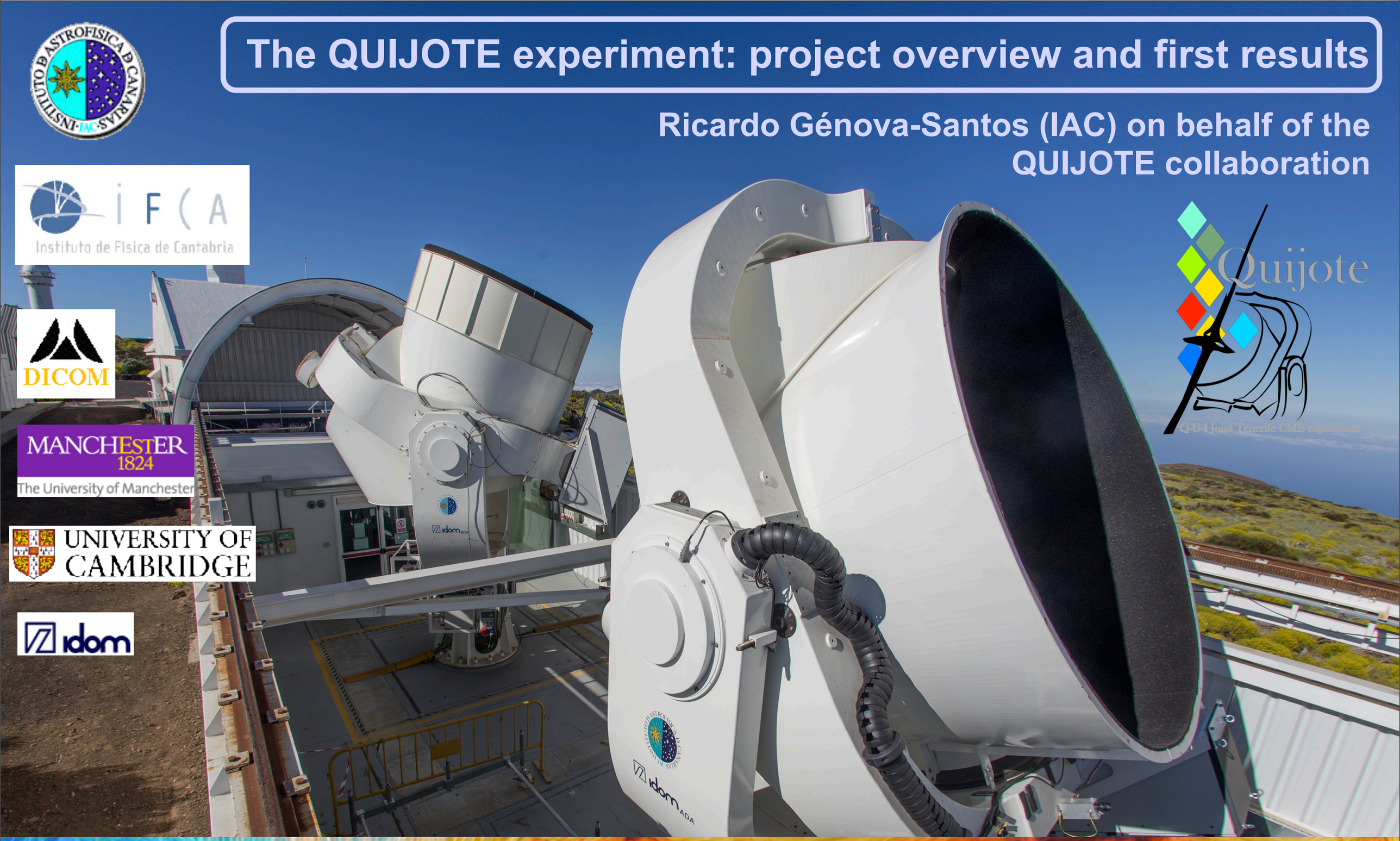
The QUIJOTE experiment: project overview and first results

Ricardo Génova-Santos (IAC) on behalf of the QUIJOTE collaboration



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:**

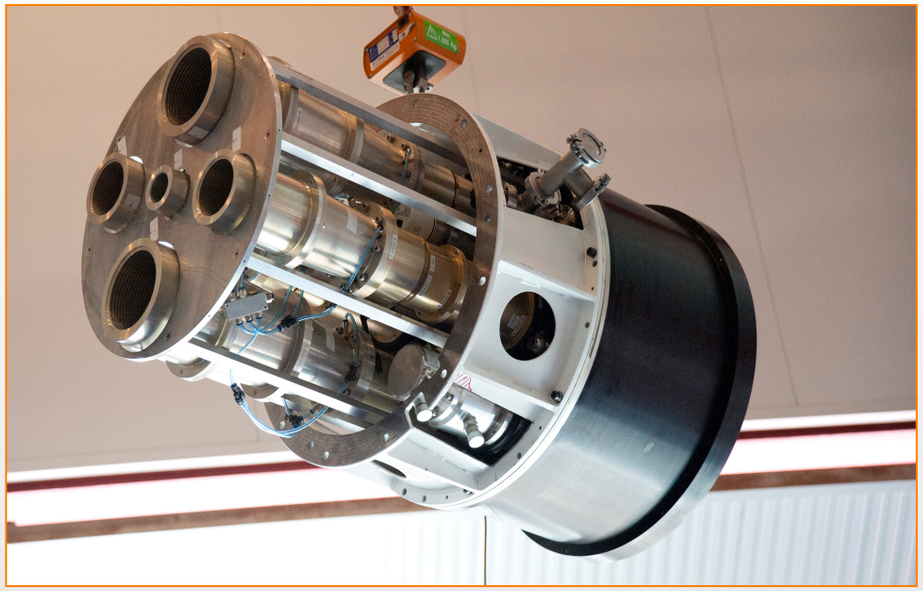
- **Phase I**:
  - First Telescope (**QT1**)
  - Fitted with a Multifrequency Instrument (**MFI**) with 4 polarimeters @ **10-20 GHz**. Started operations Nov. 2012
  - Second Instrument (**TGI**) with 31 polarimeters @ **30 GHz**. Funded; in AIV phase now
- **Phase II**:
  - Second Telescope (**QT2**). Installed in May 2014
  - **FGI** with 31 polarimeters @ **42 GHz**. Funded (2016)
- **Phase III**: extension to the South (funded one pixel @ 10-20 GHz)

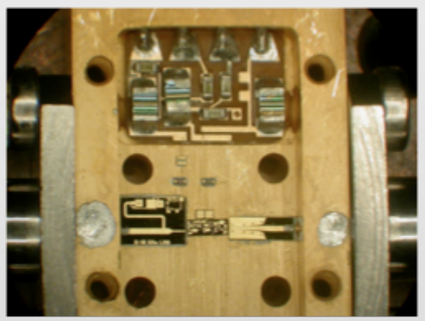
★ **Scientific operation plan:** 2012-2020

QUIJOTE Telescopes

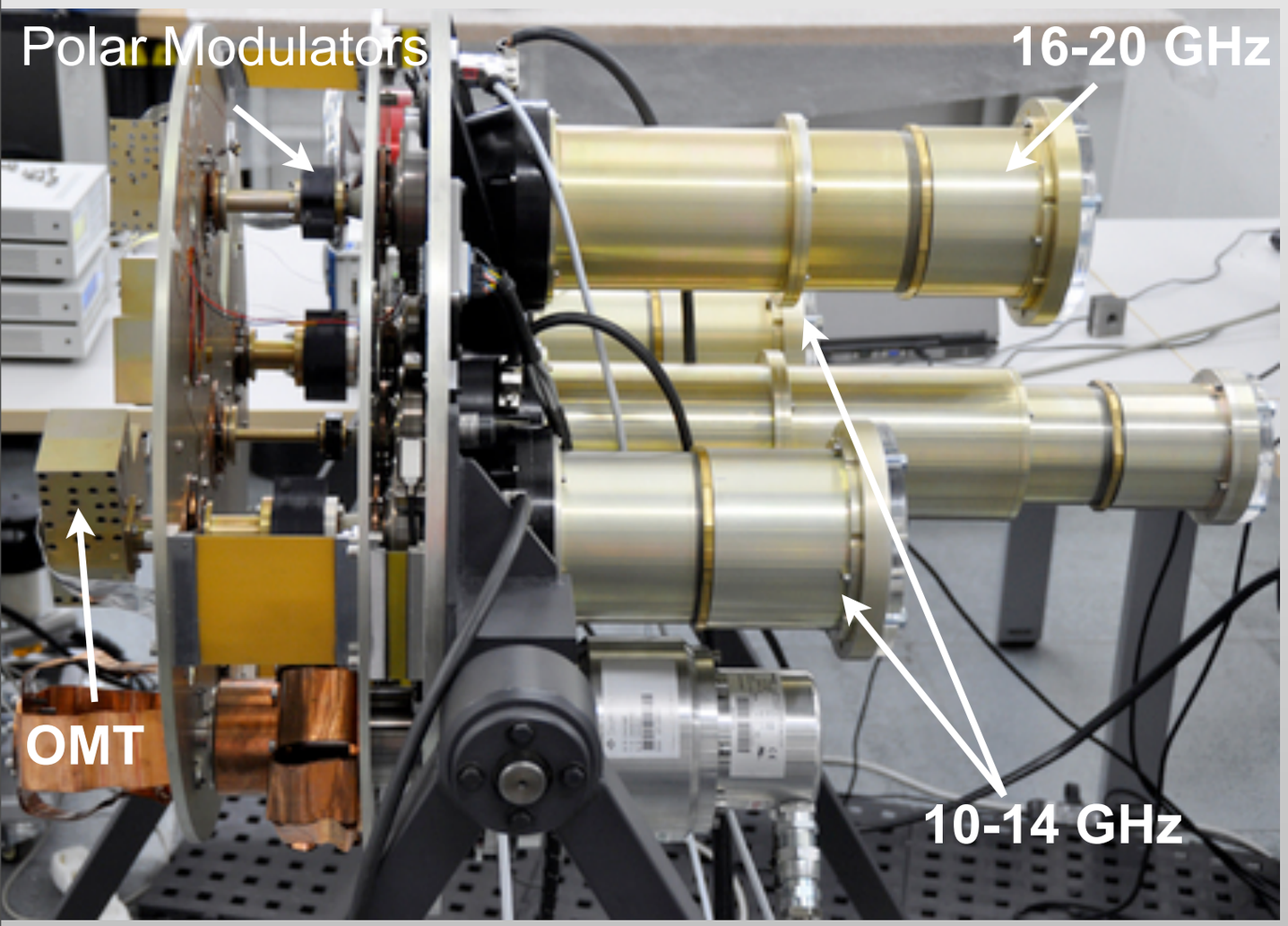
Multi-Frequency Instrument (MFI)

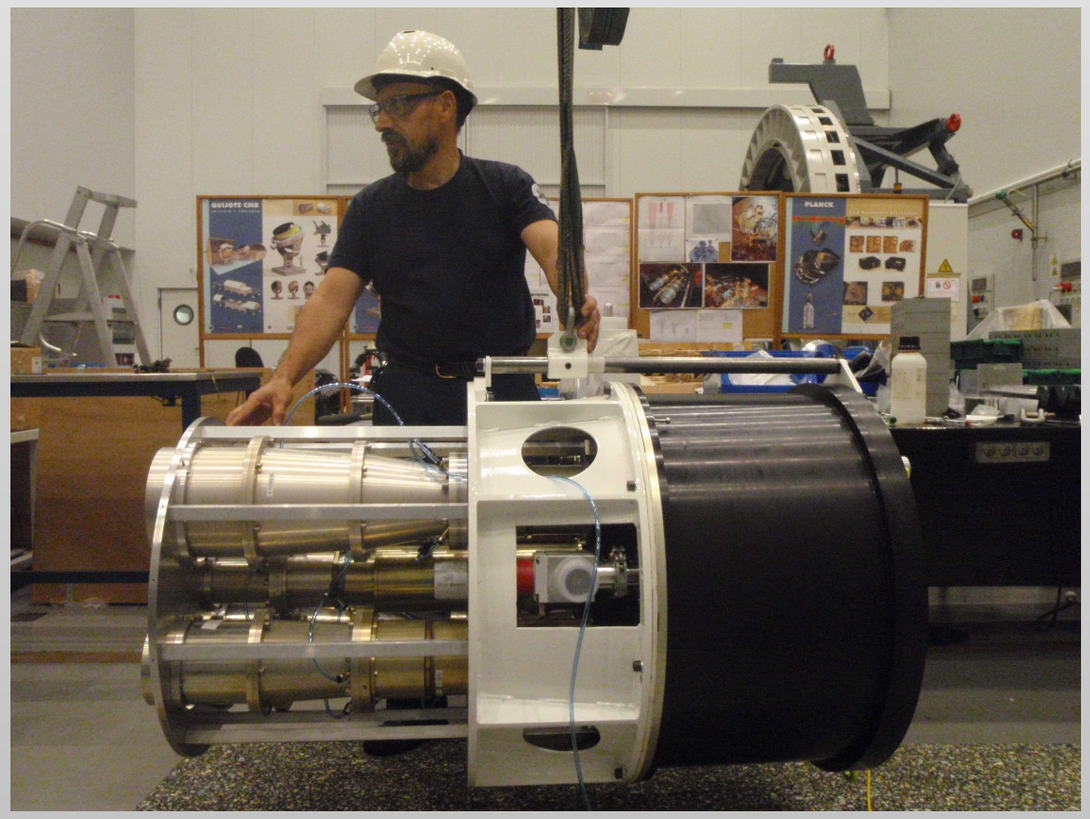
- Observing since November 2012
- 4 horns, 32 channels, covering 4 frequency bands: 11, 13, 17 and 19 GHz
- Sensitivities: ~400-600 μK·s$^{1/2}$ per channel





