New results on Anomalous Galactic Microwave Emission with the COSMOSOMAS experiment

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Outline

- Anomalous Microwave Emission in the Galaxy: Foreground X?
- The COSMOSOMAS experiment
  - Instrument setup
  - Observations
  - Maps at 11, 13, 15 and 17 GHz
- COSMOSOMAS versus WMAP, Haslam,..
  - Cross-correlation of maps
- COSMOSOMAS versus DIRBE, Hα: the anomalous microwave emission

- CONCLUSIONS

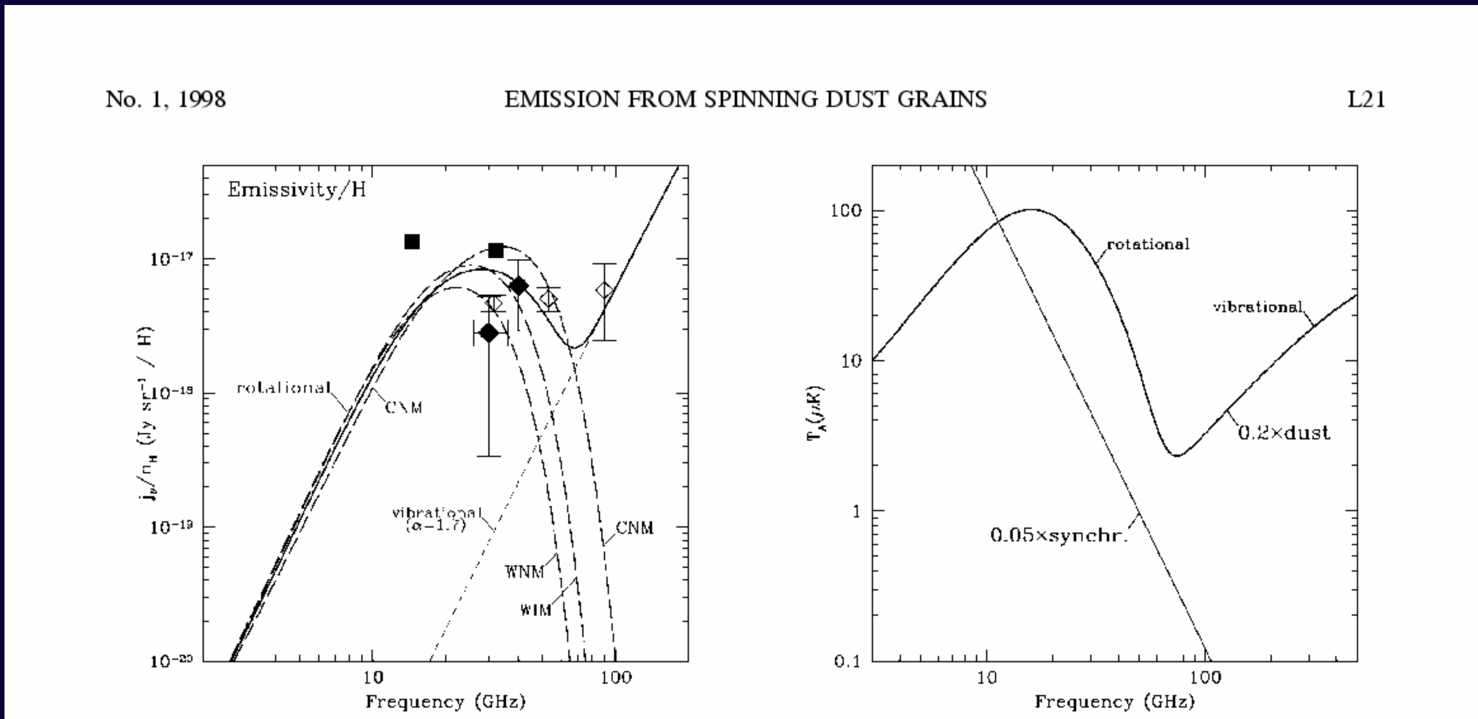
Diffuse Galactic emission

- Synchrotron radiation
- Free-free emission
- Thermal emission from dust particles
- Anomalous microwave emission
    - Cross-correlations of CMB data with far IR maps have shown the existence of a microwave emission component whose spatial distribution is traced by these maps

Anomalous microwave emission: the Foreground X?

- Evidence has been claimed by
  - Kogut et al. 1996 using COBE DMR data (7.1±1.7 μK at 53 GHz on a 7º scale)
  - Leitch et al. 1997 using OVRO data
  - de Oliveira-Costa et al. 1997 using Saskatoon (17.5 ±9.5 μK at 40 GHz on a 1º scale)
  - de Oliveira-Costa et al. (1998, 1999, 2002, 2004) using Tenerife maps (71.4 ±14.2 μK , 51.4 ±8.0 μK at 10 and 15 GHz, on a 5º scale)
  - Ganga and Hamilton (2001) using South Pole 94,
  - Banday et al.2003
- This component appears to have a rising spectrum towards low frequencies incompatible with thermal (vibrational) dust emission.
- Only marginal correlation with Hα.

Anomalous microwave emission: Spinning dust in the Galaxy?



- Electric dipole radiation associated to spinning dust has been proposed by Drain and Lazarian (1998). The properties of rotating grains suggest a turnover in the spectral energy distribution. Observations in the range 10-30 GHz are key to constrain the models.

The Cosmosomas Experiment

aimed to measure COSMOlogical Structures On Medium Angular Scales

Consists of two circular scanning instruments operating at four different frequencies in the range 10-17 GHz.

Located at Teide Observatory (altitude 2400m) Tenerife

IAC team:

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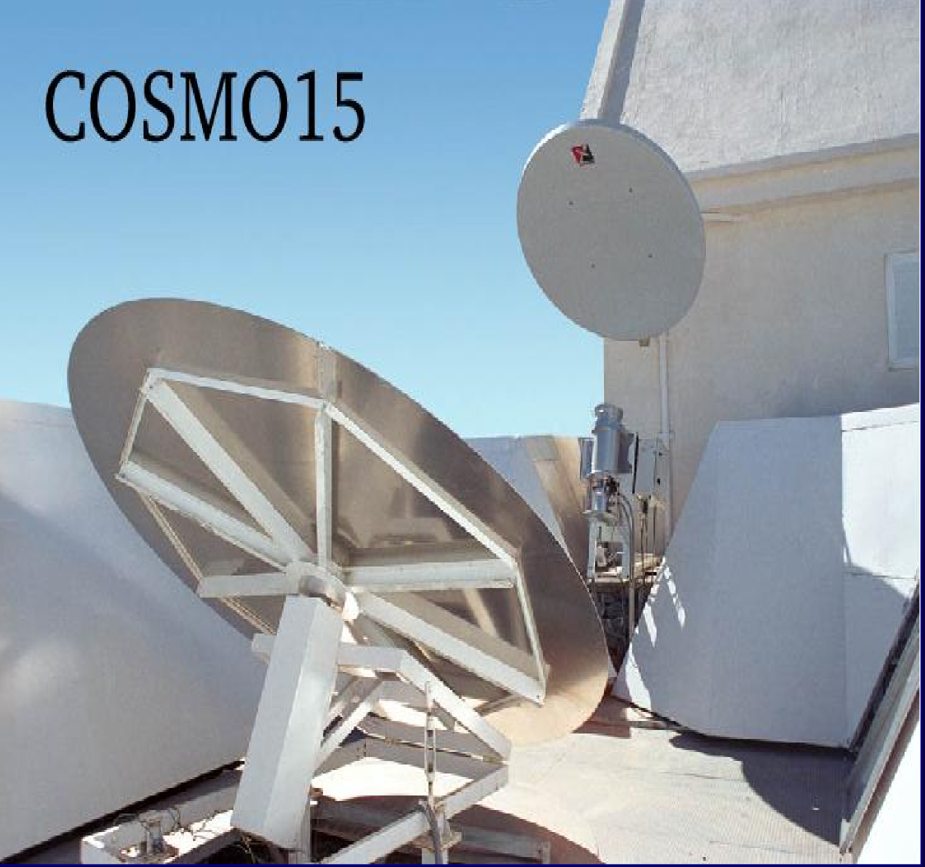
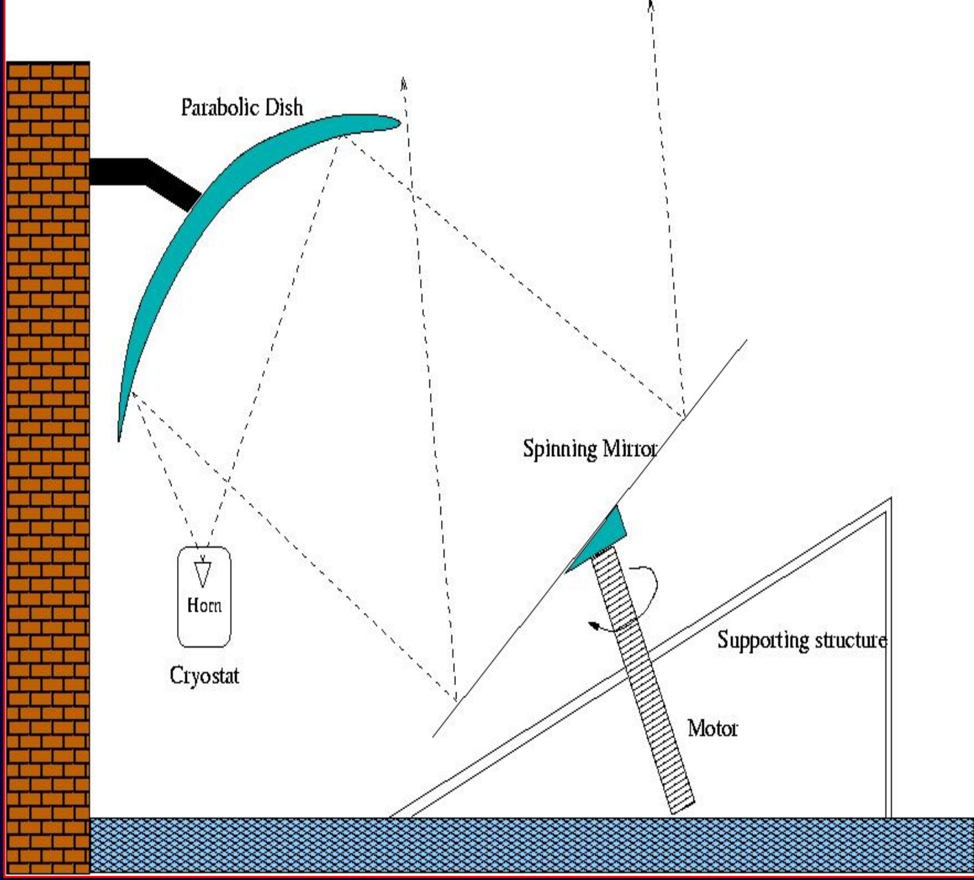
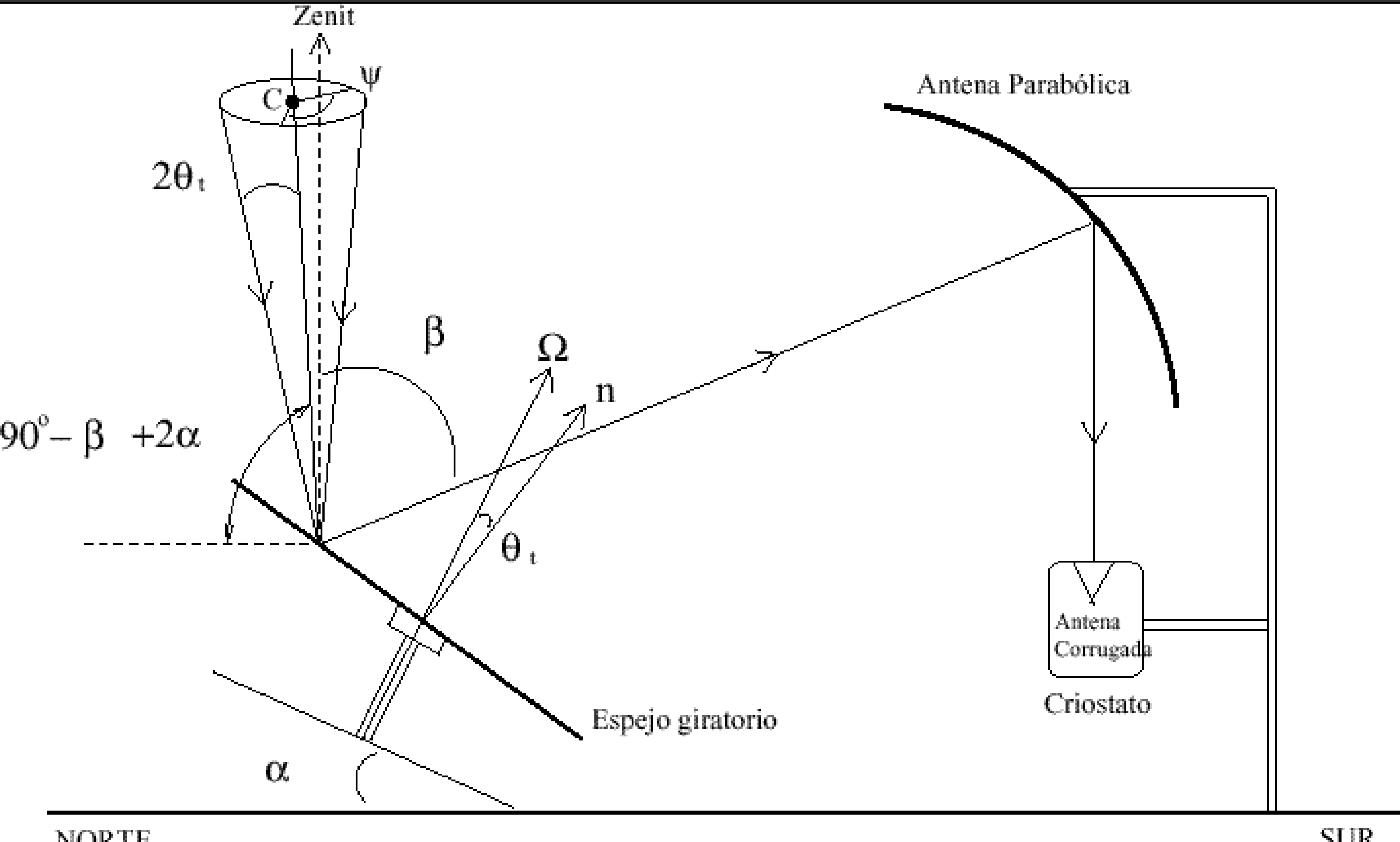


