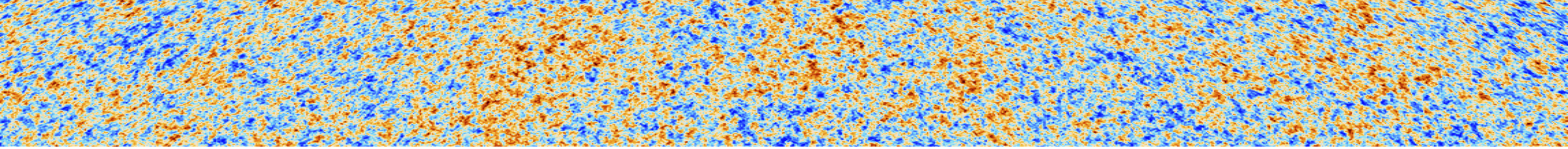


Questions for a next CMB ESA M5 mission

Carlo Burigana

INAF-IASF Bologna,

Univ. Ferrara Dip. Fisica & Scienze della Terra, INFN-Sezione di Bologna

with inputs from Italian CMB community and CORE teams

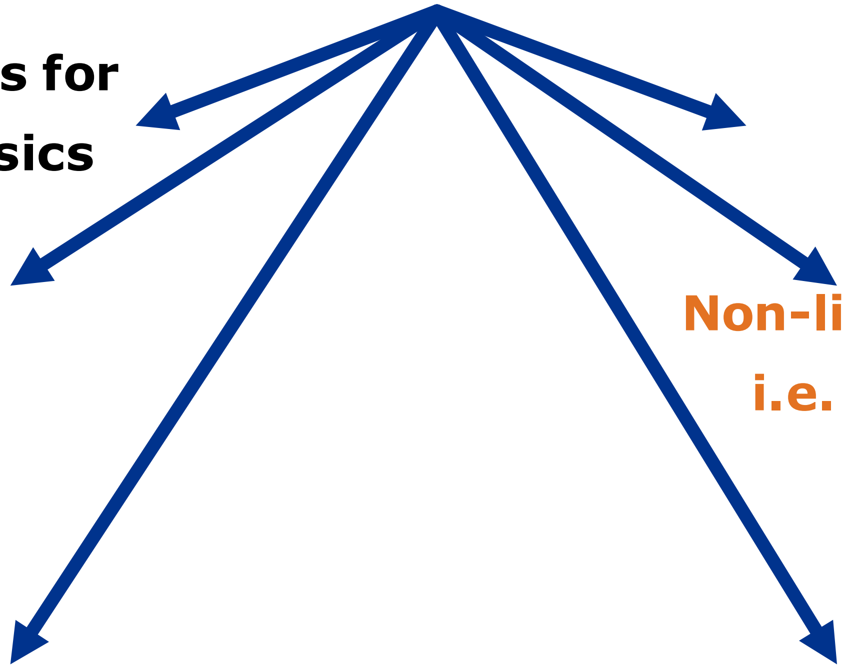
Meeting INAF - Macroarea 1

Galassie e Cosmologia

Bologna, 16-17 giugno 2016

Framework

2 faces of CMB



Fundamental tests for cosmology & physics

High precision cosmology

Linear physics i.e. simplicity, robustness

Non-linear astrophysics i.e. cosmic structures

Early Universe

Cosmic history up to late stages

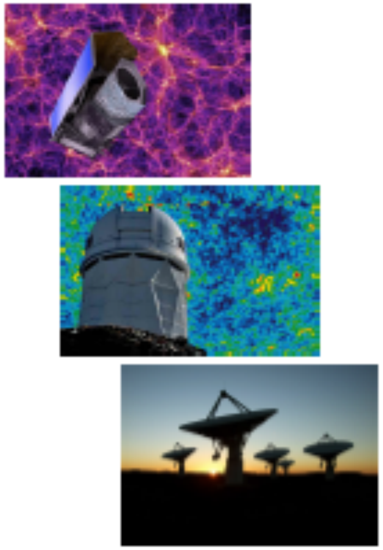
and

CMB: global & statistical information

Microwave surveys: astrophysics & specific targets

The context

- Think of a future CMB polarization mission in synergy with other CMB experiments and other cosmological probes
  - ground/balloons vs. space – who does what?
    (sensitivity, angular resolution, systematics, frequency coverage)
  - synergy with other cosmological probes
    (cosmic complementarity: accurate testing of the model)

