Title: A search for sub-degree SZ fluctuations with multi-frequency BOOMERanG-2003 CMB data

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Abstract:

A search for sub-degree SZ fluctuations with multi-frequency BOOMERanG-2003 CMB data

Alexandre Amblard
Marcella Veneziani, Asantha Cooray, Paolo Serra,
University of California, Irvine
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arxiv:0904.4313

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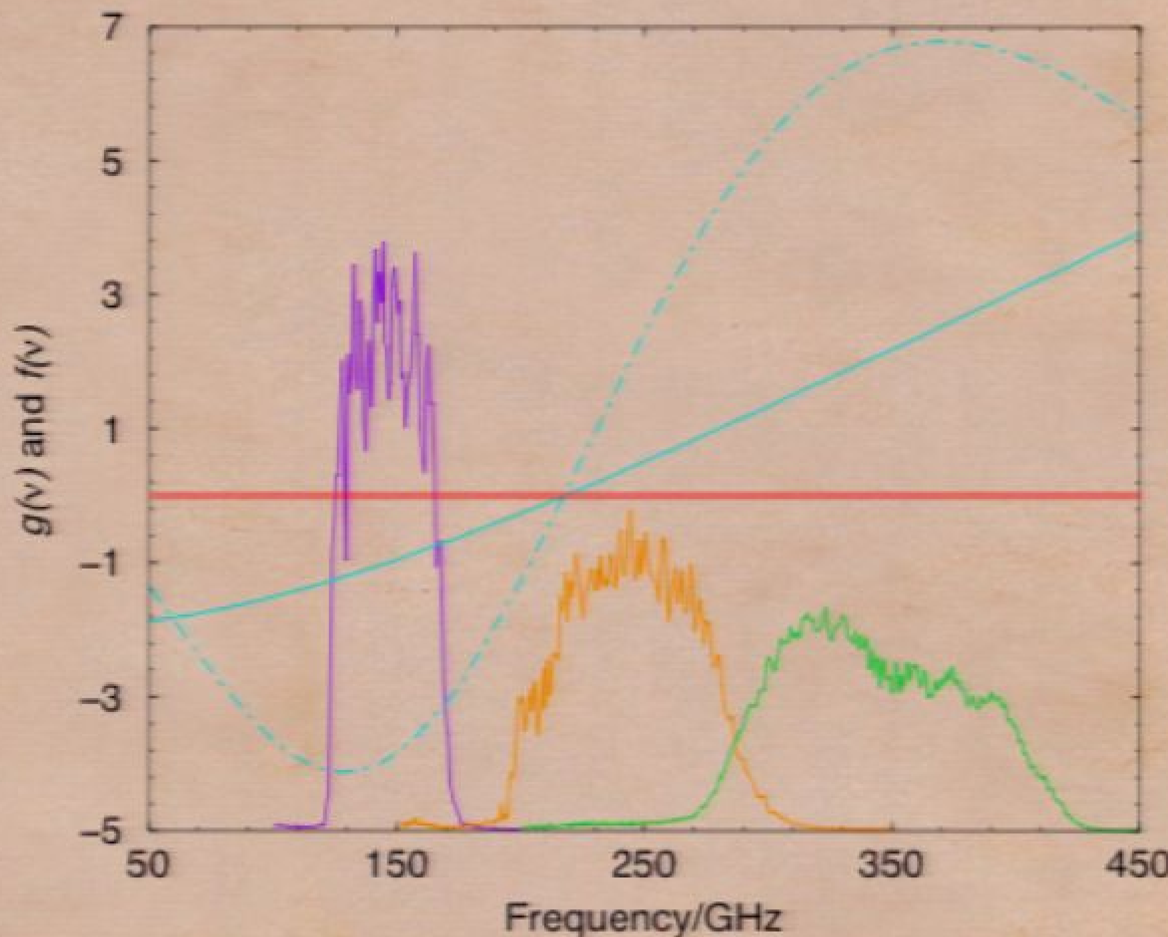
SZ effects

SZ effects:

- Thermal SZ
- Kinetic SZ

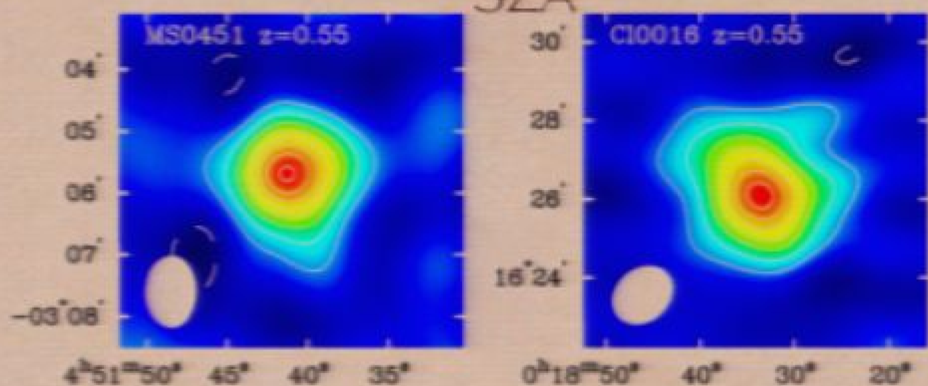
BOOMERanG frequency coverage is well suited to measure Thermal SZ.



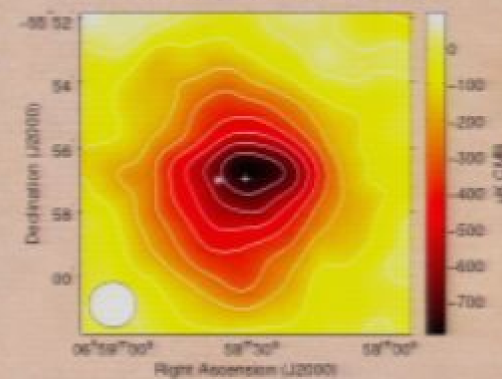
Where we are right now.

Some clusters detected:

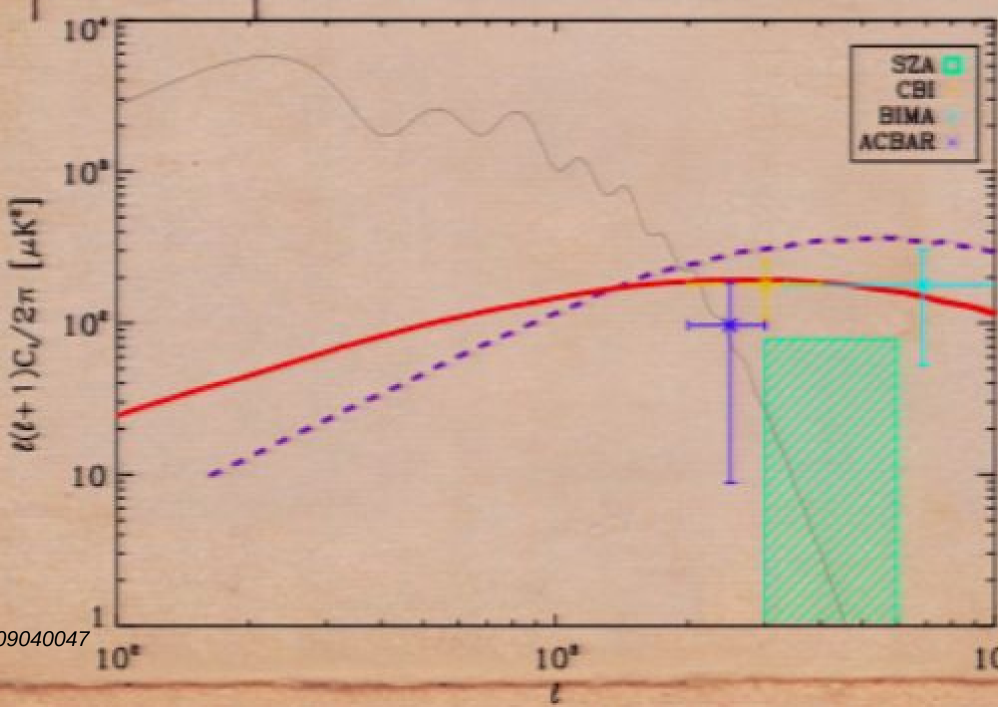
SZA



APEX-SZ/bullet cluster



a power spectrum :



Still a bit of tension between some data and some models.

