AME polarisation with QUIJOTE

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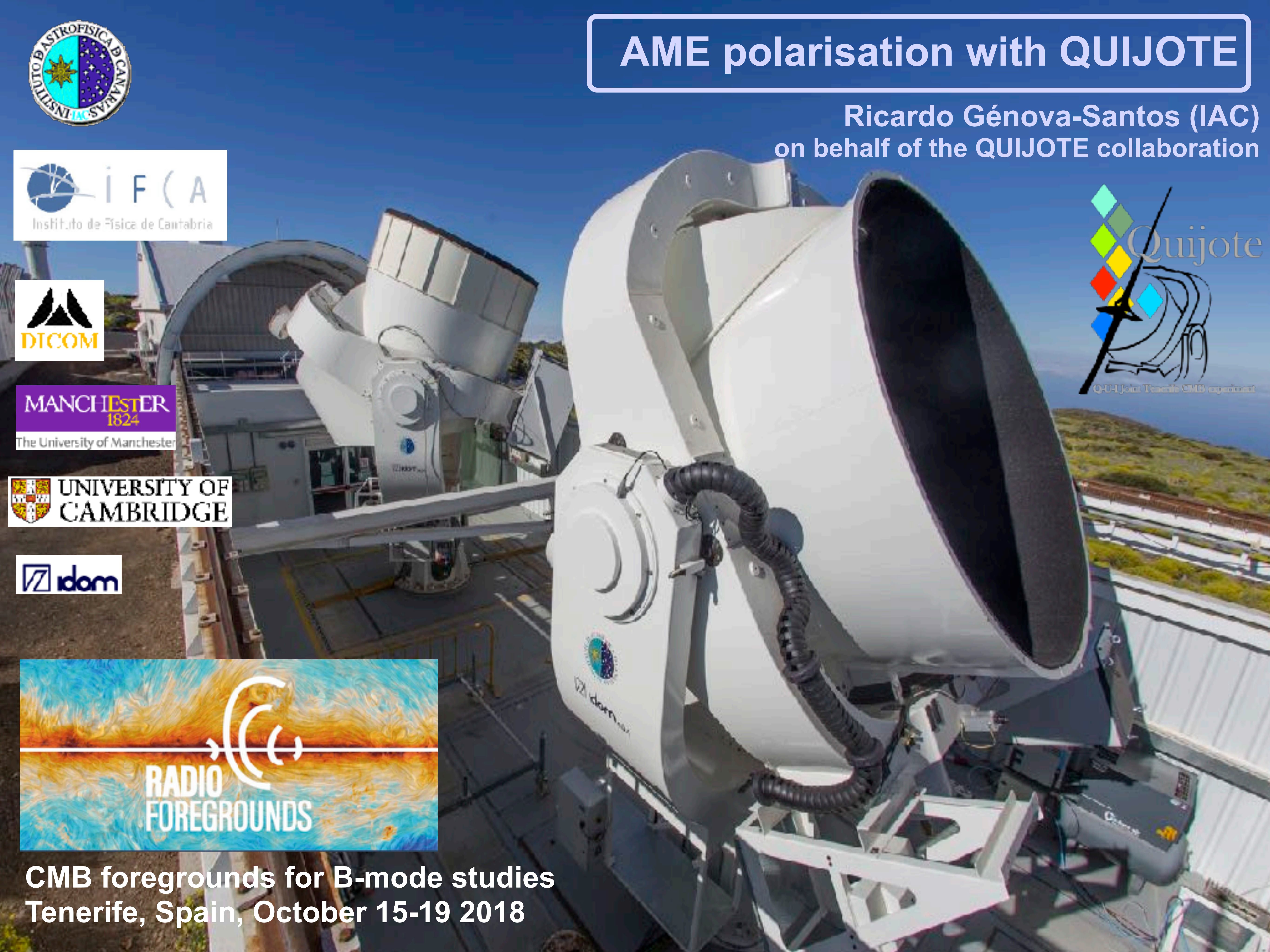
on behalf of the QUIJOTE collaboration

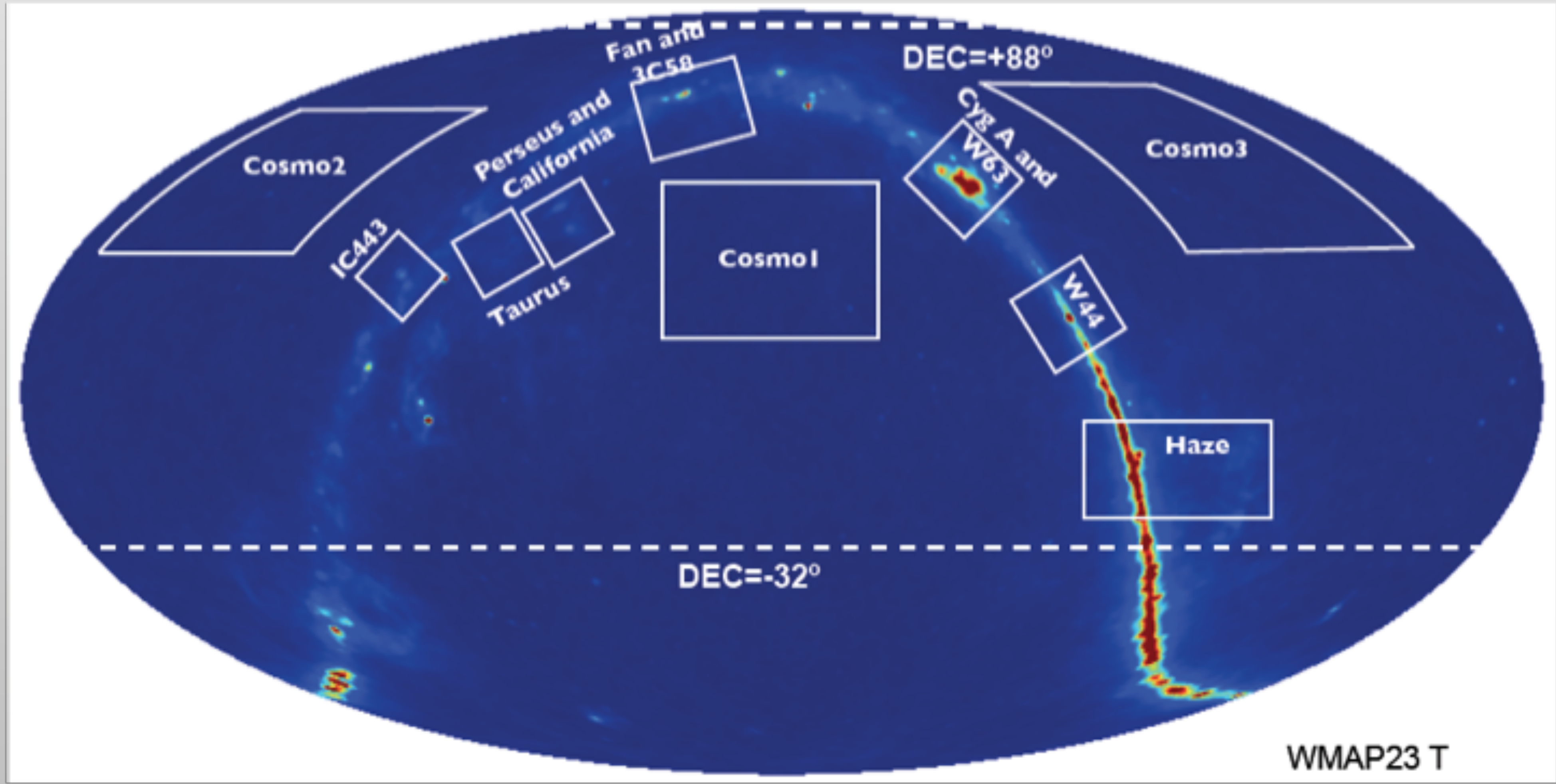


CMB foregrounds for B-mode studies
Tenerife, Spain, October 15-19 2018

Overview

★*QUIJOTE scientific results I. Measurements of the intensity and polarisation of the anomalous microwave emission in the Perseus molecular complex*. Génova-Santos et al. 2015, MNRAS, 452, 4169

★ *QUIJOTE scientific results II. Polarisation measurements of the microwave emission in the Galactic molecular complexes W43 and W47 and supernova remnant W44*. Génova-Santos et al. 2017, MNRAS, 464, 4107