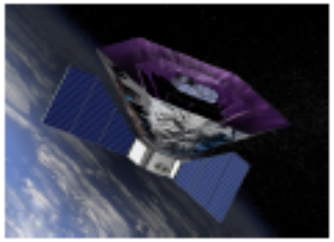


The suborbital roadmap

High resolution maps at ν < 200 GHz

PIXIE NASA

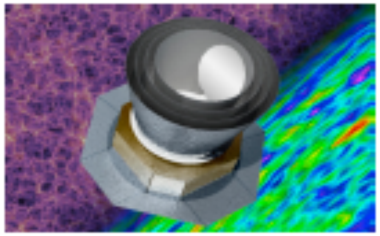
The CMB spectrum



Absolute spectrophotometry

Polarization from space

LiteBird JAXA



High sensitivity multi-channel differential polarimetry

CORE ESA

Courtesy N. Mandolesi

Scientific goals of future CMB mission(s): B-modes … but not only ☺ → scientific return even for extremely low r=T/S

In a nutshell: New science with a polarimetric and spectral survey of the **Hubble volume** from the μ–wave to the far-IR

See talks by Finelli & Liguori

5

Ultimate measurement of CMB polarization, Gaussianity, and absolute spectrum.
Search for the gravitational waves produced during inflation.

1

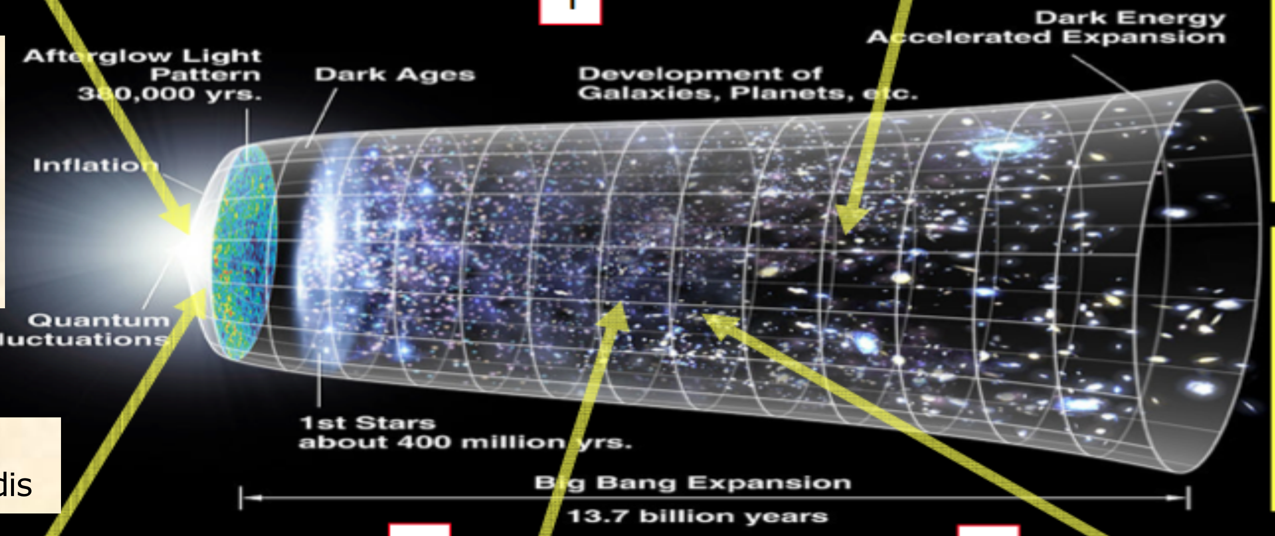
Ultimate galaxy cluster survey via Sunyaev-Zeldovich effect (SZ): ($>10^6$: all clusters with $M>10^{14}M_\odot$ within our horizon)

