scan observations in three regions**: ρ Ophiuchi, Perseus and W43.**
- First measurement of the AME low-frequency spectrum in ρ Ophiuchi.
- Improved cleaning of the LFI30 I⟶P leakage led to improved polarisation constraints.

ρ Ophiuchi: Π_{AME} < 1.1% (at 28.4 GHz)
Perseus: Π_{AME} < 1.1% (at 22.8 GHz)
W43: Π_{AME} < 0.28% (at 33 GHz)





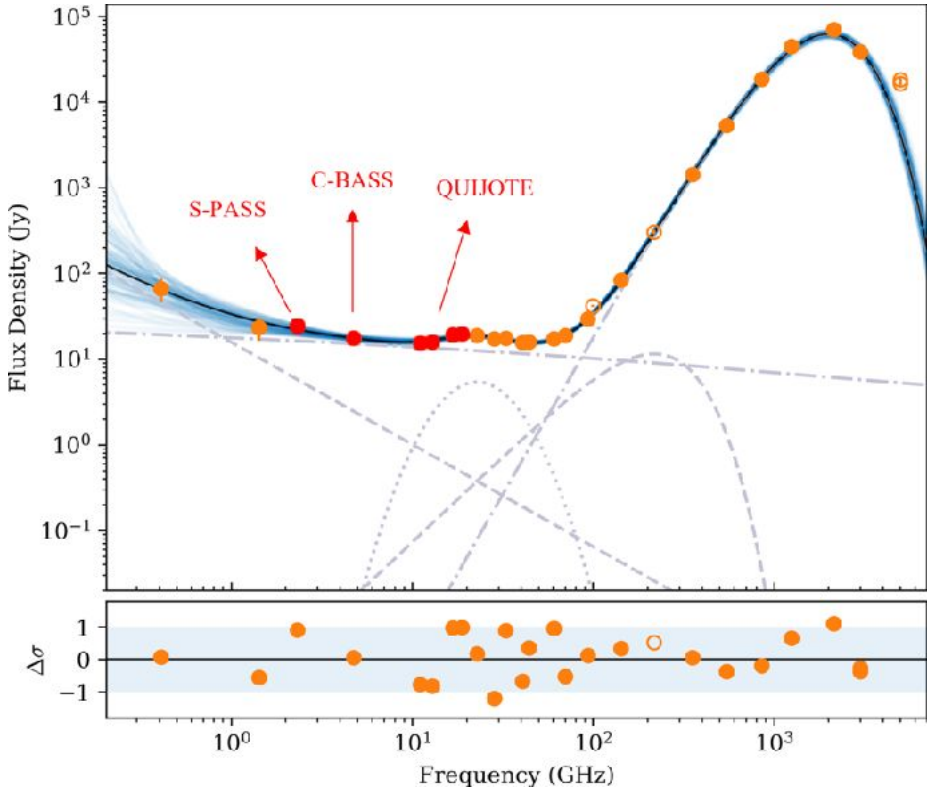
Gonzalez-Gonzalez et al. 2025

SED for AME regions

Funded by
the European Union

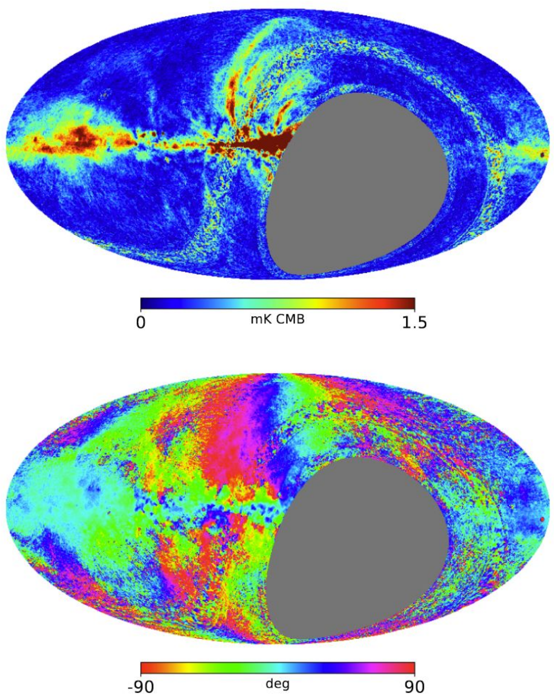
We carried out a study combining S-PASS, C-BASS, and QUIJOTE to characterize **AME in 150 Galactic clouds**, providing unprecedented constraints on its emissivity, peak frequency, and width without relying on informative priors. **This is the most comprehensive catalogue of compact AME sources to date. The improved frequency coverage provided by the three experiments is critical.**

