AME observations with COSMOSOMAS

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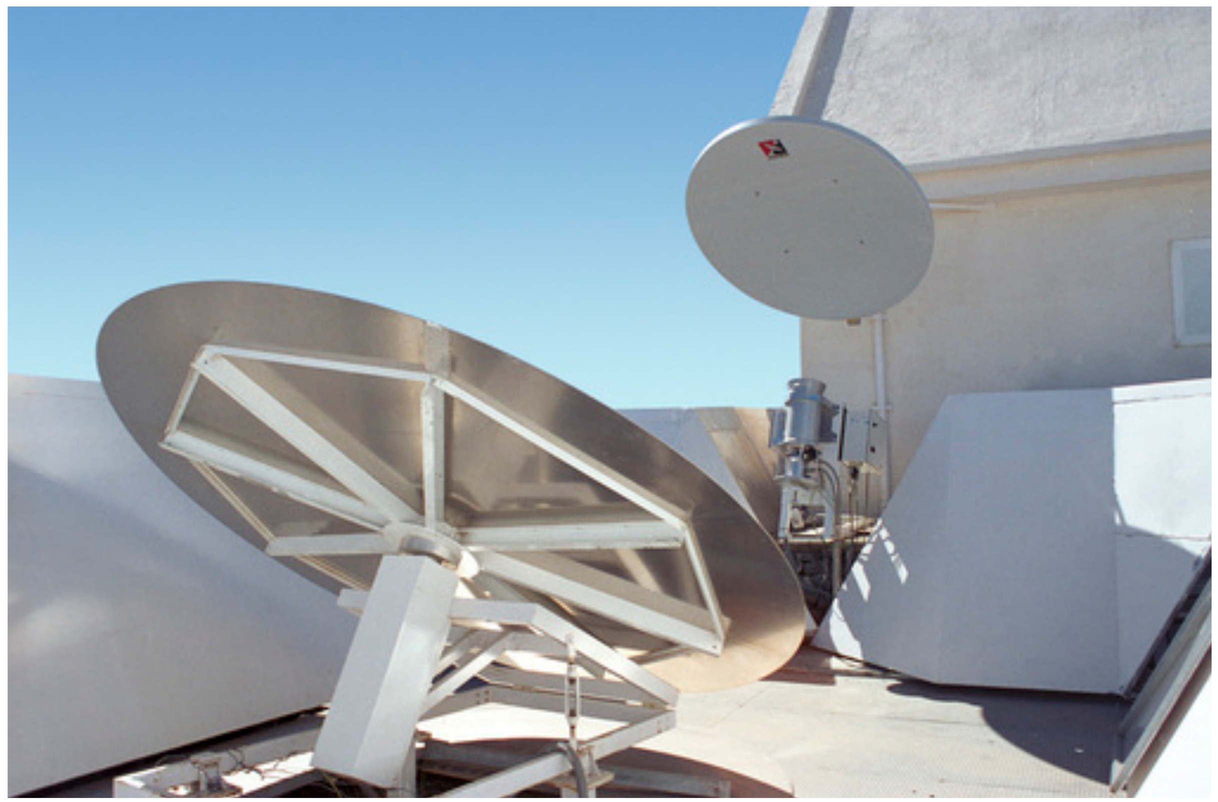
Outline

1. The COSMOSOMAS experiment
2. COSMOSOMAS observations of AME in diffuse regions (Fernández-Cerezo et al. 2006, Hildebrandt et al. 2007)
3. Perseus molecular complex
    - 3.1 First results. Total intensity (Watson et al. 2005)
    - 3.2 Polarization upper limit (Battistelli et al. 2006)
4. The Pleiades reflection nebula (Génova-Santos et al. 2011)
5. Cosmosomas AME observations in combination with Planck (Planck collaboration et al. 2011)
6. Other AME studies from the Teide observatory
7. The QUIJOTE-CMB experiment

http://www.iac.es/proyecto/cmb/cosmosomas

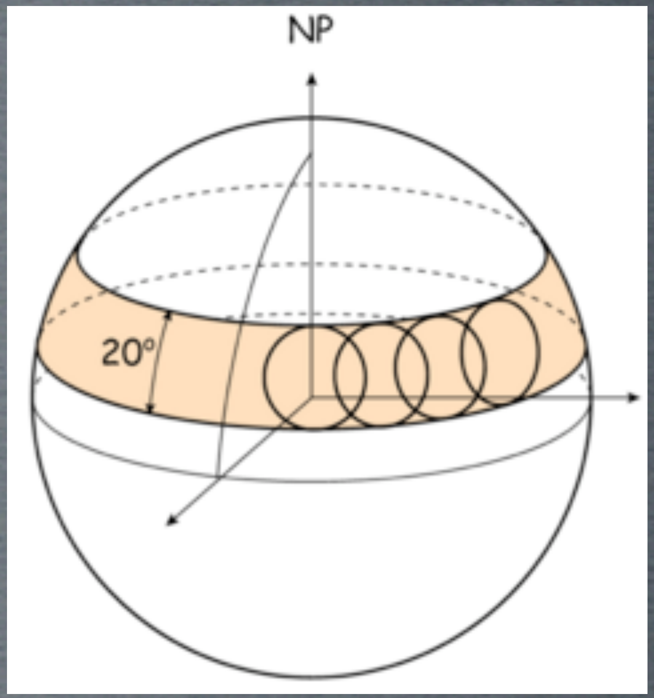
- Two circular scanning instruments
- Lock-in analysis to remove the first *7* harmonics to suppress *1/f* noise
- Located at the Teide Observatory, Tenerife. Altitutde: 2390 m. Operative: 1998-2008

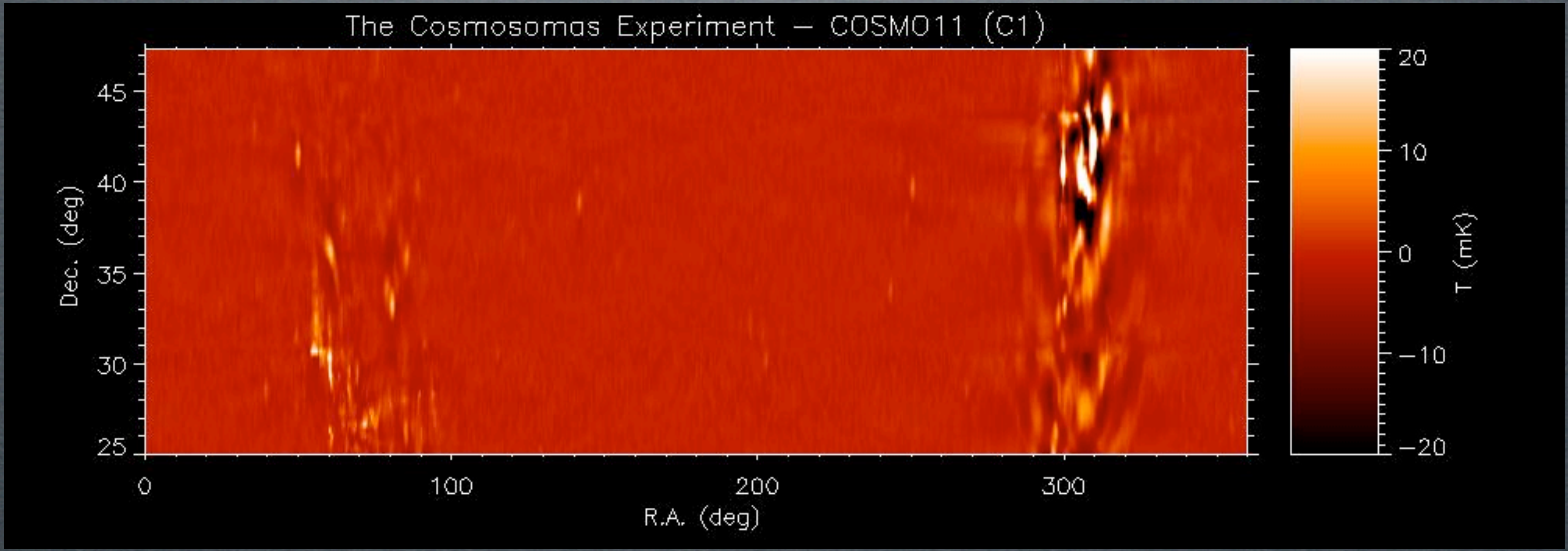
Instrument	Nchan	Freq (GHz)	Polarization	Primary diameter	Beam sizes (deg)	Sensitivity (μK/beam/
Cosmo11	2	10-12 (10.9)	Yes	2.5 m	0.9, 0.9	~650
Cosmo15	3	12-17 (12.7, 14.5 16.3)	No	3.0 m	1.0, 0.9, 0.8	~650, 750, 950



- Team members: R. Rebolo (PI), E. Battistelli, S. Fernández-Cerezo, J. Gallegos, R. Génova-Santos, C. Gutiérrez, S. Hildebrandt, R. Hoyland, J. Macías, J.A. Rubiño, R.A. Watson

- Scanning primary mirror, with a 5º tilt
- Circular path on the sky with a diameter of 20º
- 360º x 20º daily maps produced

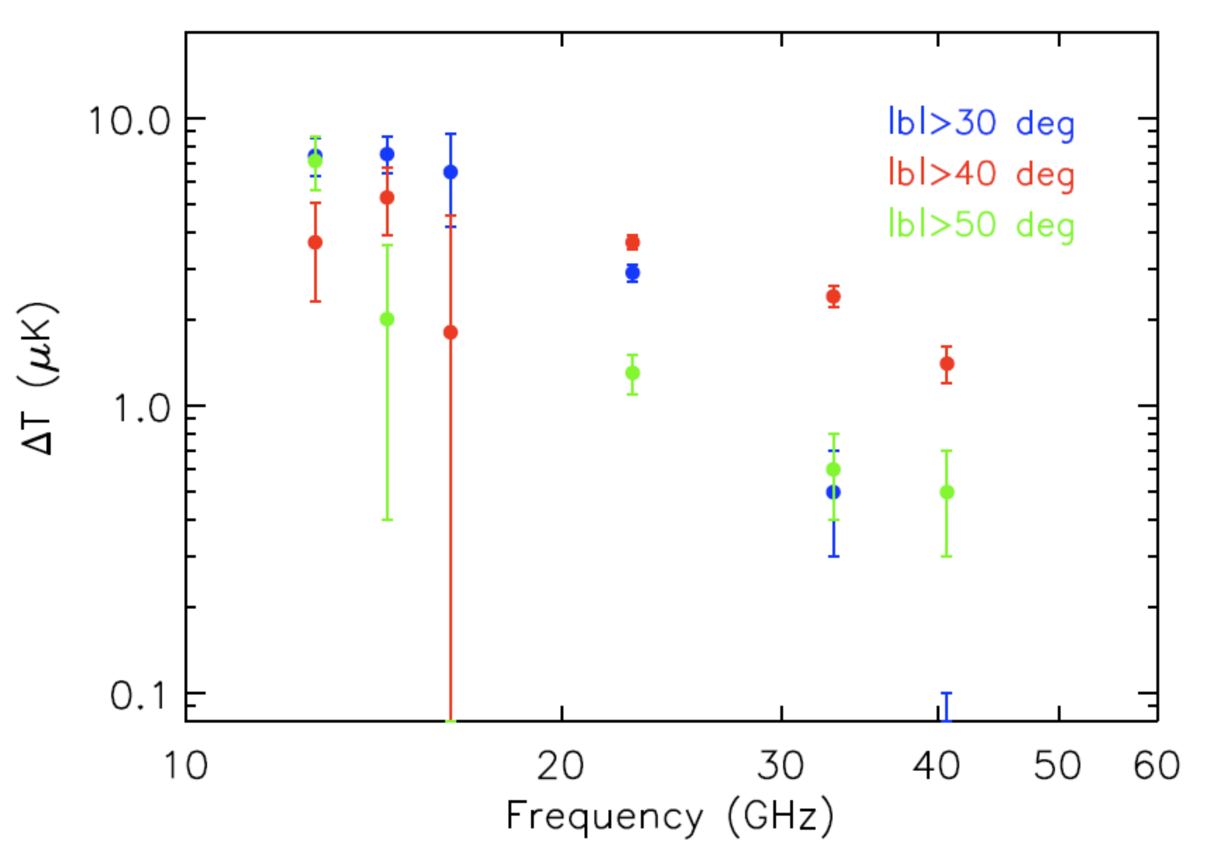




2006 COSMO15 results

- Clear correlated signals between COSMO15 channels and DIRBE maps at 100 and 240 μm over a region of 6500 deg^2 (Fernández-Cerezo et al. 2006)
- Average correlated signal 7.3 ± 0.7 μK and 5.0 ± 0.7 μK
- Signal decreases at high b
- DIRBE correlations with WMAP/COSMO15 increase with decreasing frequency. Flattening below ≈17 GHz