Legacy archive of hundreds of full-sky intensity and polarization maps from tens of GHz to few THz with extreme precision and resolution : $1\mu K_{CMB}$arcmin 1'FWHM@λ1mm

6

A complete survey of the interstellar medium in the Milky way : dust, molecular lines, magnetic field, …

CORE: designed for many of these goals



Courtesy
P. de Bernardis

4

Probe epochs before recombination and new physics using CMB spectral distortion measurements

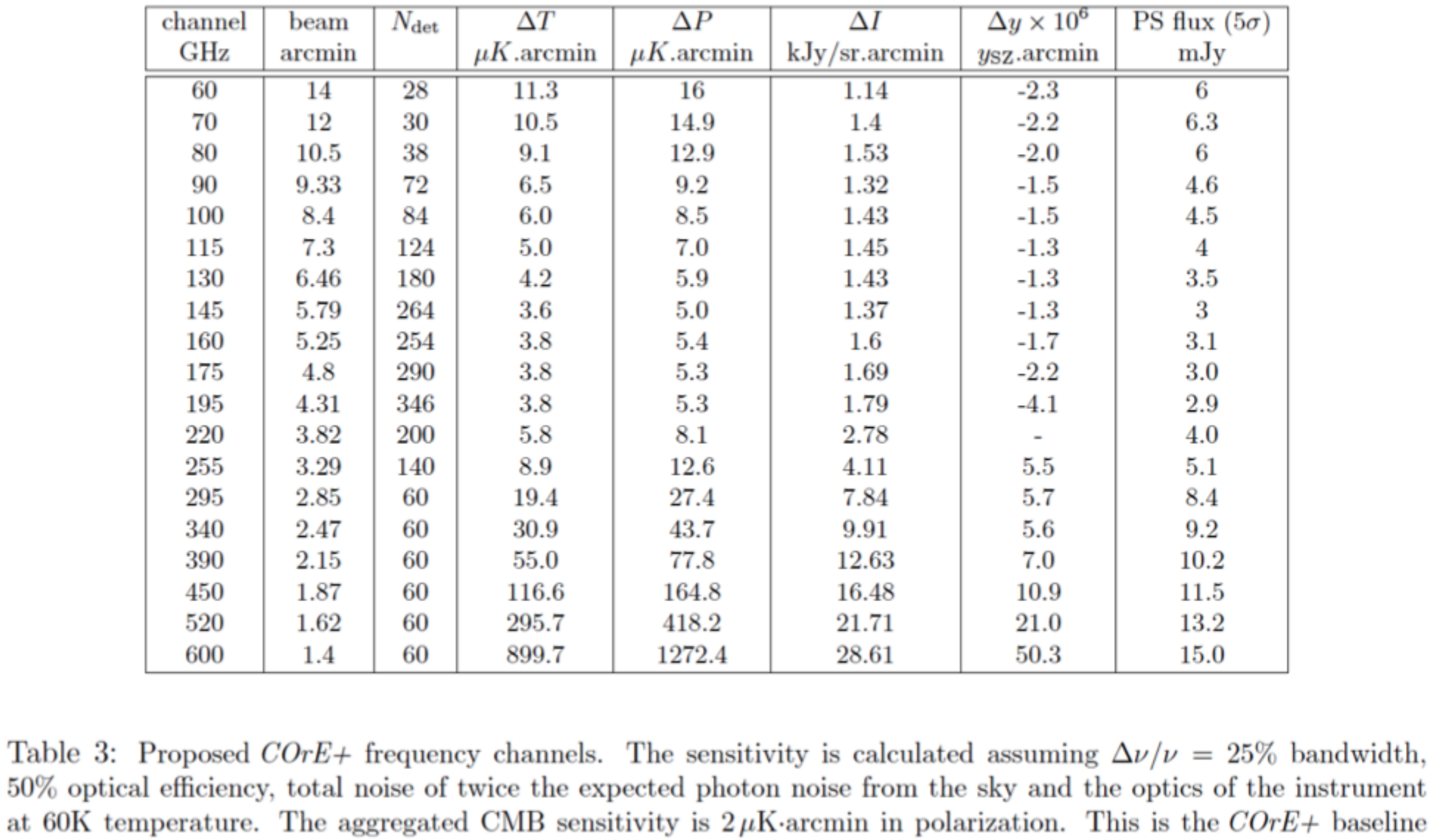
3

Map the gravitational potential all the way to z=1100 through CMB lensing

2

Probe early star formation and its evolution through precision characterization of the Cosmic Infrared Background (CIB)

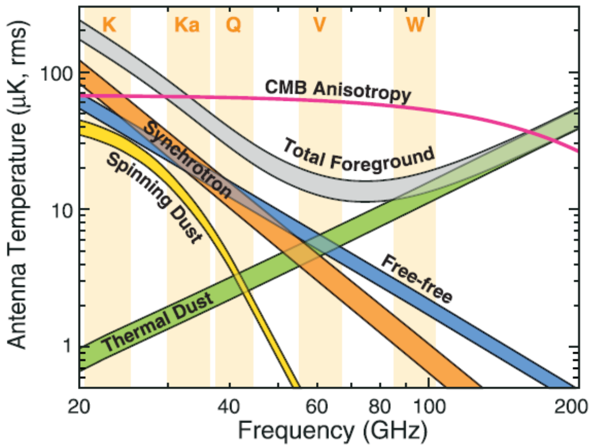
CORE channels and sensitivity



channel GHz	beam arcmin	$N_{\rm det}$	ΔT μK.arcmin	ΔP μK.arcmin	ΔI kJy/sr.arcmin	$\Delta y \times 10^6$ y_{SZ}.arcmin	PS flux (5σ) mJy
60	14	28	11.3	16	1.14	-2.3	6
70	12	30	10.5	14.9	1.4	-2.2	6.3
80	10.5	38	9.1	12.9	1.53	-2.0	6
90	9.33	72	6.5	9.2	1.32	-1.5	4.6
100	8.4	84	6.0	8.5	1.43	-1.5	4.5
115	7.3	124	5.0	7.0	1.45	-1.3	4
