The QUIJOTE experiment: project overview and first results

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Quijote

Q-U-I Joint Tenerife CMB experiment

EWASS 2015

EUROPEAN WEEK OF ASTRONOMY AND SPACE SCIENCE

22-26 JUNE

LA LAGUNA, TENERIFE

CANARY ISLANDS, SPAIN

QUIJOTE collaboration

QUIJOTE: project baseline

★ **Goals:**

- To obtain six polarization maps in the frequency 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**

★ **Site:** Teide Observatory (altitude: 2400 m, latitude: 28º), Spain

★ **Observability:** -32º<Dec.<88º (f_{sky} ~0.65)

★ **Frequencies:** **11,13, 17, 19, 30** and **42 GHz**

★ **Angular resolution:** **1 degree** (52 arcmin @ 11 GHz)

★ **Telescope and instruments:**

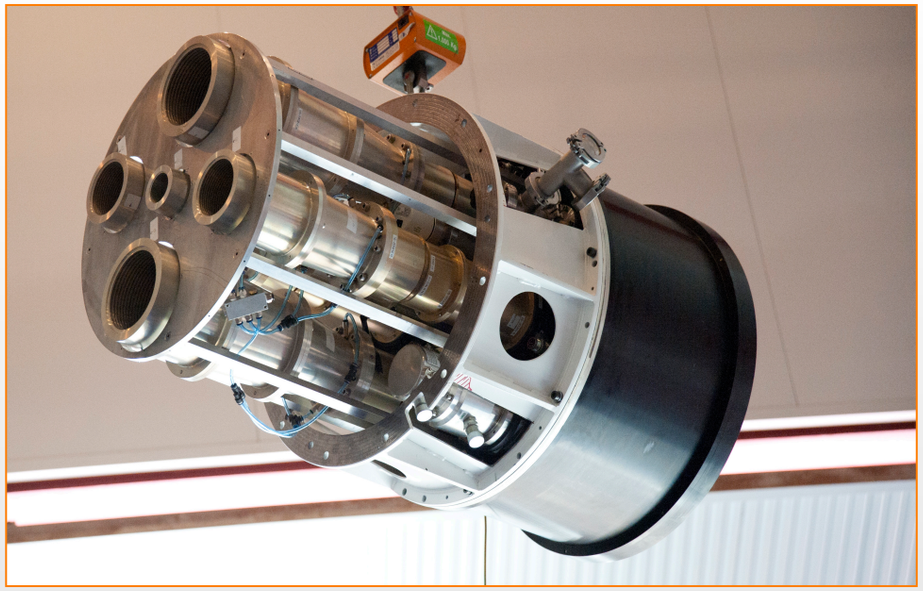
- **Phase I**:
  - First Telescope (**QT1**)
  - Equipped with a Multifrequency Instrument (**MFI**) with 4 polarimeters @ **10-20 GHz**. Started operations Nov. 2012
  - Second Instrument (**TGI**) with 31 polarimeters @ **30 GHz**. Funded; in AIV phase now
- **Phase II**:
  - Second Telescope (**QT2**). Installed in May 2014
  - **FGI** with 31 polarimeters @ **42 GHz**. Funded (Late 2015/2016)

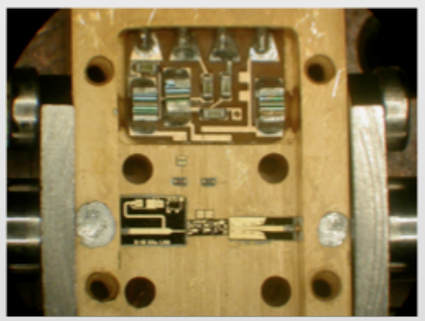
★ **Scientific operation plan:** 2012-2020

QUIJOTE Telescopes

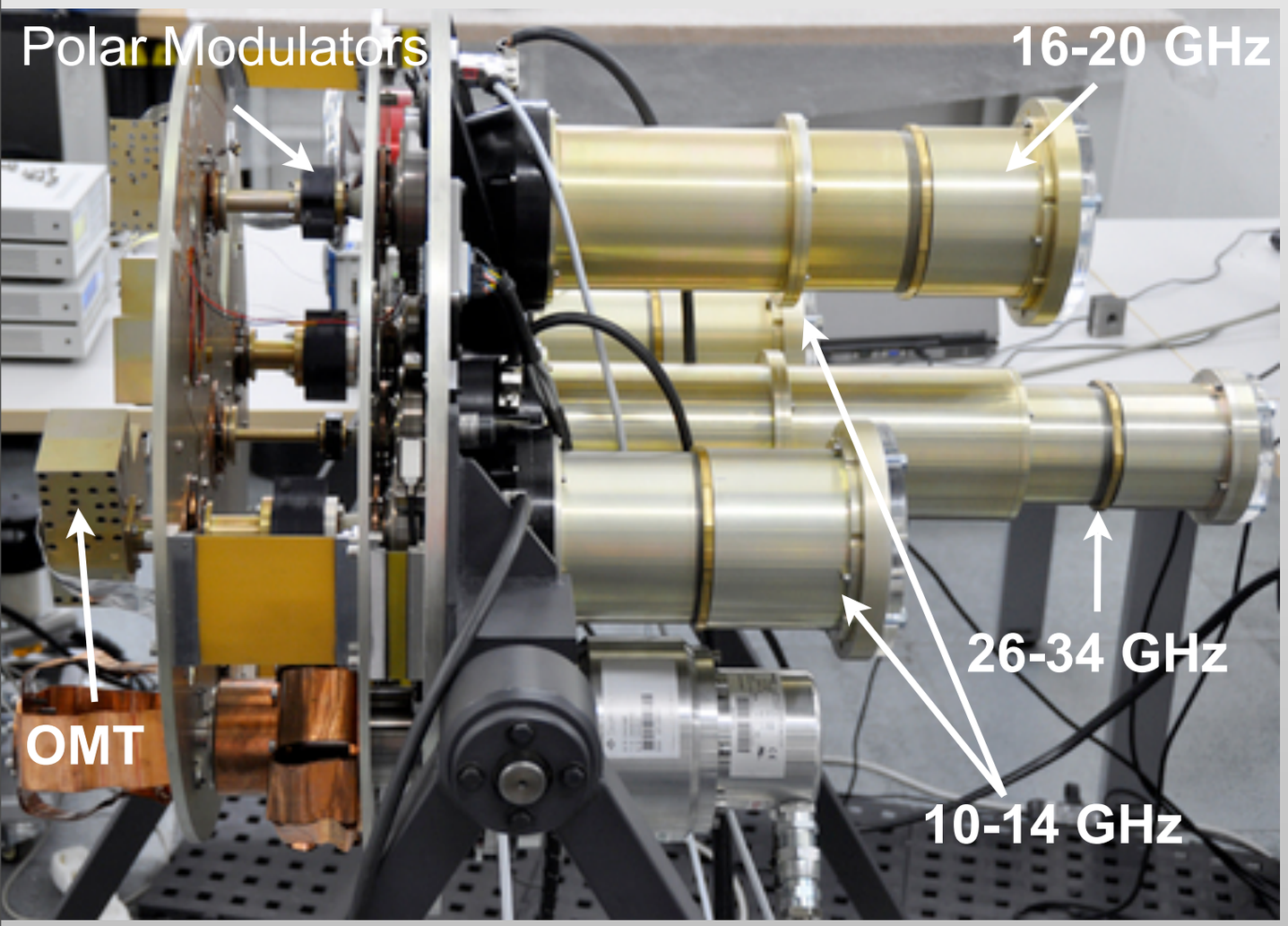
Multi-Frequency Instrument (MFI)

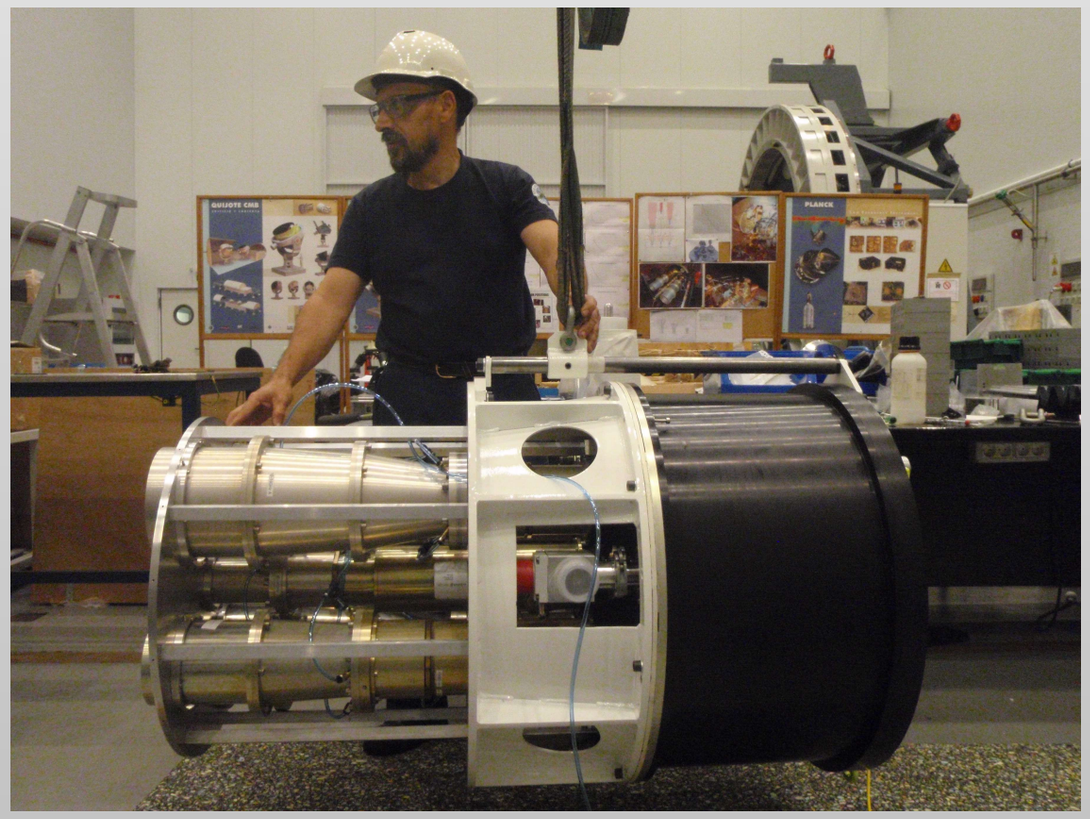
- Observing since November 2012
- 4 horns, 32 channels, covering 4 frequency bands: 11, 13, 17 and 19 GHz
- Sensitivities: ~400-600 μK·s$^{1/2}$ per channel