COSMO15/WMAP
correlations with DIRBE 100m



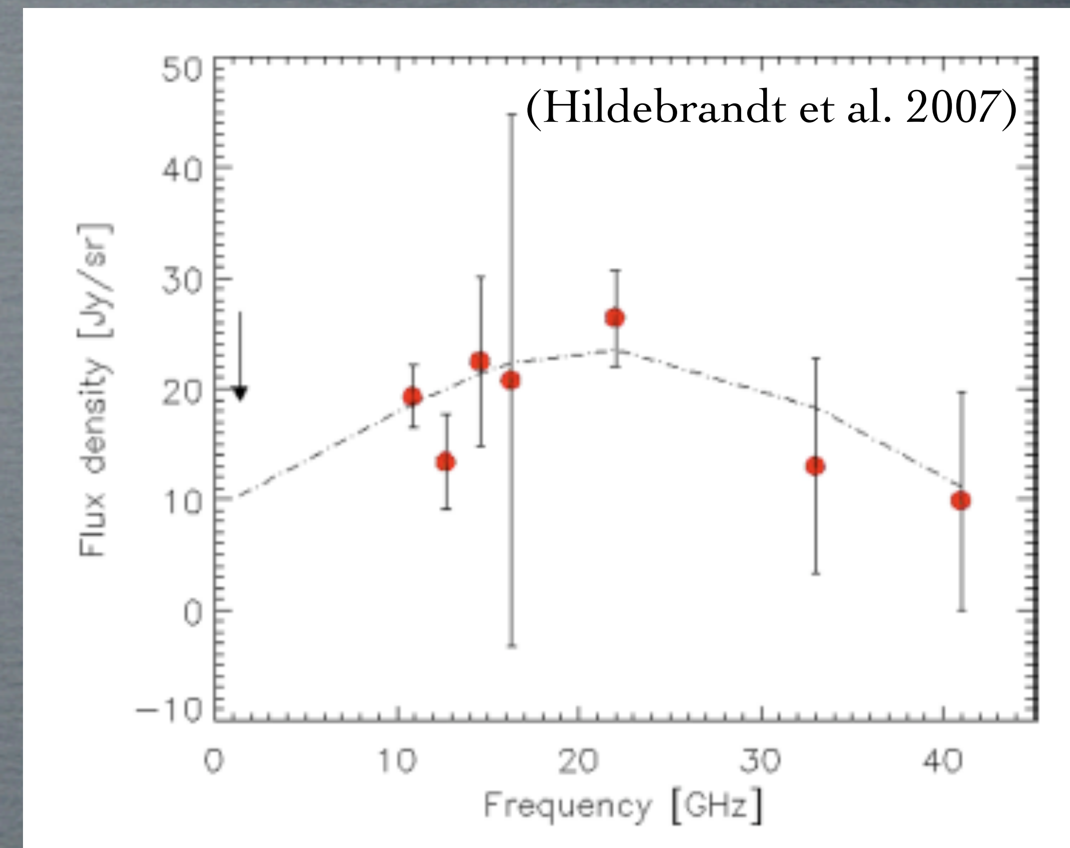
Template	σ Template	C1	C2	C3	*WMAP_K*	*WMAP_Ka*	*WMAP_Q*	*WMAP_V*	*WMAP_W*
				$\|b\| > 30°$					
408 MHz	4.88×10^5 μK	17.0 ± 1.1	12.3 ± 1.2	15.4 ± 2.4	4.7 ± 0.3	2.1 ± 0.3	1.7 ± 0.3	1.1 ± 0.3	0.6 ± 0.3
408 MHz (Dss)	4.79×10^5 μK	9.3 ± 1.1	8.7 ± 1.2	7.3 ± 2.4	3.7 ± 0.3	2.0 ± 0.3	1.8 ± 0.3	1.4 ± 0.3	1.1 ± 0.3
1420 MHz	2.54×10^4 μK	20.7 ± 1.1	13.7 ± 1.2	13.2 ± 2.5	5.2 ± 0.3	2.1 ± 0.3	1.4 ± 0.3	0.6 ± 0.3	0.0 ± 0.3
Hα	0.07 R	2.6 ± 1.1	1.4 ± 1.2	−2.2 ± 2.4	0.1 ± 0.2	0.5 ± 0.2	0.1 ± 0.2	0.1 ± 0.2	0.4 ± 0.2
DIRBE 100 μm	0.11	7.4 ± 1.1	7.5 ± 1.1	6.5 ± 2.3	2.9 ± 0.2	0.5 ± 0.2	0.0 ± 0.1	−0.4 ± 0.2	−0.5 ± 0.2
DIRBE 240 μm	0.27	6.0 ± 1.1	3.4 ± 1.1	6.5 ± 2.4	2.1 ± 0.2	0.3 ± 0.2	0.1 ± 0.2	−0.4 ± 0.2	−0.4 ± 0.2

(Fernández-Cerezo et al. 2006)

2007 COSMO11 results

COSMO11,15/WMAP correlations with DIRBE 100m

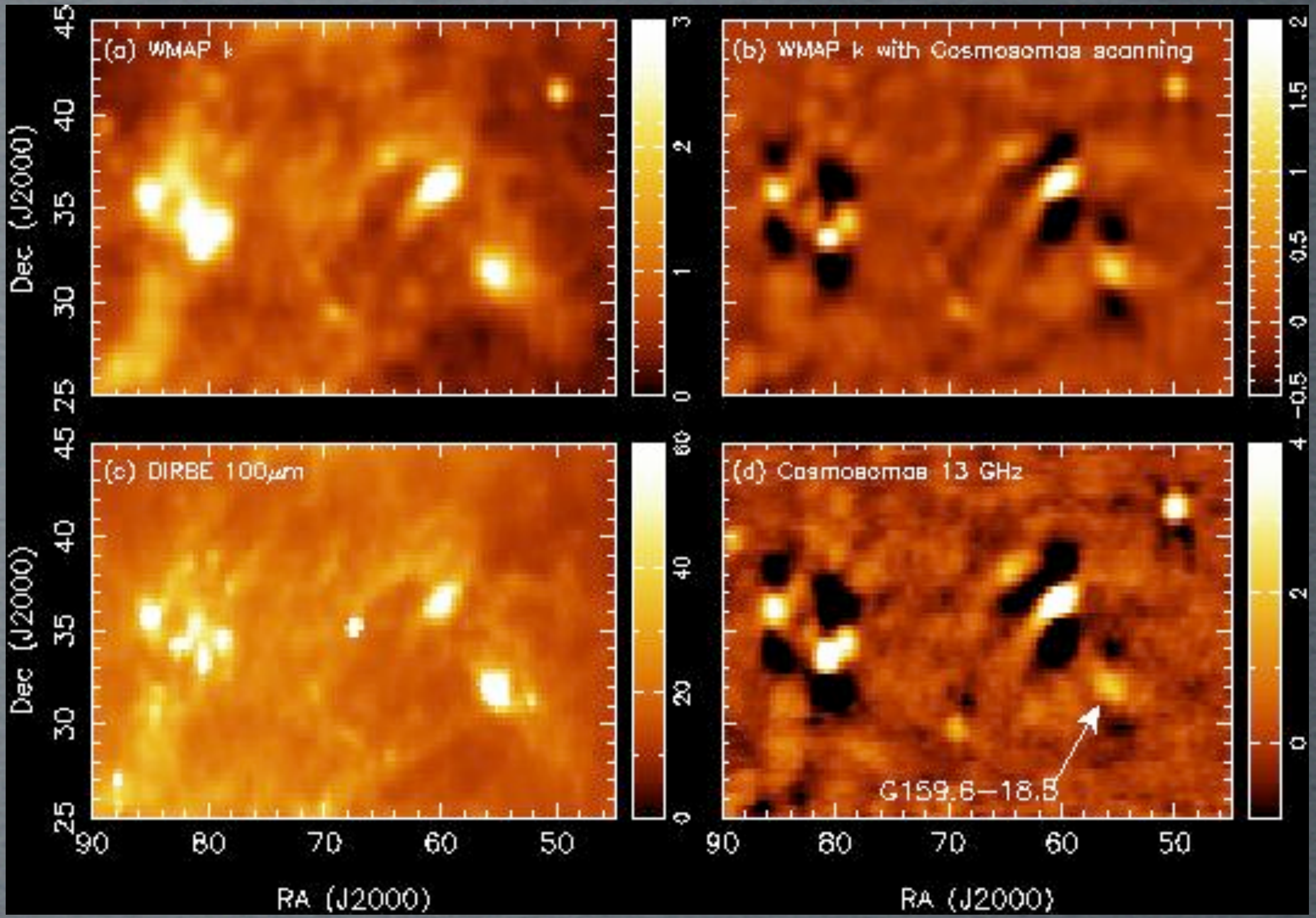
- Clear correlated signals between COSMOSOMAS channels and DIRBE maps at 100 and 240 μm over a region of 6500 deg^2 (Hildebrandt et al. 2007)
- b-dependence indicates Galactic origin. Still significant at |b|>50º
- Important fraction coming from bright dusty regions, where the free-free is not well traced
- Spinning dust model favoured over power-law