130	6.46	180	4.2	5.9	1.43	-1.3	3.5
145	5.79	264	3.6	5.0	1.37	-1.3	3
160	5.25	254	3.8	5.4	1.6	-1.7	3.1
175	4.8	290	3.8	5.3	1.69	-2.2	3.0
195	4.31	346	3.8	5.3	1.79	-4.1	2.9
220	3.82	200	5.8	8.1	2.78	-	4.0
255	3.29	140	8.9	12.6	4.11	5.5	5.1
295	2.85	60	19.4	27.4	7.84	5.7	8.4
340	2.47	60	30.9	43.7	9.91	5.6	9.2
390	2.15	60	55.0	77.8	12.63	7.0	10.2
450	1.87	60	116.6	164.8	16.48	10.9	11.5
520	1.62	60	295.7	418.2	21.71	21.0	13.2
600	1.4	60	899.7	1272.4	28.61	50.3	15.0

Table 3: Proposed *COrE+* frequency channels. The sensitivity is calculated assuming $\Delta\nu/\nu = 25\%$ bandwidth, 50% optical efficiency, total noise of twice the expected photon noise from the sky and the optics of the instrument at 60K temperature. The aggregated CMB sensitivity is $2\,\mu$K·arcmin in polarization. This is the *COrE+* baseline

rms fluctuations in T & P: CMB vs foregrounds
Change of paradigm from *Planck* maps



WMAP 9

75-85% sky coverage

Planck **in T:** 81-93% sky coverage - 1° FWHM

c.f. common mask 78%

Microwave sky complexity: **more relevant components!**

Many parameters!