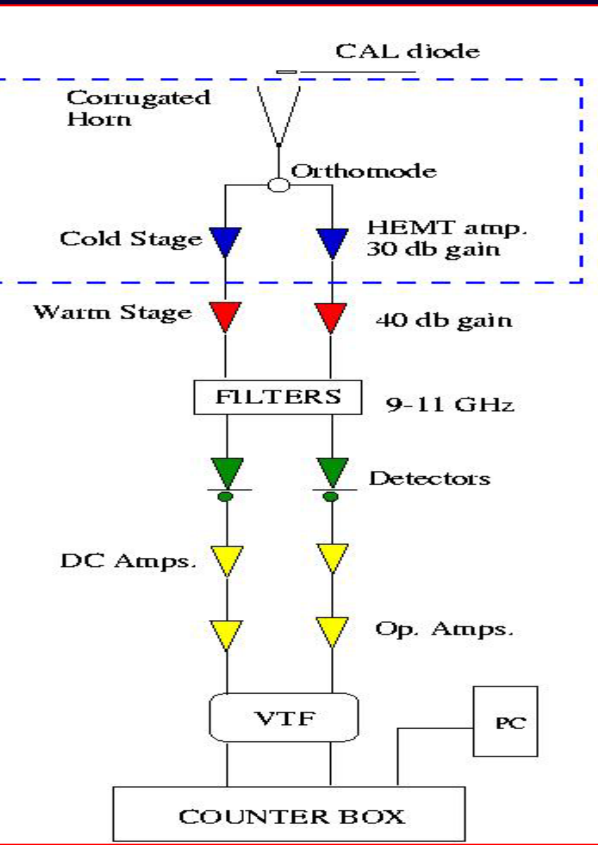


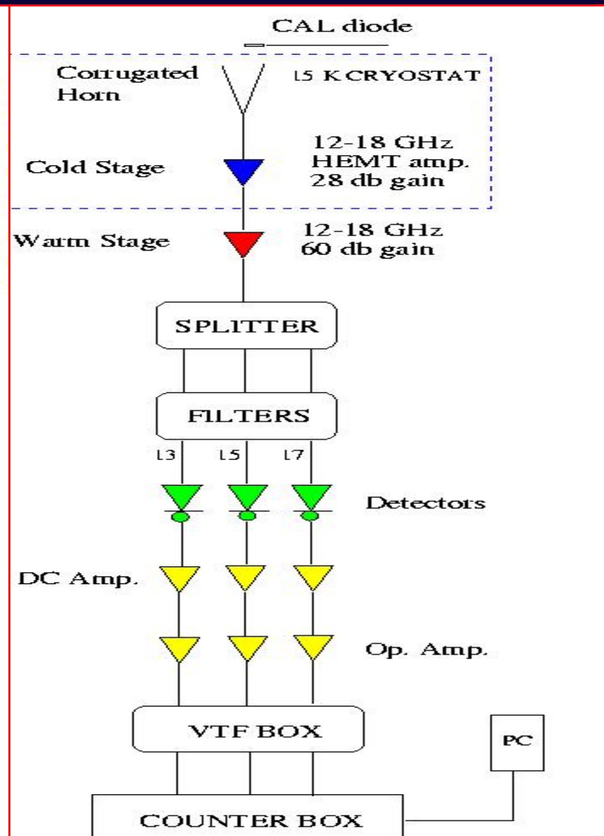
COSMO15 at Teide Observatory.

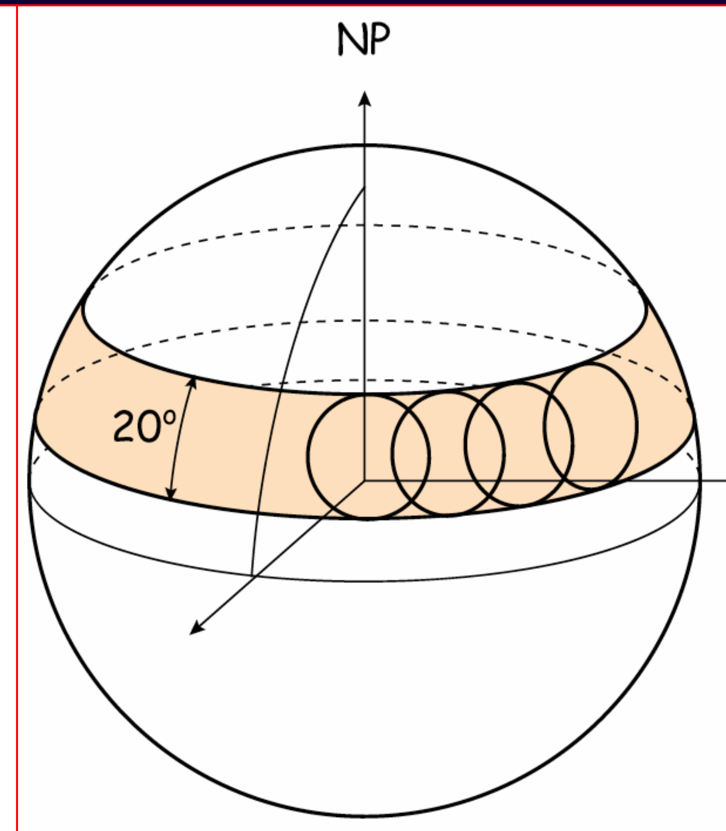
Left: Instrumental setup, showing the 2.5 m flat primary mirror, the 2.4 m parabolic, and the HEMT-based receiver cooled at 20 K.

Right,: Optical system. The tilted flat primary rotates at 1 Hz allowing to scan 20 deg circles in the sky in each revolution.