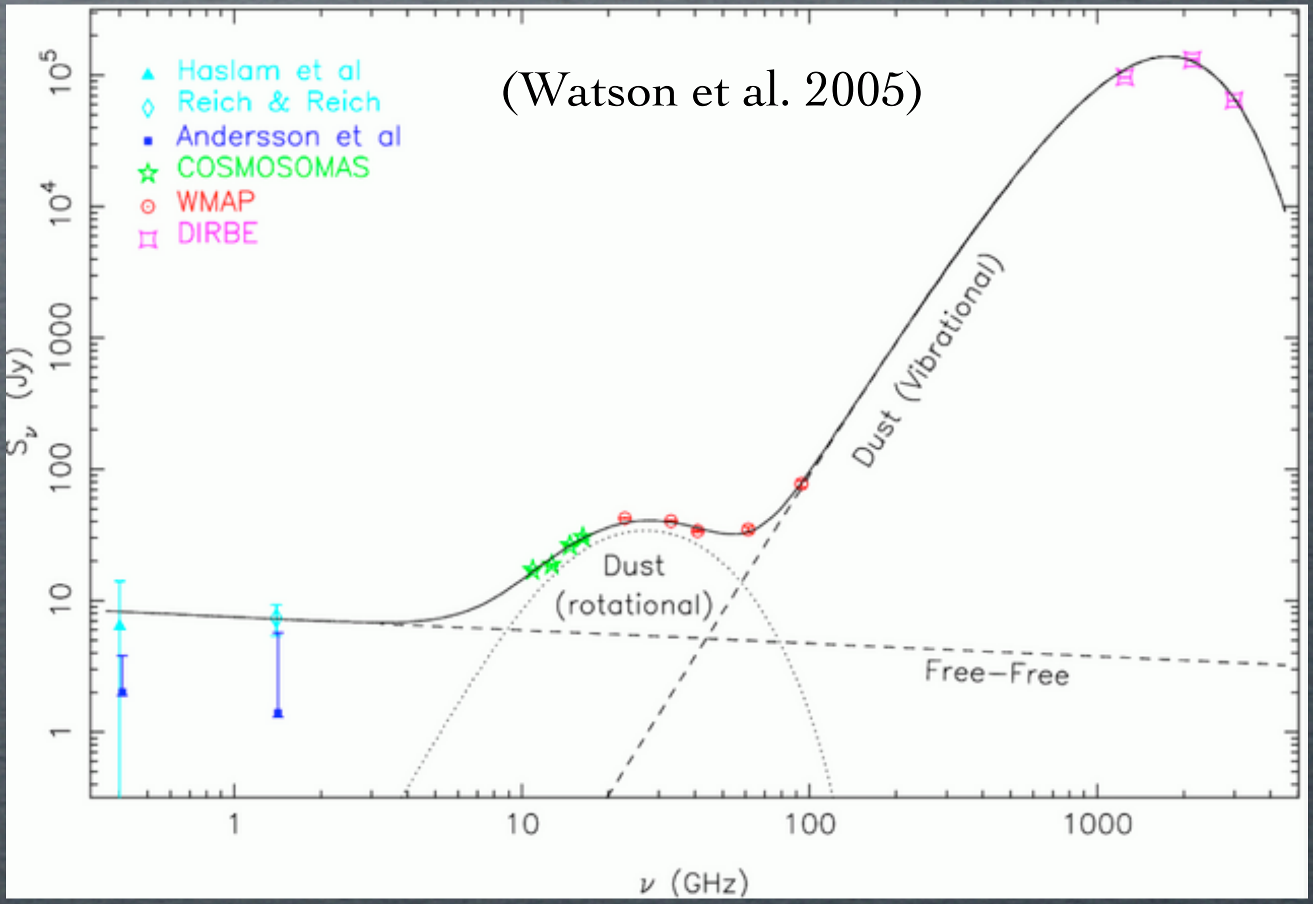


Template	1420 MHz	C11 $_1$	C11 $_2$	C13	C15	C16	WMAP_K	WMAP_Ka	WMAP_Q	WMAP_W
					$\|b\| > 30^o$					
A 100	525.1 ± 569.1	**9.1 ± 0.9**	**10.1 ± 0.8**	**4.4 ± 0.9**	**4.9 ± 1.1**	**7.0 ± 2.7**	**2.7 ± 0.3**	**0.7 ± 0.3**	0.3 ± 0.2	−0.1 ± 0.2
DIRBE08	518.0 ± 578.1	**11.4 ± 0.9**	**12.5 ± 0.8**	**5.8 ± 0.9**	**6.3 ± 1.2**	**5.9 ± 2.9**	**2.8 ± 0.3**	**0.7 ± 0.3**	0.3 ± 0.2	−0.2 ± 0.2
DIRBE10	616.0 ± 566.1	**9.7 ± 0.9**	**11.3 ± 0.8**	**3.7 ± 0.9**	1.9 ± 1.2	5.2 ± 2.9	**2.1 ± 0.3**	0.5 ± 0.3	0.2 ± 0.2	−0.3 ± 0.2
					$\|b\| > 40^o$					
A 100	−617.0 ± 663.0	**6.2 ± 1.0**	**7.2 ± 1.0**	0.4 ± 1.2	**3.4 ± 1.4**	1.5 ± 3.5	**1.5 ± 0.3**	**0.6 ± 0.3**	0.3 ± 0.3	0.1 ± 0.3
DIRBE08	−955.0 ± 663.0	**6.1 ± 1.1**	**7.4 ± 1.0**	1.0 ± 1.2	2.3 ± 1.4	0.0 ± 3.5	**1.2 ± 0.3**	0.5 ± 0.3	0.2 ± 0.3	0.0 ± 0.3
DIRBE10	−314.0 ± 657.1	**4.7 ± 1.0**	**6.2 ± 0.9**	1.4 ± 1.2	−0.7 ± 1.5	−0.6 ± 3.5	**0.8 ± 0.3**	0.3 ± 0.3	0.2 ± 0.3	−0.1 ± 0.3
					$\|b\| > 50^o$					
A 100	**−1487.0 ± 732.1**	**2.6 ± 1.2**	1.8 ± 1.1	**2.6 ± 1.3**	**3.6 ± 1.6**	−2.8 ± 4.0	**1.4 ± 0.3**	0.5 ± 0.3	0.3 ± 0.3	0.2 ± 0.3
DIRBE08	**−1660.0 ± 731.1**	1.6 ± 1.2	1.6 ± 1.1	**2.6 ± 1.3**	2.0 ± 1.6	−5.0 ± 4.0	**0.9 ± 0.3**	0.4 ± 0.3	0.2 ± 0.3	0.0 ± 0.3
DIRBE10	−651.1 ± 723.0	**2.8 ± 1.1**	**4.4 ± 1.0**	**3.6 ± 1.3**	0.2 ± 1.6	−5.0 ± 3.9	**0.8 ± 0.3**	0.2 ± 0.3	0.2 ± 0.3	−0.1 ± 0.3

Intensity

- G159.6-18.5 lies within the Perseus molecular complex, at a distance of 260 pc
- Region heated by the O9.5-B0 V star HD-278942
- Watson et al. (2005) found a rising spectral index of +1.4 between 11 and 17 GHz in Cosmosomas data, and a 9σ excess in WMAP-1yr data at 22 GHz with respect to standard free-free emission
- Not explained by UC HII regions or GPS sources
- First unambiguous detection of AME in an individual cloud
- Residual AME spectrum well fitted by a spinning dust model (WNN+MC)

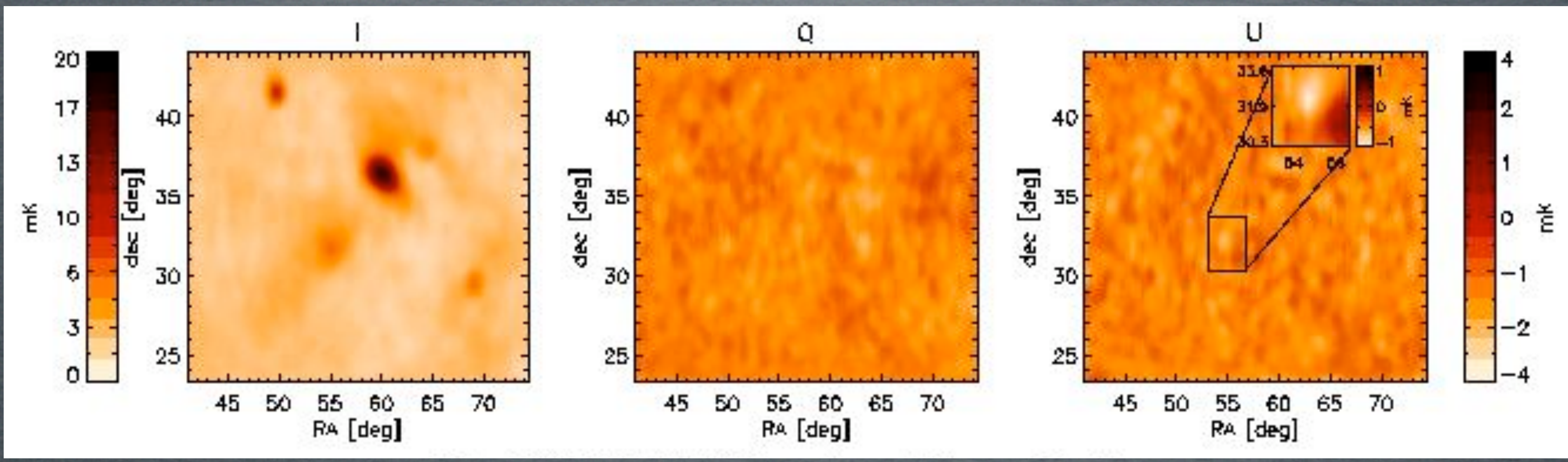




(Watson et al. 2005)

Polarization constraints

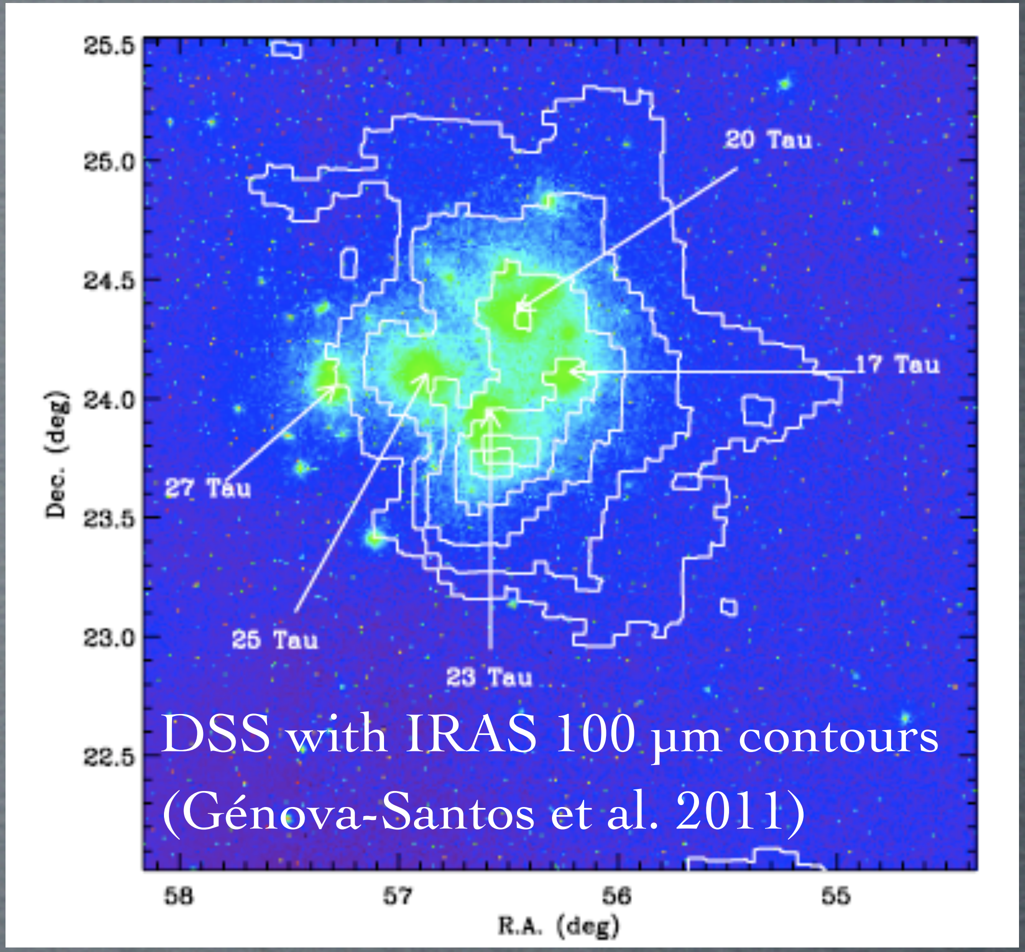
- Used the two COSMO11 receivers ($C11_1$ and $C11_2$), sensitive to orthogonal polarizations
- $Q = I_{0^\circ} - I_{90^\circ}$ measured between 2004 March and 2005 May. $U = I_{+45^\circ} - I_{-45^\circ}$ measured between 2005 June and 2006 February
- Systematics assessment through nearby NGC1499 and 3C84. Less than 1%



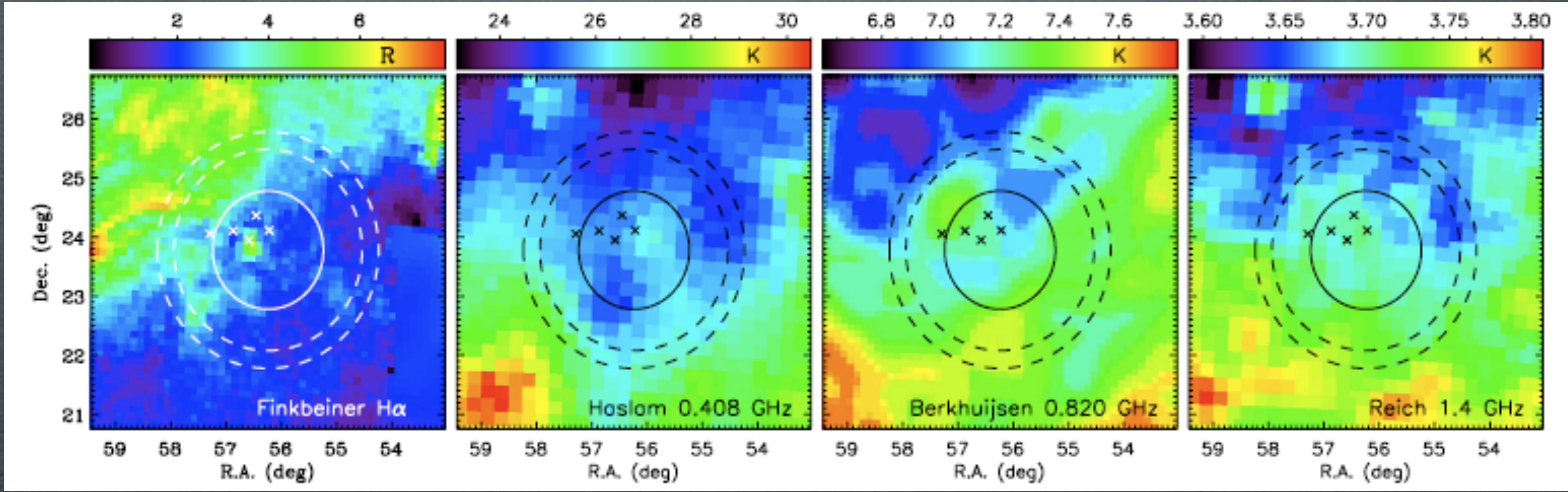
(Battistelli et al. 2006)

- Result: $Q/I = -0.2 \pm 1.0$ %, $U/I = -3.4\ {+1.8}{-1.4}$ %, $\Pi = 3.4\ {+1.5}{-1.9}$ % (2σ)
- First constraints on the polarization properties of AME
- This result indicates that the particles responsible for AME are not significantly aligned in a common direction. Fully consistent with the prediction from electric dipole emission

- Pleiades reflection nebula, located within the Taurus complex at distance of 125 pc
- Dust emission detected long ago (Castelaz et al. 1987)
- Bright Merope molecular cloud south of 23 Tau, detected in CO maps (Federman & Wilson 1984)
- White 1984 identified atomic and molecular phases
- Very low optical depth (E_{B-V} ~ 0.03-0.07 mag), except for the area of the Merope MC (E_{B-V} ~ 0.35)
- n_g ~ 100-500 cm^{-3}, T_g ~ 20 K (Federman & Wilson 1984, White 1984, Gordon & Arny 1984)
- Predicted very low free-free emission, <0.03 Jy. $I_{H\alpha}$ ~ 0.12 R (0.092 R before corr). EM=0.27 cm^{-6} pc

