The QUIJOTE experiment: component separation analyses with MFI data and TFGI commissioning results

Mateo Fernández Torreiro
Batiment 1, Bureau 337
mateo@fernandeztorreiro.com @torreiror
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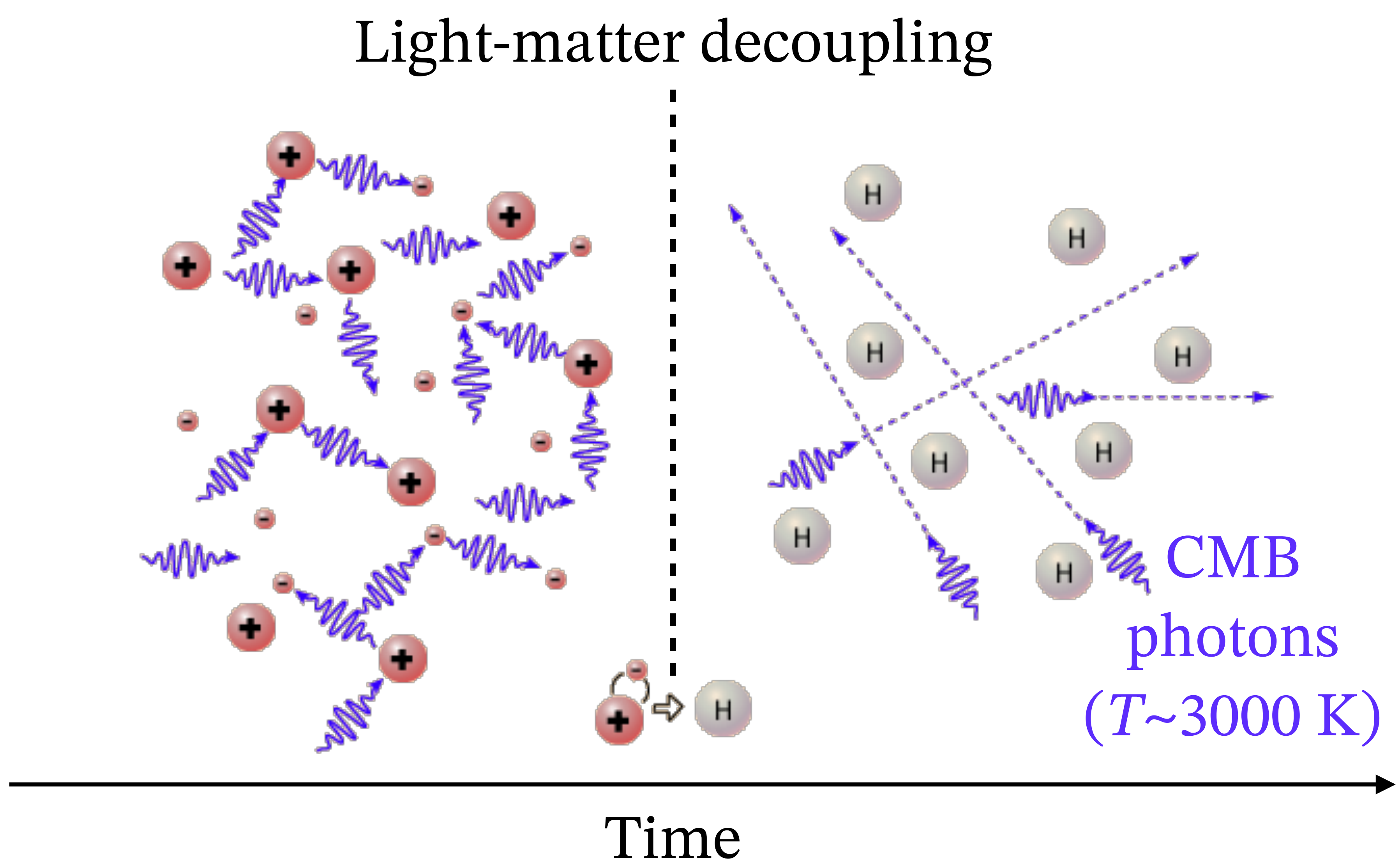
1. Introduction: the CMB

1.1. Thermal history of the Universe

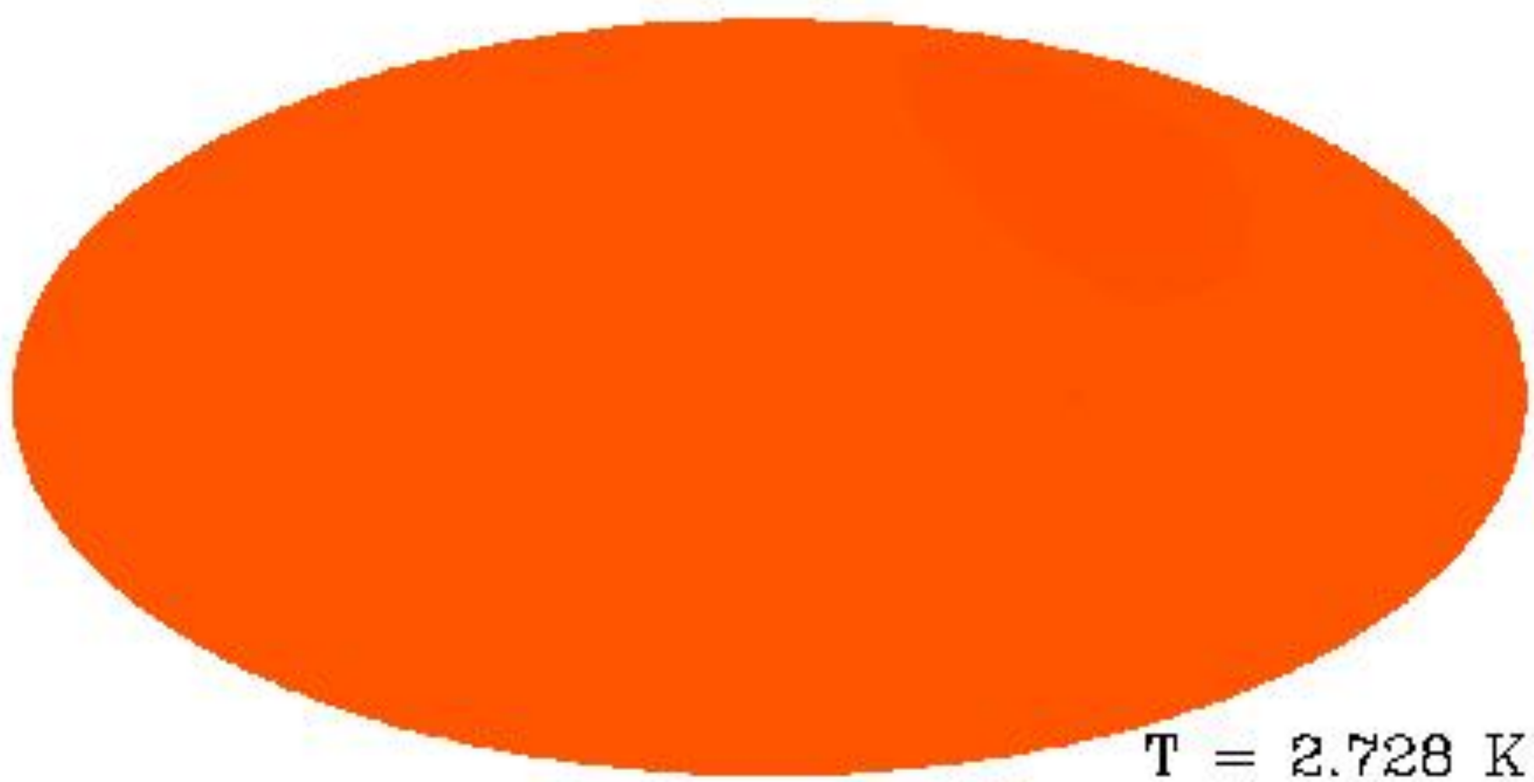
The Cosmic Microwave Background was formed when the Universe was 380000 years old, when the Universe became transparent to light.



1.1. Thermal history of the Universe

The energy of CMB photons have decreased following the expansion of the Universe from ~3000 K to 2.72548±0.00057 K (Fixsen+2009).

The CMB is the best known BB, and at first its signal is isotropic through the sky.