LNA

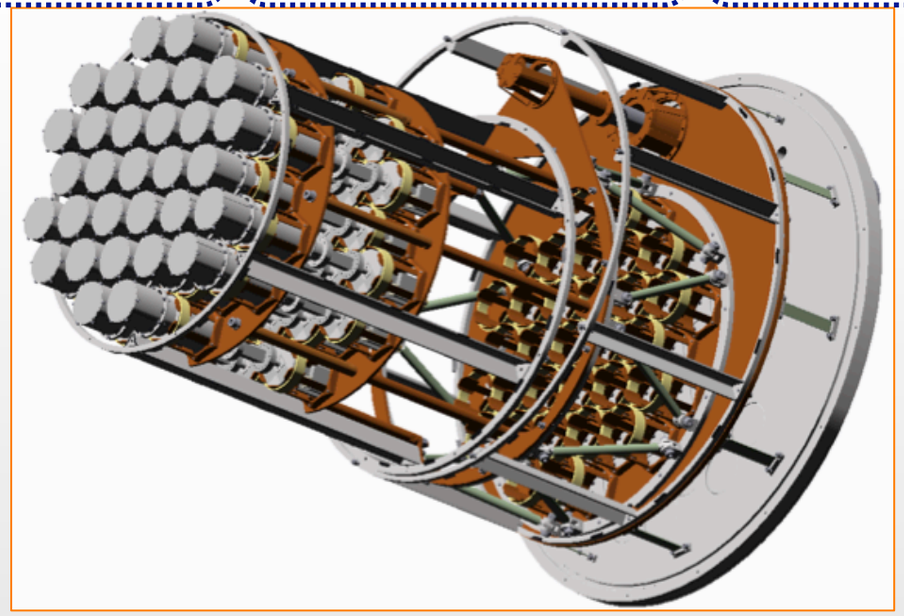


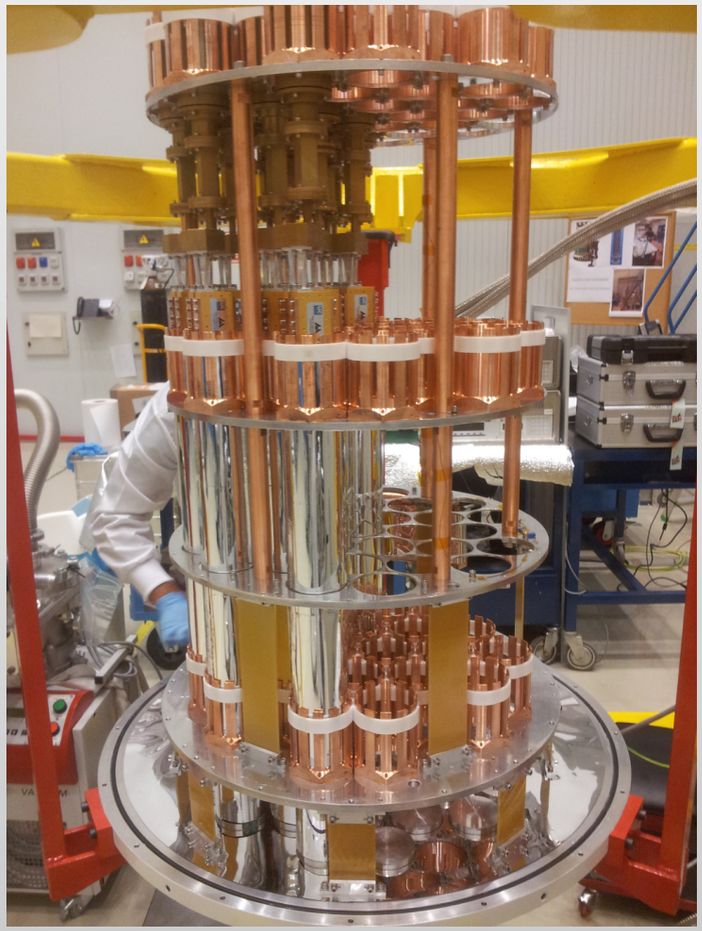


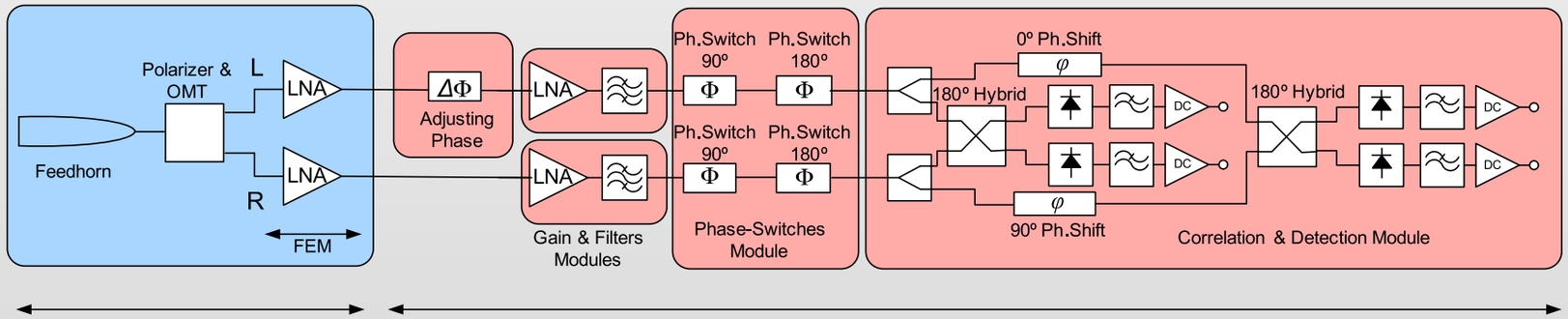
Thirty GigaHertz Instrument (TGI)

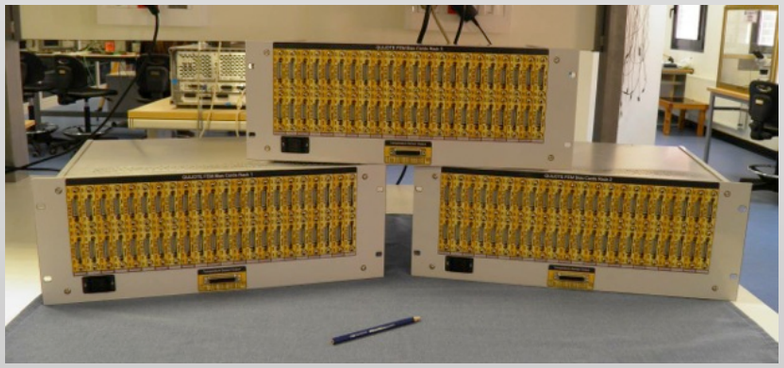
- Currently on AIV phase
- 31 pixels at 30 GHz
- Expected sensitivity of the full array: ~50 μK·s$^{1/2}$

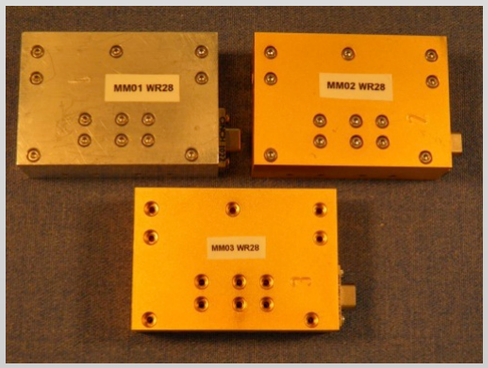
- The FGI will consist of 31 pixels at 42 GHz, with sensitivity ~60 μK·s$^{1/2}$

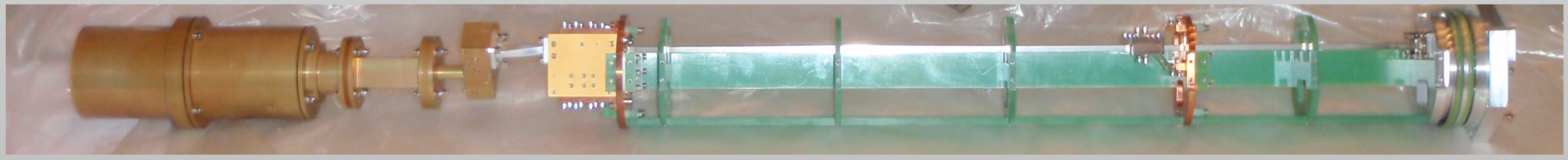






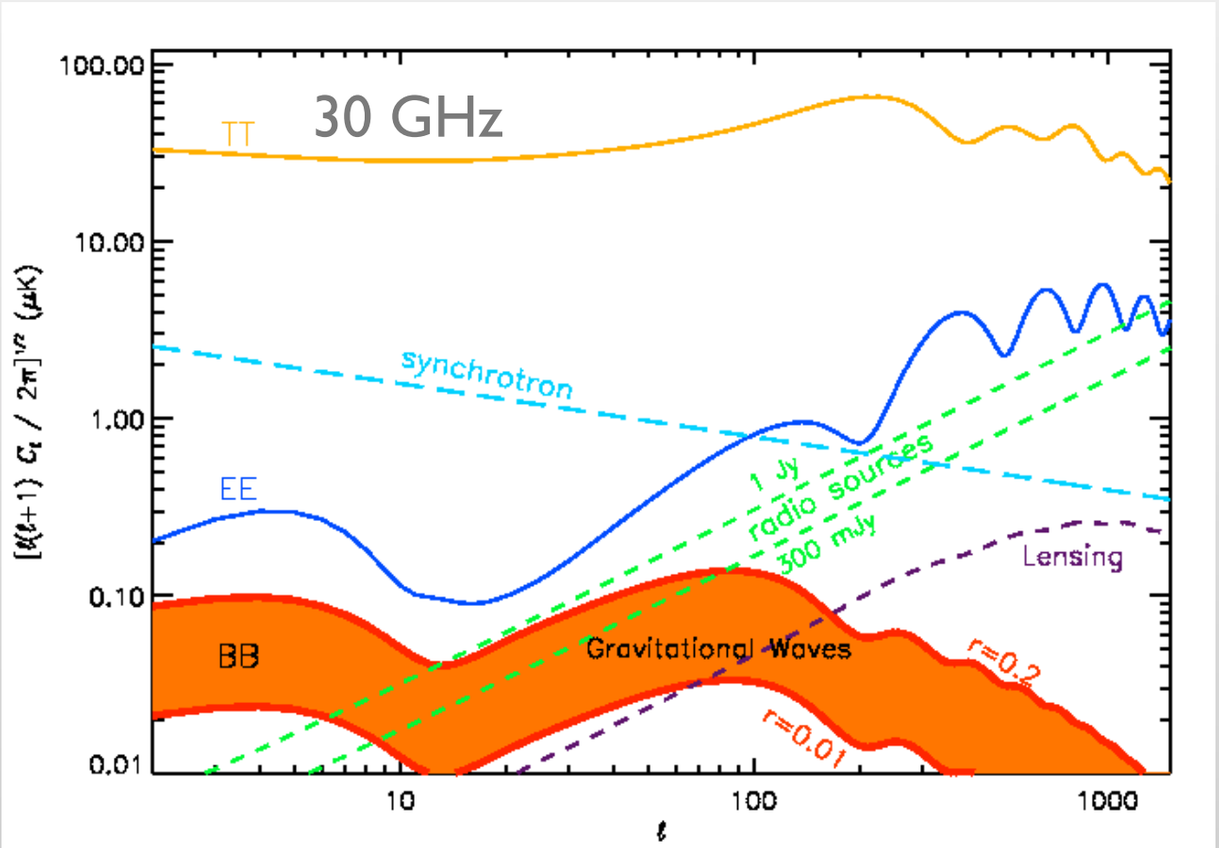


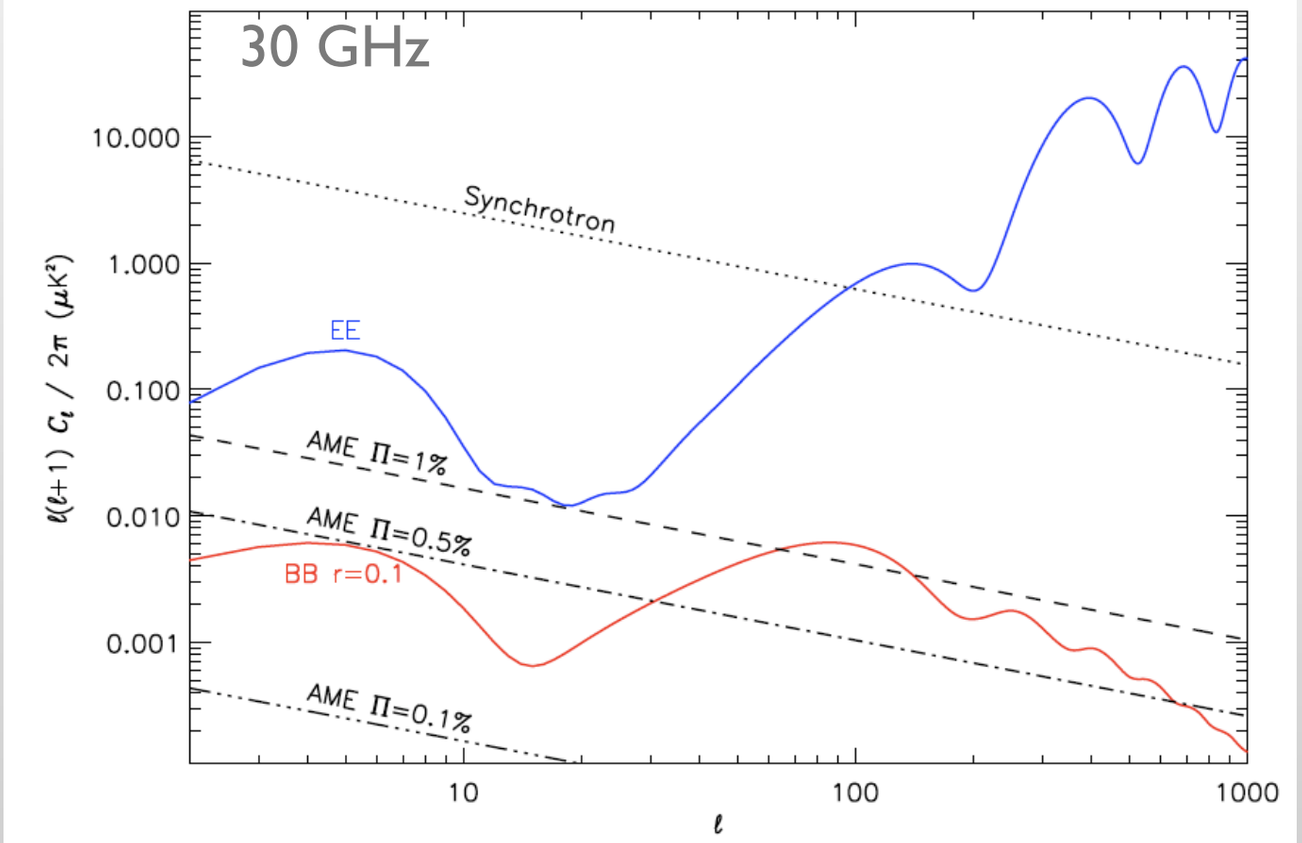




Science with the MFI

- **Shallow Galactic survey**. Covering 20,000 deg^2 (finished - more than 5000 hours)
  - ≈ **20 μK/(beam 1º)** with the MFI @ 11, 13, 17 and 19 GHz, in both Q and U
- **Deep cosmological survey**. It will cover around 3,000 deg^2. After 1 year
  - ≈ **10 μK/(beam 1º)** with the MFI @ 11, 13, 17 and 19 GHz