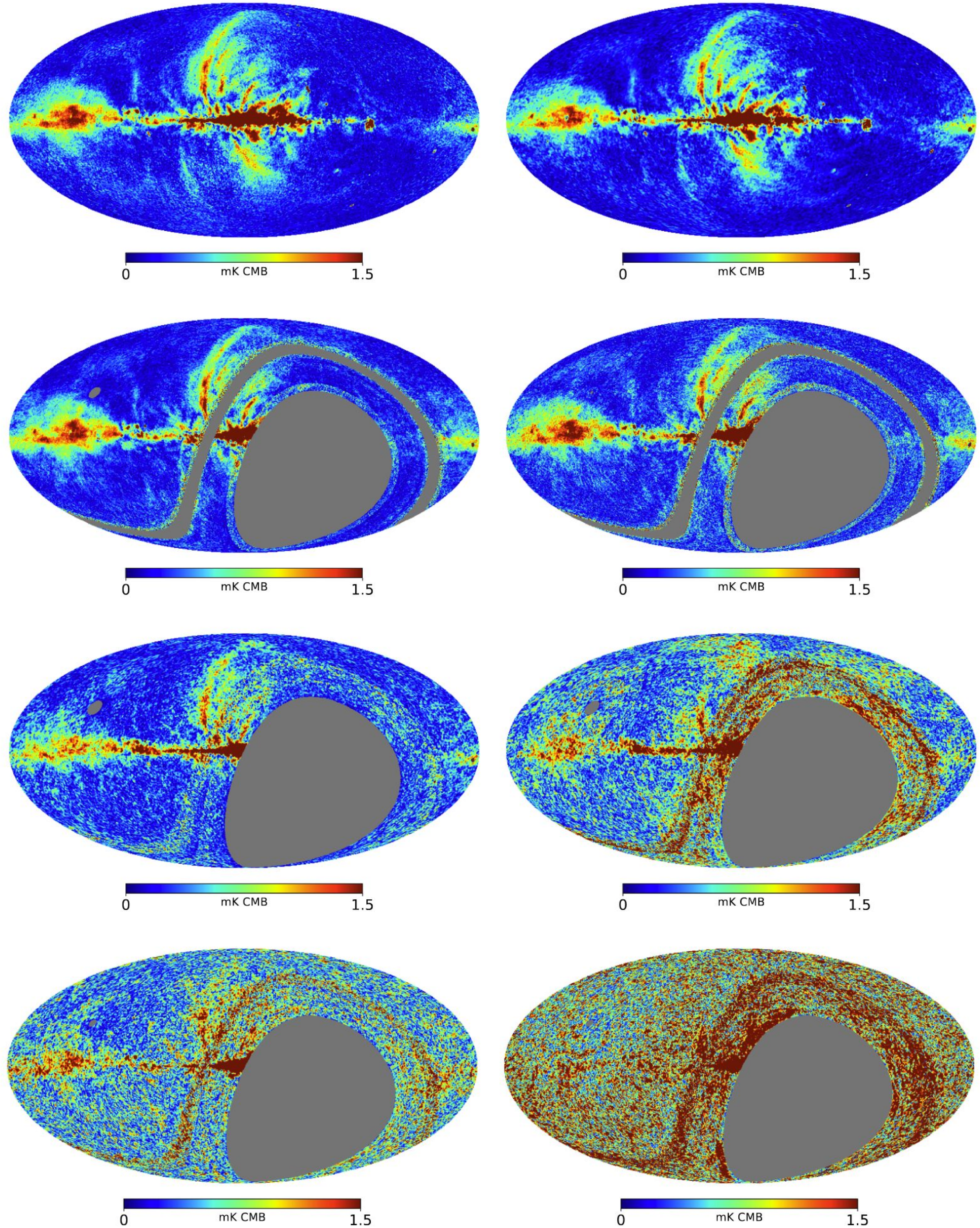
Example: Spectral energy distribution of source G040.52+02.53, with the key RadioForegrounds+ datasets labelled, emphasizing why they are needed for reliably characterizing the AME component. Best-fit to individual components are displayed in grey, with the dotted line representing the AME contribution.