Zenit
ψ
C
$2\theta_t$
β
Ω
n
$90^{\circ} - \beta \;\; +2\alpha$
θ_t
Antena Parabólica
Antena Corrugada
Criostato
Espejo giratorio
α
NORTE
SUR

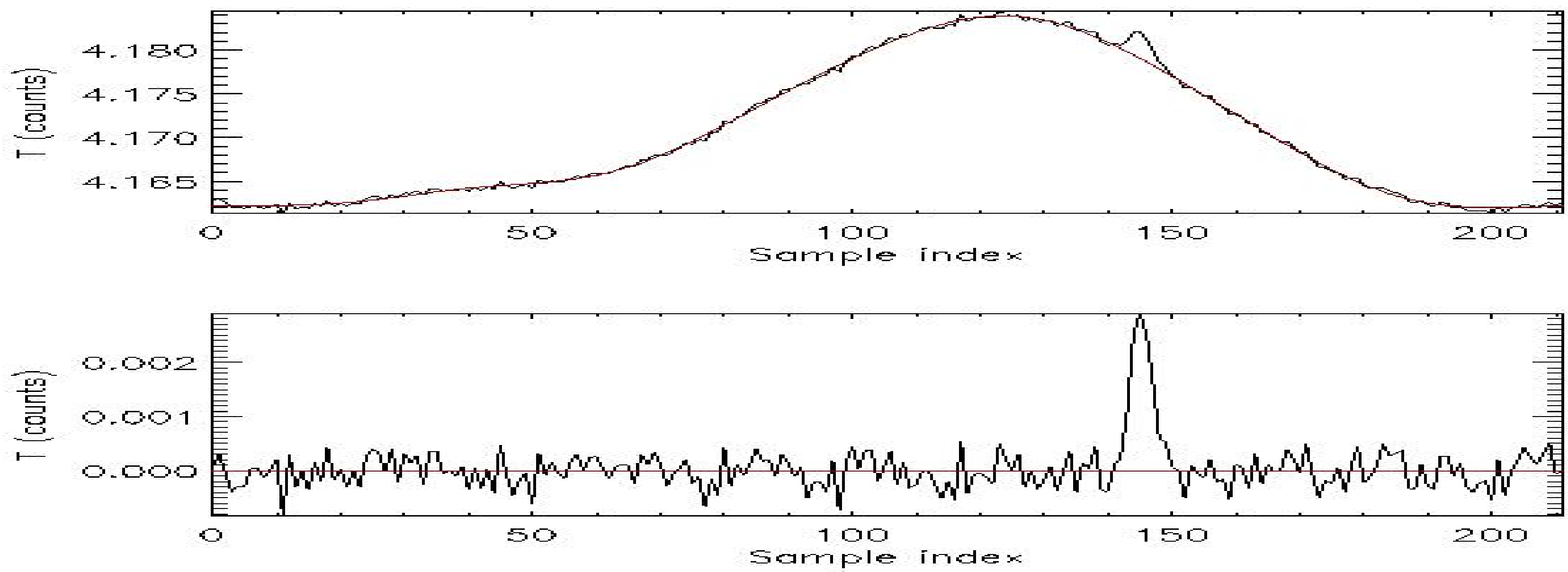






COSMOSOMAS provides 4 daily maps of microwave emission at 11, 13, 15 and 17 GHz with spatial resolution ~1 degree in a sky region of ~7000 sq.degrees. Each map with sensitivity of ~ 900 μK/beam.

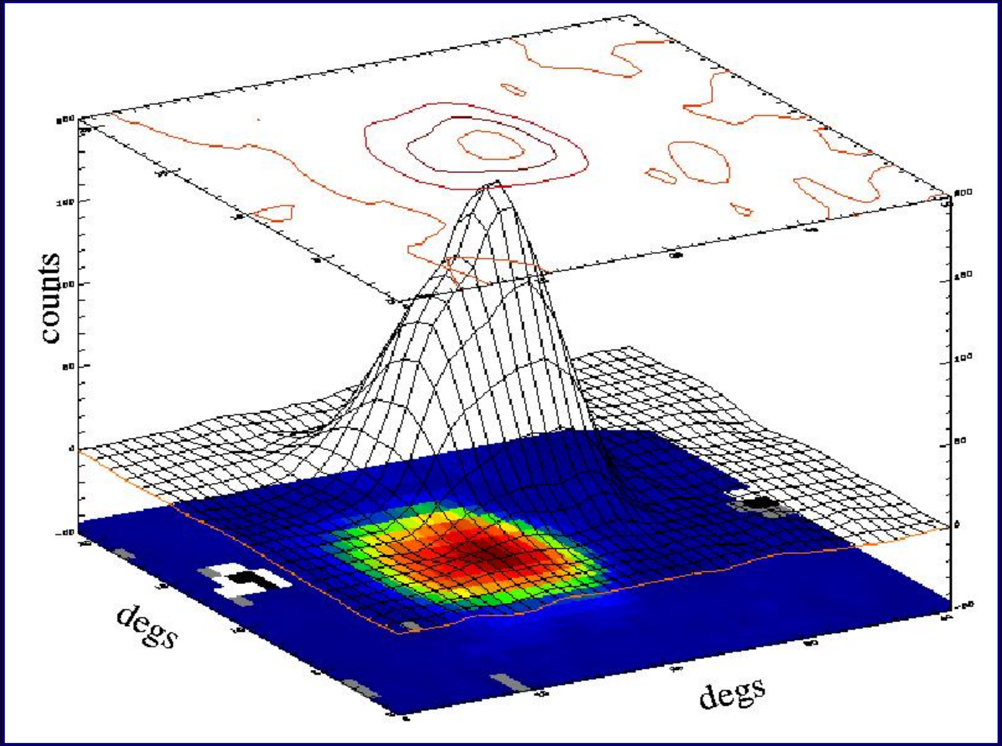
Signal recorded during one spin of COSMOSOMAS and atmospheric demodulation



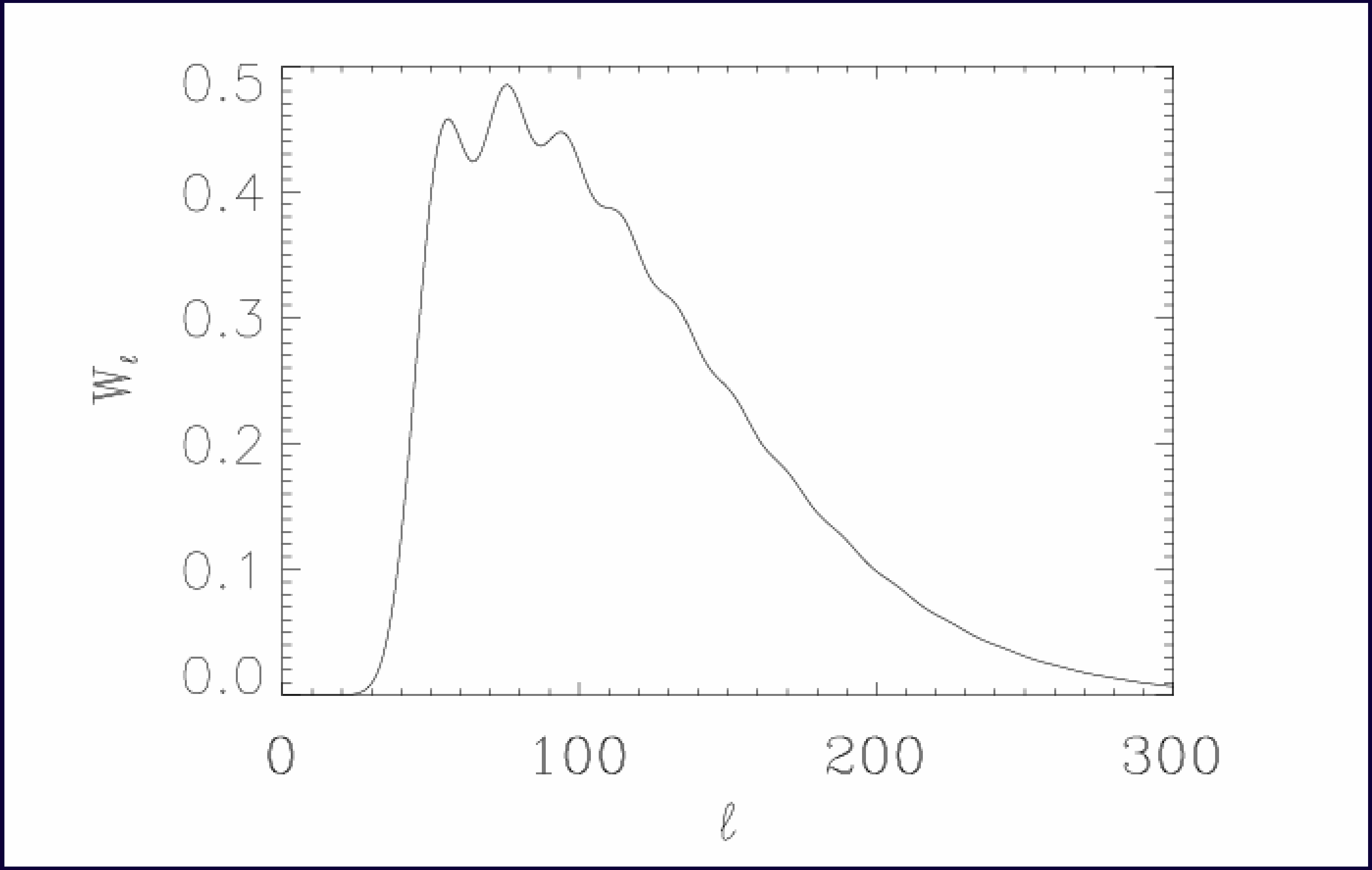
Details of the experiment and data processing:
Gallegos et al. (2001) MNRAS, 327, 1178

Beam pattern:Response to a point source

Daily calibration: Cygnus A and/or Tau A uncertainty ~10 % (Baars et al. model corrected at high frequency with WMAP fluxes)



COSMOSOMAS window function



COSMOSOMAS .
First year of data

About 100 useful maps stocked at each frequency.
25% of the whole sky
200,000 observed data points

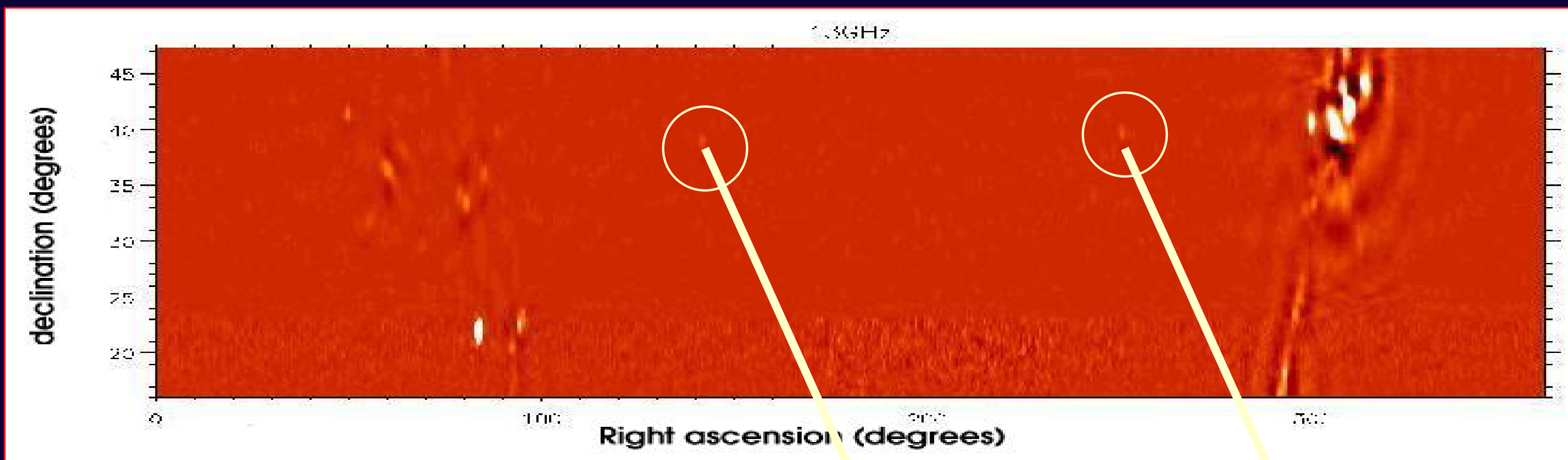
Achieved sensitivity at high Galactic latitude:

~ 90, 90 and 140 $\mu K/beam$

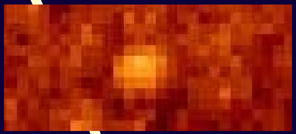
at

13, 15 and 17 GHz, respectively.

