CMB observations from MITO

Millimetre & Infrared Testa Grigia Observatory

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Summary

- MITO telescope and Testa Grigia observatory
- Foto-MITO
- S-Z on Coma cluster and H_0 determination
- T_{CMB} *vs* z @ galaxy cluster
- 2004 observational campaign: disentangling primary and secondary anisotropy and search for diffuse SZ effect:
  - Observational goals
  - Observational strategy
  - Data analysis
  - **VERY** preliminary results

MITO telescope

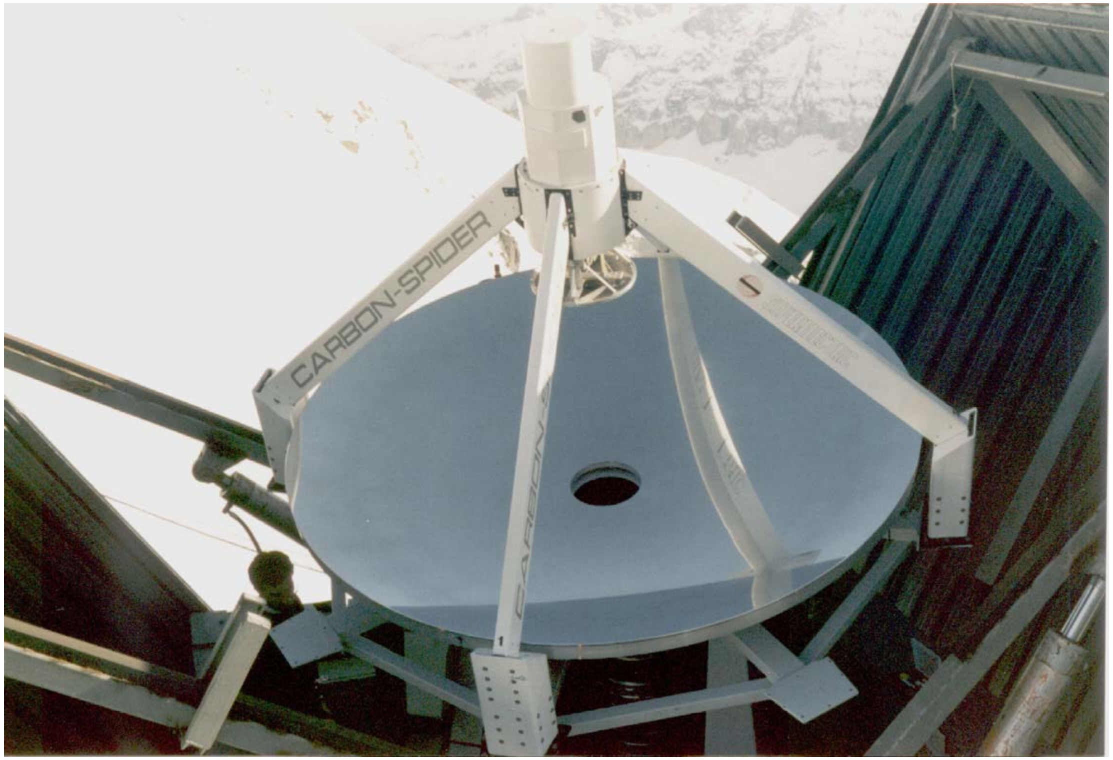
and

Testa Grigia observatory

MITO telescope

- Cassegrain in altazimuthal configuration with 2.6 m primary mirror optimised for differential measurements

- Wobbling secondary mirror around a neutral point digitally controlled: 2 or 3 fields modulation



- Signal modulation and demodulation through lock-in amplifiers

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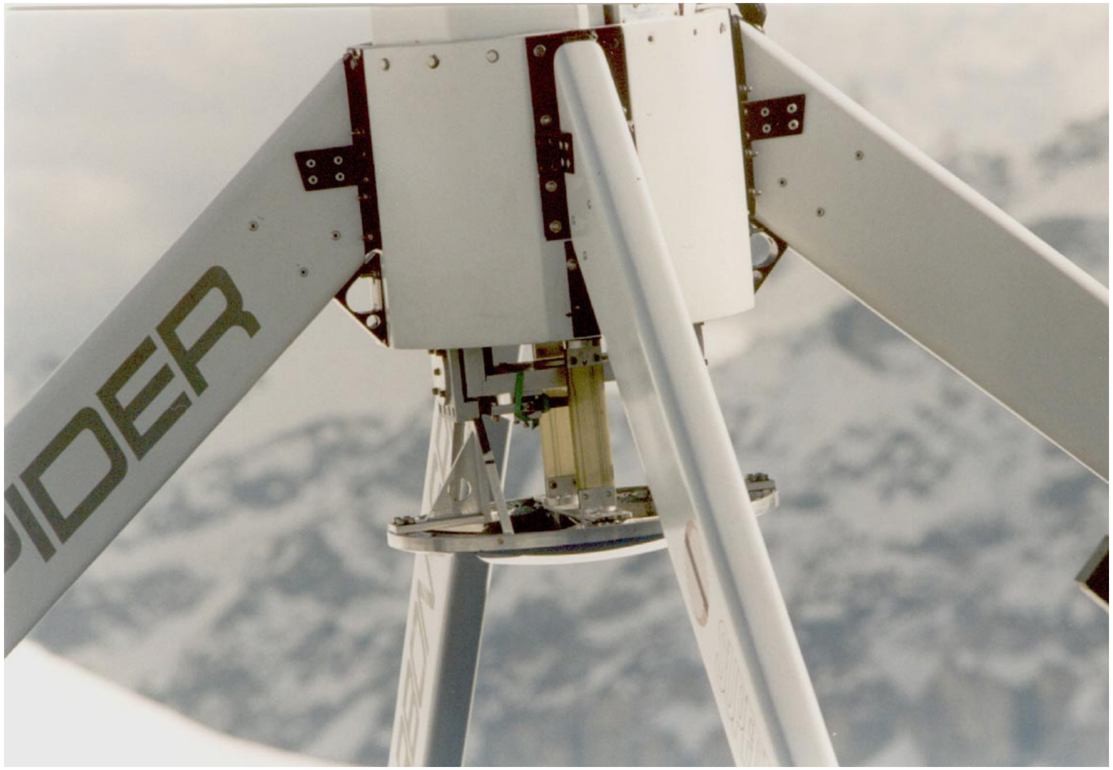
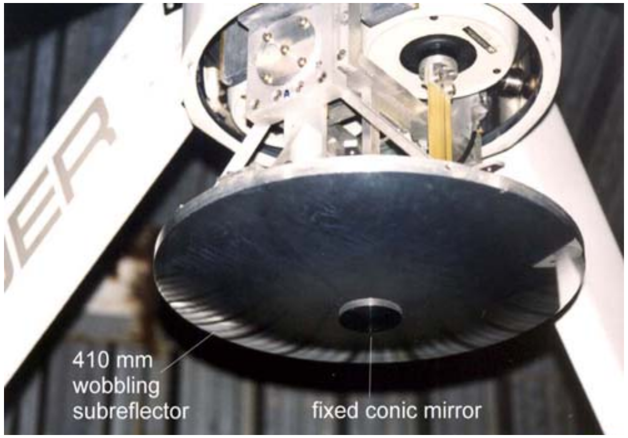
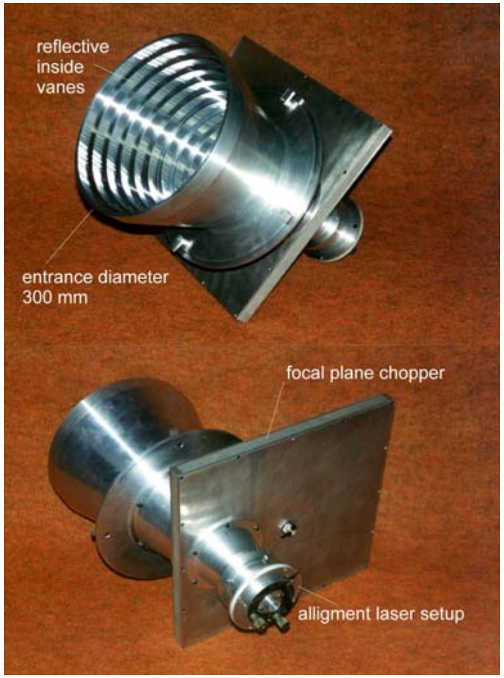


- Signal modulation and demodulation through lock-in amplifiers

MITO telescope

- Reduction of systematics:
  - Conical mirror on the secondary mirror (avoids Narcissus effect)
  - Primary mirror shields with vanes (stabilizes the offset)
  - Baffle in the primary hole (reduces the emissivity of the hole)





Testa Grigia observatory

– Testa Grigia observatory –

– Plateau Rosà –

– Valle d'Aosta – Italy –

– 3480 m a.s.l. –

– 45° 56' 03" N – 07° 42' 26" E –

- Precipitable water vapour along telescope l.o.s. is responsible of transmittance @ mm wavelengths
    - Low water vapour content
    - High atmospheric transmission
    - Stability between channels: high correlation and Gaussian (single mode) distribution of ratios