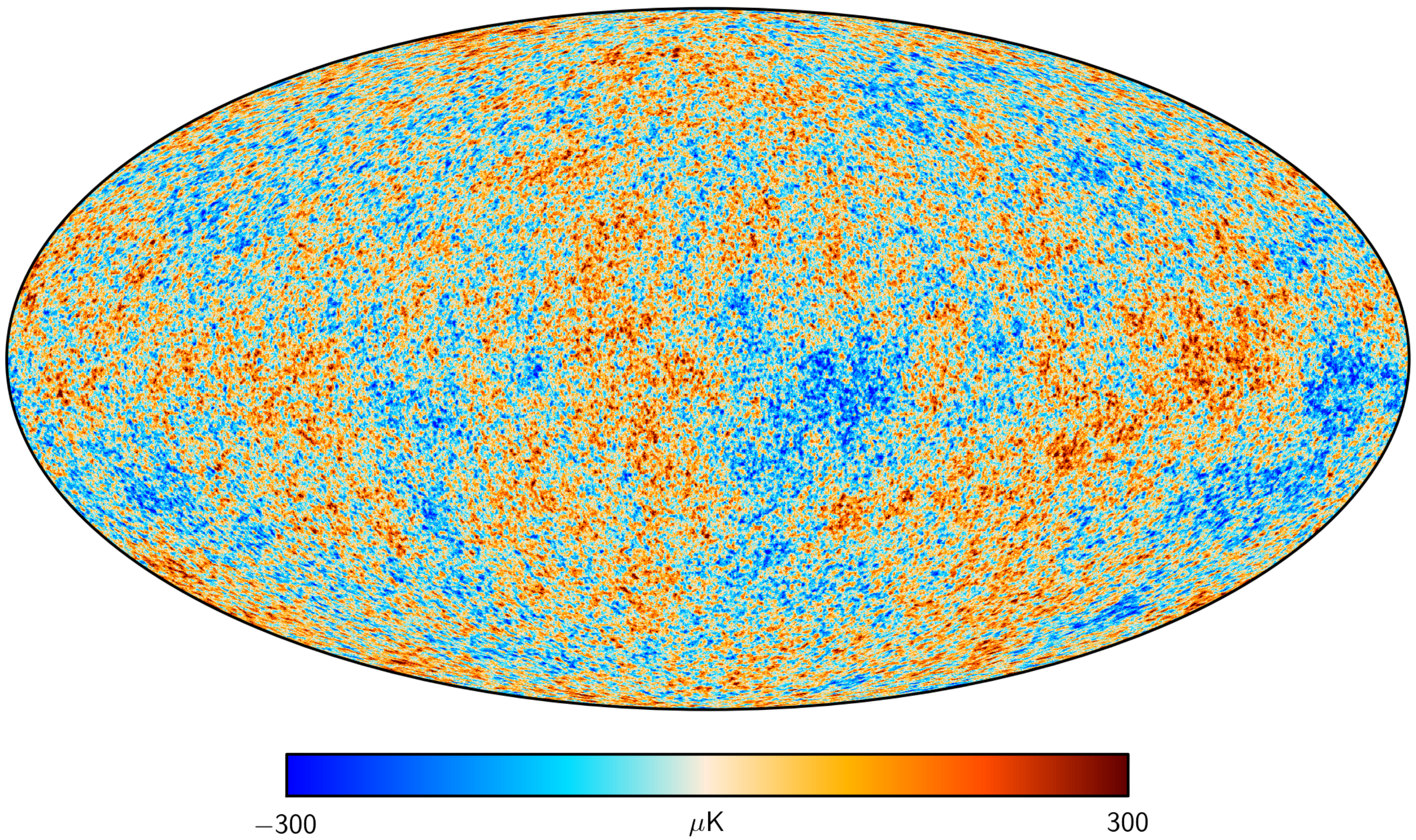


© LAMBDA / NASA (scale is actually 0-4 K)

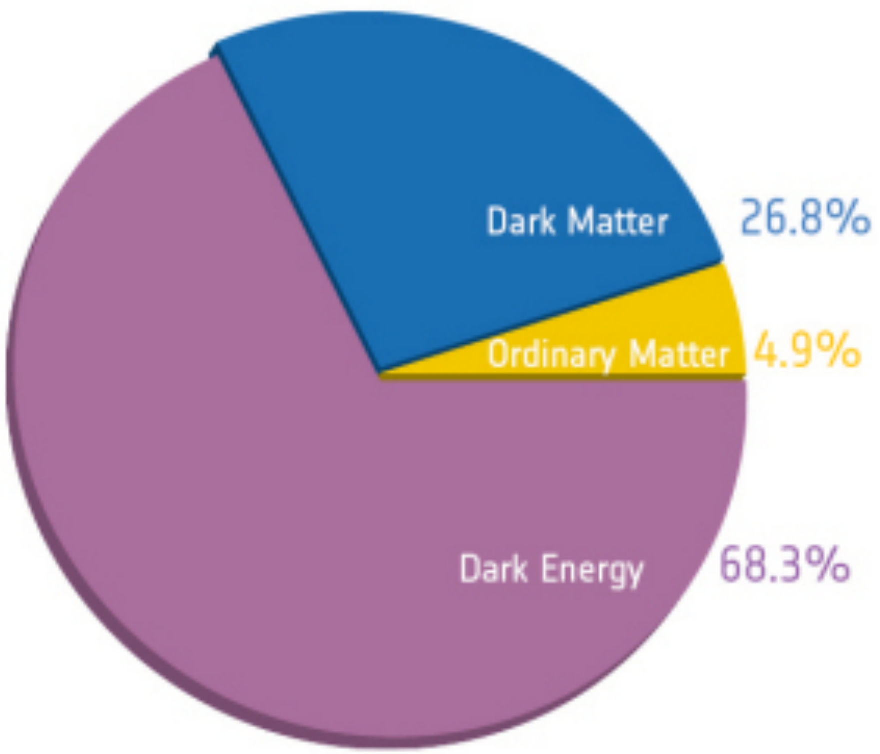
1.1. Thermal history of the Universe

However, the CMB shows anisotropies at the 10 ppm level.

Extensive cosmological information has been derived from the analysis of these anisotropies and their power spectrum, both in intensity and polarization.



© Planck Collaboration+2020



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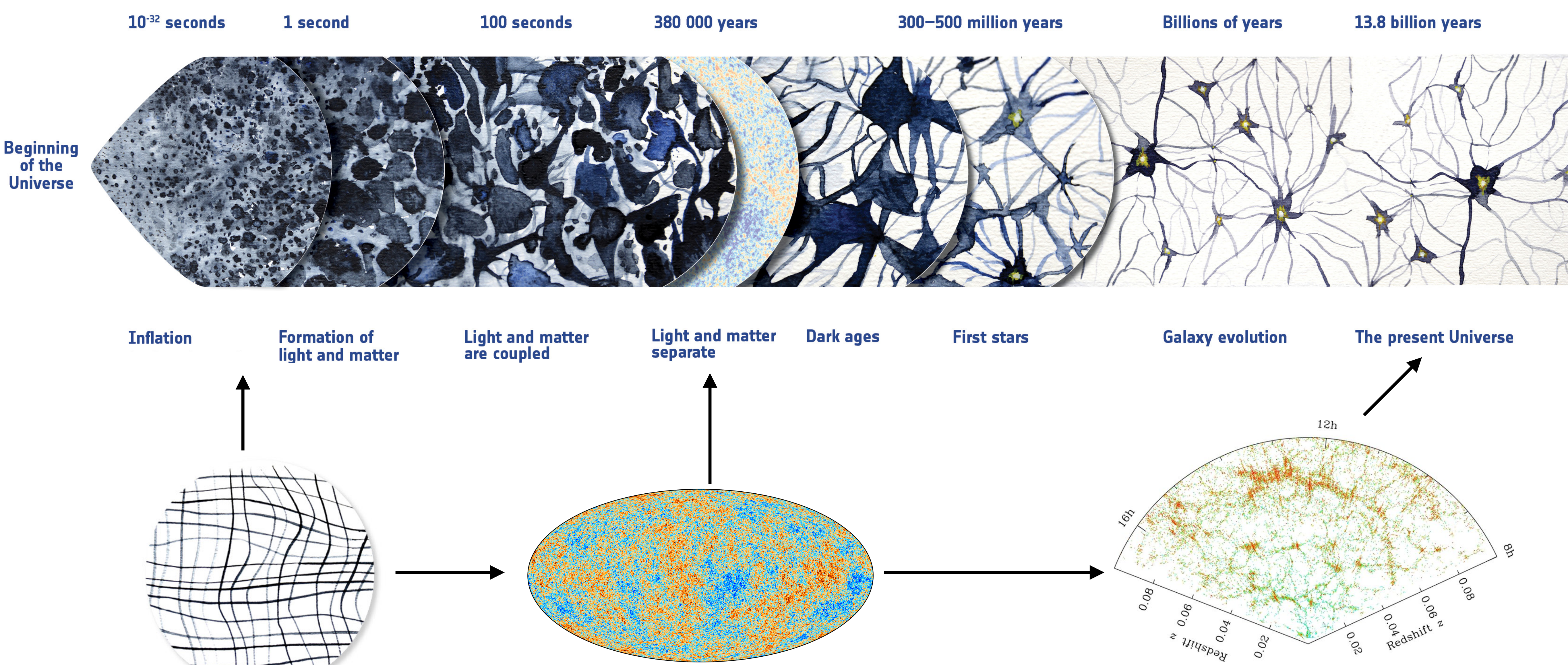
1.1. Thermal history of the Universe

The CMB anisotropies are seeded by primordial fluctuations generated during inflation, when these fluctuations got stretched to larger scales.