SZA: Sharp et al 09

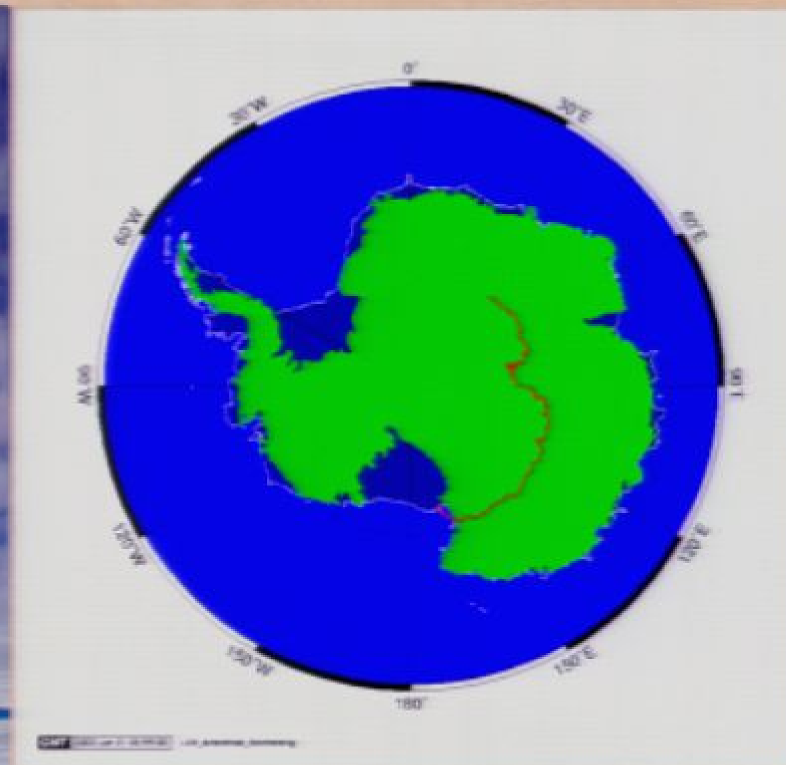
CBI : Sievers et al 09

BIMA :Dawson et al 06

ACBAR : Reichardt et al 08

BOOMERanG 2003

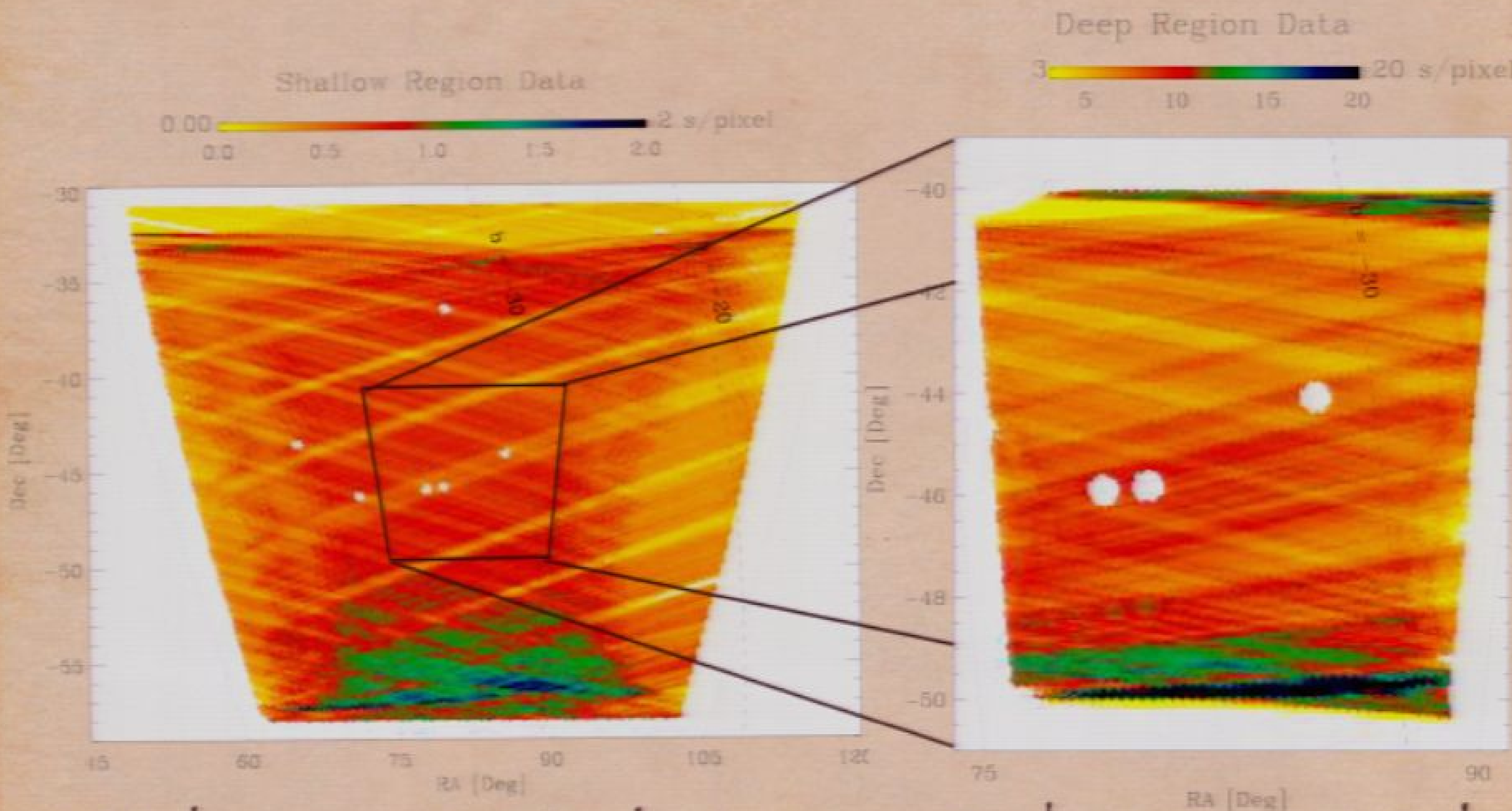
Launch January 6th 2003 05:00 UT, terminated on January 21st 06:59



311 hours of data spent on 3 fields :

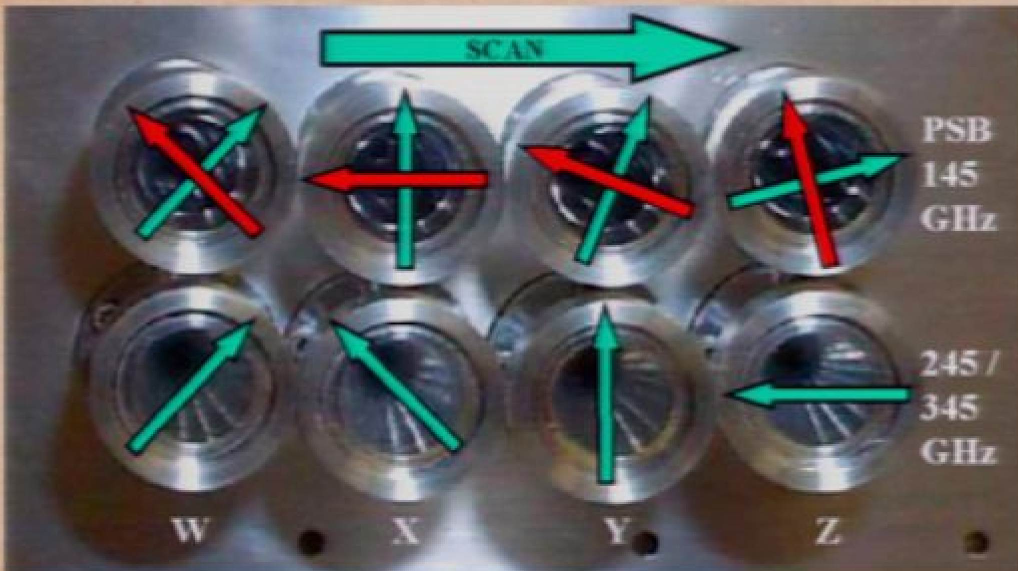
- 75 hours on a shallow field
- 120 hours on a deep field
- 30 hours over the Galactic plane

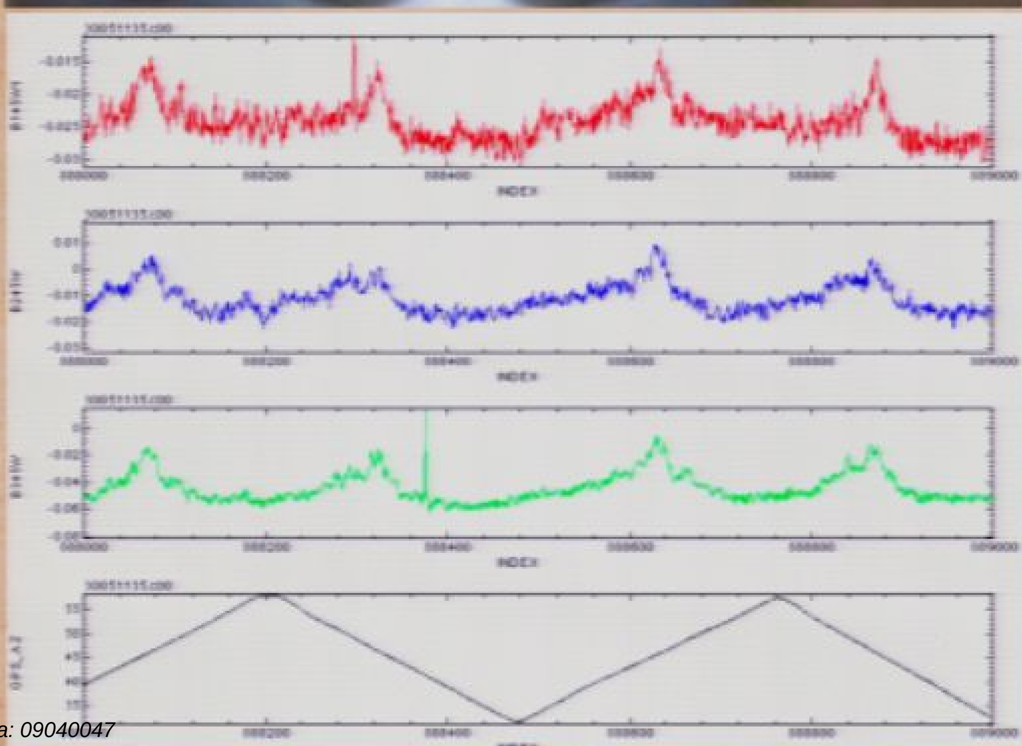
BOOMERanG 2003



75 hours on ≈ 760 deg^2

120 hours on ≈ 90 deg^2





- Total number of detectors :
  - 8 bolometers @ 145 GHz
  - 4 bolometers @ 245 GHz
  - 4 bolometers @ 345 GHz
- Removed 2 detectors previously known for high noise (Masi et al 06): 245X and 345Z
- Removed 2 detectors, we found have higher noise: 145Z2 and 345Y
  - 7 bolometers @ 145 GHz
  - 3 bolometers @ 245 GHz
  - 2 bolometers @ 345 GHz

The DataSet

For the 3.4' pixel deep region :

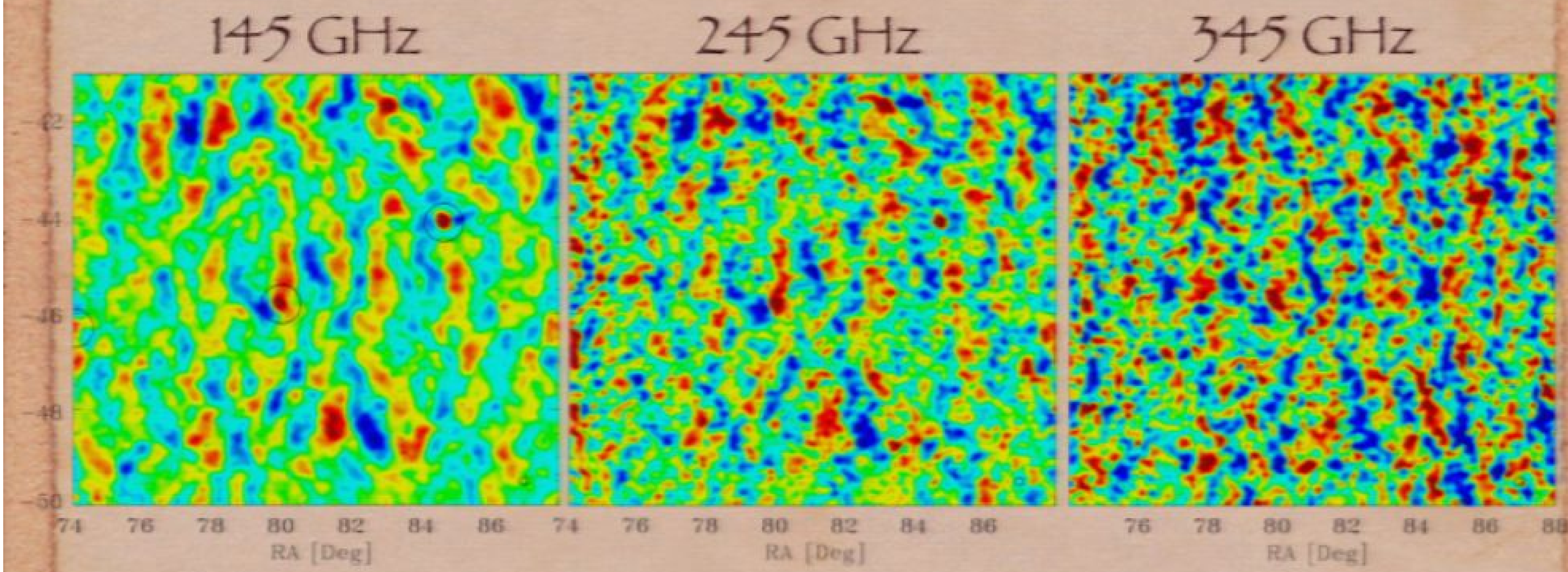
B03 INSTRUMENT SUMMARY

$\langle\nu\rangle$ GHz	$\frac{\mathrm{MJy/sr}}{\mathrm{K_{CMB}}}$	θ_{phys} FWHM	$\theta_{eff}{}^{a}$ FWHM	NET[b] $\mu\mathrm{K_{CMB}}\sqrt{\mathrm{s}}$	$\sigma_{pix}{}^{c}$ $\mu\mathrm{K_{CMB}}$	$s(\nu)= g(\nu)/g(\nu_{RJ})$
145	388	9.95′	11.5′	63	18	0.5
245	462	6.22′	8.5′	161	50	-0.2
345	322	6.90′	9.1′	233	72	-1.0

Beams allow to go up to l~1200

Calibration error 2, 8, 13 % @145, 245, 345 GHz

BOOMERanG03 maps



Trace of CMB, dust and radio sources.