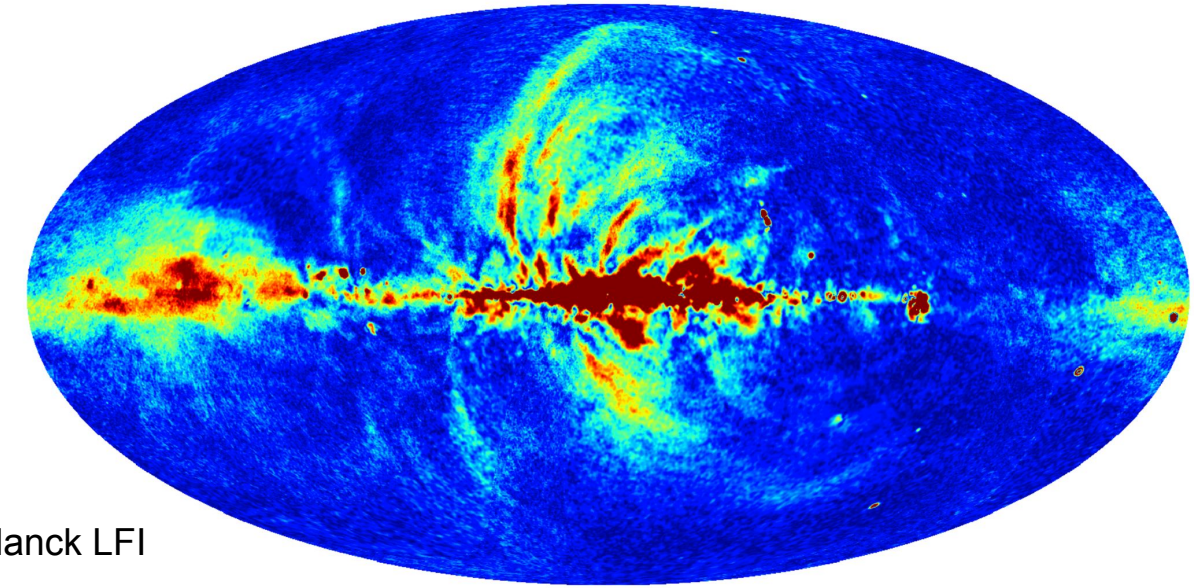


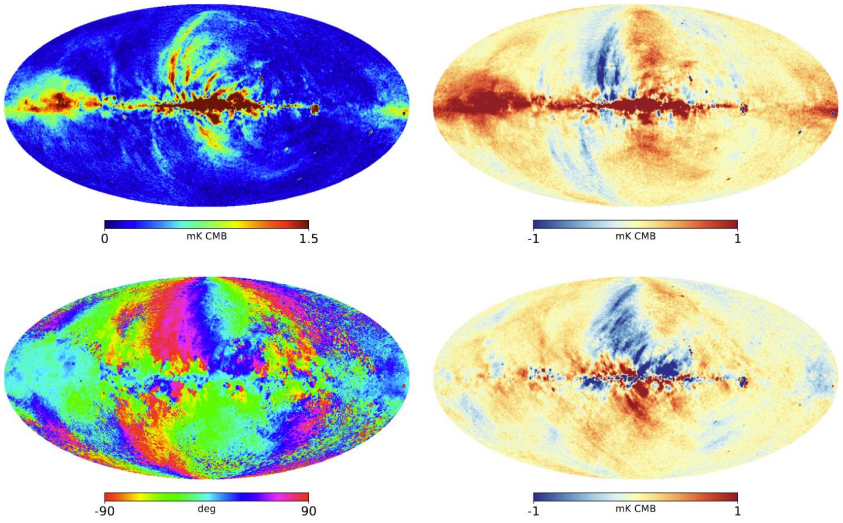
Cepeda-Arroita et al. in prep.