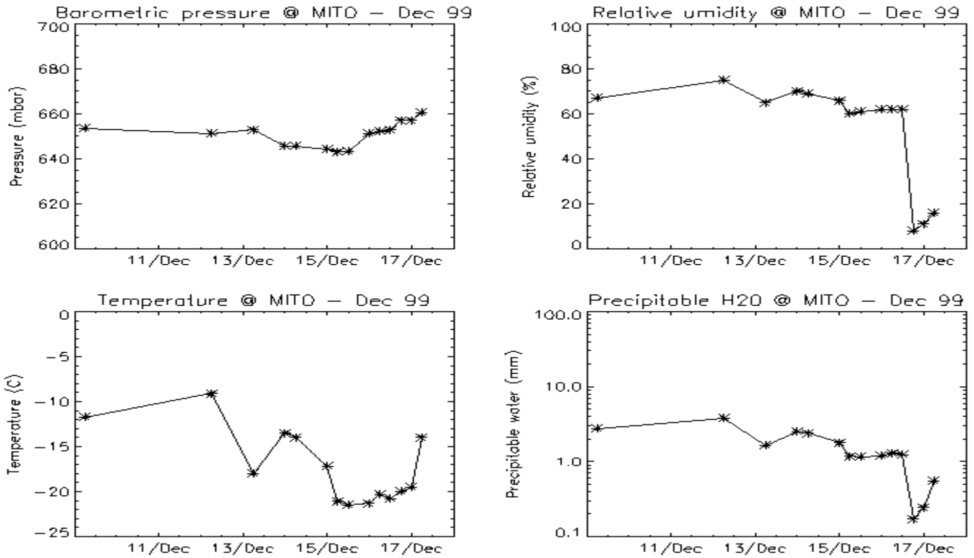
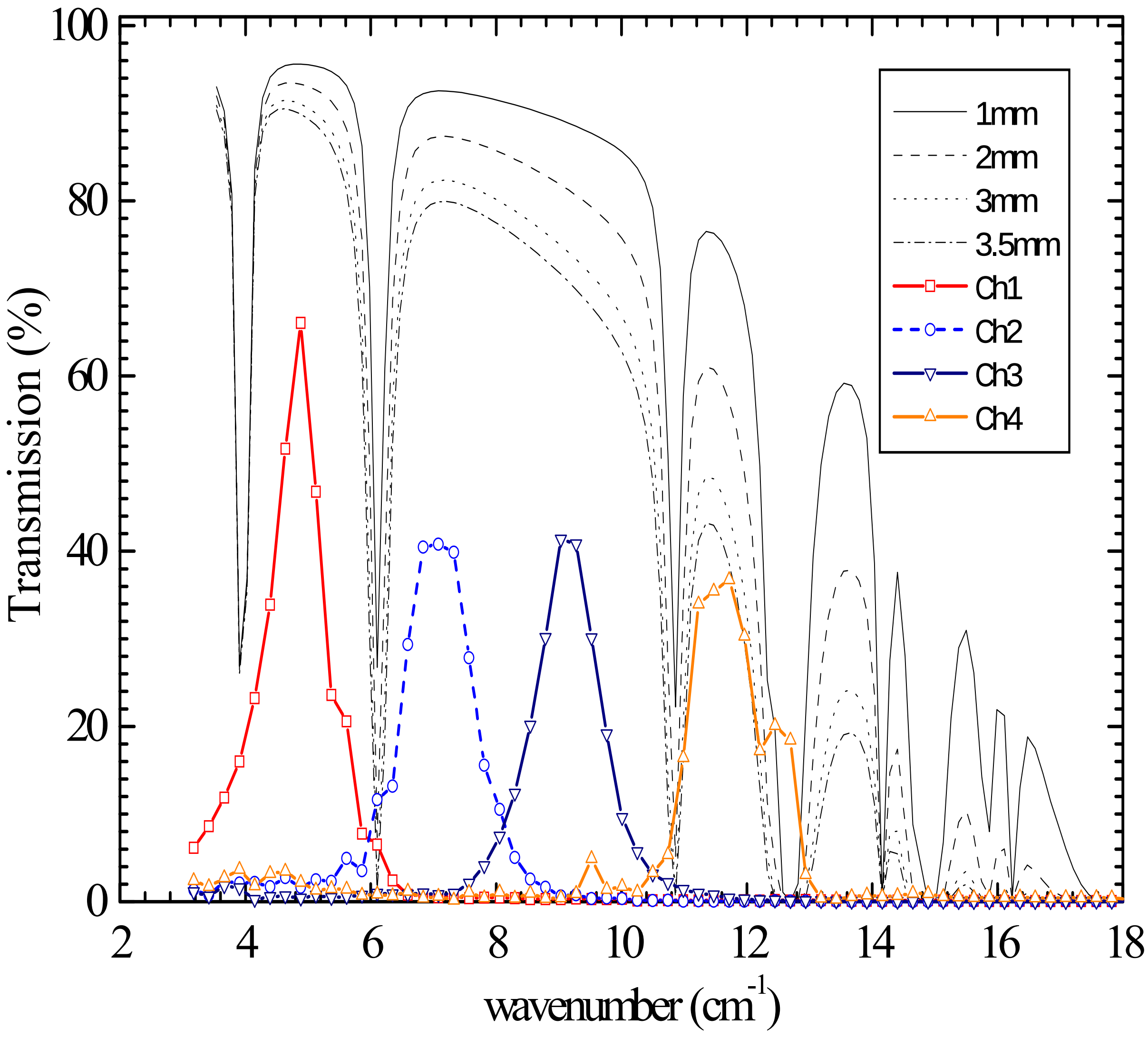


Foto-MITO

Foto-MITO frequencies



Ch1: ν=143GHz Δν=30GHz

Ch2: ν=214GHz Δν=30GHz

Ch3: ν=272GHz Δν=32GHz

Ch4: ν=353GHz Δν=26GHz

4 models for 4 different pwc

Foto-MITO:

-4 channels

-single-pixel / multi-frequency

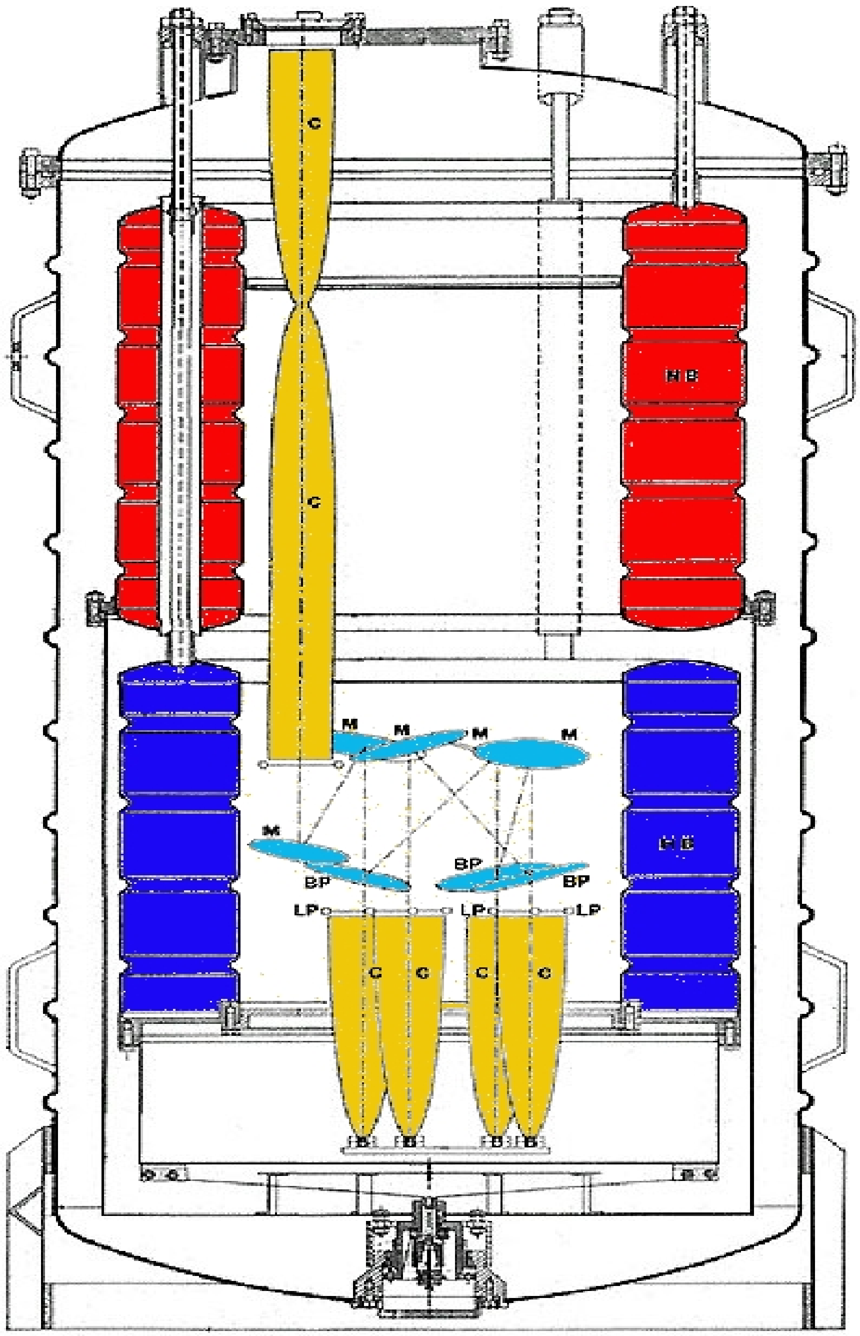
-16 arcmin FWHM (same for the 4 channels)