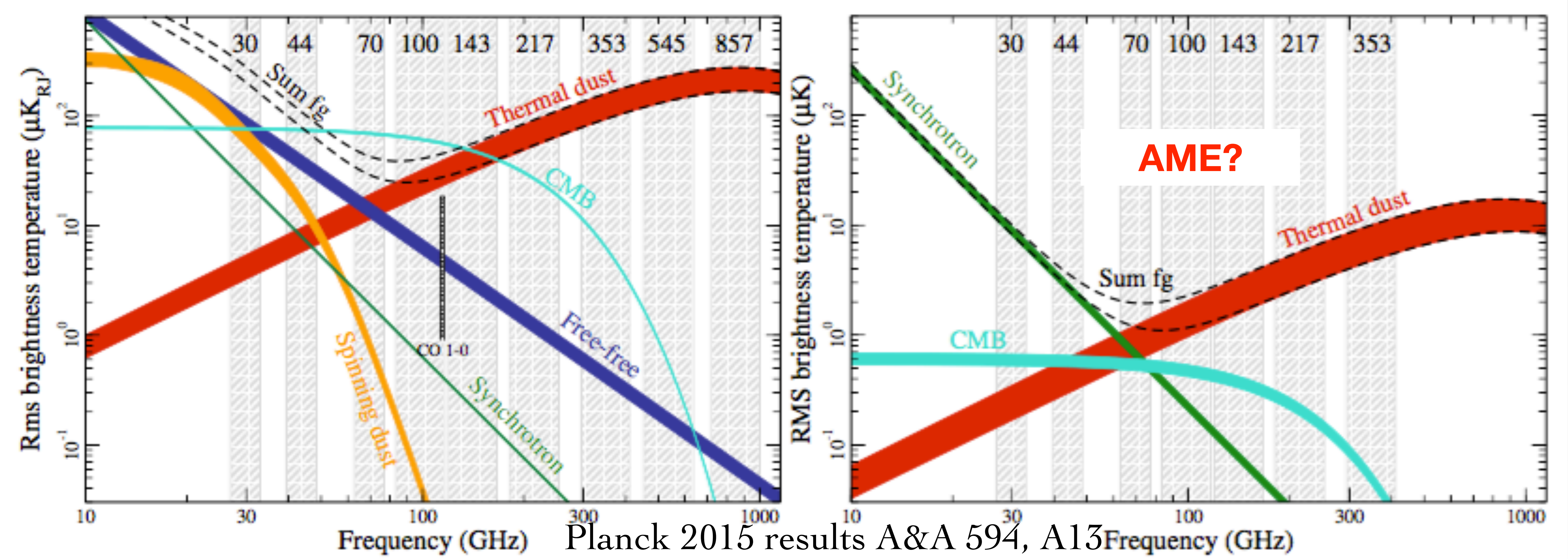
CMB foregrounds in polarisation

★ Synchrotron: maximum polarisation fractions of the order of 50%, on average ≈10-25%

★ Thermal dust: up to 20%, on average ≈10% (Planck Intermediate Results IXX, 2015)

★ Free-free: ideally could be up to 10% on the borders of HII regions, due to Thomson scattering. But these are smooth, and typically <1%

★ AME: ?

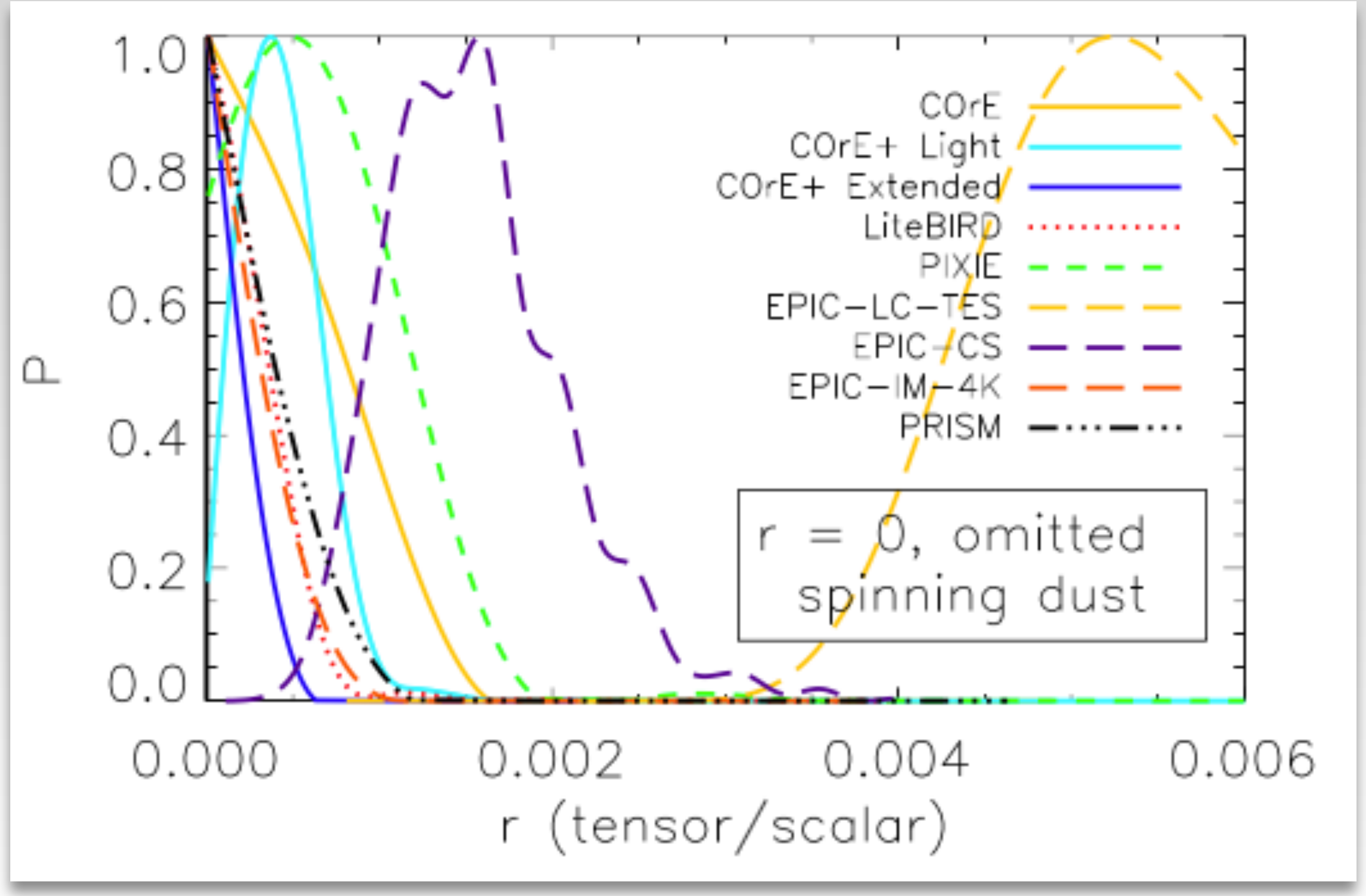


Planck 2015 results A&A 594, A13

Impact of ignoring the AME

★ We may not have to worry about AME in polarisation

- But ignoring an AME component with Π=1% may lead to significant biases in r (Remazeilles et al. 2016)



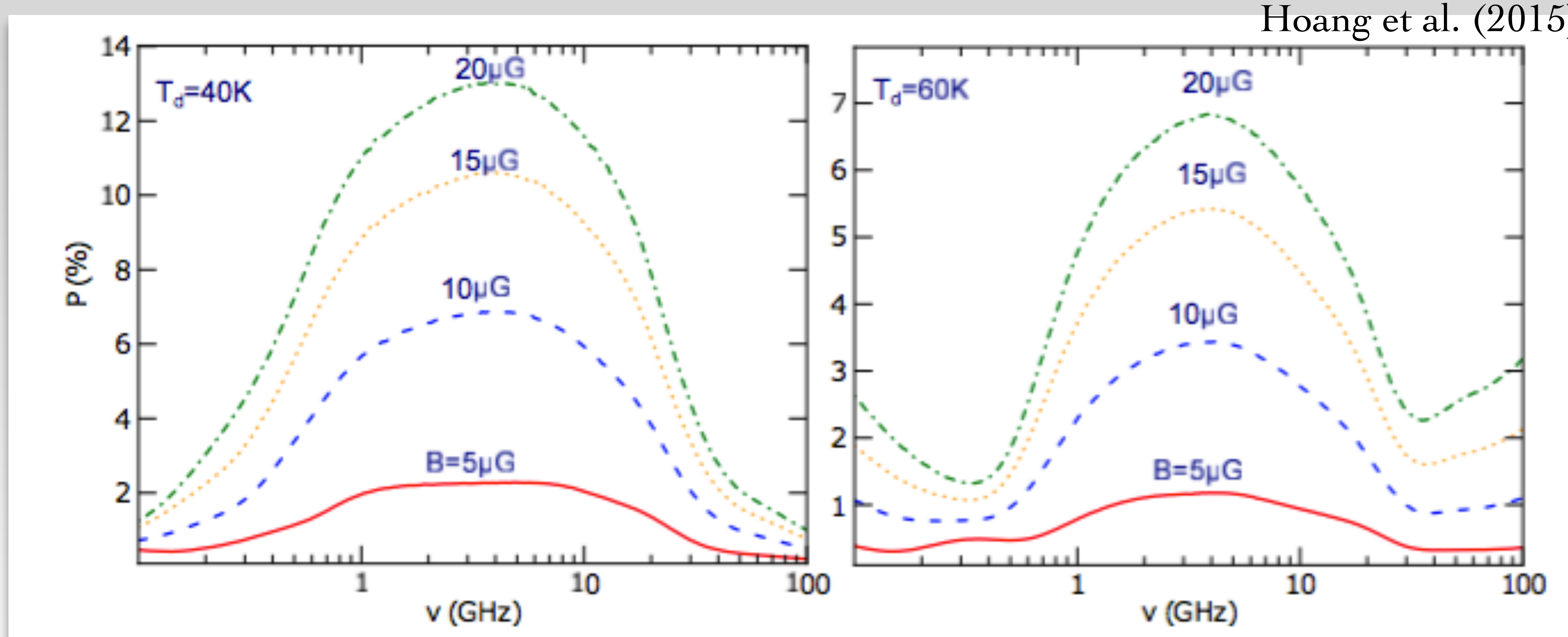
(Remazeilles et al. 2016)