★ The MFI maps will provide valuable information about the polarization properties of:

- Synchrotron emission: should dominate the emission at the MFI frequencies. WMAP 23 GHz shows it to be polarized at ~5-15%, depending on the Galactic latitude
- Anomalous microwave emission: little known about its polarization. Best upper limits on the polarization fraction: <1% (López-Caraballo et al. 2011, Dickinson et al. 2011)

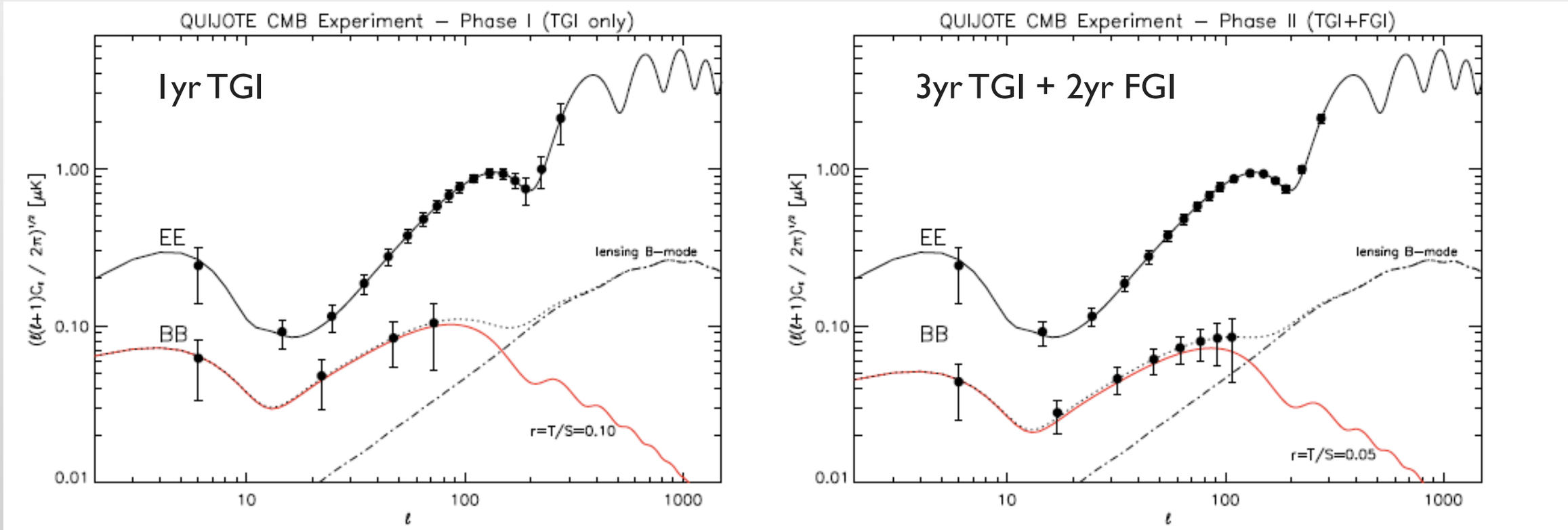
Science with the TGI and FGI

- **Shallow Galactic survey**. Covering 20,000 deg^2. 5 months

  ≈ 2 μK/(beam 1º) with the TGI @ 30 GHz and with the FGI @ 40 GHz, afer 5 months

- **Deep cosmological survey**. It will cover around 3,000 deg^2. 1 year

  ≤ 1 μK/(beam 1º) with the TGI @ 30 GHz and with the FGI @ 40 GHz



★ **Left**: example of the QUIJOTE-CMB scientific goal after the Phase I. It is shown the case for 1 year (effective) observing time with the TGI, and a sky coverage of 3,000 deg^2. The red line corresponds to the primordial B-mode contribution in the case of **r = 0.1**

★ **Right**: QUIJOTE-CMB Phase II. Here we consider 3 years of effective operations with the TGI, and that during the last 2 years, the FGI will be also operative. The red line now corresponds to **r = 0.05**

MFI observations status

Commissioning phase
(November 2012 – March 2013)

- Calibrators (>100 hrs observing CRAB, CASS-A, Moon, Jupiter, sky dips)
- Polarization tests
- Local interference map (~10 h)
- Tsys calibration (~10h)
- Science demonstration cases:
  - Cygnus loop (~1h)
  - Fan region (> 135 h)
  - Perseus molecular cloud (200h)

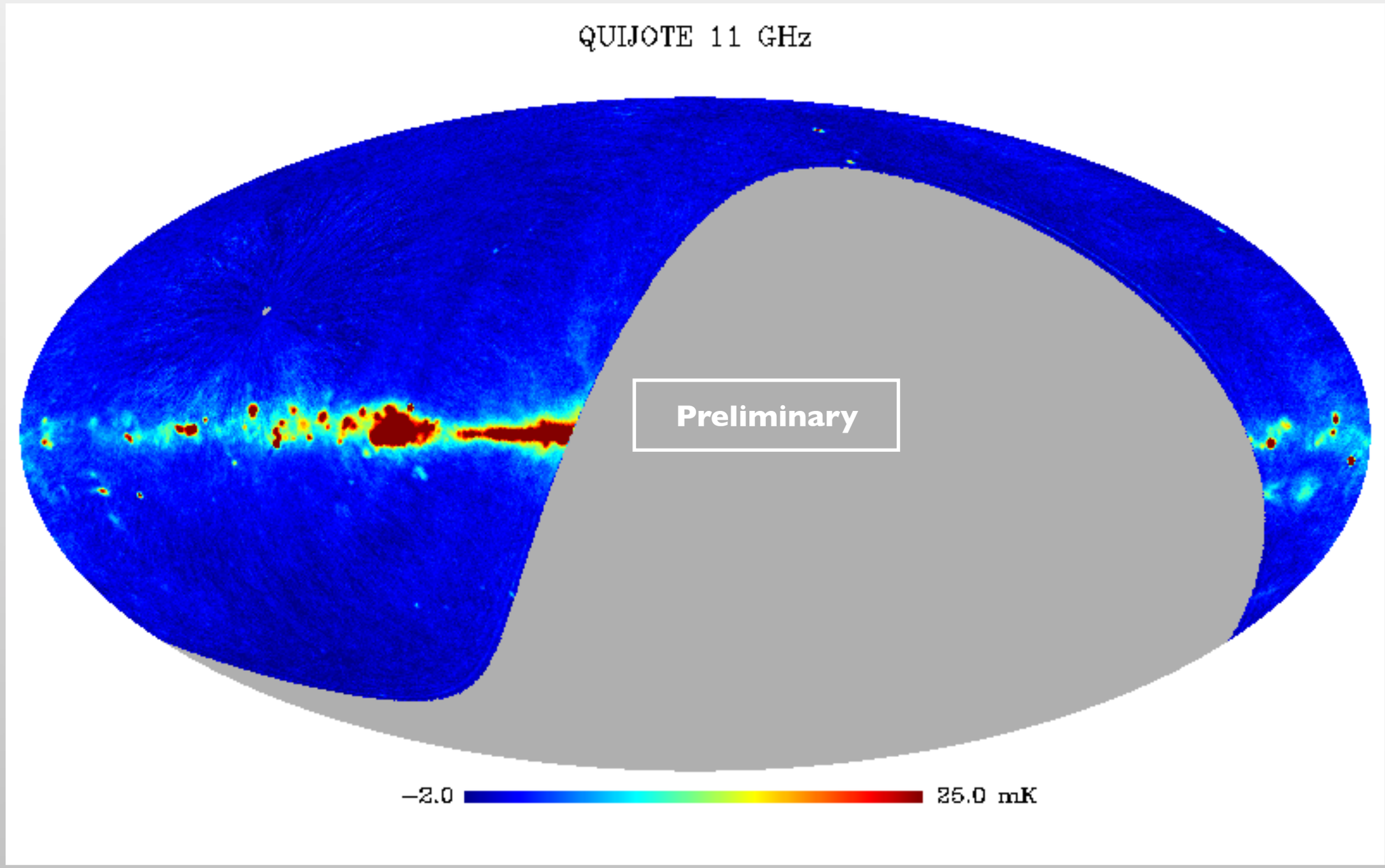
Science phase
(April 2013 - now)

- Wide survey (5200h)
- Cosmological fields (2000h)
- Daily calibrators (Crab, Cas A, Jupiter, sky dips)
- 3C58 and the Fan region (170h)
- Galactic Haze (550h)
- Perseus molecular cloud (300h)
- SNRs: IC443 (250h), W63 (250h), W44 and W47 (200h)
- Taurus region (400h)

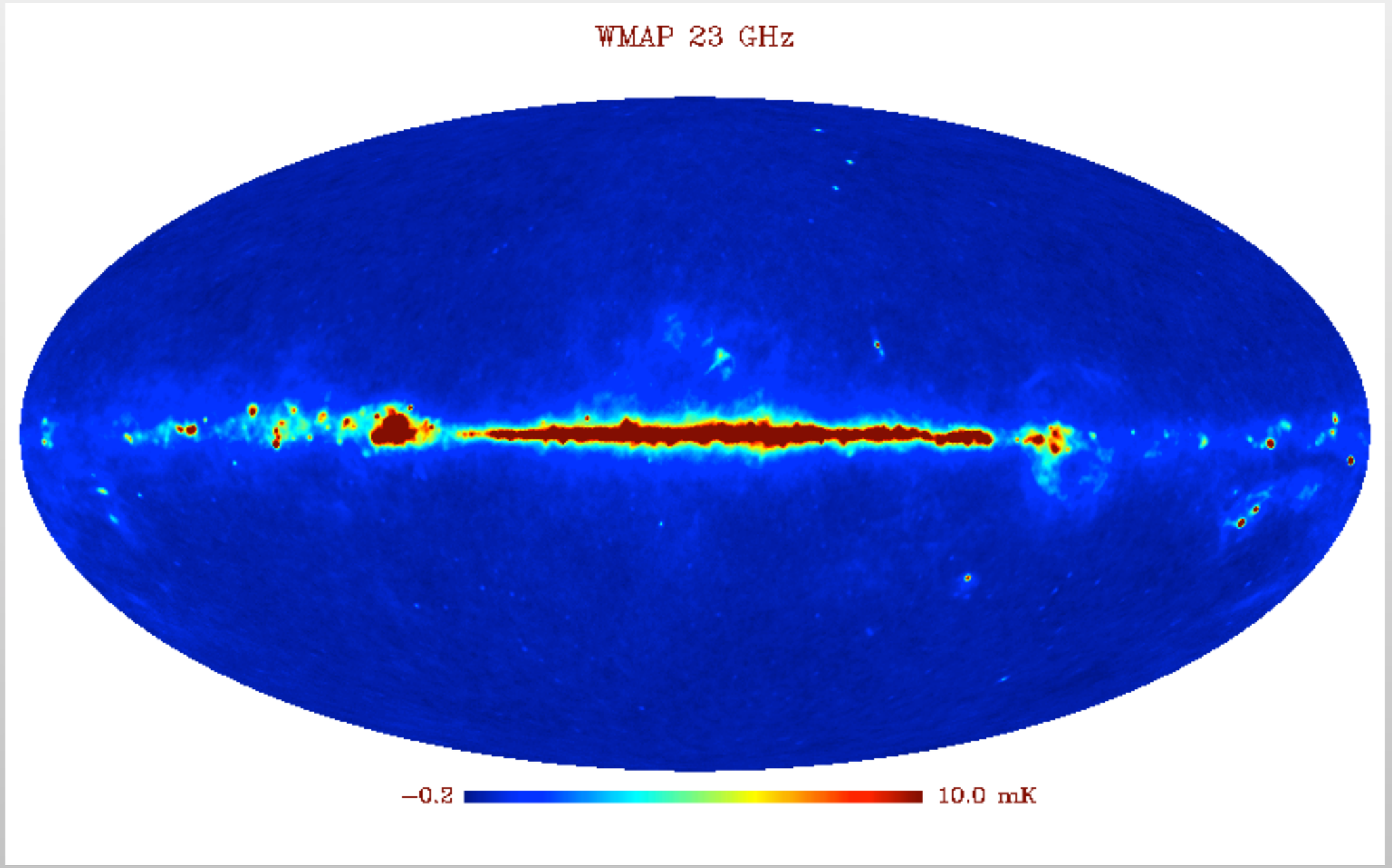
Total: **10700 h** (447 effective days), with 49% efficiency