Isolating the SZ

Given a number of frequencies, one can use an internal linear combination to keep a specific source (Tegmark et al 96, Tegmark et al 03):

$$a_{\ell m} = \sum_{freq=i} w_\ell^i a_{\ell m}^i \qquad \mathbf{w}_\ell = \frac{\mathcal{C}^{-1}\mathbf{e}}{e^T \mathcal{C}^{-1} e}$$

Combining the different frequencies with the "optimal" weights :

$$\mathrm{C_{SZ}} = w^T \mathcal{C} w$$

➡ Minimize the total variance : signal + noise

Isolating the SZ

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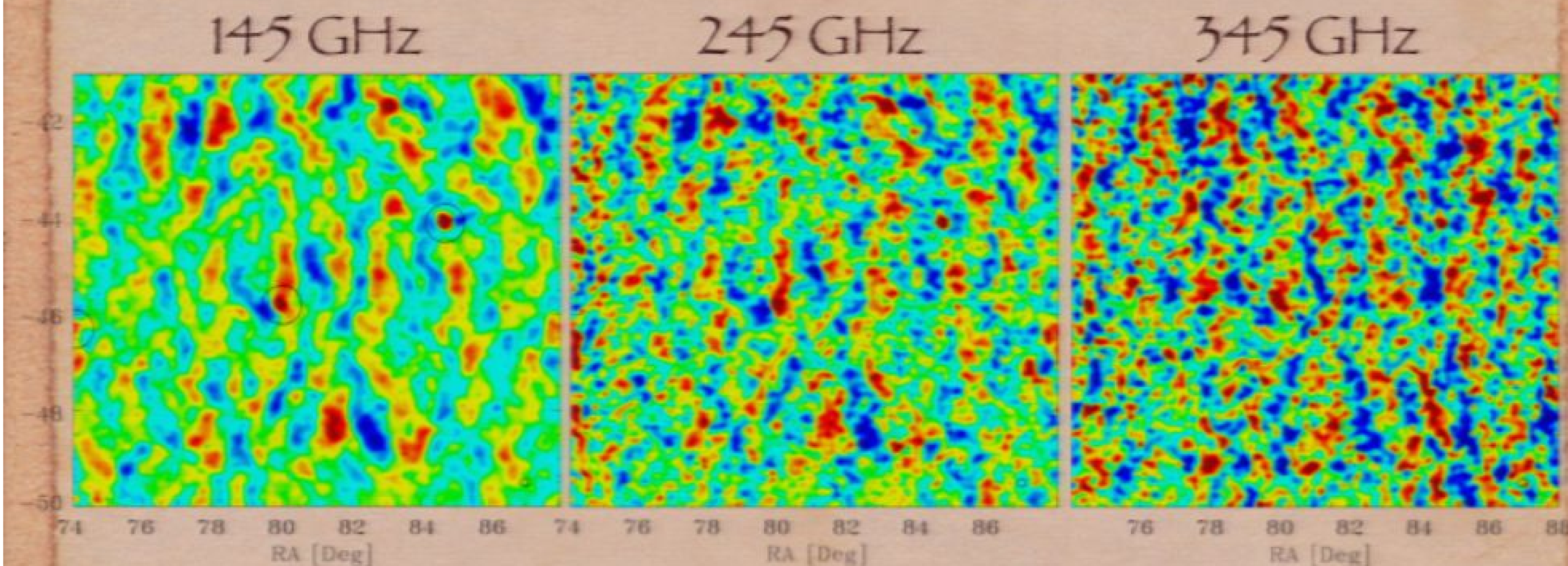
BOOMERanG03 maps



Trace of CMB, dust and radio sources.

Isolating the SZ

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Combining the different frequencies with the "optimal" weights :

$$\mathrm{C}_{\mathrm{SZ}} = w^T \mathcal{C} w$$

Minimize the total variance : signal + noise

More aggressive foregrounds subtraction

We used only cross-spectra to minimize primarily the "foreground" residuals, not the noise and divided by $s(\nu_i)$ (Cooray et al 00):

$$\mathbf{C}_{ij} = \sum_{l \in b,m} \sum_{u,v} \frac{\langle a_{lm}^{i,u} a_{lm}^{j,v\star} \rangle}{s(\nu_i) s(\nu_j) b_l^{i,u} b_l^{j,v}} \quad \text{with } u \neq v, \text{ if } i = j$$

$s(\nu)$: SZ frequency spectrum

b^i_l : beam function

i,j : indices of the frequency

u,v : indices of the detector

145-145 GHz : 21 pairs

145-245 GHz : 21 pairs

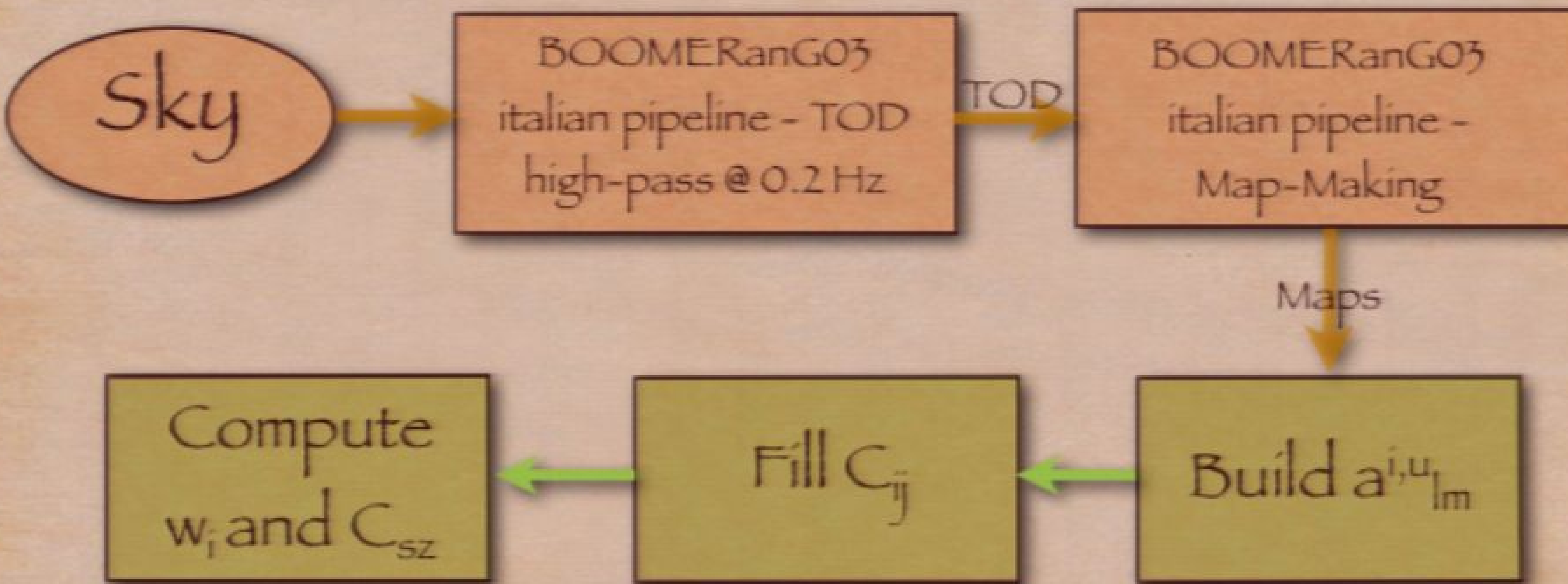
145-345 GHz : 14 pairs

245-245 GHz: 3 pairs

245-345 GHz: 6 pairs

345-345 GHz: 1 pair

Analysis Roadmap



Preliminary Result

SZ POWER SPECTRUM ESTIMATES

	bin 1	bin 2	bin 3
ℓ-range	250-450	450-700	700-1200
	Optimal weights		
w_{145GHz}	0.9323	0.8514	0.7289
w_{245GHz}	0.4193	0.3771	0.3002
w_{345GHz}	-0.3515	-0.2285	-0.0292
Raw SZ	236	164	538

w_{145}/s_{145}	1.88	1.71	1.47
w_{245}/s_{245}	-1.94	-1.74	-1.39
w_{345}/s_{345}	0.35	0.22	0.03

→ Not all CMB is removed and other residuals might be there
+ no error estimate
We Need Simulations

Simulations

We included the following emissions :

- CMB
- Noise

↕ 200 random Gaussian CMB & BOOMERanG noise realizations

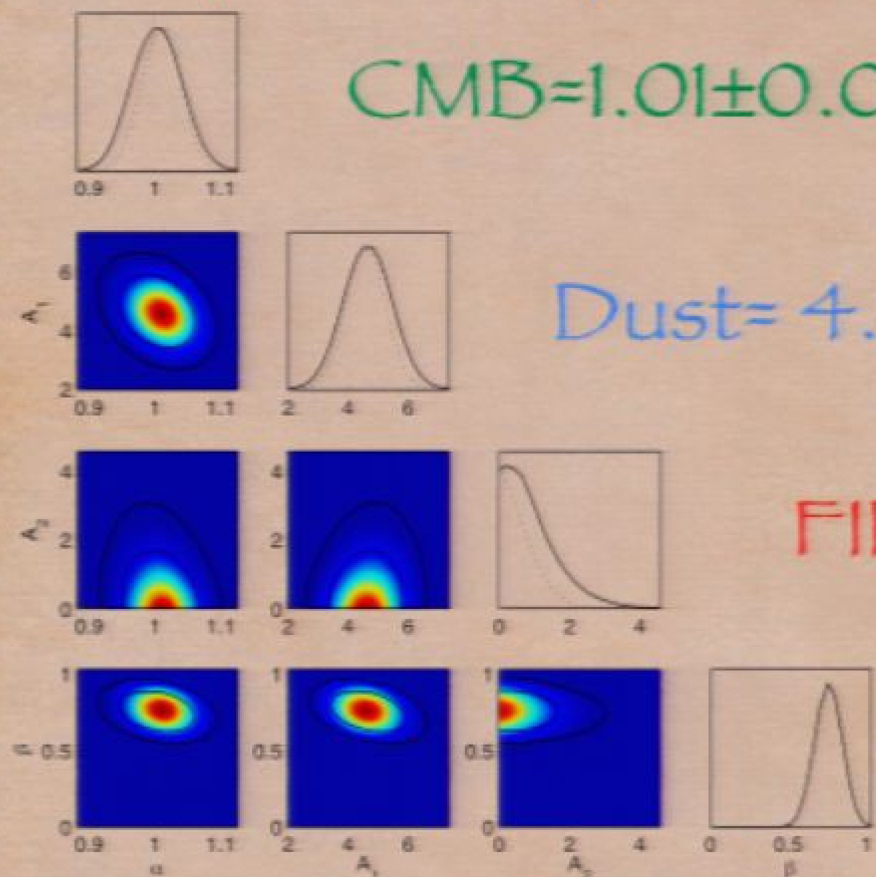
- Galactic dust → model 8 of Finkbeiner et al 99
- Radio point sources
- FIRB

↕ Planck Sky Model (Leach et al. 08, Delabrouille et al 09)

We used 1 set of simulations with the predictions from these models: ❖ p_{cmb}=1, p_{dust}=1., p_{radio}=1., p_{FIRB}=1.