COSMOSOMAS_13



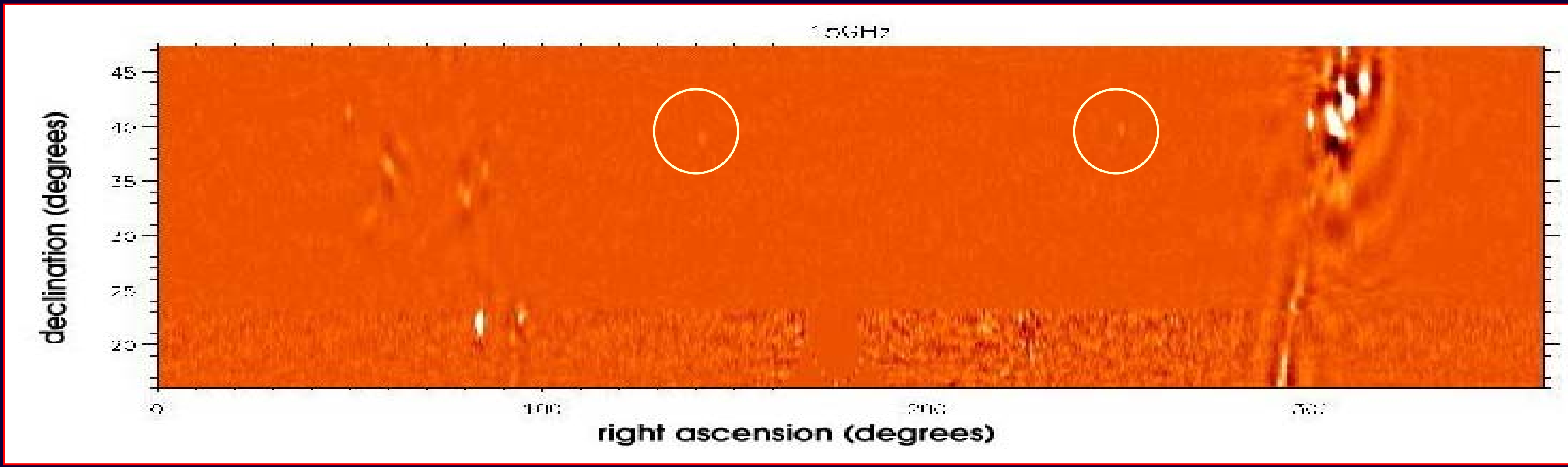
Beam FWHM=54’ x 66’
Pixelization 20’ x 20’
25% of the whole sky



4C39.25
Flux 6.0 Jy

3C345
Flux 6.3 Jy

COSMOSOMAS_15

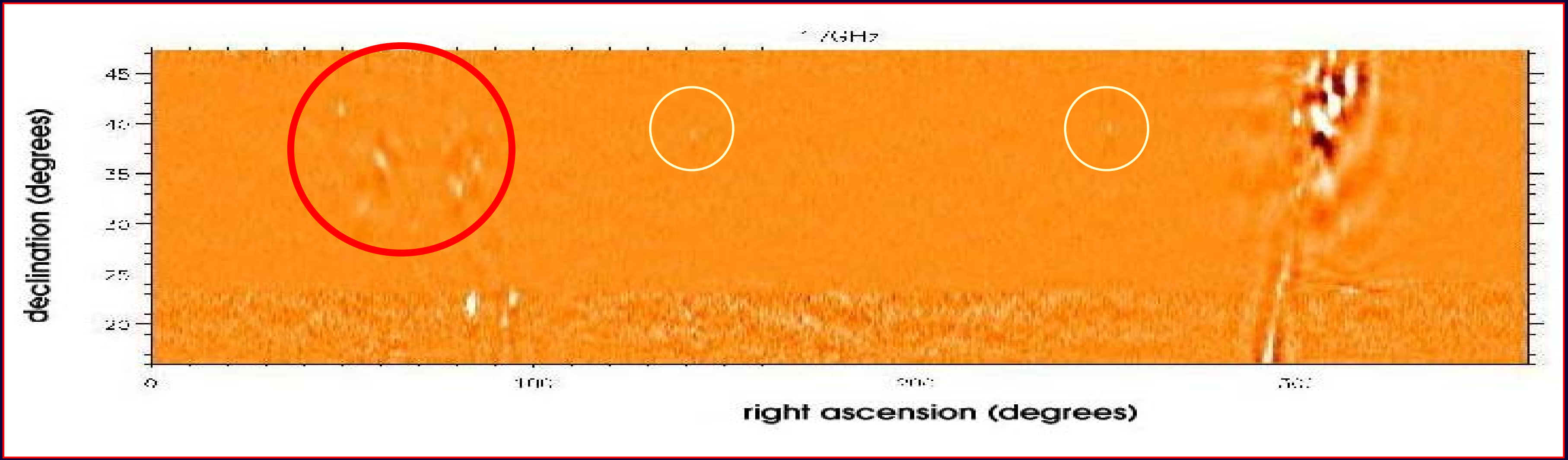


FWHM= 49’ x 60’

Pixelization 20’ x 20’

25% of the whole sky

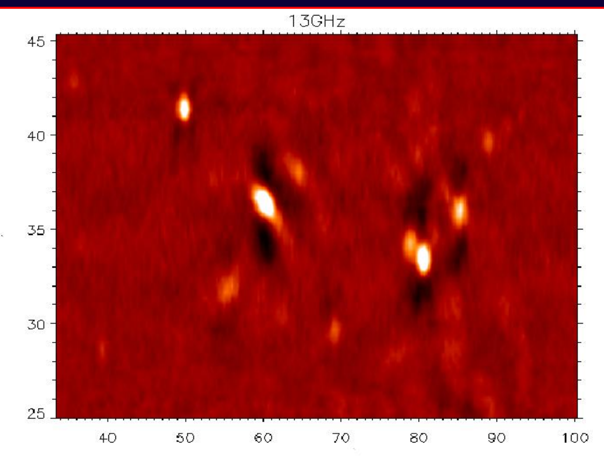
COSMOSOMAS_17

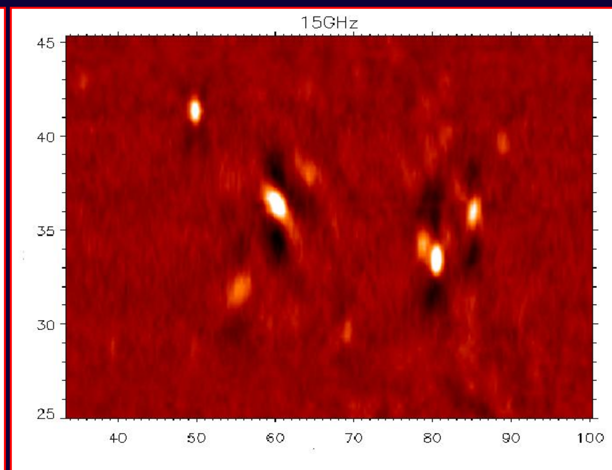


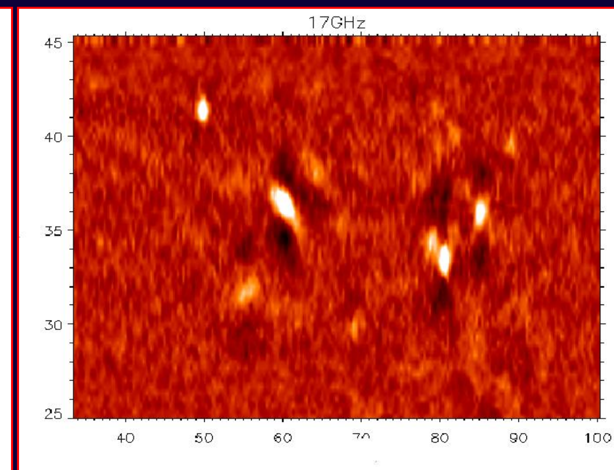
FWHM=46’ x 51’
Pixelization 20’ x 20’
25% of the whole sky

COSMOSOMAS

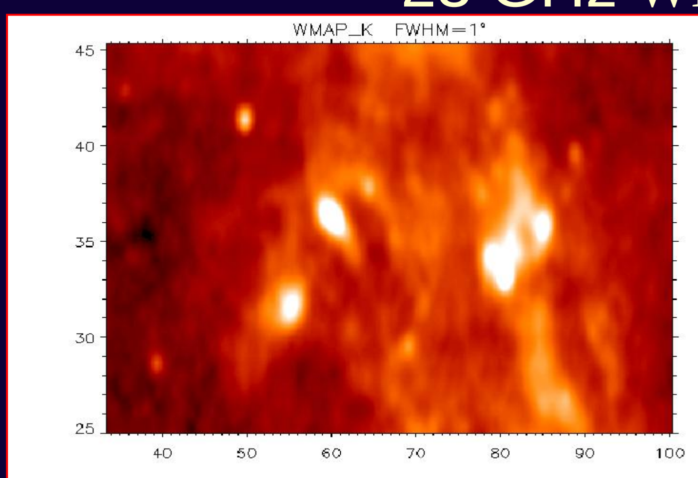
13 GHz 15 GHz 17 GHz

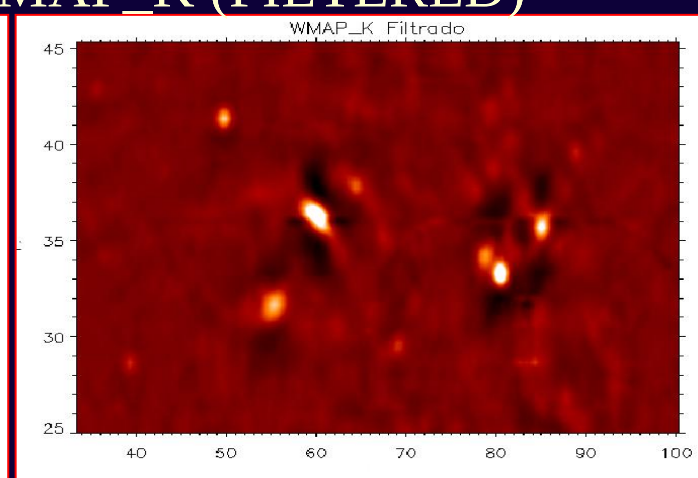






23 GHz WMAP_K (FILTERED)





Cross correlation method

e.g. de Oliveira-Costa 98

$$\vec{y} = \vec{n} + \vec{x}_{cmb} + \alpha\, \vec{x}_{gal} + \vec{y}_{gal},$$

- x_{CMB} contribution of the fluctuating component of the CMB
- x_{gal} brightness fluctuations of the Galactic template map