Anomalous Microwave Emission - Models

★ Models of AME in polarisation:

- Spinning dust polarisation typically predicted to be very low
- Lazarian & Draine (2000): 6-7% at 2-3 GHz, 4-5% at 10 GHz
- Hoang et al. (2013): peak of **1.5% at 3 GHz**, dropping at higher frequencies. Slightly higher values for strong magnetic fields (Hoang et al. 2015)

Hoang et al. (2015)



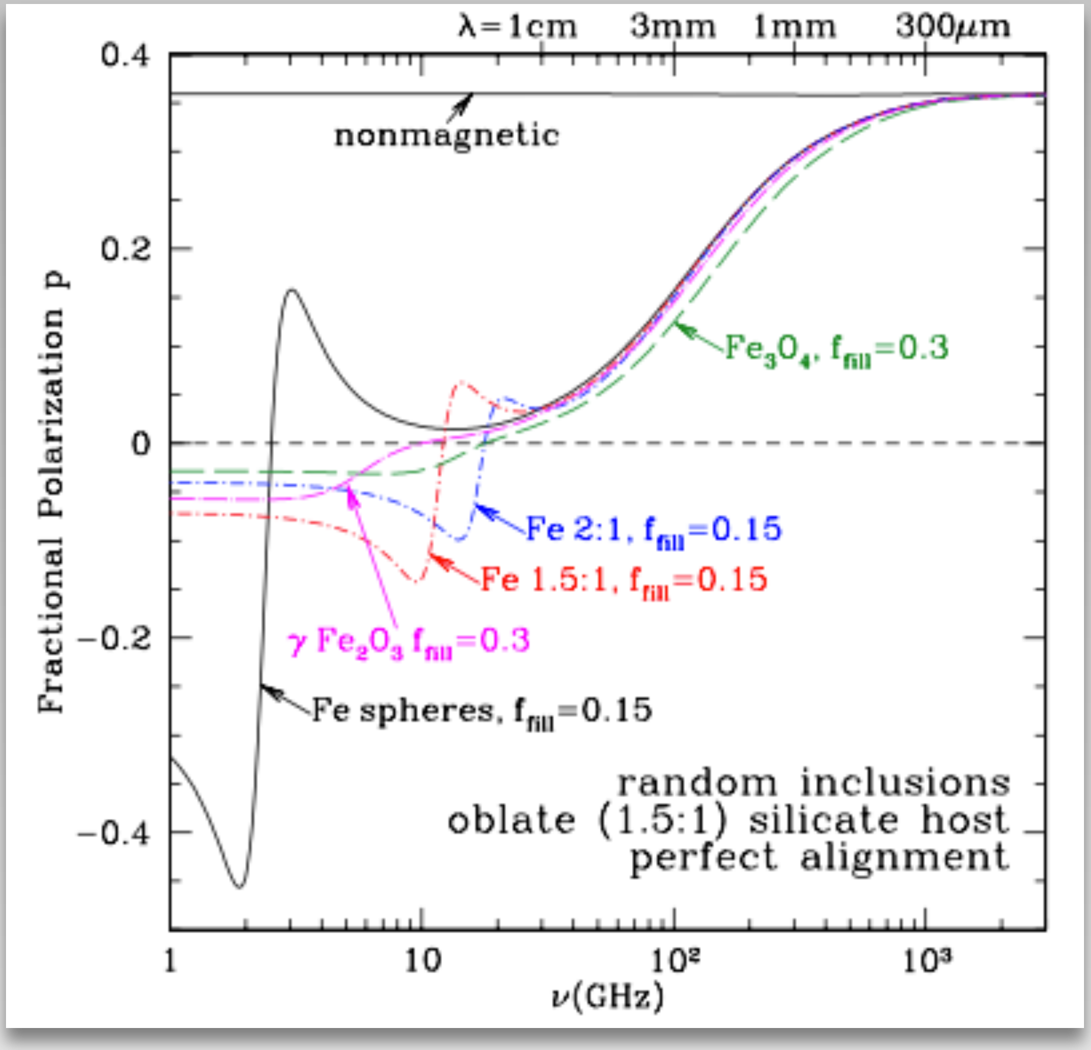
- Difficult to predict. Many free parameters!
- Also: Draine & Hensley (2016) suggested that quantum dissipation of alignment will lead to practically zero polarisation

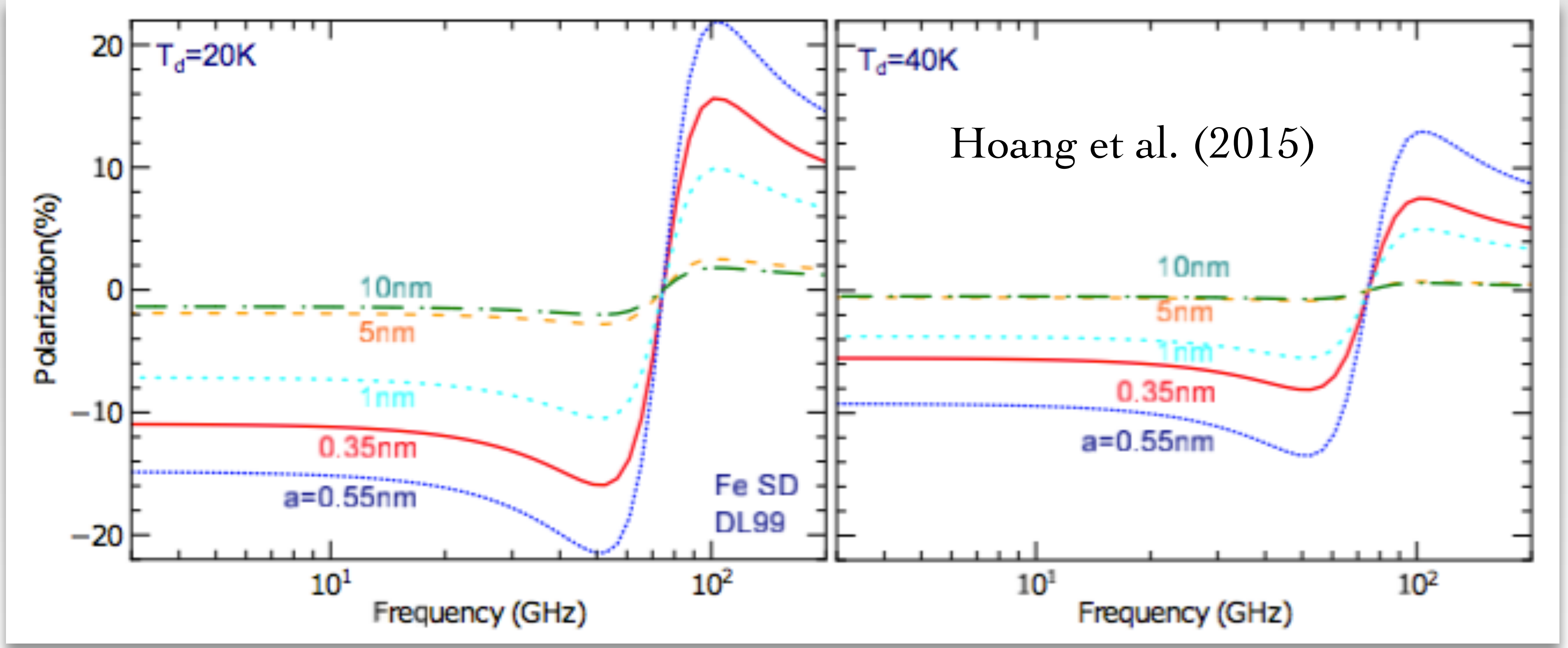
Anomalous Microwave Emission - Models

Draine & Hensley (2013)

★ Models of AME in polarisation:

- Magnetic dust polarisation expected to be higher
- Up to 40 % if grains are oriented in a single magnetic domain (Draine & Lazarian 1999)
- More realistic model with randomly oriented magnetic inclusions predict lower levels, **<5%** at 10-20 GHz (Draine & Hensley 2013)
- Also lower levels found by Hoang et al. (2015)