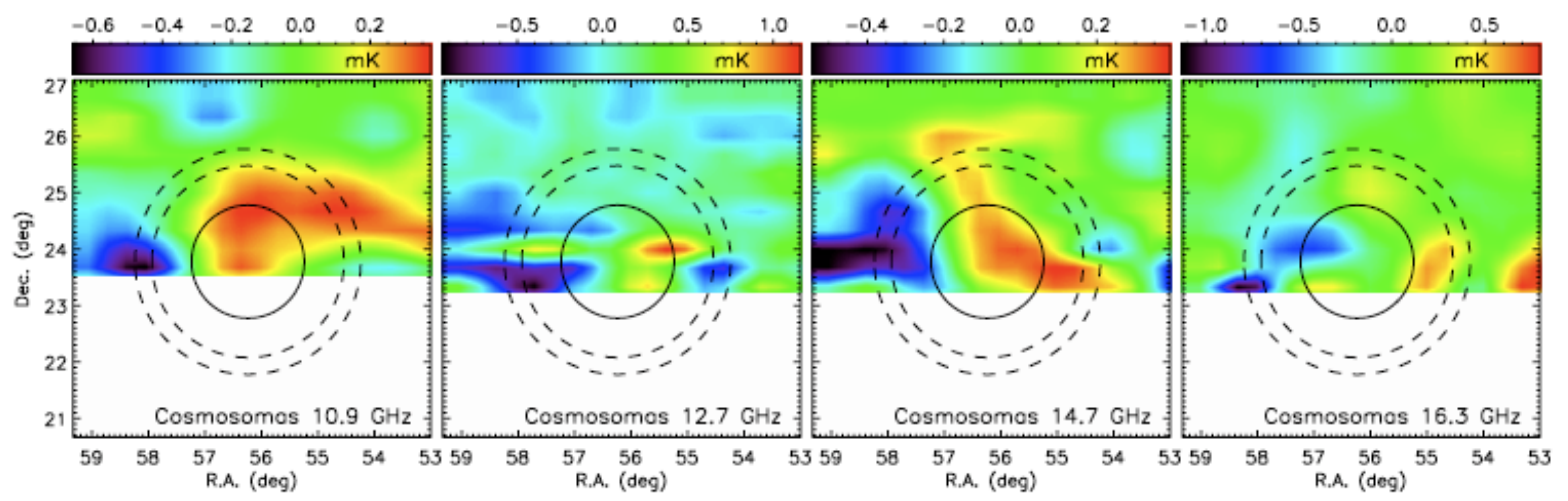


DSS with IRAS 100 μm contours (Génova-Santos et al. 2011)

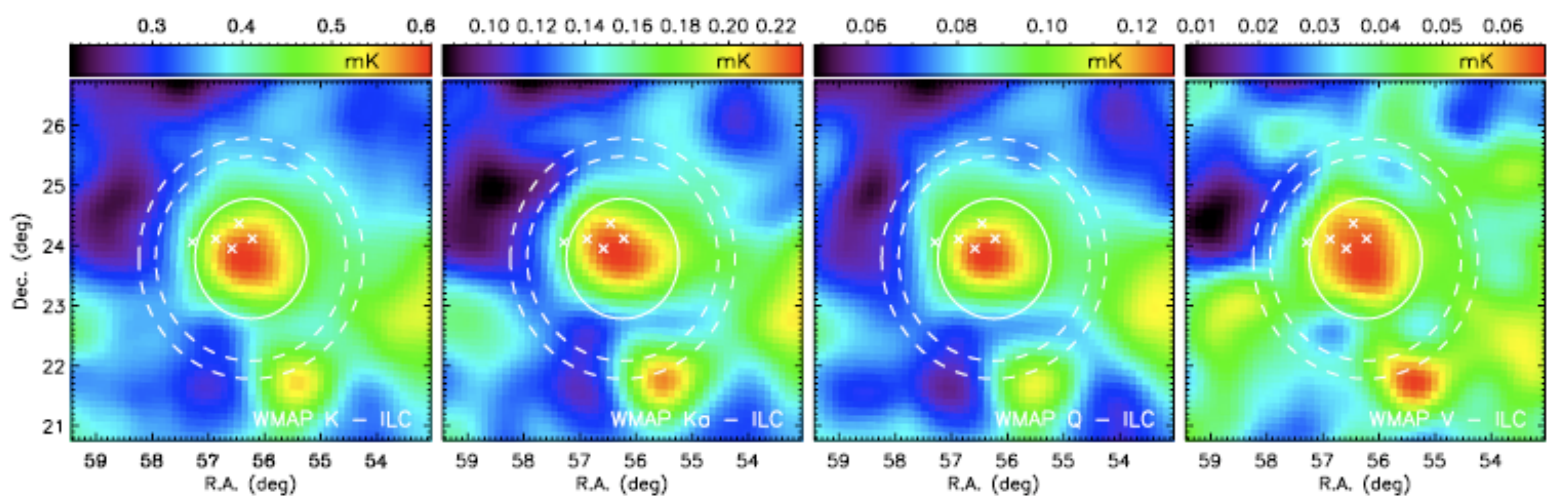


Maps

Cosmosomas maps. No clear emission. 3σ upper limits will be derived



WMAP maps



(Génova-Santos et al. 2011)

Fluxes

- Case A. No CMB subtraction
- Case B. CMB subtracted using ILC

Fluxes and Dust-correlated Emissivities

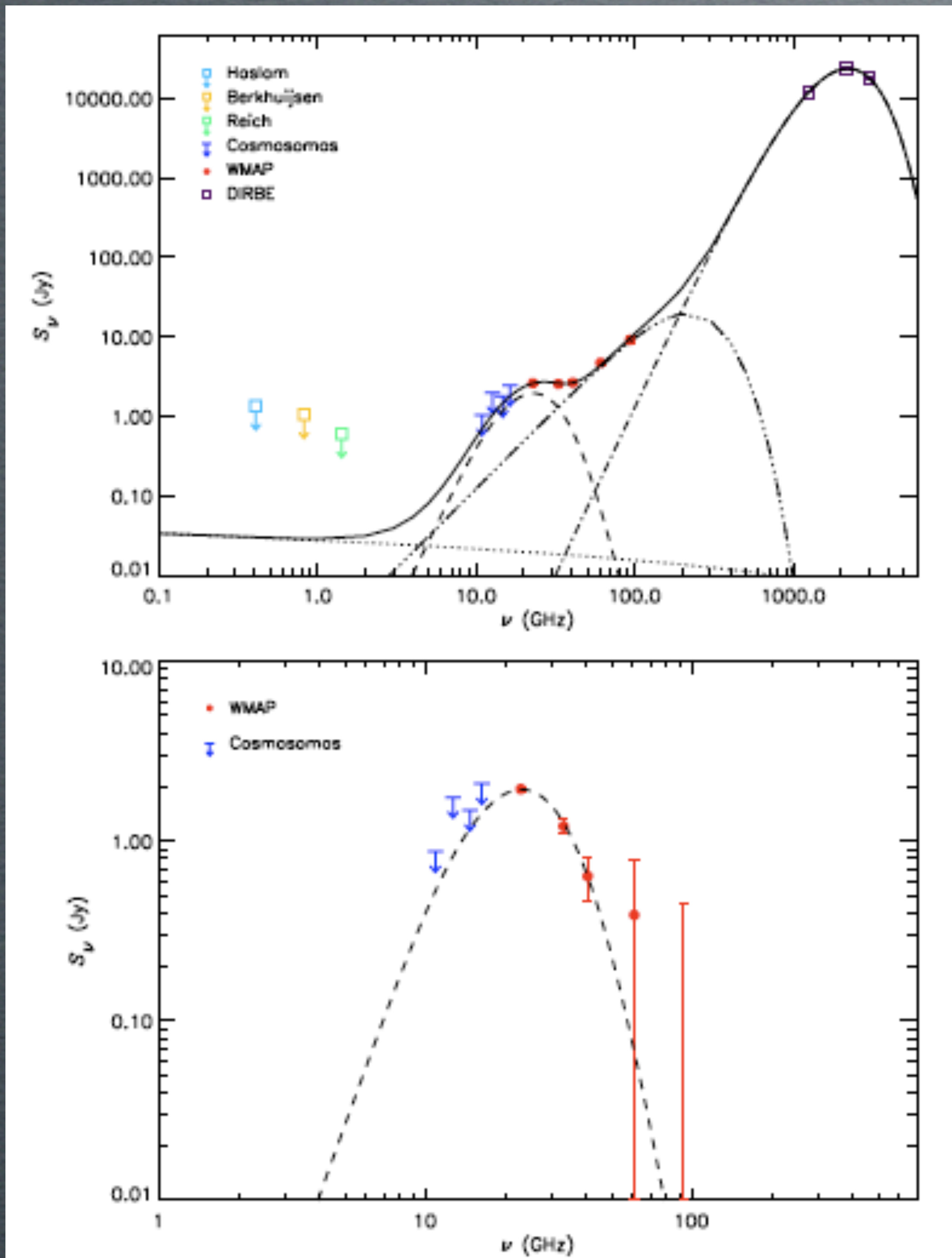
ν (GHz)	Case A Flux (Jy)	Case A Residual Flux (Jy)	Case A Correlation μK (MJy sr^{-1})$^{-1}$	Case B Flux (Jy)	Case B Residual Flux (Jy)	Case B Correlation μK (MJy sr^{-1})$^{-1}$
0.408	<1.14	<1.11	...	<1.14	<1.11	...
0.820	<0.89	<0.87	...	<0.89	<0.87	...
1.42	<0.51	<0.49	...	<0.51	<0.49	...
10.9	<1.04	<0.87	...	<0.94	<0.91	...
12.7	<1.97	<1.75	...	<1.83	<1.80	...
14.7	<1.77	<1.48	...	<1.58	<1.56	...
16.3	<2.43	<2.08	...	<2.20	<2.17	...
22.8	2.60 ± 0.06 (± 0.51)	1.95 ± 0.06	3.01 ± 0.27	2.15 ± 0.12	2.12 ± 0.12	4.36 ± 0.17
33.0	2.55 ± 0.10 (± 1.06)	1.21 ± 0.12	0.66 ± 0.17	1.61 ± 0.15	1.55 ± 0.15	2.01 ± 0.09
40.7	2.64 ± 0.15 (± 1.59)	0.64 ± 0.17	−0.32 ± 0.16	1.24 ± 0.18	1.12 ± 0.18	1.03 ± 0.03
60.8	4.71 ± 0.36 (± 3.37)	0.39 ± 0.40	−0.77 ± 0.16	1.75 ± 0.38	1.23 ± 0.38	0.59 ± 0.02
93.5	9.12 ± 0.89 (± 7.03)	−0.52 ± 0.97	−0.25 ± 0.12	2.94 ± 0.90	0.37 ± 0.90	1.10 ± 0.05
1249.1	11931 ± 185	9 ± 394	...	11931 ± 185	−366 ± 195	...
2141.4	23469 ± 249	−14 ± 595	...	23469 ± 249	618 ± 262	...
2997.9	17959± 89	1 ± 375	...	17959 ± 89	−47 ± 101	...