Synch: 2 +

Dust: 3 (* 2 ?)

FF: 2 (EM,T_e)

Spinning dust: 3loc+1glob

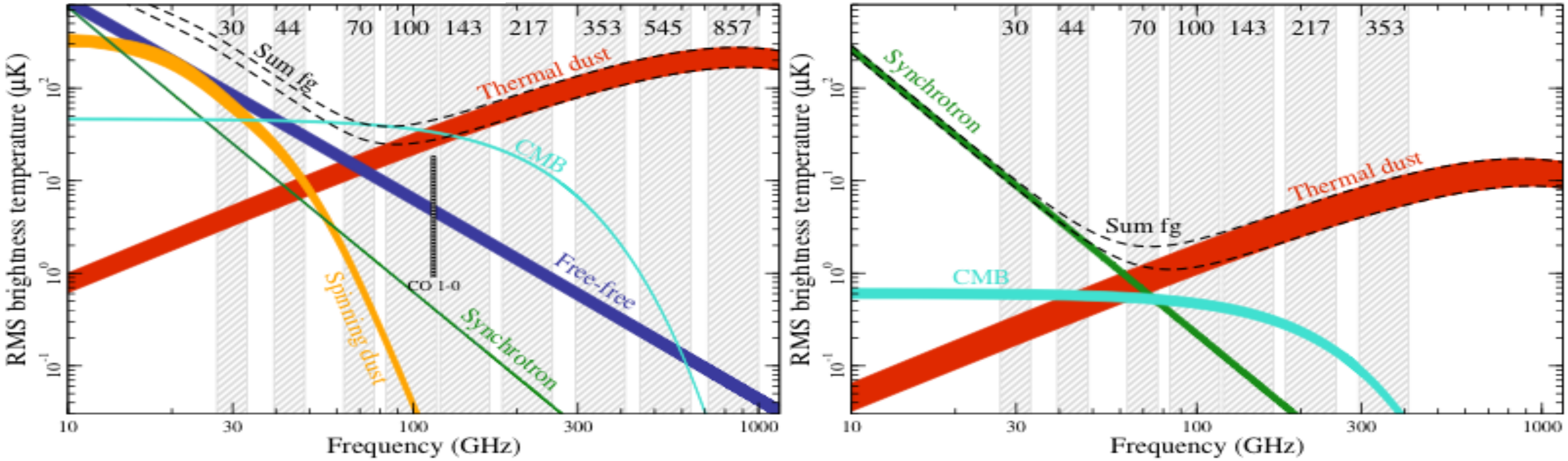
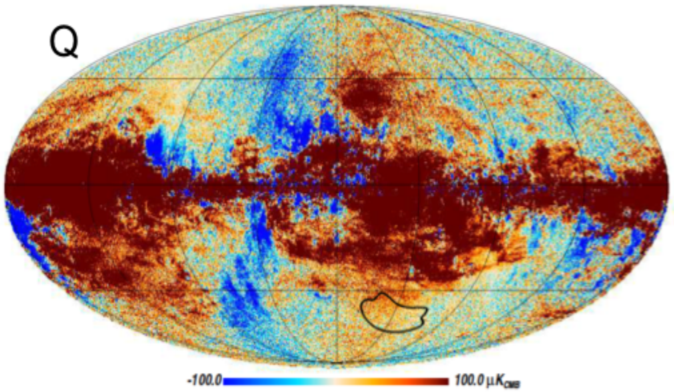