QUIJOTE polarised loops and spurs (Peel et al., in prep)









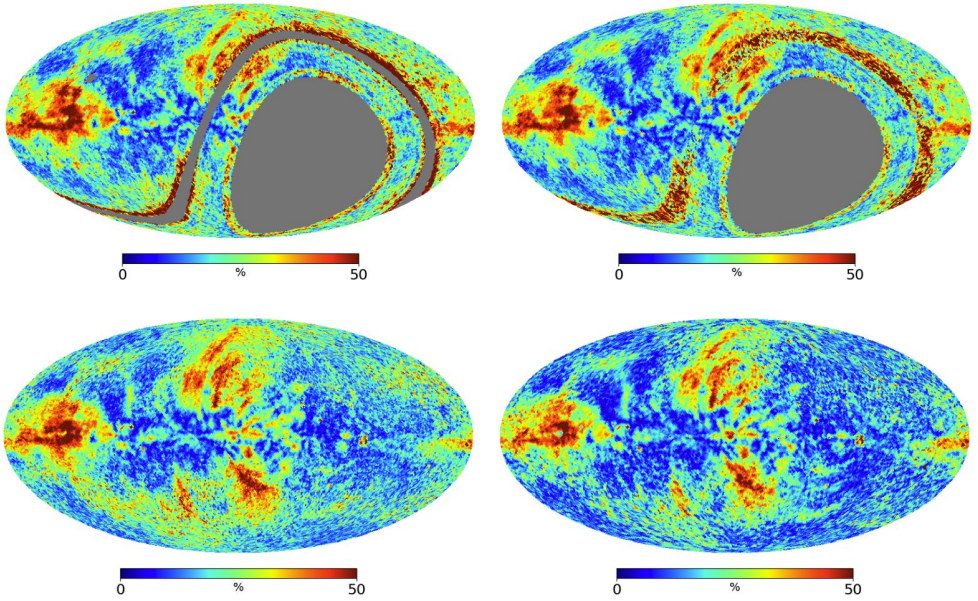
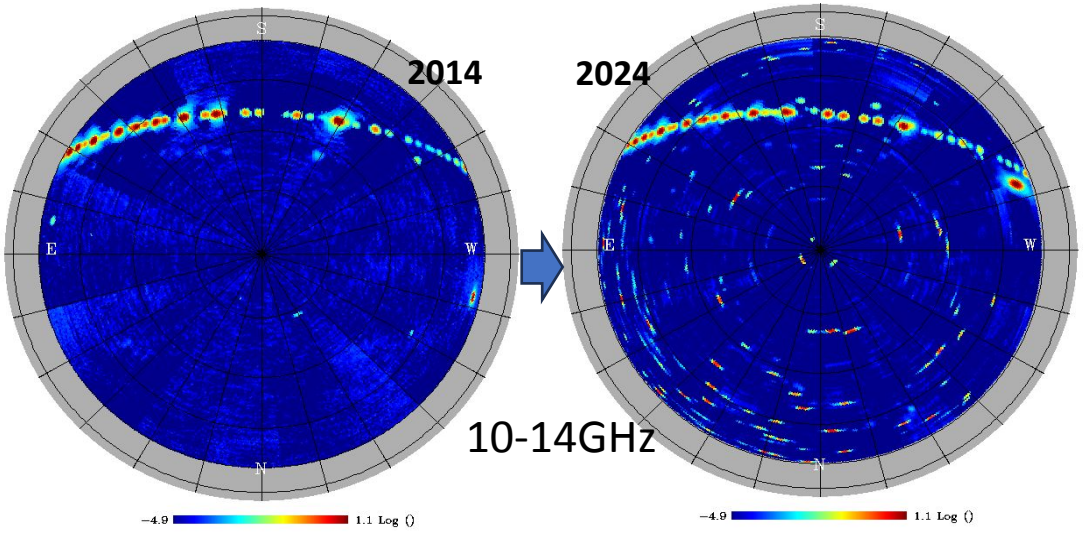


Figure 7. Nside = 64 Polarisation fraction maps, using the Haslam 408 MHz map extrapolated with $\beta = -3.1$. Top: left, MFI 11 GHz. Right: MFI weighted. Bottom: left, WMAP K-band. Right: Planck 30.