LNA

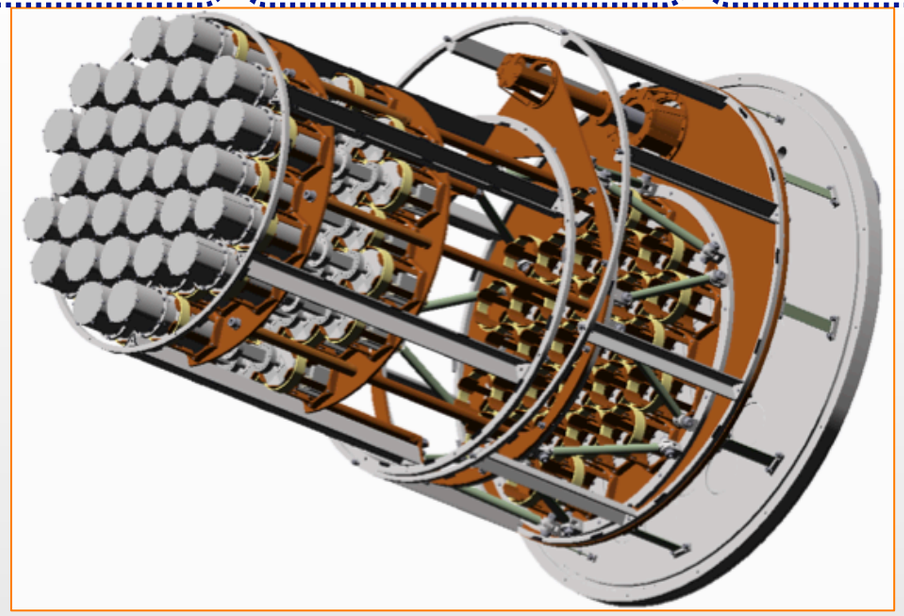


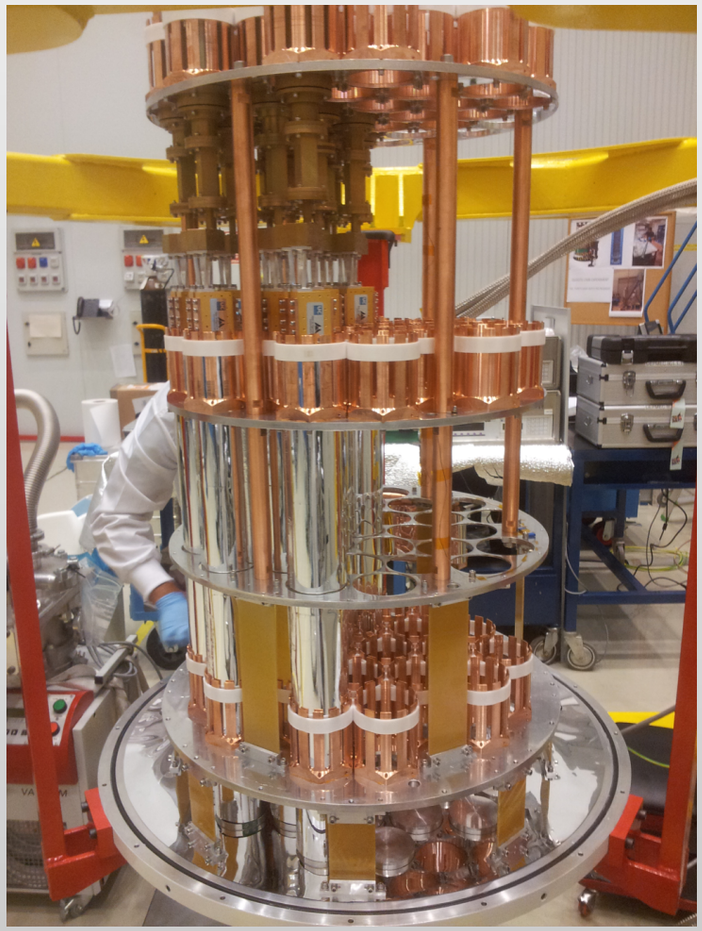


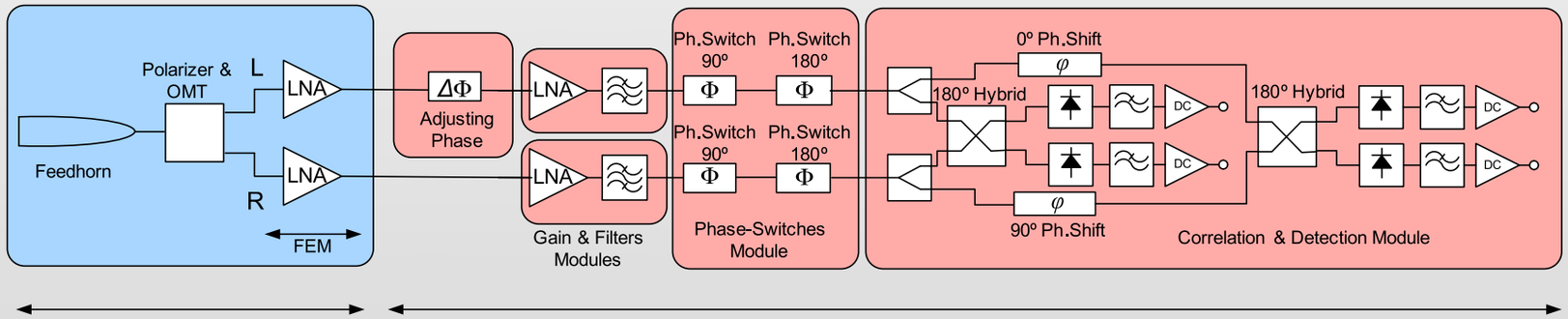
Thirty GigaHertz Instrument (TGI)

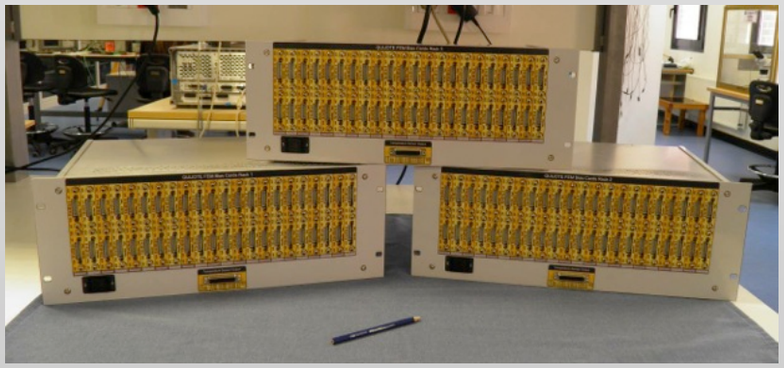
- Currently on AIV phase
- 31 pixels at 30 GHz
- Expected sensitivity of the full array: ~50 μK·s$^{1/2}$

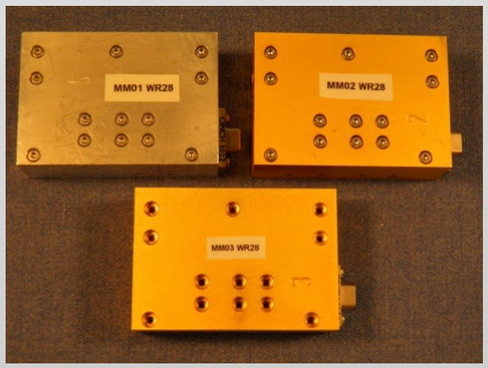
- The FGI will consist of 31 pixels at 42 GHz, with sensitivity ~60 μK·s$^{1/2}$

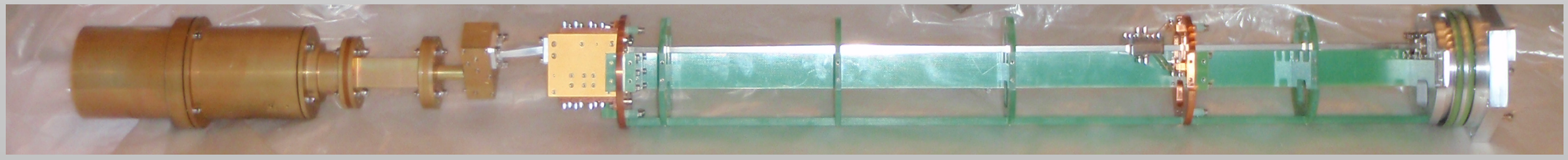






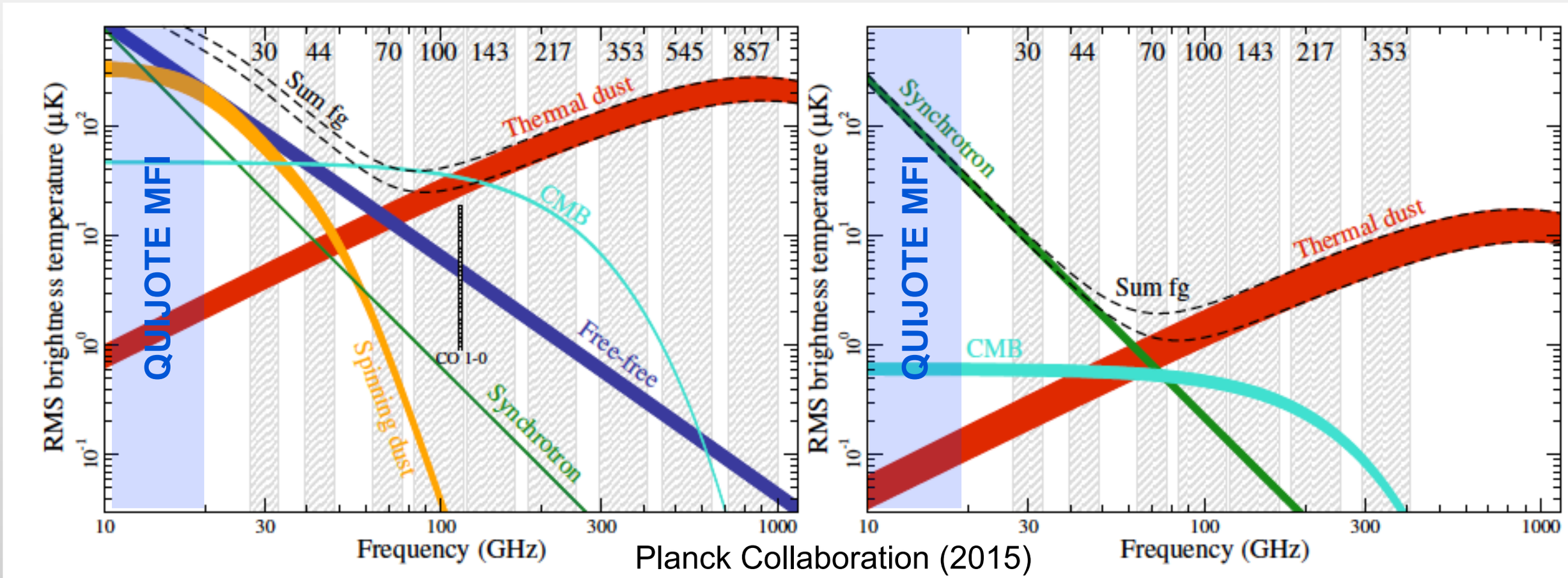






Science with the MFI

★ Characterization of foreground contamination at low frequencies (synchrotron and anomalous microwave emission - AME)