Wide survey

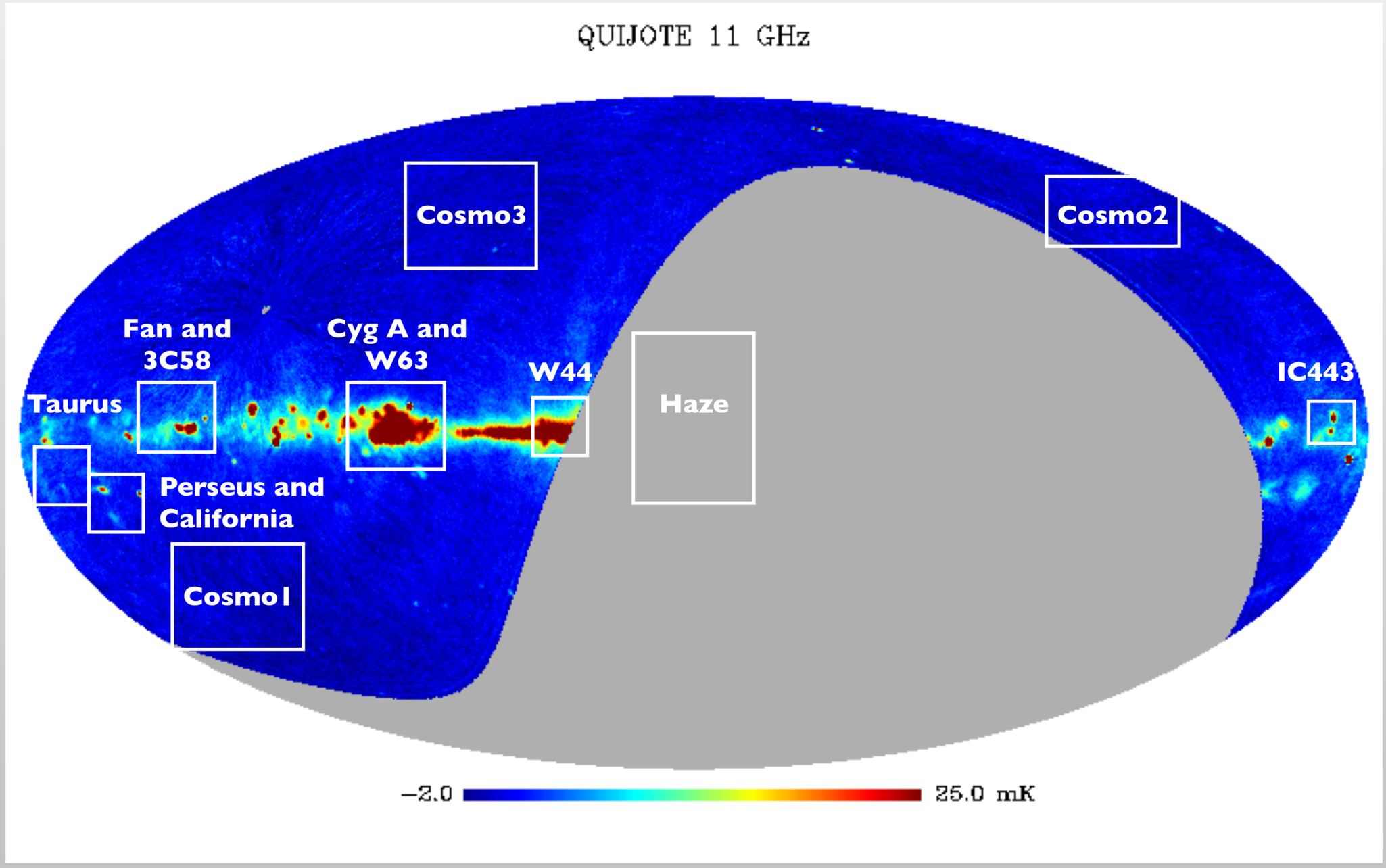
- Full mapping of the northern sky at each of the four MFI frequencies
- Nominal mode (continuous rotation around AZ). More than 5000 h
- Sensitivity: ~20 μK/beam in Q,U and, ~50 μK/beam in I
- Map resulting from 700 h:



Wide survey



QUIJOTE individual fields

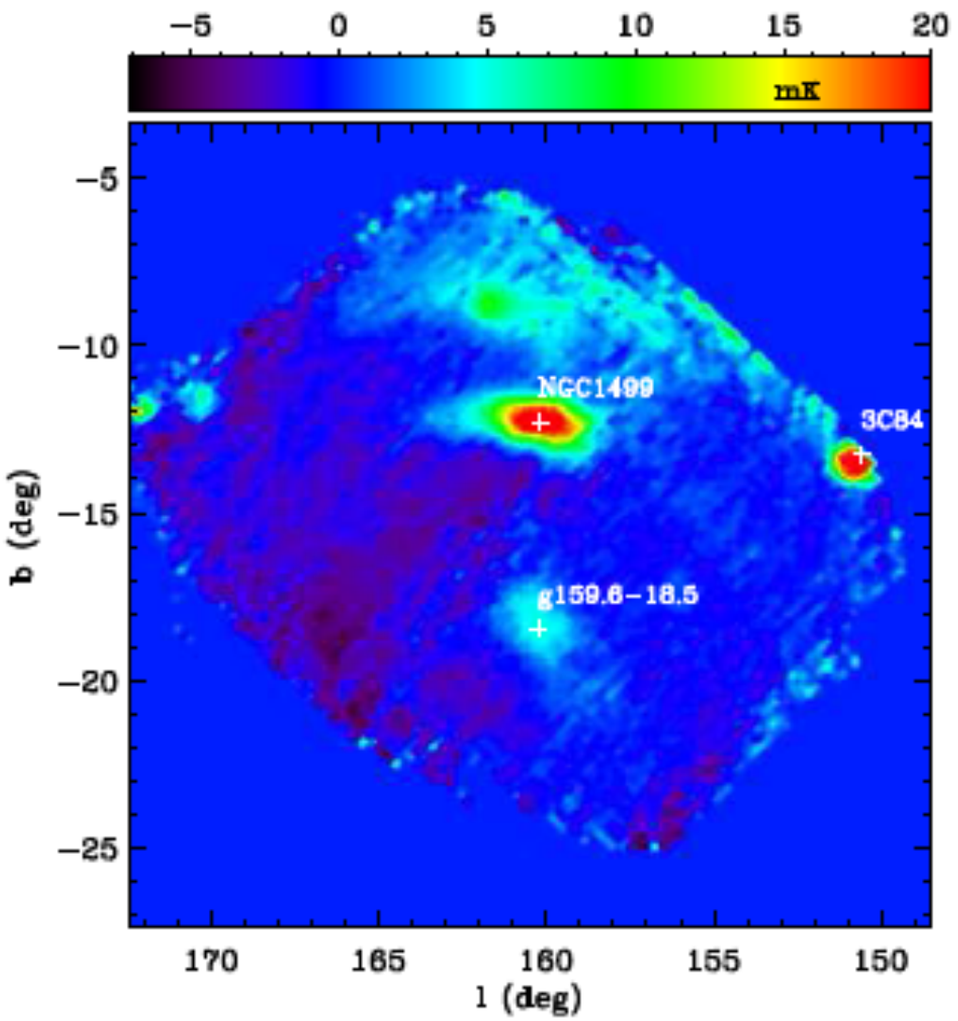


Perseus molecular complex

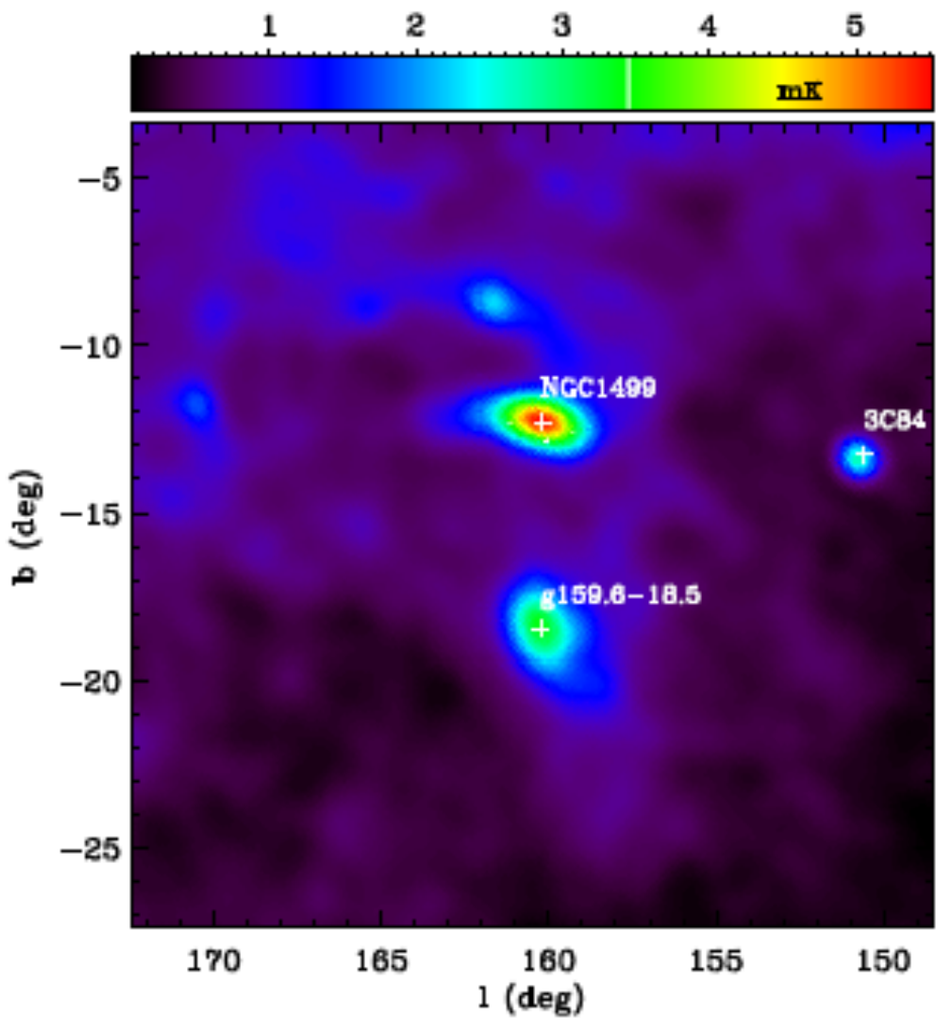
• One of the first objects where the Anomalous Microwave Emission was well characterized, using observations from the COSMOSOMAS experiment (Watson et al. 2005)

• Large observation program (~150 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 (Watson et al. 2005, Planck collaboration 2011)