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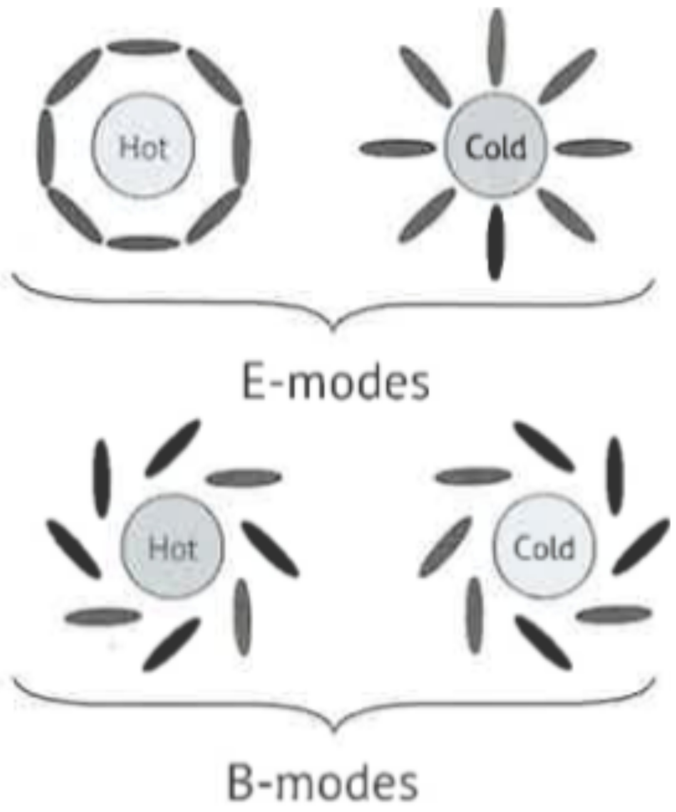
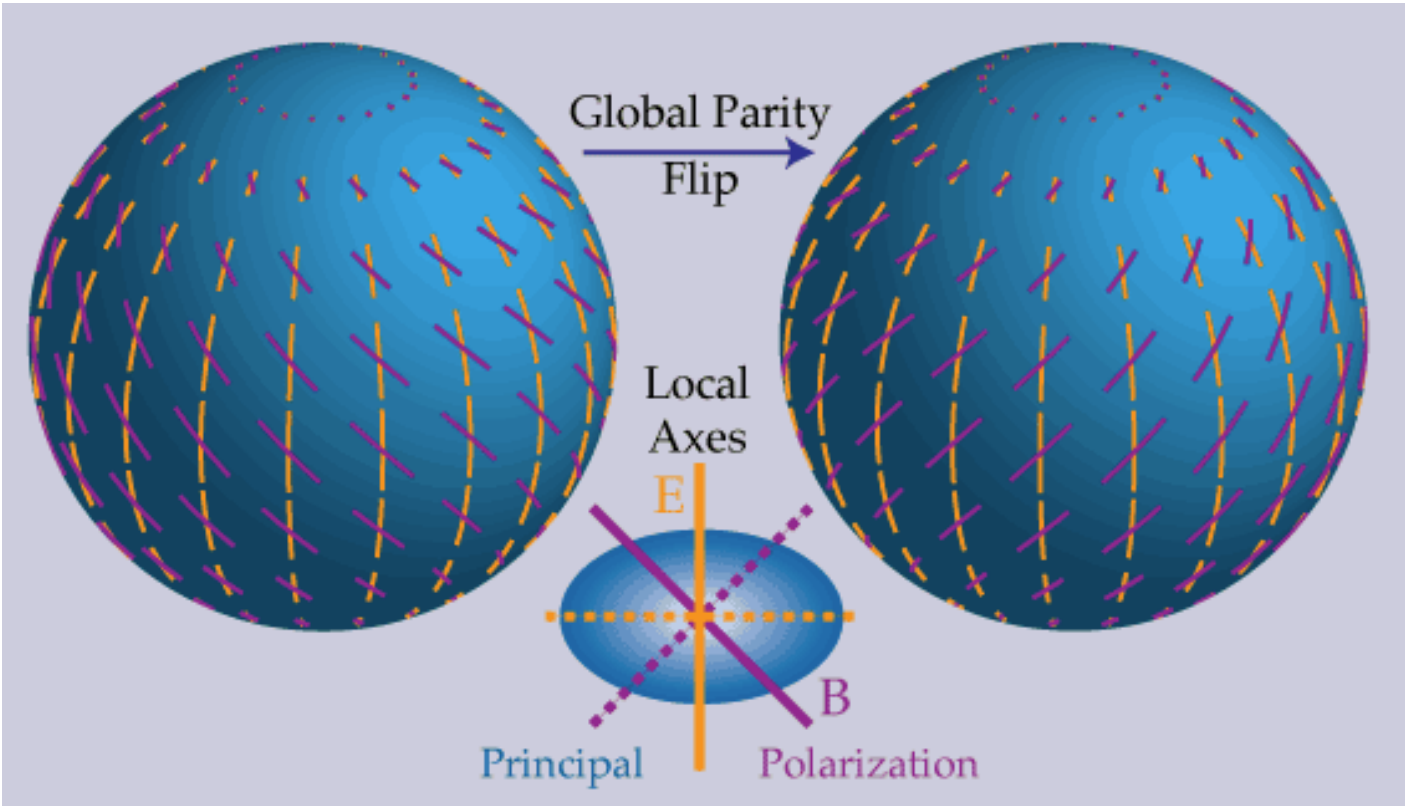
1.2. CMB polarization E and B-modes

Two different modes of polarization can show up in CMB anisotropies: E-modes and B-modes. Only the latter change under parity changes.

Only **tensor perturbations** can produce B-modes. The ratio between the E- and B- components is called the tensor-to-scalar ratio, or *r*.



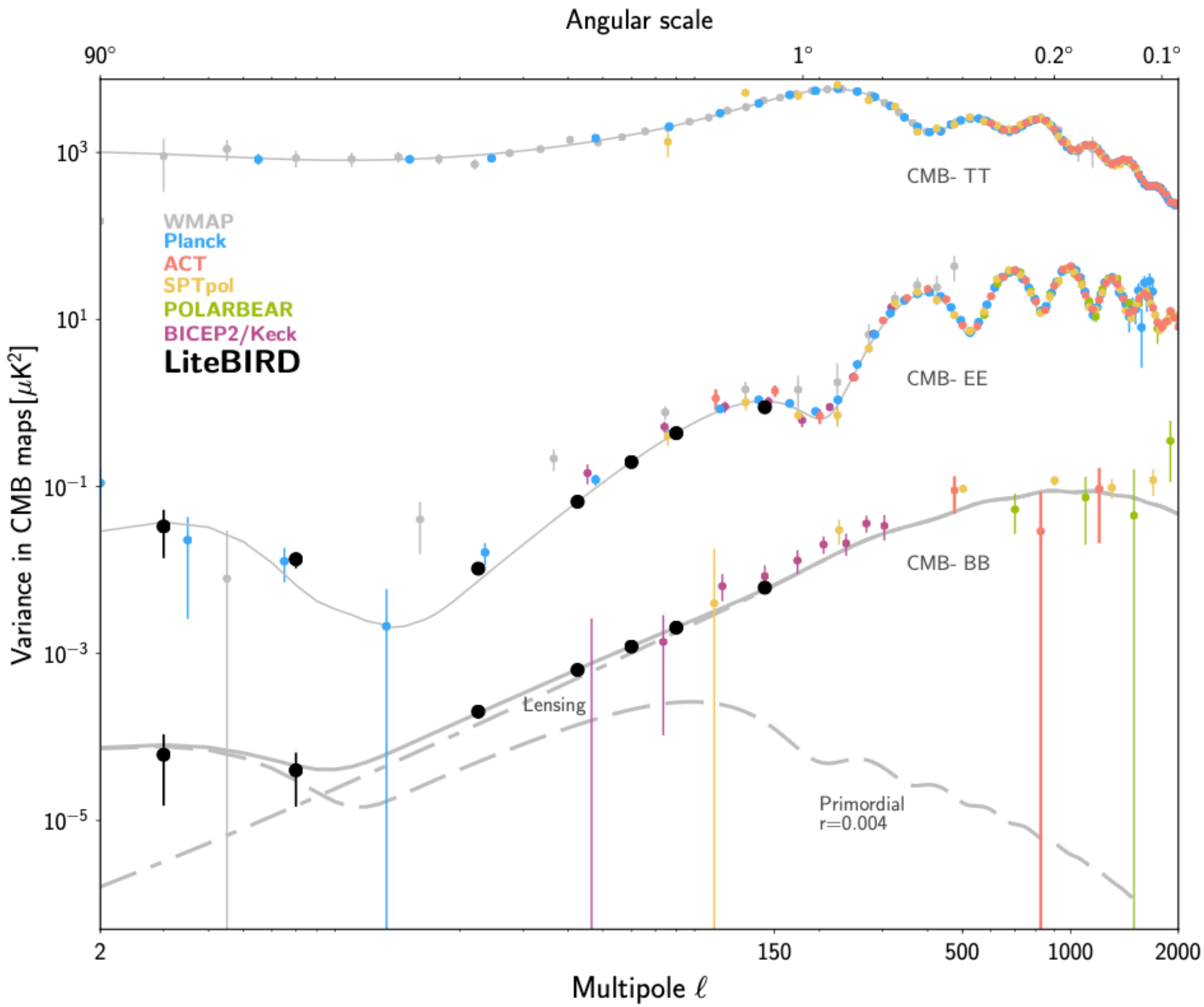


1.3. Present and future of r measurements

Current best constrain (BICEP/Keck + *Planck*):
$r < 0.036$
(95% C.L.)
(Ade+2021)

SO (2023-2027):
$\delta r \leq 0.002$

LiteBIRD (2029 launch date):
$\delta r \sim 0.001$



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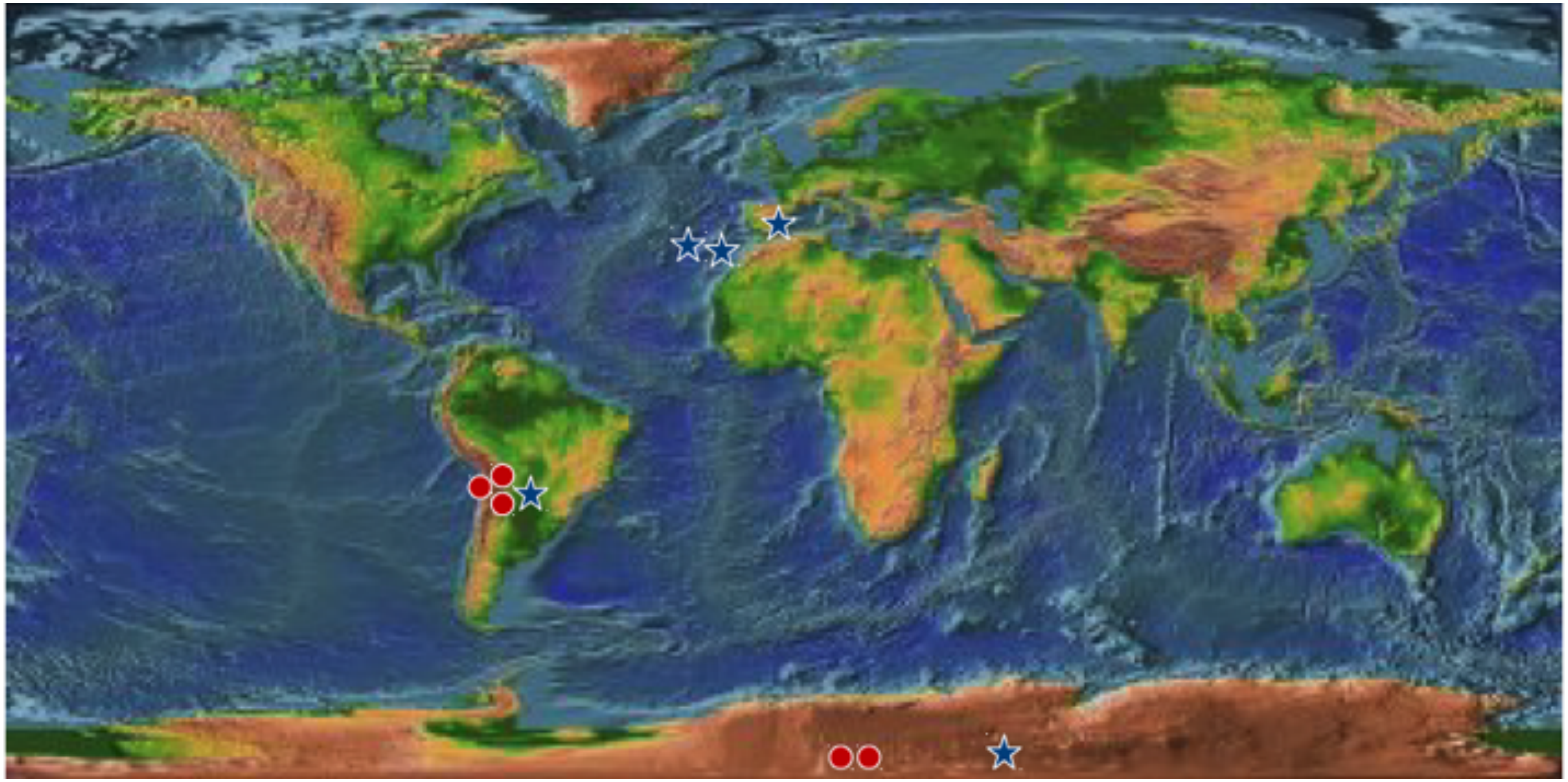
2. The QUIJOTE experiment