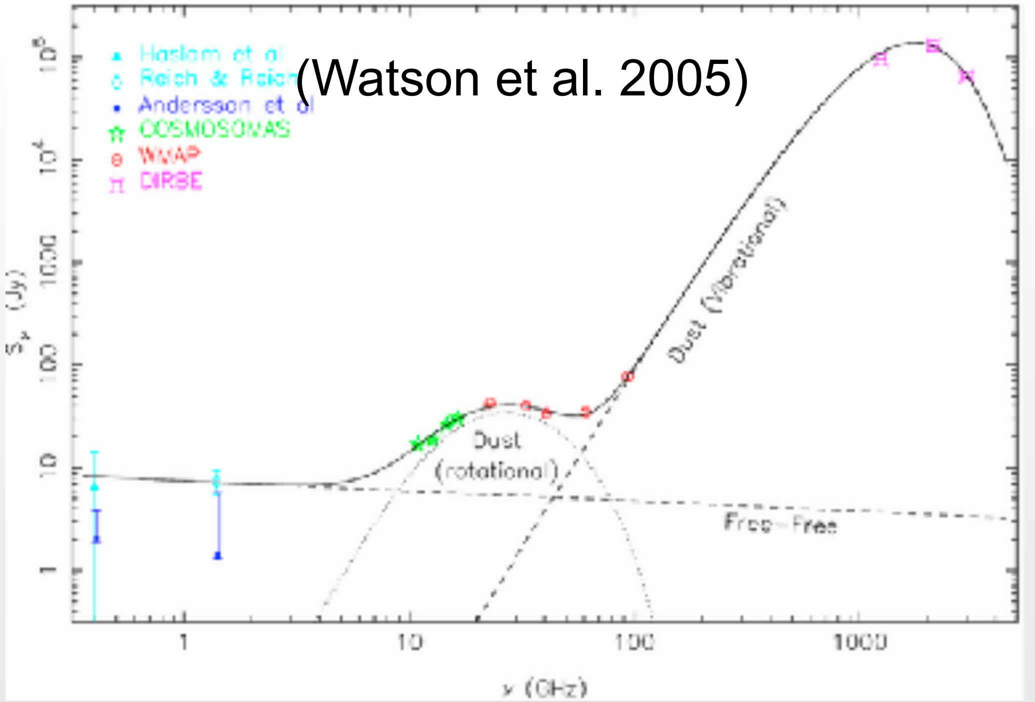


- Again, difficult to predict! These models contain many underlying assumptions

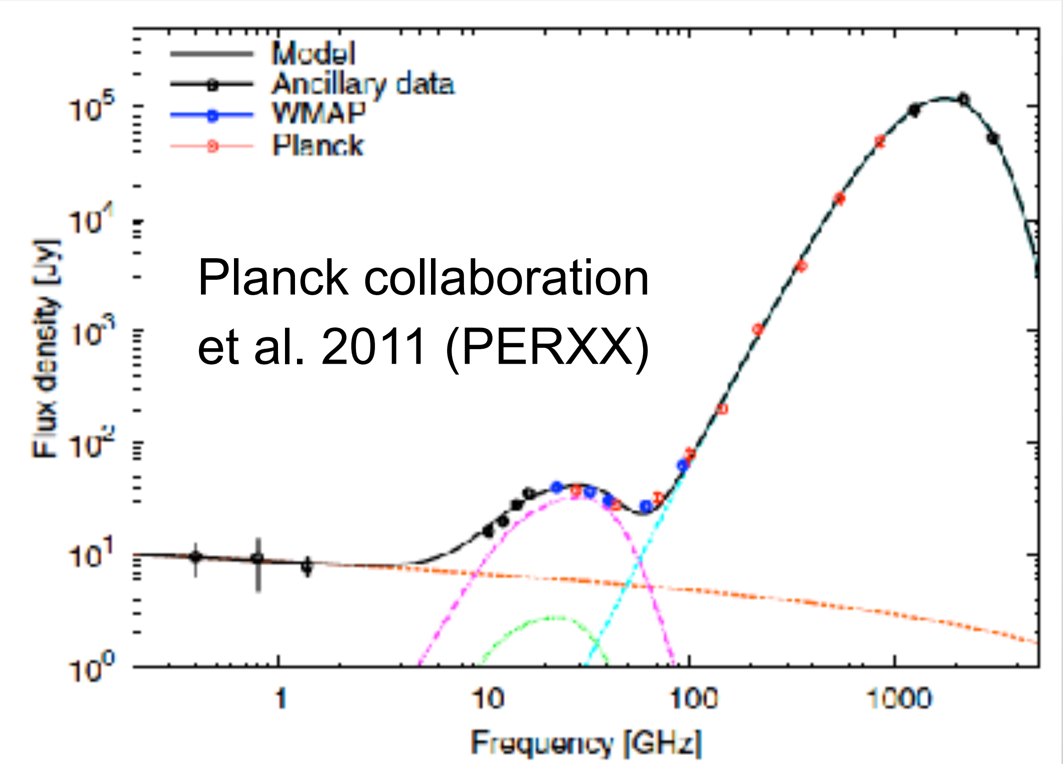
G159.6-18.5 - Perseus MC

★ Perseus molecular cloud complex - giant molecular cloud ($1.3\times10^4\ M_\odot$) at 260 pc, subtending 6º×2º, and including 6 dense cores: B5, IC348, B1, NGC1333, L1455 and L1448 (Cernicharo et al. 1985)

- ★ Contribute dust-correlated emission in the Tenerife experiment at 10 and 15 GHz (de Oliveira-Costa et al. 1999)
- ★ Confirmed by Watson et al. (2005) using data from the COSMOSOMAS experiment at 11-17 GHz
- ★ Using VSA data at 33 GHz Tibbs et al. (2010) found that most of the emission is diffuse
- ★ Tibbs et al. (2011,2013) combining Spitzer and AMI concluded that AME may be originated in small grains rather than in PAHs
- ★ Planck data (Planck collaboration, PERXX 2011, also PIPXV 2014) confirmed the AME nature



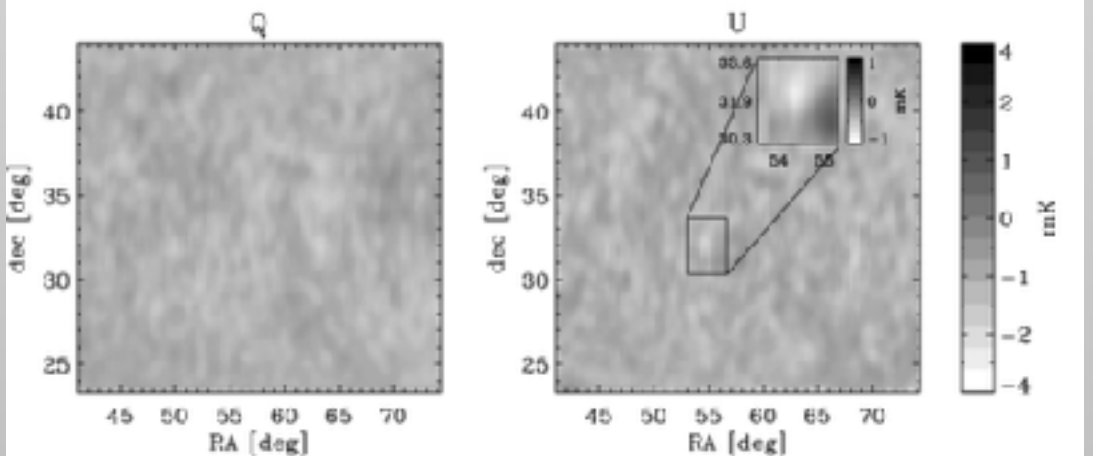
(Watson et al. 2005)



Planck collaboration et al. 2011 (PERXX)

★ Polarisation constraints:

- Battistelli et al. (2006) found marginal polarisation with $\Pi = 3.4\pm1.7$ % at 11 GHz, using COSMOSOMAS
- Upper limits from WMAP 23 GHz, $\Pi < 1\%$ (95% CL) (López-Caraballo et al. 2011, Dickinson et al. 2011)



Battistelli et al. (2006)