MFI2 Instrument (10-20 GHz)

- **MFI upgrade (MFI2 @ QT-1)**. Aim: to increase the integration speed of the MFI by a factor 3.
- **5 horns**. Three @ 10-14GHz, and two @ 16-20GHz.
- Full digital back-end (FPGAs) RFI removal (TV sats, Megaconstellations Starlink, OneWeb, Kuiper, at 10.7-12.7GHz, 17-19GHz, ++).
- **Status**: Installed at QT1. Comissioning with old MFI DAS started March 2024. New DAS (FPGA based) for late 2024.
- First light: March 15th, 2024. Using old MFI DAS (no polarization measurements yet).
- **Operations**: 3 effective years.



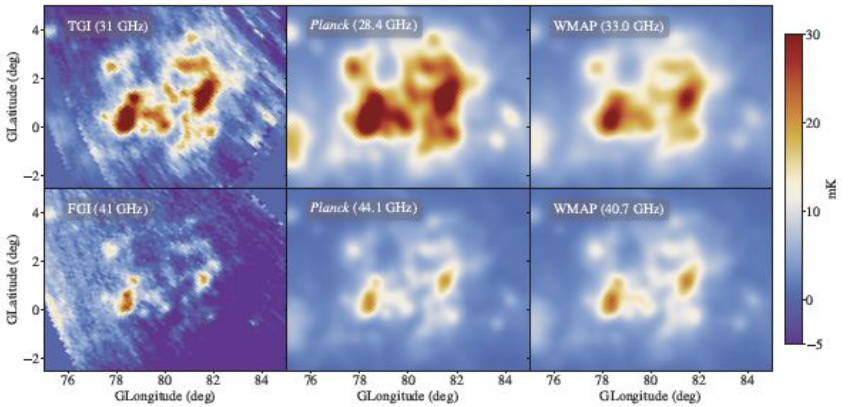
TGI (30 GHz) and FGI (40GHz): Commissioning

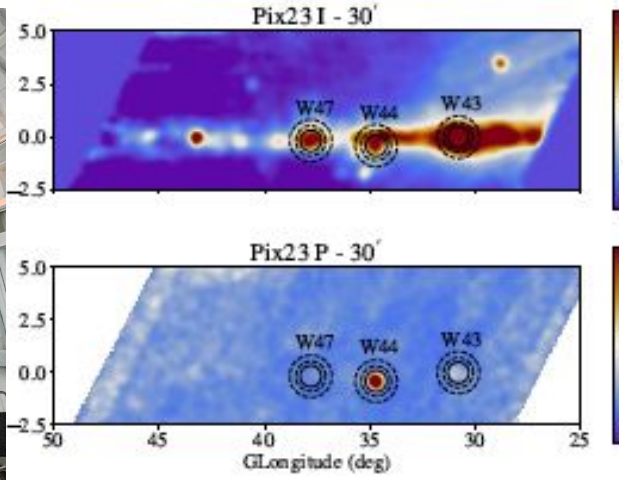
- **TFGI**: Dec 21 – Oct 22. Observations 7 pixels: Perseus, W43+W44, Cygnus area, calibrators.
- Currently installing 19 pixel configuration for next observation run
- **Two papers in prep.:** calibration and first results

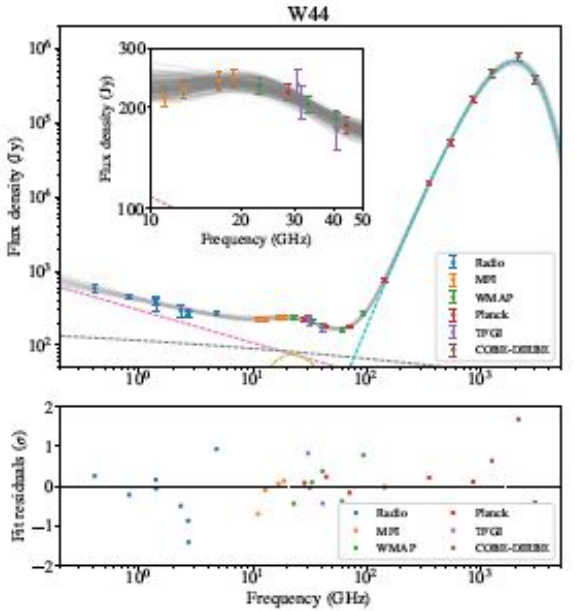
Cygnus area. ~24 h, 1 channel
(Fernandez-Torreiro et al. in prep)

W43-W44 region. 220 h, 330 deg2.