Quijote 11 GHz



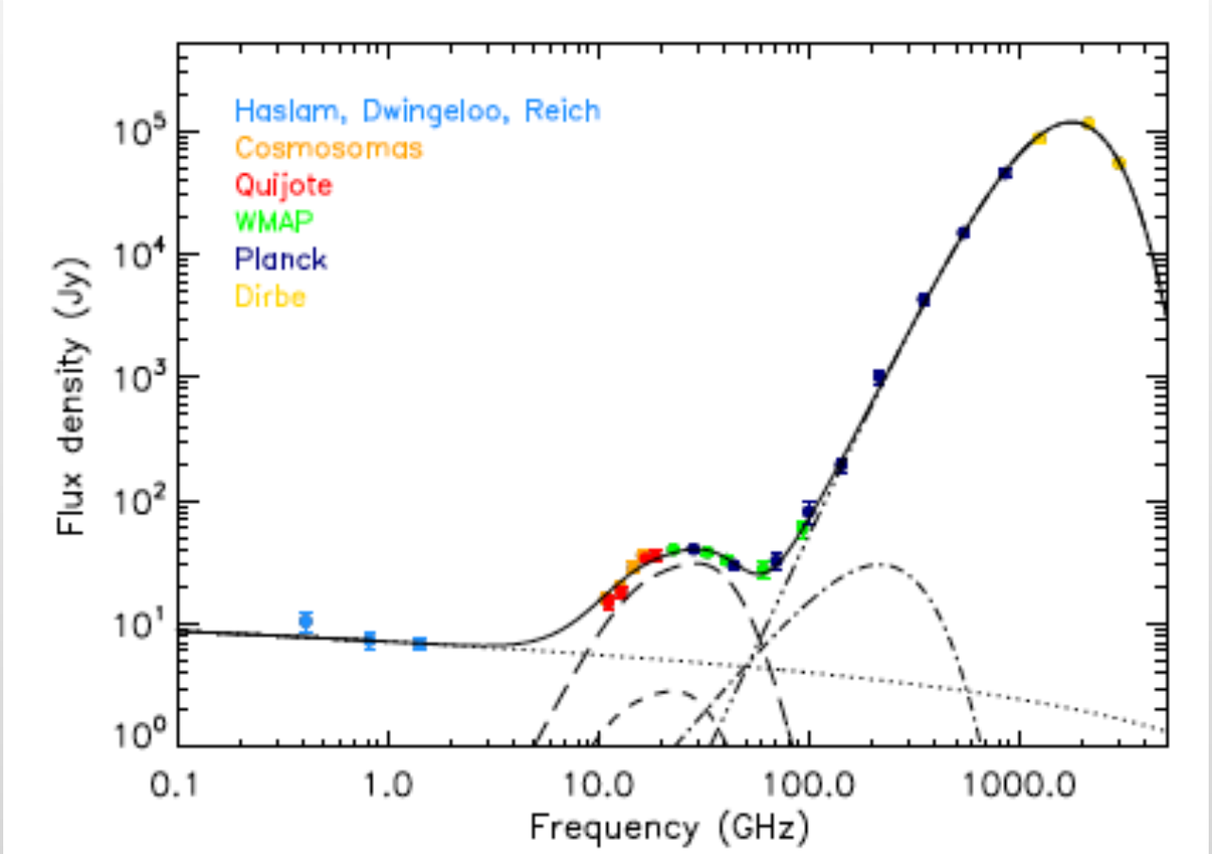
WMAP 23 GHz



• First QUIJOTE paper: Génova-Santos et al. (2015), arXiv:1501.04491 (accepted in MNRAS)

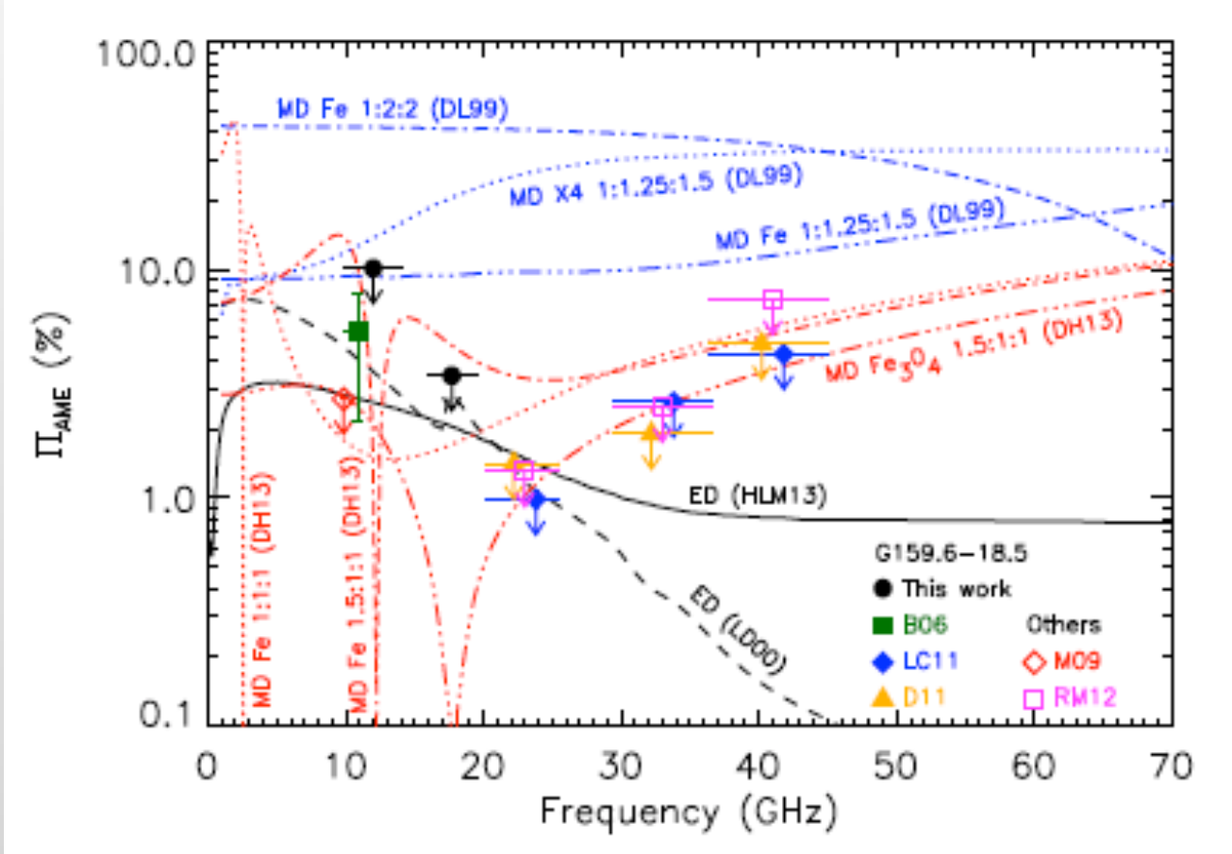
Perseus molecular complex

SED modelling on G159.6-18.5 in intensity



- AME (spinning dust) shows up at intermediate frequencies
- Simultaneous fit of all components gives χ^2/dof = 1.08
- Most precise spinning dust spectrum to date (13 independent data points in the relevant range)

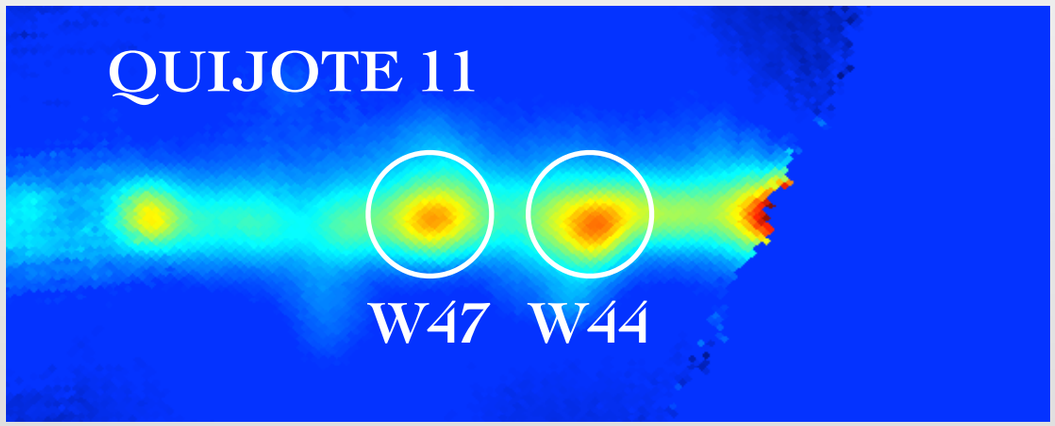
Constraints on the AME polarization

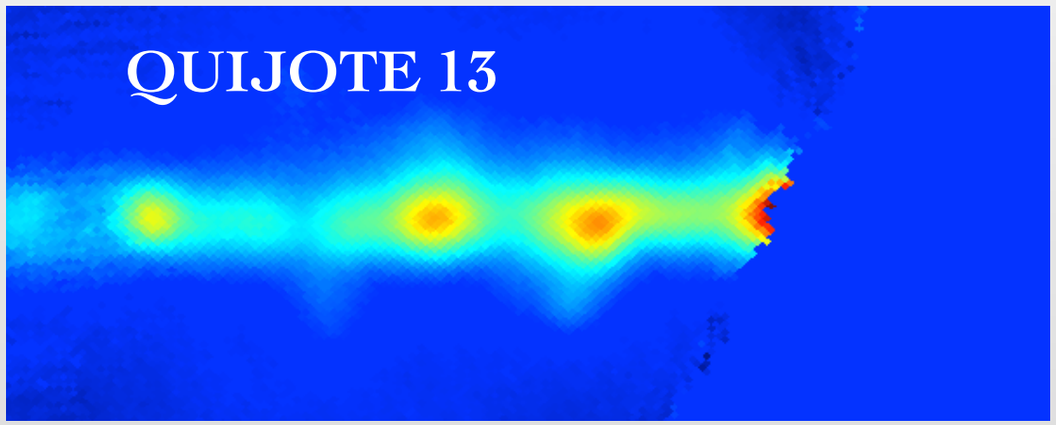


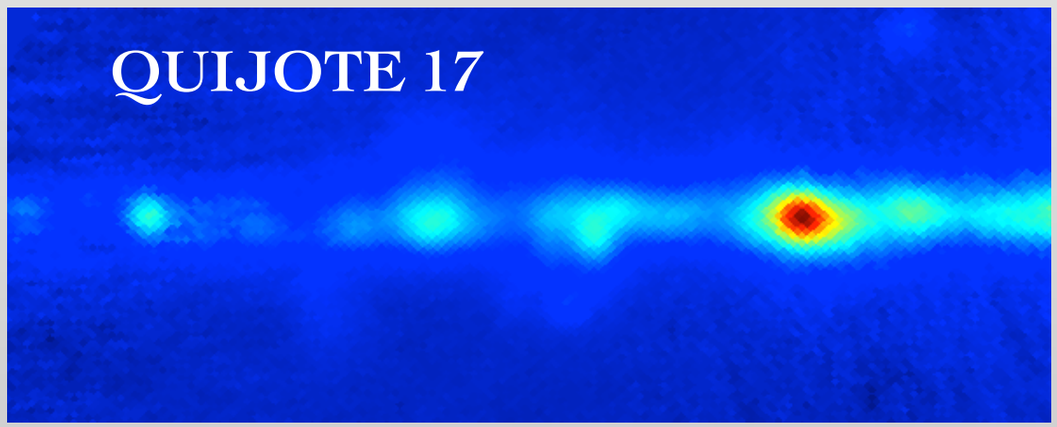
- **No polarization detection**.
- $\Pi < 6.3\%$ at 12GHz and $< 2.8\%$ at 18GHz (95% C.L.)
- Models predict up to 2-3% in this range
- Stringent upper limits can be derived from WMAP at 23GHz (López-Caraballo et al. 2011) where the signal is expected to be lower

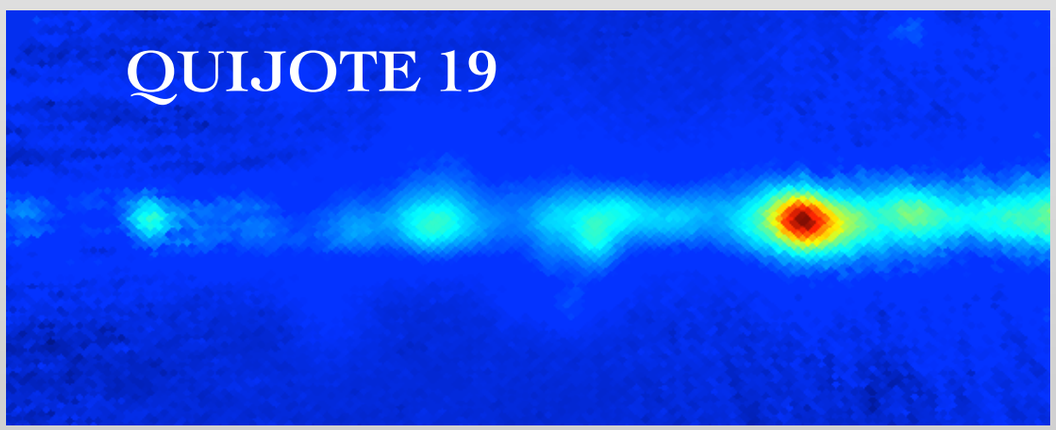
W44 and W47

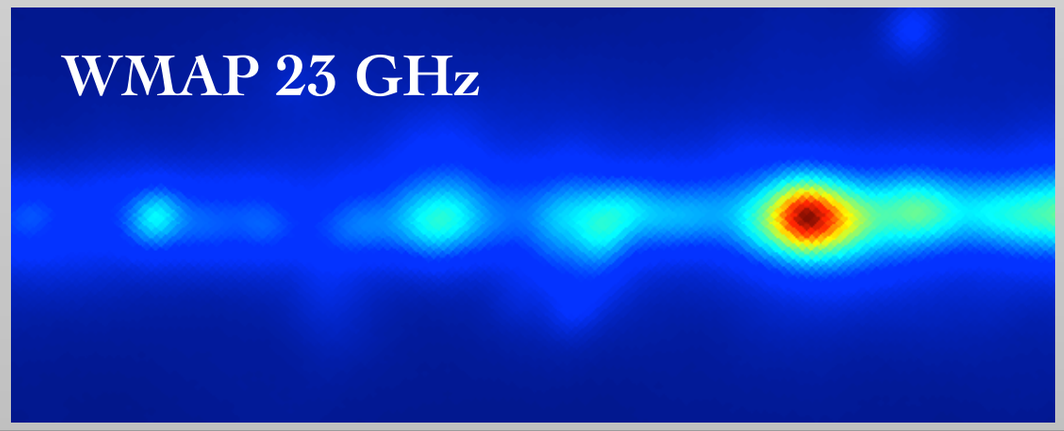
- W44 is a bright SNR, W47 is a molecular complex
- AME detected using WMAP/Planck, and C-BASS at low-frequency (Irfan et al. 2015)
- QUIJOTE observations through raster scans (200 hours)
- Intensity 20º x 8º maps along the Galactic plane centred on (l,b)=(36º,0º)

