First scientific results from QUIJOTE

—

constraints on radio foregrounds

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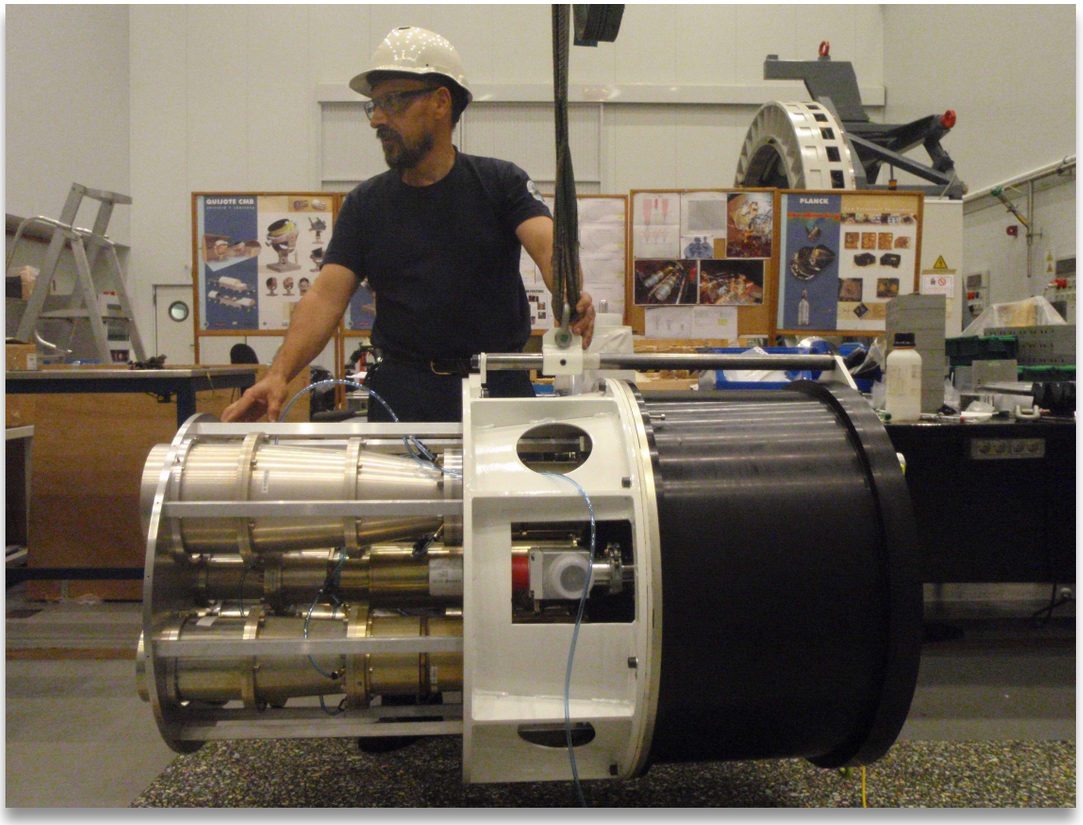
@ CMB Foregrounds, UCSD, 2017/11/29

The QUIJOTE experiment

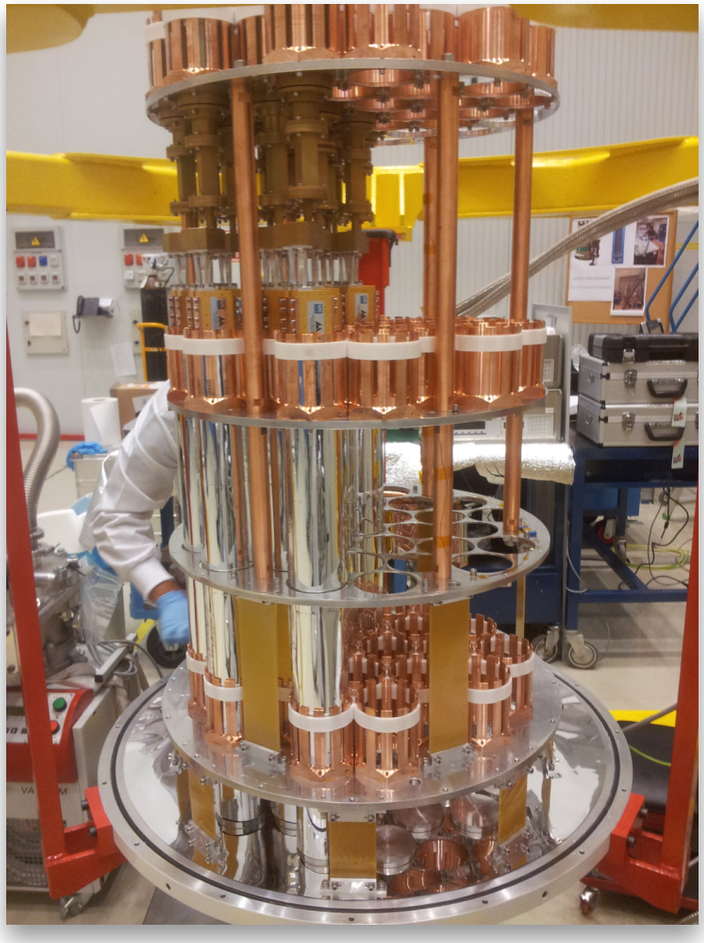
The QUIJOTE experiment

- **MFI:**
  - In operations since Nov. 2012.
  - 4 horns, 32 channels. Covering 4 frequency bands: 11, 13, 17 and 19 GHz.
  - Sensitivities: ~400-600 μK $s^{1/2}$ per channel.
  - **MFI upgrade (2018)**. Funds secured. Aim: to increase the integration speed by a factor of x3

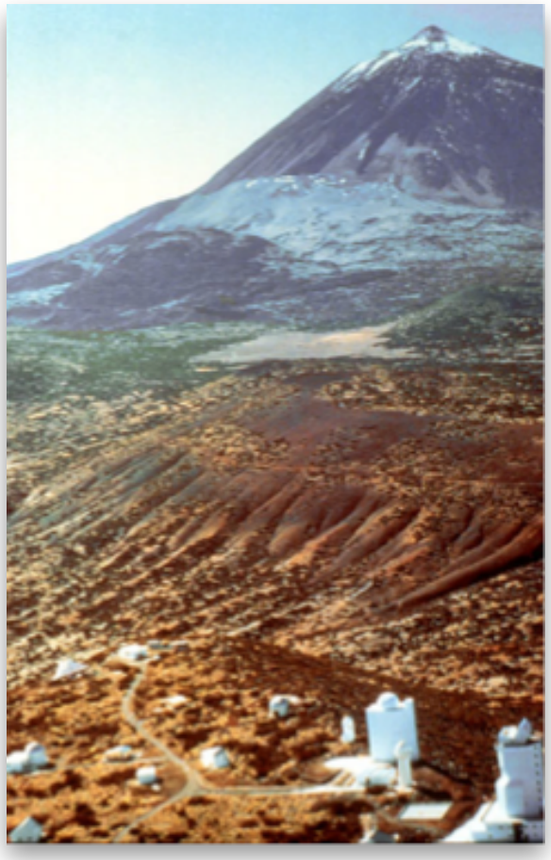


- **TGI:** 31 pixels at 30 GHz. Measured sensitivity: 50 μK $s^{1/2}$ for the full array. First light May 12th 2016. In commissioning phase.

- **FGI**: 31 pixels at 40 GHz. Expected sensitivity: 60 μK $s^{1/2}$ for the full array. Will use the same TGI cryostat



The QUIJOTE experiment



- **Site**: Teide Observatory (altitude 2400 m, 28.3º N, 16.5 W)
- **Sky coverage**: -32º < Dec. < 88º (fsky=0.65).

- **Frequencies**: 11, 13, 17, 19, 30 and 42 GHz.
- **Angular resolution**: 0.92º to 0.26º

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

- **Telescope and instruments:**
  - **Phase I**:
    - Equipped with a Multifrequency Instrument (MFI) with 4 polarimeters @ 10-20 GHz. Started observations Nov. 2012
    - Second Instrument (TGI) with 31 polarimeters @ 31 GHz. Under commissioning (first light: 12 May 2016)
  - **Phase II**:
    - FGI with 31 polarimeters @ 42 GHz. Under fabrication

Science goals

- The MFI maps provide valuable information about the polarisation properties of:

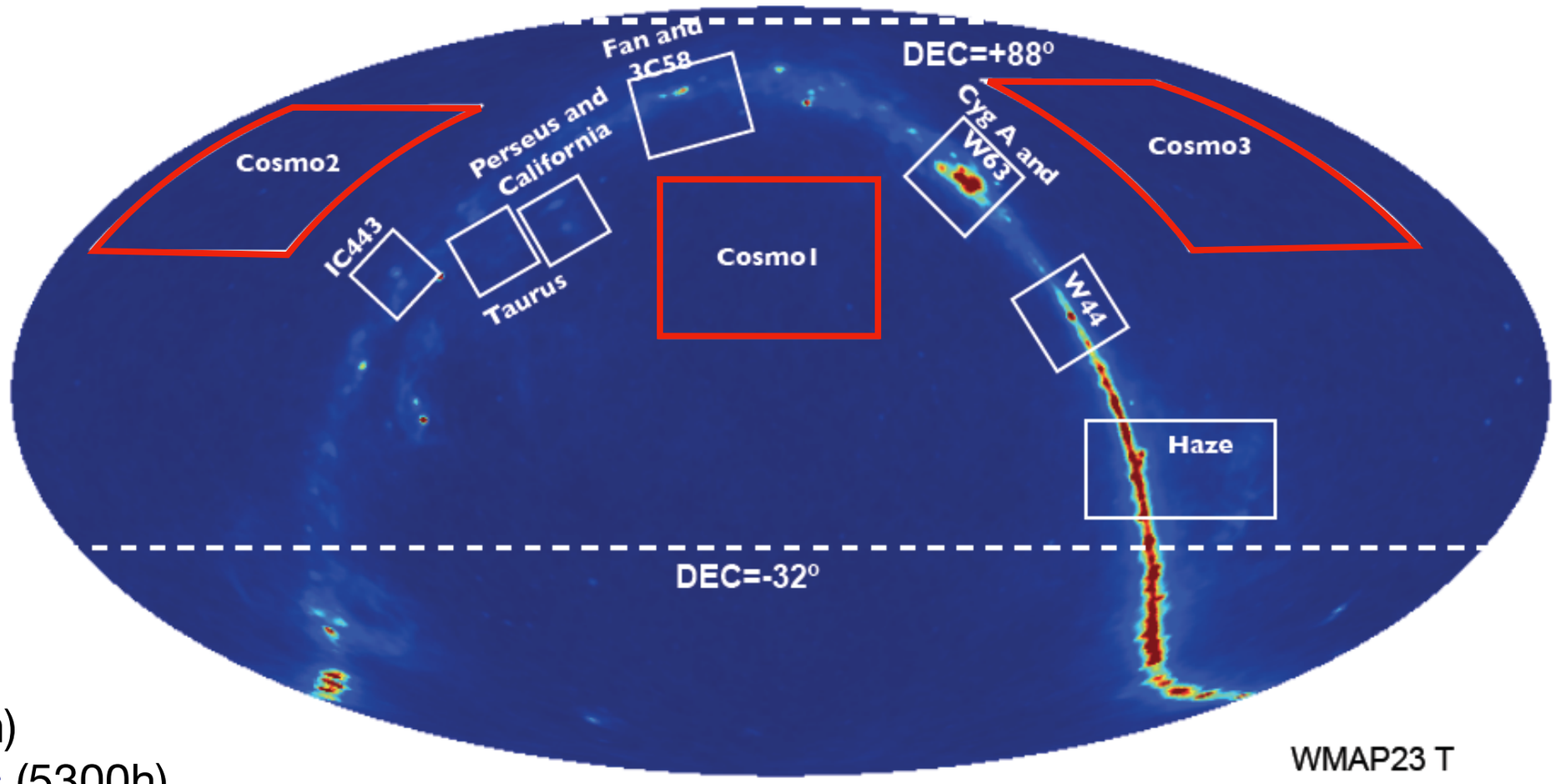
  – **Synchrotron emission:** should dominate the emission at the MFI frequencies. WMAP 23 GHz shows it to be polarised at ~5-15%, depending on the Galactic latitude

  – **Anomalous microwave emission:** little known about its polarisation. Best upper limits on the polarisation fraction: <0.2% (Génova-Santos et al. 2016), previously <1% (LC11, D11)

- 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**

Science goals

Observing strategy: Deep observations in selected areas using **raster scans**, plus **wide survey**



MFI science phase
(April 2013 - now)

- Wide survey (8500h)
- Cosmological fields (5300h)
- Daily calibrators (Crab, Cas A, Jupiter, sky dips)
- 3C58 and the Fan region (450h)
- Galactic Haze (930h)
- Perseus molecular cloud (300h)
- SNRs: IC443 (270h), W63 (250h), W44 and W47 (210h)
- Taurus region (450h)

→ Total: **21,000 h** (2.4 years) with 45 % efficiency

Science goals

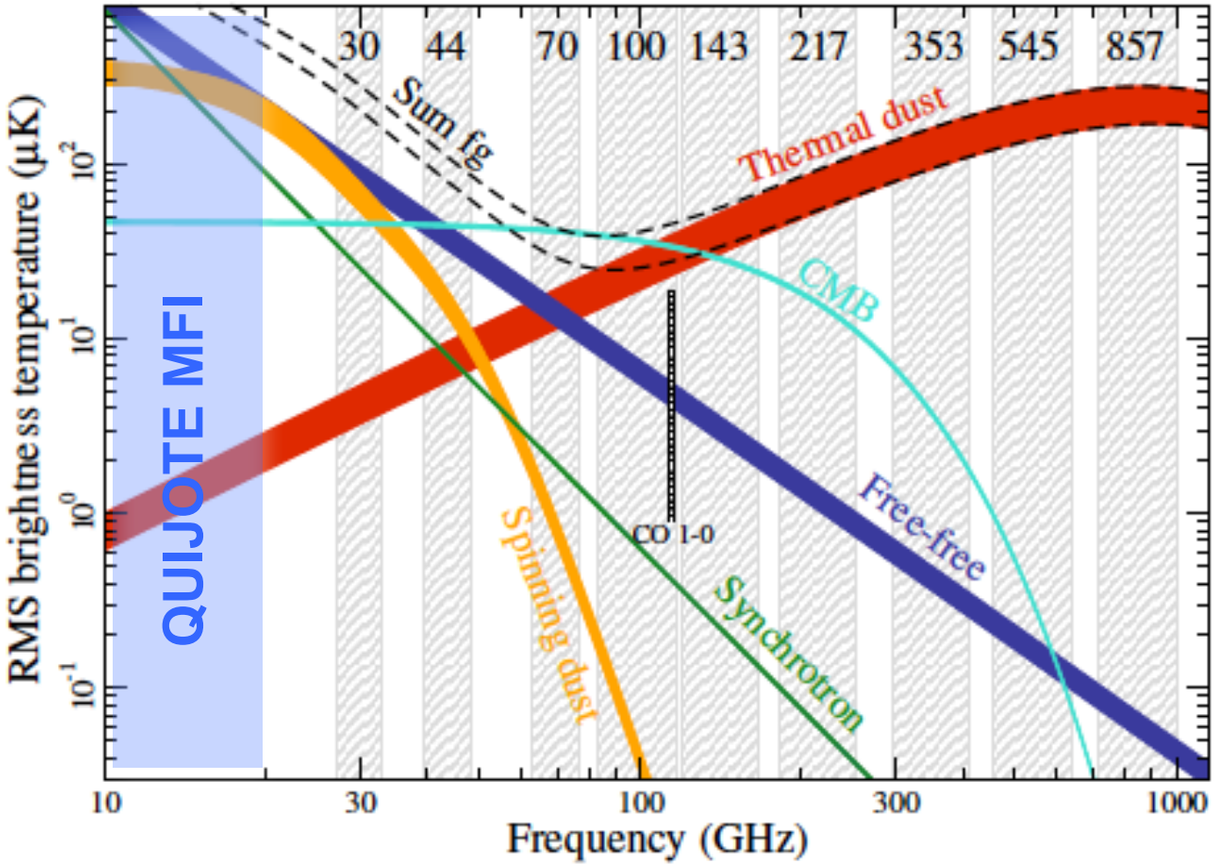
- **Shallow Galactic survey**. Covering 25,000 deg² **— 15 μK/(beam 1º)**
- **Galactic regions**. Covering few hundred deg².
  - ≈ **30-40 μK/(beam 1º)** with the MFI @ 11, 13, 17 and 19 GHz, in both Q and U.
- **Deep cosmological survey**. It will cover around 3,000 deg² in 3 separated fields.

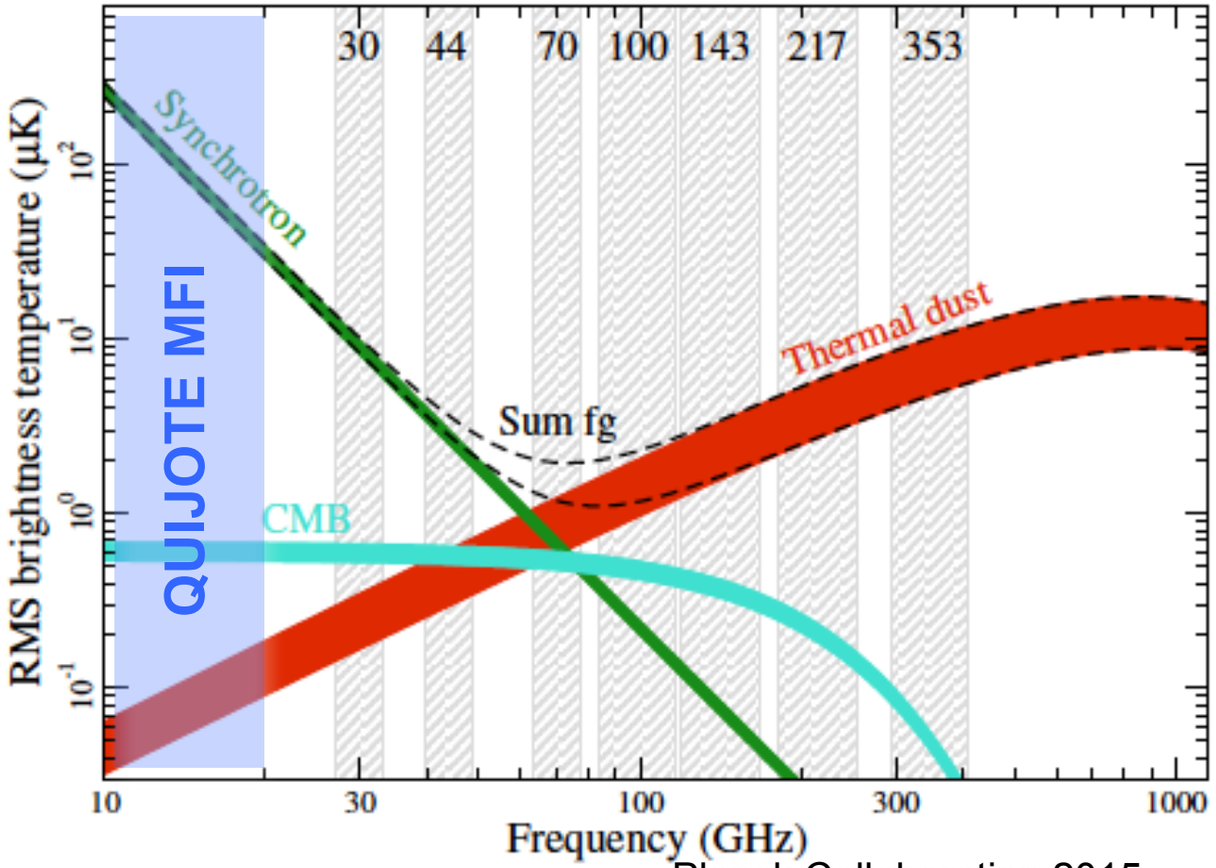
The scientific goal is to reach r=0.05 after 3 years of operations of the TGI+FGI.