- *17.7* σ detection of AME at 23 GHz

- Dust emissivity, 4.36 ± 0.17 μK/(MJy sr^{-1}) at 22.8 GHz / 100 μm, lower than in dust clouds (~ 11 - 35 μK/(MJy sr^{-1}); Davies et al. 2006), and more similar to HII regions (3.3 ± 1.7 μK/(MJy sr^{-1}); Dickinson et al. 2007)

SED modelling

A - CMB + molecular phase



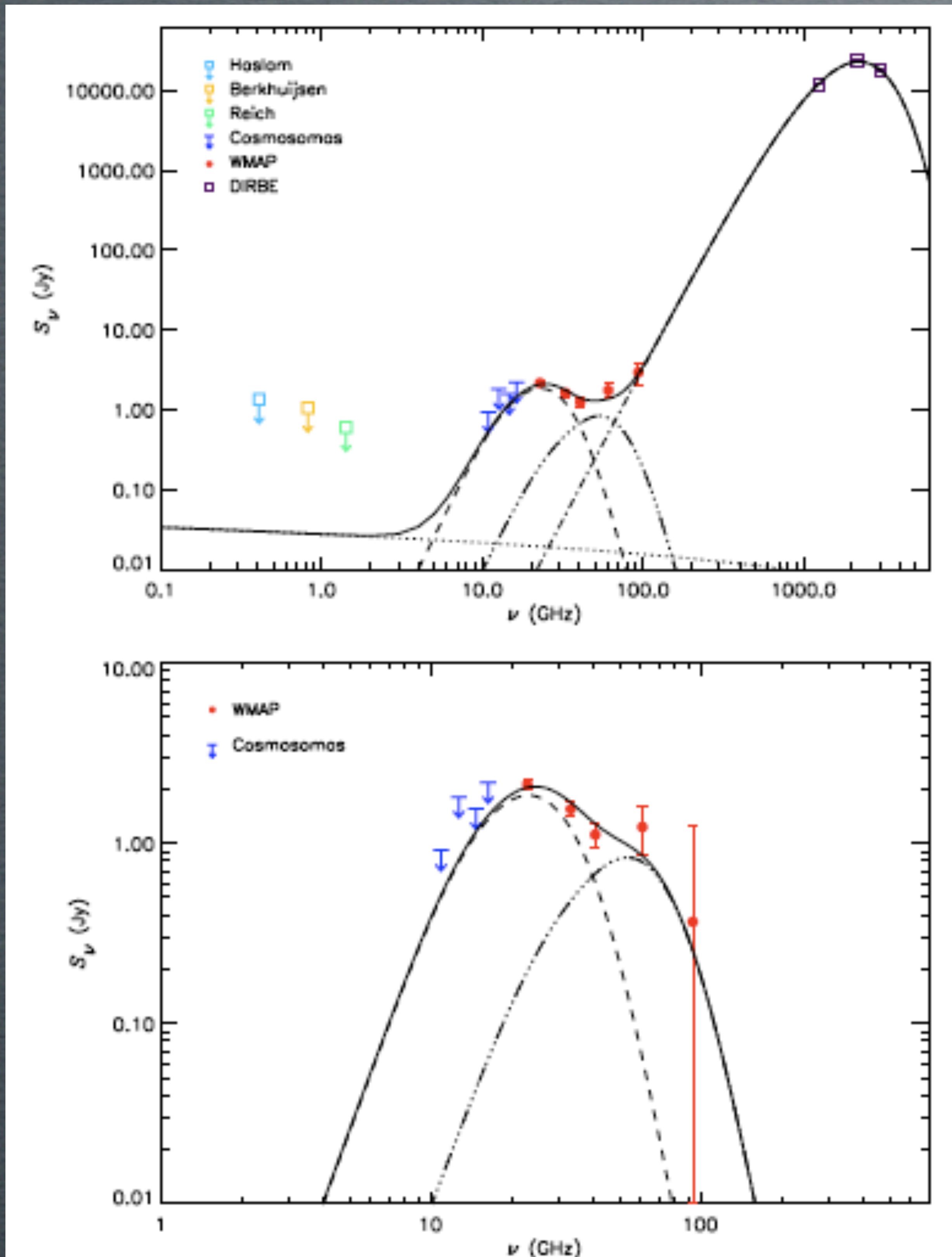
SD spectra from SPUDST.2

Model Parameters		
T_e (K)	8000	
EM (cm^{-6} pc)	0.267	
	Molecular	Atomic
n_H (cm^{-3})	300	200
T_g (K)	20	1000
χ	0.03	10
x_H (ppm)	9.2	373
x_C (ppm)	1	100
y	1	0.1
β (D)	9.34	9.34
	Case A	
N_H (10^{20} cm^{-2})	6.94 ± 0.22	...
τ_{100}	$(6.09 \pm 0.06)\times10^{-4}$	
β_d	2.29 ± 0.02	
T_d (K)	20.12 ± 0.03	
ΔT_{cmb} (μK)	42.2 ± 1.9	
	Case B	
N_H (10^{20} cm^{-2})	6.60 ± 0.11	0.30 ± 0.01
τ_{100}	$(3.302 \pm 0.004) \times 10^{-4}$	
β_d	1.869 ± 0.004	
T_d (K)	22.008 ± 0.005	

- N_H much lower than other AME regions (117×10^{20} cm^{-2} in Perseus and 171×10^{20} cm^{-2} in ϱ-Ophiuchi)
- Consistent with Bohlin et al. (1978) scaling relation, 5.8×10^{20} cm^{-2} (using E_{B-V} = 0.1 mag)

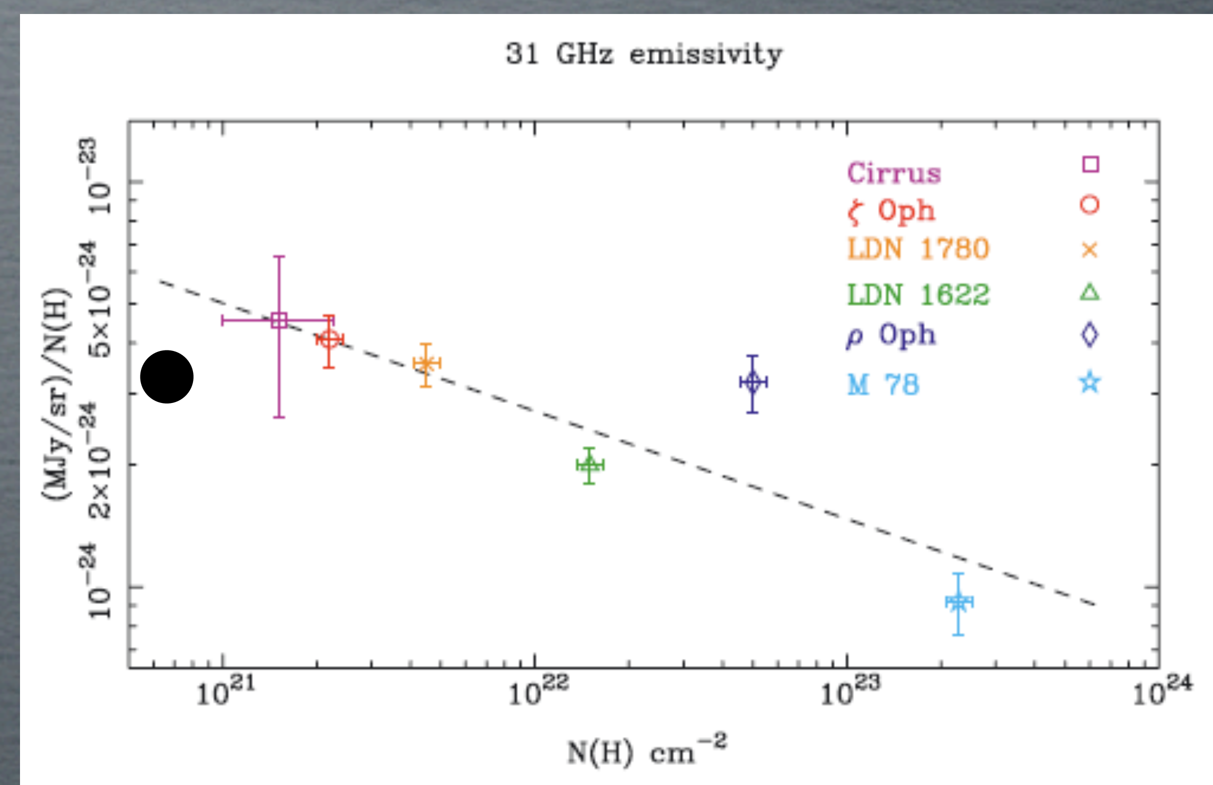
SED modelling

B - Atomic + molecular phases



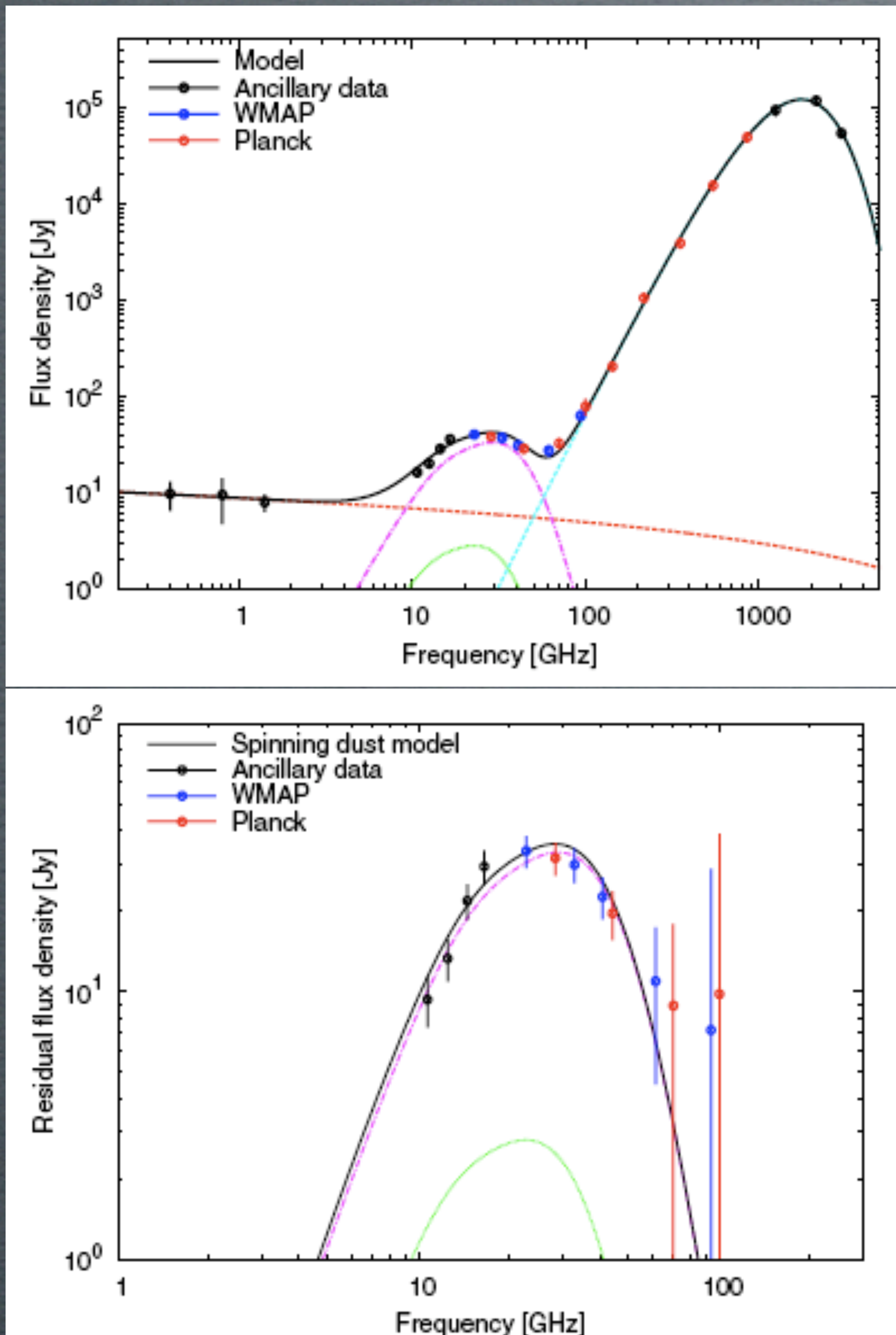
SD spectra from SPUDST.2

- Emissivity at 31 GHz (intensity at 31 GHz divided by hydrogen column density): $(3.03 \pm 0.33)\times10^{-24}$ MJy sr^{-1} cm^{2}

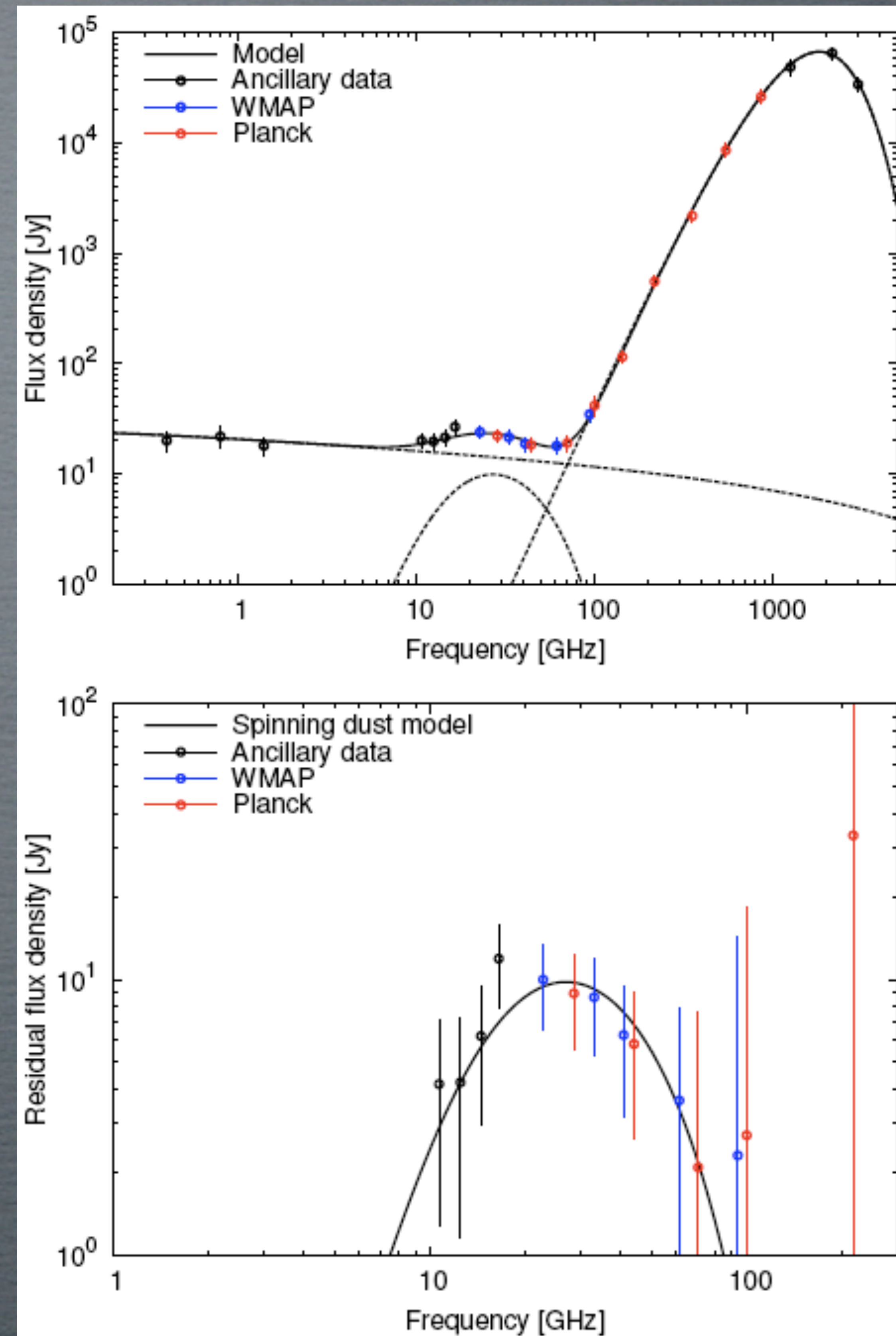


(Vidal et al. 2011)