-cold refocussing optics and multimesh beam-splitters

-Winston cones

-Composite bolometers with NTD germanium thermistor

-Cryostat with bi-stadium closed cycle fridge He^4-He^3: $\Rightarrow$ 290mK



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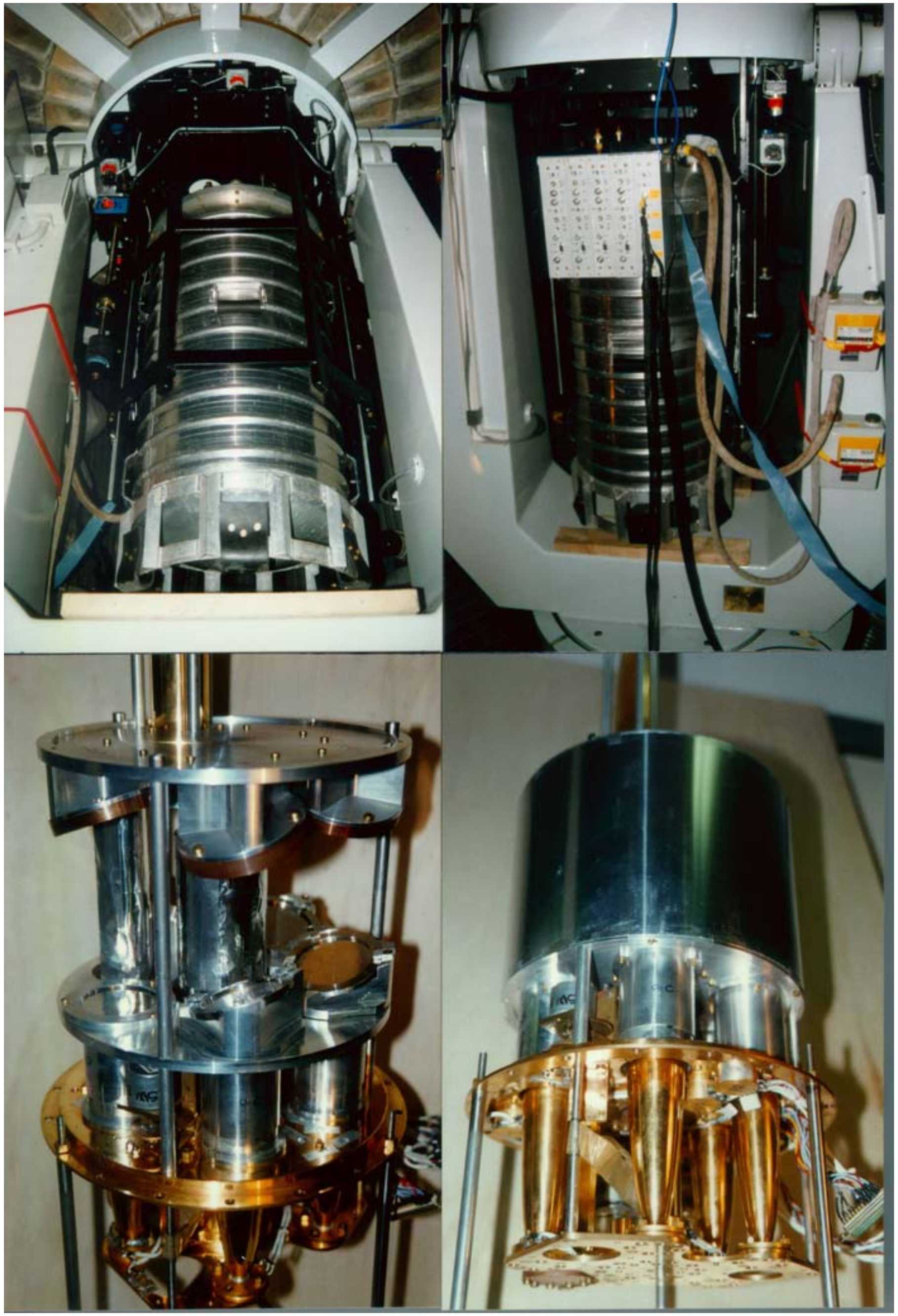


S-Z on Coma cluster

and

H_0 determination

H_0 from S-Z effect and X-ray data

- S-Z effect allows us to determine (MITO+OVRO+WMAP)

$$y = \int n_e(r) \frac{kT_e(r)}{m_e c^2} \sigma_T dl = d_A \int n_e(r) \frac{kT_e(r)}{m_e c^2} \sigma_T d\zeta$$

- Bremmstrahlung X-ray emission (ROSAT)

$$S_X \propto \int n_e^{\,2}(r) \Lambda(T_e) dl = d_A \int n_e^{\,2}(r) \Lambda(T_e) d\zeta$$

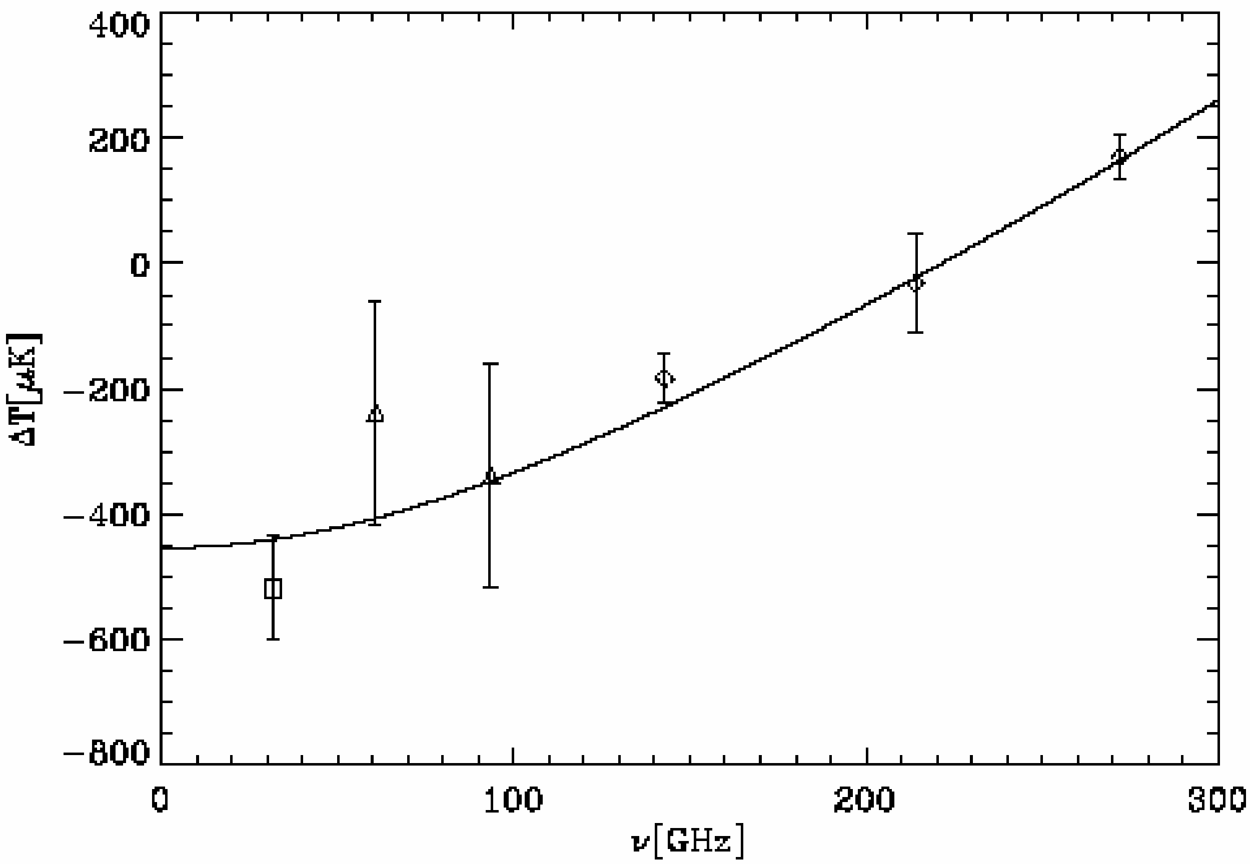
- β-isothermal model *(Cavaliere & Fusco-Femiano A&A, 49, 137, 1976)*

$$n_e(r) = n_{e0} [1 + (r / r_c)^2]^{-3\beta/2}$$

- Combining these two we obtain n_e e d_A

$$H_0 = 4\pi c (1+z)^4 \frac{\sigma_T^2 S_{X0} \theta_c}{\Lambda} \frac{\left(\int f_n \right)^2}{\int f_n^{\,2}} \frac{1}{\tau^2} g(z, \Omega_M, \Omega_\Lambda)$$

S-Z on Coma cluster



MITO

$\Delta T_{143GHz} = (-184 \pm 39)\mu K$

$\Delta T_{214GHz} = (-32 \pm 79)\mu K$

$\Delta T_{272GHz} = (+172 \pm 36)\mu K$

WMAP

$\Delta T_{60GHz} = (-240 \pm 180)\mu K$

$\Delta T_{93GHz} = (-340 \pm 180)\mu K$

OVRO

$\Delta T_{32GHz} = (-520 \pm 83)\mu K$

MITO (*De Petris et al., 2002 ApJ, 574, L119 & Savini et al. , 2003 NA, 8, 727*)

OVRO (*Mason et al. ApJ, 2001 555, L11*)

WMAP (*Bennet et al. ApJ, 2003 148, 97-117*)

ΔSZ stat. 1σ

$\Rightarrow \quad \tau_{COMA} = (5.35 \pm 0.57 \pm 0.10)\ 10^{-3}$

ΔT_e

Results

β non isothermal model

$$T_e = T_{e0}\left(\frac{n_e}{n_{e0}}\right)^{\gamma-1} \Rightarrow T_e(r) = T_{e0}\left[1+\left(\frac{r}{r_c}\right)^2\right]^{-3\beta(\gamma-1)/2}$$

$$\beta \rightarrow \beta_{\mathrm{var}}(\gamma) = 4\beta_{iso}/(3+\gamma)$$

γ	H_0	ΔH_0
1.00	83.5	25.5
1.05	83.2	25.8
1.10	82.6	25.5
1.15	82.1	25.5
1.20	82.0	25.5
1.25	81.9	25.6
1.30	82.0	25.6
1.35	82.1	25.8
1.40	82.4	25.9
1.45	82.7	26.1
1.50	83.0	26.2
1.55	83.6	26.4
1.60	84.0	26.8
1.65	84.6	27.1