  - ≈ **10 μK/(beam 1º)** after 1 year with the MFI @ 11, 13, 17 and 19 GHz.
  - ≈ **1 μK/(beam 1º)** after 1 year with the TGI and FGI @ 30 and 40 GHz.

→ radio foregr.

→ cosmo

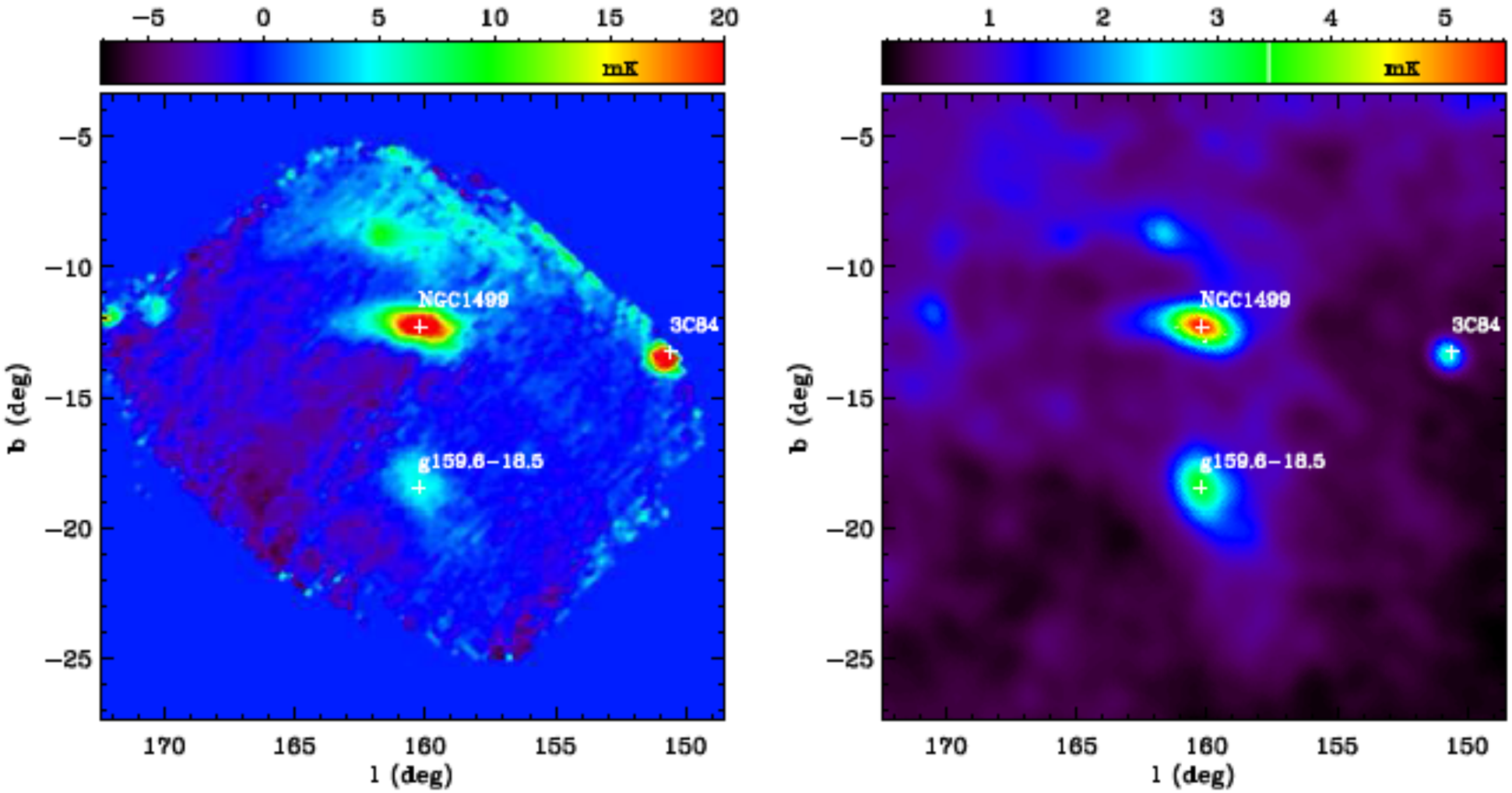




Planck Collaboration 2015

Perseus molecular complex

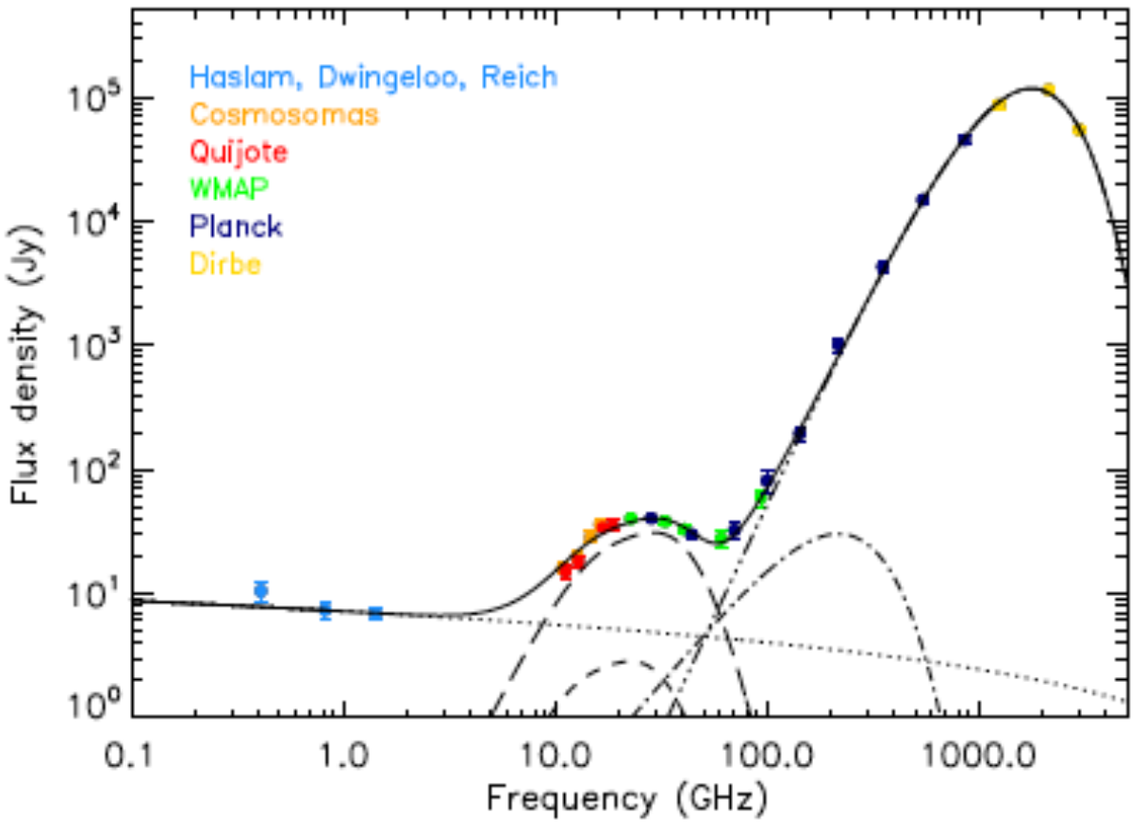
- ~200 hours, 12/2012 to 04/2013, on an area covering ~250 deg^2 around the Perseus molecular complex.
- One of the brightest AME regions on the sky (Watson et al. 2005, Planck collaboration 2011)
- Final integration time ~3000 s/beam, yielding a final map sensitivity of ≈30 μK/beam