G160.26-18.62



G173.6+2.8

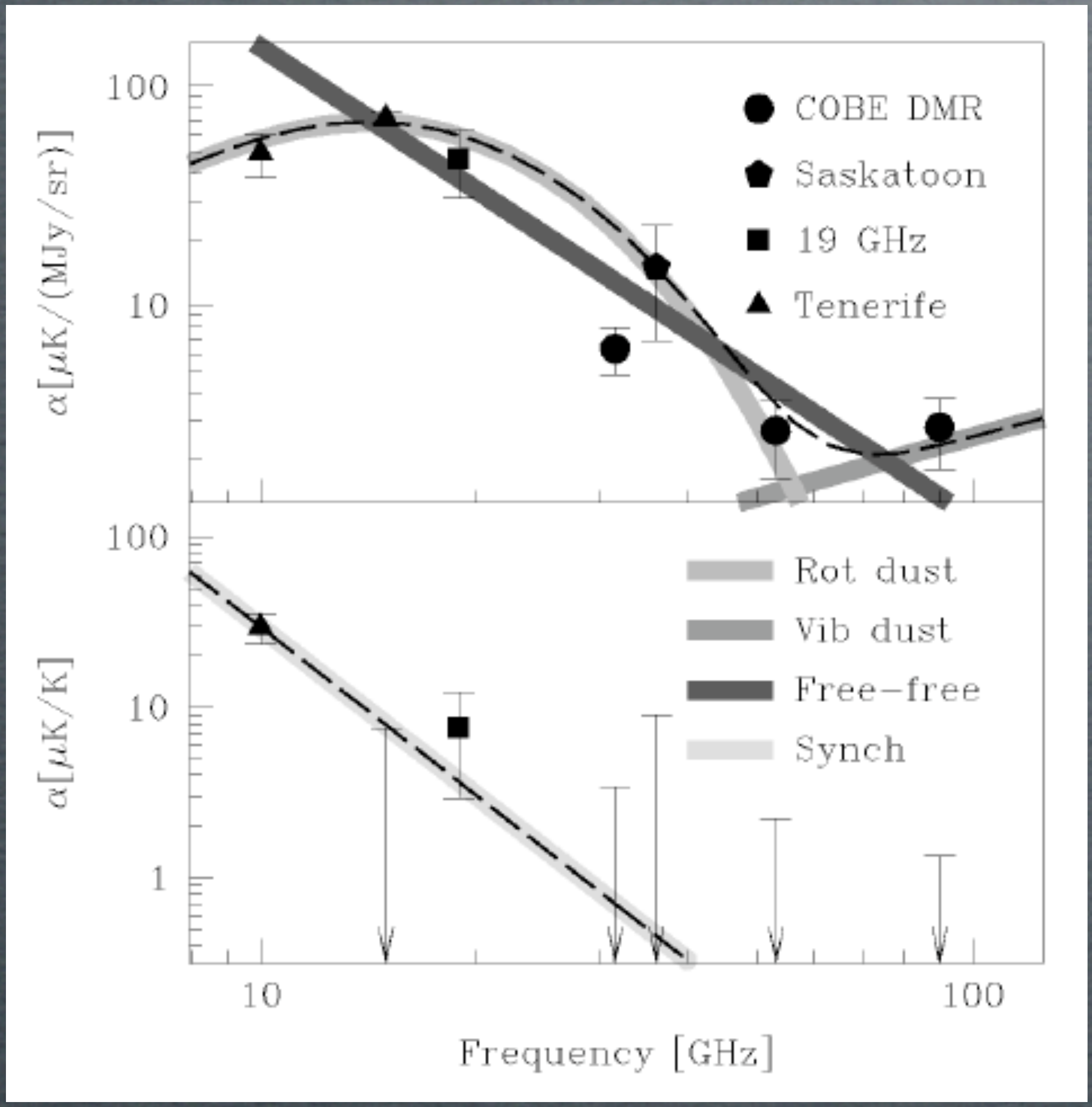


Ancillary data ⇔ COSMOSOMAS

Tenerife experiments

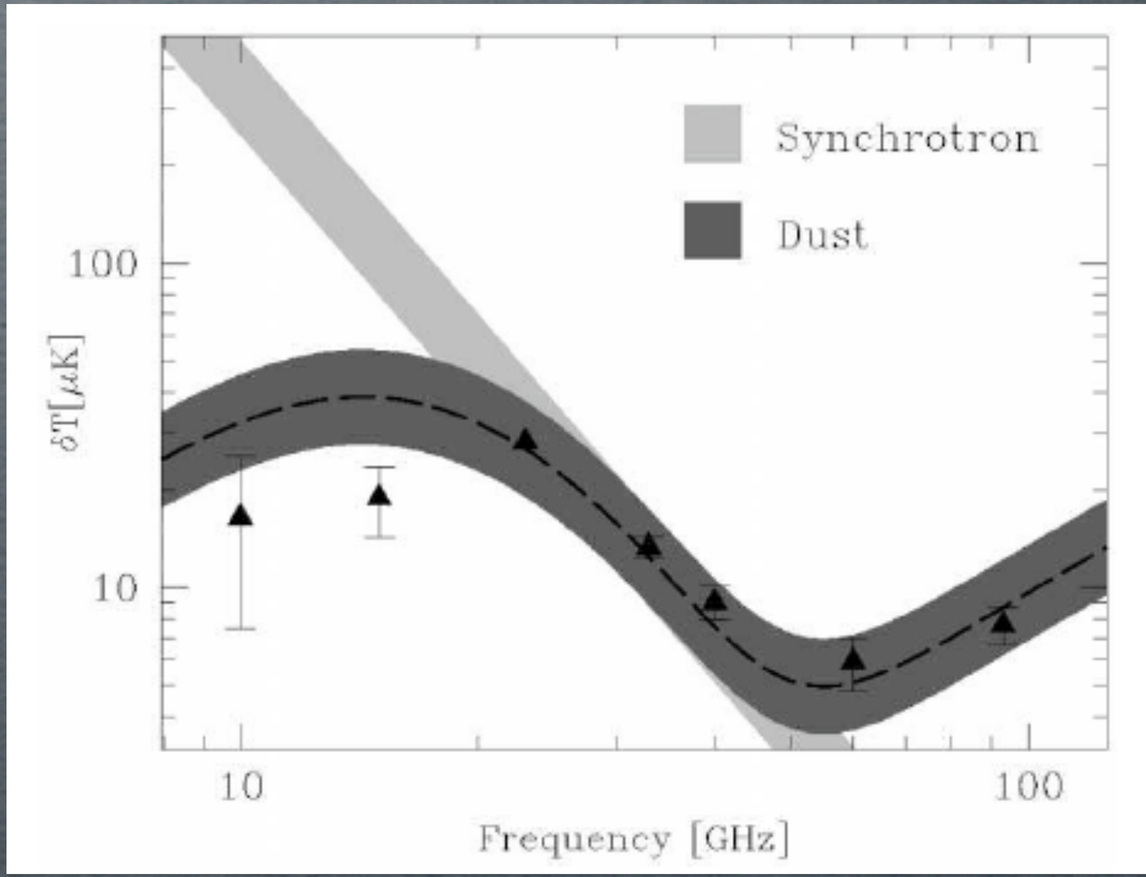
- Three double-antenna radio-telescopes at 10, 15 and 33 GHz
- Colaboration between the IAC and JBO
- Operative: 1984-2000
- Statistical detections of AME: de Oliveira-Costa et al. (1999, 2002, 2004), Mukherjee et al. 2001

Correlations with Dirbe



(de Oliveira-Costa et al. 1999)

Correlations with WMAP-K band

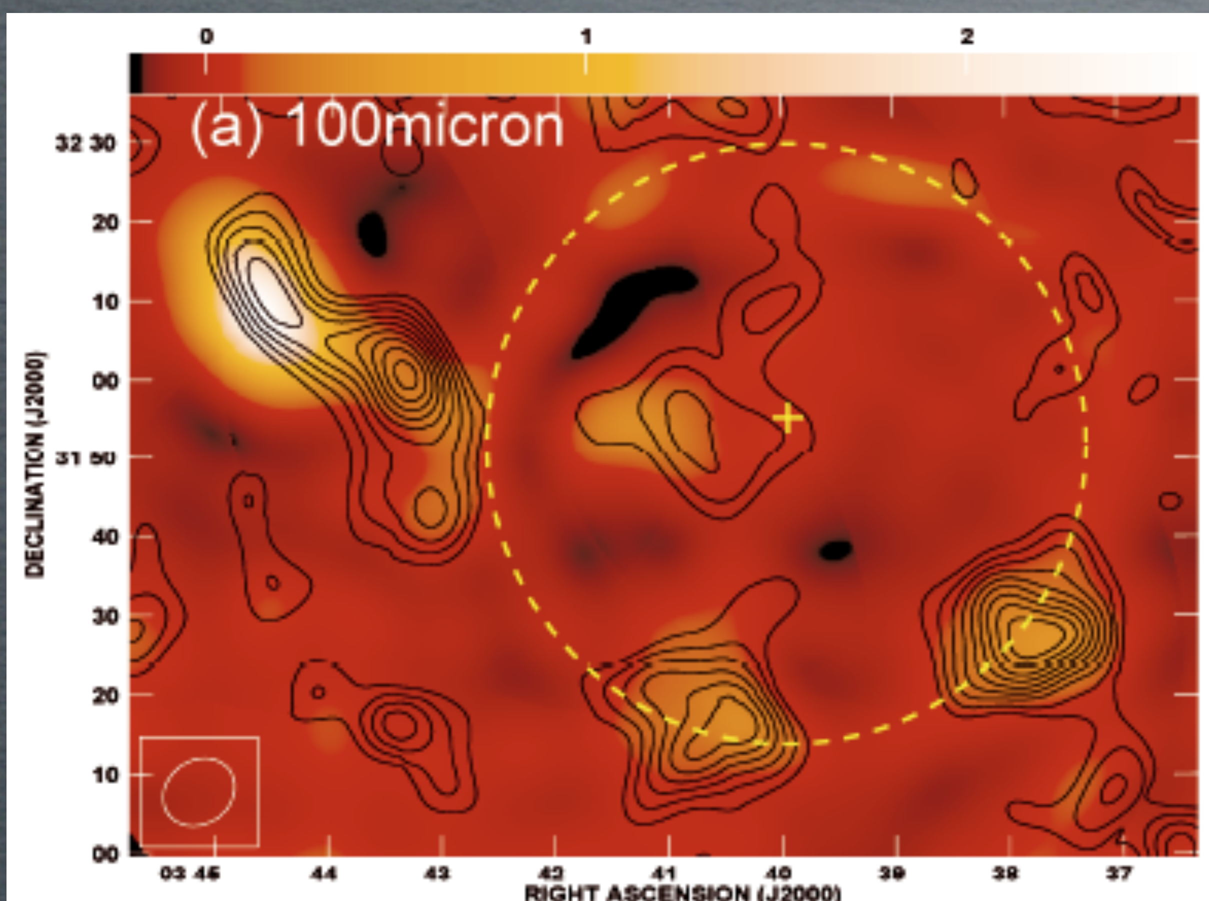


(de Oliveira-Costa et al. 2004)