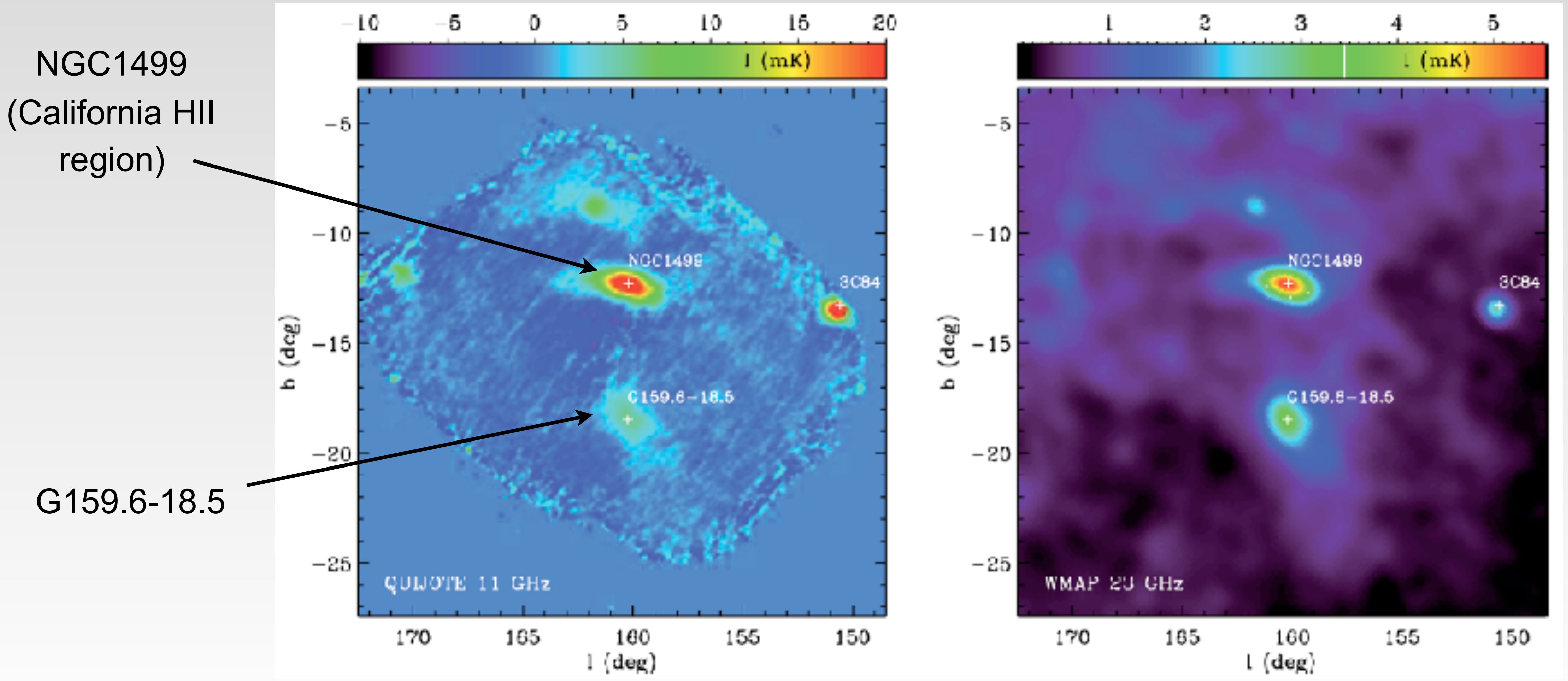
QUIJOTE observations on the Perseus MC

★ QUIJOTE observations (IQU) in four bands: 11.2, 12.9, 16.7 and 18.7 GHz (0.87º and 0.65º FWHM)

★ 194 h of data (23% removed) between 2012 December and 2013 April

★ 50×10^3 raster scans at constant EL and ΔAZ=12º

★ Final map-sensitivity: $\sigma_I \approx 95$ μK/deg^2, $\sigma_{Q,U} \approx 25$ μK/deg^2



Génova-Santos et al. (2015)

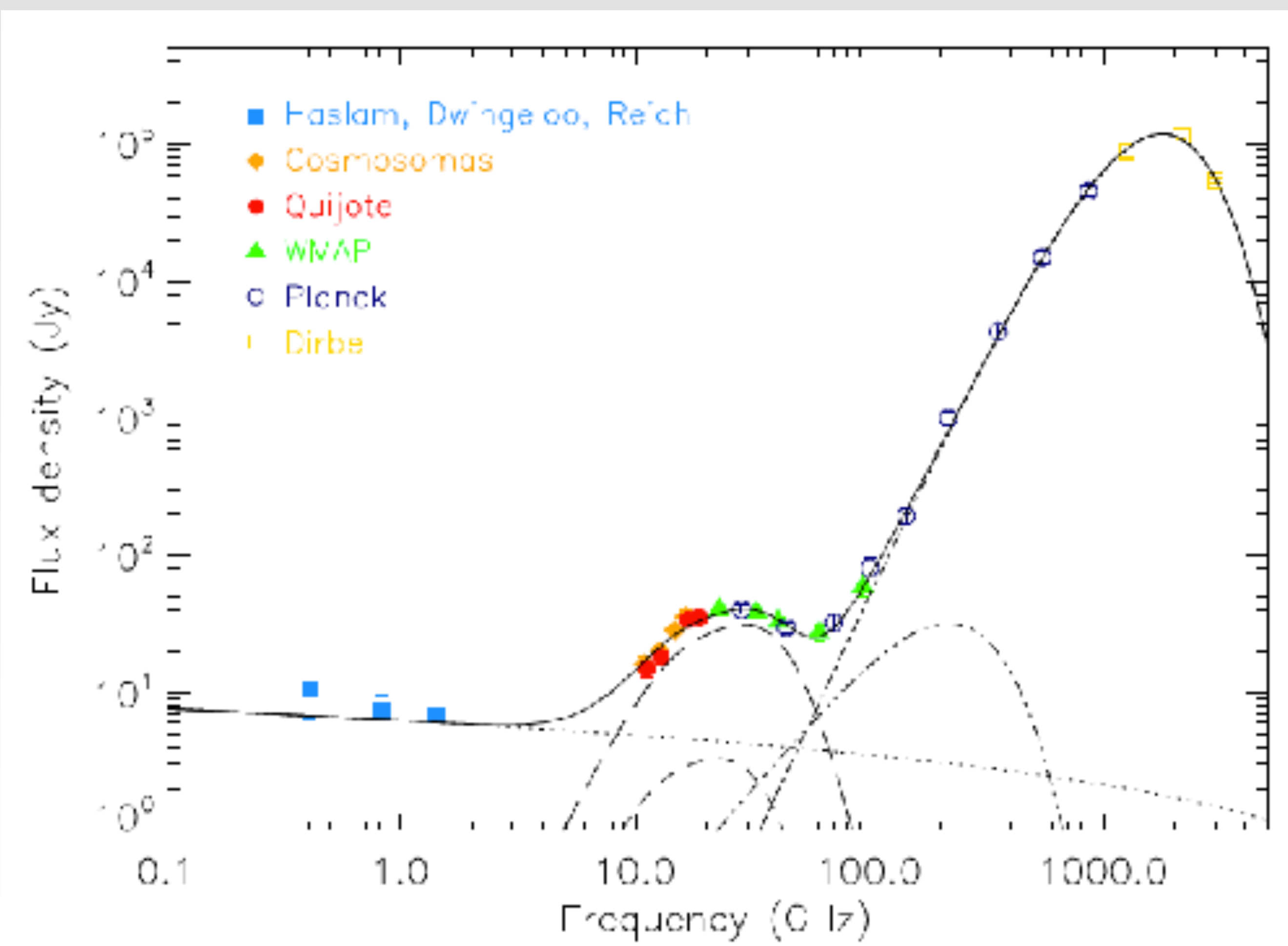
QUIJOTE observations on the Perseus MC

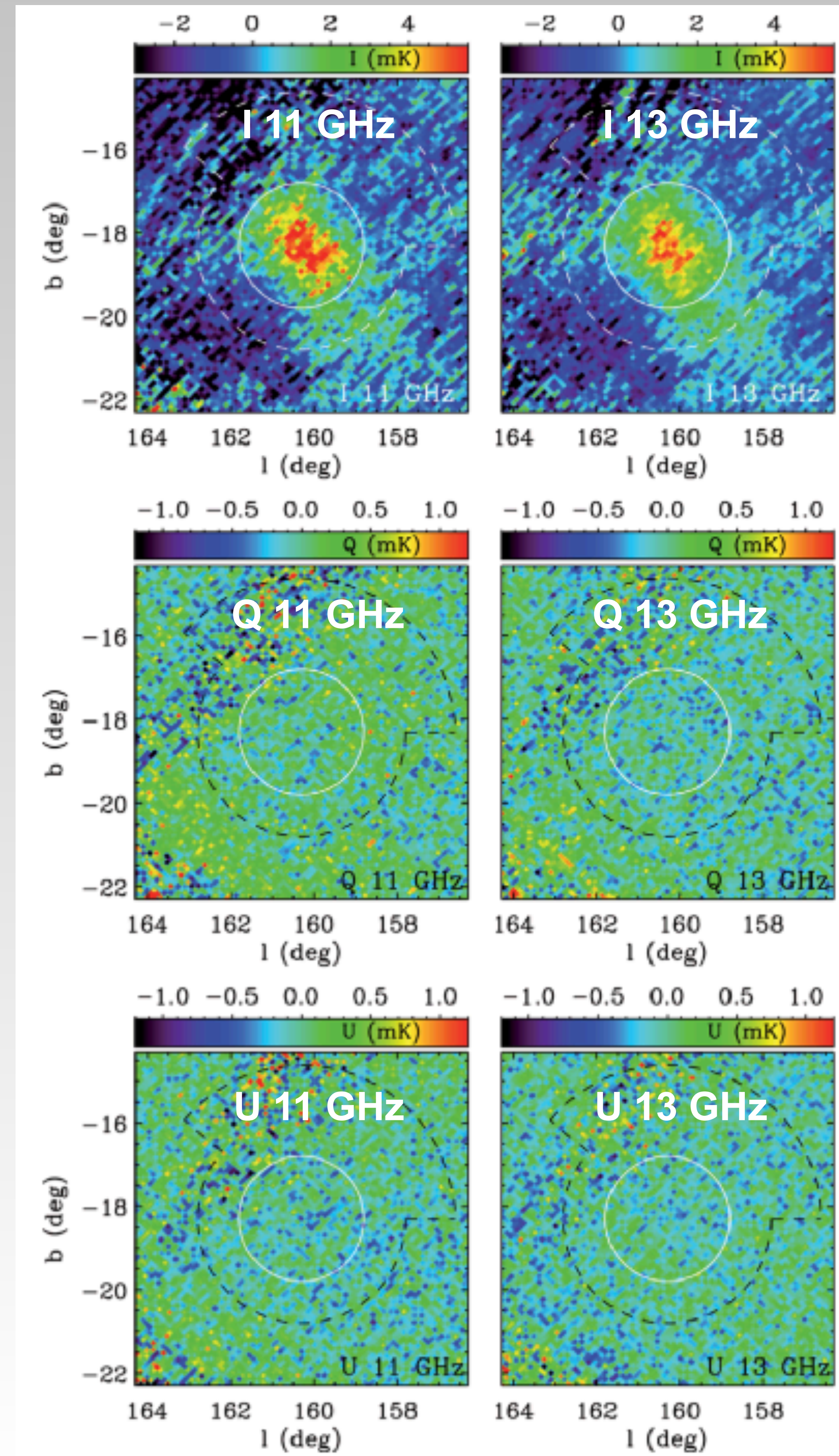
Génova-Santos et al. (2015)