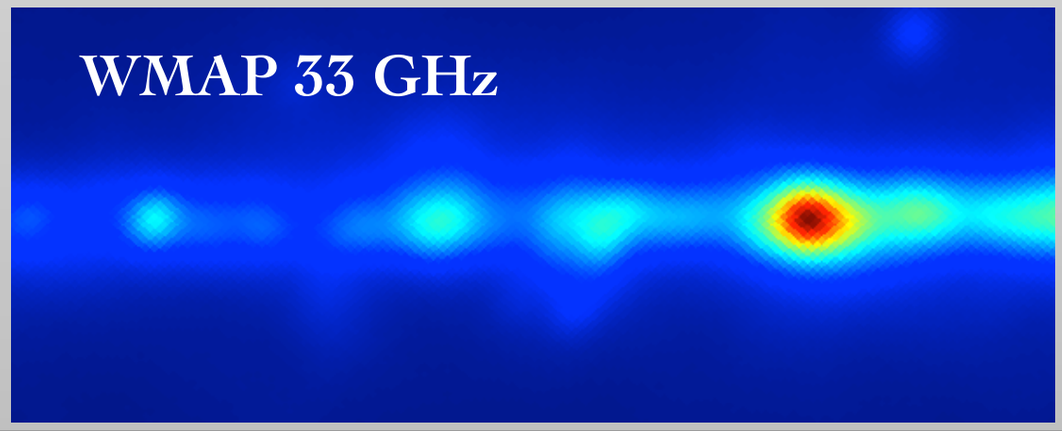












W44 and W47

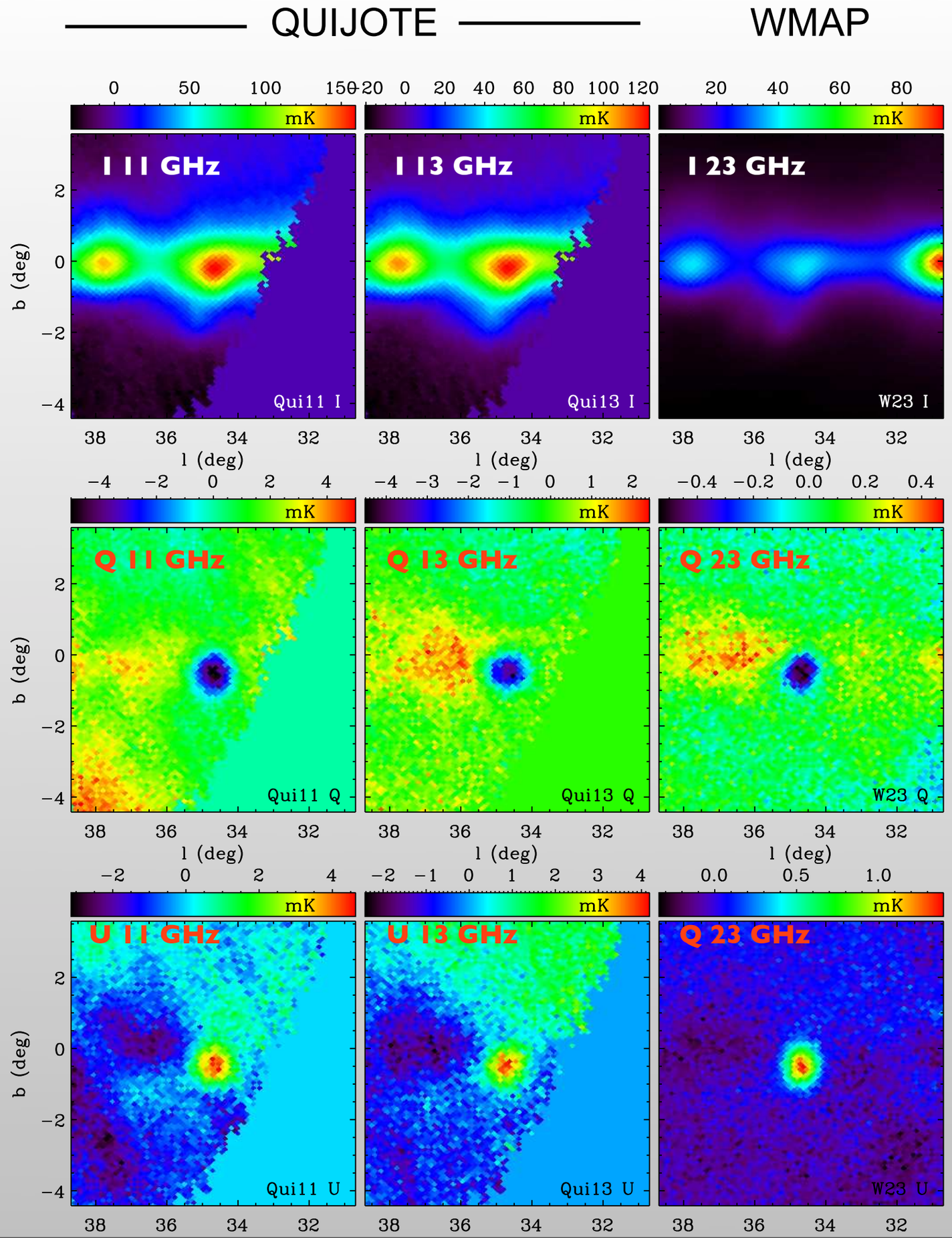
- Intensity and polarization maps on W44, from QUIJOTE and WMAP

- Masked region in QUIJOTE towards the right due to contamination from geostationary satellites

- Good spatial correlation in intensity and in polarization between QUIJOTE and WMAP

- Polarized synchrotron emission seen in W44, as well as diffuse polarized emission from the Galactic plane

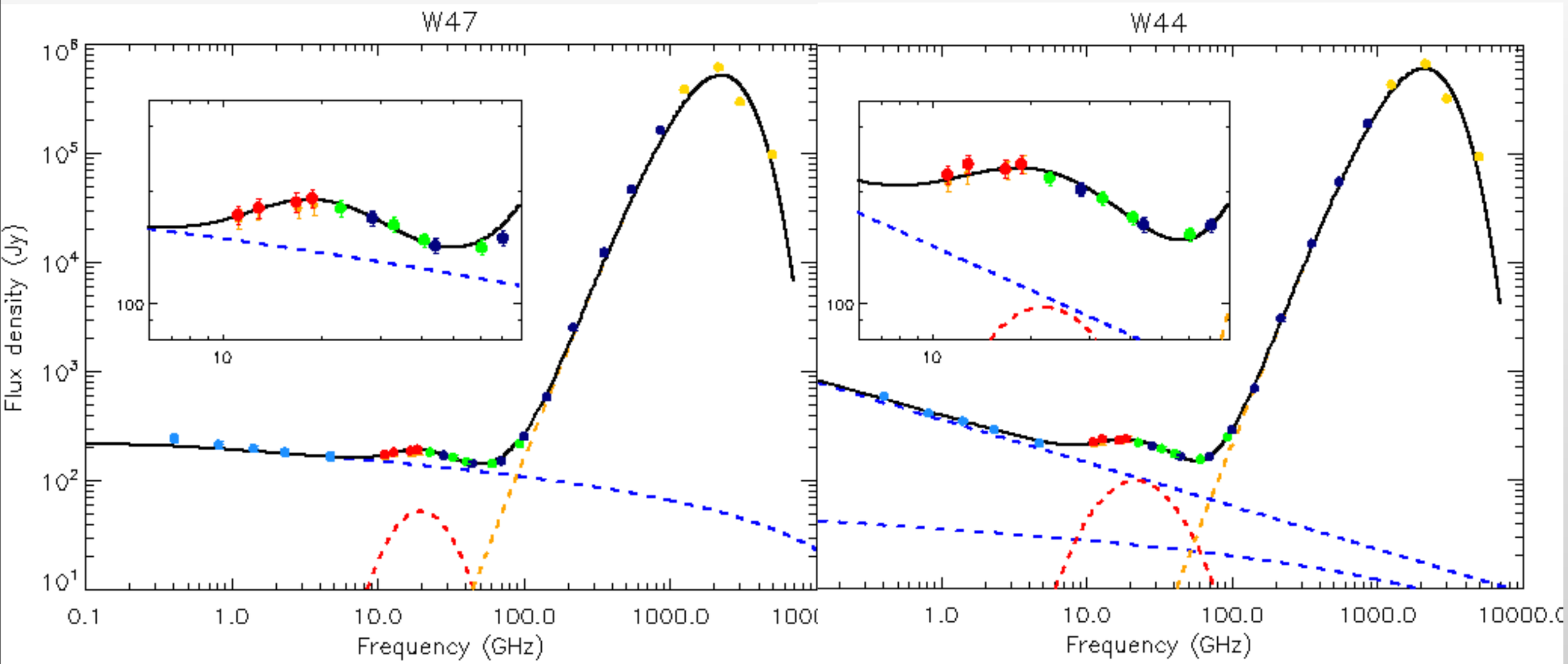
- No polarized signal is detected from W47, as its emission is dominated by free-free



W44 and W47

- SEDs of the two regions

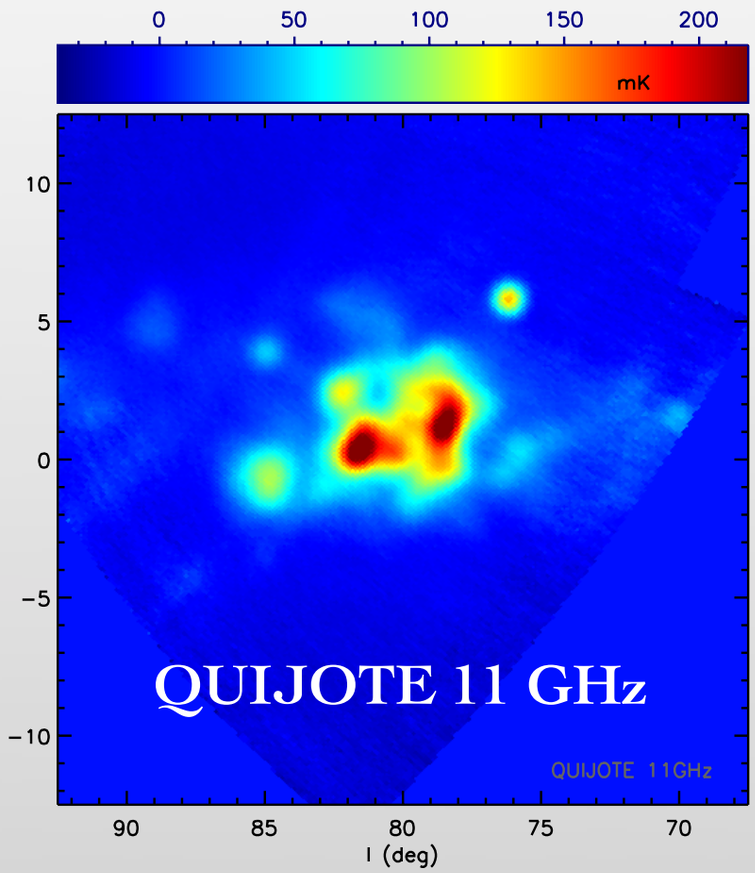
Génova-Santos et al. (in prep.)