β isothermal model

H_0= (84 ± 26) km/(s Mpc)

⇒ The non isothermal model drives to variations < 5%

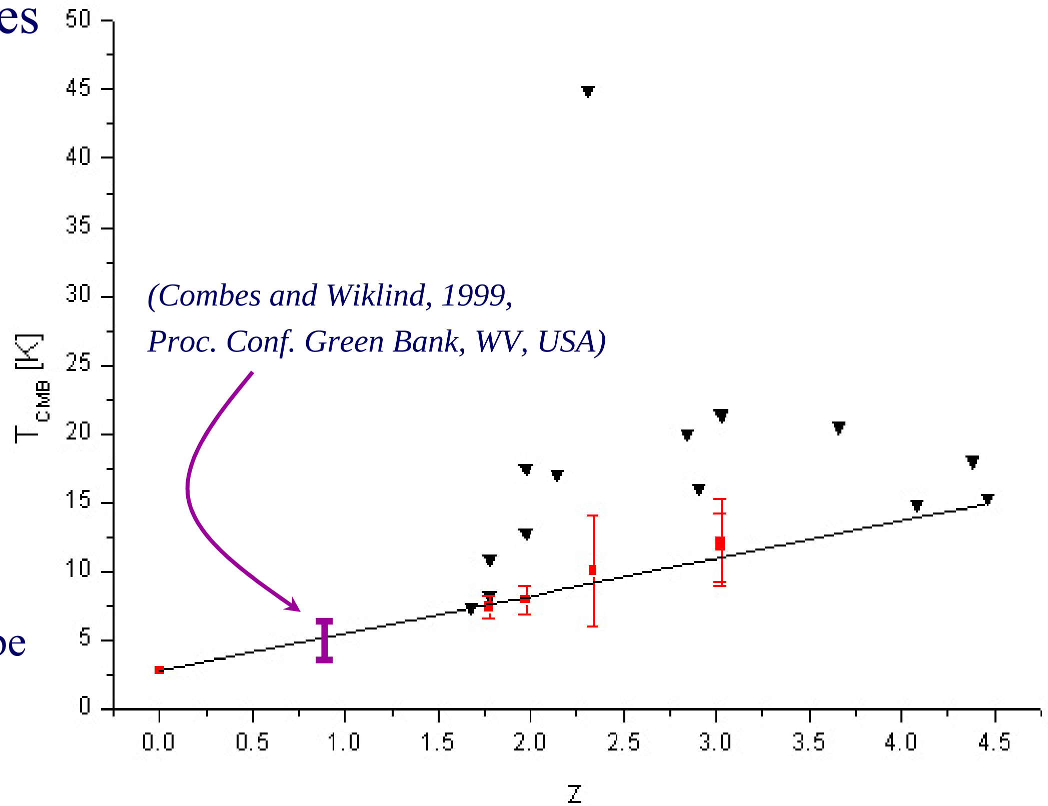
sometimes in literature this has been overestimated due to infinite extended models and to the consideration that $\beta \neq \beta_{\mathrm{var}}$

(Battistelli et al. 2003, ApJ 598:L75-L78)

$T_{CMB}(z)$ vs z

The proposed method is alternative to…

- UV lines from atoms and molecules excited by the CMB → T_{exc}
- T_{exc} depends on the CMB and:
  - Physical medium condition
  - PARTICLES COLLISIONS
  - ⇒ UPPER LIMITS
- Direct mm lines detection is more challenging but:
  - Lower systematics because can be done in diffuse regions ⇐ no collision
  - It is a direct measurement
  - Many lines for confirmation



constraints on alternative cosmologies (95%CL)

$T(z)=T(0)(1+z)^{(1-a)}$

(*Lima et al.,2000 MNRAS, 312,747*)

$T(z)=T(0)[1+(1+d)z]$

(*Lo Secco et al., 2001 Phys.Rev.D,64, 123*)

$$a = -0.05 \pm 0.13$$

$$d = 0.10 \pm 0.28$$

T(z) at Galaxy cluster

*(R. Fabbri, F. Melchiorri & V. Natale, 1978 ApJ & SS **59**, 223*

*Rephaeli Y., 1980 ApJ **241**, 858)*

- The SZ CMB intensity variation can be written as:

thermal *kinetic* *rel. corr.*

$$\Delta I = \frac{2k^3T^3}{h^2c^2}\frac{x^4e^x}{\left(e^x-1\right)^2}\int d\tau\left[\theta f_1(x) - \frac{v_p}{c} + R\left(x,\theta,v_p\right)\right]$$

  - $x = h\nu/kT$
  - $\theta = kT_e/mc^2$
  - $f_1(x) = x\coth(x/2) - 4$ (thermal S-Z)
  - v_p/c (kinetic S-Z)
  - $R(x,\theta, v_p)$ (rel. corr.)

$$y = \int \theta d\tau$$

- In the Standard Model:

$$x(z) = \frac{h\nu(z)}{kT(z)} = \frac{h\nu_0(1+z)}{kT_0(1+z)} = \frac{h\nu_0}{kT_0} = x_0$$

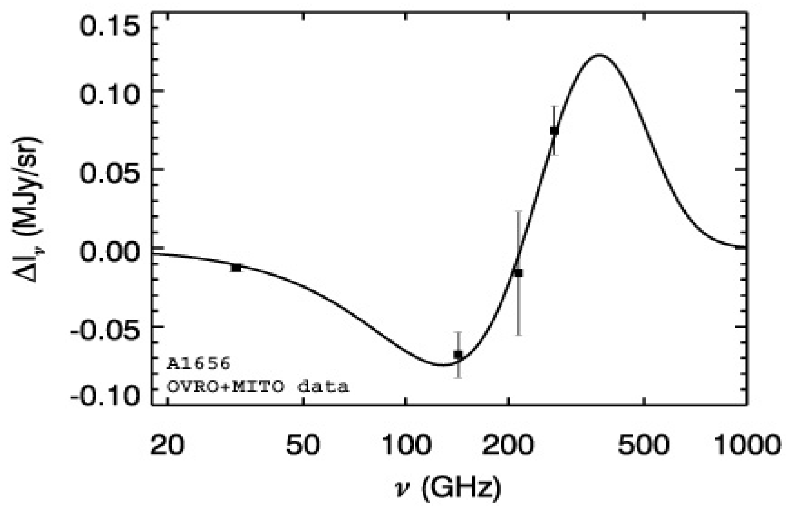
- If $T(z)=T_0(1+z)^{(1-a)}$:

$$x(z) = \frac{h\nu_0(1+z)}{kT_0(1+z)^{(1-a)}} = \frac{h\nu_0}{kT_0(1+z)^{-a}} = x_0(1+z)^a$$

Multifrequency measurements of S-Z

- SuZie and MITO (+OVRO) have produced multifrequency SZ measurements:

De Petris et al., 2002, ApJ. ***574****, L119*

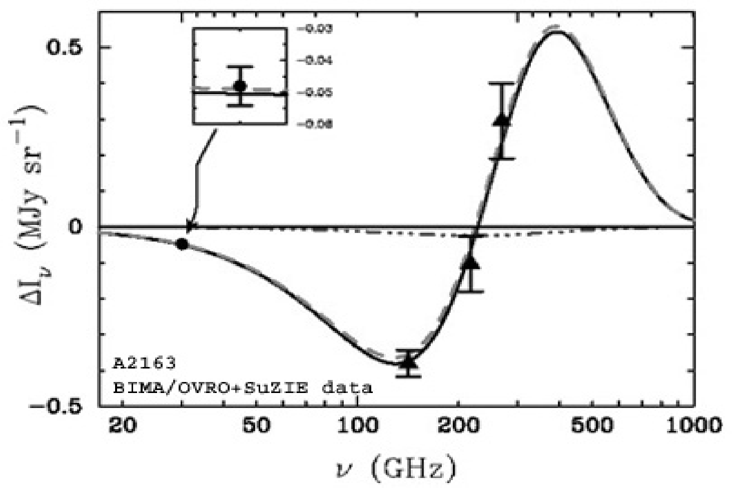


- In principle we may perform a fit leaving T_{CMB} as a free parameter

- However we will have a degeneracy between the comptonization parameter y and T_{CMB}

- Furthermore this measurement is affected by a calibration uncertainty due to the fact that sources of calibration (planets) have a well known spectrum but not well known absolute temperature

$$\Delta S_i = G_i A\Omega\Big|_i \int_0^\infty \Delta I(\nu)\varepsilon_i(\nu)d\nu$$



Holzapfel et al. ApJ, 1997, ***479****, 17*

How to measure T(z) from S-Z

- The estimator is built from the various ratios between S-Z measurements at different frequencies and then we have fitted it with the expected value. The quantity

$$\frac{\Delta S_i}{\Delta S_j} = \frac{G_i}{G_j}\frac{A\Omega|_i}{A\Omega|_j}\frac{\int_0^\infty \frac{x^4 e^x}{(e^x-1)^2}\left\{\int d\tau\left[\theta f_1(x) - \frac{v_p}{c} + R(x,\theta,v_p)\right]\right\}\cdot\varepsilon_i(\nu)d\nu}{\int_0^\infty \frac{x^4 e^x}{(e^x-1)^2}\left\{\int d\tau\left[\theta f_1(x) - \frac{v_p}{c} + R(x,\theta,v_p)\right]\right\}\cdot\varepsilon_j(\nu)d\nu}$$