- Sensitivities of ~10 μK/deg in polarization.
- Extrapolated sensitivities for full array as expected.
- W44 detected in polarization at 10sigma.

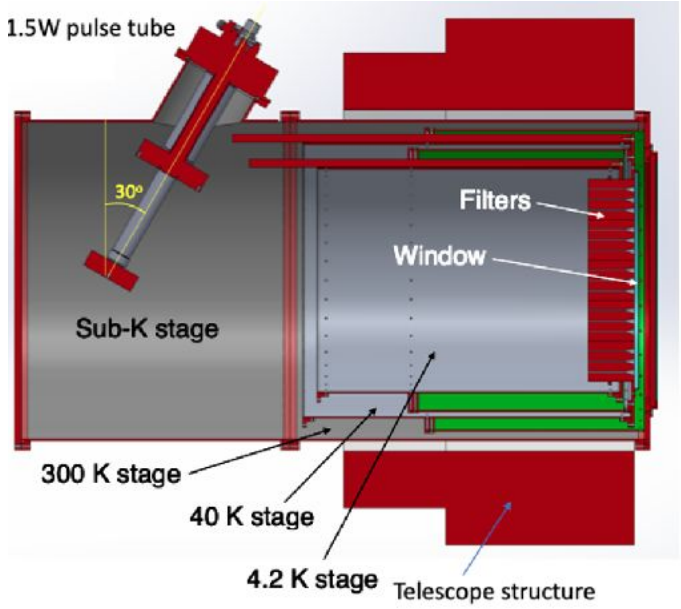


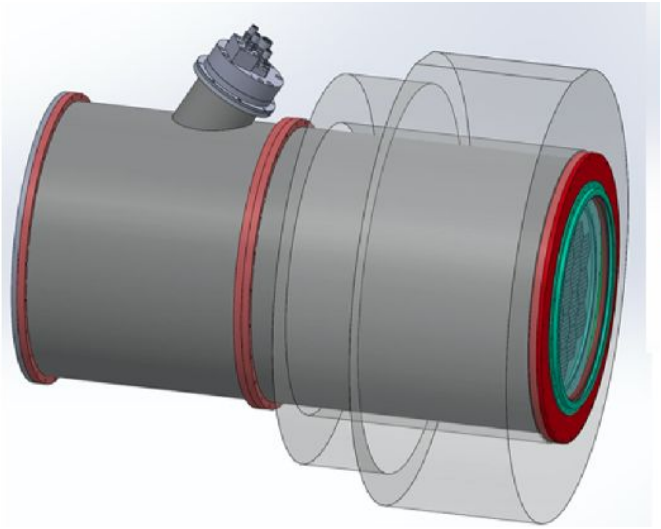




NGI: a W-band camera (85-110 GHz) for QUIJOTE

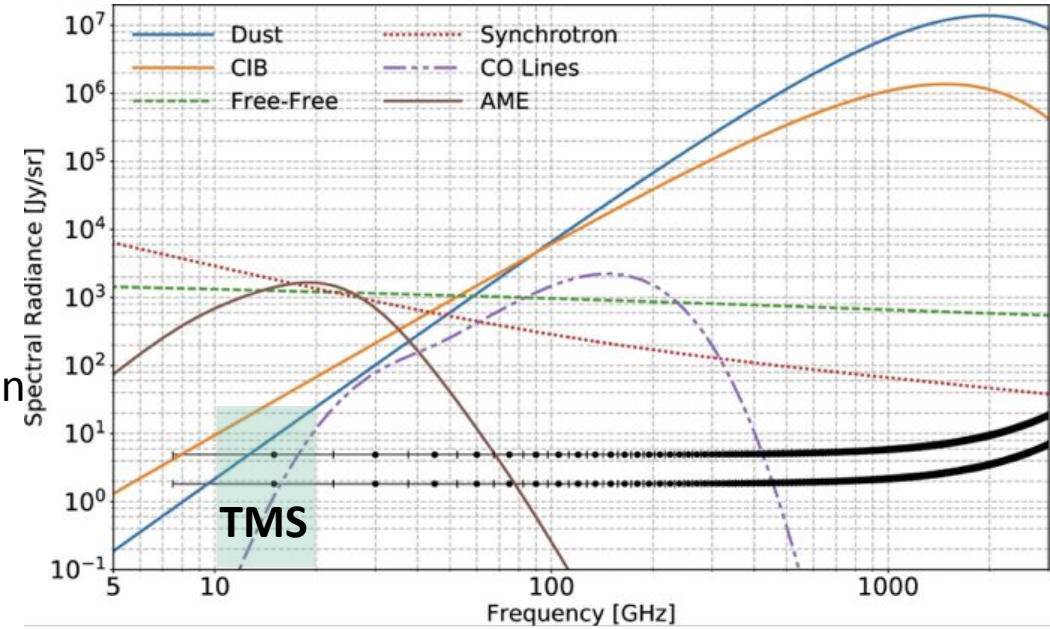
- **Scientific collaboration between two QUIJOTE nodes (IAC, IFCA) and University of Rome La Sapienza: 90GHz Instrument (NGI).**
- The Sapienza team has recently developed a 400 KIDs W-band camera (MISTRAL) for the Sardinia Radio Telescope (Paiella & JLTP 209, 889 (2022).
- **Cryostat**: pulse tube refrigerator for the first stages plus absorption refrigerator to reach 150mK.
- **Polarization modulation unit**: HWP and a rotating mechanism to rotate at a constant speed (room temperature). The rotating mechanism is based on a magnetic levitation system.