★ Fitted SED consistent with spinning dust (high-density molecular phase component plus low-density atomic phase component)

★ Polarisation constraints:

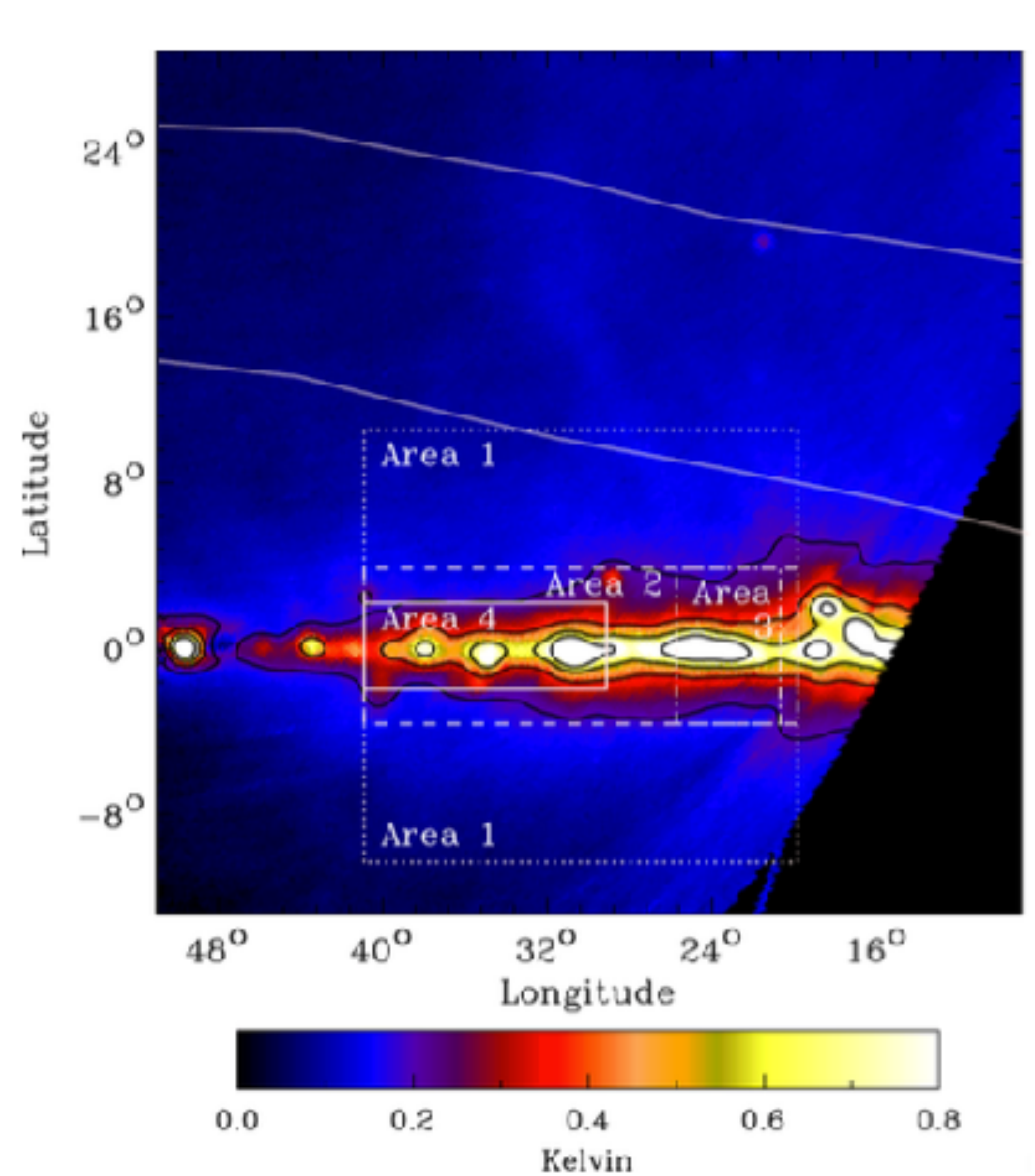
- $\Pi_{AME} < 6.3\%$ at 12 GHz (95% CL)
- $\Pi_{AME} < 2.8\%$ at 18 GHz (95% CL)