2.1. The Teide Observatory

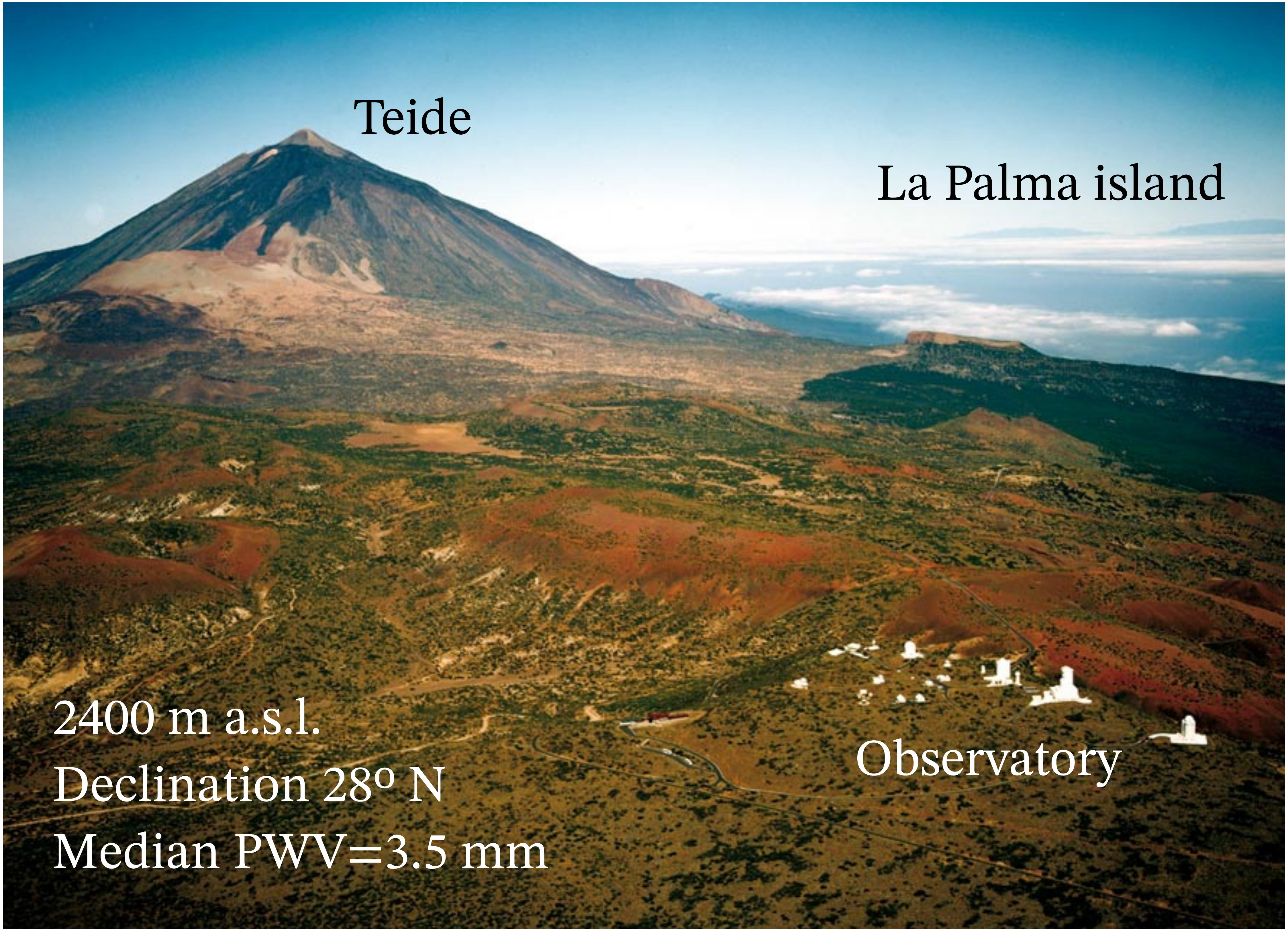
Most of CMB ground-based observatories are placed on the South hemisphere (Chile and the South Pole), thus limiting the observable sky.



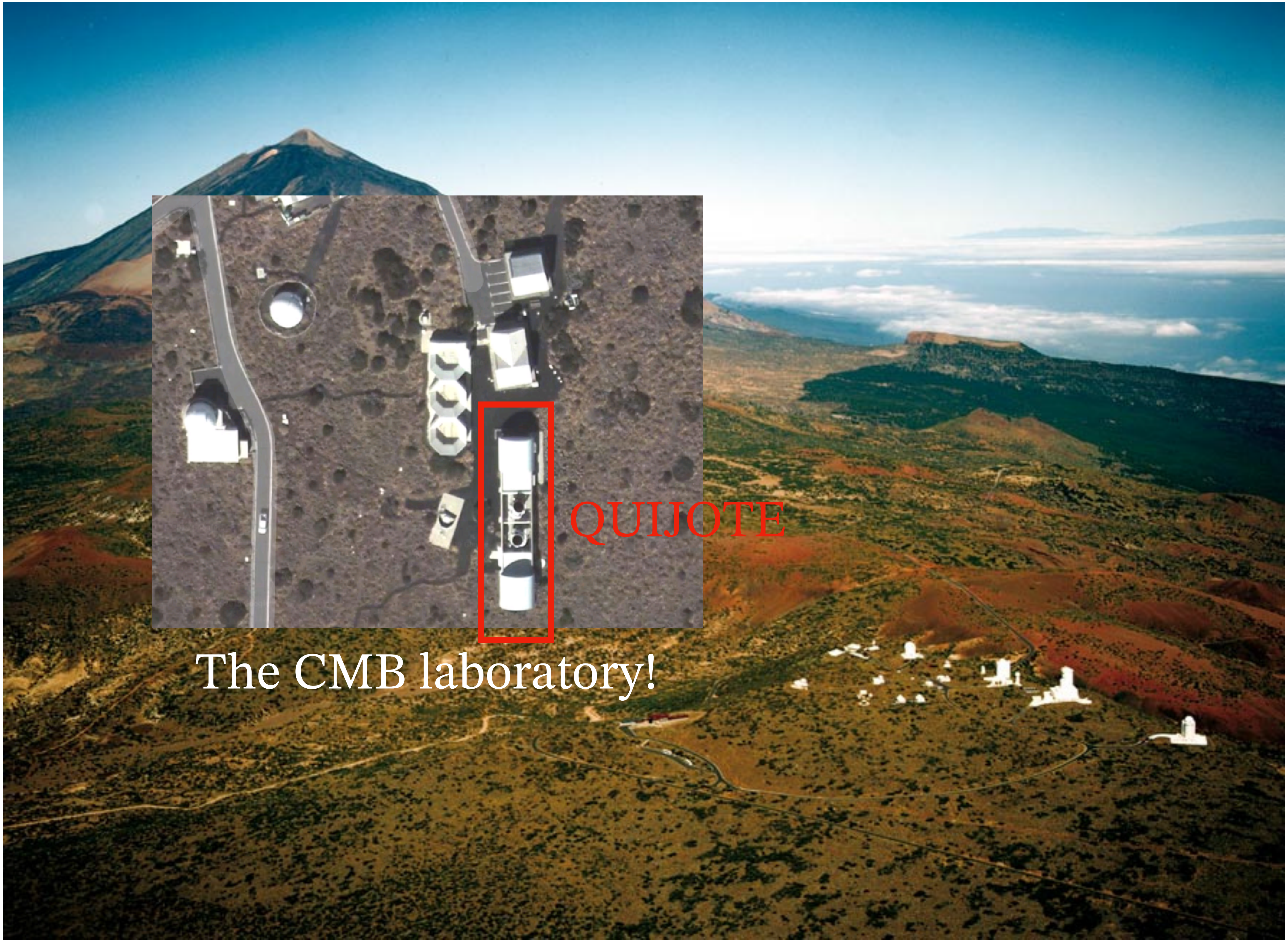
★ Europe: Pico Veleta (IRAM/Granada), Tenerife, Llama (Argentina), South Pole