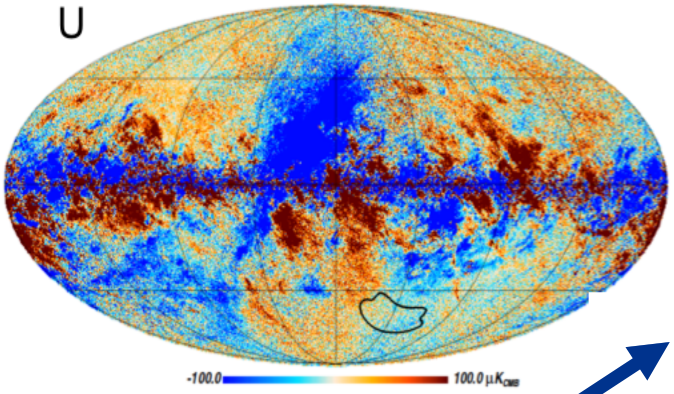
Fig. 16. Brightness temperature rms as a function of frequency and astrophysical component for temperature (*left*) and polarization (*right*). For temperature, each component is smoothed to an angular resolution of 1° FWHM, and the lower and upper edges of each line are defined by masks covering 81 and 93 % of the sky, respectively. For polarization, the corresponding smoothing scale is 40′, and the sky fractions are 73 and 93 %.

Planck 353 GHz full sky maps in polarization

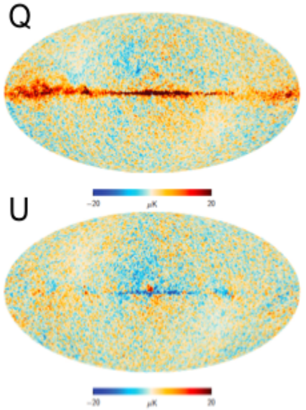
Planck first results on dust polarized emission:

- 353 GHz polarized maps are dominated by Galactic dust emission





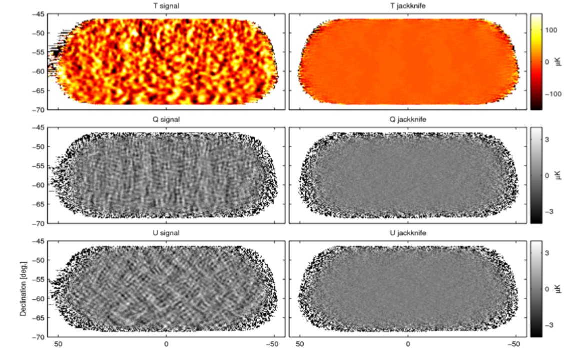
For comparison, Planck 70 GHz is close to the minimum of Galactic foreground emission



Bicep2, Keck Array and Planck Collaboration

High observed degree of polarization (P/I)obs up to 18%

B2+Keck 150 GHz T/Q/U maps of small sky patch



57 nK deg (3.4 µK arcmin) when adding 2012/13 Keck data - by far the deepest maps ever made - but apodized and filtered...