- First QUIJOTE paper: Génova-Santos et al. (2015), MNRAS, 452, 4169

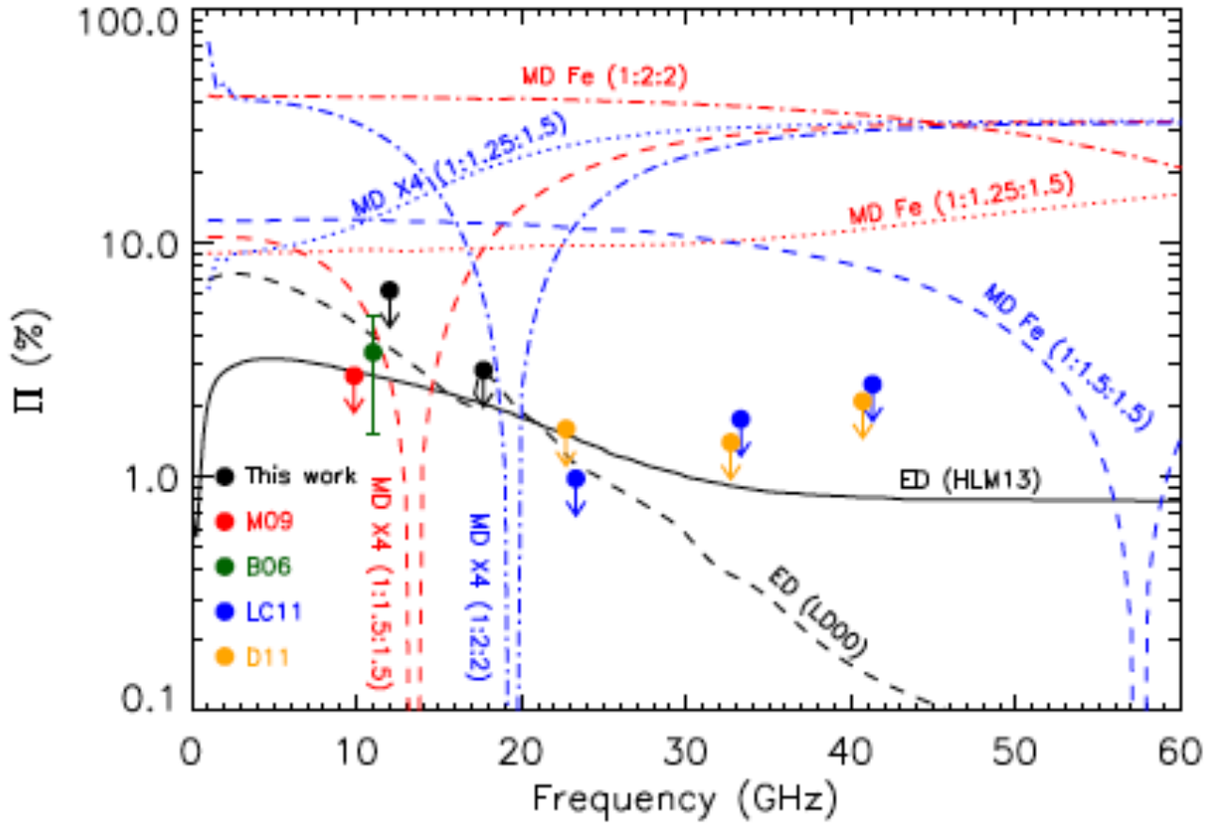
Perseus molecular complex

SED modeling for G159.6-18.5



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

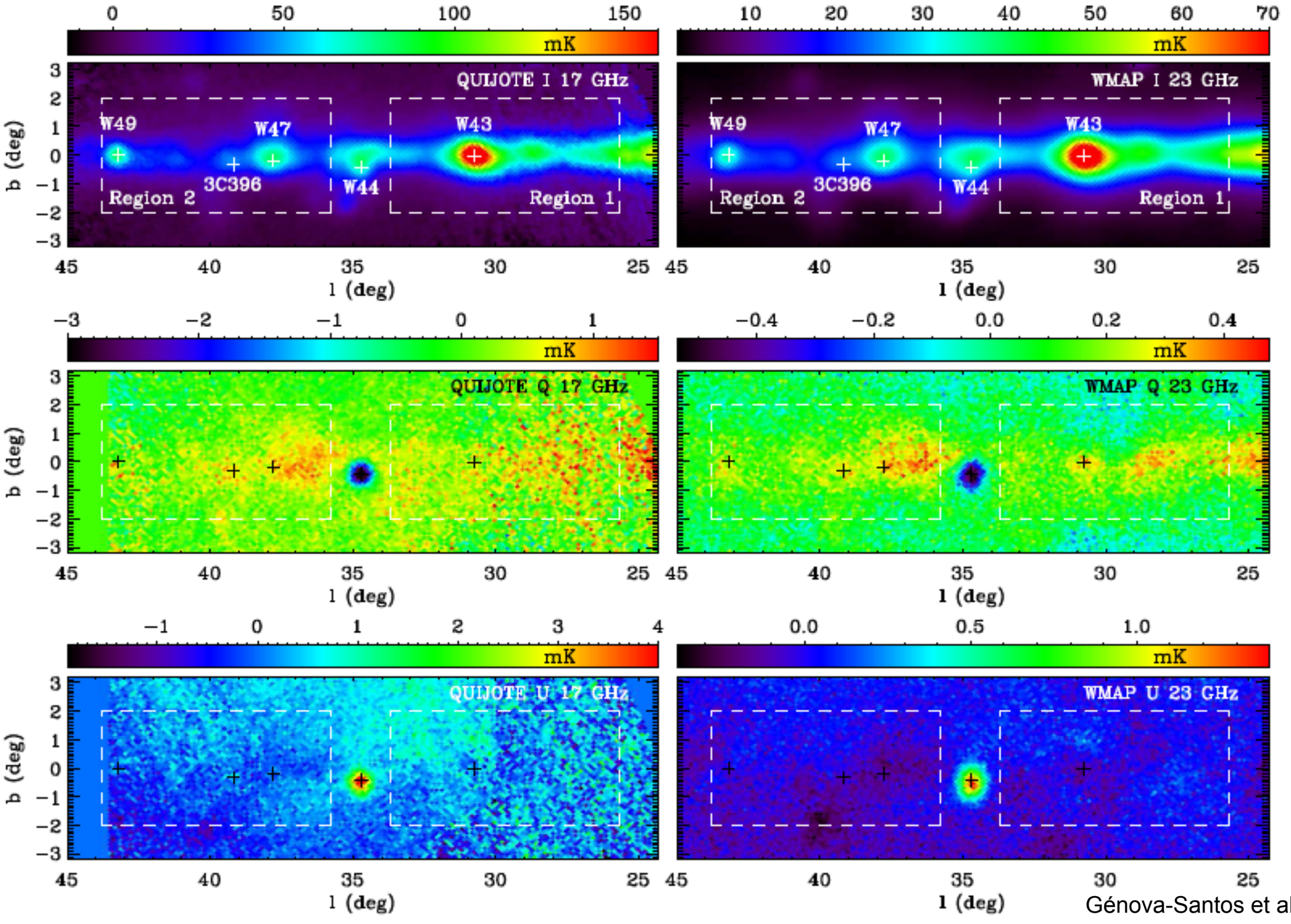
Limits on AME polarization



- **No polarization detection.**
- **Π < 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. Both W43 and W47 are molecular complexes)



Génova-Santos et al. (2017)

W43, W44 and W47

- Fits to intensity SEDs
- Fit AME with the a 3-parameter parabola:

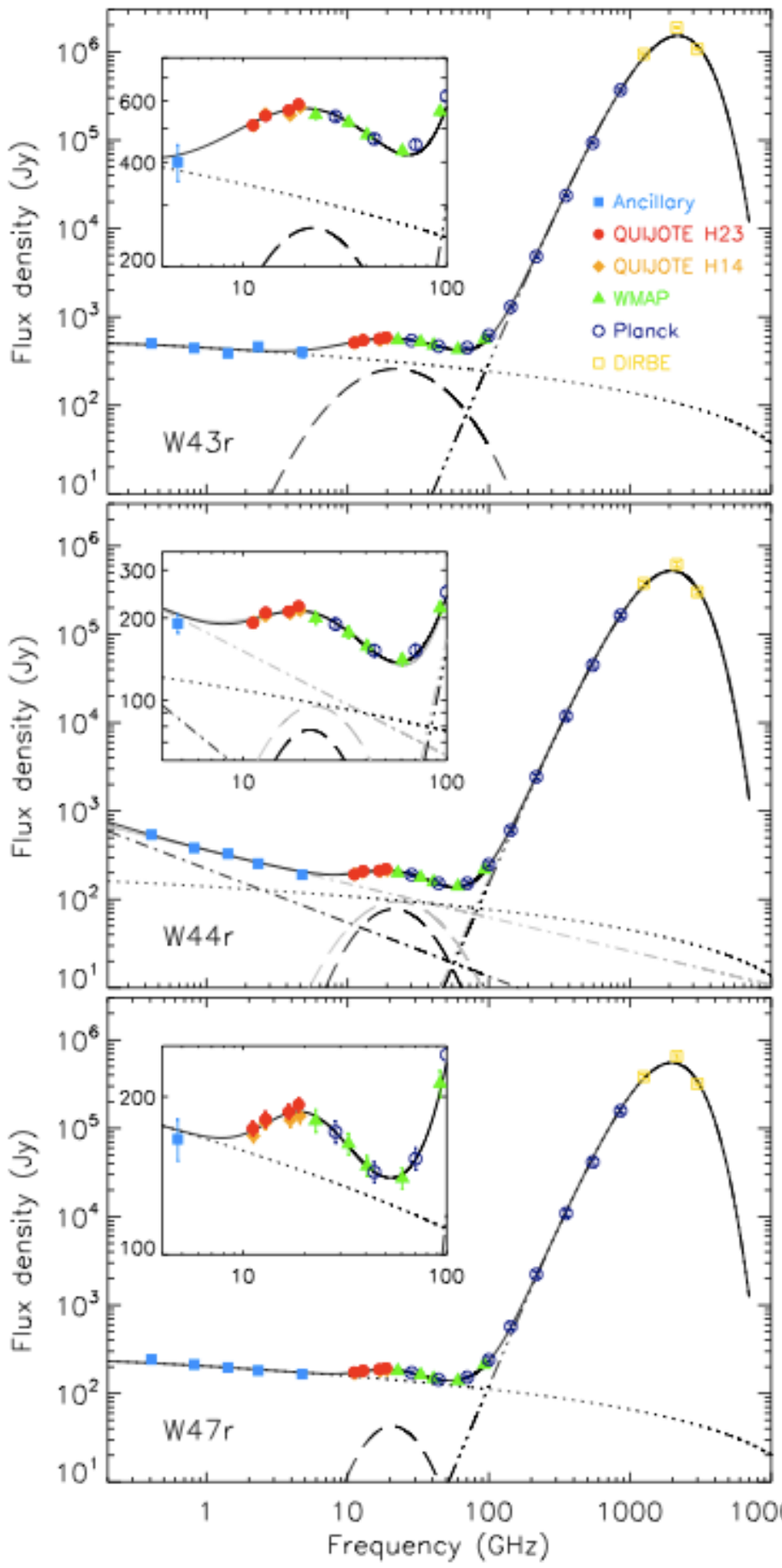
Region	S_{AME} (Jy)	*EM* (cm^{-6} pc)	χ^2/dof
W43	258 ± 7	3911 ± 68	5.4
W44	78 ± 6	1264 ± 22	1.0
W47	43 ± 2	1849 ± 20	1.0

- *EM* estimates from Commander or from RRL (Alves et al. 2015):