Fitting our "Foreground" templates

$C_l^{data} = p_{cmb} \times C_l^{cmb} + p_{dust} \times C_l^{dust} + p_{radio} \times C_l^{radio} + p_{FIRB} \times C_l^{FIRB}$



CMB=1.01±0.04

Dust= 4.6±0.8

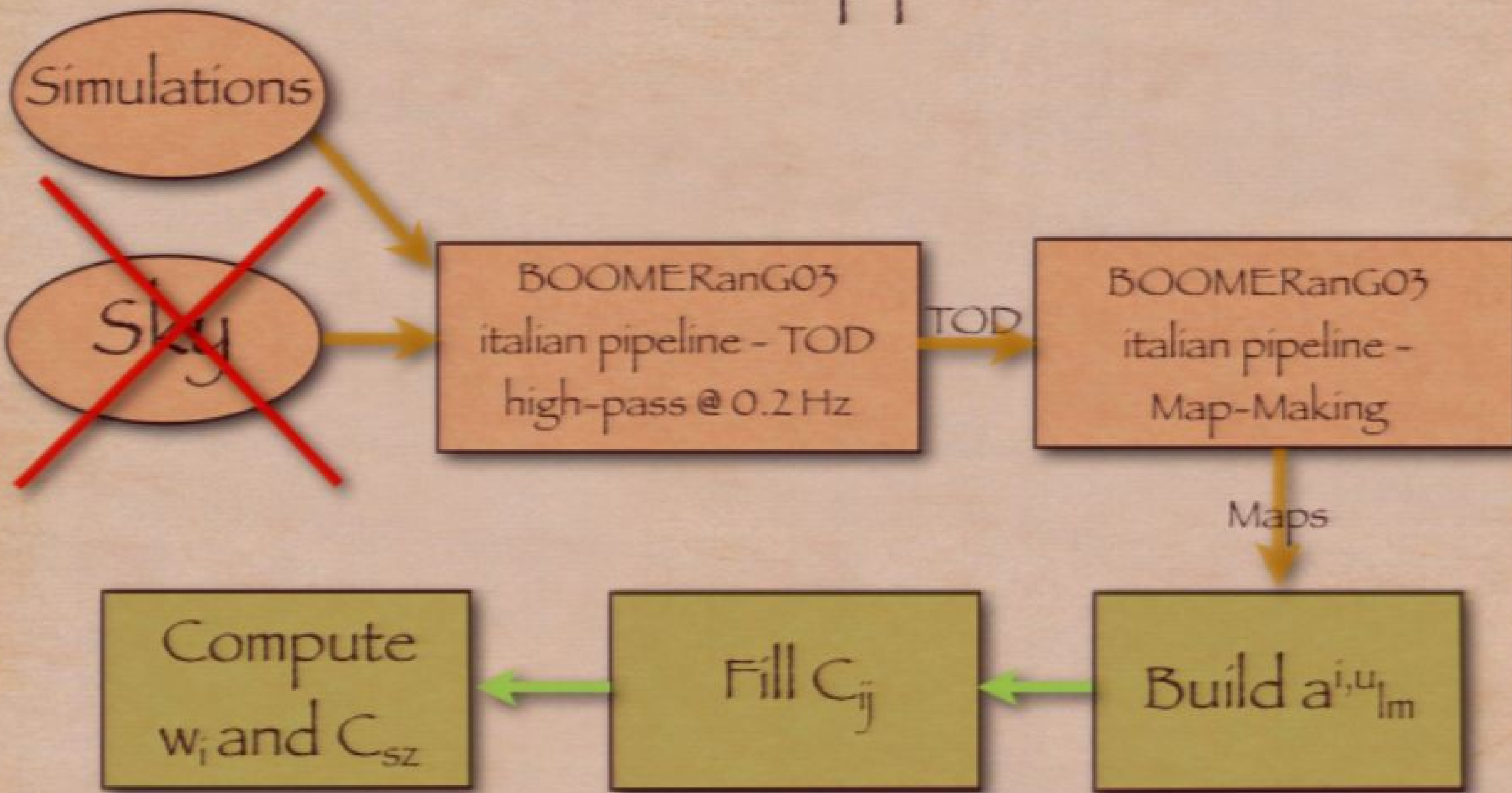
FIRB <0.7

Radio PS =0.76±0.07

Two more sets : ❖ $p_{cmb}=1$, $p_{dust}=4.6$, $p_{radio}=0.76$, $p_{FIRB}=0.7$

❖ $p_{cmb}=1$, $p_{dust}=4.6$, $p_{radio}=0.76$, $p_{FIRB}=0.0$

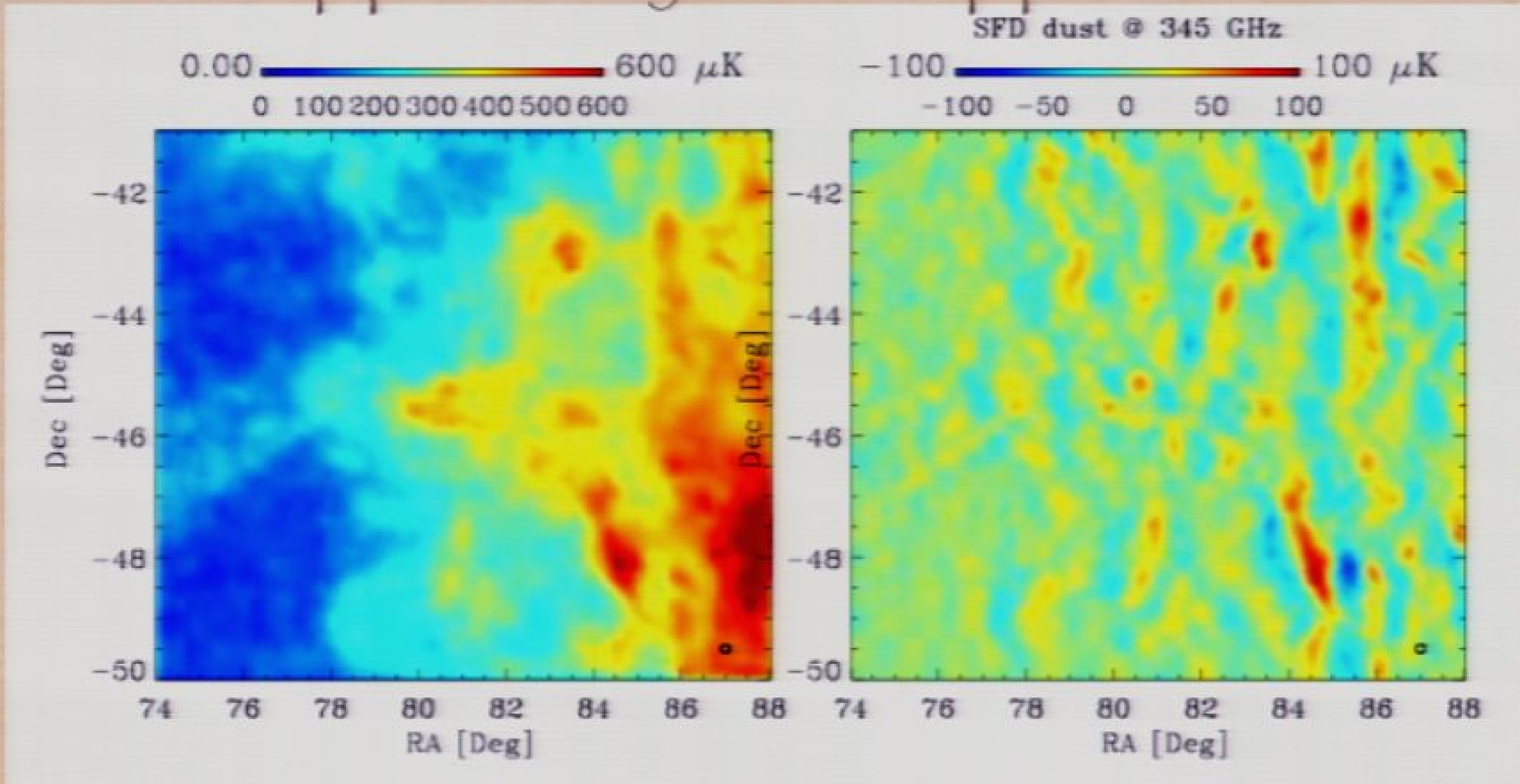
Simulation pipeline



Each simulation goes through the complete pipeline.

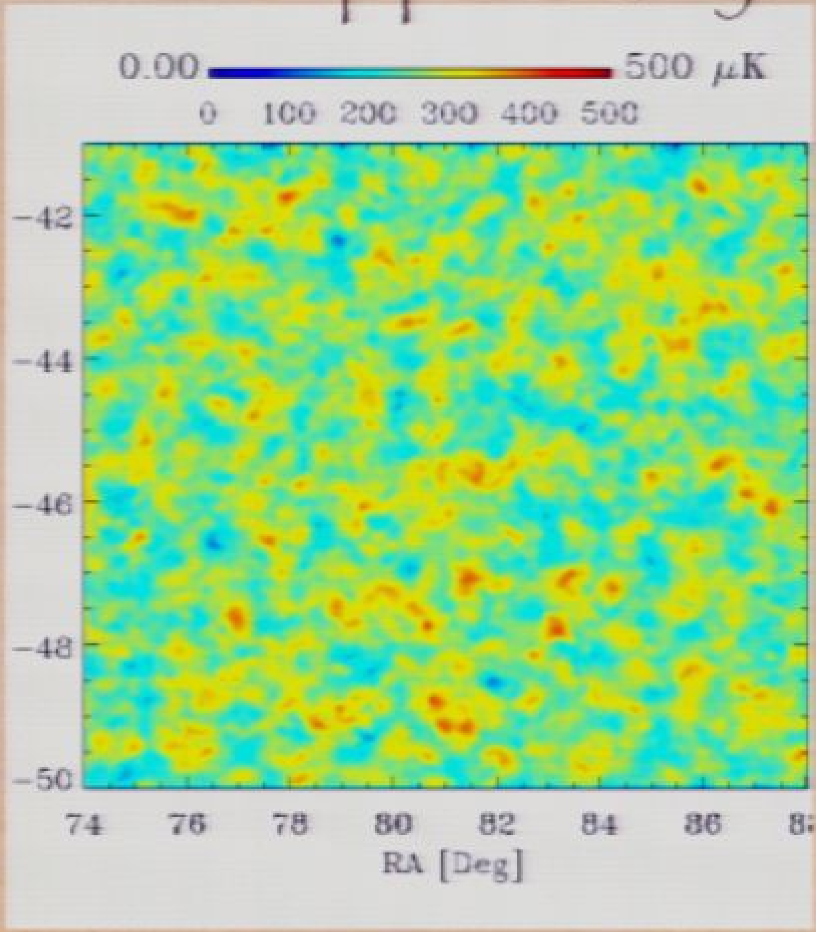
Dust at 345 GHz

before pipeline (sky) after pipeline (measured)