● America: Atacama (Chile) and the South Pole

2.1. The Teide Observatory



2.1. The Teide Observatory



2.2. QUIJOTE - the telescopes

QUIJOTE: Q-U-I JOint Tenerife Experiment

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

Instituto de Física de Canarias · IAC

IFCA Instituto de Física de Cantabria

MANCHESTER 1824 The University of Manchester

UNIVERSITY OF CAMBRIDGE

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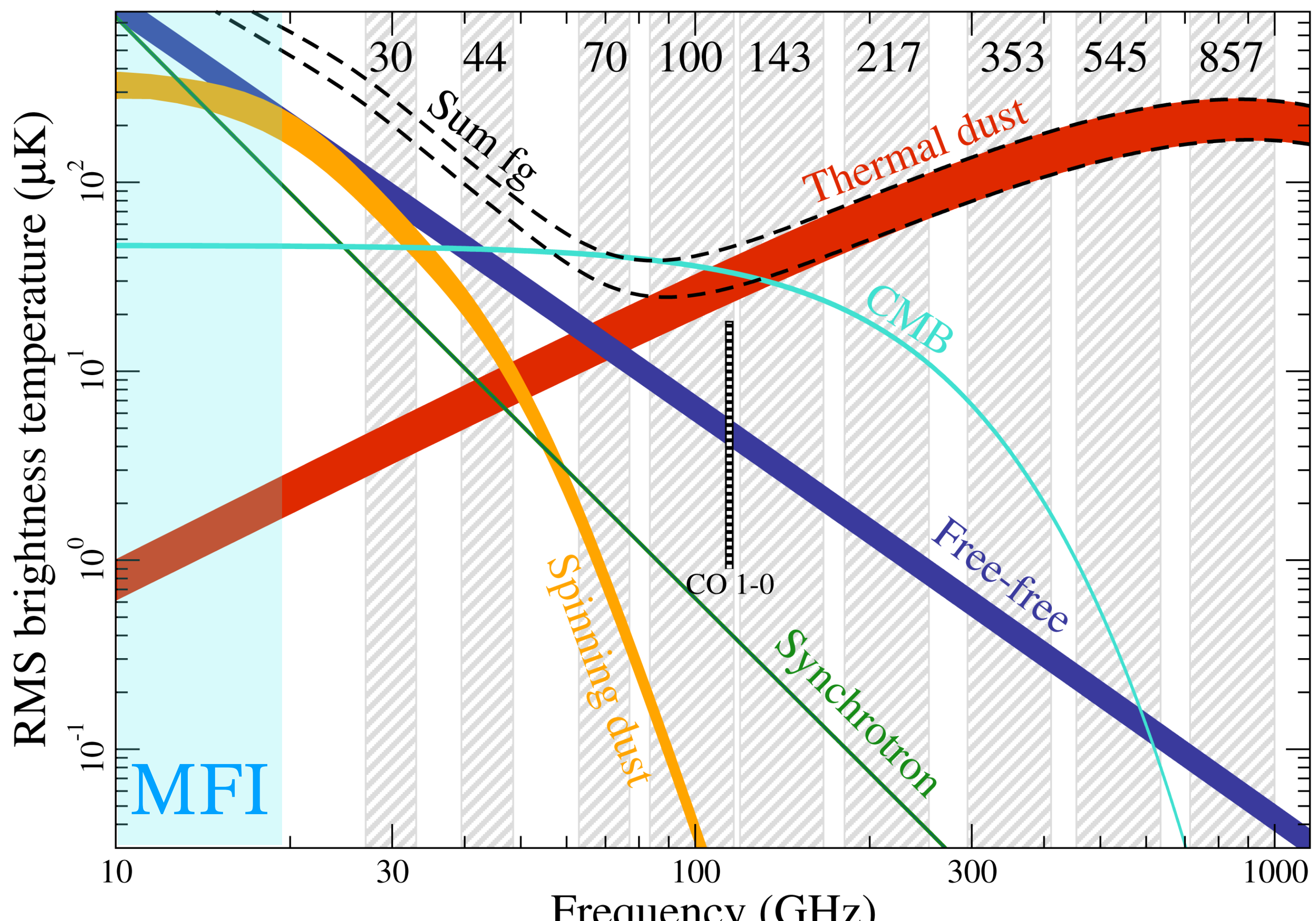
3. CMB Foregrounds

3.1. CMB foregrounds

All other emission components different from the CMB. Four components at microwave frequencies (1-100 GHz / 30 - 0.3 cm):

- Synchrotron
- Free-free
- Thermal dust (TD) emission
- Anomalous Microwave Emission (spinning dust)



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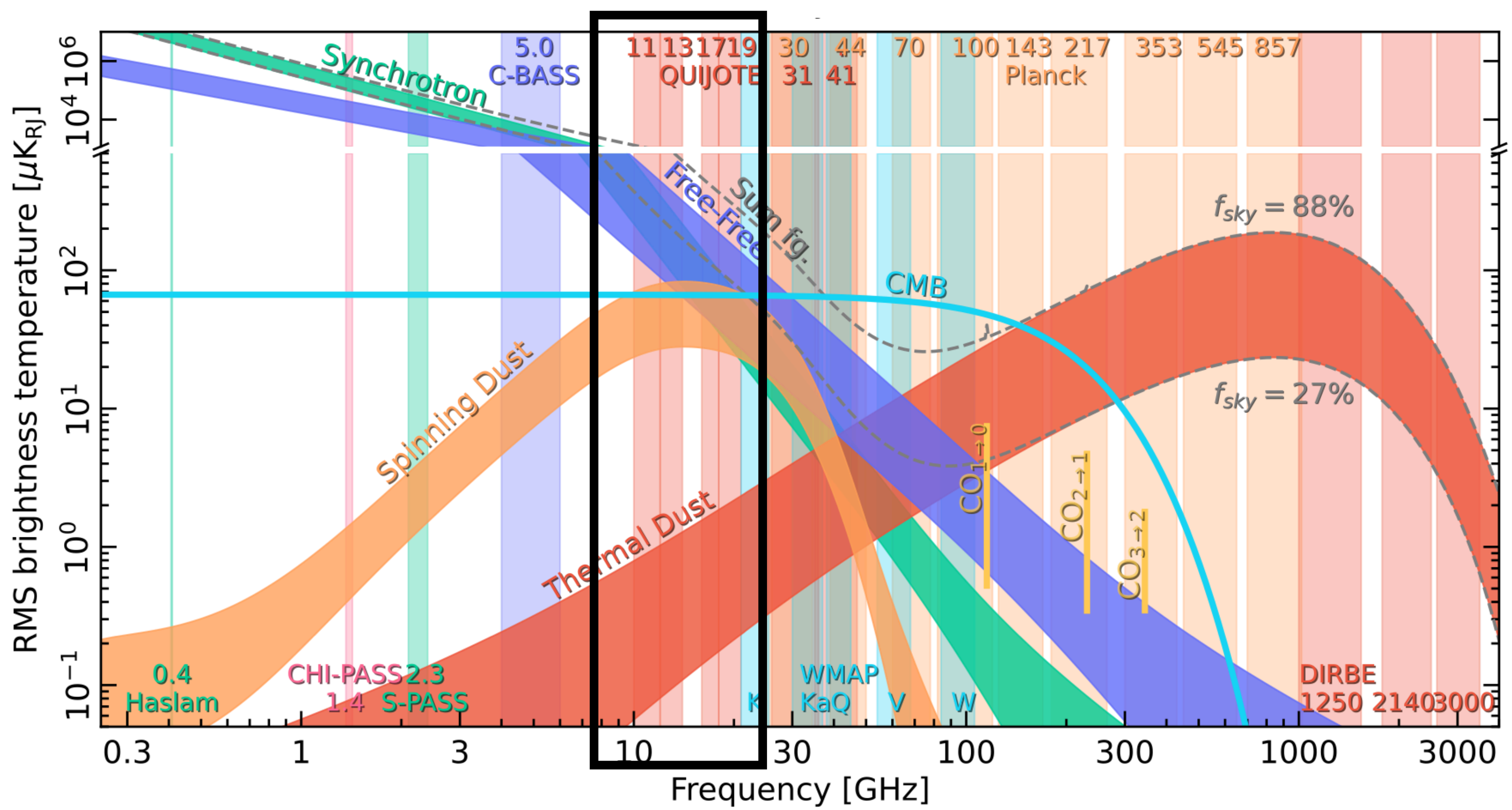
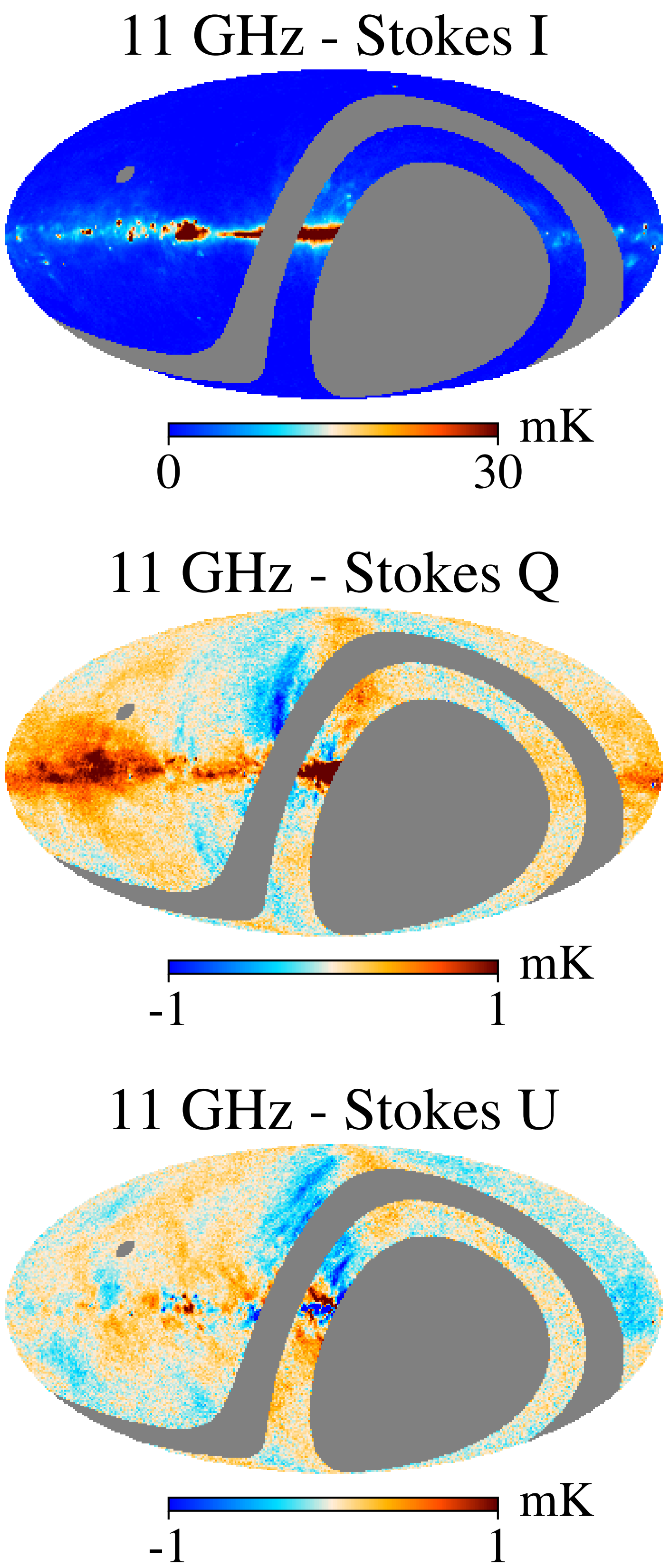


Andersen+2023 (BEYONDPLANCK Collaboration)

3.2. The role of MFI

Focused on providing superb polarization measurements, it covered a spectral region where data were especially scarce.