IS INDEPENDENT ON THE CALIBRATION UNCERTAINTY

IF WE CAN DISENTANGLE KINETIC AND THERMAL S-Z, IS INDEPENDENT ON y (UNFORTUNATELY NOT ON T_e, BUT IT HAS BEEN TESTED, AS WELL AS ε_i and $A\Omega_i$)

Results

- COMA: z=0.0231

$$T^*_{COMA} = 2.726^{+0.078}_{-0.064} K$$

$$T_{COMA}(z) = 2.789^{+0.080}_{-0.065} K$$

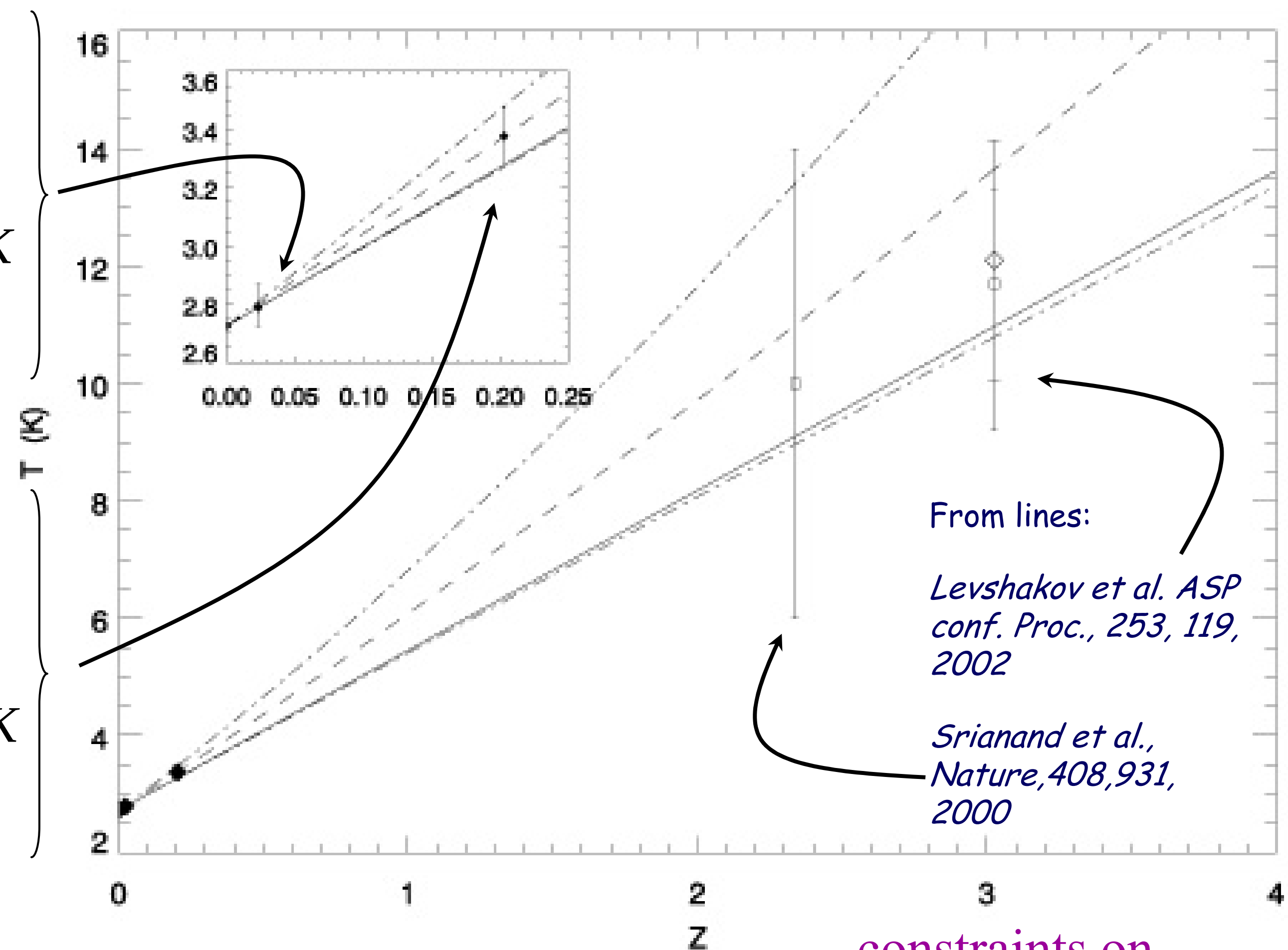
ΔT_e negligible

- A2163: z=0.203

$$T^*_{A2163} = 2.807^{+0.084}_{-0.085} K$$

$$T_{A2163}(z) = 3.377^{+0.101}_{-0.102} K$$

$\Delta T_e \Rightarrow 2\ 10^{-2} K$



$$a = -0.16^{+0.34}_{-0.32}$$

$$d = 0.17 \pm 0.36$$

constraints on alternative cosmologies (95%CL)

(Battistelli et al. 2002, ApJ 580, L101-L104)

2004 observational campaign: disentangling primary and secondary anisotropies and search for diffuse S-Z effect

VSA observation of Corona Borealis

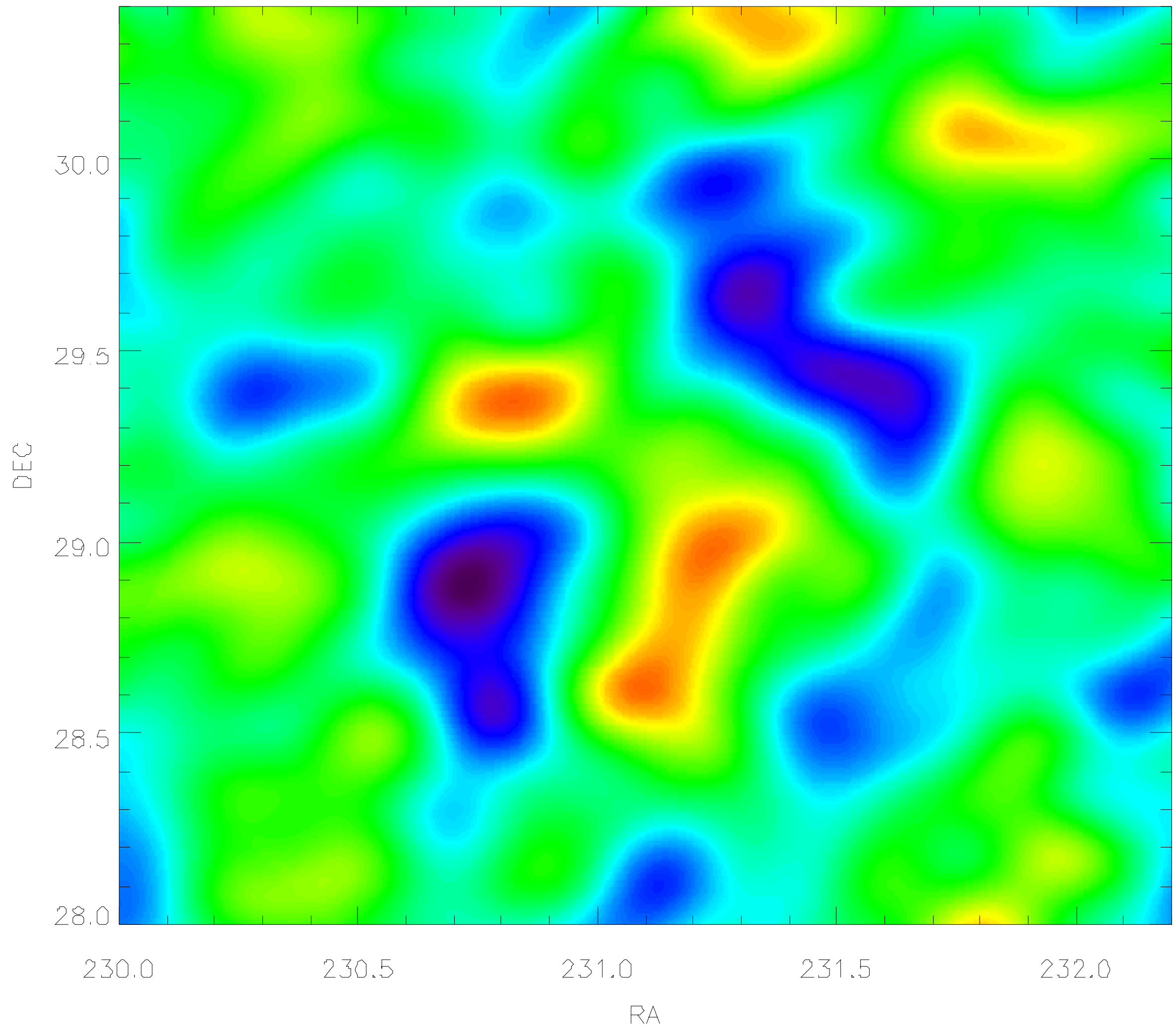
- 14-elements heterodyne interferometer array installed on Teide observatory (Tenerife-Spain)
  *(Watson, R. et al. MNRAS, **341**, 1057-1065, 2003)*