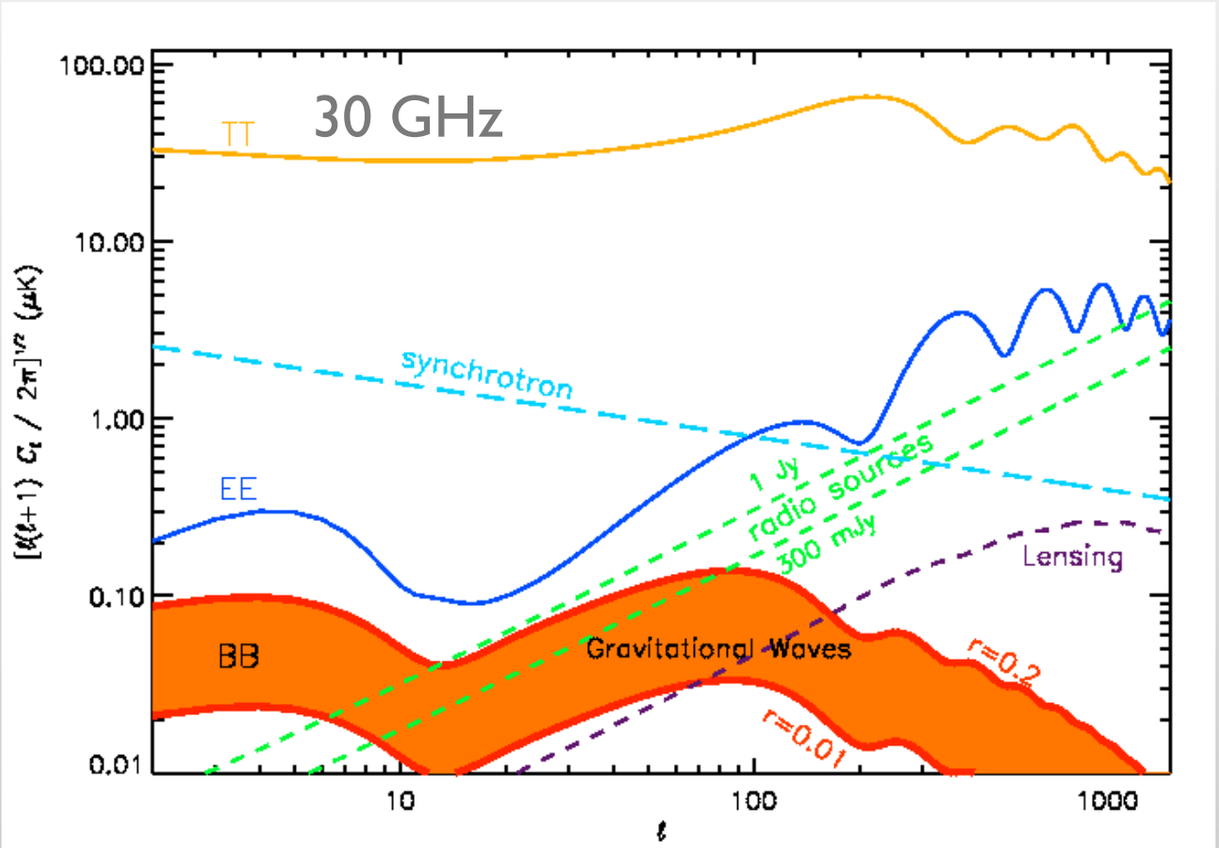
Planck Collaboration (2015)

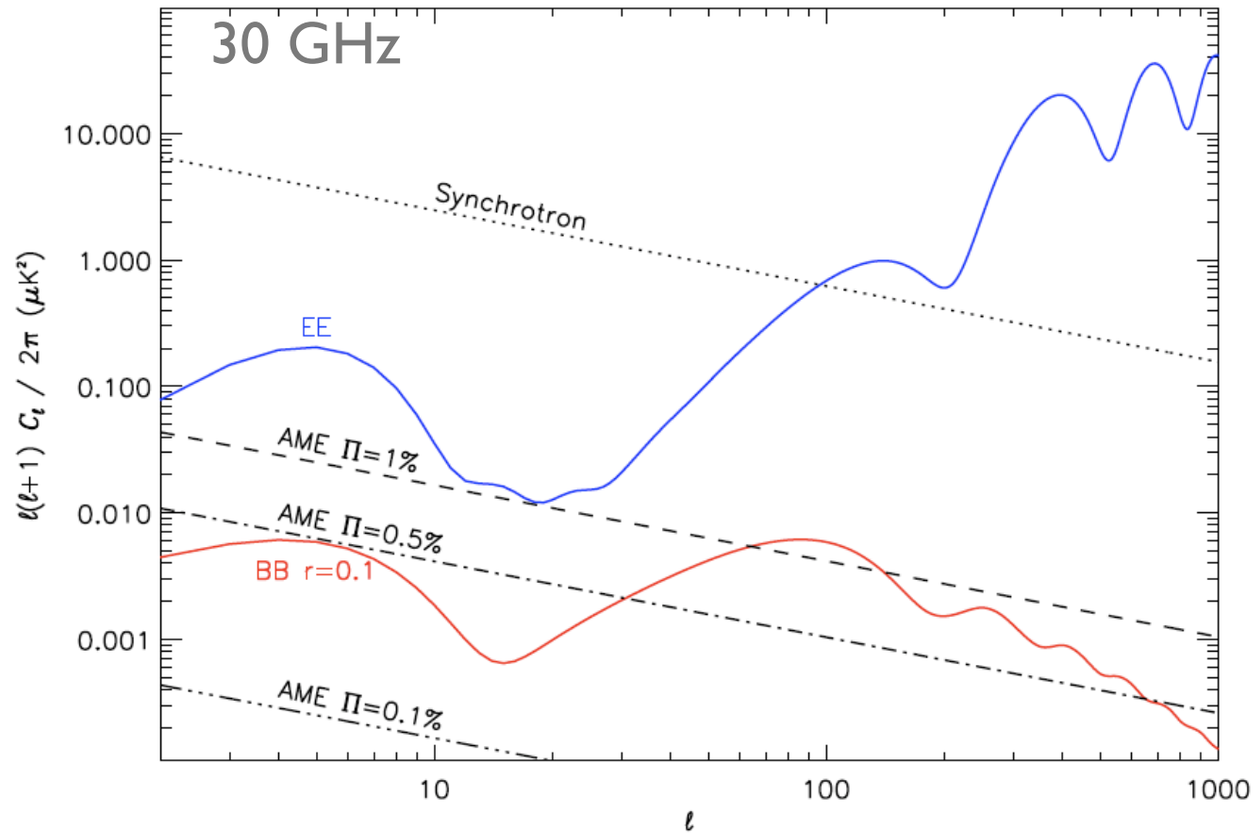
★ Only experiment performing multi-frequency observations below 40 GHz. Can provide the most accurate characterization of the synchrotron polarization

★ Complement to Planck at low-frequencies

Science with the MFI

- **Wide Galactic survey**. Covering 20,000 deg^2 (more than 5000 hours accumulated so far)
  - ≈ **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 is known about its polarization. Best upper limits on its polarization fraction: <1% (López-Caraballo et al. 2011, Dickinson et al. 2011)

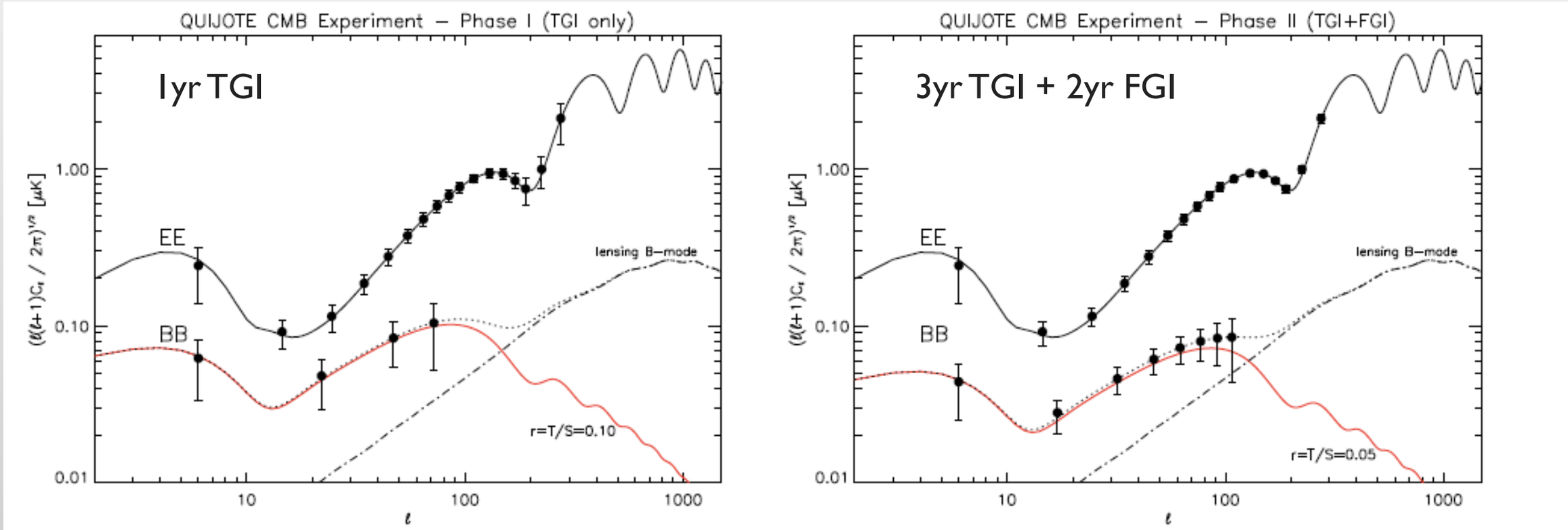
Science with the TGI and FGI

- **Wide 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)

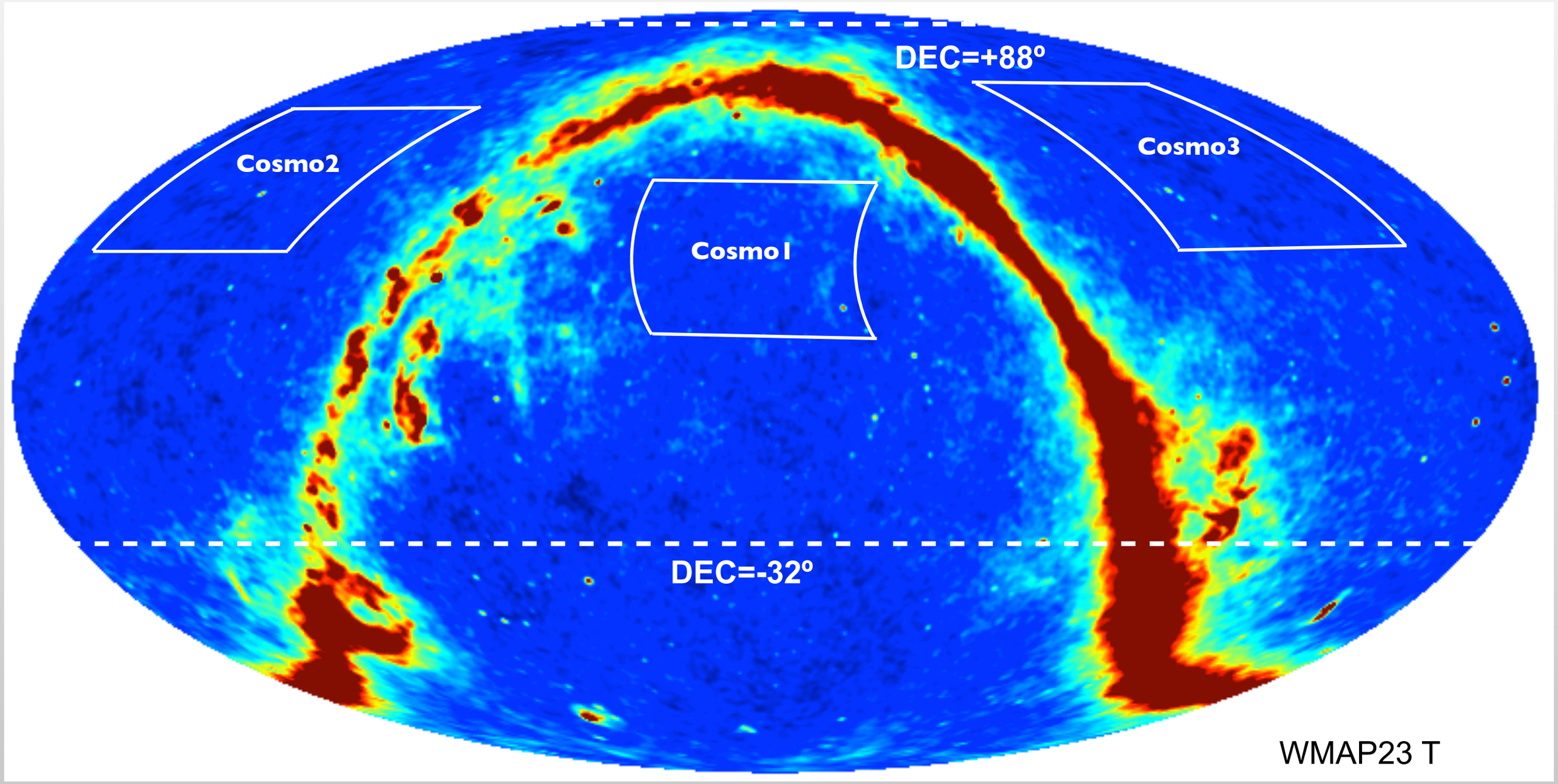
Science phase
(April 2013 - now)

- Wide survey (5400h)
- Cosmological fields (2600h)
- Daily calibrators (Crab, Cas A, Jupiter, sky dips)
- 3C58 and the Fan region (450h)
- Galactic Haze (750h)
- Perseus molecular cloud (300h)
- SNRs: IC443 (250h), W63 (250h), W43, W44 and W47 (200h)
- Taurus region (450h)