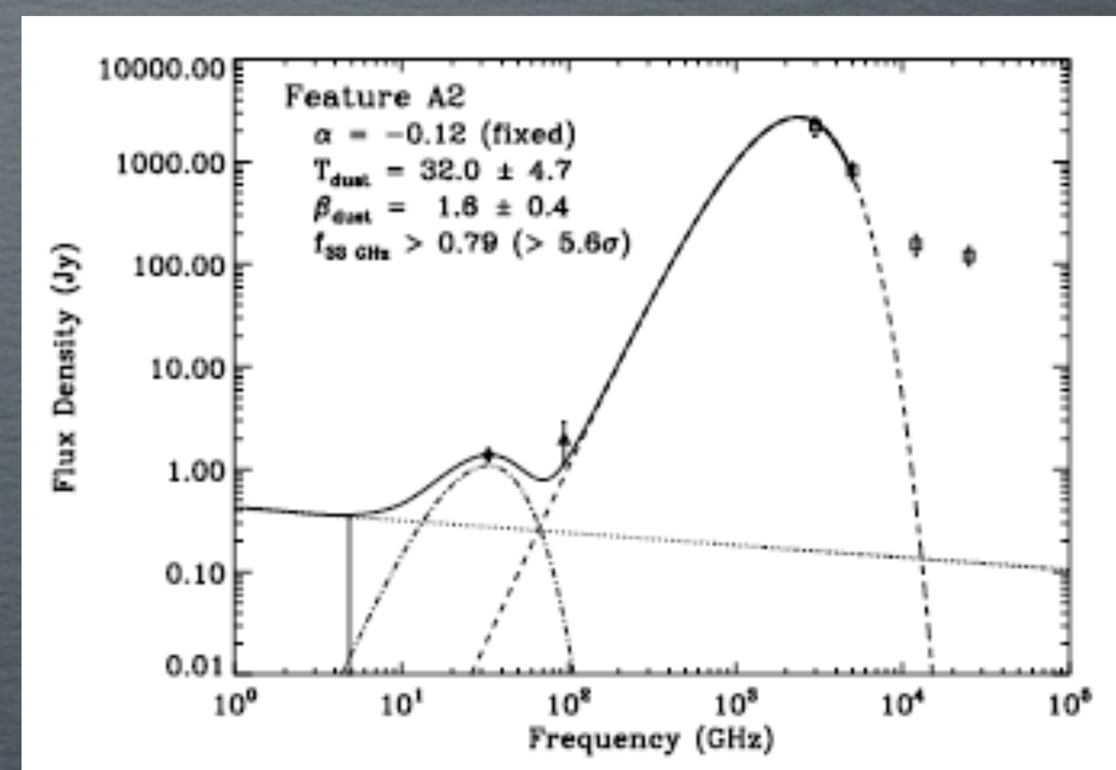
VSA

- 14-antennae interferometer at 33 GHz
- Colaboration between Cambridge, JBO and the IAC
- Operative: 2001-2008

- Follow-up of Perseus at 33 GHz, contours, over-plotted on IRIS 100 μm



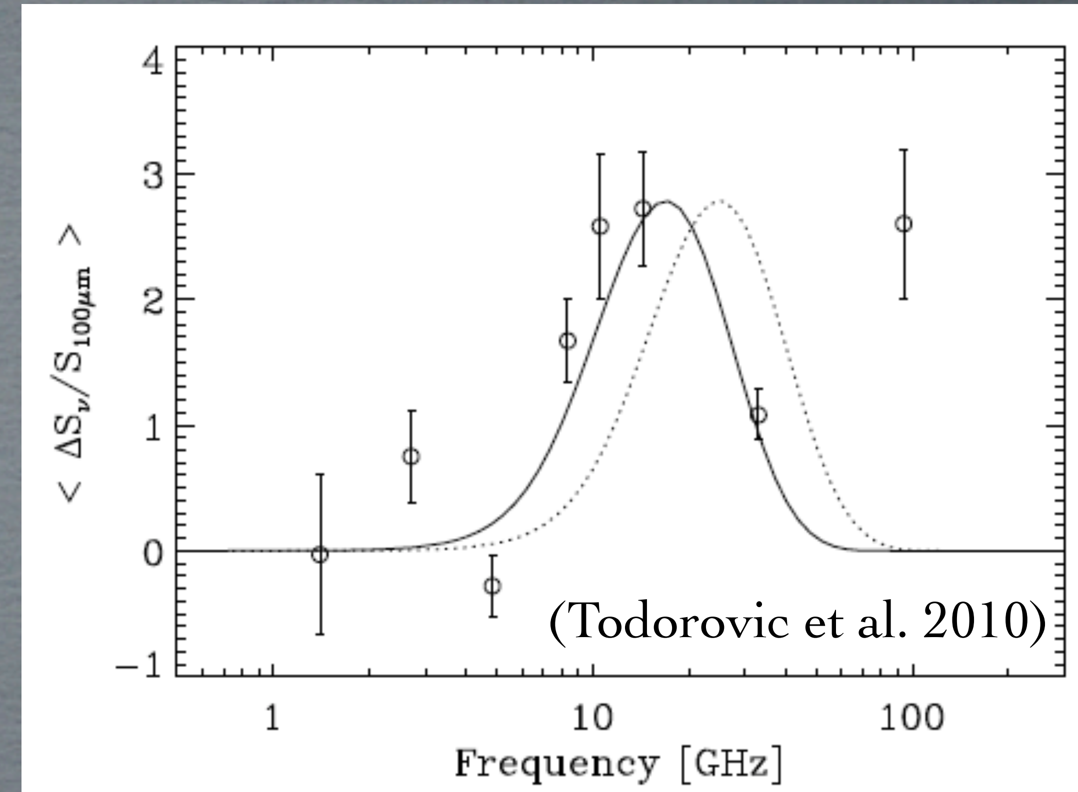
≈10% of the diffuse flux density detected by COSMOSOMAS



(Tibbs et al. 2010)

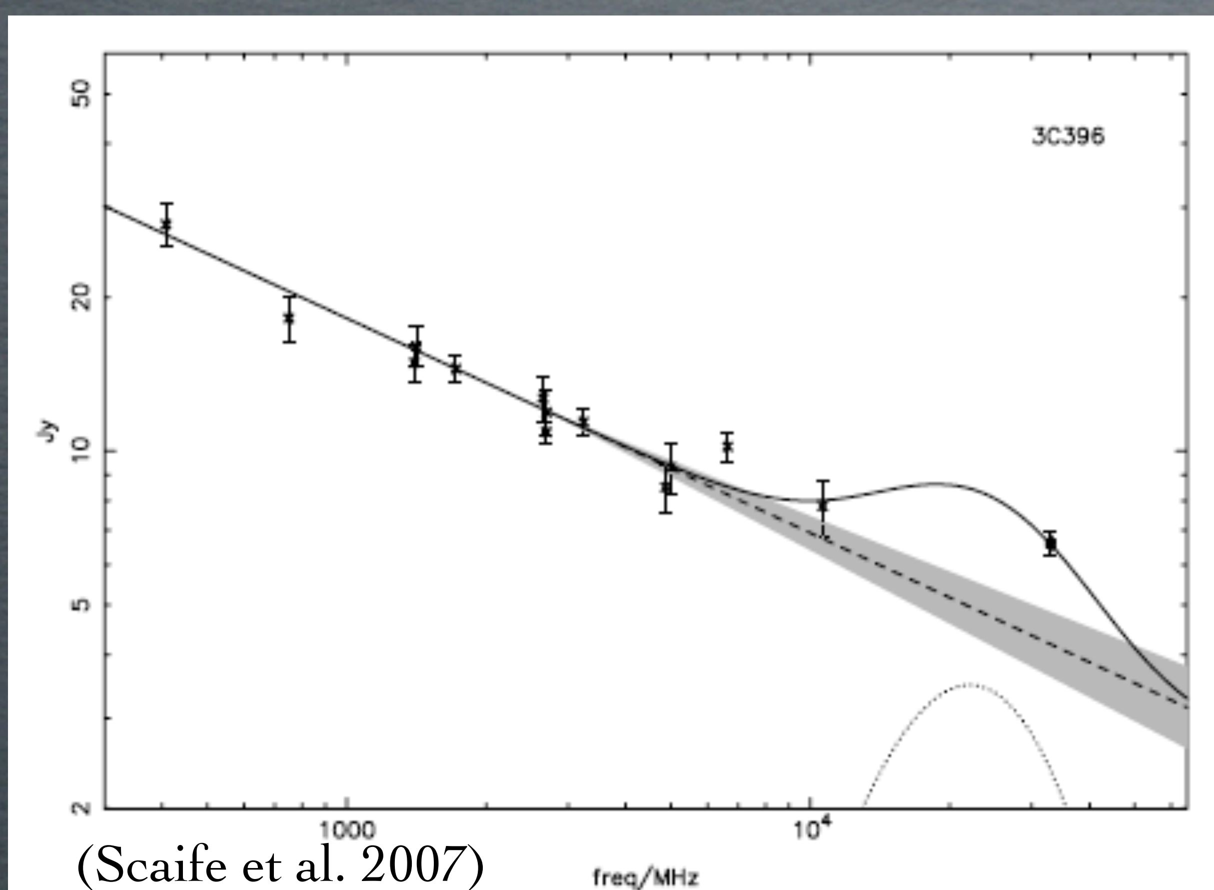
VSA

- Galactic plane survey l = 27°-46°, |b|<4° (Todorovic et al. 2010)
- Evidence of AME found towards 9 HII regions
- AME peak at 15 GHz. Average radio/FIR emissivity of 4.65±0.40 μK/(MJy/sr)$^{-1}$

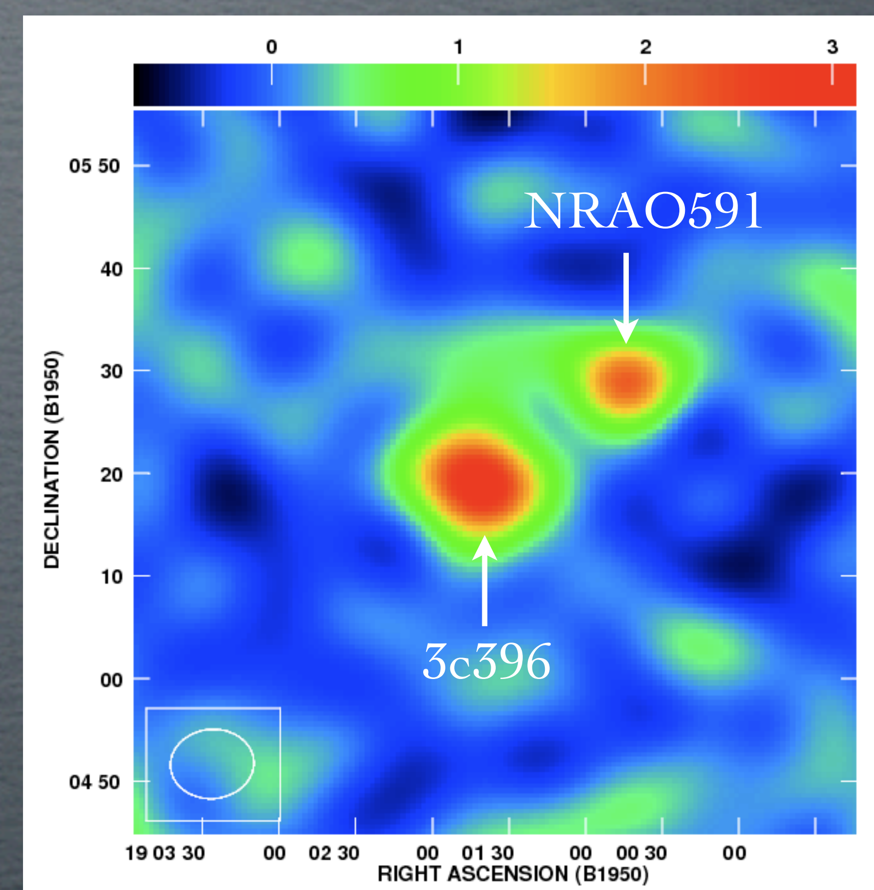


(Todorovic et al. 2010)

- Tentative detection of AME found towards 3C396 SNR (Scaife et al. 2007)



(Scaife et al. 2007)



The Q-U-I JOint TEnerife Experiment

❖ Aims:

- To constrain (or to detect) the primordial B-mode signal it r>0.05 (main science driver)
- To complement Planck at low frequencies. In combination with Planck, improve the sensitivity to r
- To measure polarized foregrounds (synchrotron and AME) with high sensitivity, in order to correct them in future space missions aiming at r=0.001

❖ Telescopes and instruments. Two phases, fully funded:

- Phase I. First telescope (QT1), a multi-frequency instrument (MFI) @ 11-30 GHz, a second instrument (TGI) with 31 polarimeters @ 30 GHz and a polarized source subtractor @ 30 GHz
- Phase II. Second telescope (QT2), and a third instrument (FGI) with ~40 polarimeters @ 42 GHz