Bicep2, Keck Array and Planck Collaboration

Planck Collaboration: Dust polarization at high latitudes

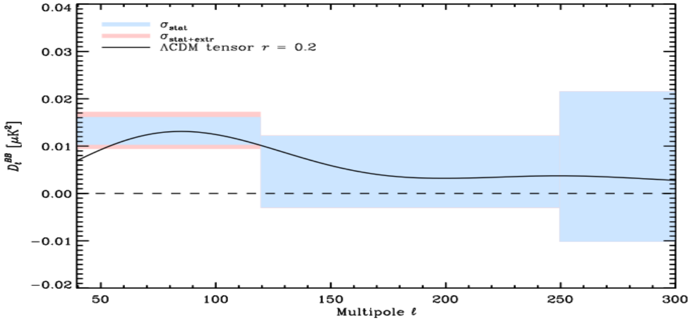
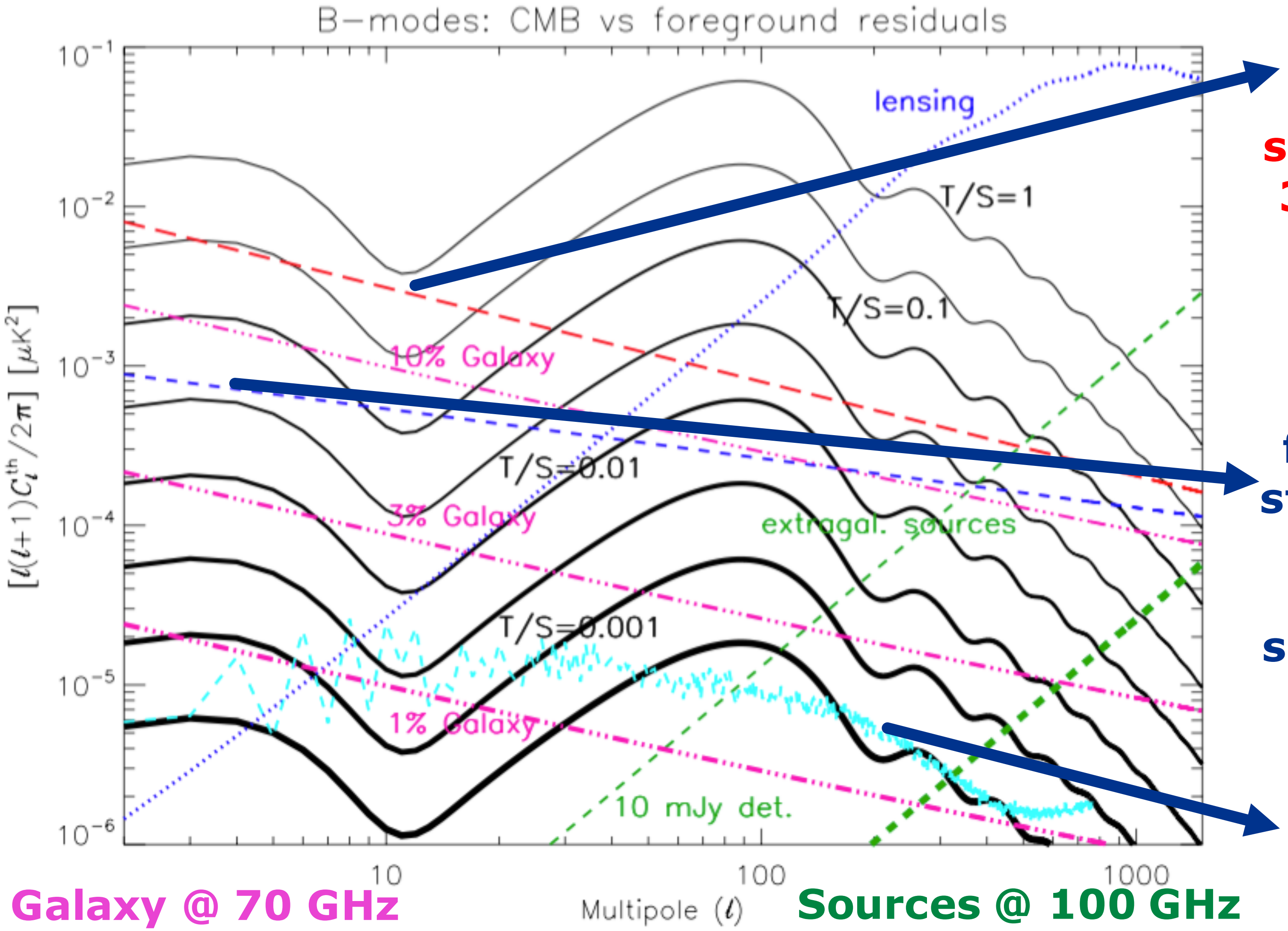


Fig. 9: *Planck* 353 GHz $\mathcal{D}_\ell^{BB}$ angular power spectrum computed on $M_{\rm B2}$ defined in Sect. 6.1 and extrapolated to 150 GHz (box centres). The shaded boxes represent the $\pm 1\,\sigma$ uncertainties: blue for the statistical uncertainties from noise; and red adding in quadrature the uncertainty from the extrapolation to 150 GHz. The *Planck* 2013 best-fit ΛCDM $\mathcal{D}_\ell^{BB}$ CMB model based on temperature anisotropies, with a tensor amplitude fixed at $r = 0.2$, is overplotted as a black line.