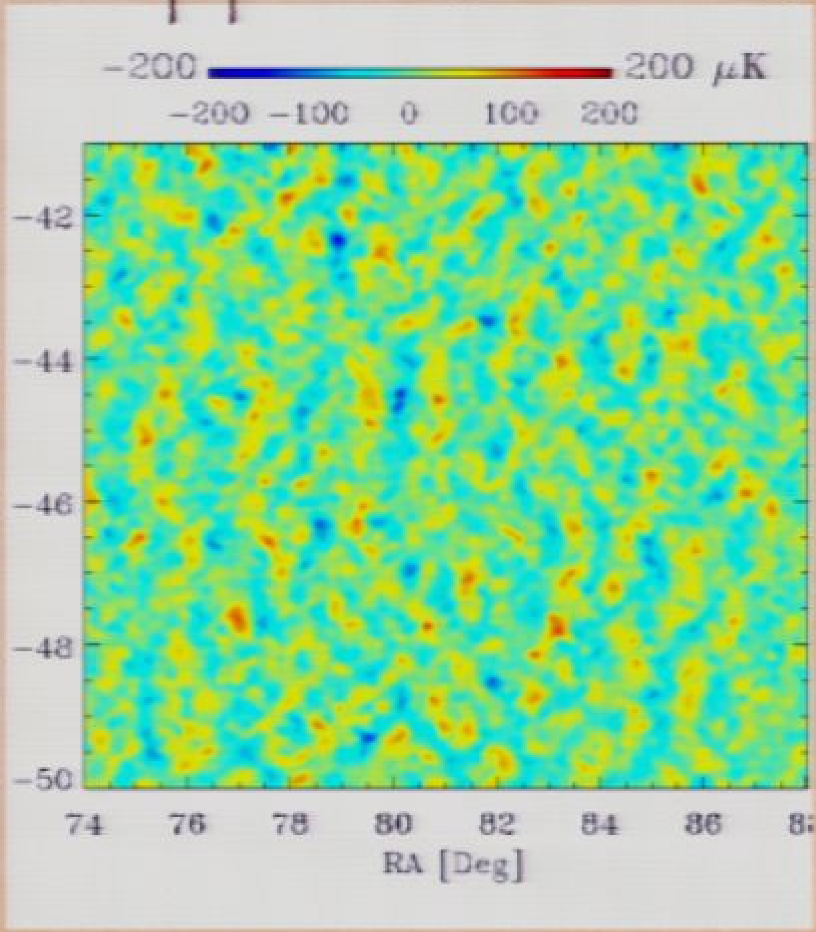


FIRB at 345 GHz

before pipeline (sky)

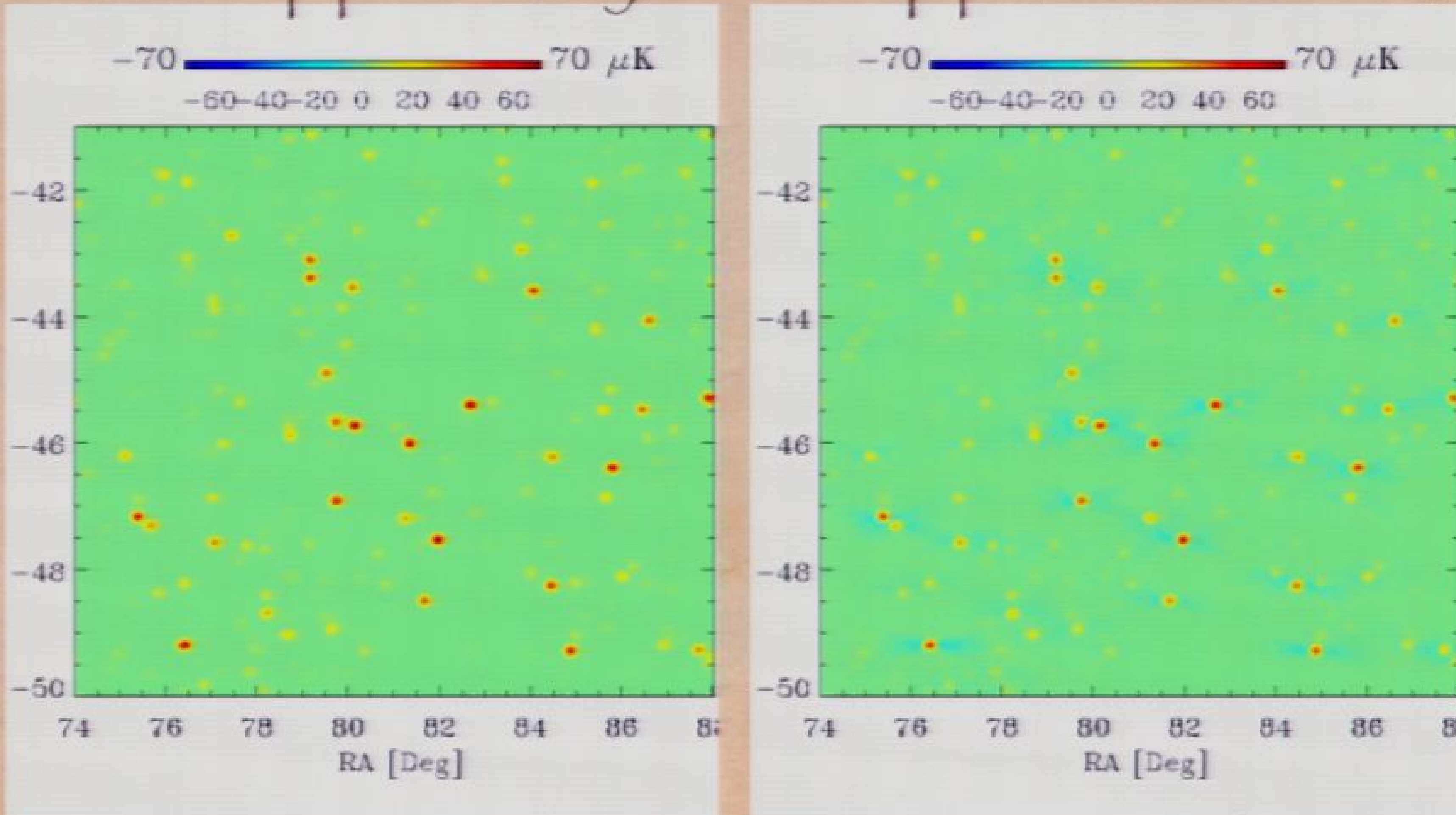


after pipeline (measured)



Radio PS at 145 GHz

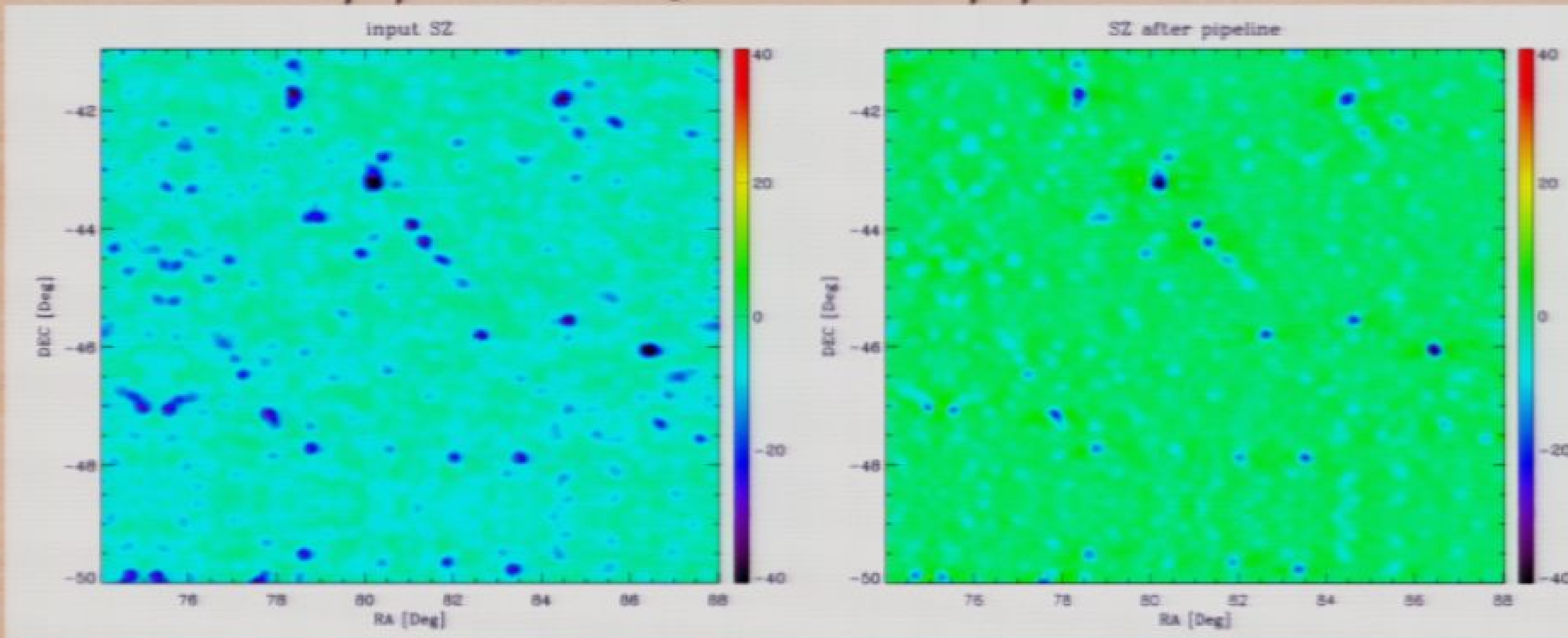
before pipeline (sky) after pipeline (measured)



SZ at 145 GHz

(from White 03*)

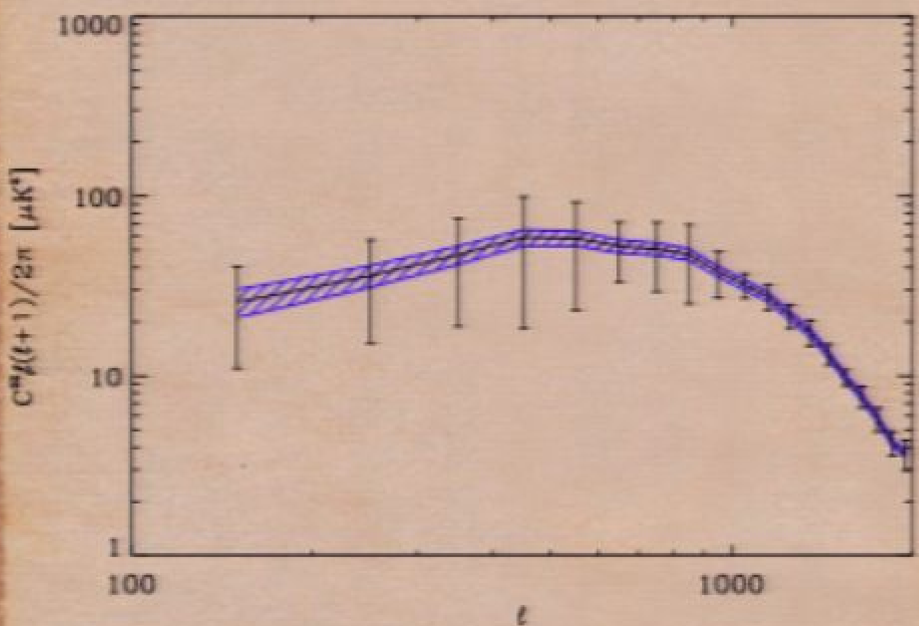
before pipeline (sky) after pipeline (measured)