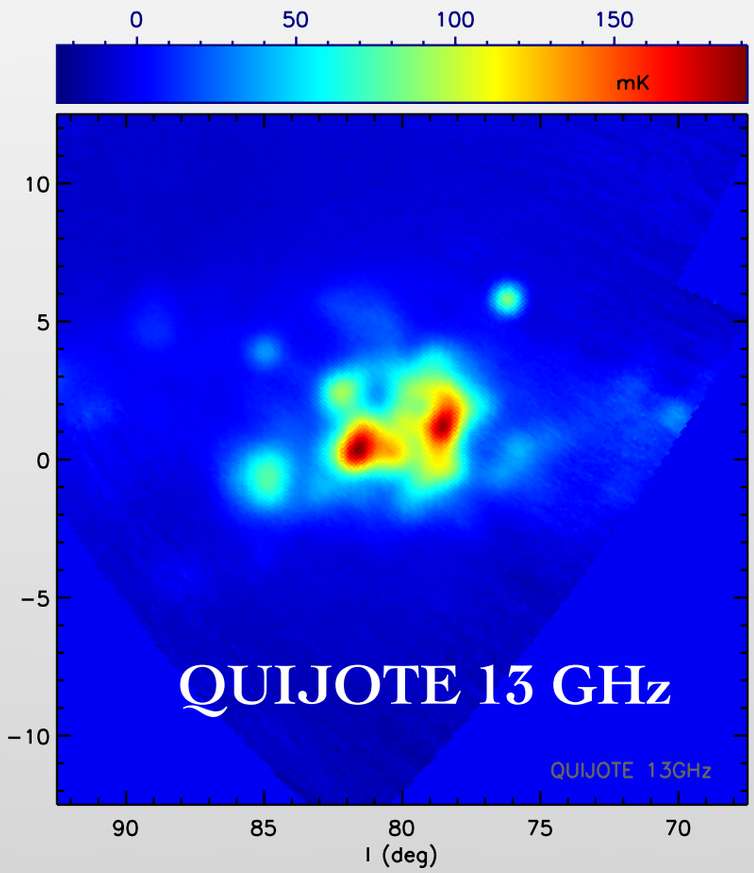


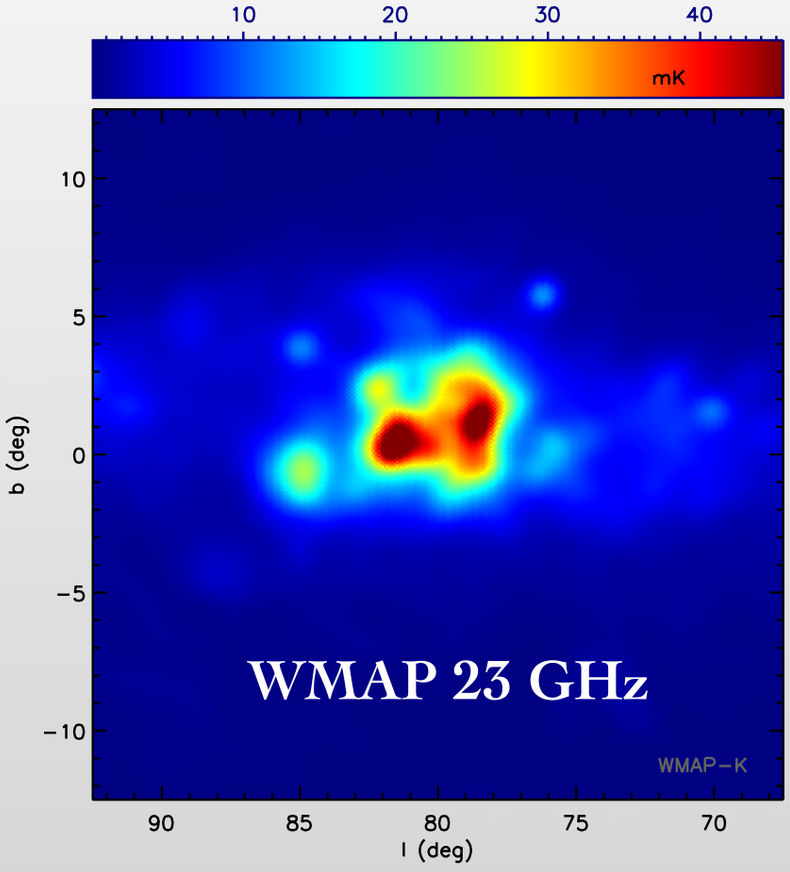
- The four QUIJOTE data points confirm the downturn at low-freq due to spinning dust
- AME peak even brighter than Perseus, although the free-free emission in W47 and the synchrotron emission in W44 are stronger
- Possibility to set constraints on the AME polarization fraction. Caveat: needs an accurate subtraction of the synchrotron polarization in the case of W44!

Cyg A and W63

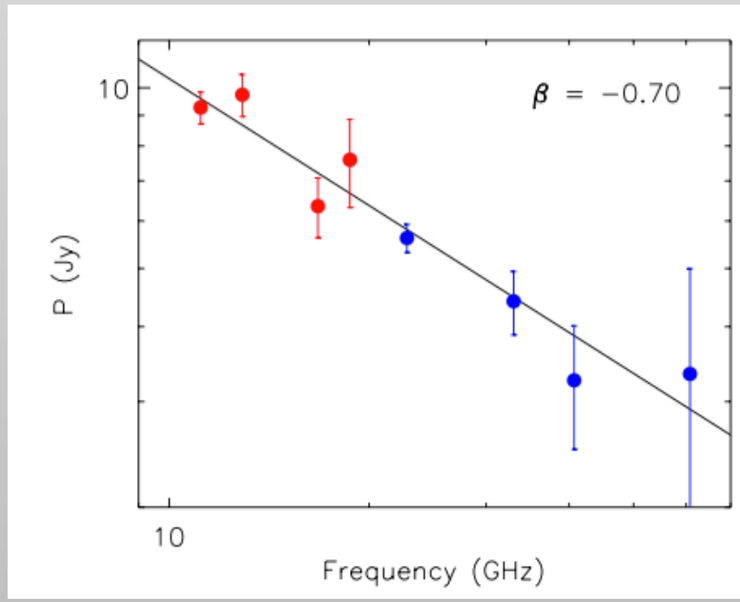
- Data in raster mode (W63 region) for ~250hrs
- Destripping map-making solution, with 2.5s baseline