Total: **12600 h** (525 effective days), with 50% efficiency

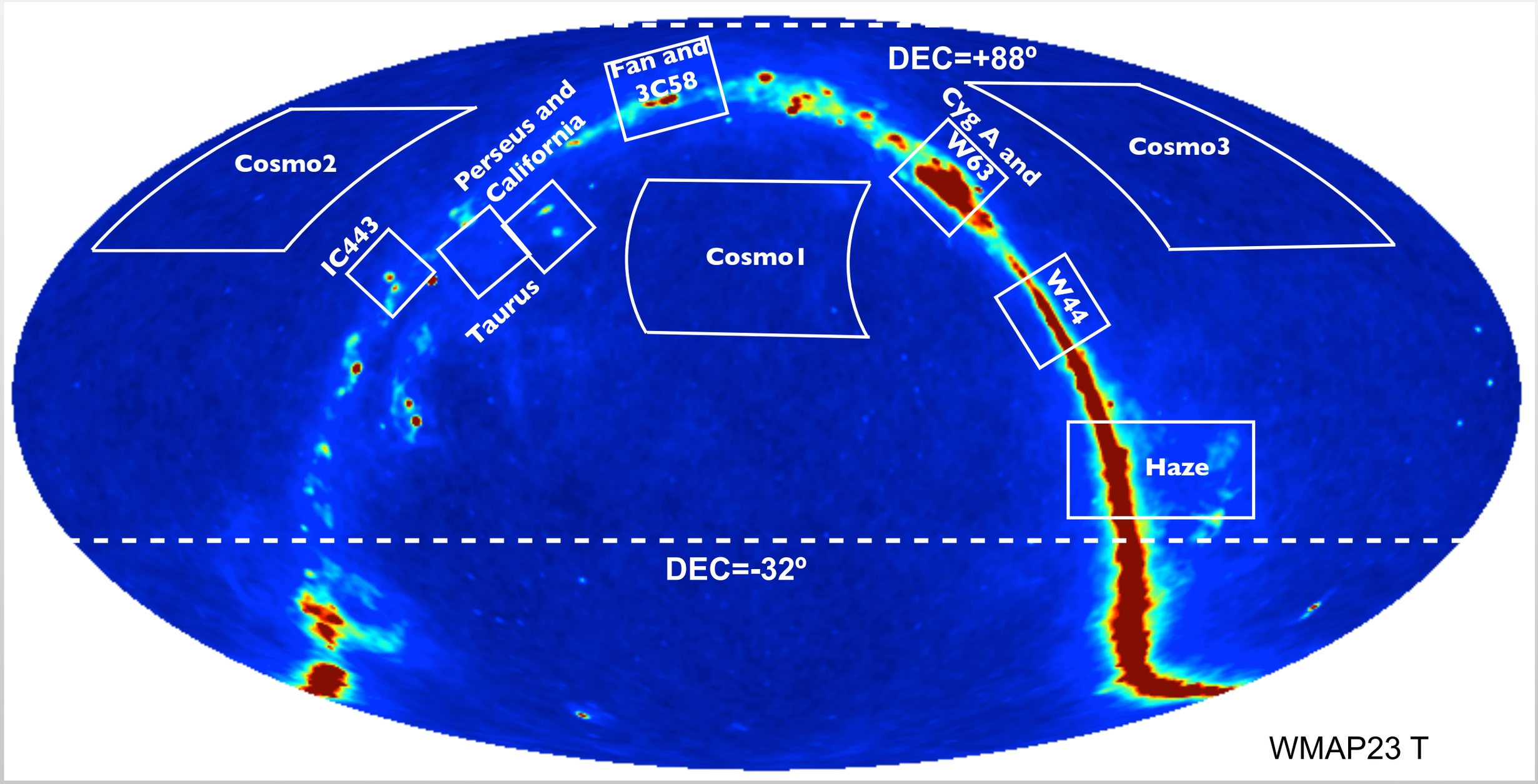
QUIJOTE sky coverage

- Cosmological fields



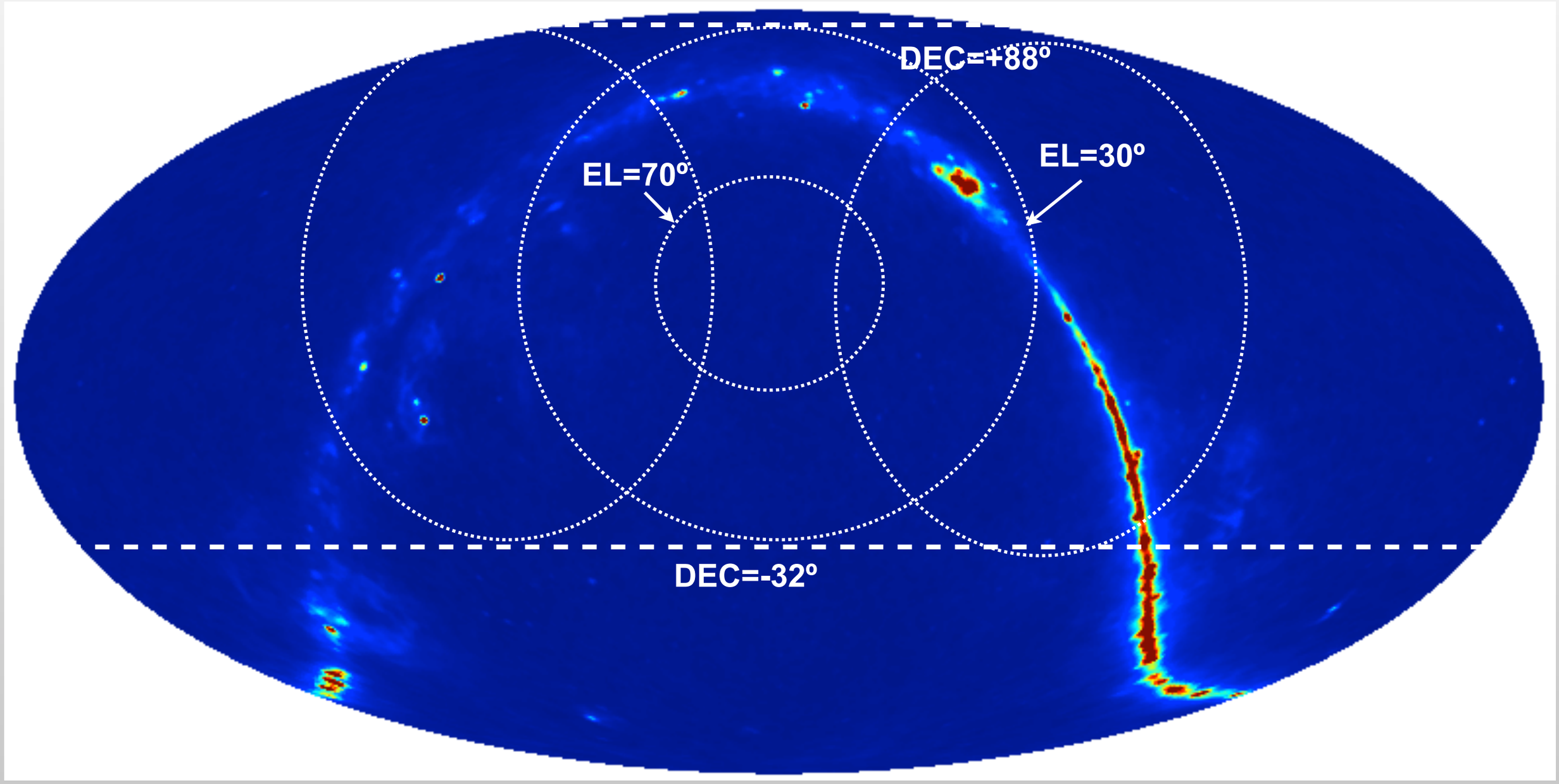
QUIJOTE sky coverage

- Other individual fields



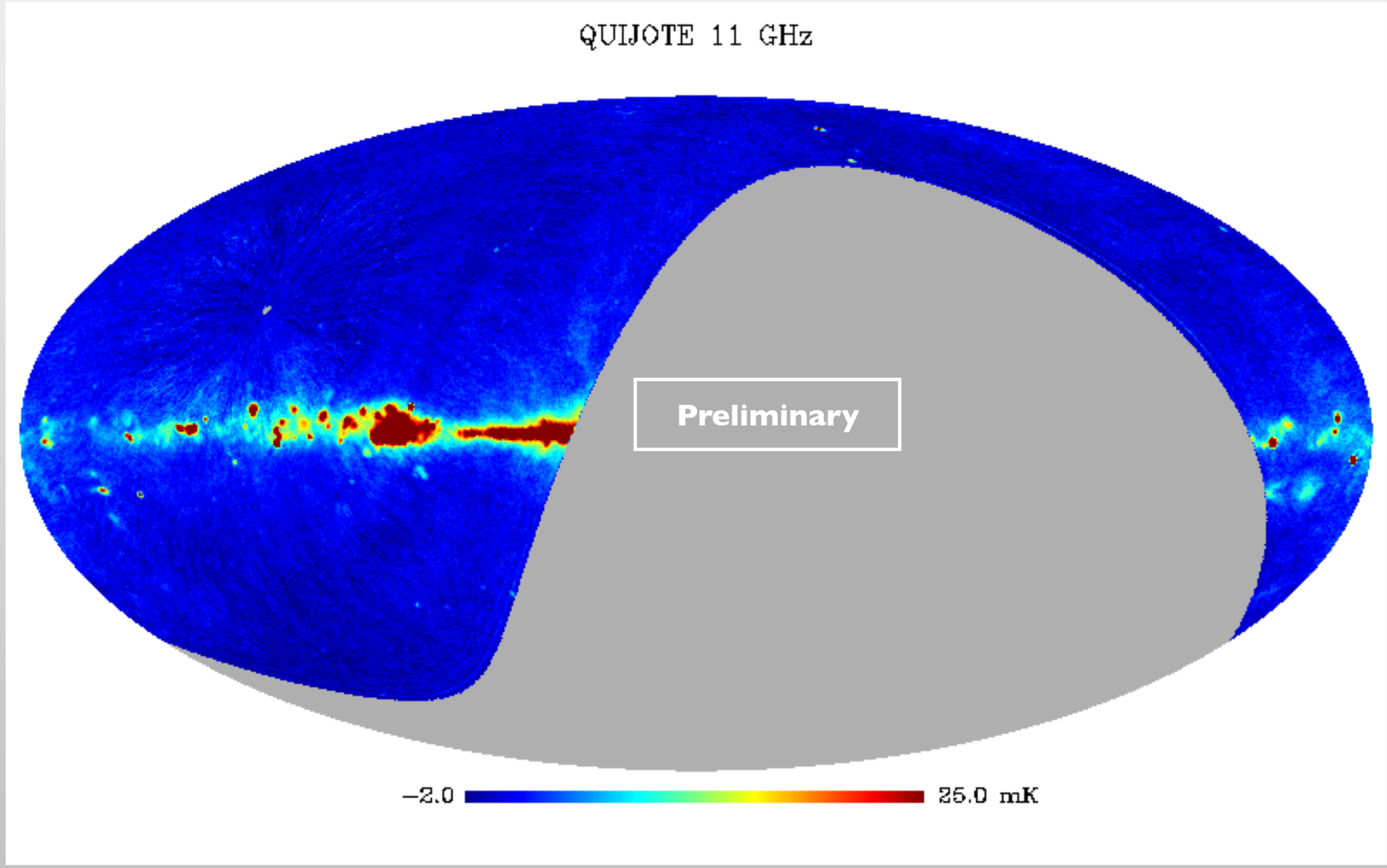
QUIJOTE sky coverage

- Wide survey (full northern scky between Dec=-23º and Dec=88º

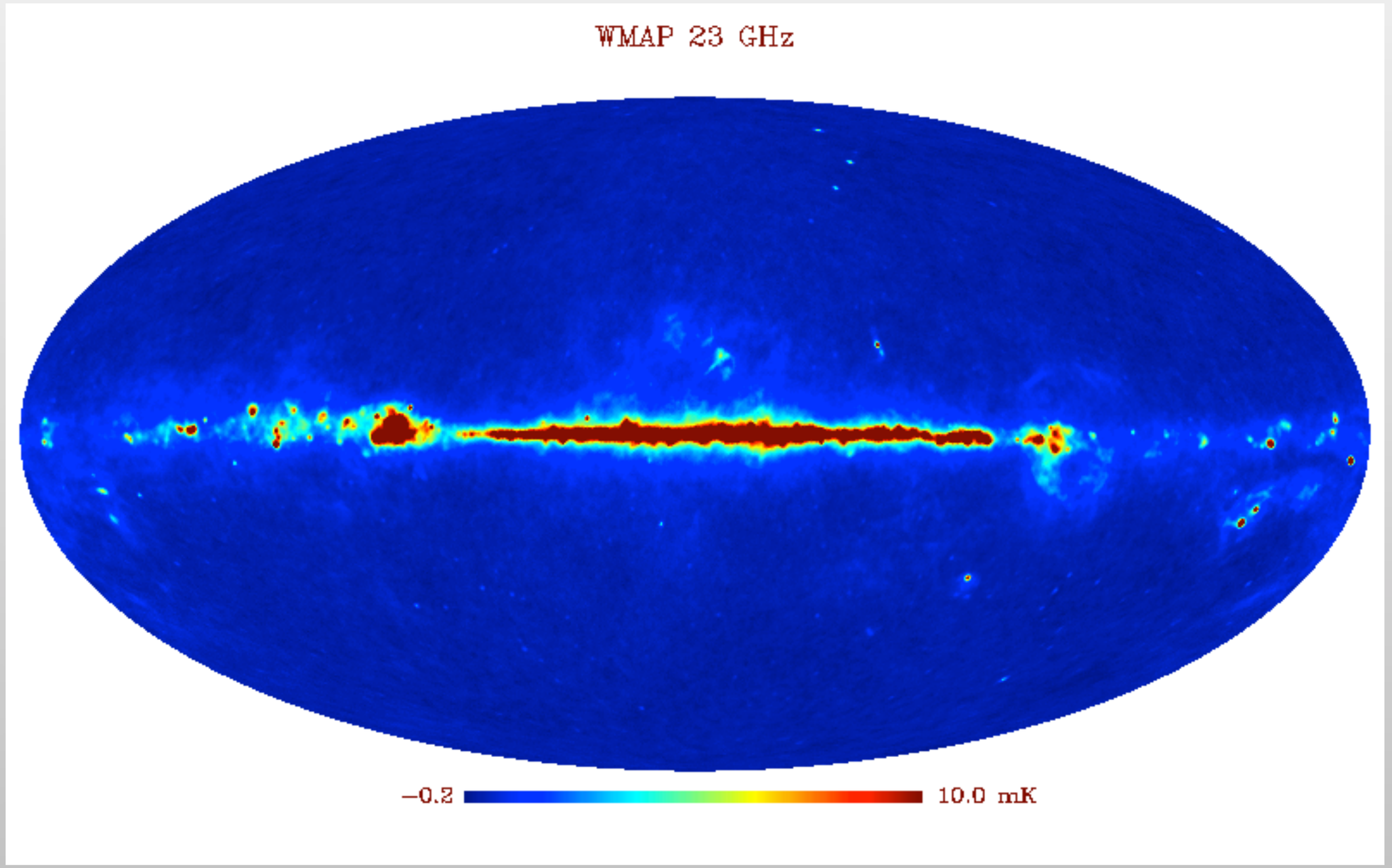


Wide survey