*http://mwhite.berkeley.edu/tSZ/PlanckSZ/

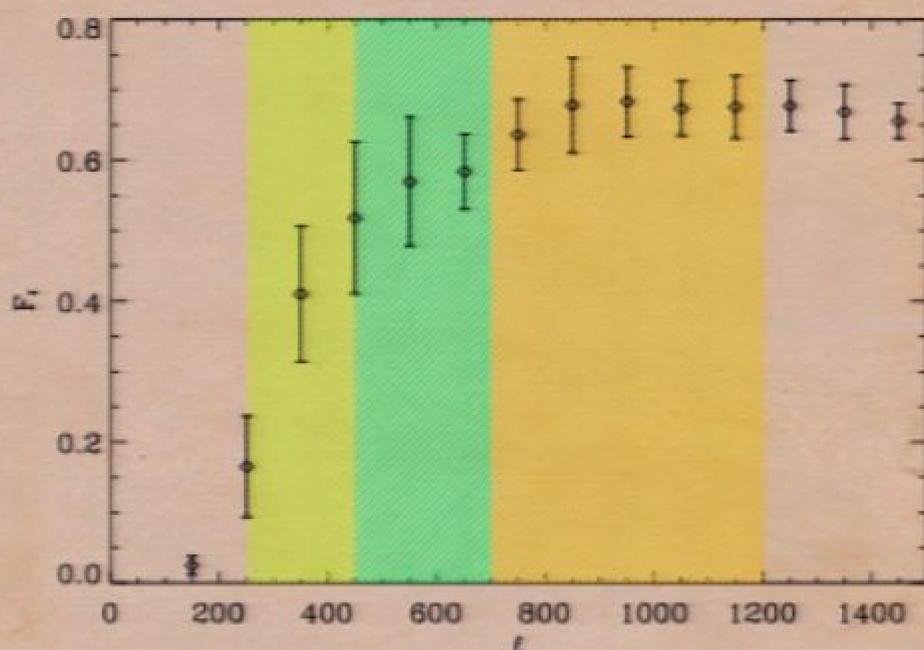
SZ filtering

Power spectra of 10 SZ simulations



SZ variance 2-6 times larger than Gaussian CV

SZ transfer function for BOOMERanG scan-strategy and filtering



$F_0 = 0.5 \pm 0.1$ (20%)

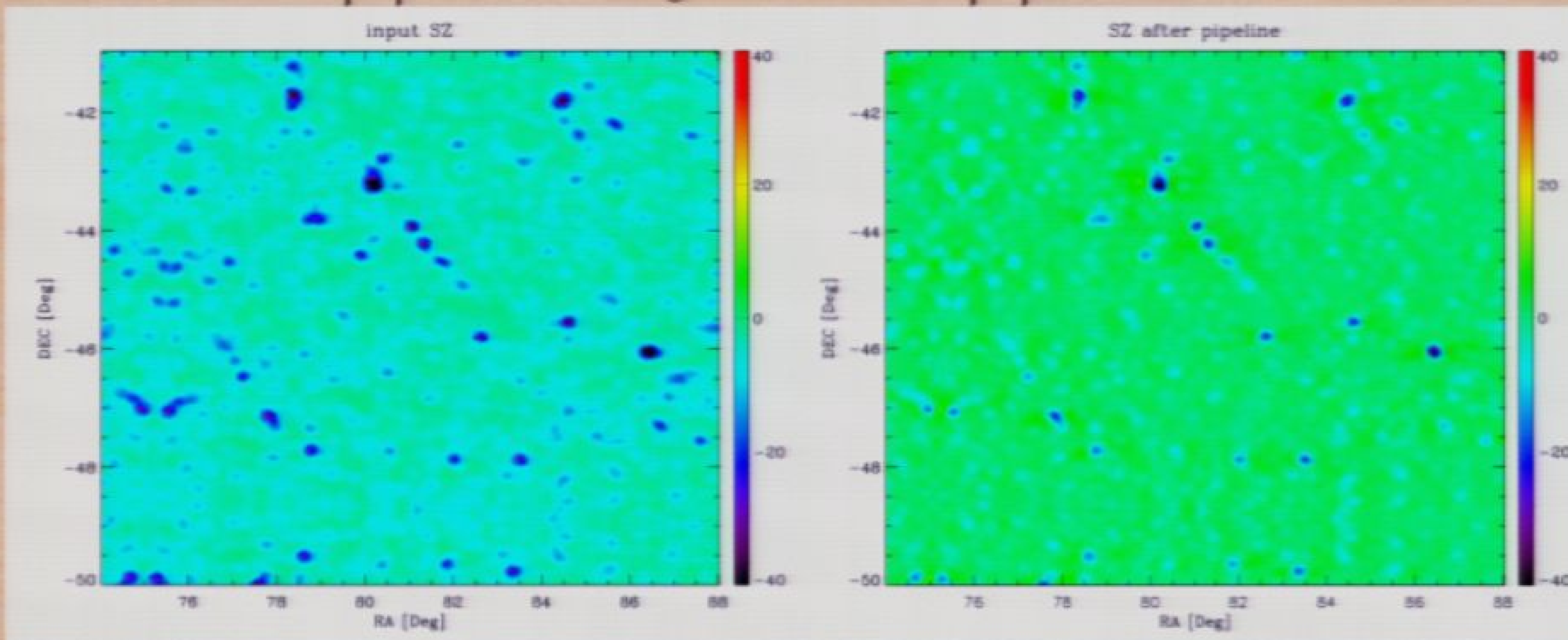
$F_1 = 0.6 \pm 0.05$ (8.3%)

$F_2 = 0.7 \pm 0.04$ (5.7%)

SZ at 145 GHz

(from White 03*)

before pipeline (sky)　　after pipeline (measured)



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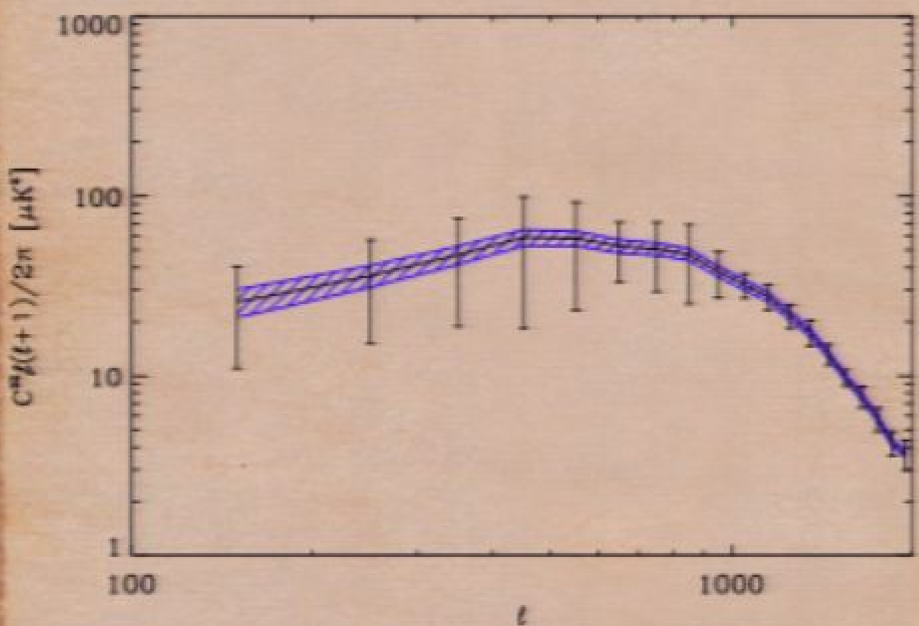
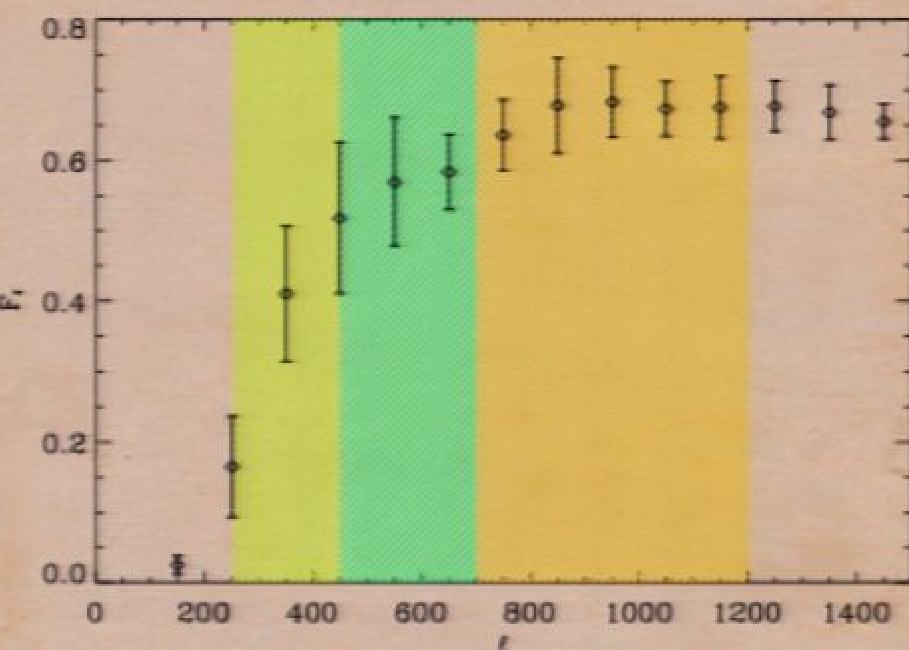
Power spectra of 10 SZ simulations



SZ variance 2-6 times larger than Gaussian CV

SZ transfer function for BOOMERanG scan-strategy and filtering



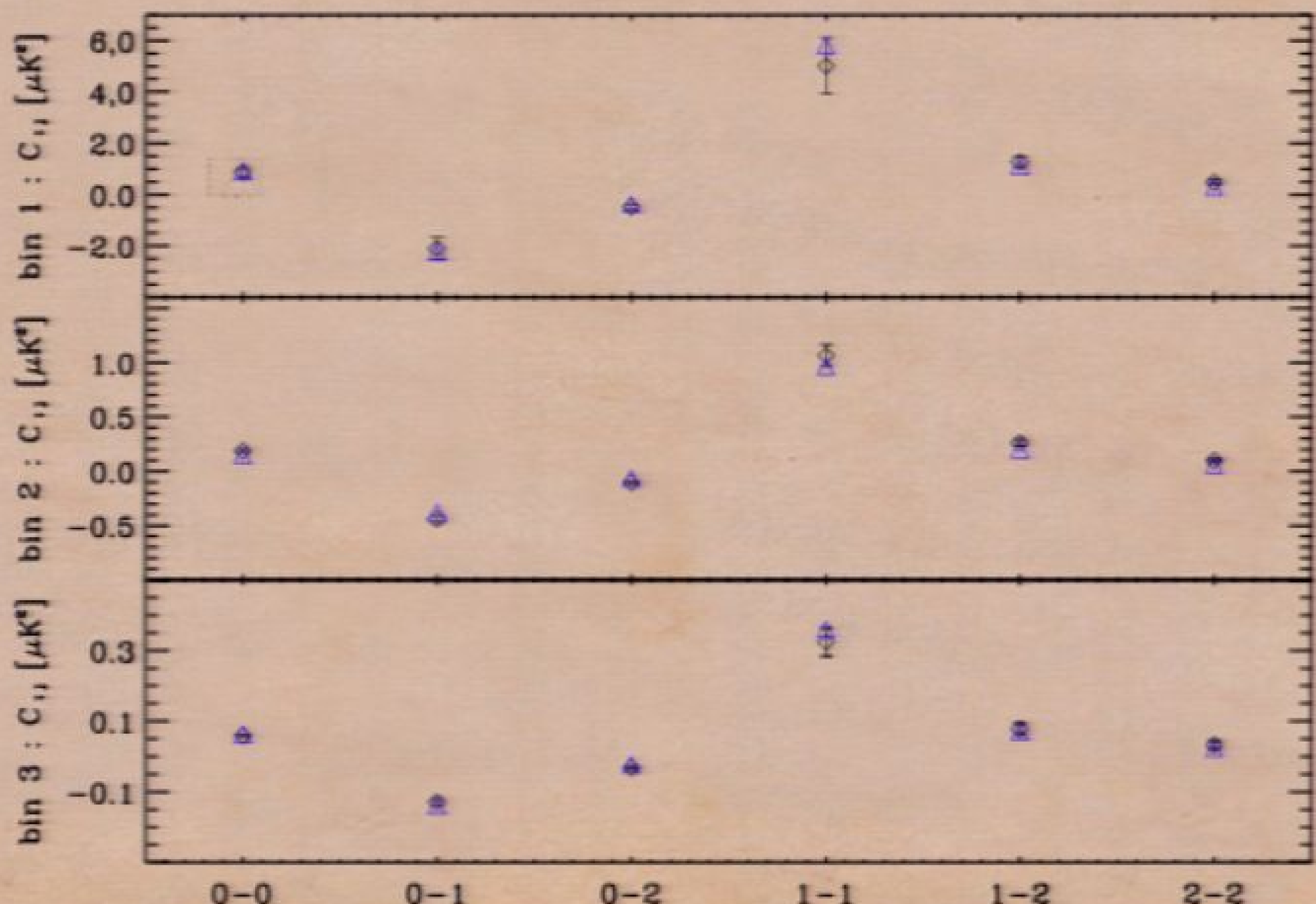
$F_0 = 0.5 \pm 0.1$ (20%)