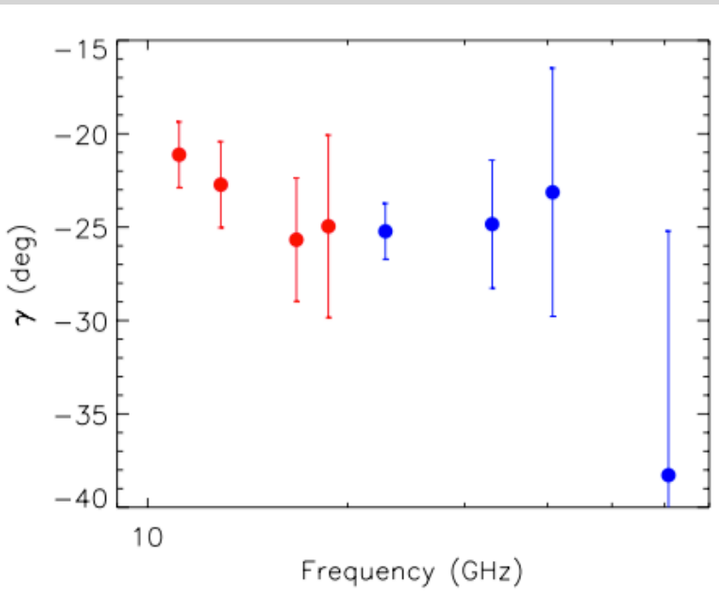






- Polarization SED on W63

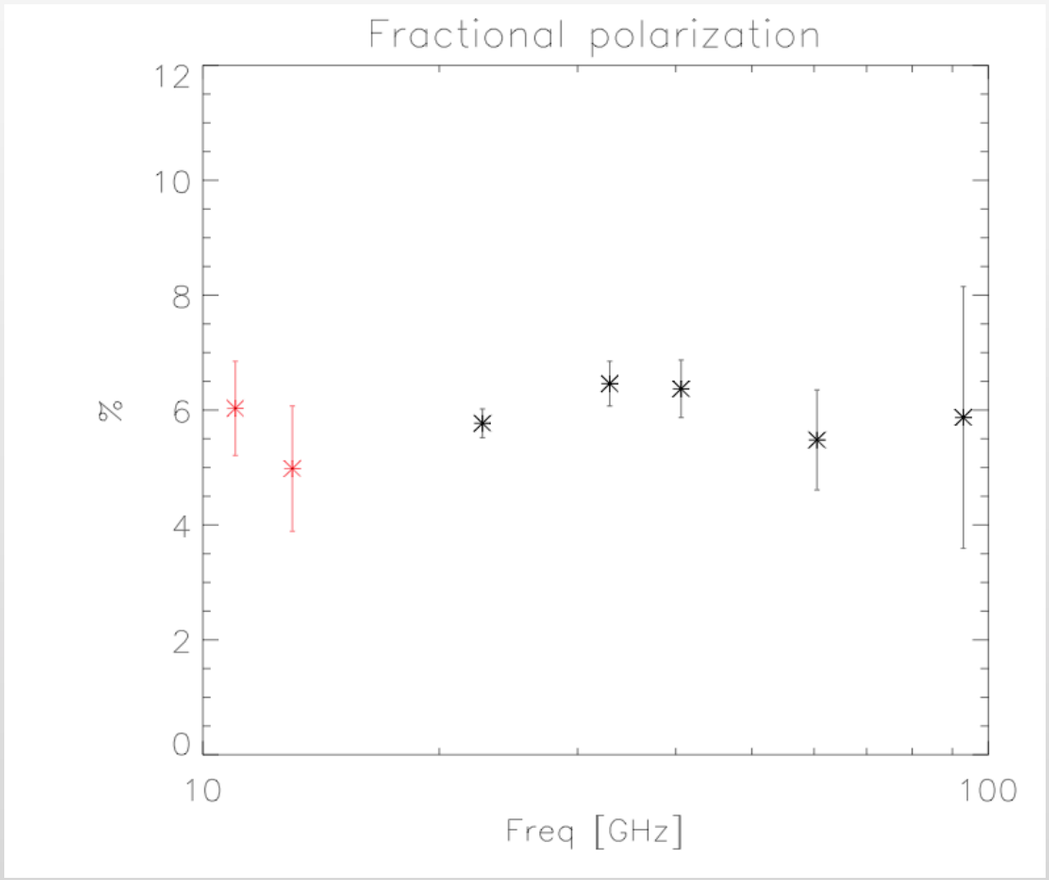


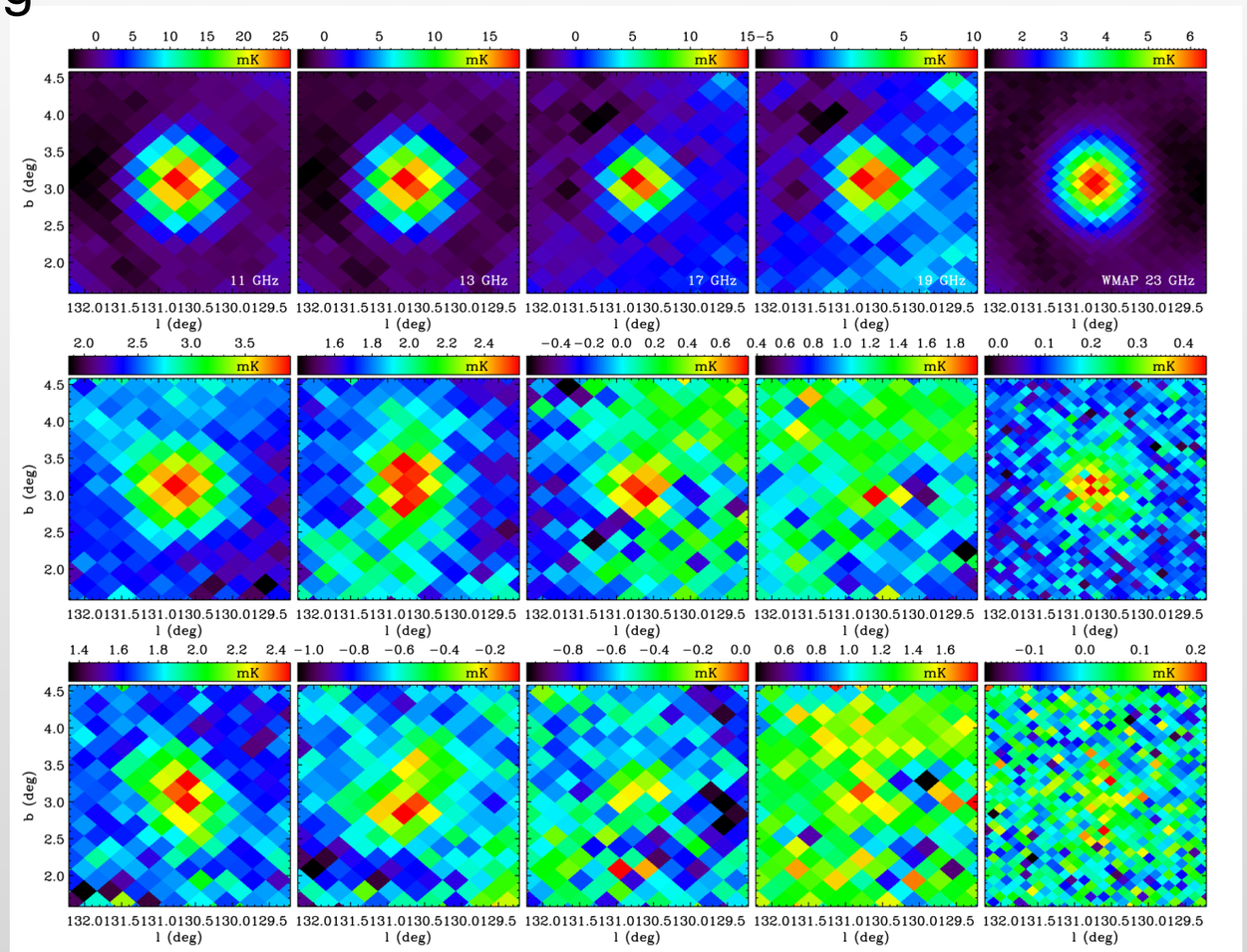


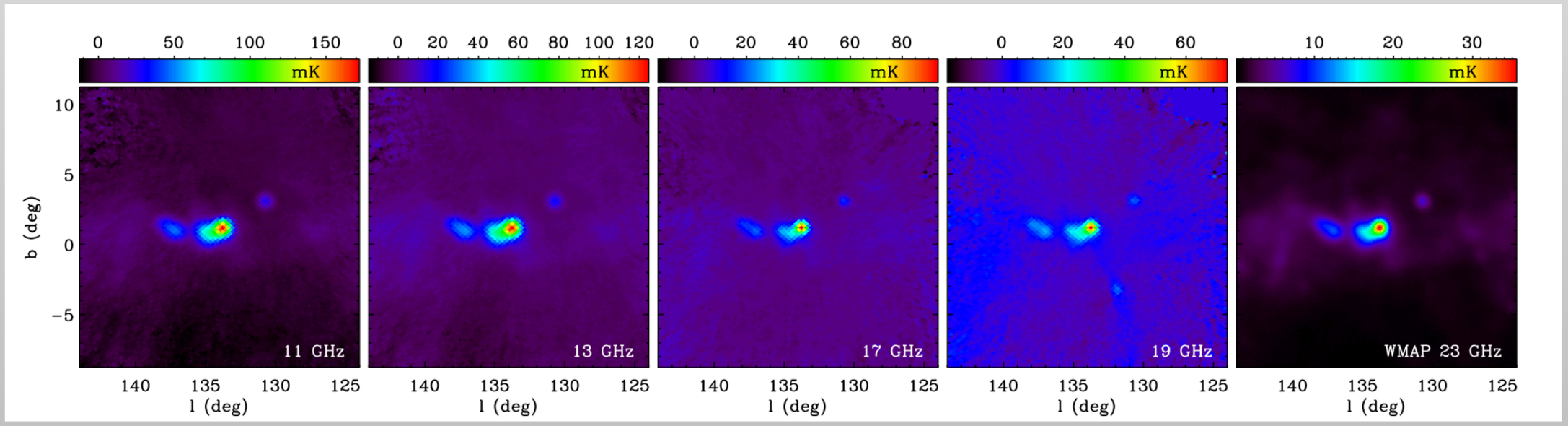
Fan and 3C58

Peláez-Santos et al. (in prep.)

- Data in raster mode for ~200hrs, on ~400 deg^2



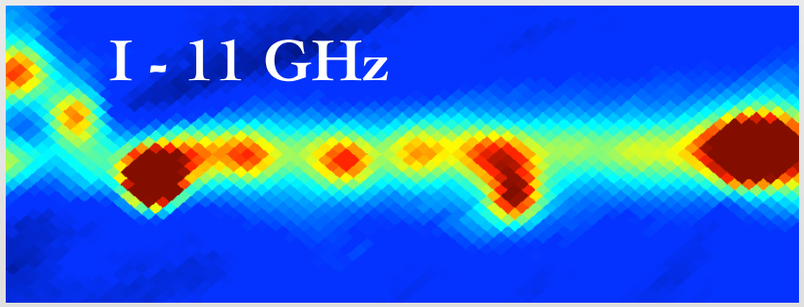


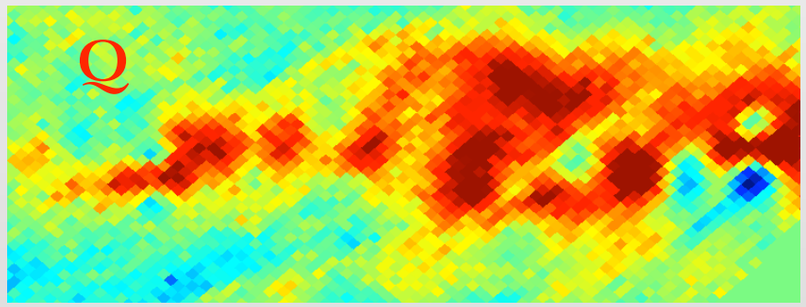


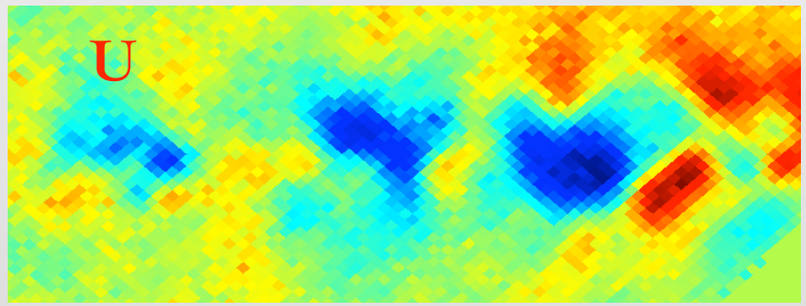
Galactic Haze

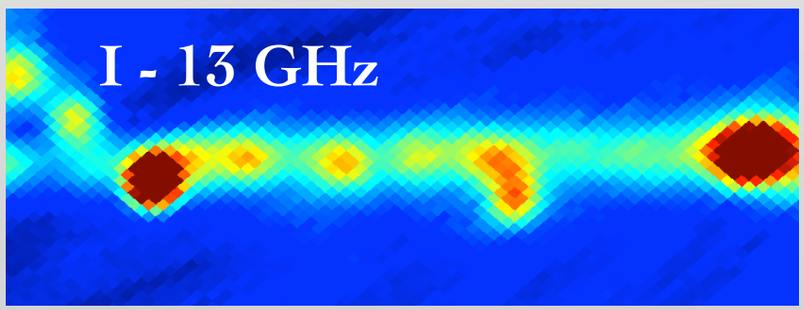
- Large observation program still ongoing (~300 hours), on an area covering ~1000 deg^2 around the Galactic centre
- The goal is to study the polarization of the Galactic Haze emission

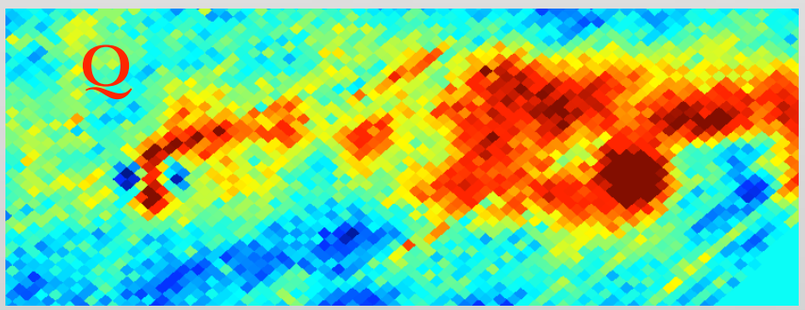
- Preliminary 11 and 13 GHz maps (20×6 deg^2) of the Galactic plane around the Galactic centre, in comparison with WMAP 23 GHz

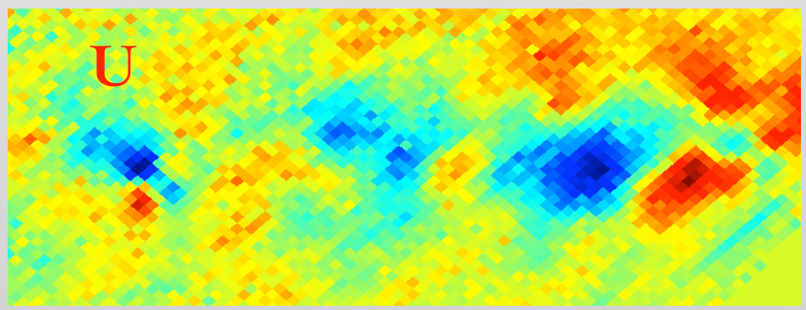


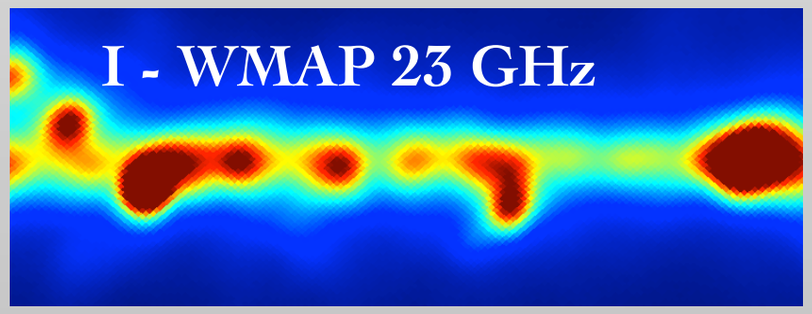


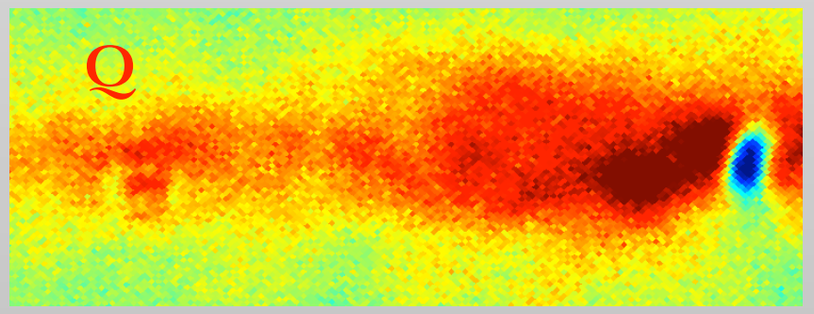


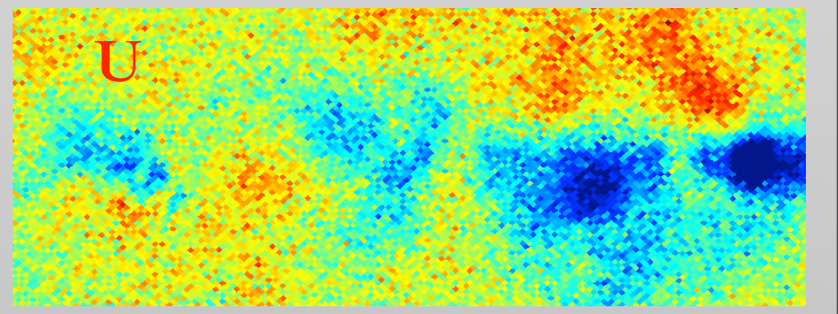












- Quijote maps trace the large-scale polarized emission, but fail to detect polarized emission from Sgr-A (possible Faraday depolarization?)

Conclusions

- **QUIJOTE** is a polarization experiment designed with the aim of reaching a level of r=0.05 in the B-mode angular power spectrum

- QUIJOTE is able to measure the synchrotron and AME polarization to an unprecedent sensitivity, and at a different frequency range from other existing experiments. **Excellent complement to PLANCK at low frequencies**

- **MFI (10-20 GHz)** on **QT1** had first light on Nov. 2012. Since then, we are doing routine observations on selected Galactic regions and Cosmological fields. **MFI and QT1 are performing well**, producing intensity and polarization maps at 4 frequencies

- **First MFI papers are being finished**. In particular, we have preliminary constraints on the AME polarization from the Perseus molecular cloud. The diffuse Galactic polarization is detected along the Galactic plane in two different data-sets. Several SNRs, etc.

- **QT2 is installed. TGI (30 GHz)** to be commissioned during next month, and FGI (40 GHz) will follow

- One year of observations with the TGI should allow to reach a sensitivity r=0.1. Combined FGI/ TGI data should allow to reach r=0.05 after 3 years of operation

Quijote

Q-U-I Joint Tenerife CMB experiment