- Full mapping of the northern sky at each of the four MFI frequencies
- Nominal mode (continuous rotation around AZ). 5400 h so far
- Sensitivity: ~20 μK/beam in Q,U and, ~50 μK/beam in I
- Map resulting from 700 h:



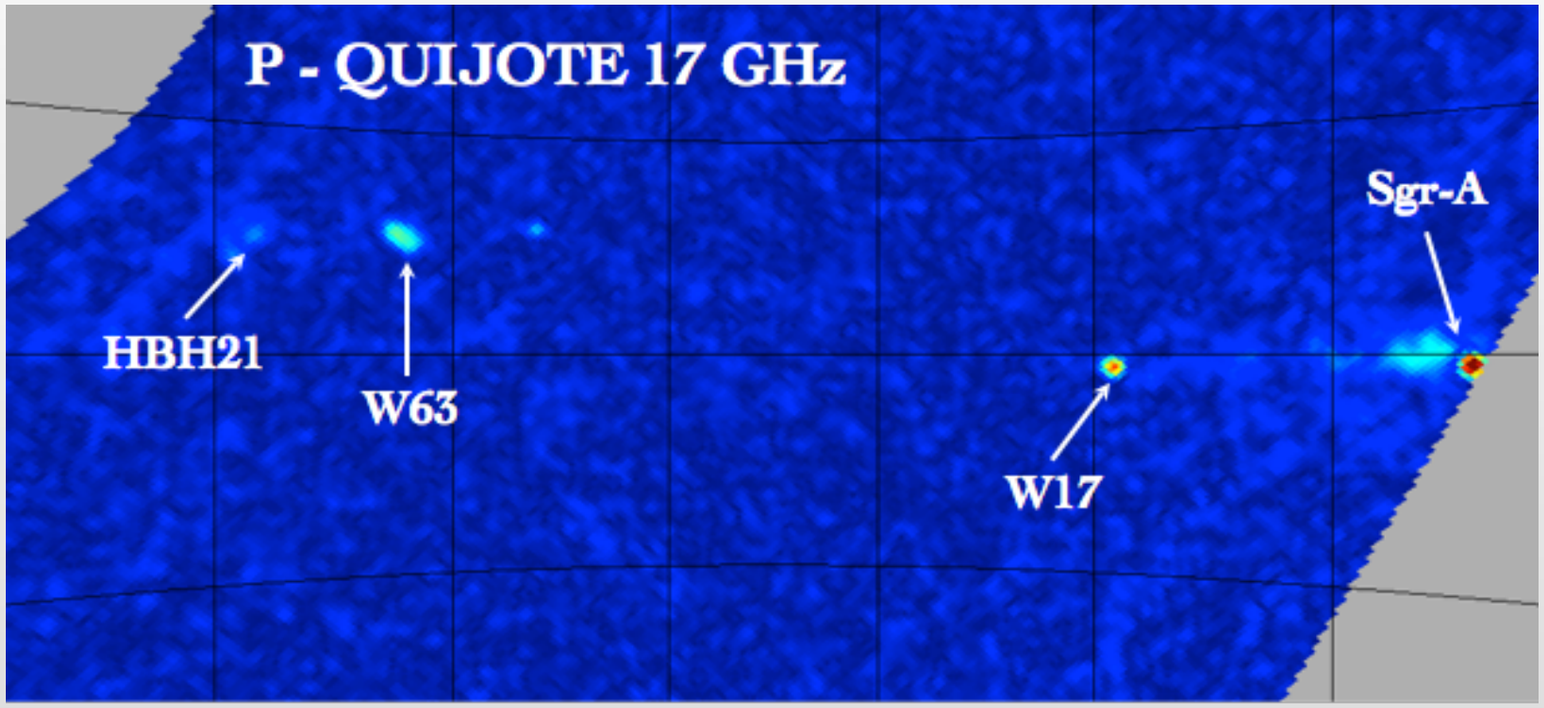
Wide survey

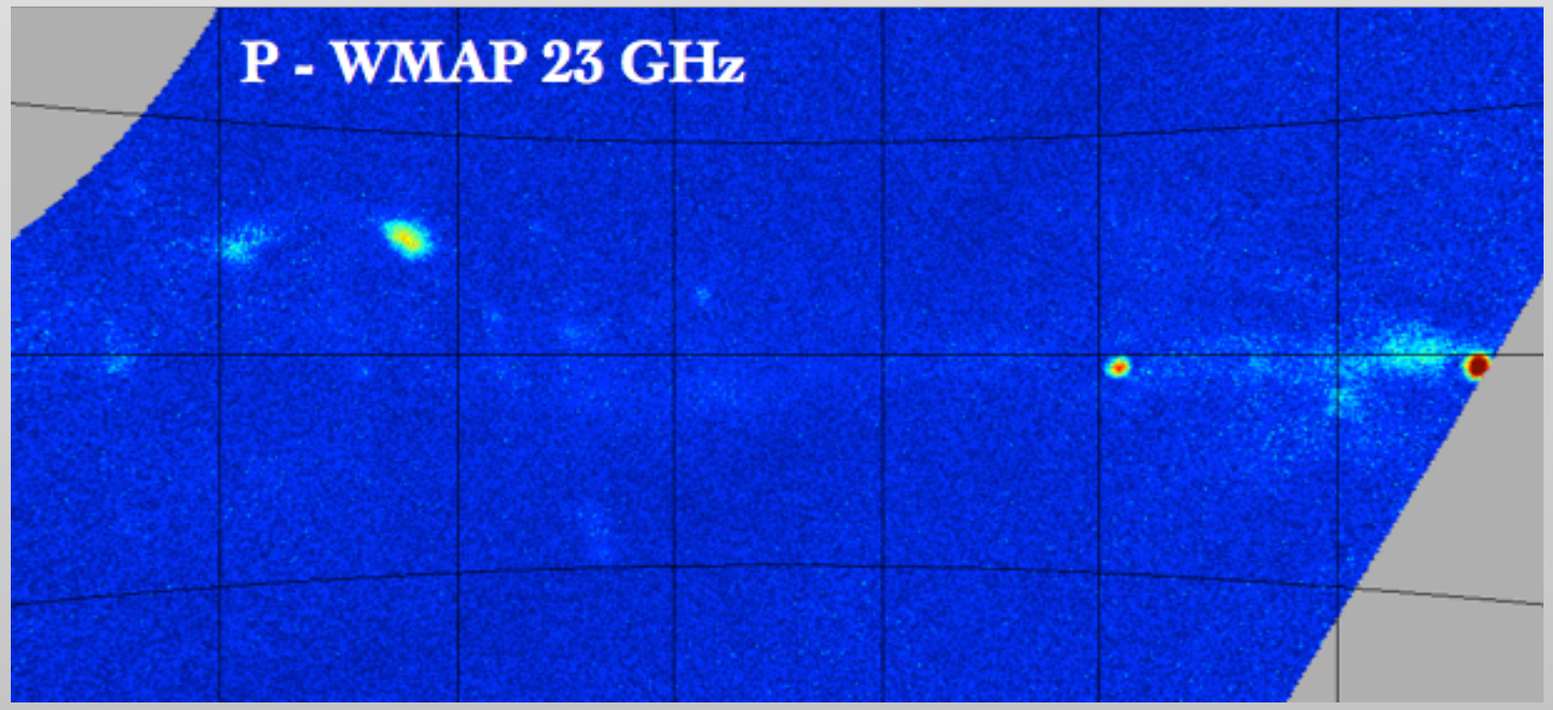


Wide survey

- Polarized intensity @ 17 GHz, compared with WMAP @ 23 GHz

- Preliminary map-making, which allows to reveal compact objects, as well as some diffuse emission