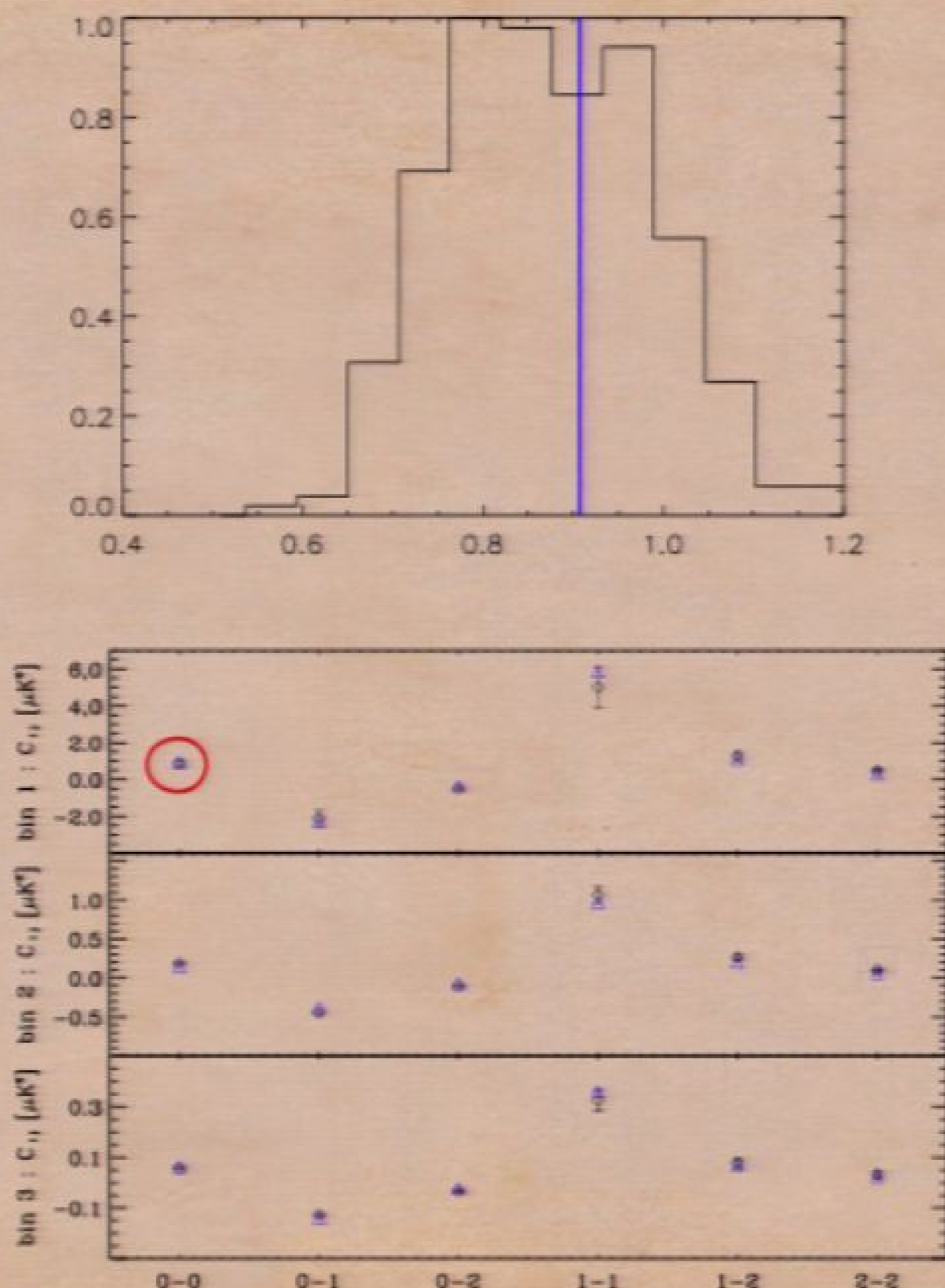
$F_1 = 0.6 \pm 0.05$ (8.3%)

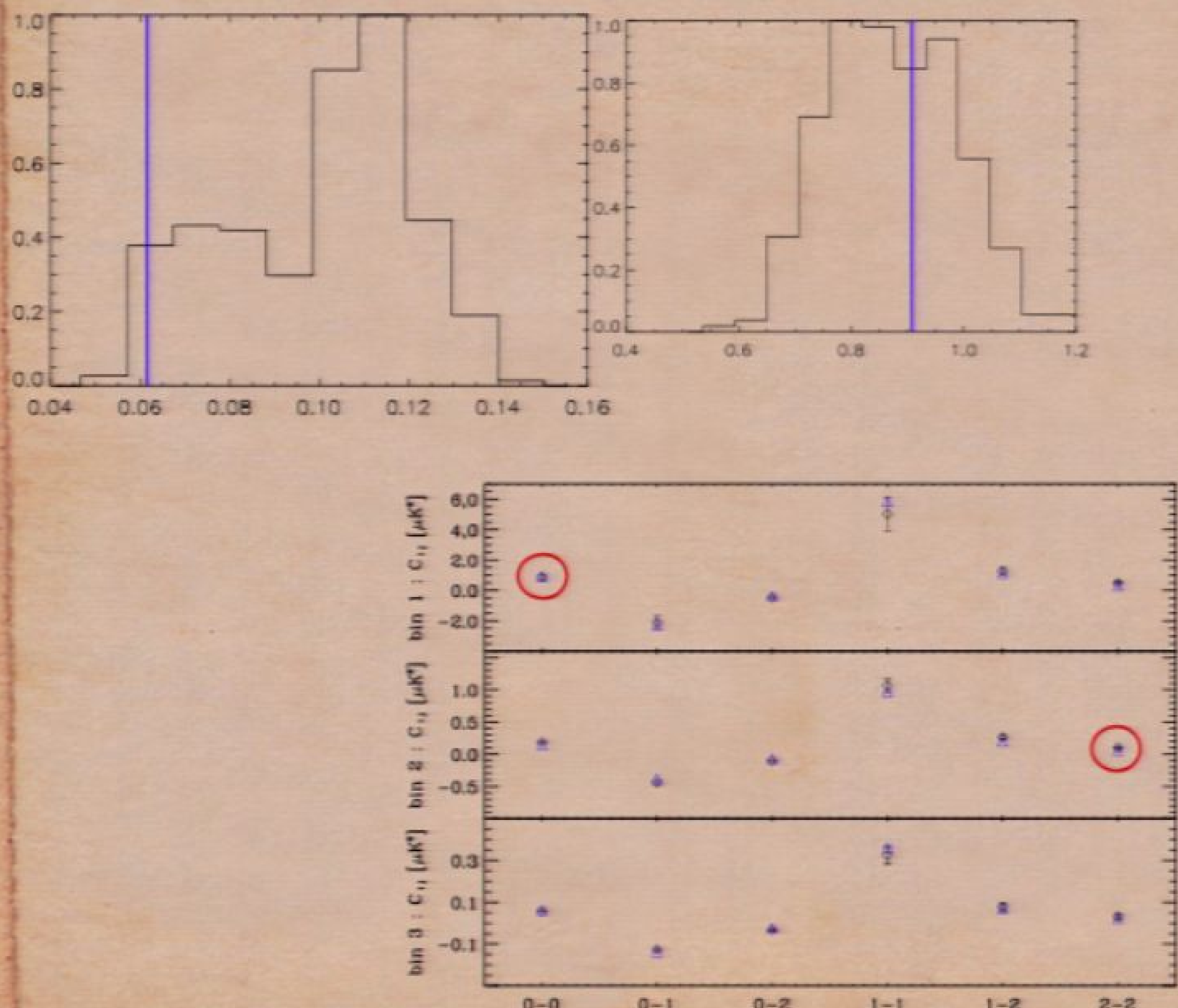
$F_2 = 0.7 \pm 0.04$ (5.7%)

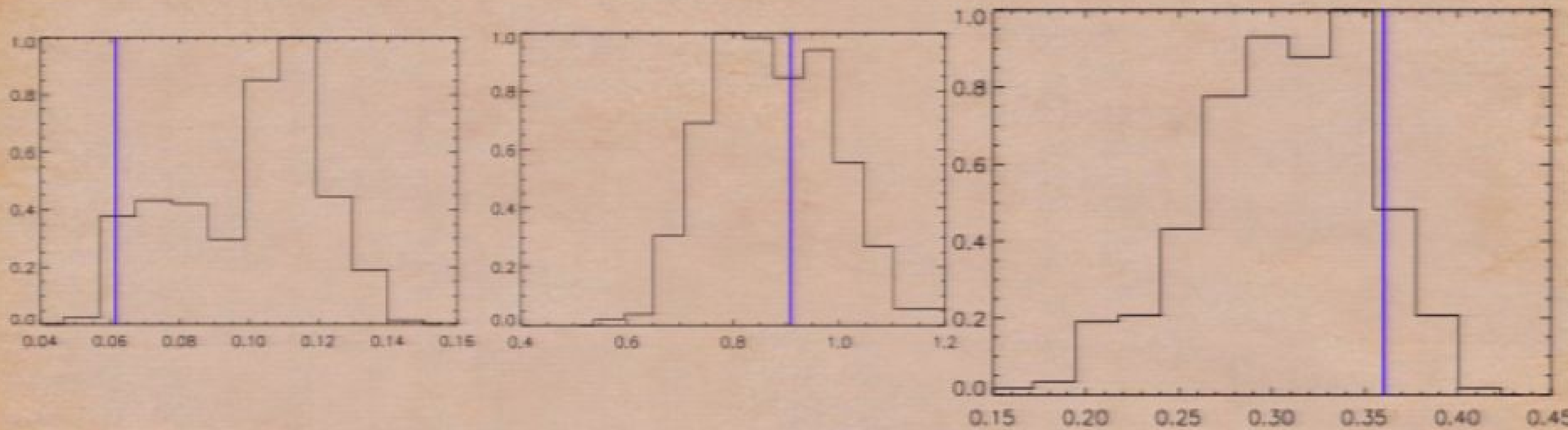
Some data/simulations comparison

$$\mathbf{C}_{ij} = \sum_{l \in b,m} \sum_{u,v} \frac{\langle a_{lm}^{i,u} a_{lm}^{j,v\star} \rangle}{s(\nu_i)s(\nu_j)b_l^{i,u} b_l^{j,v}} \quad \text{with } u \neq v, \text{ if } i = j$$