- 26 < ν < 36GHz

- primary beam of 2°.0

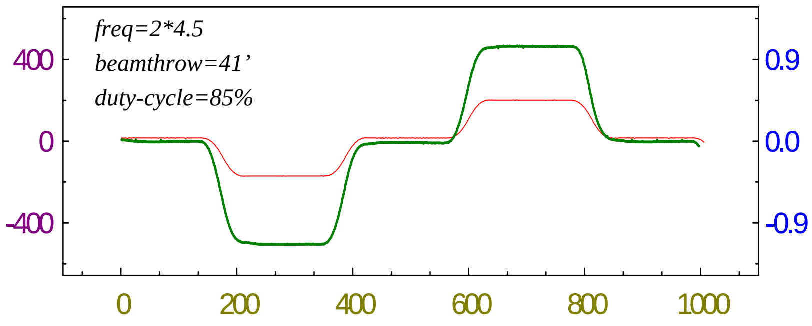
- synthesised beam of 11’ @ 33GHz

- A detailed study of cold spots in VSA Corona Borealis maps is presented elsewhere i.e. *Genova-Santos et al. 2004 in prep.*



Observational strategy

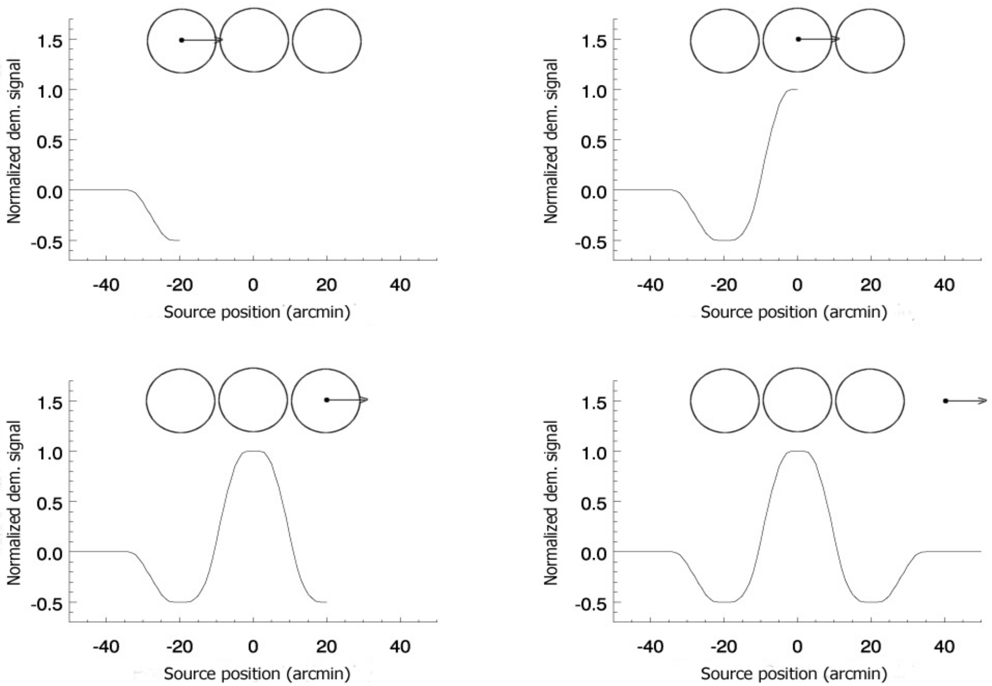
- 3 fields sky modulation @ constant elevation and 2nd armonic demodulation:
  - Efficient removing of the atmosphere emission even with a linear gradient



- Drift scan on the source
  - Efficient removing of the atmosphere
  - No microfony

  but

  - ***Not much integration time on the source***
  - ***Rotation of the reference field***



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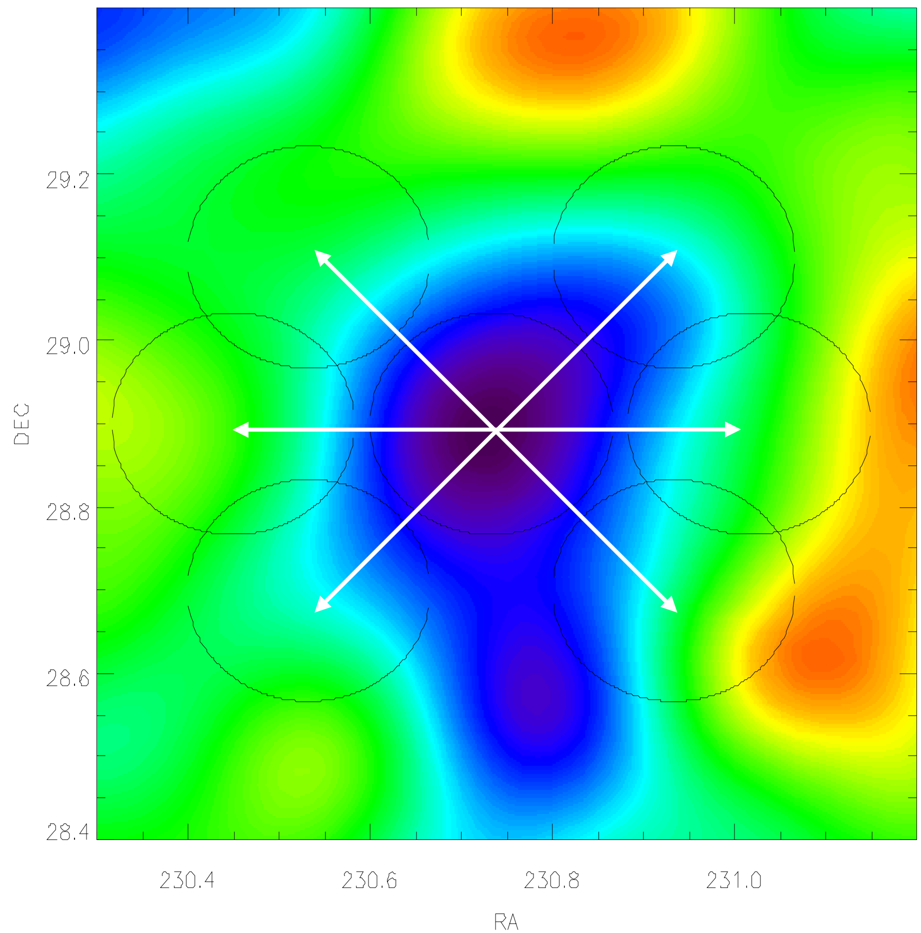
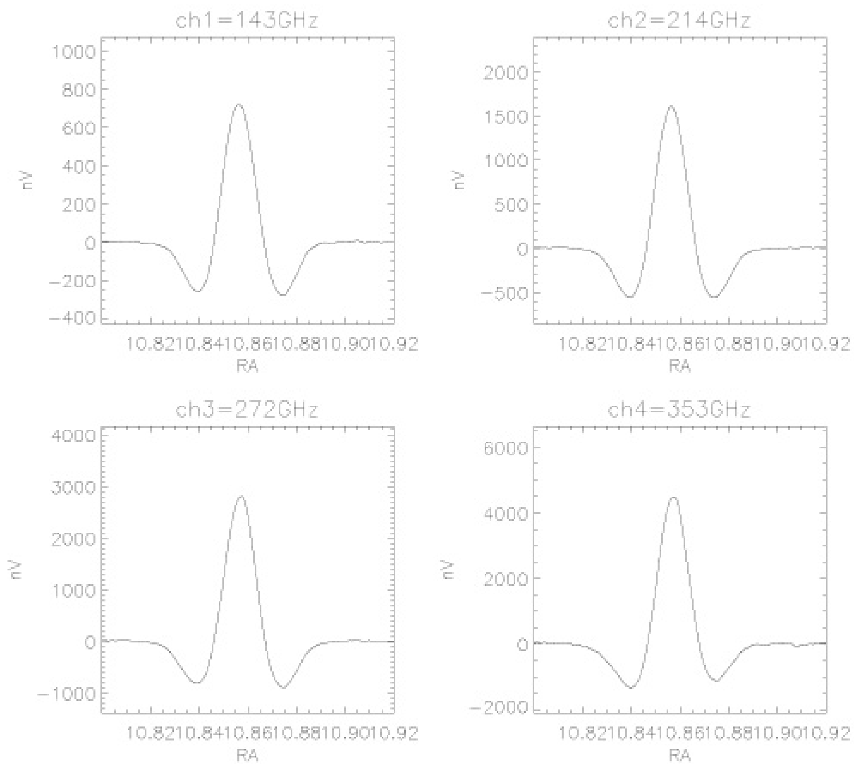
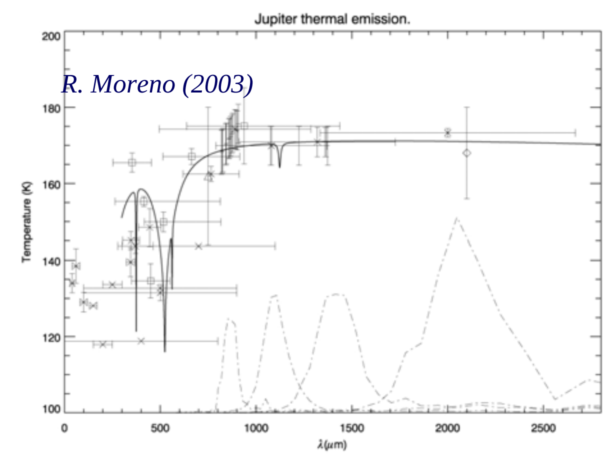


Observational strategy

CALIBRATION

- Calibration on Jupiter: 170K @ mm. However point source, different spectral behaviour and not well known absolute temperature