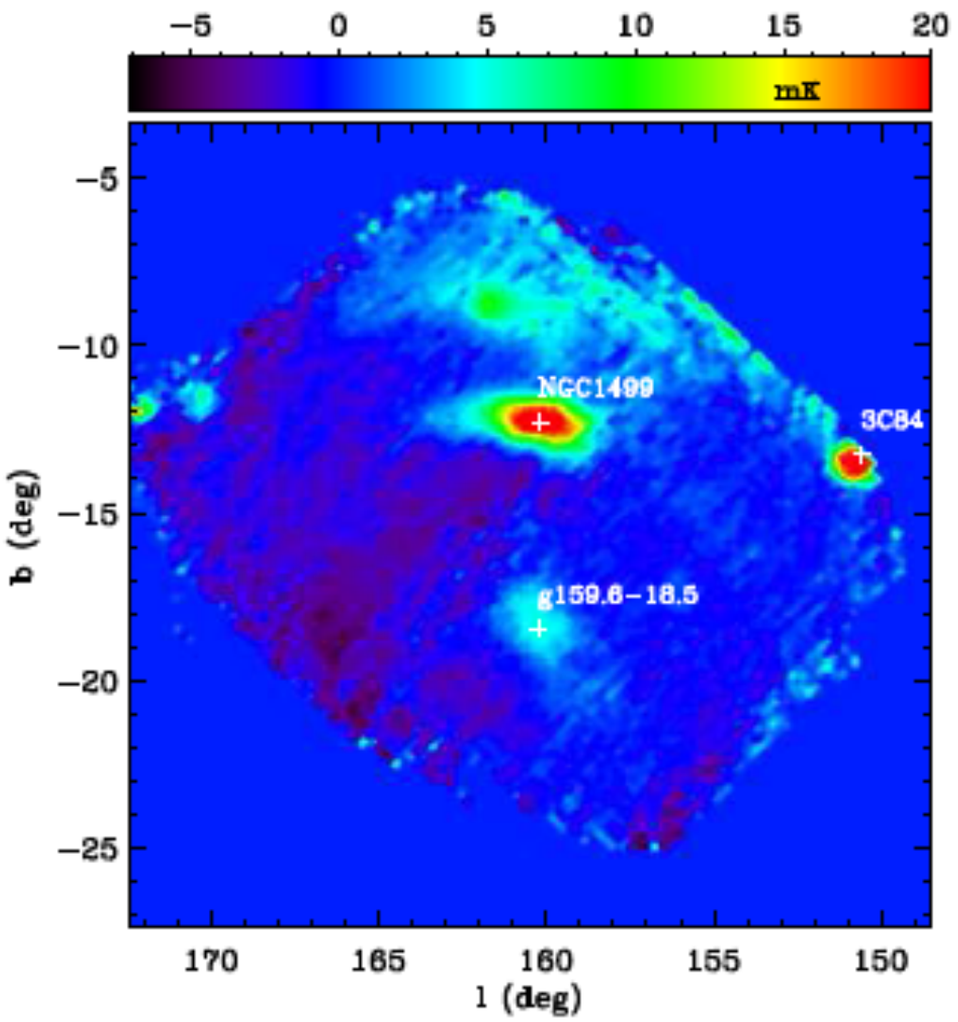


Perseus molecular complex

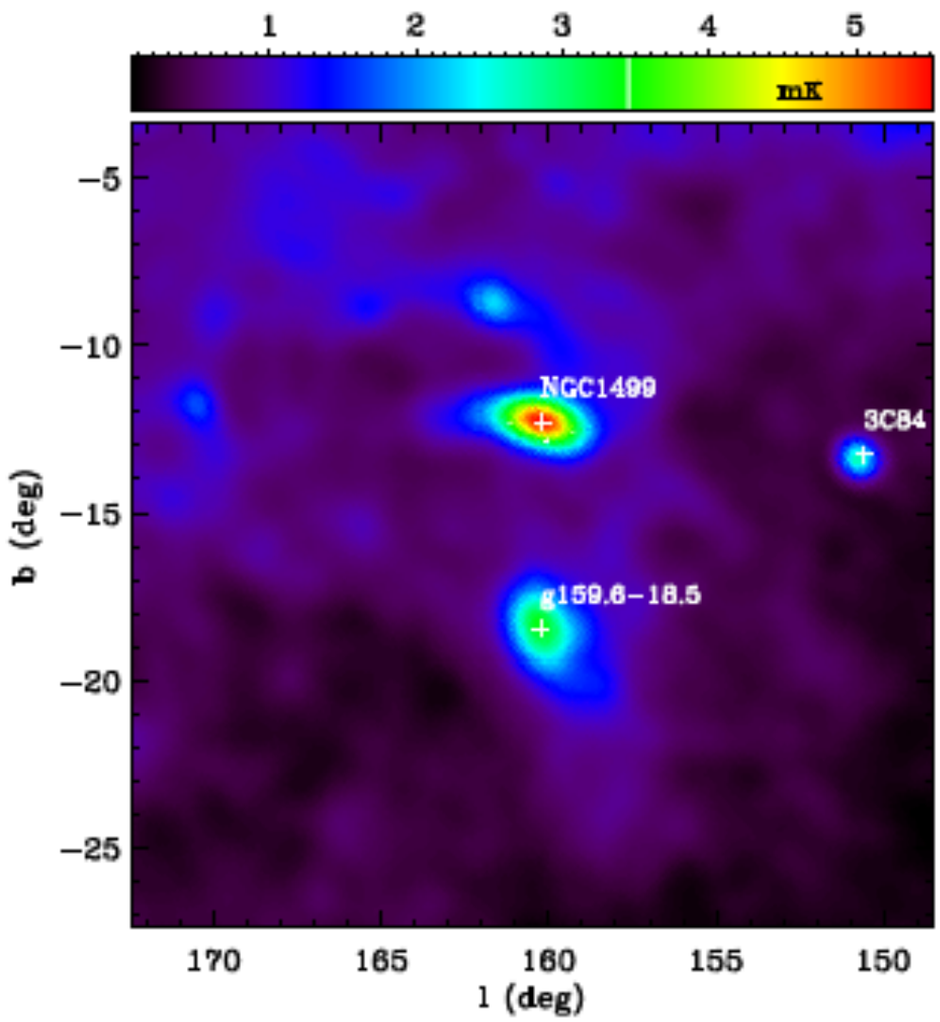
- One of the first objects where the Anomalous Microwave Emission was well characterized, using observations from the COSMOSOMAS experiment (Watson et al. 2005)

- 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

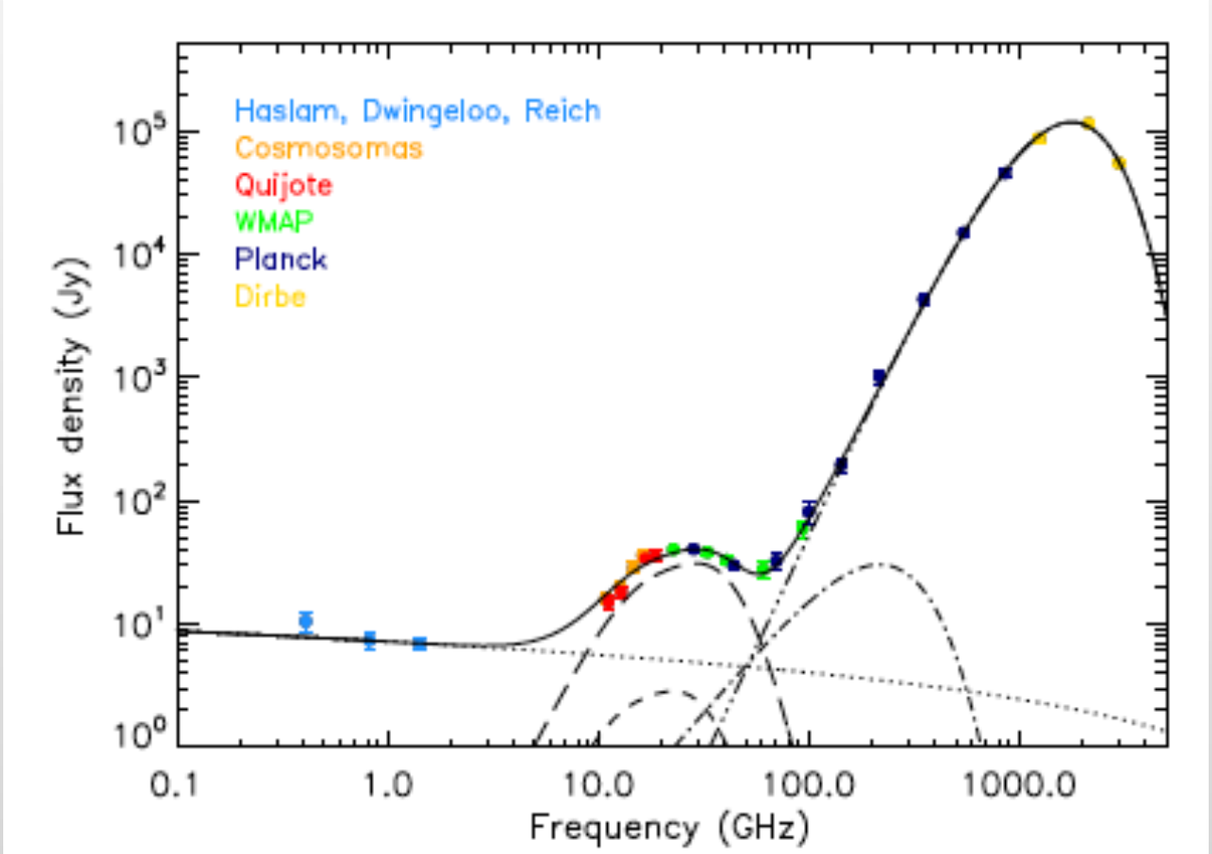


- First QUIJOTE paper: Génova-Santos et al. (2015), arXiv:1501.04491

Perseus molecular complex

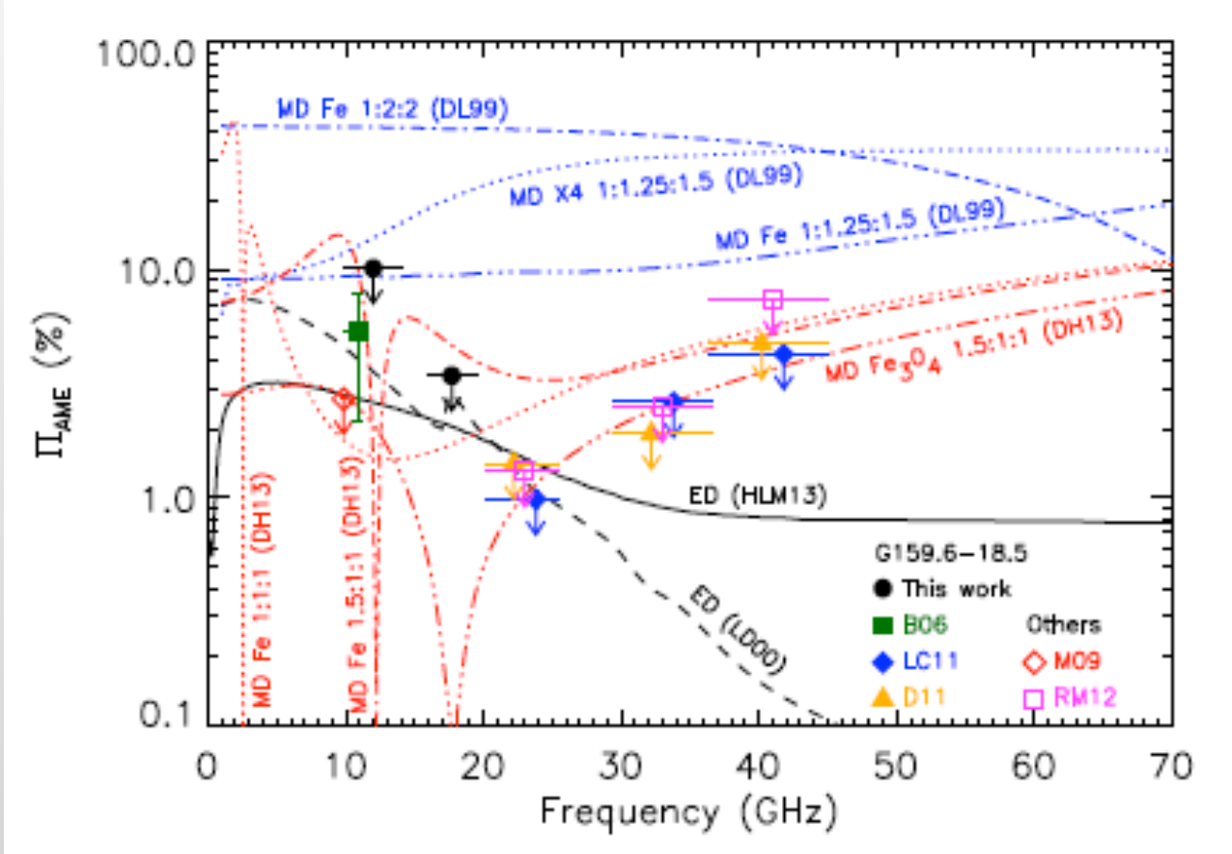
Génova-Santos et al. (2015)

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)