α converts units of the Galactic template into antenna temperature

y_{gal} represents any residual Galactic contribution which is uncorrelated with x_{gal}

$$C \equiv \langle \mathbf{y}\mathbf{y}^T \rangle - \langle \mathbf{y} \rangle \langle \mathbf{y}^T \rangle = \langle \mathbf{x}_{\mathrm{CMB}} \mathbf{x}_{\mathrm{CMB}}^T \rangle + \langle \mathbf{n}\mathbf{n}^T \rangle$$

where $< \vec{x}_{cmb}\, \vec{x}_{cmb}^T >$ and $< n\, n^T >$ are the covarianze matrix of the CMB fluctuations and the noise respectively.

Cross correlation method

e.g. de Oliveira-Costa 98

In the case of white noise and noise dominating over astronomical signals we have

$$C_{ij} \approx < n_i \, n_j > \approx \sigma_i^2 \, \delta_{ij}.$$

minimizing $\chi^2 = (\vec{y} - \alpha \, \vec{x}_{gal})^T C^{-1} (\vec{y} - \alpha \, \vec{x}_{gal})$ we obtain

the minimum varianze estimator for α,

$$\alpha = \frac{\vec{x}_{gal}^T C^{-1} \vec{y}}{\vec{x}_{gal} C^{-1} \vec{x}_{gal}} \qquad (4)$$

with a varianze

$$\delta\alpha^2 = \frac{1}{\vec{x}_{gal} C^{-1} \vec{x}_{gal}} \qquad (5)$$

In the case of correlated noise or when the amplitude of the CMB signal is significant as compared with the amplitude of the noise, the covarianze matrix C is different. In this case, the expresion 4 gives unbiased estimations for α, but the associated varianze is,

$$\delta\alpha^2 = \frac{\vec{x}_{gal}^T C^{-1} C' C^{-1} \vec{x}_{gal}}{(\vec{x}_{gal}^T C^{-1} \vec{x}_{gal})^2} \tag{6}$$

which is larger that the value given by 5.

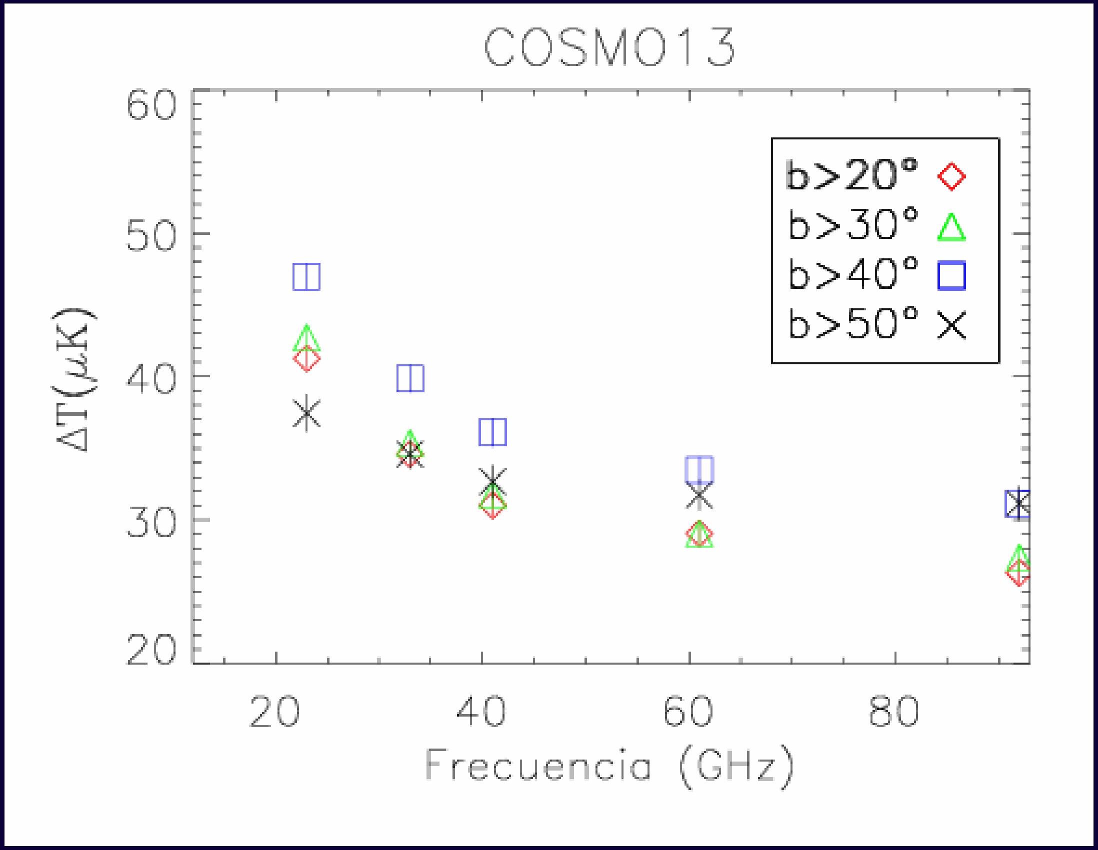
The signal contained in the observations $\vec{y}$, due to the signal present in $\vec{x}_{gal}$, is the result to multiply $\vec{x}_{gal}$, σ_{gal} with the α coefficient,

$$\Delta T \pm \delta\Delta T = \alpha\, \sigma_{gal} \pm \delta_\alpha\, \sigma_{gal}. \tag{7}$$

Masks

We adopt the Kp0 mask for the Galaxy.
We mask point radiosources.

Cross-correlation of COSMOSOMAS and filtered WMAP

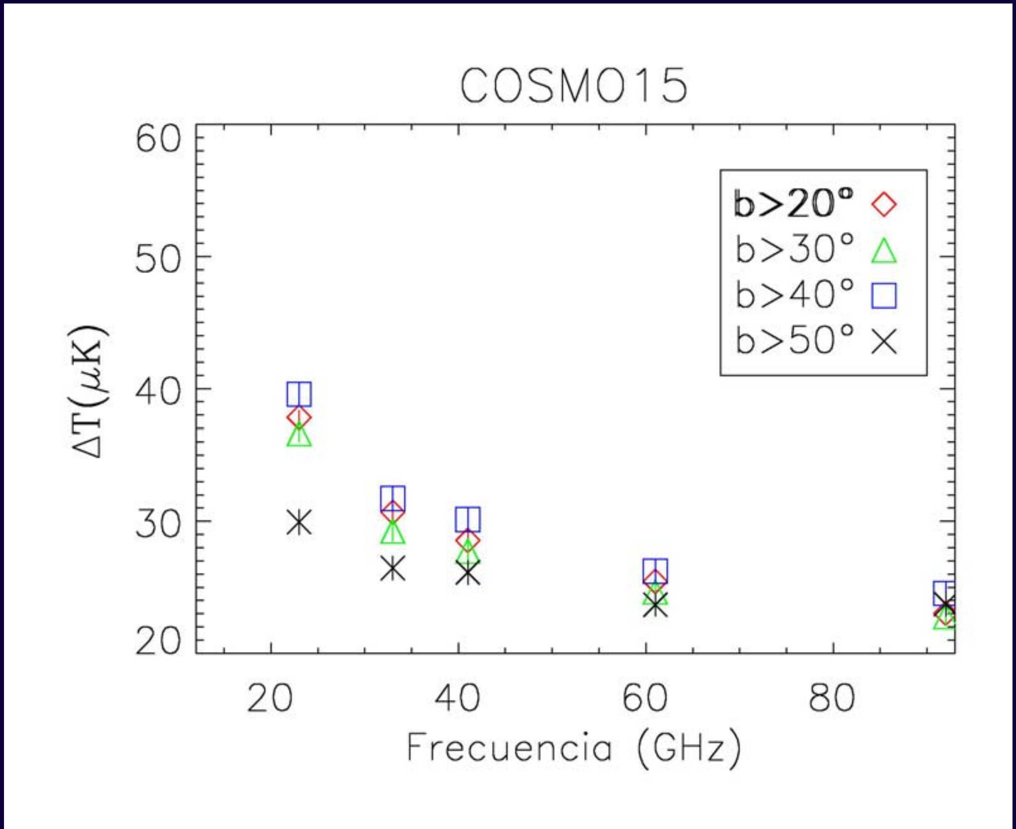


b > 30° →

ΔT_{CMB} = *29.1± 0.8 μK* (WMAP_61, σ=29.0 μK)

ΔT_{CMB} = *27.5± 0.8 μK* (WMAP_94, σ=28.7 μK)

Cross-correlation of COSMOSOMAS and WMAP



b > 30°

ΔT_{CMB} = *24.6± 1.1 μK* (WMAP_61, σ=29.0 μK)

ΔT_{CMB} = *22.8± 1.1 μK* (WMAP_94, σ=28.7 μK)

Cross-correlation COSMOSOMAS and WMAP

$$b > 30° \quad \begin{cases} \Delta T_{CMB} = 33.6 \pm 2.3\ \mu K \text{ (WMAP\_61)} \\ \Delta T_{CMB} = 31.7 \pm 2.3\ \mu K \text{ (WMAP\_94)} \end{cases}$$