- In intensity, its data help resolving synchrotron, free-free and AME degeneracies.
- In polarisation, the data work as a reliable tracer of synchrotron, as free-free and AME are expected to be negligible polarized.

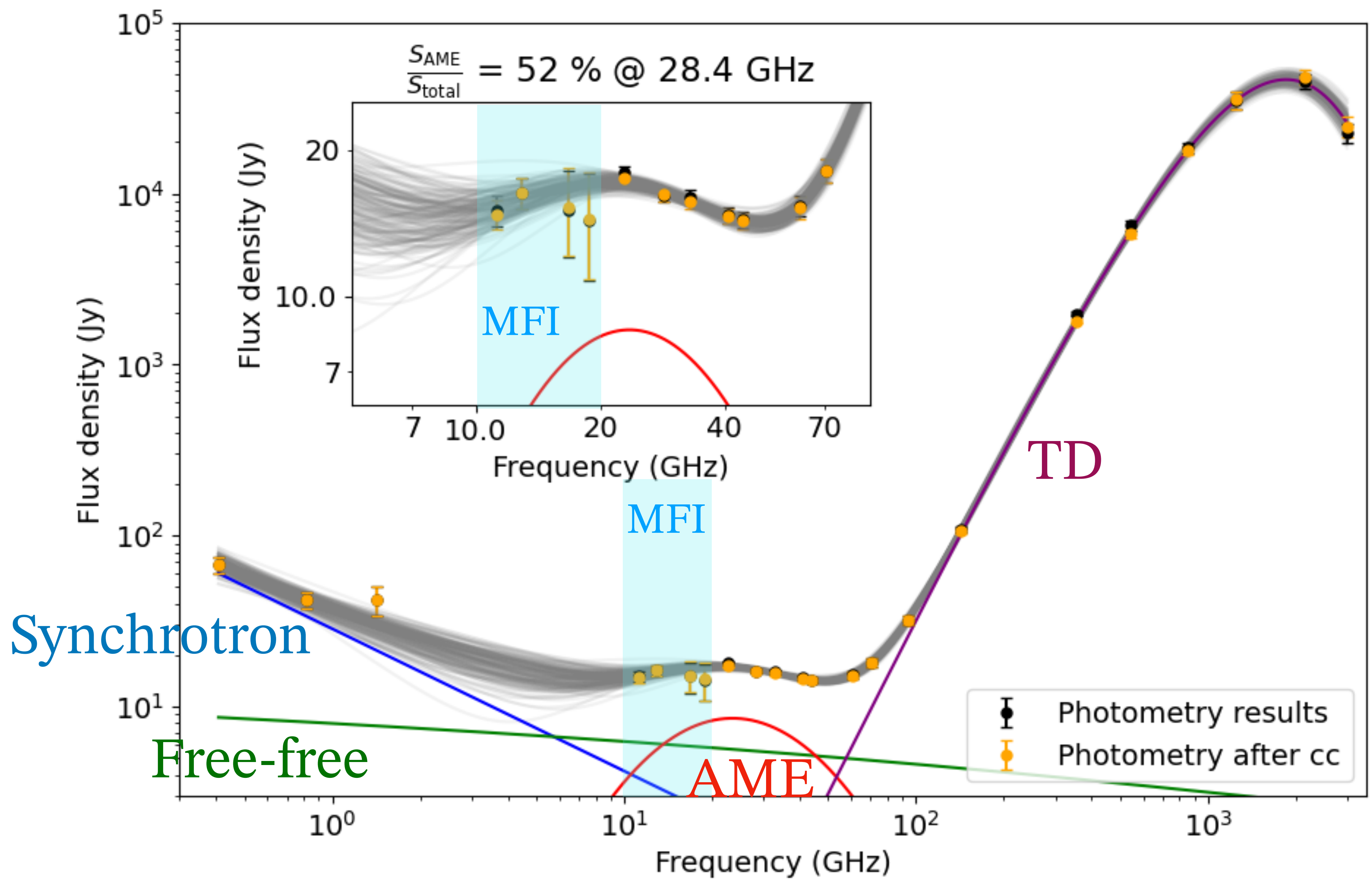


The MFI Wide Survey (Rubiño-Martín+2023) consisted of a full scan of the north hemisphere (29000 deg^2 accounting for 3 years of observations) at the four instrument frequencies: 11, 13, 17 and 19 GHz. These data were released to the community in early 2023 and is accessible here or through LAMBDA.

4. Component separation analyses with MFI data

2.1. SED data and parametrization

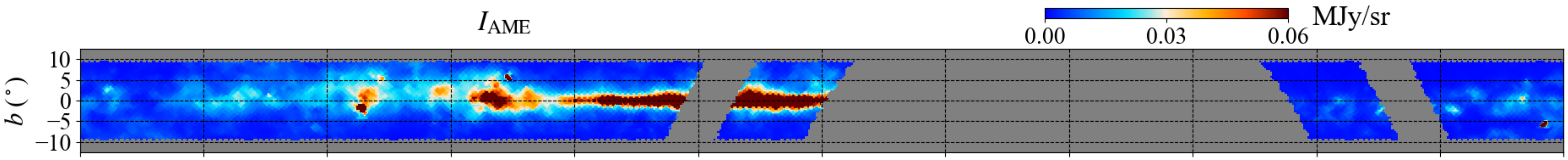
Parametrization of spectral energy distribution (SEDs) in five components: the previously presented foregrounds and the CMB anisotropies. Preparation of a MCMC MLE to find the optimal combination of the five.

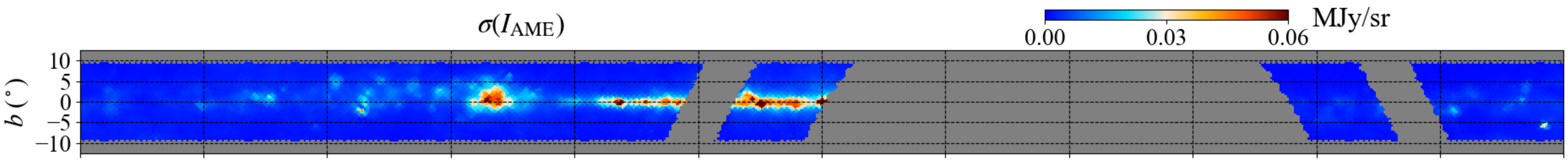


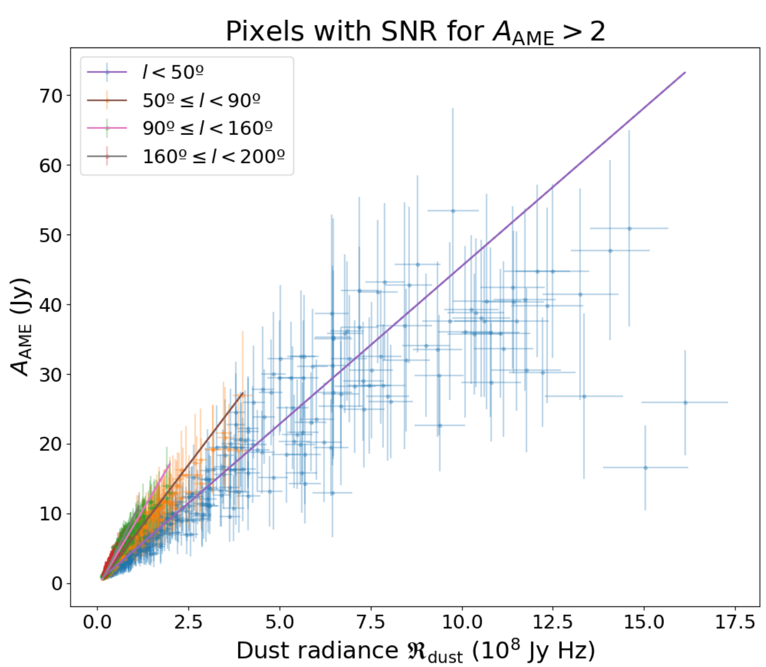
2.2. Study of the Galactic plane

Fernández-Torreiro et al. 2023, MNRAS, 526, 1343

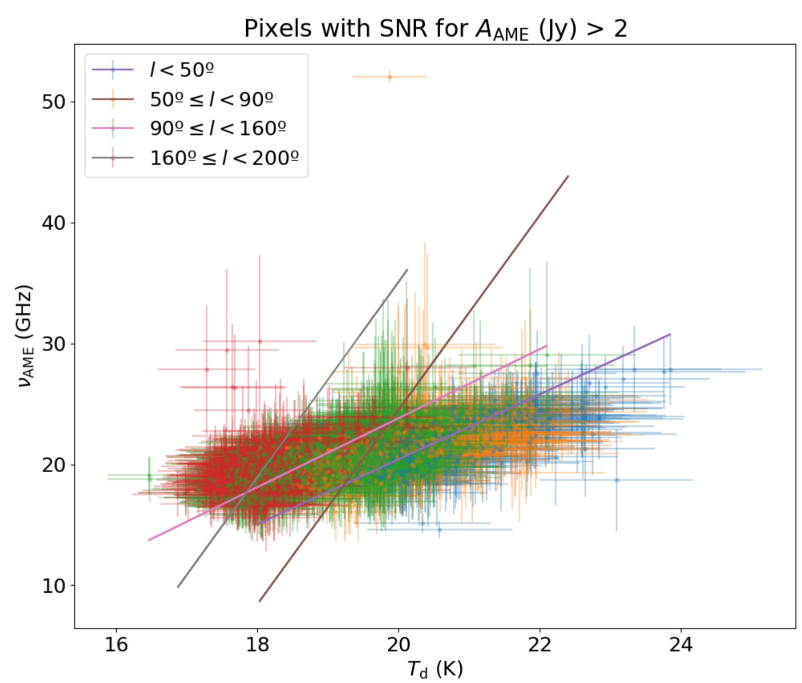
Fitted the previous SED for every pixel in the Galactic plane and built maps for the parameters driving the componentes. Emphasis on the results for the AME ones and their dependences with TD.