- Responsivity: Ch1: (462±46) μK/nV

  Ch2: (377±46) μK/nV

  Ch3: (426±43) μK/nV

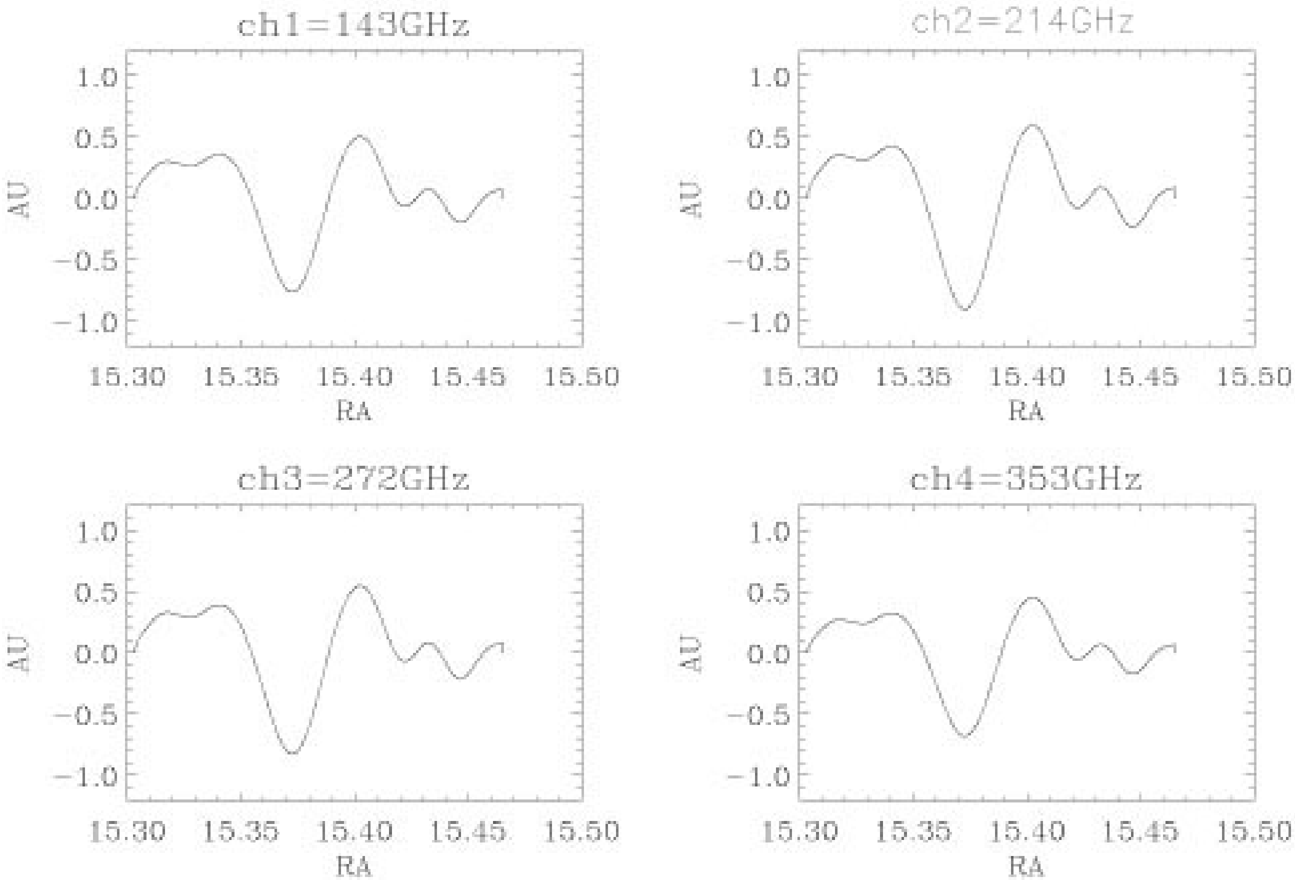
  Ch4: (317±32) μK/nV

- Secondary calibrators: Saturn, tau-A

Simulations

- From VSA map, the equivalent maps @ MITO's frequencies for anisotropies and simulating an SZ signal in Corona B
- Degradation for the transfer function of the lock-in, for the time constant of the bolometers and for the beam of the instrument
- Drift-scan simulation @ the experimental coordinates (8 sims for each d.s.)
- Normalization to the first MITO channel

Primary anisotropies



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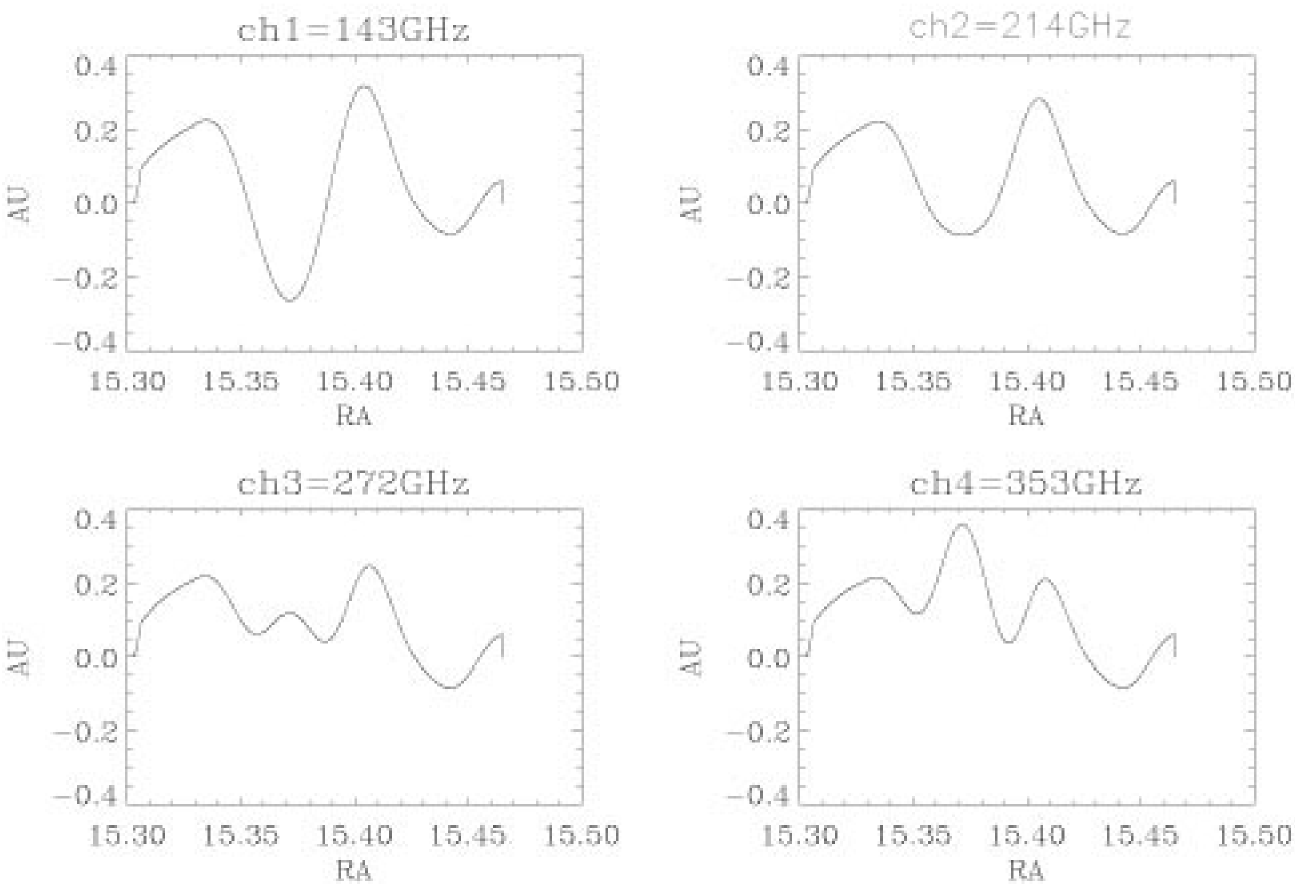
Secondary anisotropies (inverse Compton)



Decorrelation

- Diff measurements ⇒ subtraction of constant and linear gradient atm. emission

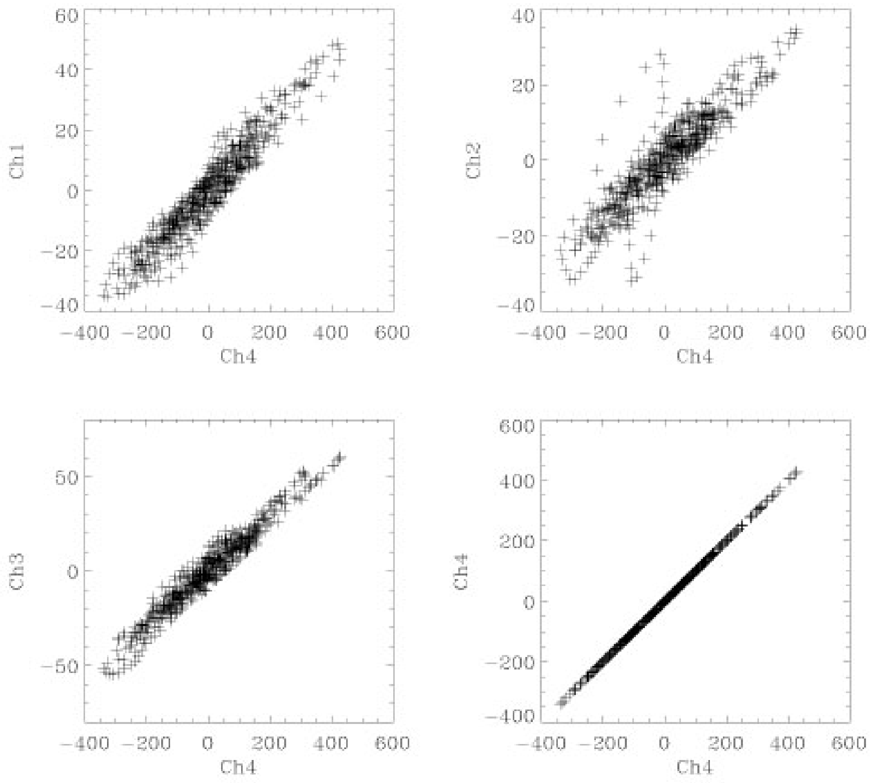
still

- Atmospheric fluctuations are present ⇒ decorrelation with the channel that is more sensitive to it
  i.e. 4th MITO’s channel