- **Aim**: to reach a survey depth of 4 uK.arcmin in 2000 sq.deg after 2 years of integration.
- **KIDs**. 500 detectors (dual polarization).
- **Status**: Conceptual design almost finished. Call for tender for the detailed design and fabrication of the cryostat and cold structure (40K, 4K and 0.15 K layers) to be started by the end of the year.

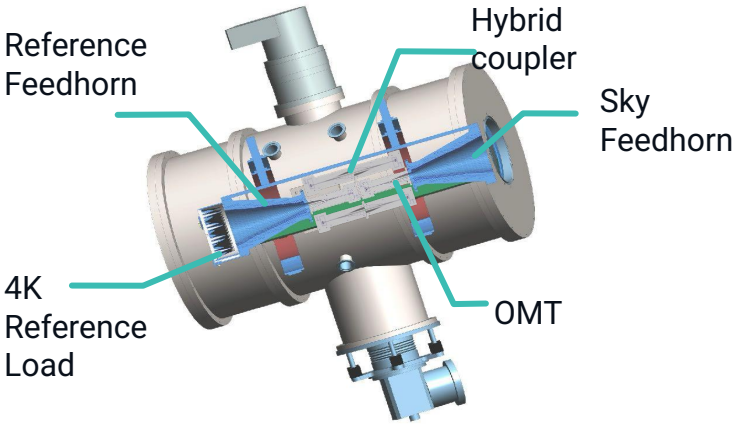


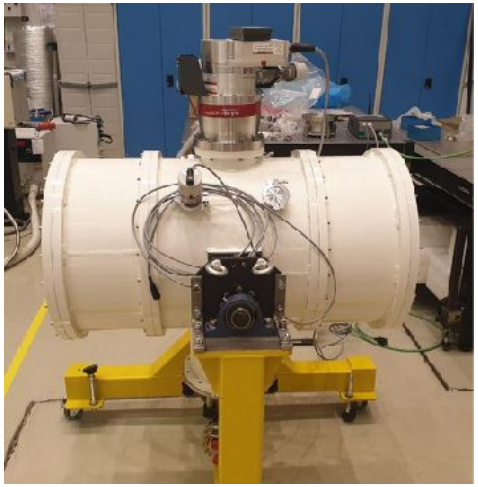


Tenerife Microwave Spectrometer

- **10-20GHz absolute sky spectrum**
- **Spectral distortions**
- **spectral properties of the synchrotron and anomalous microwave emission from our Galaxy,**
- **Absolute calibration scale for the QUIJOTE experiment**, as well as an accurate (sub-percent) relative calibration scale for the four QUIJOTE MFI frequencies (11, 13, 17 and 19 GHz).
- **Currently under construction**