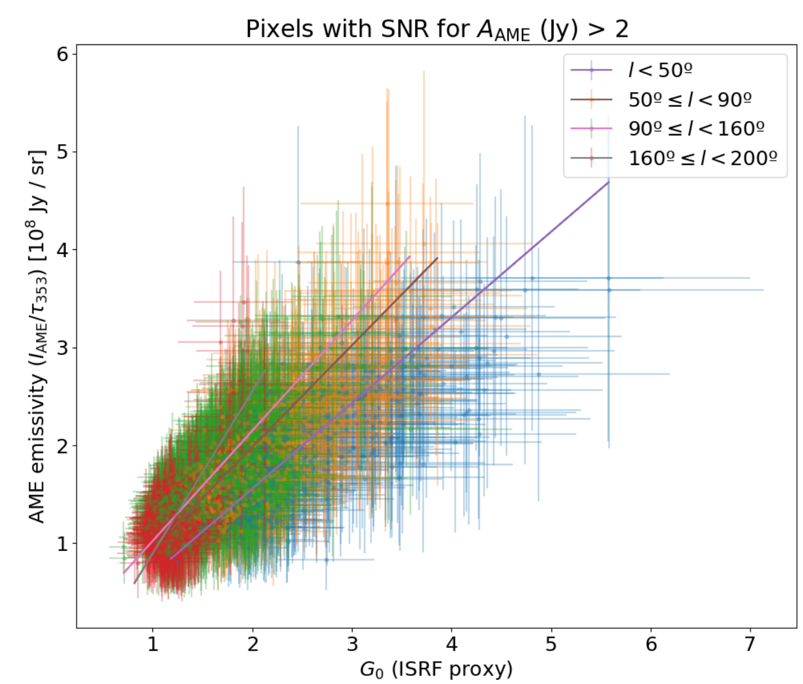




AME and TD intensities



AME spin freq with TD temp



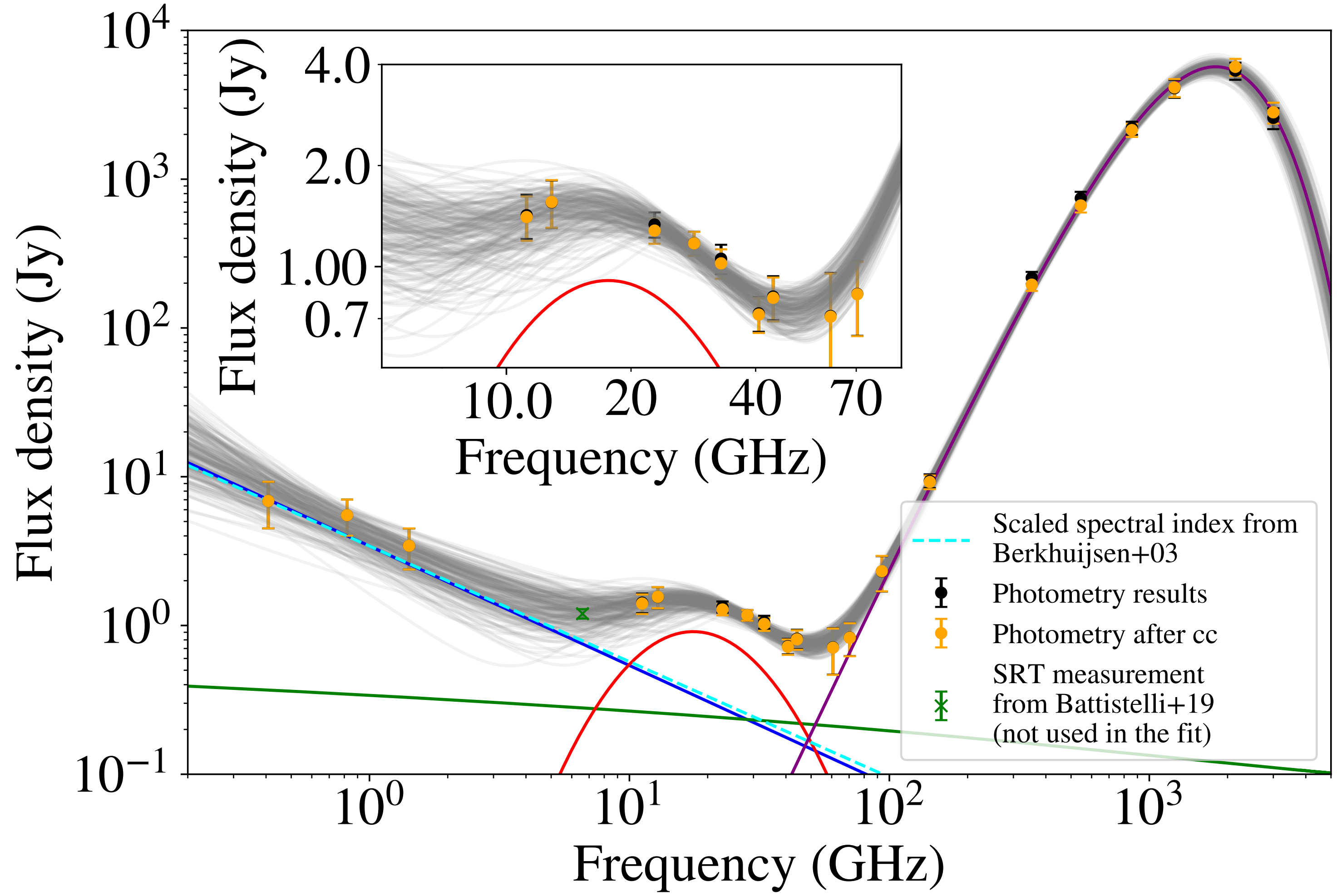
AME emissivity with ISRF

2.3. Study of the AME in M31

Fernández-Torreiro et al. 2024, MNRAS, 527, 11945

Fitted the integrated SED for M31 and estimated the probability of an AME component in the Galaxy (proposed bu previous works e.g. Battistelli+2019). First galaxy to have an AME detection on its integrated spectrum. 3rd extragalactic AME detection overall.

- 3.6σ detection of AME
- Models without an AME component strongly disfavored by statistical tests (χ^2, AIC, BIC....)
- Similar AME behavior (emissivity) to that in the GP
- First upper levels on the AME polarization fraction in an extragalactic object.

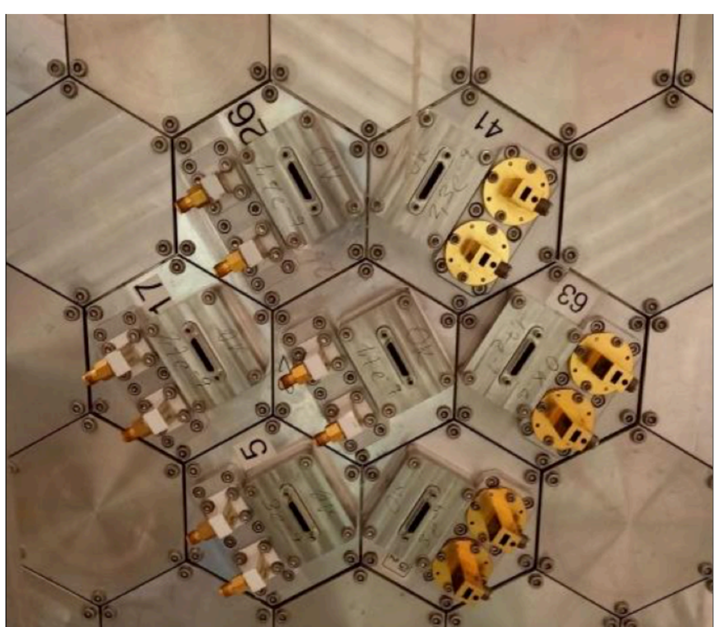


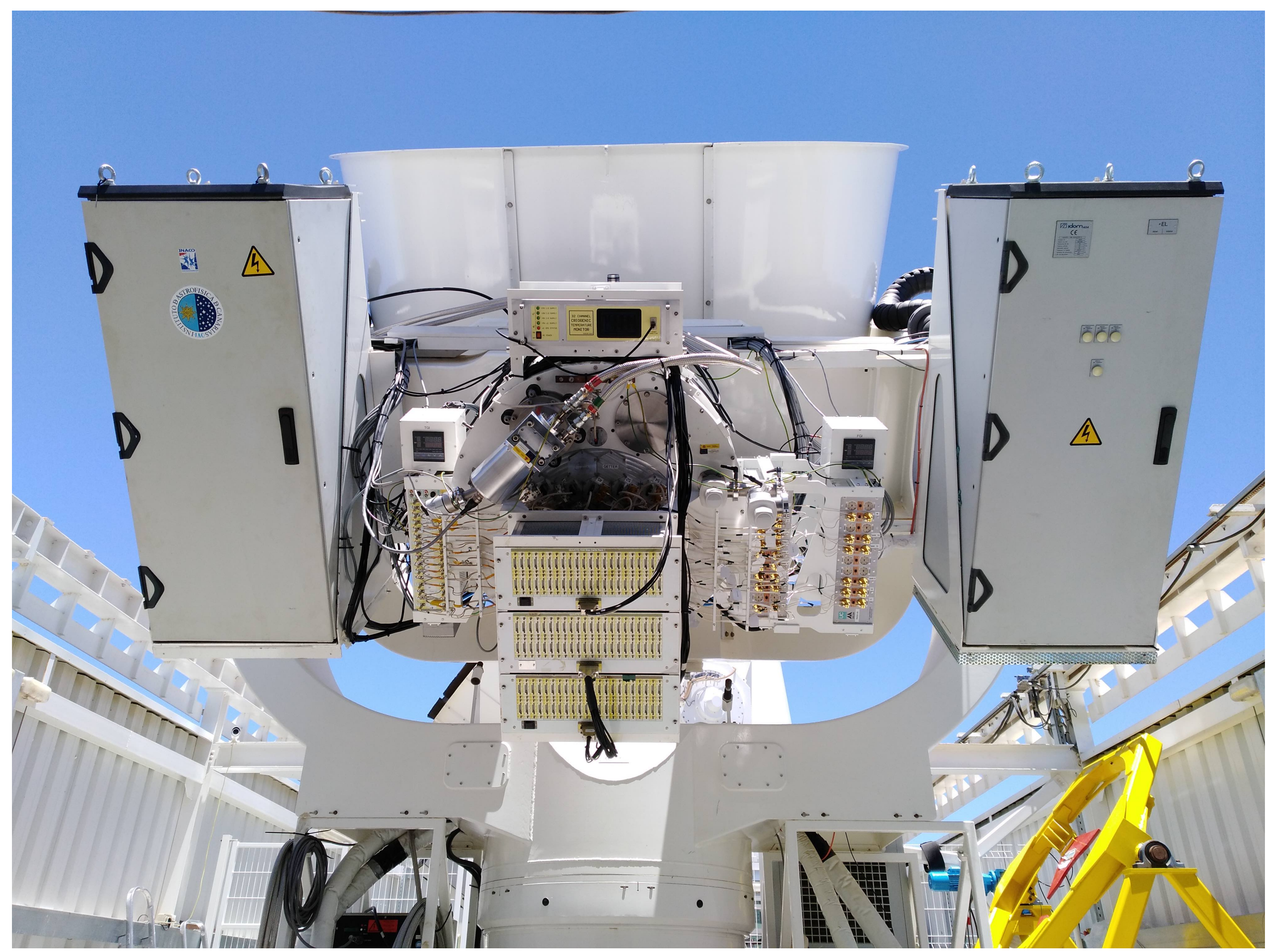
5. The future: the TFGI. Measuring *r* from the North Hemisphere

5.1. TFGI commissioning

Opposite to MFI, the TFGI is not focused on the characterization of foregrounds at large angular scales. Instead, the main goal of the instrument is to produce deep, polarized CMB observations of cosmological fields - i.e. regions with low foreground contamination. This will allow the instrument to put constrains on *r* as low as 0.05.