- The decorrelation threshold has been set to 0.85

- Some drift scans needed additive filter in the Fourier space

95% *90%* *97%*



Decorrelation + Fit

- Decor. together with the best fit i.e. in the 4th ch there is also a cosmological signal

$$Ch_{i\_res}^{j} = Ch_i^j - a_i^j (Ch_4^j - w^j Ani_4^j - v^j SZ_4^j) - w^j Ani_i^j - v^j SZ_i^j$$

where:

-i=ch's=1,2,3 -j=ds's=1,2…105

-Ani_i^j/SZ_i^j=simulations

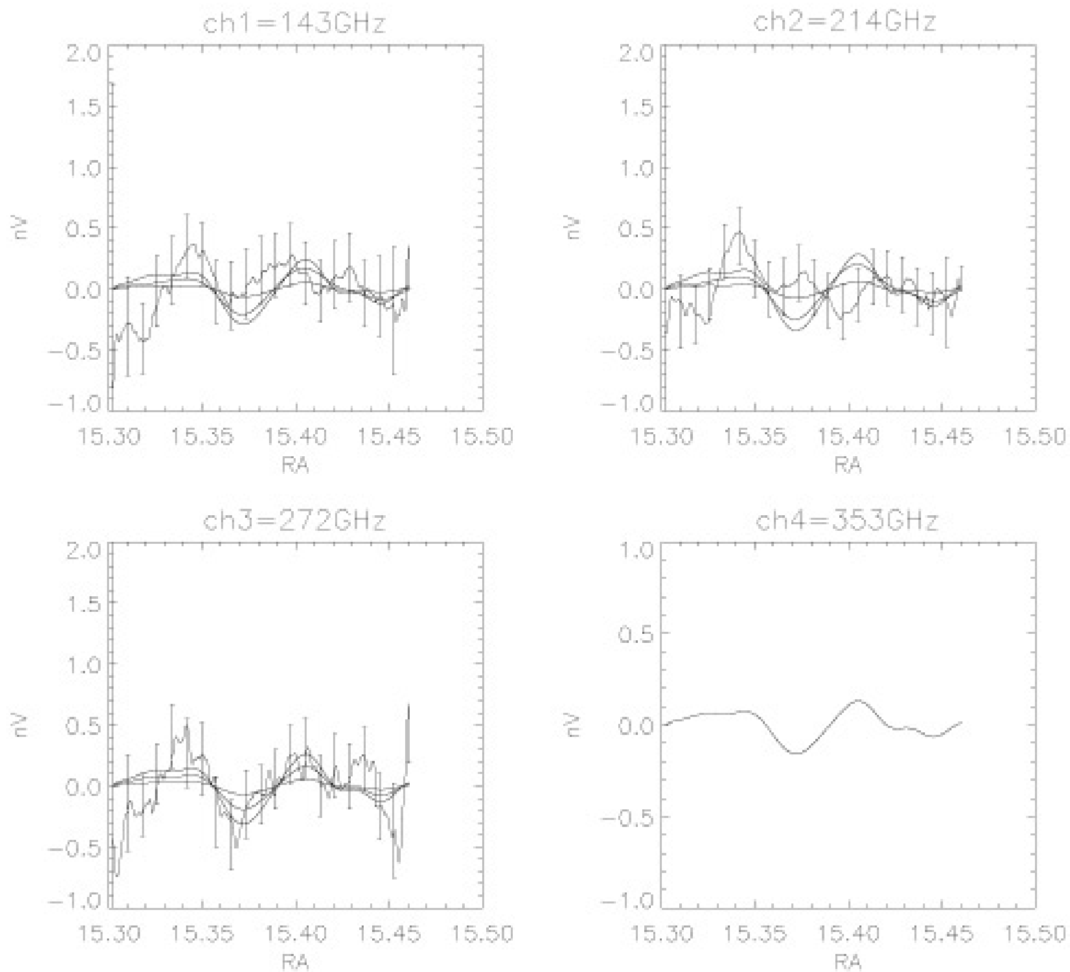
-a_i^j is the ratio between the atm. contribution between Ch_i and Ch_4

-v ≈[nV] and w ≈[nV] for the 1st MITO channel to be multiplied by responsivity

- The fit has to be performed with the three Ch's together not to have a degeneracy for w and v

VERY PRELIMINARY results

- Then we combine all the final parameters w or v
- Since the reference field rotates while we operate the drift scans we cannot average the residuals but only do “visual” plots to keep control on the fits
- We get a good fit for primary anisotropies and an upper limit for SZ



VERY PRELIMINARY results

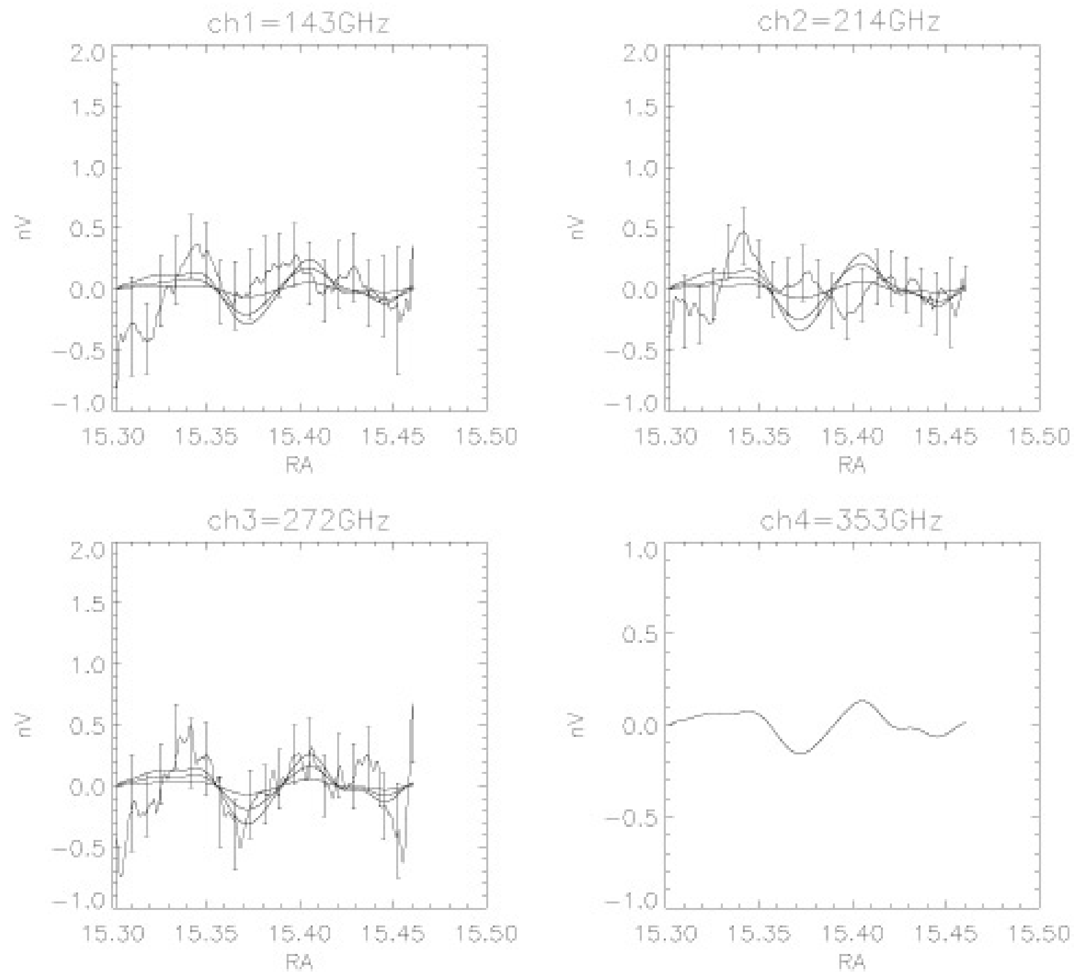
$w = [0.24 \pm 0.13]\ nV$

$v = [-0.056 \pm 0.35] nV$

$v < 0.3 nV$

$|\Delta T^{Ani}_{MITO1}| = [111 \pm 61] \mu K$

$|\Delta T^{SZ}_{MITO1}| < 70 \mu K$



- EVIDENCE FOR PRIMARY ANISOTROPIES LEAVING ROOM FOR POSSIBLE SECONDARY INTERACIONS FROM DIFFUSE GAS

Conclusions

- MITO telescope has been used for measurements of the S-Z effect in Coma cluster

- We have compared MITO measurements with ROSAT X-ray data to get H_0

- Multifrequency S-Z measurements have allowed to measure T_{CMB} *vs* z @ galaxy cluster

- The increase of the observational frequency coverage and the possibility to achieve multi-frequency observations with similar calibration methodology will allow to increase the power of these analysis

- Preliminary results of measurements on Corona Borealis (and the comparison with VSA data) have shown evidence for primary anisotropies leaving room for possible secondary interaction between the CMB photons and diffuse gas