Implied CMB fluctuations in antenna temperature in the combined COSMOSOMAS map

b > 30°

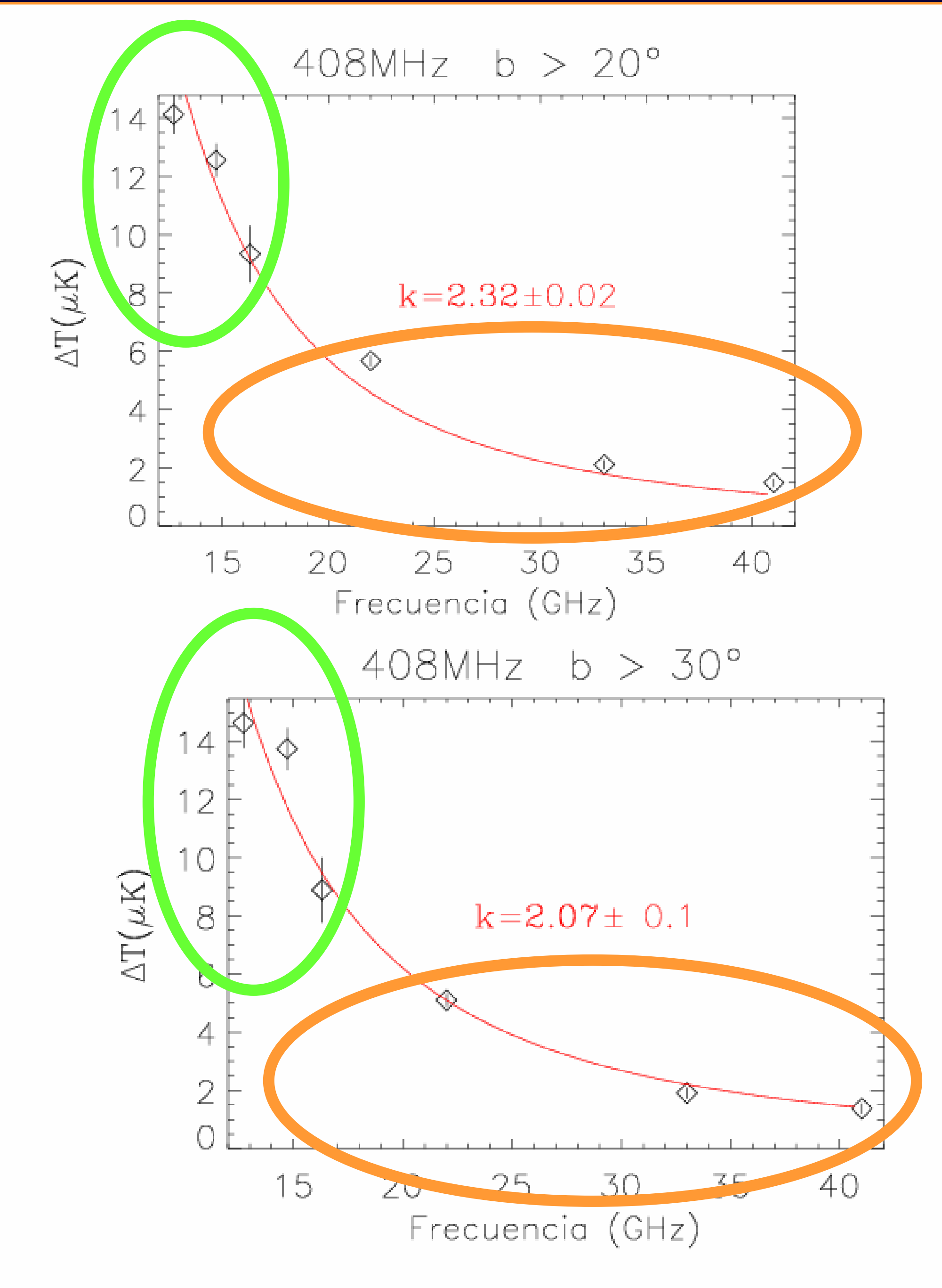
$\Delta T_{CMB} = 29.1 \pm 0.7\ \mu K$ (WMAP_61)

$\Delta T_{CMB} = 27.3 \pm 0.7\ \mu K$ (WMAP_94)

Monte Carlo simulations: pixels of template maps are re-arranged in random order.

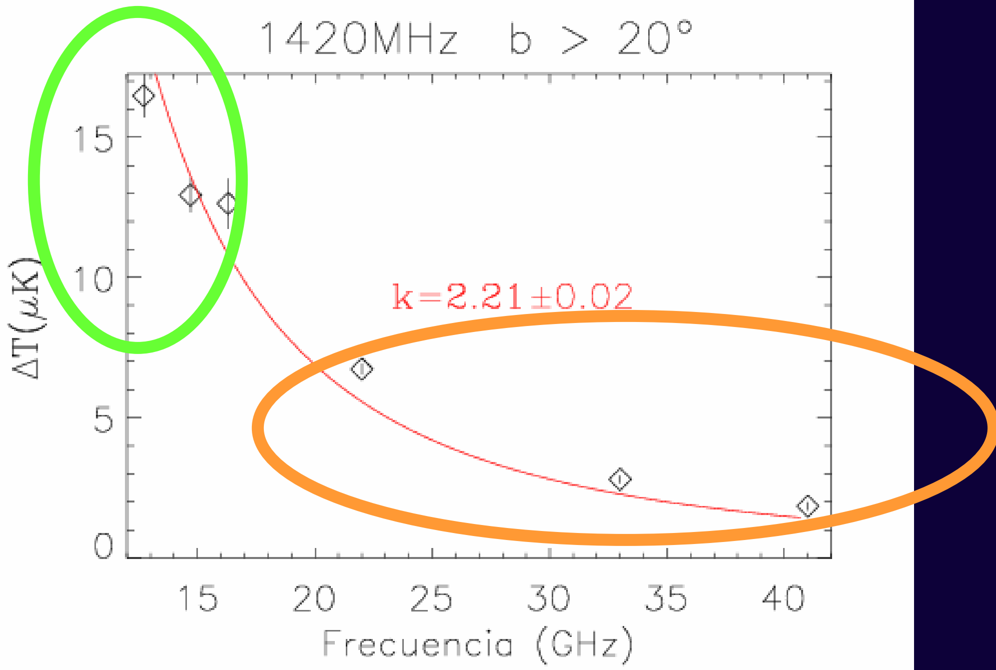
We find the distribution of the α´s consistent with zero mean and with standard deviations about a factor 1.2 larger than the formal errors.