❖ Basic facts

- Site: Teide observatory (2400 m a.s.l.)
- Sky coverage: 10,000 deg^2
- Angular resolution: 0.92° to 0.28°

The QUIJOTE collaboration

- **Instituto de Astrofísica de Canarias (IAC)**

  R. Rebolo (PI), J.A. Rubiño-Martín (PS), M. Aguiar, R. Génova-Santos, F. Gómez-Reñasco, J.M. Herreros (PM), R. Hoyland (InstS), C.H. López-Caraballo

- **Instituto de Física de Cantabria**

  E. Martínez-González, B. Barreiro, F.J. Casas, R. Fernández-Cobos, D. Herranz, M. López-Caniego, P. Vielva

- **DICOM - Universidad de Cantabria**

  E. Artal, B. Aja, J.L. Cano, L. de la Fuente, A. Mediavilla, J.P. Pascual, E. Villa

- **JBO - University of Manchester**

  L. Piccirillo, R. Battye, R.D. Davies, R.J. Davis, C. Dickinson, S. Harper, B. Maffei, G. Pisano, R.A. Watson

- **University of Cambridge**

  K. Grainge, M.P. Hobson, M. Brown, A. Challinor, A.N. Lasenby, R.D.E. Saunders, P.F. Scott, H. Smith

- **IDOM**

  J. Ariño, B. Etxeita, A. Gómez, C. Gómez, G. Murga, J. Pan, R. Sanquirce, A. Vizcargüenaga

- Receivers: coherent detectors
- Polarization detection: polar modulators
- Observing strategy: deep observations in selected sky areas using raster scans (~3,000 deg^2), and a large survey (~10,000 deg^2) using the "nominal mode" (similar to Cosmosomas)

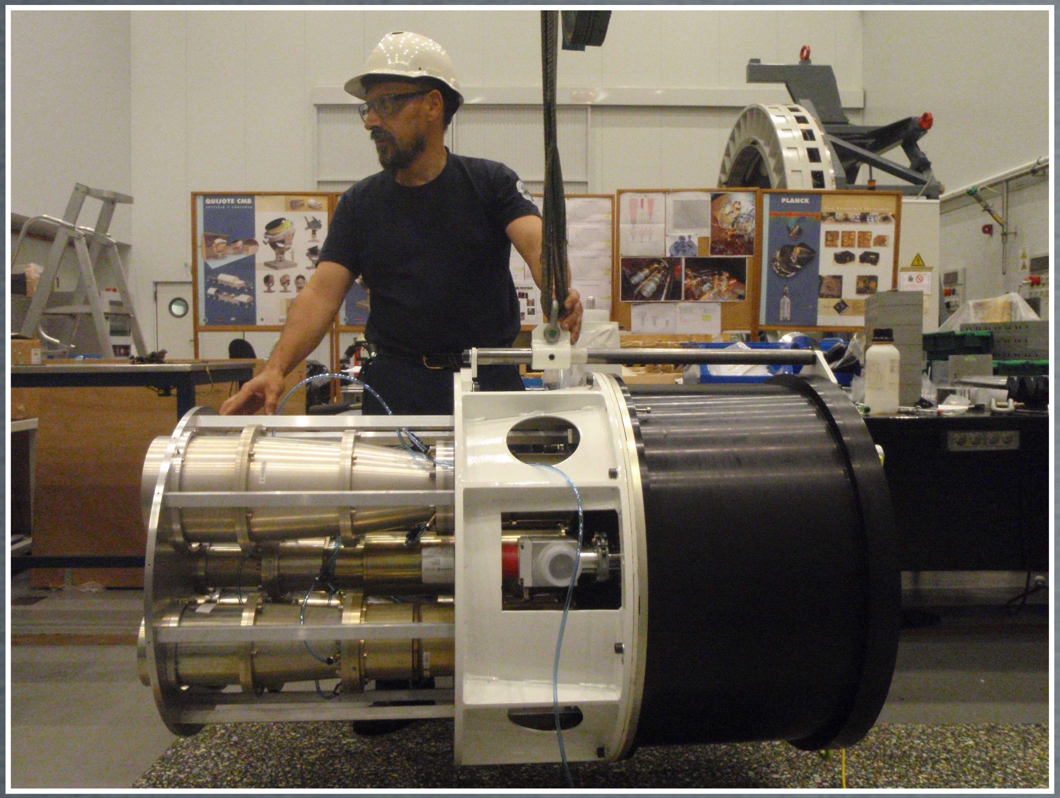
	MFI					TGI	FGI
Frequency (GHz)	11	13	17	19	30	30	40
Bandwidth (GHz)	2.0	2.0	2.0	2.0	8.0	8.0	10.0
Number of channels	8	8	8	8	2	124	160
Beam FWHM (deg)	0.92	0.92	0.60	0.60	0.37	0.37	0.28
T_{sys} (K)	25	25	25	25	35	35	45
Sensitivity (μK $s^{1/2}$)	280	280	280	280	390	50	50
Sensitivity (Jy $s^{1/2}$)	0.30	0.42	0.31	0.38	0.50	0.06	0.06

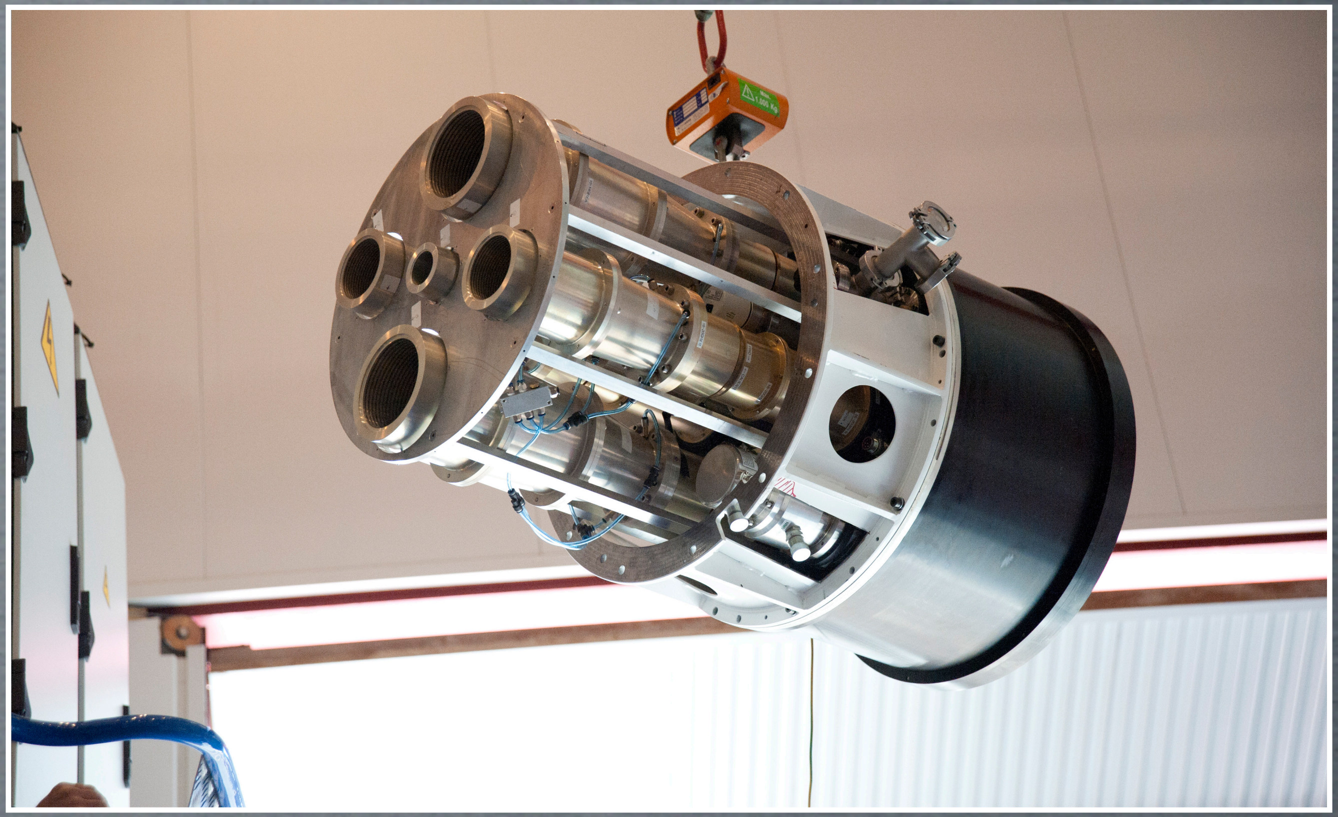
- Telescopes:
  - Alto-azimutal mount. Maximum speed around AZ axis: 0.25 Hz. Maximum zenith angle: 60º
  - Cross-dragonian design. 2.25 m (primary), 1.9 m (secondary)

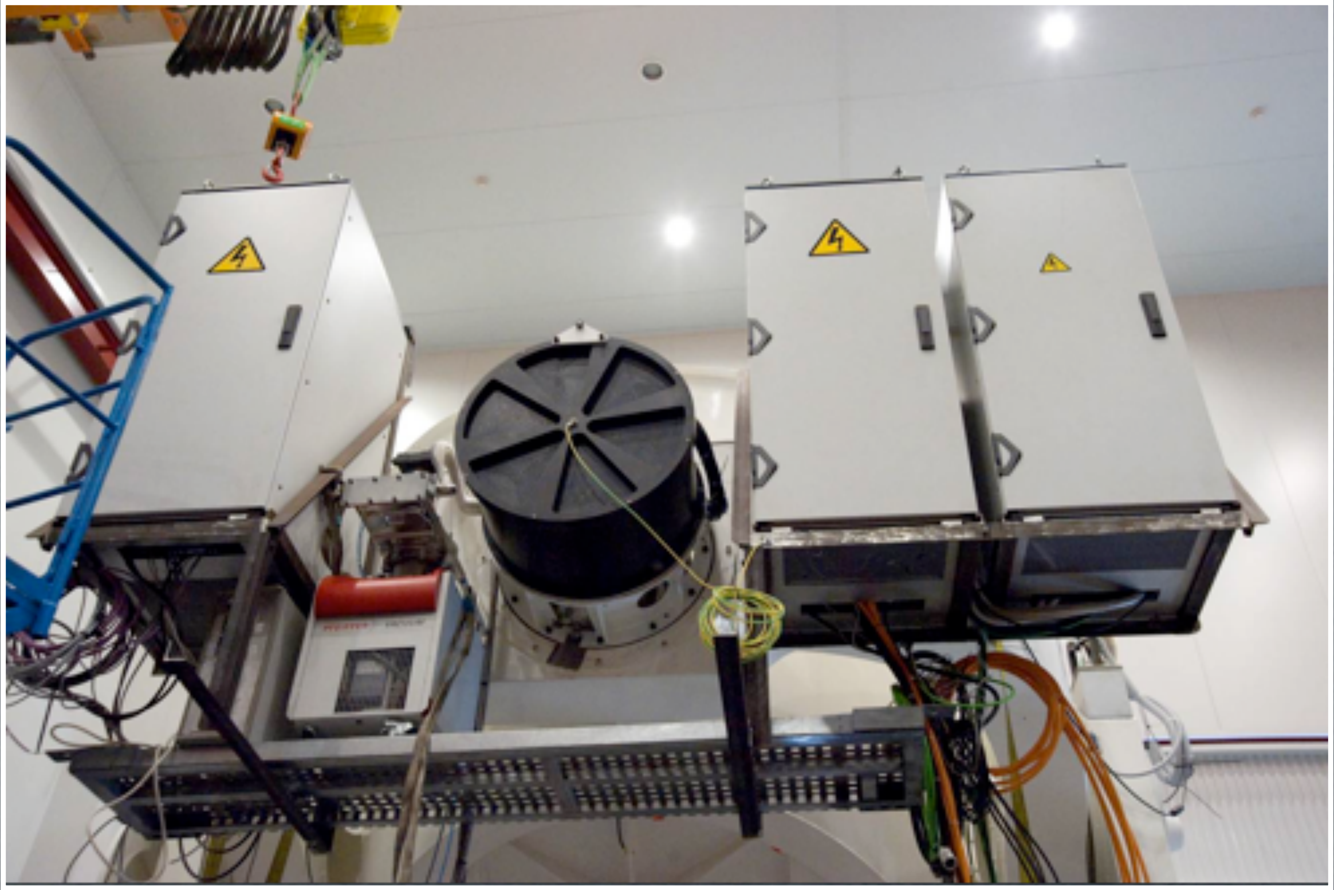
QT1

- Installed at the Teide Observatory on 3 May 2012
- Currently undertaking commissioning

MFI







- Integration tests of the MFI and the QT1 in the AIV room (February - March 2012)
- Currently, undertaking final modifications and last vacuum tests
- Final integration at the observatory will take place on September 2012