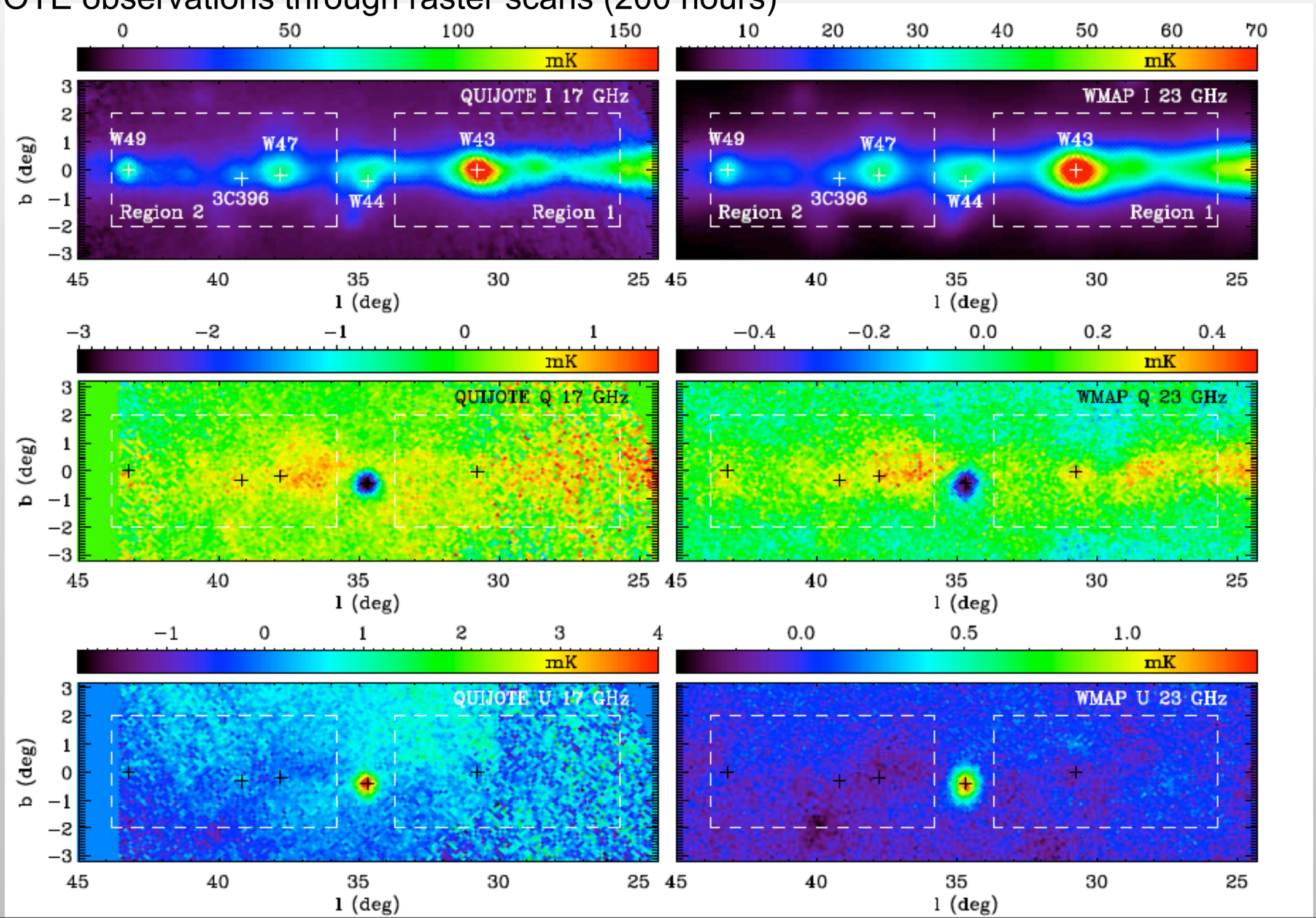
Constraints on the AME polarization



- **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

W43, W44 and W47

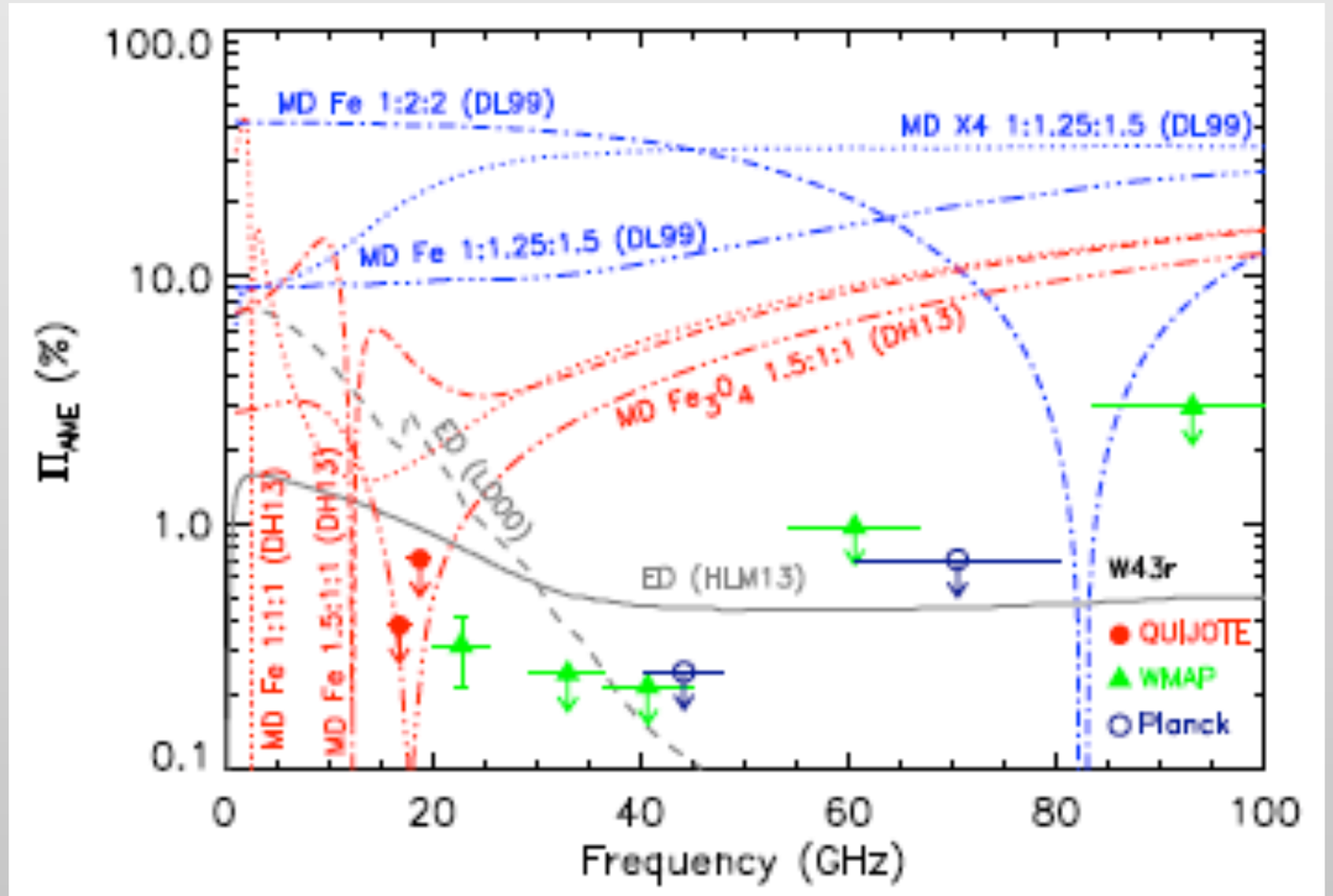
- W44 is a bright SNR, W43 and W47 are molecular complexes
- AME detected using WMAP/Planck, and C-BASS at low-frequency (Irfan et al. 2015)
- QUIJOTE observations through raster scans (200 hours)



W43, W44 and W47

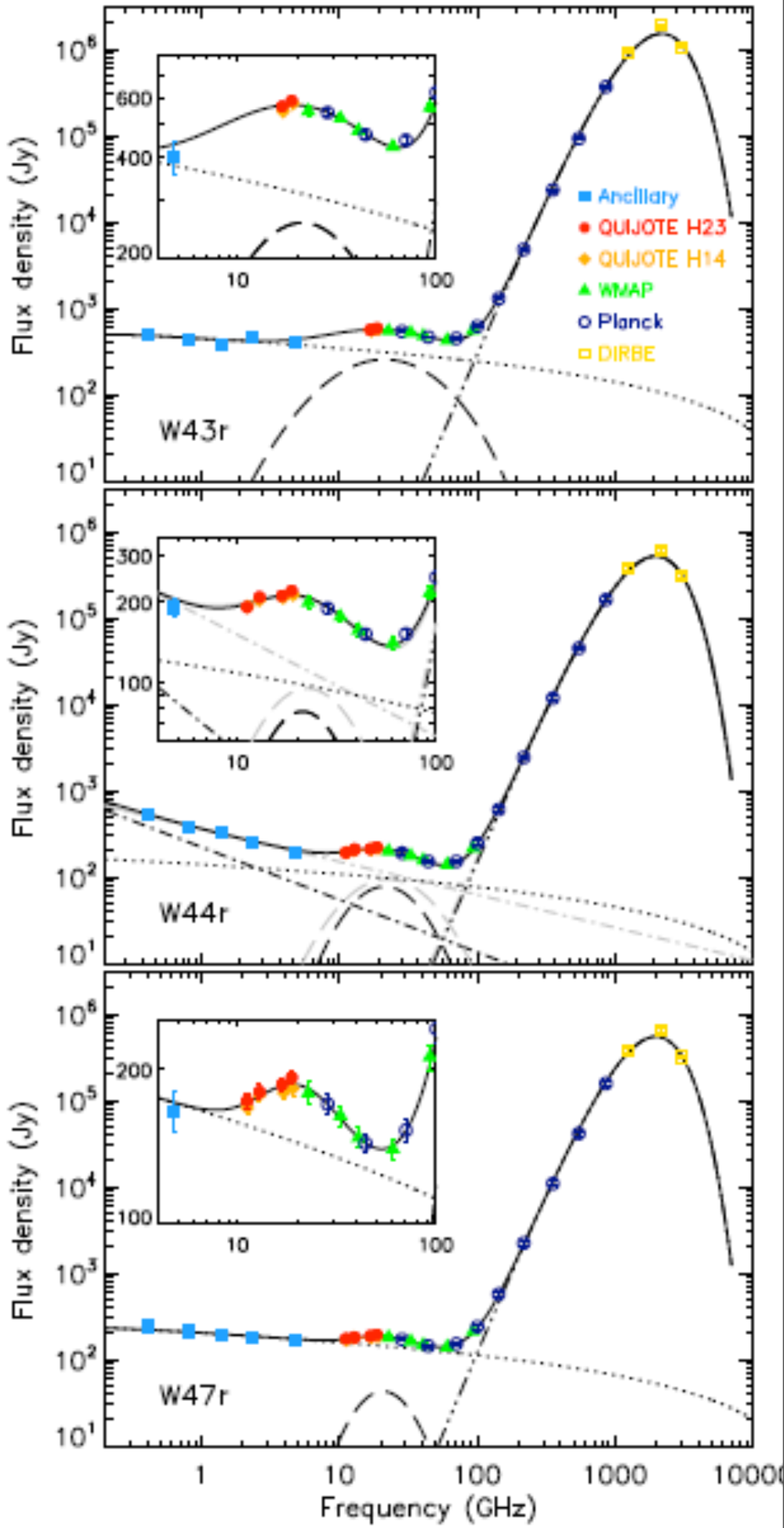
- SEDs of the three regions. QUIJOTE 10-20 GHz data confirms the presence of spinning dust emission in this region
- HII regions W43 and W47 fitted with a combination of free-free and AME
- W44 SNR includes synchrotron in the model

- Strongest upper limits on the AME polarization (in W43):



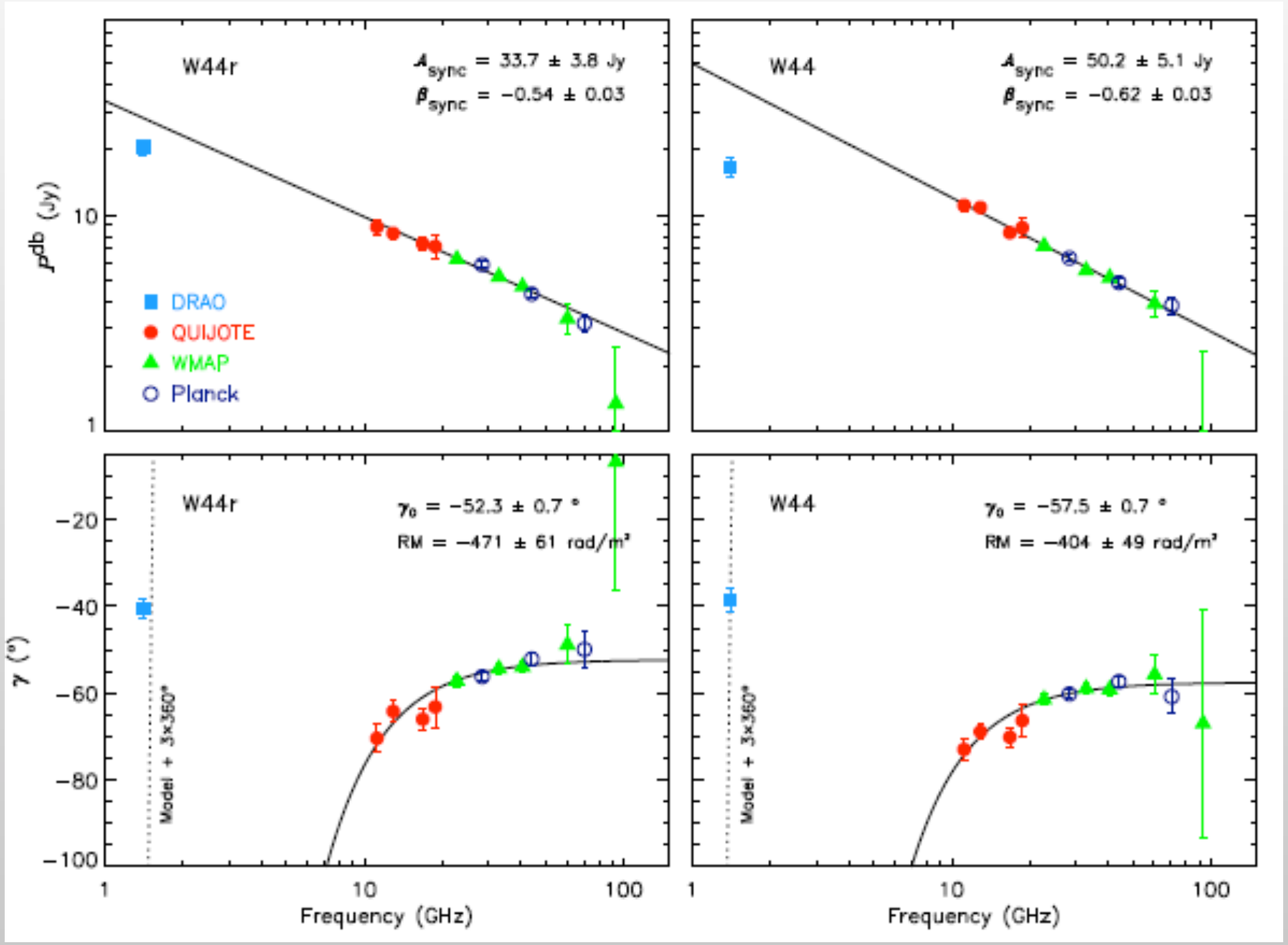
<0.38% @ 17 GHz, **<0.22%** @ 41 GHz

(Previous best upper limits on AME pol were <1%)