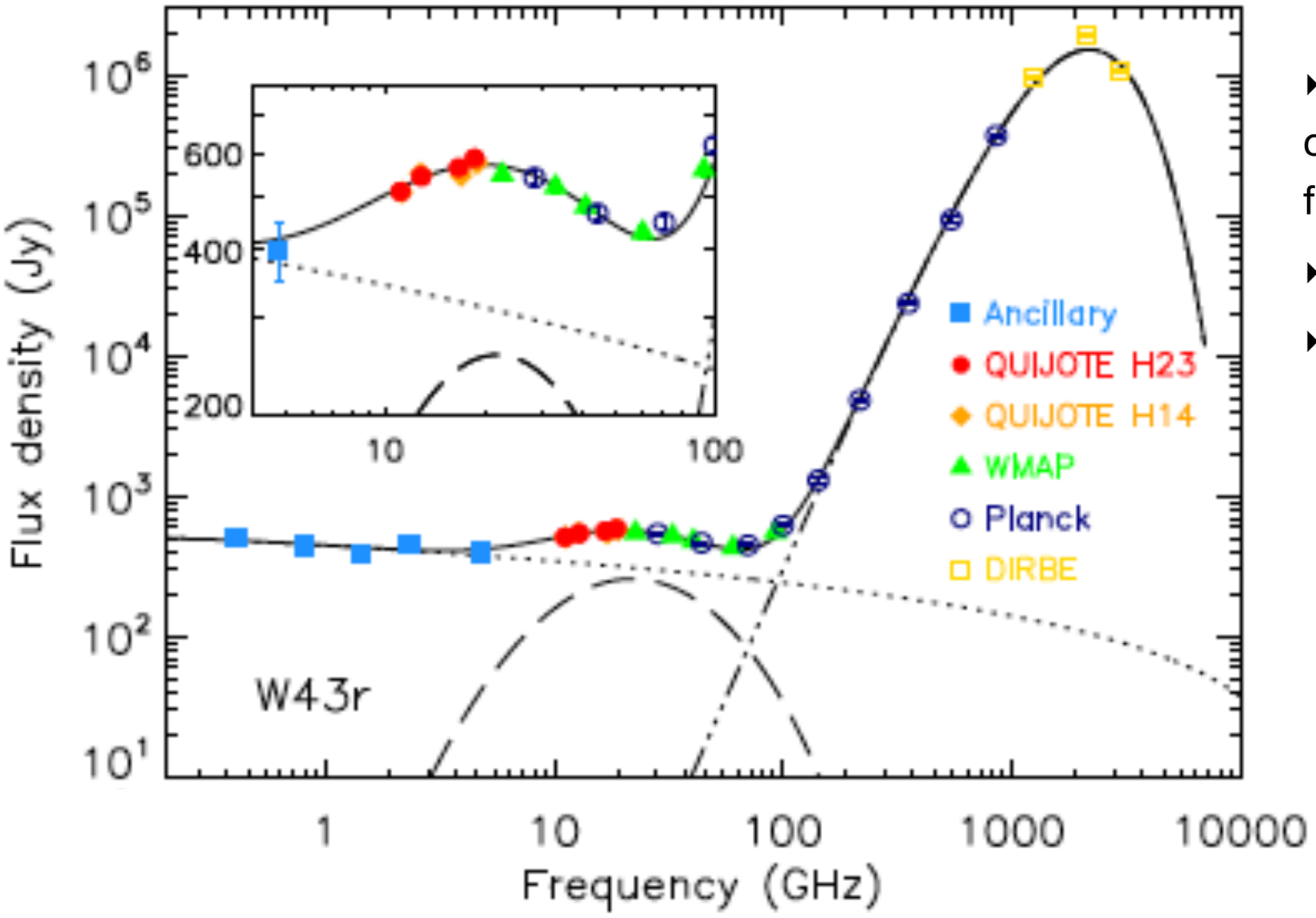
Region	Commander	RRL
W43	5888	4020 - 6190
W44	1667	990 - 1340
W47	1806	1360 - 1840

Commander seems to overestimate the free-free and underestimate the AME

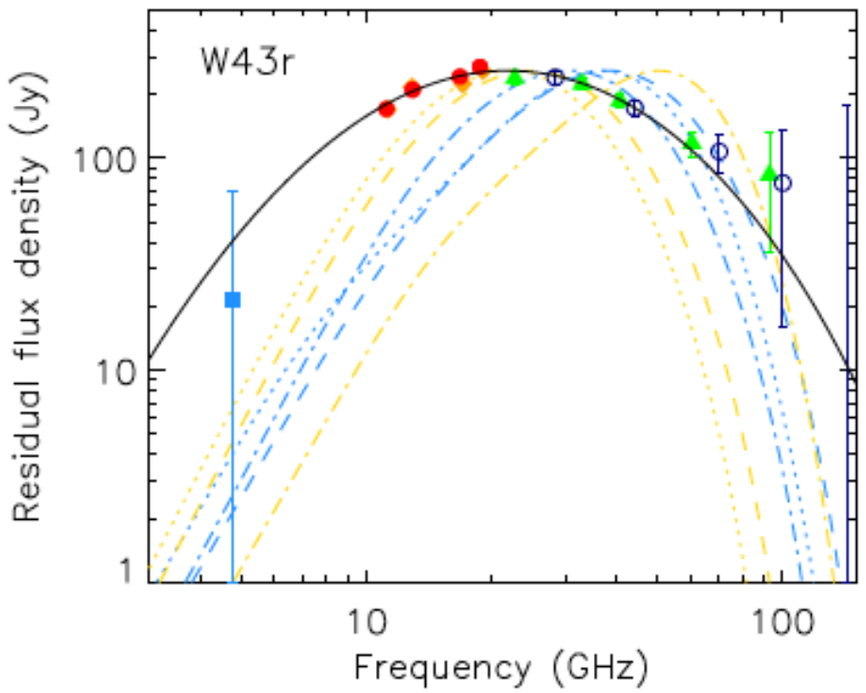
Génova-Santos et al. (2017)



W43 molecular complex



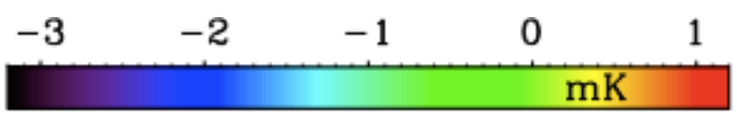
- The four QUIJOTE data points confirm the **downturn** at low-frequencies due to spinning dust.
- Free-free dominated intensity SED.
- AME peak brighter than Perseus.

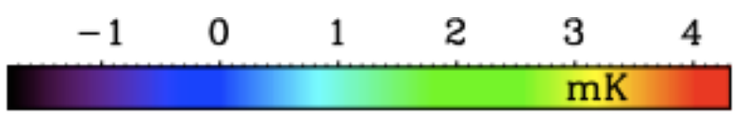


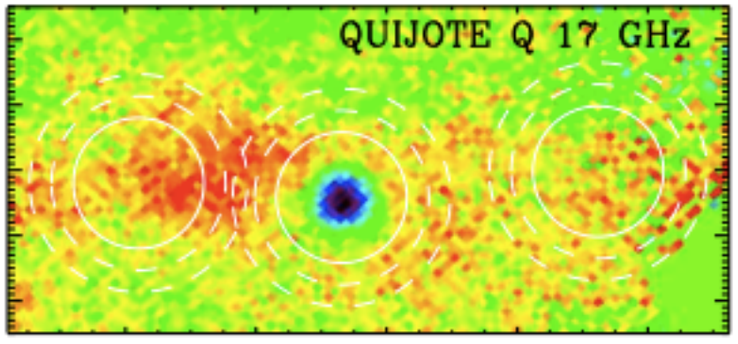
Génova-Santos et al. (2017), arXiv:1605.04741.

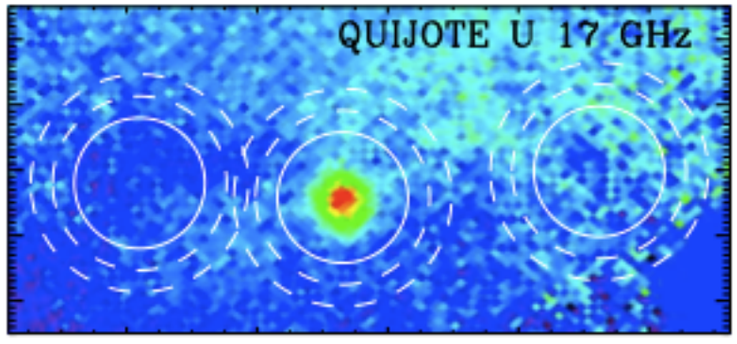
Upper limits on the polarisation of W43

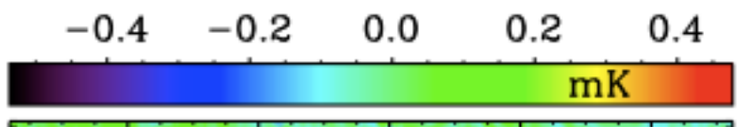
- Maps consistent with zero at the position of W43
- Residual diffuse synchrotron polarisation (or free-free polarisation from the HII region at 23 and 33 GHz)
- Limits on the AME polarisation fraction **Π_{AME} < 0.39%** at 18.7 GHz and **< 0.22%** at 40.6 GHz (95% CL)
- Improvement by a factor >4 on previous best constraints (Π_{AME} < 1% from López-Caraballo et al. 2011, Dickinson et al. 2011)