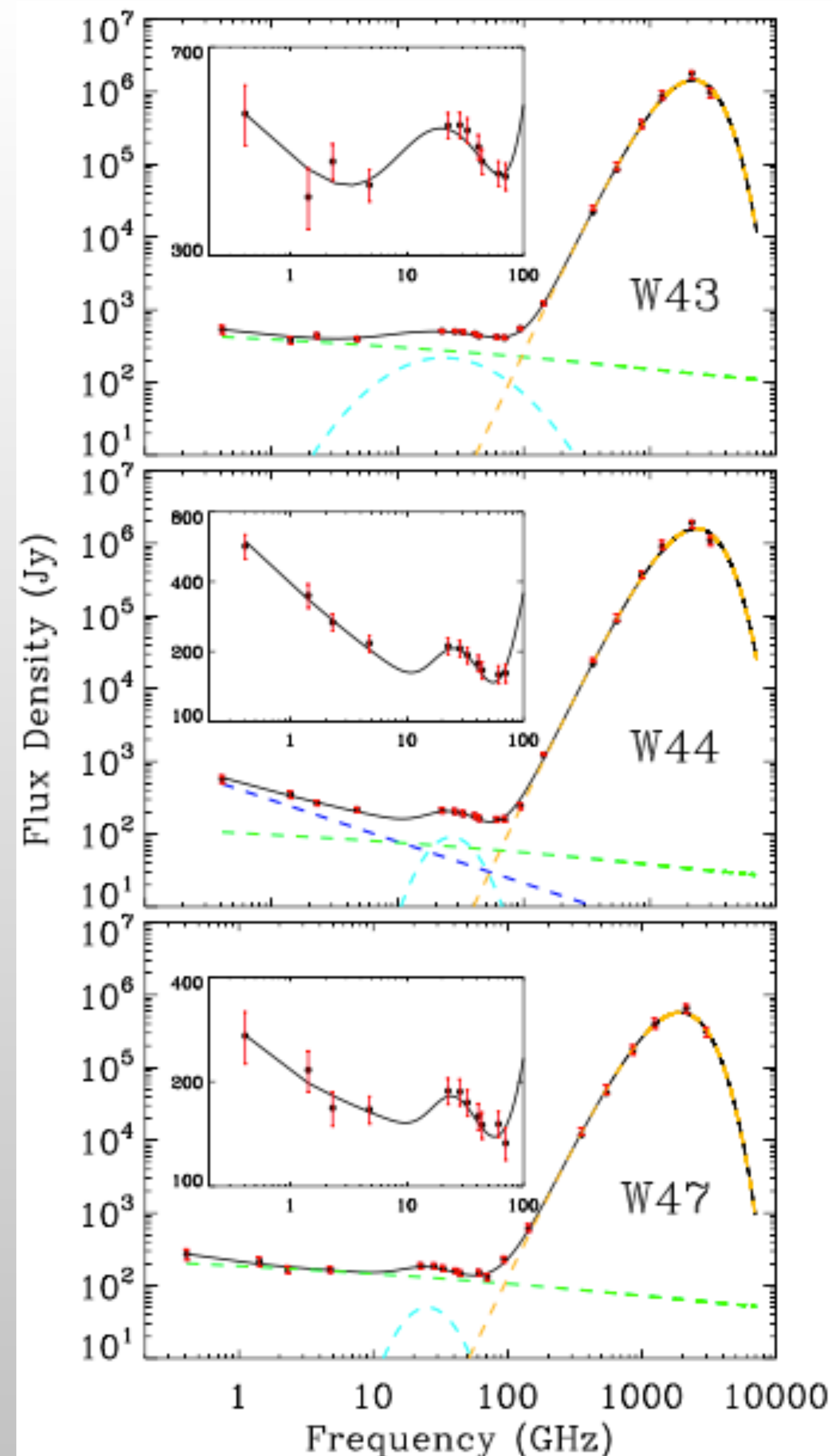


QUIJOTE observations on W43, W44, W47

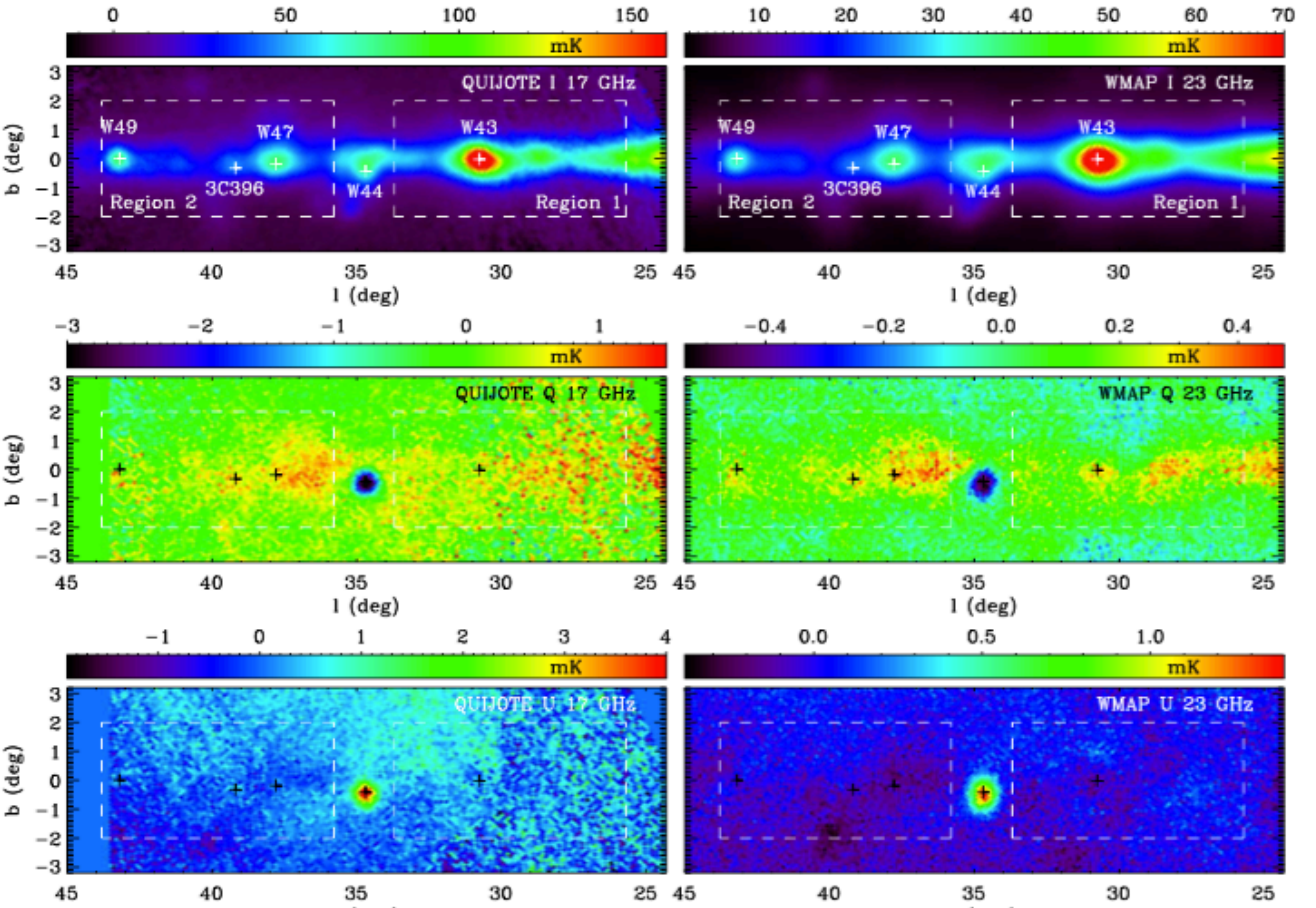
★ Previous study by CBASS at 5 GHz in the molecular complexes W43 and W47 and SNR W44 (Irfan et al. 2015)



(Irfan et al. 2015)



QUIJOTE maps



Intensity SEDs

★ Aperture photometry around each source, 60/80/100 arcmin

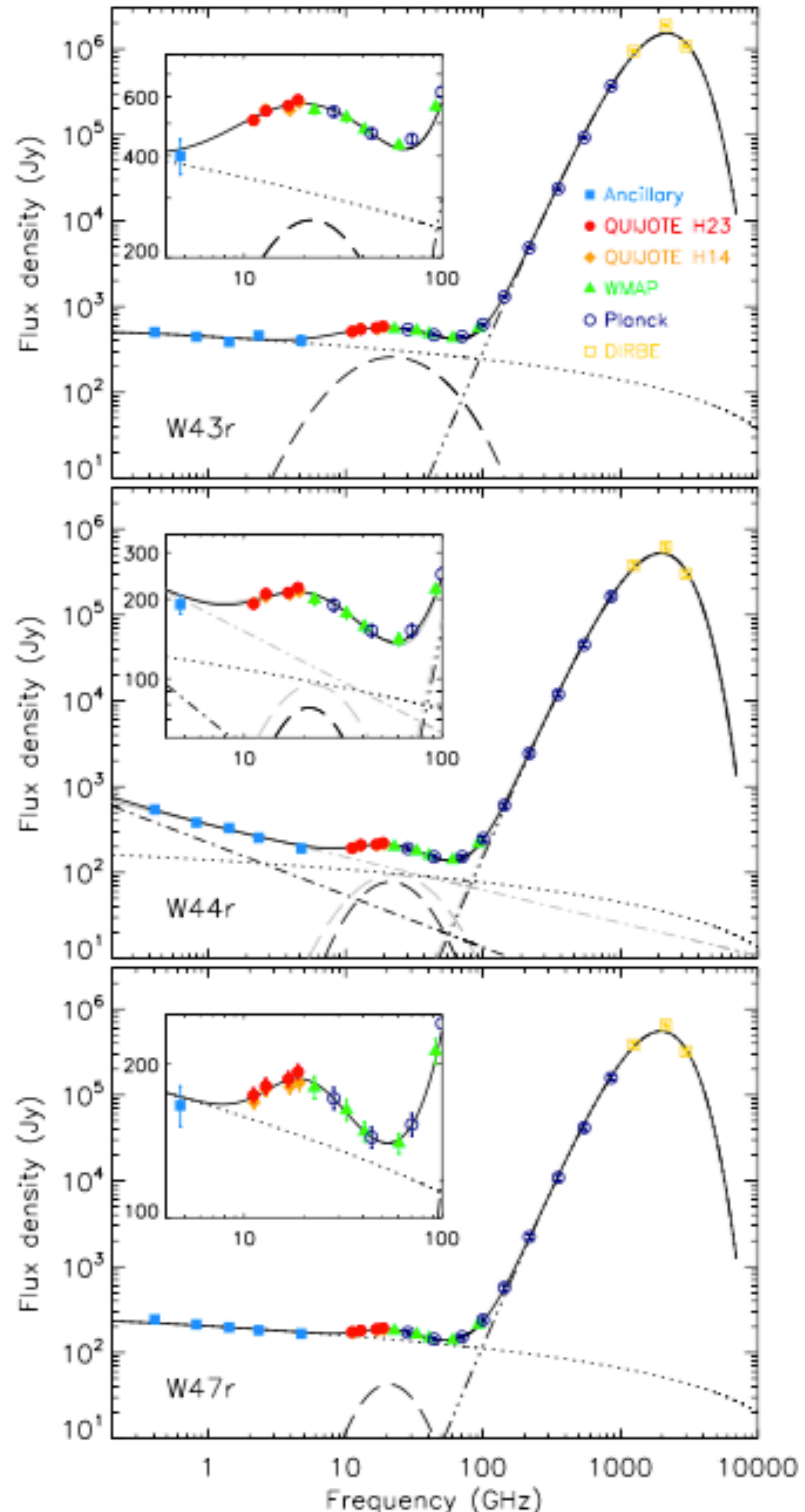
★ Fitted AME with Bonaldi et al. (2007) model

Region	S_{AME} (Jy)	*EM* ($cm^{-6}pc$)	χ^2/dof
W43	258 ± 7	3911 ± 68	5,4
W44	78 ± 6	1264 ± 22	1
W47	43 ± 2	1849 ± 20	1

★ Estimates of the EM from Commander or from RRL (Alves et al. 2012)

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

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



Intensity SEDs

★ Improve of the best-fit parameters once the QUIJOTE data are included:

	W43r		W44r		W47r	
Parameter	With QUIJOTE	Without	With QUIJOTE	Without	With QUIJOTE	Without
EM (cm^{-6} pc)	3911 ± 68	3882 ± 126	1264 ± 22	999 ± 42	1849 ± 20	1854 ± 37
$S_{\rm sync}^{\rm 1GHz}$ (Jy)	–	–	222 ± 7	255 ± 9	–	–
$\beta_{\rm sync}$	–	–	-0.61 ± 0.04	-0.52 ± 0.04	–	–
m_{60}	1.56 ± 0.36	1.18 ± 0.51	3.38 ± 1.36	2.64 ± 3.85	5.21 ± 1.41	5.75 ± 1.16
$\nu_{\rm AME}^{\rm peak}$ (GHz)	22.2 ± 1.1	20.5 ± 6.0	21.4 ± 1.0	23.7 ± 6.7	20.7 ± 0.9	22.6 ± 2.7
$S_{\rm AME}^{\rm peak}$ (Jy)	258.1 ± 6.9	260.3 ± 15.9	77.7 ± 5.5	73.3 ± 9.2	42.8 ± 2.3	39.7 ± 5.6
$\beta_{\rm dust}$	1.75 ± 0.05	1.78 ± 0.06	1.75 ± 0.04	1.74 ± 0.05	1.87 ± 0.04	1.87 ± 0.05
$T_{\rm dust}$ (K)	22.2 ± 0.7	22.0 ± 0.7	20.1 ± 0.4	20.2 ± 0.5	19.6 ± 0.4	19.6 ± 0.5
τ_{250} ($\times 10^{-3}$)	4.02 ± 0.50	4.18 ± 0.55	2.25 ± 0.21	2.21 ± 0.24	2.49 ± 0.23	2.49 ± 0.26
$\chi^2_{\rm red}$	5.4 (0.9)	6.5 (1.3)	1.0 (0.3)	1.4 (0.4)	1.0 (0.3)	1.3 (0.4)