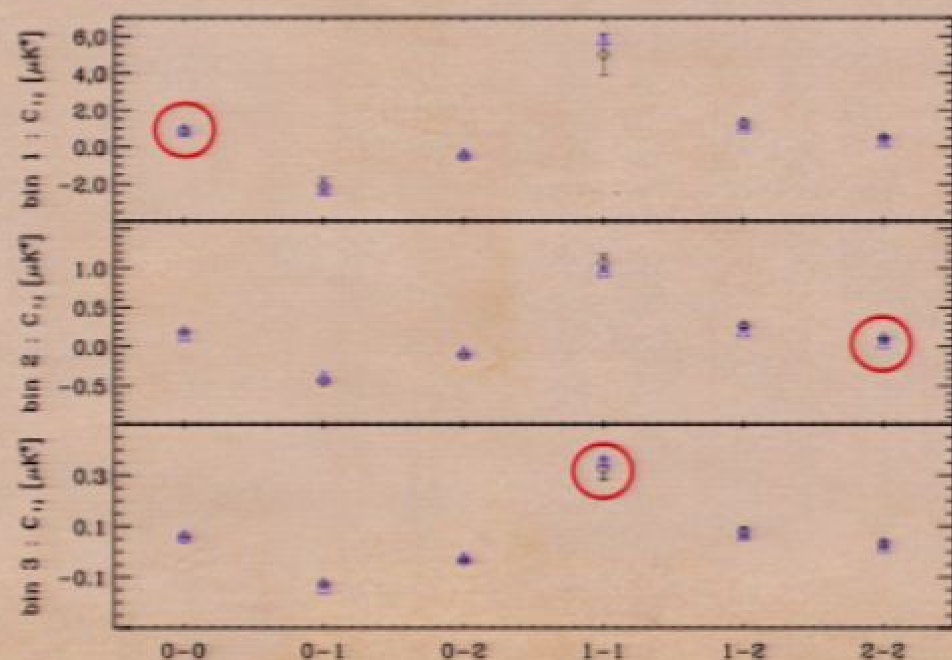



1.0
0.8
0.6
0.4
0.2
0.0
0.4
0.6
0.8
1.0
1.2
bin 1 : C$_{ij}$ [μK^2]
bin 2 : C$_{ij}$ [μK^2]
bin 3 : C$_{ij}$ [μK^2]
0-0
0-1
0-2
1-1
1-2
2-2


0.0
0.2
0.4
0.6
0.8
1.0
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.4
0.6
0.8
1.0
1.2
bin 1 : C_ij [μK²]
bin 2 : C_ij [μK²]
bin 3 : C_ij [μK²]
6.0
4.0
2.0
0.0
-2.0
1.0
0.5
0.0
-0.5
0.3
0.1
-0.1
0-0
0-1
0-2
1-1
1-2
2-2



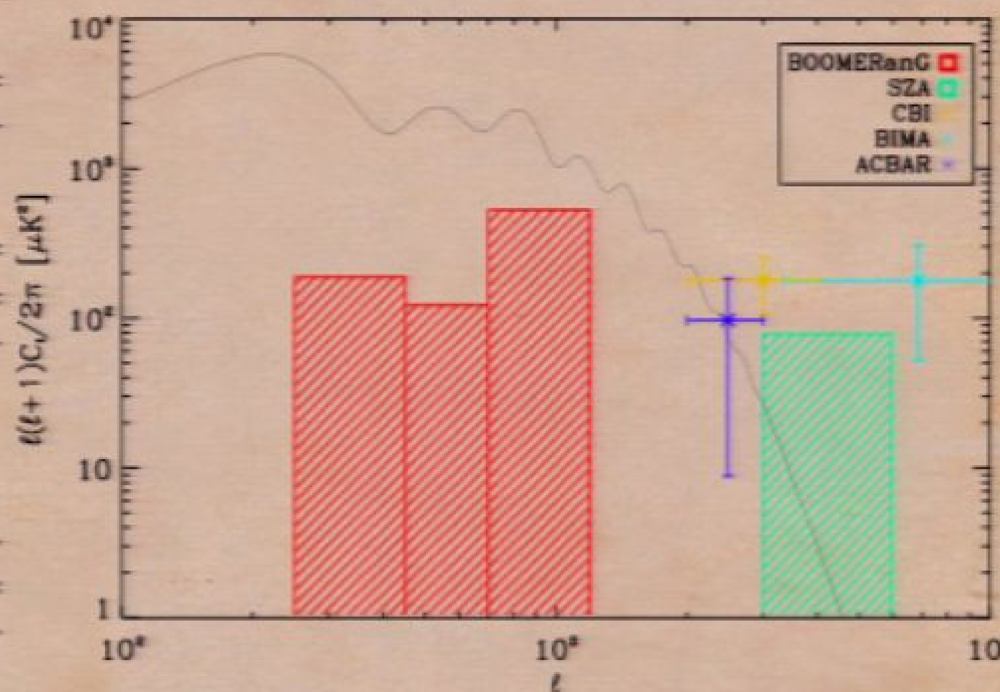
0.04 0.06 0.08 0.10 0.12 0.14 0.16
0.4 0.6 0.8 1.0 1.2
0.15 0.20 0.25 0.30 0.35 0.40 0.45



bin 1 : C_ij [μK²]
bin 2 : C_ij [μK²]
bin 3 : C_ij [μK²]
0-0 0-1 0-2 1-1 1-2 2-2

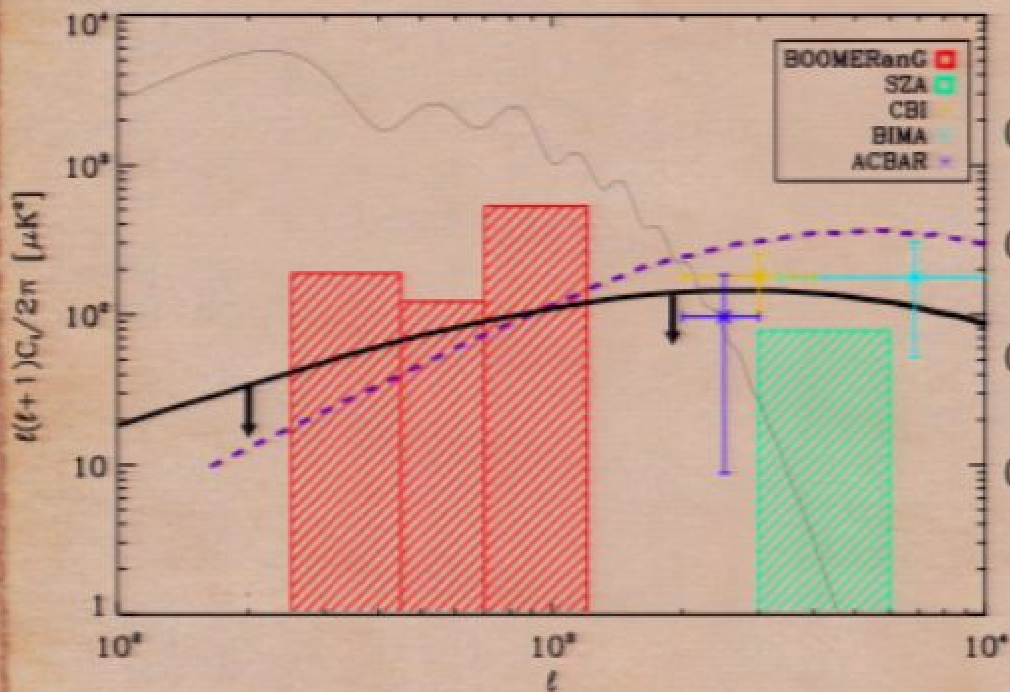
Results

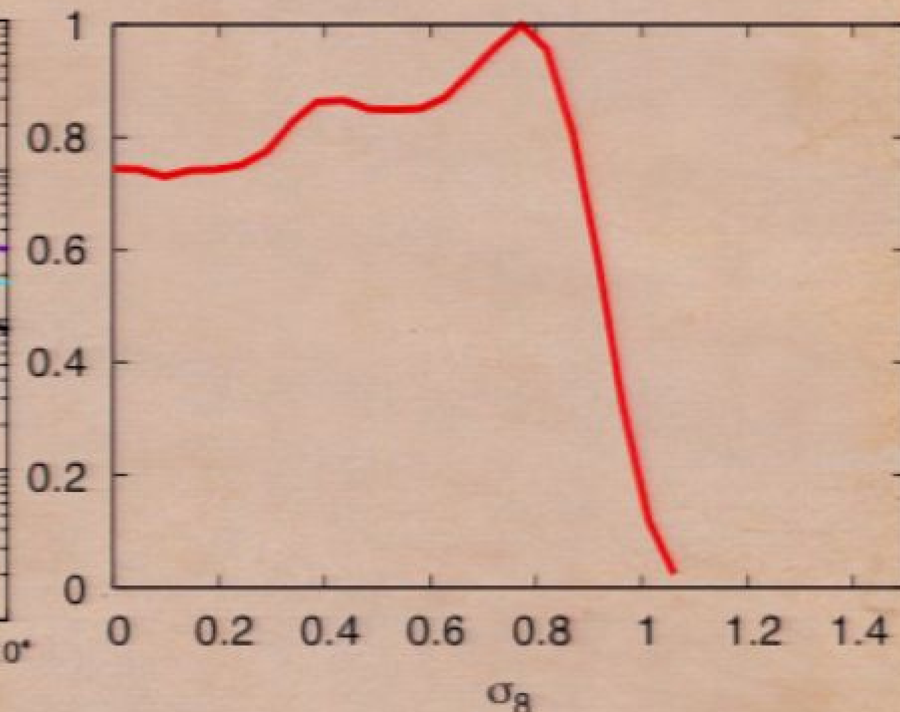
SZ Power Spectrum Estimates	bin 1	bin 2	bin 3
ℓ-range	250-450	450-700	700-1200
Optimal weights			
w_{145GHz}	0.9323	0.8514	0.7289
w_{245GHz}	0.4193	0.3771	0.3002
w_{345GHz}	-0.3515	-0.2285	-0.0292
Raw SZ	236	164	538
Residuals			
CMB	53	36	70
Instr. noise	92	12	-95
Galactic dust	68	82	138
FIRB	44	81	195
Radio sources	3	7	58
Total residual	247	202	338
SZ Band Power Uncertainties			
Instr. & cosmic var.	154	116	280
Foregrounds	37	79	145
Beam	3	5	44
Calibration	121	77	63
Transfer func.	2	3	11
Final SZ Band Power	-11 ± 199	-38 ± 160	200 ± 325



The combined limit of the 3 BOOMERanG limits is 234 μK^2 at 2σ

Constrain on σ_8





Finally results : combined constrain gives $\sigma_8 < 0.96$ at 95% confidence

Conclusions

- We put a limit of 234 μK^2 (2σ) on SZ emission between l of 250 and 1200

- Major uncertainty come from FIRB and high noise at 345 GHz

- Planck should be able to do better with more frequencies and better sensitivity

arxiv:0904.4313