W43, W44 and W47

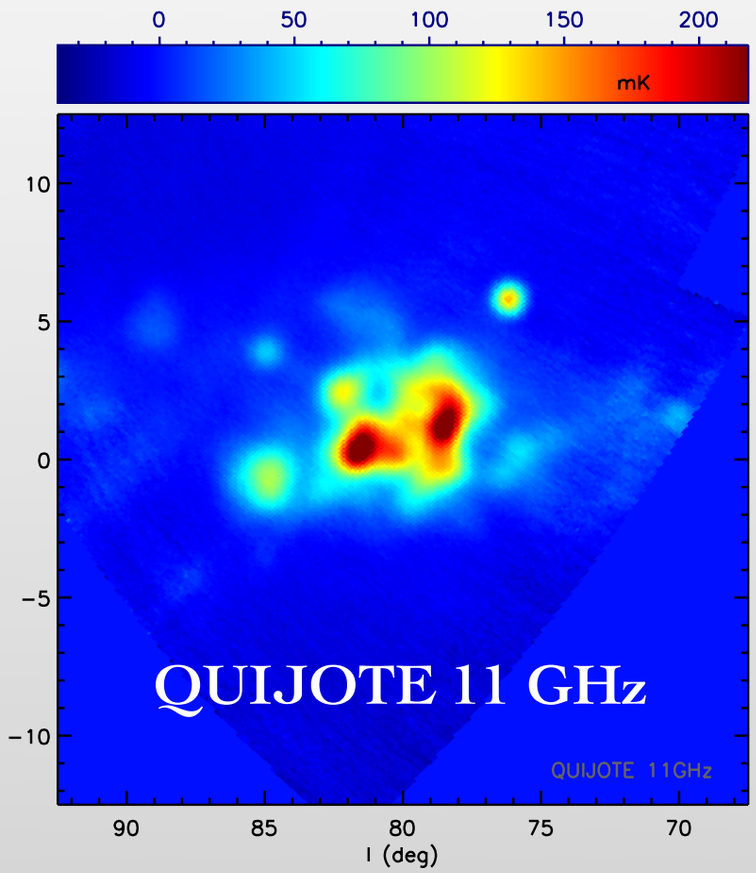
- Characterization of the W44 SED in polarization:

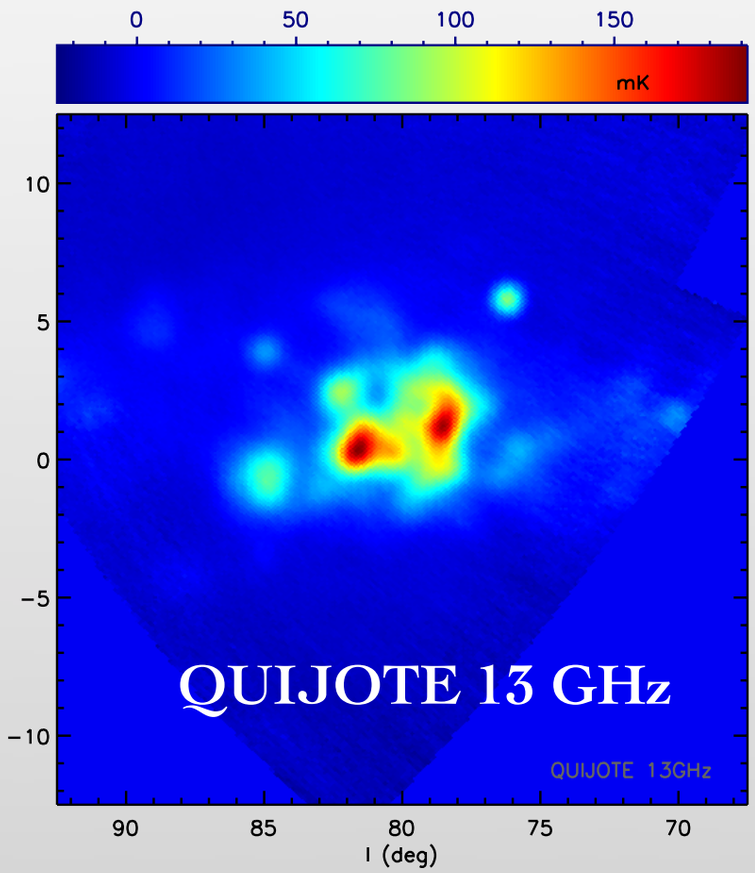


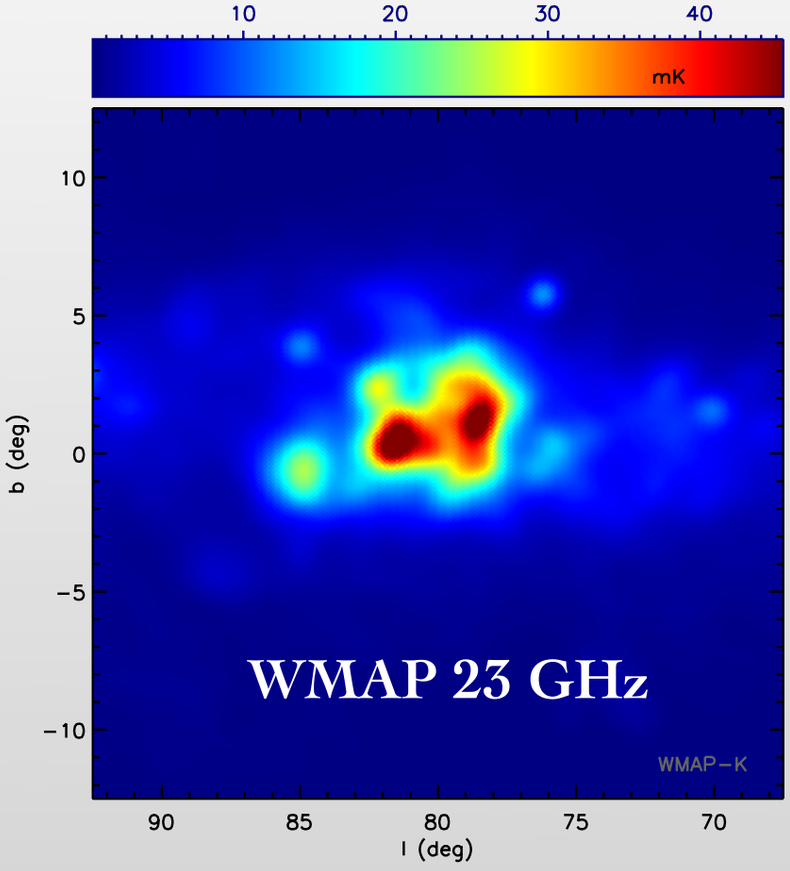
- Spectral index consistent with intensity
- Measurement of Faraday rotation (RM=-404±49 rad/m^2)

Cyg A and W63

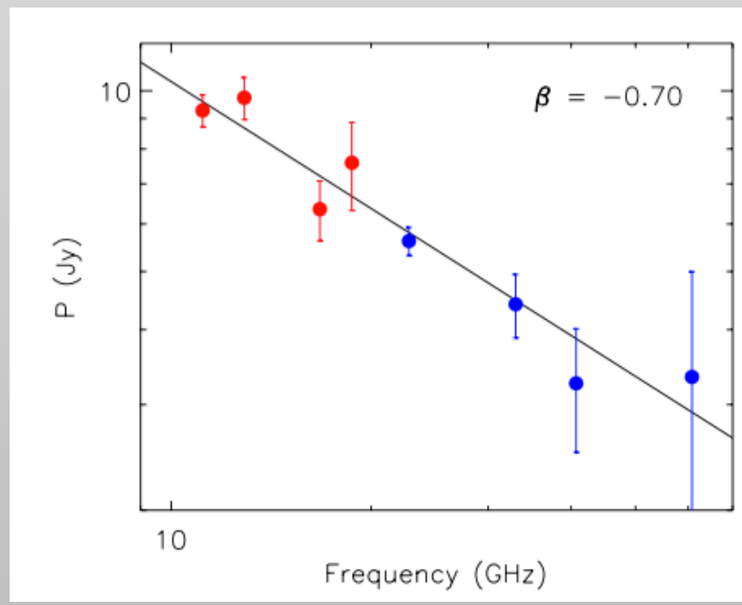
- Data in raster mode (W63 region) for ~250hrs
- Destripping map-making solution, with 2.5s baseline

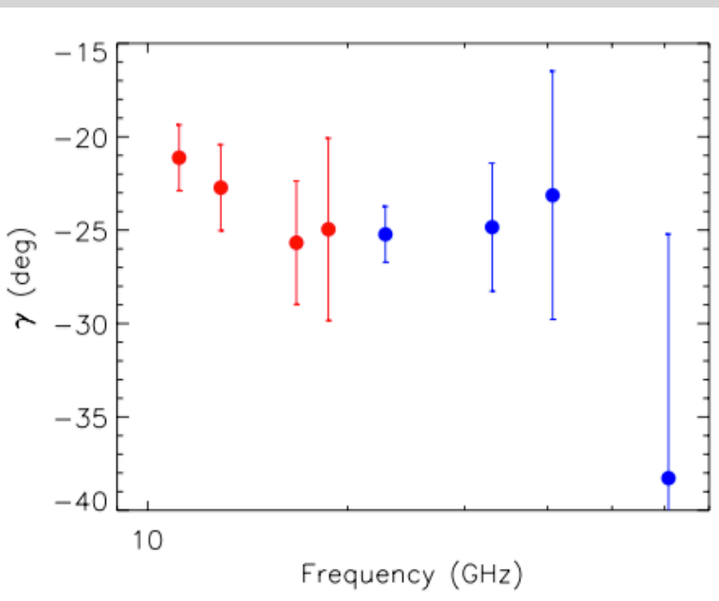






- Polarization SED on W63

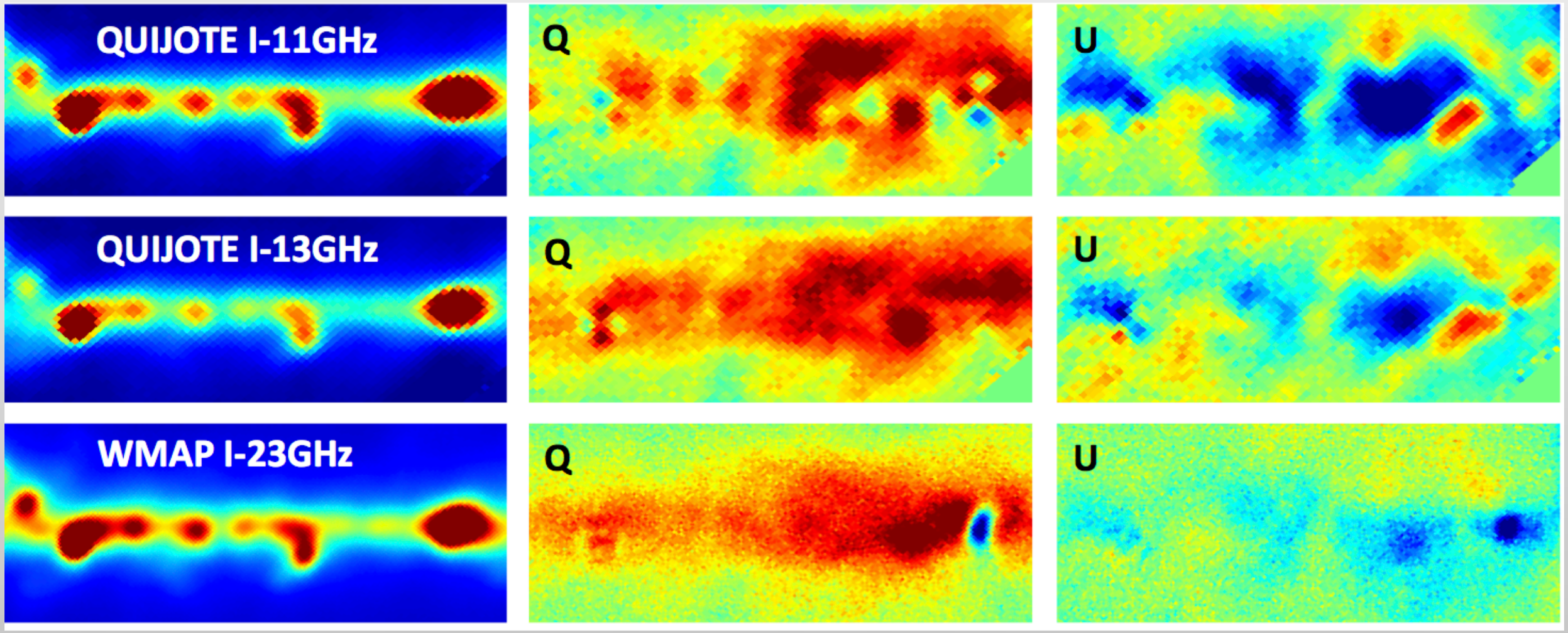




Galactic Haze

- Large observation program still ongoing (~750 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 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 TGI/ FGI data should allow to reach r=0.05 after 3 years of operation


Quijote
Q-U-I Joint Tenerife CMB experiment


Thank
You
Merci
Gracias
Obrigado
Danke
Grazie
Mèsi
Xièxie
Dziakuju
Chokrane
Kiitos
GraziasAgimus
Takk
aDank
ThintKo
Buznyg
Blagodaram
Merce
Terima Kasih
Rahmat
Arigatō
Hvala
Gracies
Spacibo
KamSahHamnida
Tak
Dankie
Acio
Molashakkeram
GraziasAgo
TänanVäga
Gracie
KopKhunKha
Saha
Multumesc
CámOn
Efharisto
Bayarlalaa
Tenki
Tanemirt
Takk
Barak Allahu Fik
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Burkal
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Merci
Dakujem
Tailku