★ Error bars on EM and $S_{\rm AME}$ are improved by a factor ~2

★ Error bars on the AME peak frequency better by a factor ~6

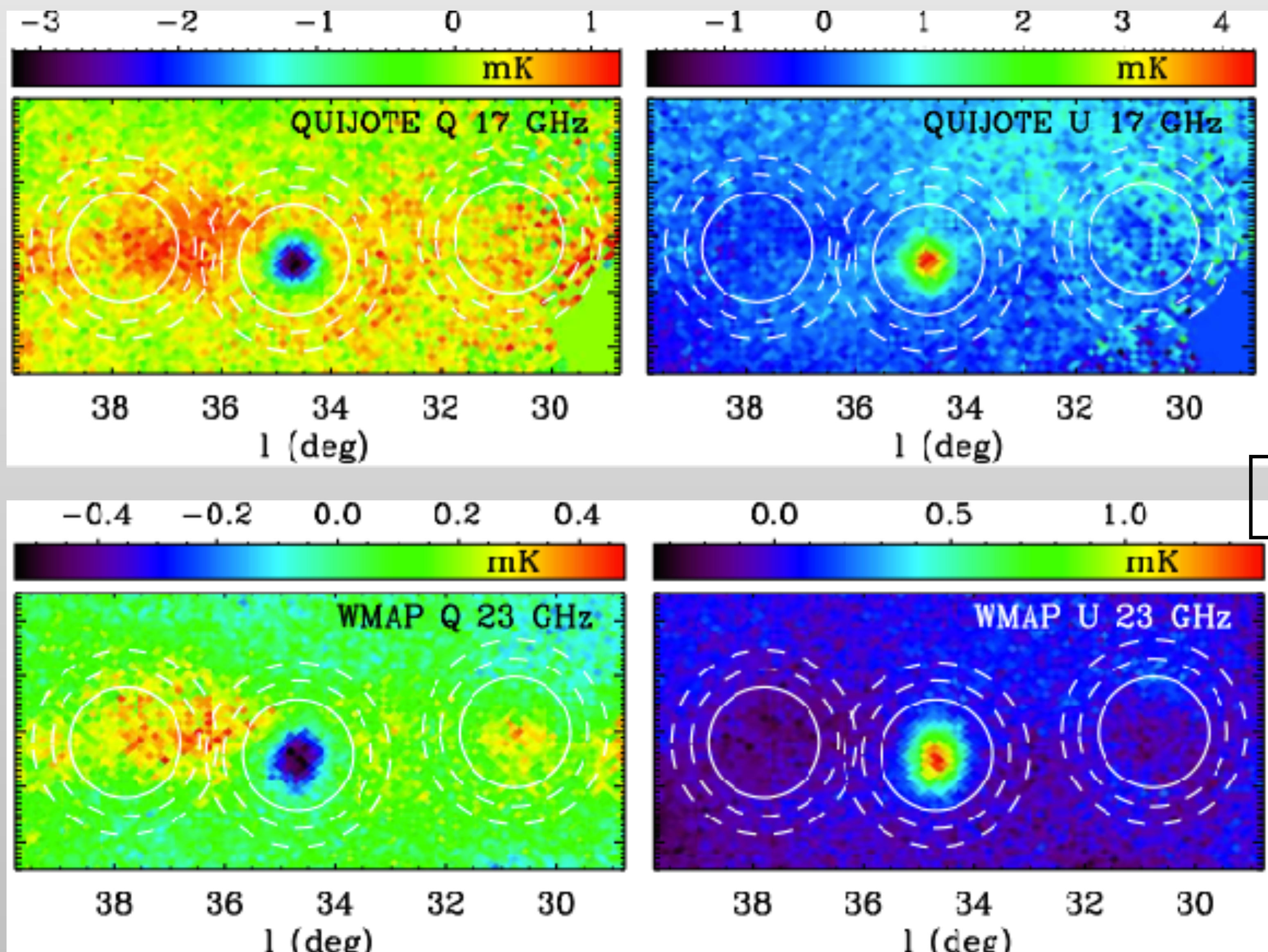
Upper limits on the polarisation of W43

★ Maps consistent with zero polarisation 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)

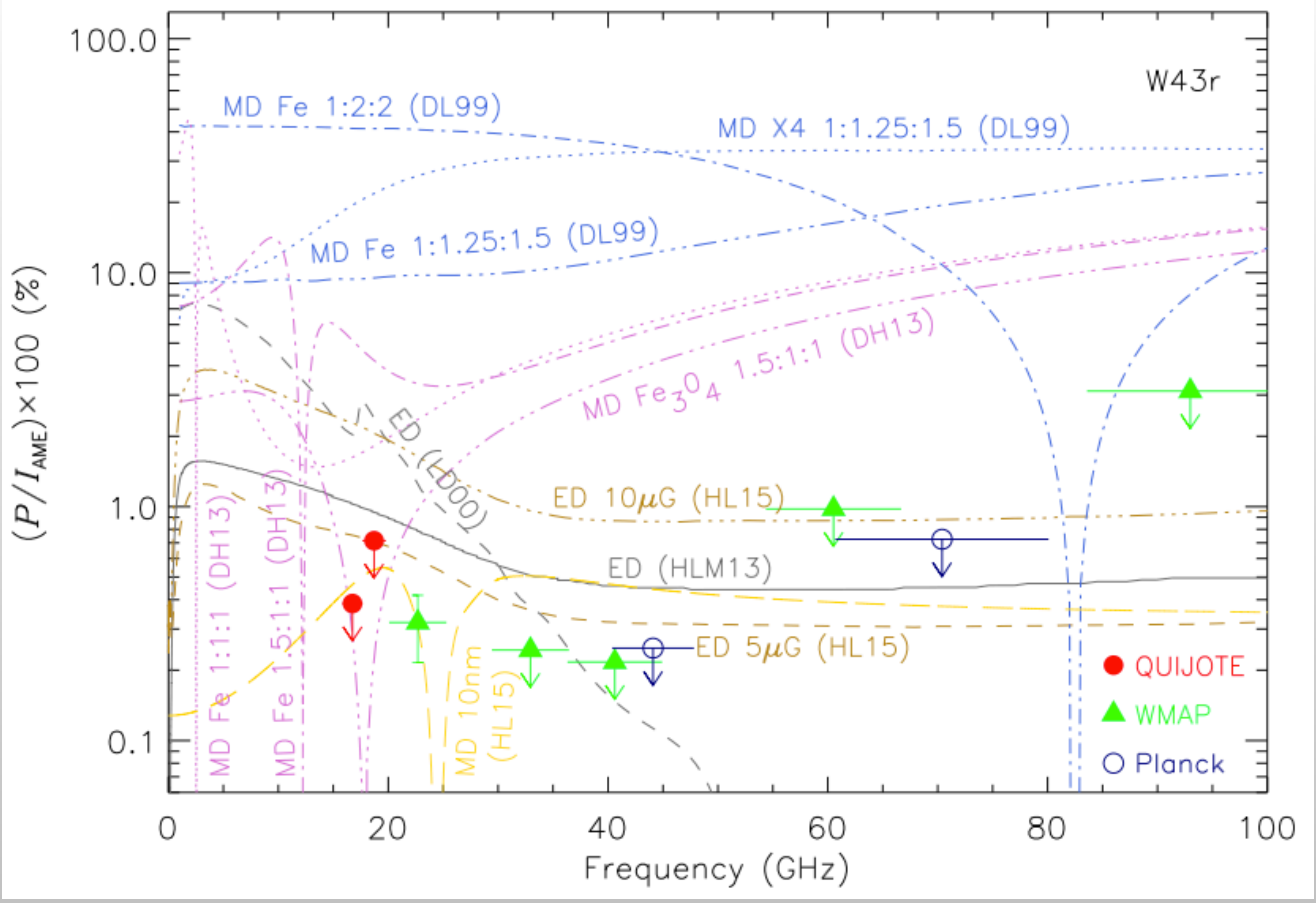
★ Improve by a factor more than 4 on previous best constraints (Π_{AME} < 1% from López-Caraballo et al. 2011 and Dickinson et al. 2011)



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 the models:



Conclusions

★ QUIJOTE MFI instrument brings intensity and polarisation data in four new frequencies (11, 13, 17 and 19 GHz) relevant for AME studies. Useful for:

- Improving the modelling of the AME in intensity, together with a better determination of the free-free and synchrotron
- Improve polarisation upper limits

★ Improves the separation of free-free, synchrotron and AME provided by Commander

★ Improve the determination of SD parameters by a factor up to 6

★ Together with WMAP allows to derive the most stringent constraints to-date on the AME polarisation ($\Pi_{AME} < 0.39\%$ at 18.7 GHz and $<0.22\%$ at 40.6 GHz) in W43 - improve by a factor >4 over previous constraints, and set constraints on the models