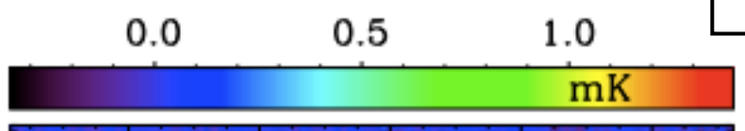


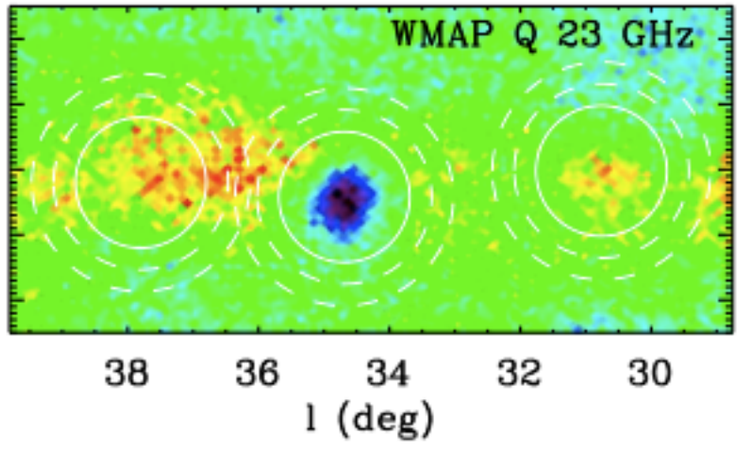


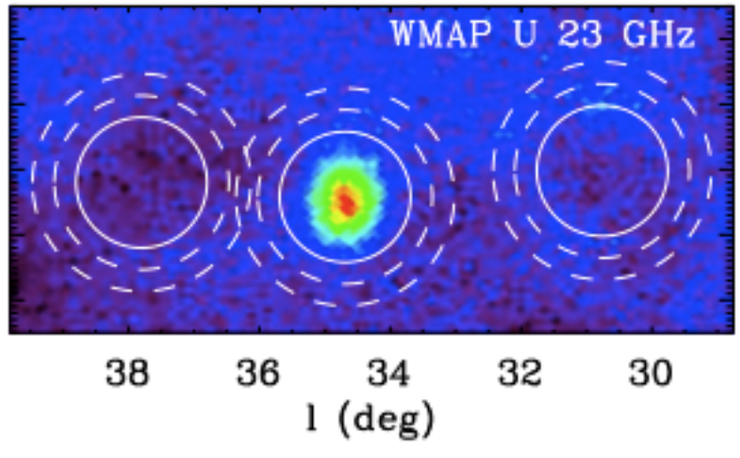








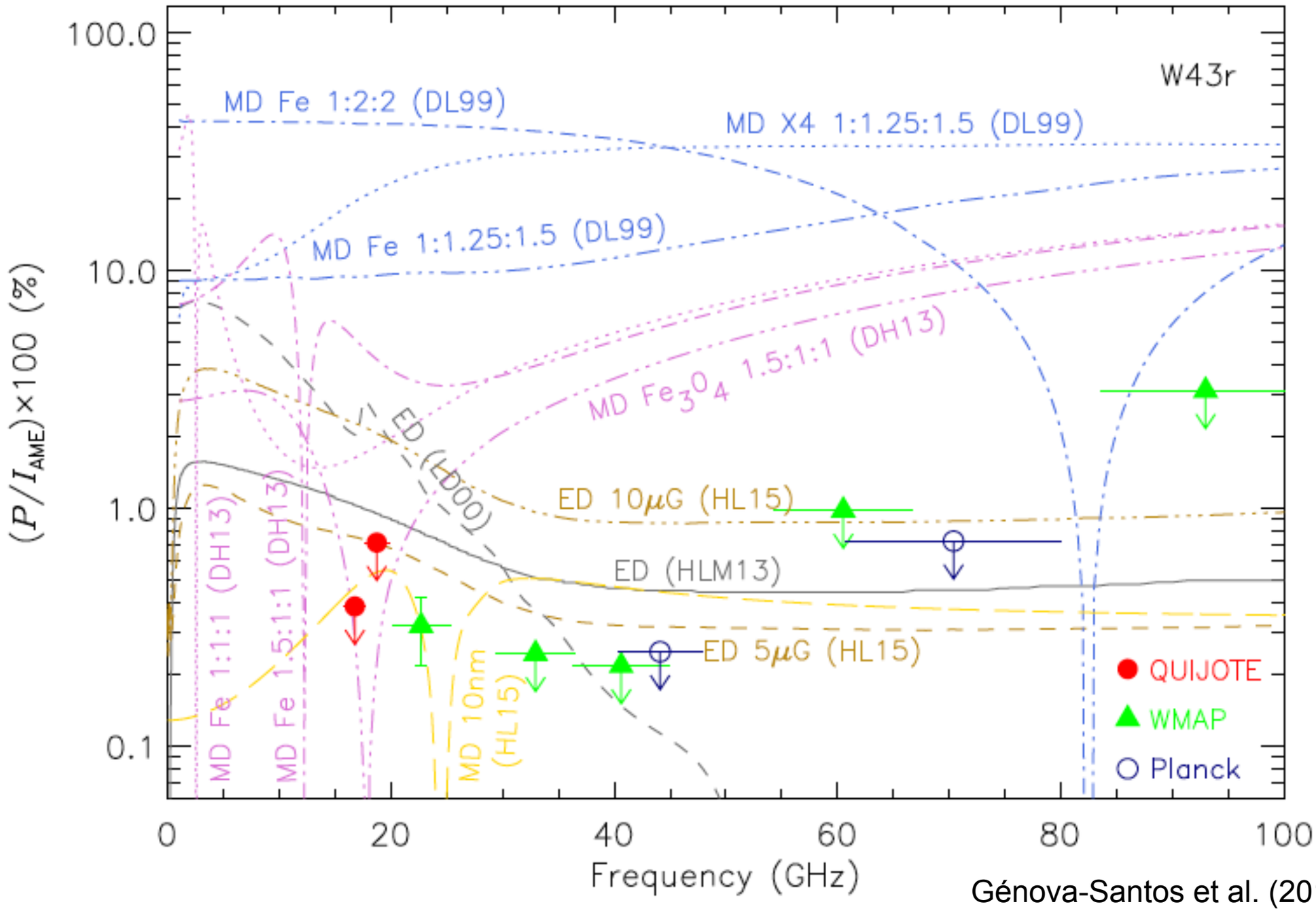




Freq.	W43r		
(GHz)	I_{AME} (Jy)	P^{db} (Jy)	$(P/I_{AME})^{db}$ ×100 (%)
1.40	–	6.31 ± 1.59	–
16.7	241 ± 12	< 0.93	< 0.39
18.7	269 ± 13	< 1.93	< 0.71
22.7	238 ± 16	0.77 ± 0.23	0.32 ± 0.10
32.9	224 ± 15	$0.10^{+0.21}_{-0.10}$	< 0.24
40.6	186 ± 14	< 0.40	< 0.22
44.1	172 ± 14	< 0.43	< 0.25
60.5	118 ± 16	< 1.14	< 0.98
70.4	107 ± 21	< 0.74	< 0.73
93.0	92 ± 48	< 2.81	< 3.12

Upper limits on the polarisation of W43

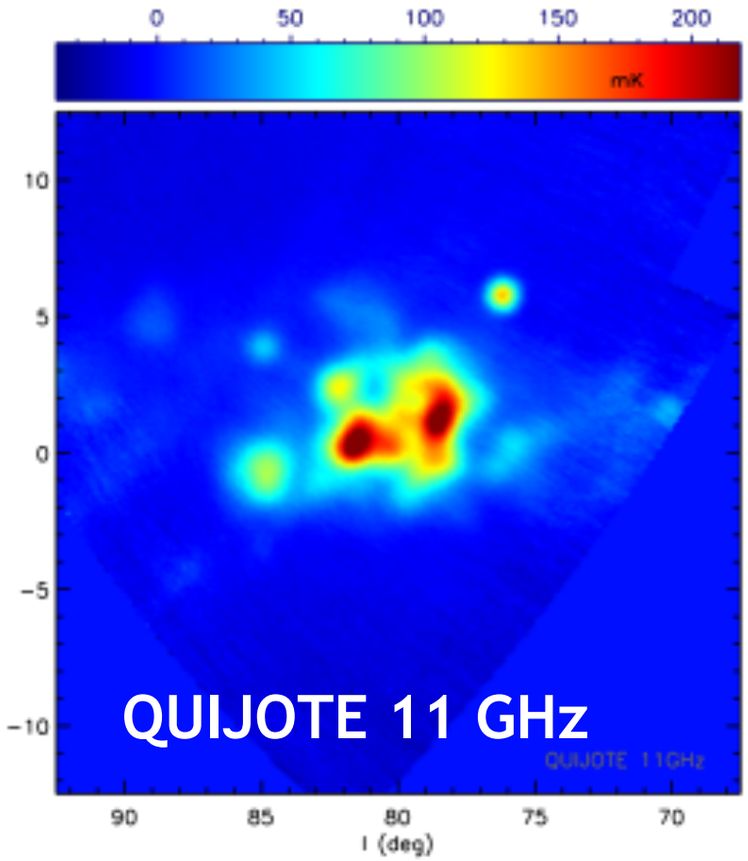
Constraints on AME polarization fraction and comparison with ED models. **Best upper limits to date** (< 0.4% at 17GHz from QUIJOTE, and < 0.22% at 23GHz from WMAP).