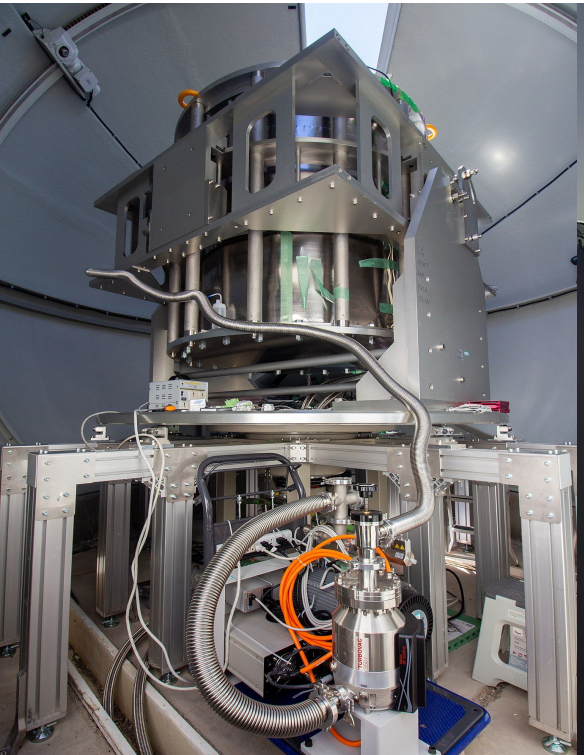






GroundBIRD

- **30cm mirror cooled to 4K:** cross-dragone reflectors inside cryostat
- **150 and 220GHz**: ~160 MKID detectors, 110 and 780 uK arcmin sensitivity
- **Fast rotation**: up to 20rpm (mostly observing at 5-10rpm)
- **Large angular scales:** map 40% of the sky to get to l~10
- **Constrain optical depth to reionisation:** Lee et al. (2021), ApJ, 915, 88, σ_T =0.030 with the simulated GroundBIRD maps, σ_T = 0.012 when combined with QUIJOTE
- **Scientific observations ongoing:** remote controlled observations, can observe up to 22h/day (2h needed for regeneration, also have to avoid the Sun)



Summary & Outlook

Searching for primordial B-modes and SD science

QUIJOTE

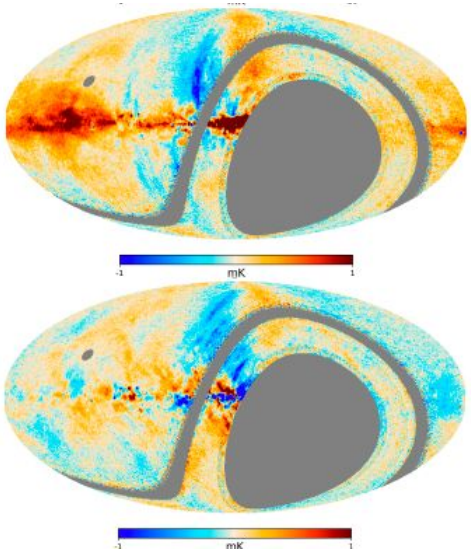
QT1 + MFI 10-20 GHz: 2012-2018.

- **Foreground studies with MFI data (RadioForegroundsPlus)**
  - Synchrotron (spatial variability, curvature, dust-synchrotron correlation).
  - AME modelling (spectral parameters; AME pol. fraction).

QT1 + MFI2 (10-20 GHz): 2024-2027.

QT2 + TGI (30 GHz) and FGI (40 GHz): 2018-2027.

QT2 + NGI (90GHz): 2027-. Design phase.



Combination QUIJOTE with other experiments: 2024-2028.

- **At Teide: Groundbird** (150, 220GHz), **LSPE-STRIP** (43, 90GHz).
- Lower frequencies (CBASS, SPASS). **RadioForegroundsPlus**.

TMS

TMS 10-20 GHz: 2025-2030.

- **Galactic Foregrounds** (monopole).
- **Radio Synchrotron Background (ARCADE2) excess:**
  - Dark matter models (axions, dark photons); cosmic strings.
- **Instrument design + data analysis pipelines for SD experiments.**

Funded by the European Union