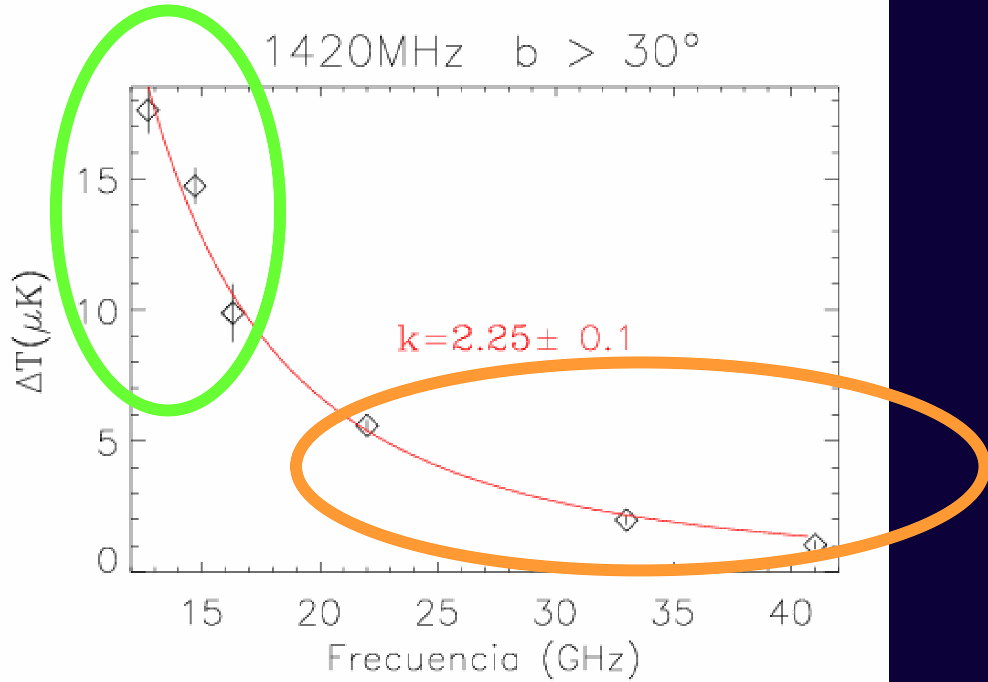
Correlation with Haslam 408 MHz



COSMOSOMAS

WMAP





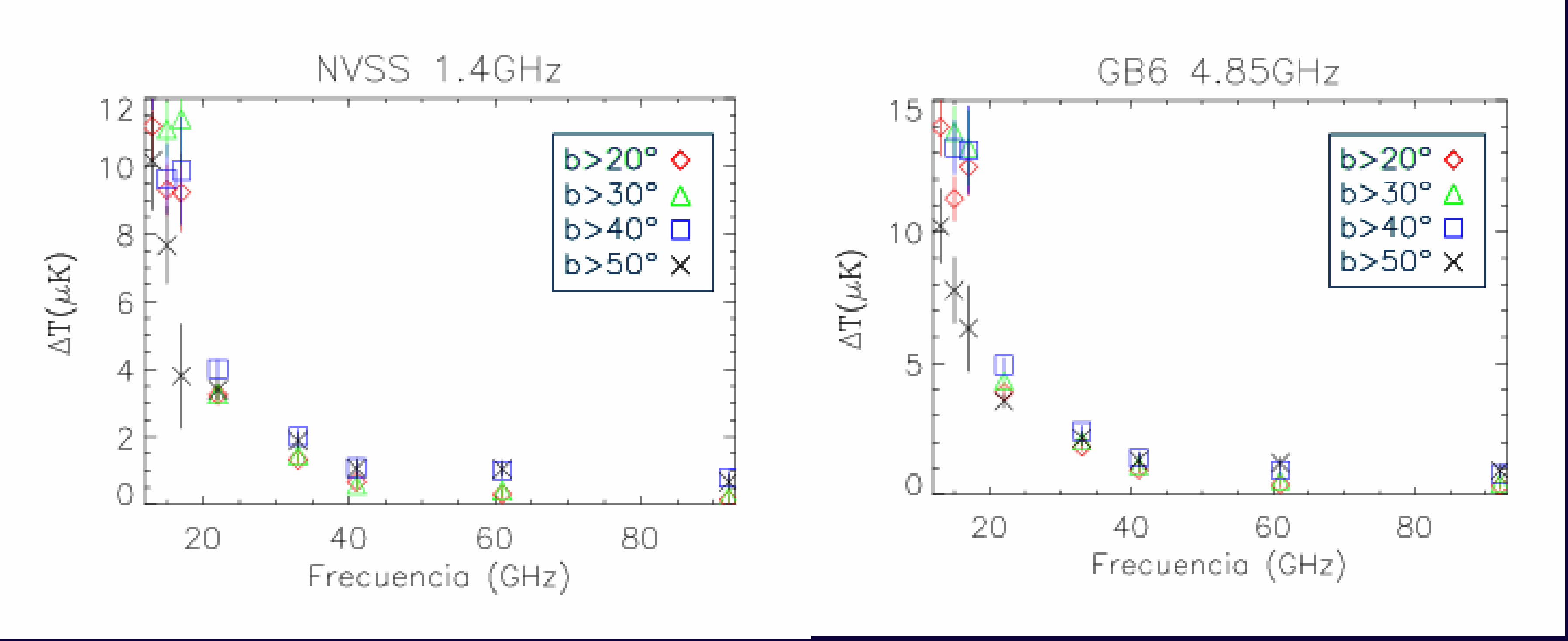
Correlation with 1420 MHz map

Reich and Reich

COSMOSOMAS

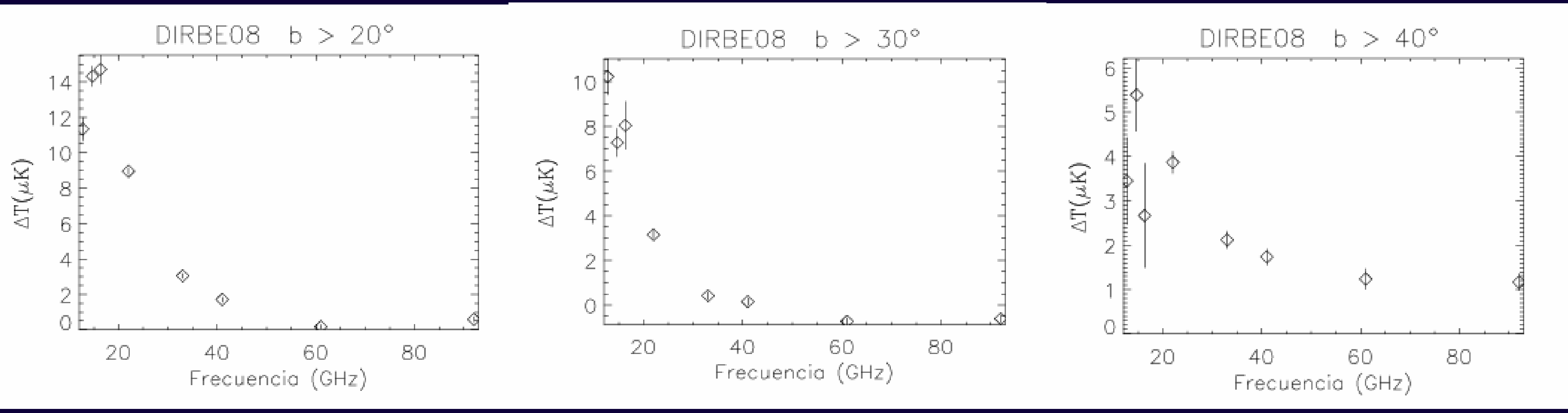
WMAP

Cross-correlation of COSMOSOMAS with Catalogues of radiogalaxies



Contribution from unresolved radiosources?
Toffolati et al. 1998, updated model predict fluctuations in antenna temperature of about 25 μK at 15 GHz.

Correlations with DIRBE 100 μm



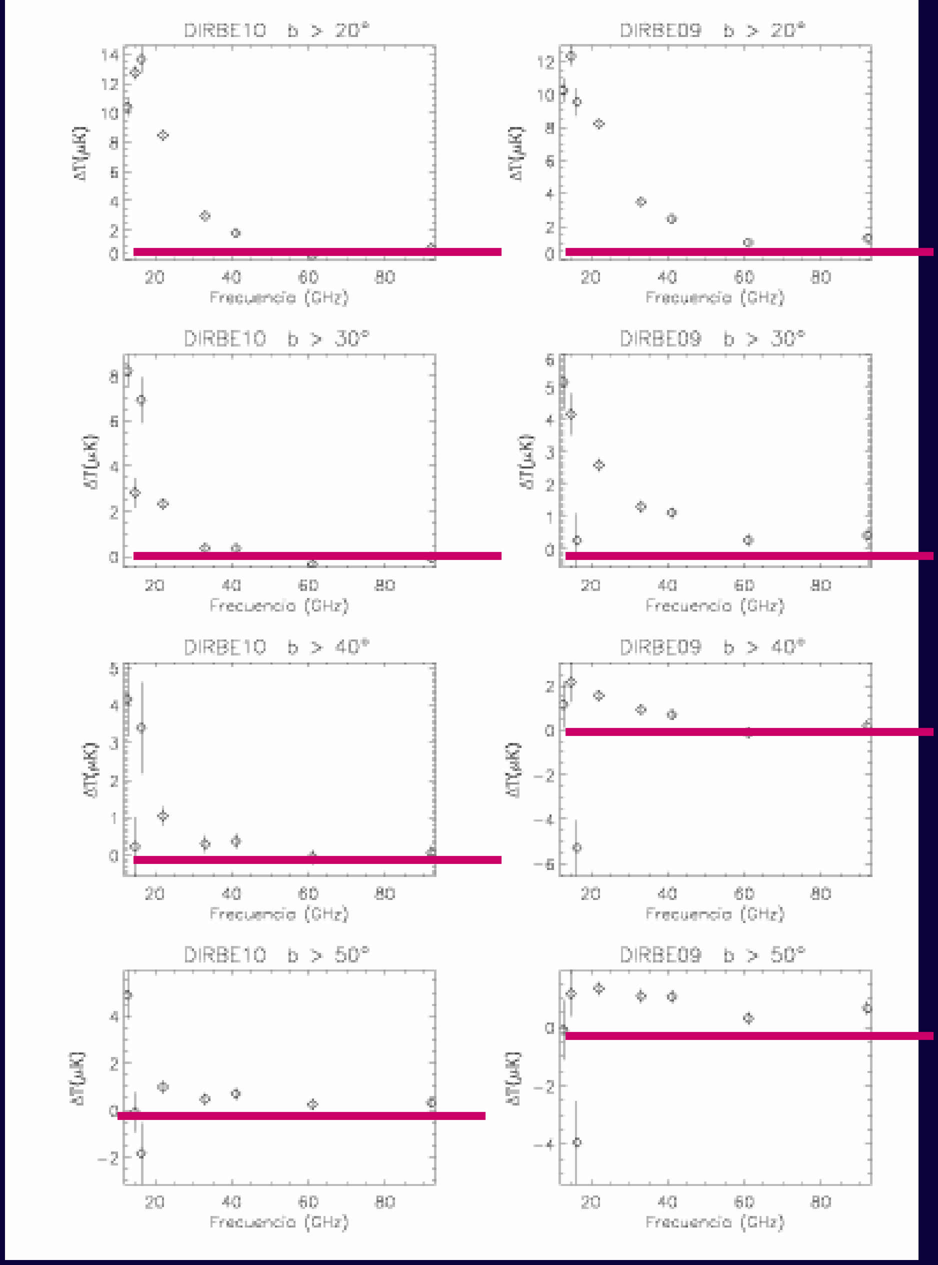
	COSMOSOMAS			WMAP				
	13 GHz	15 GHz	17 GHz	23 GHz	33 GHz	41 GHz	61 GHz	94 GHz
b>20 deg	17.5 ± 1.0	17.8 ± 0.7	18.0 ± 1.0	9.2 ± 0.2	3.5 ± 0.1	2.4 ± 0.2	0.9 ± 0.1	1.2 ± 0.2
b>30 deg	13.4 ± 1.3	7.5 ± 0.8	8.4 ± 1.3	3.9 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	0.1 ± 0.2	0.2 ± 0.2
b>40 deg	5.3 ± 1.6	4.2 ± 1.1	2.8 ± 1.4	4.1 ± 0.3	2.4 ± 0.2	2.1 ± 0.2	1.7 ± 0.2	1.7 ± 0.2

Checking results

Rotation of templates.
We checked our results against template maps rotated around the Galactic poles. The Galaxy was rotated in 10 different angles. We found a zero average correlation. The rms of the correlations appears to be a factor 2 larger than the formal statistical error bar of our cross-correlation method.