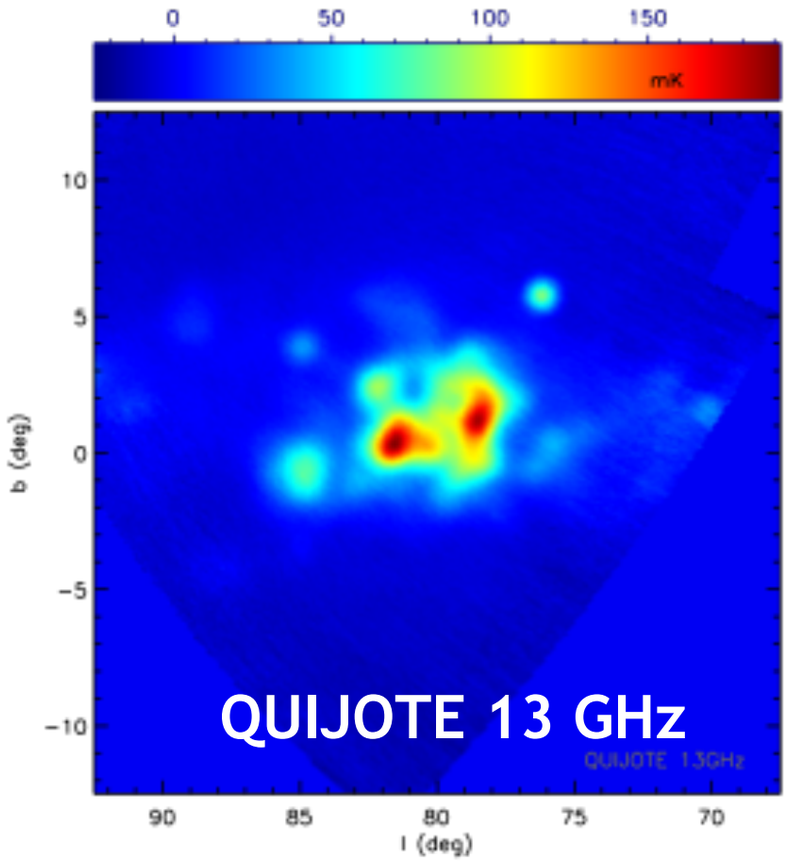


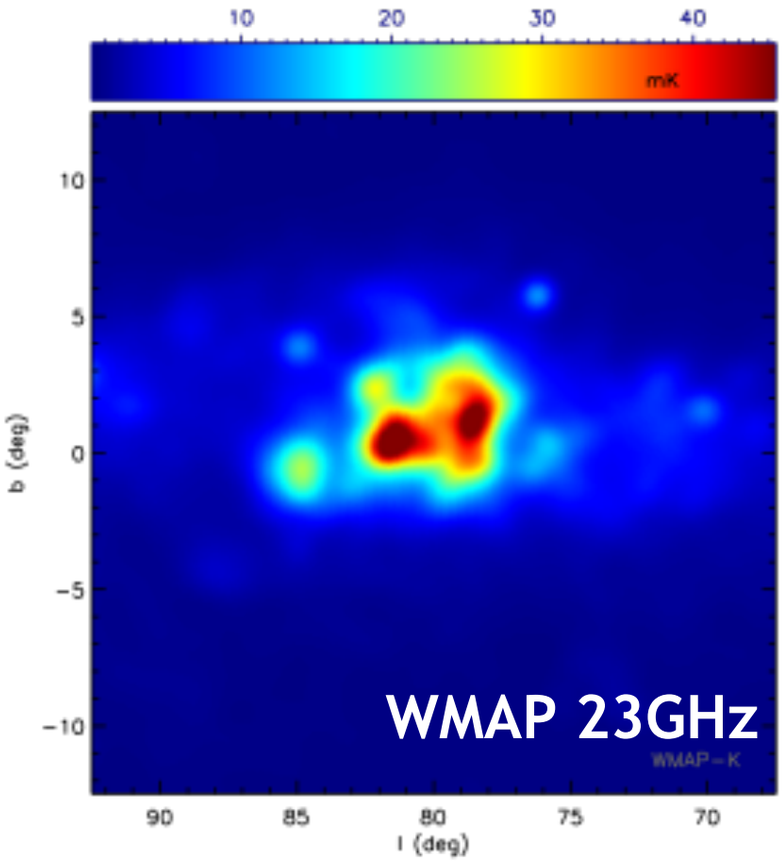
Génova-Santos et al. (2017)

Cygnus region

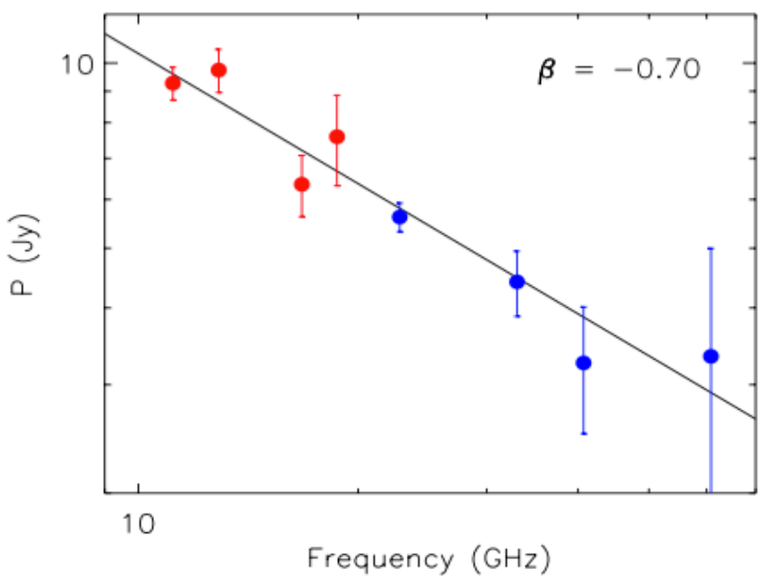
- Data in raster mode (W63 region) for ~250 hrs.

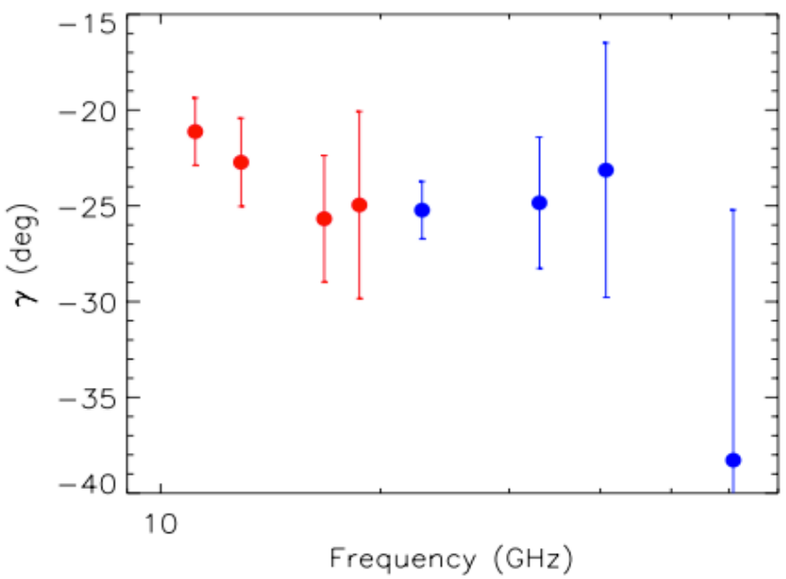






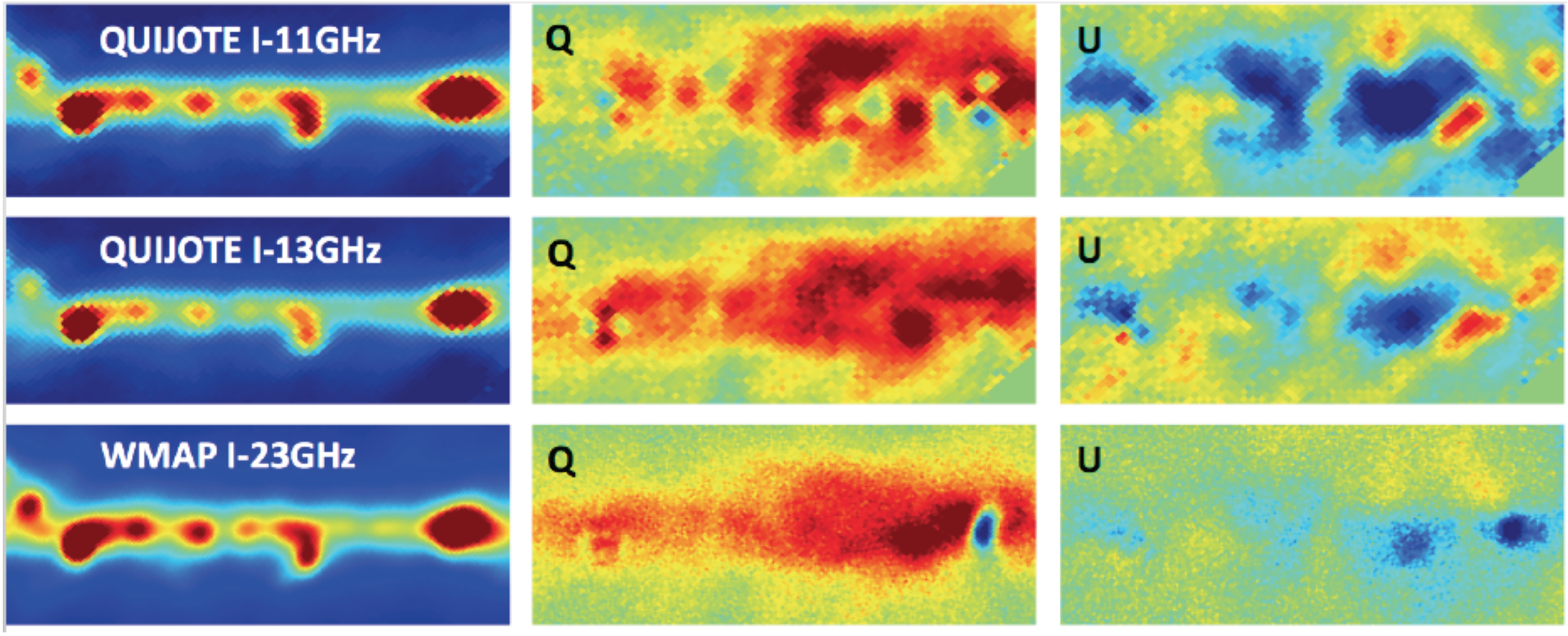
Polarization SED on W63:





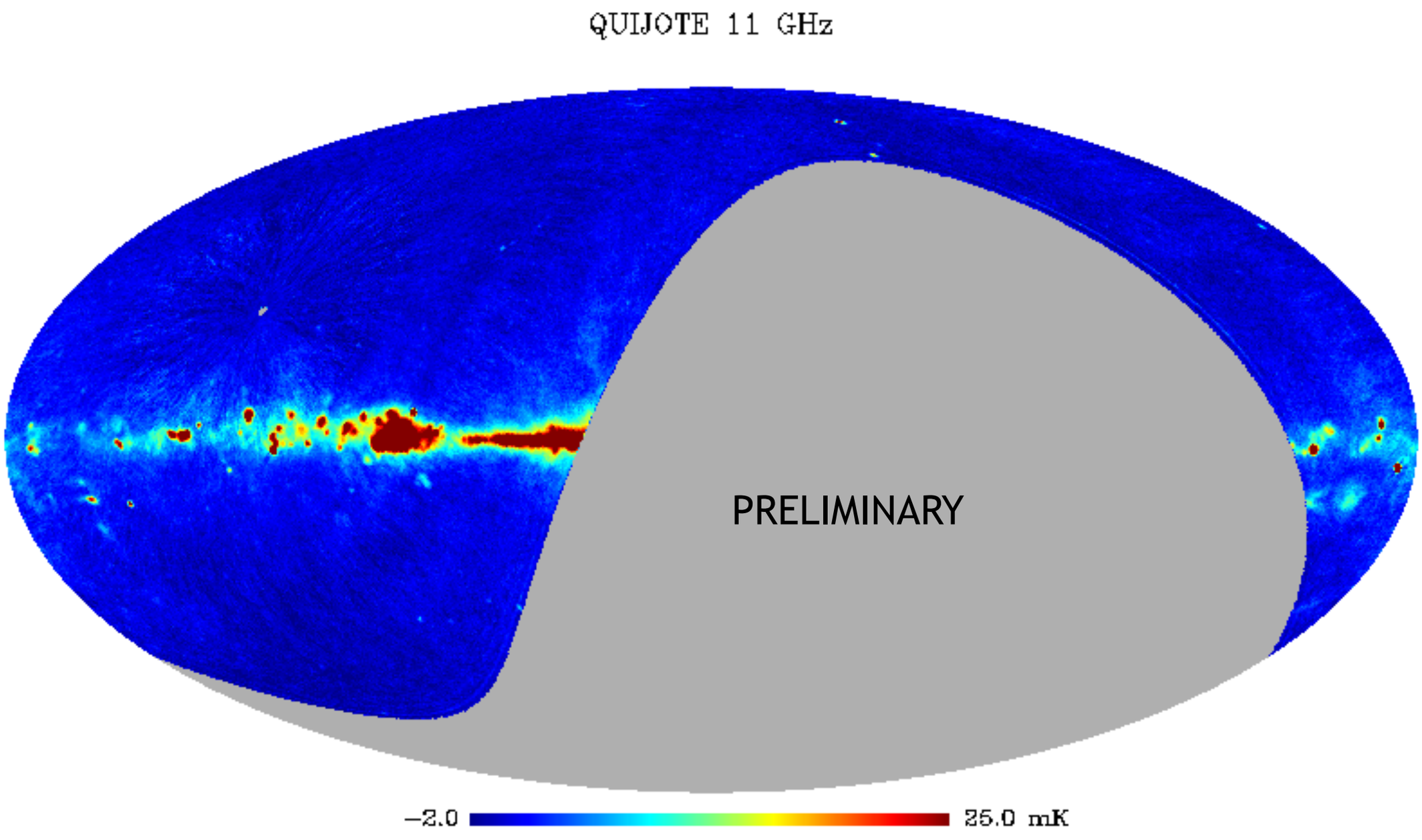
Galactic centre

- Large observation program still ongoing (~800h), on an area covering ~1000 deg^2 around the Galactic centre.
- The goal is to study the polarised emission in the region, with particular interest on the characterisation of the Haze emission (Fermi bubbles)
- Preliminary 11 and 13 GHz maps (20x6 deg^2) of the Galactic plane around the Galactic centre, in comparison with WMAP 23 GHz.



Wide survey

- 8,500 hrs on a region of 25,000 deg^2 in the northern sky.
- Still on-going (will reach ~10000 hrs).
- Goal: ~15 μK/beam in Q,U and, ~50 μK/beam in I.
- Example of QUIJOTE maps from 700 h observations.



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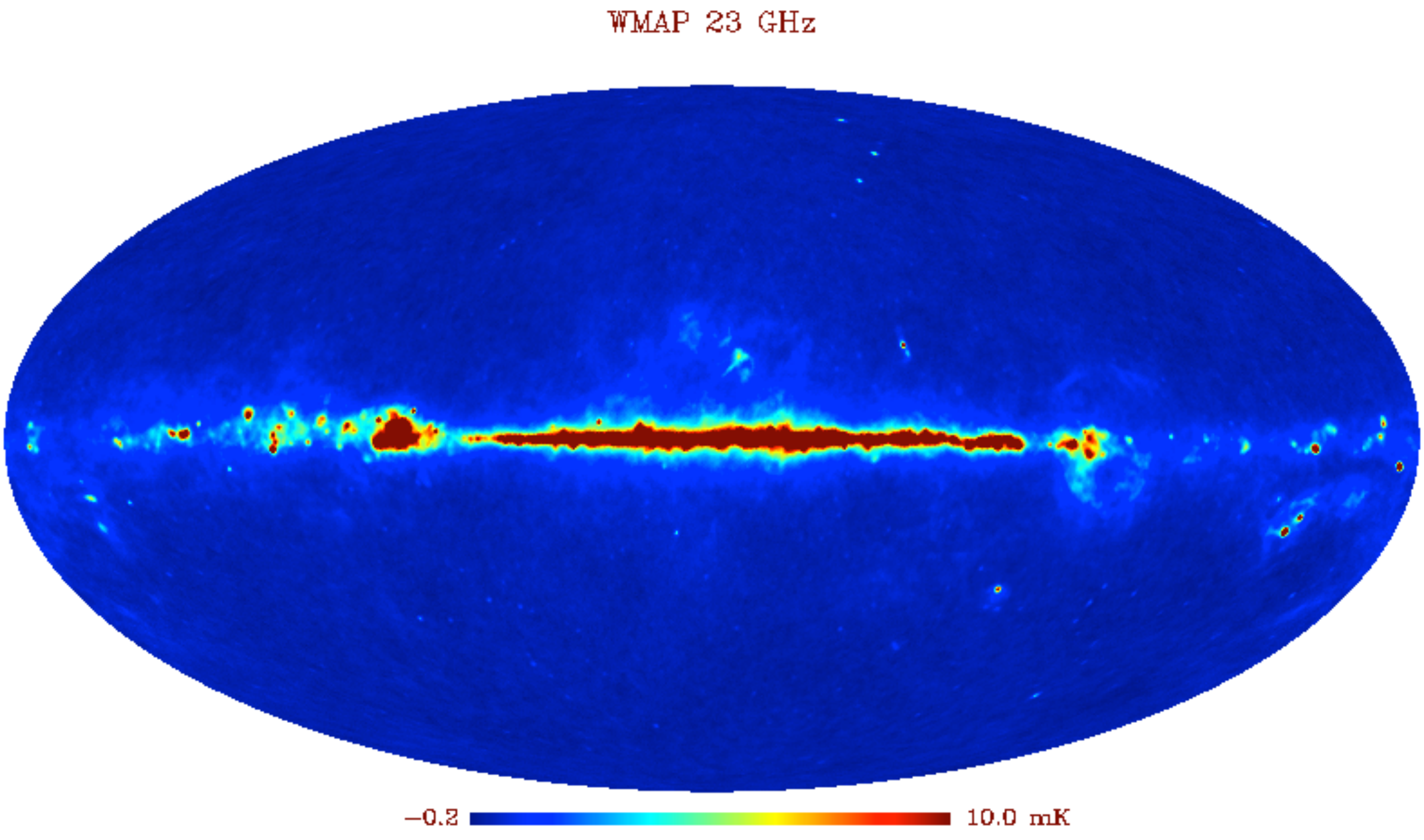


RADIOFOREGROUNDS project

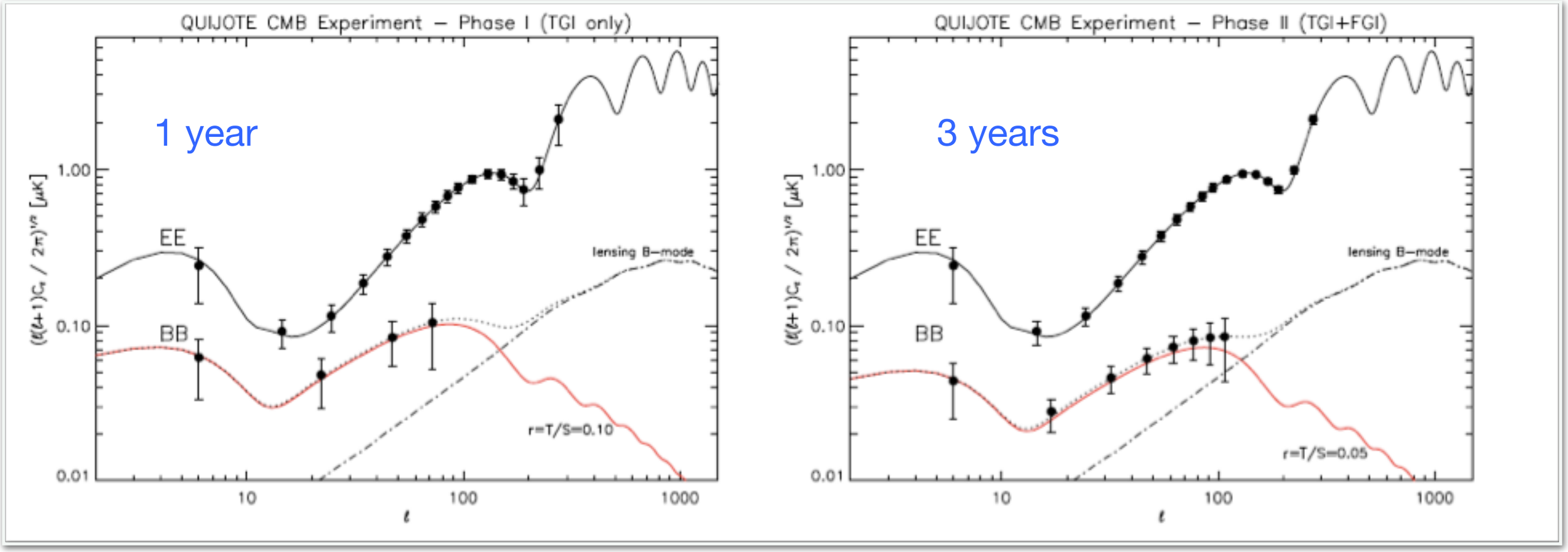
http://www.radioforegrounds.eu

H2020-COMPET-2015. Grant agreement **687312:**
"Ultimate modelling of Radio Foregrounds" (RADIOFOREGROUNDS).

3-year grant (IAC; IFCA; Cambridge; Manchester; SISSA; Grenoble; TREELOGIC).
This project will provide specific products:

a) state-of-the-art legacy maps of the synchrotron and the anomalous microwave emission (AME) in the Northern sky;
b) a detailed characterisation of the synchrotron spectral index, and the implications for cosmic-rays electron physics;
c) a model of the large-scale properties of the Galactic magnetic field;
d) a detailed characterisation of the AME, including its contribution in polarisation; and
e) a complete and statistically significant multi-frequency catalogue of radio sources in both temperature and polarisation.
f) specific (open source) software tools for data processing, data visualisation and public information.

Cosmology with TGI and FGI



- **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**

Conclusion

- Observations and instruments:
  - Wide survey (fsky = 65 %) and raster scans of particular regions
  - 6 frequencies on 3 instruments: 11,13,17,19, 30, 40 GHz

- Data and scientific results:
  - World most sensitive polarisation data in the MFI frequency range
  - Confirmation of the downturn of the SED of the AME
  - Found stronger AME intensity in several Galactic regions
  - Put best constraints on the AME polarisation fraction

- Future objectives:
  - Detailed characterisation of the synchrotron, AME, … in diffuse ISM
  - Reach the constraint $r < 0.05$ on the CMB B-modes

thank you