The commissioning phase lasted from Nov 2021 to October 2022 with 7 pixels installed in the focal plane.



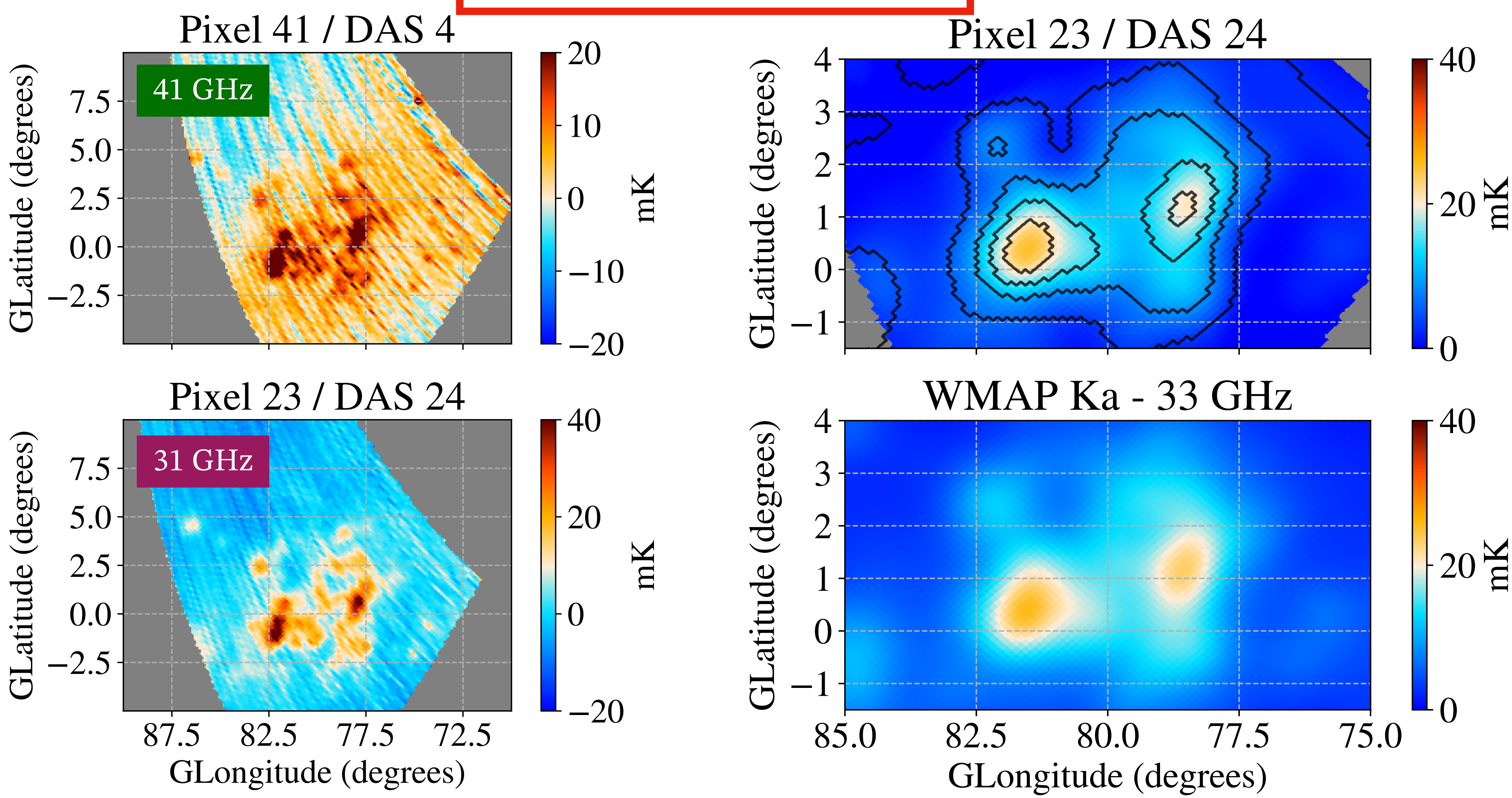


5.2. Observations of scientific regions

Fernández-Torreiro et al. in prep

Cygnus region: maps still affected by noise (especially from atmospheric $1/f$ noise). However, the morphology of the astrophysical emission is recovered well.

PRELIMINARY !!!!

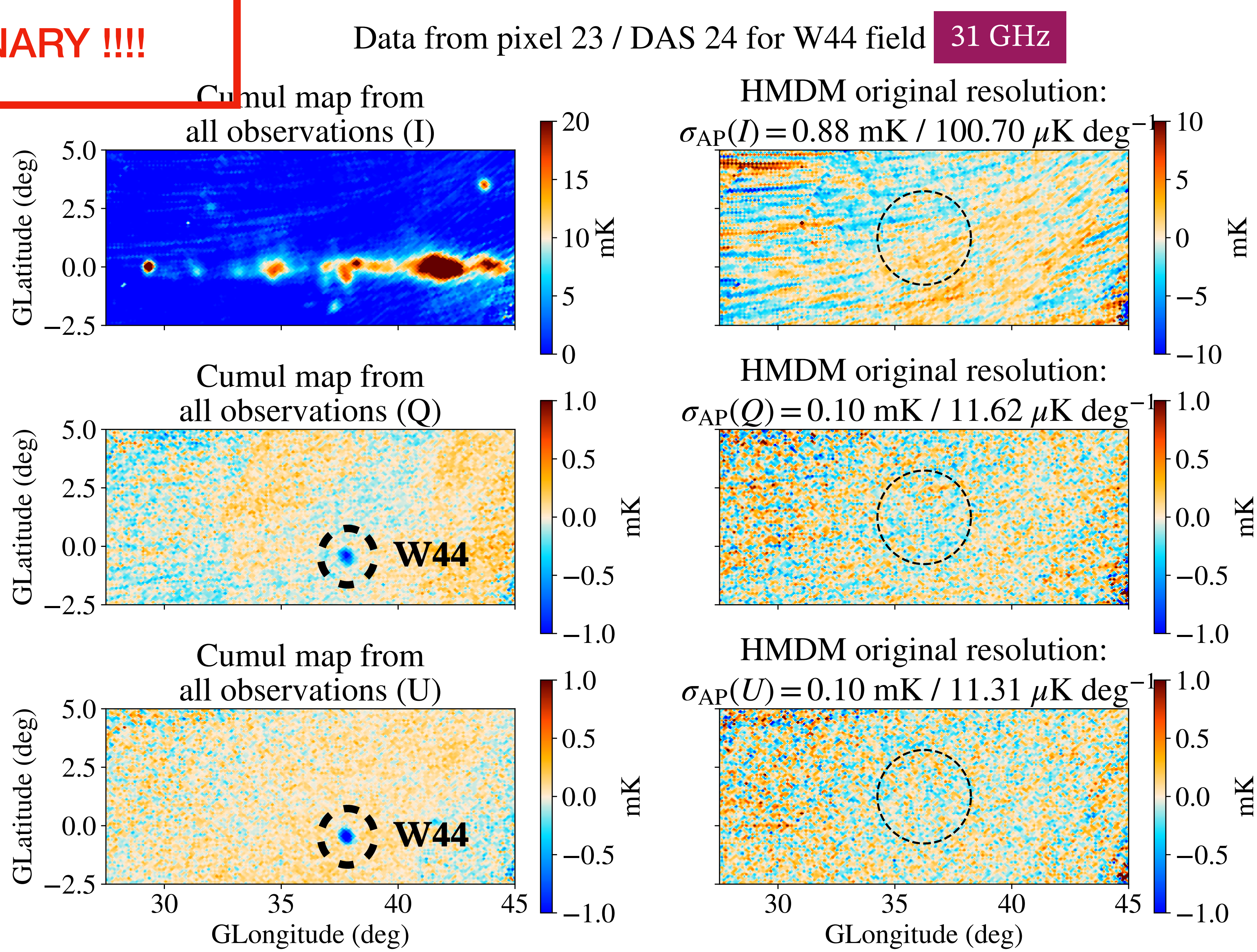


5.2. Observations of scientific regions

Fernández-Torreiro et al. in prep

W44, region on the Galactic plane. Observed for longer, so the imprint of the noise structures is lower.

PRELIMINARY !!!!



5.3. Final performance evaluation

Fernández-Torreiro et al. in prep

The final sensitivity level for this region is 10 $\mu\mathrm{K\,deg}^{-1}$. This implies that TFGI would require around 3000 hours of integration time to meet is design goal, 1 $\mu\mathrm{K\,deg}^{-1}$, on the larger cosmological fields once the full set of 30 detectors is installed. This accounts to 1/3 of the total time from the MFI WS (~9000 h).

1 $\mu\mathrm{K\,deg}^{-1}$at 36 GHz is 0.05 $\mu\mathrm{K\,deg}^{-1}$at 93GHz. Hensley+2022 quoted 0.19 and 0.06 $\mu\mathrm{K\,deg}^{-1}$ sensitivities at 93 GHz for SO LAT and SAT

The TFGI is thus in line to achieve a similar sensitivity to that from one SAT, while observing the sky with a resolution 4 times finer.

Thanks for your attention.
Questions?