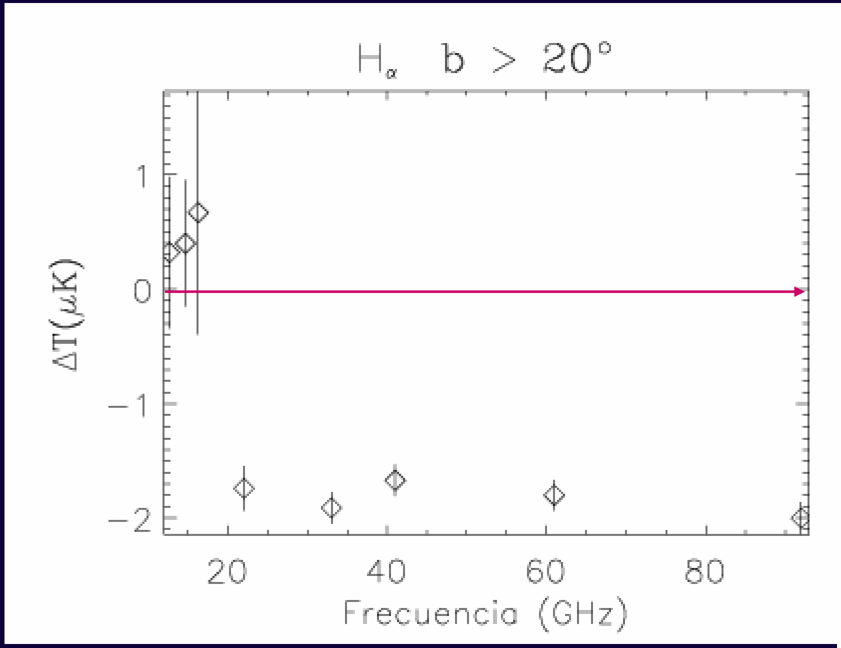
Cross-correlation with DIRBE

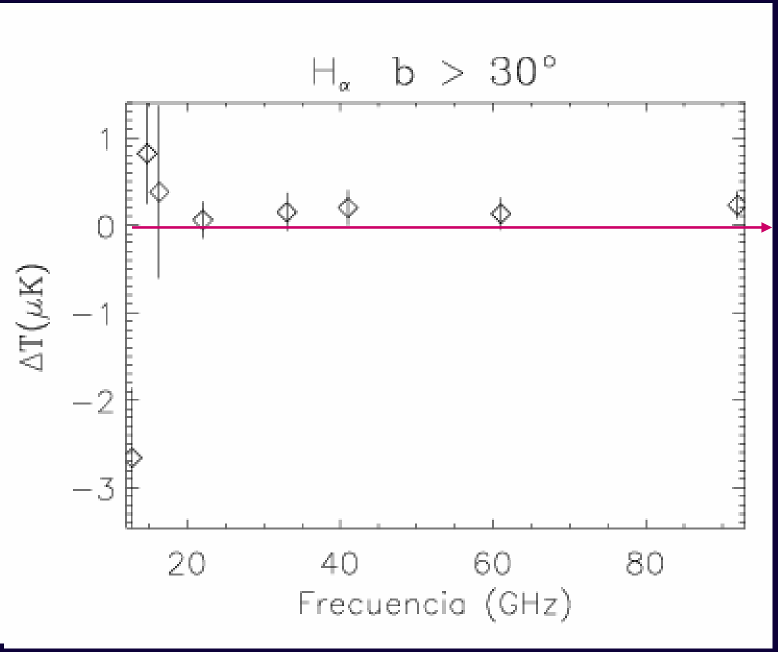
DIRBE10
240 μm



DIRBE09
140 μm

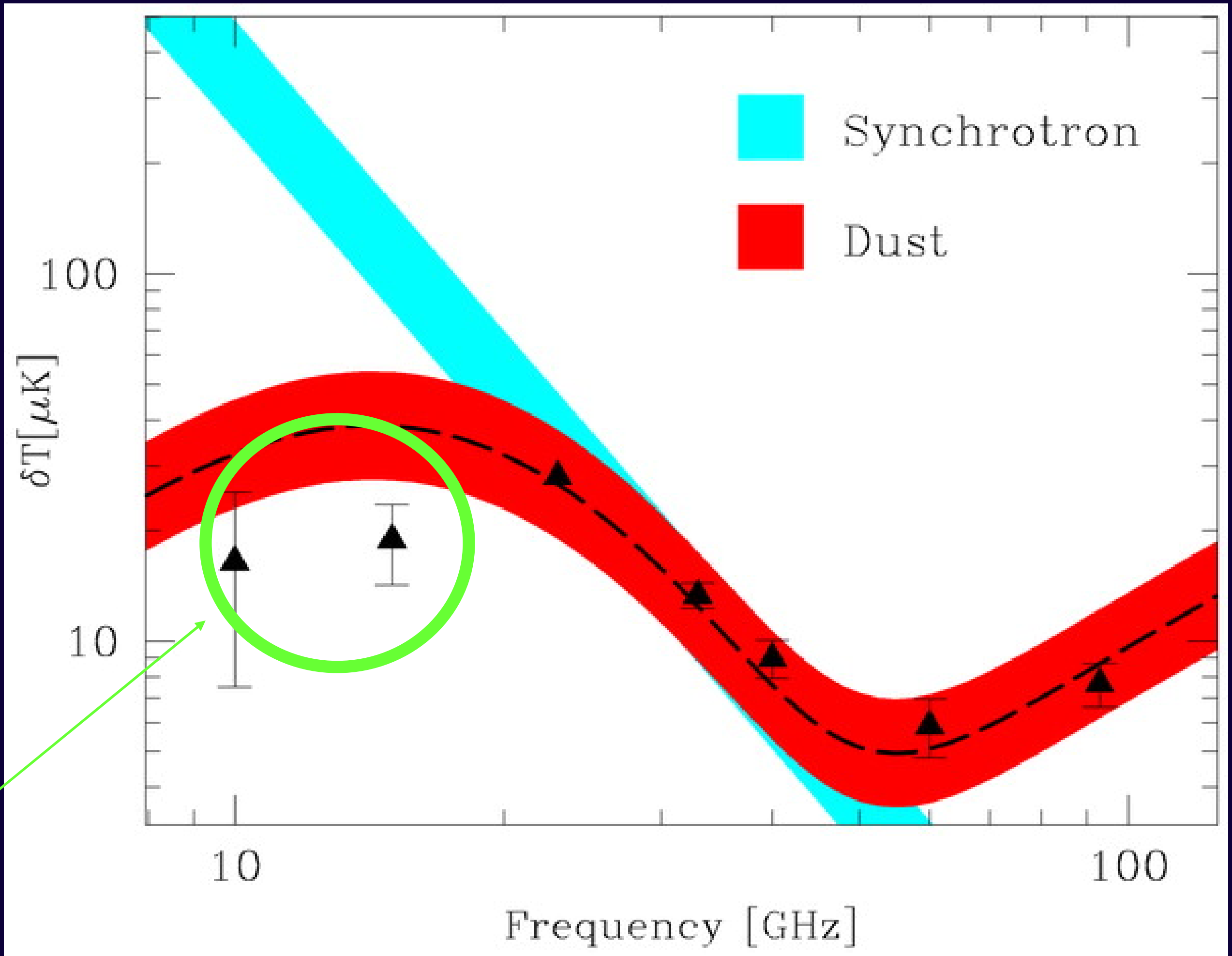
Cross-correlations with Hα maps (Finkbeiner 2003)





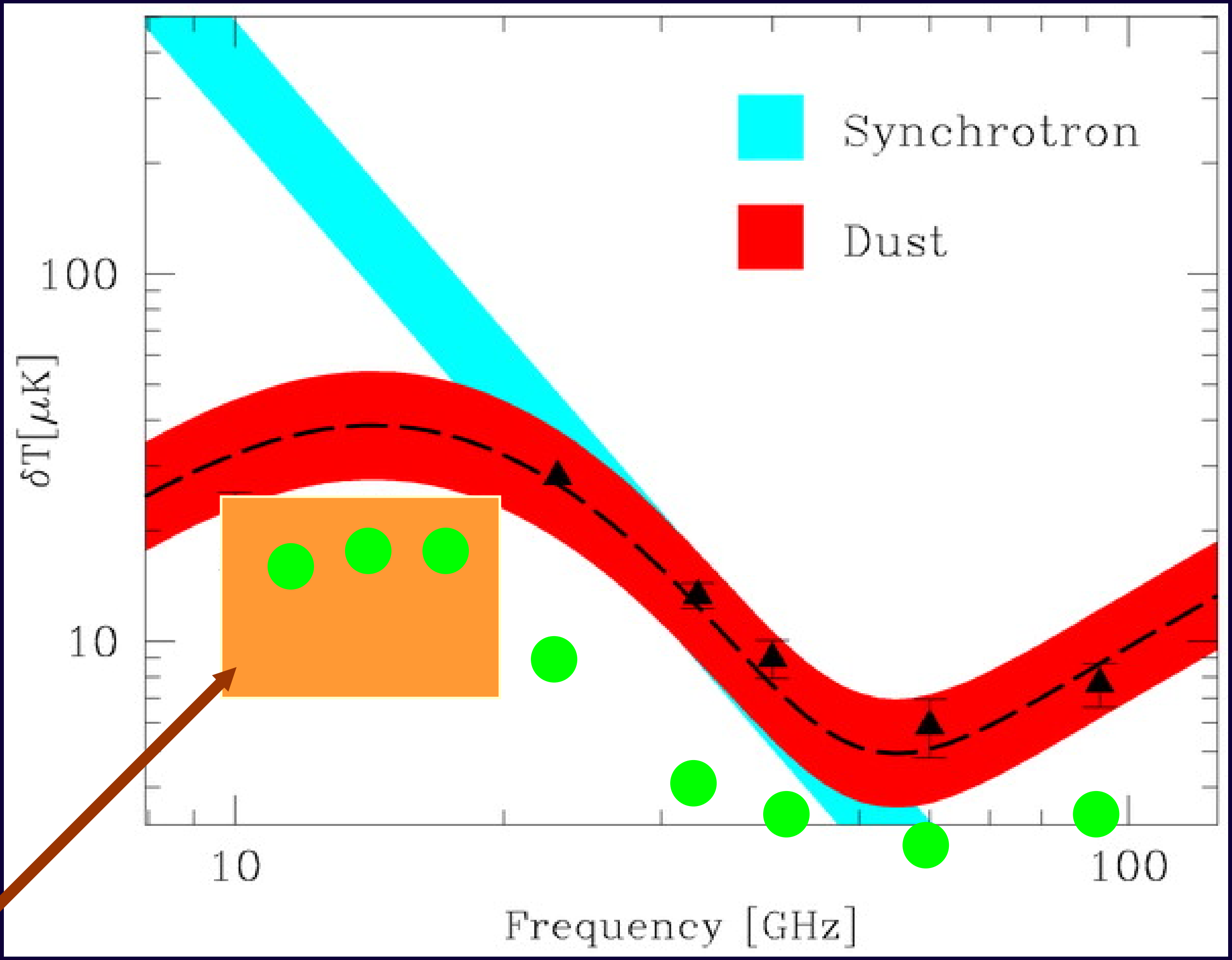
Consistent with zero !

Cross-correlations with WMAP_K "synchrotron map"
Bennet et al. 2003



Tenerife
Experiment 10-15 GHz maps

de Oliveira-Costa et al. 2004



COSMOSOMAS cross-correlation with DIRBE 100 μm, b>20

CONCLUSIONS

- The COSMOSOMAS CMB data agree well with WMAP, detecting the WMAP CMB signal (~29 μK) at about 15σ
- Synchrotron: The COSMOSOMAS data are correlated with 408 MHz and 1420 MHz maps. The antenna temperature - frequency dependence of the Haslam-correlated signal is described with a power-law with index $|\nu| < 2.3$.
  - Contamination by unresolved radiosources at the frequencies and angular scales of the COSMOSOMAS data may explain this small value for the index..

CONCLUSIONS

- The DIRBE-correlated signal may turn out to be the dominant foreground seen by COSMOSOMAS.
  - It decreases significantly as we go to higher Galactic latitudes and higher frequencies. Most of the signal is detected between 20< b <40.
  - The largest correlations are found with the100 μm map.There are significant detections (>2 σ) at 140 and 240 μm.
  - The DIRBE-correlated signal is also detected in all the frequencies of WMAP. At b>20 it contributes less than 5% to the antenna temperature fluctuations in WMAP_Q and progressively less as we increase the frequency
  - We find a remarkable agreement with predictions from spinning dust models.