Dust essentially everywhere → need for space!

Crucial for understanding the nature of B-mode polarization signal

Impact of residuals foregrounds (including e.g. subdominant components / complexity in dominant components



Residual from dust starting from 353 GHz for an error in beta_dust of 0.01

Residual from synch starting from 30 GHz for an error in slope of 0.02

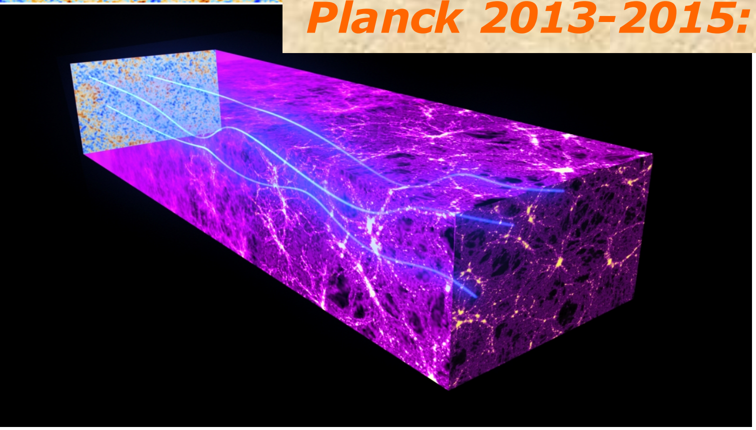
Estimate of AME, assuming pol. degree of 2%

Galaxy @ 70 GHz

Sources @ 100 GHz

CORE: lensing & delensing through arcmin resolution

Planck 2013-2015: 25-40 σ detection



Matter distribution deflects CMB photons → map de-focusing

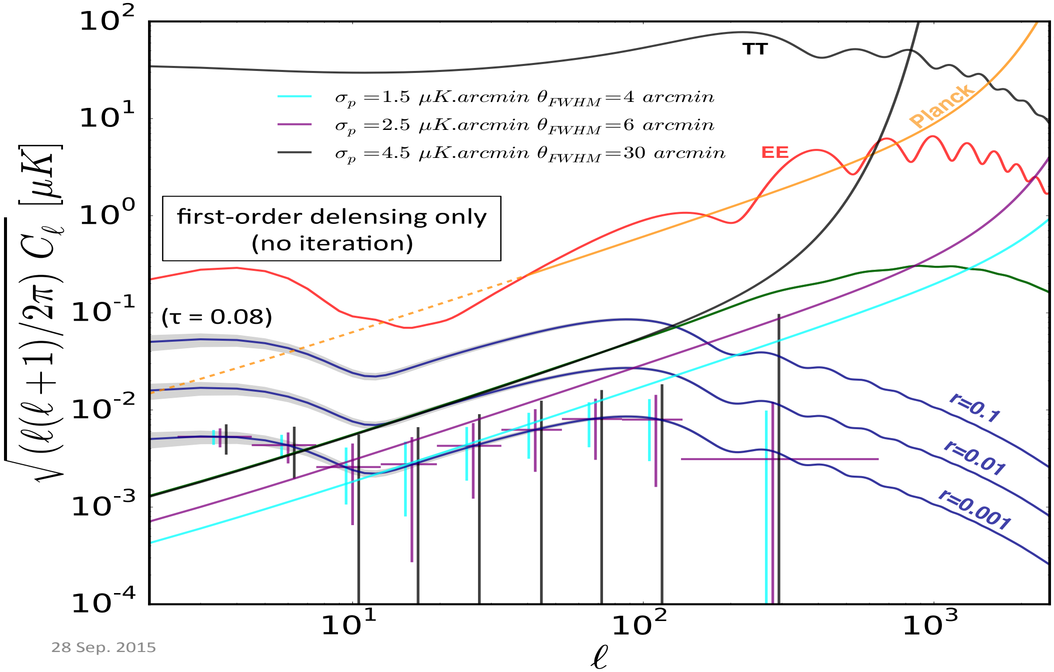
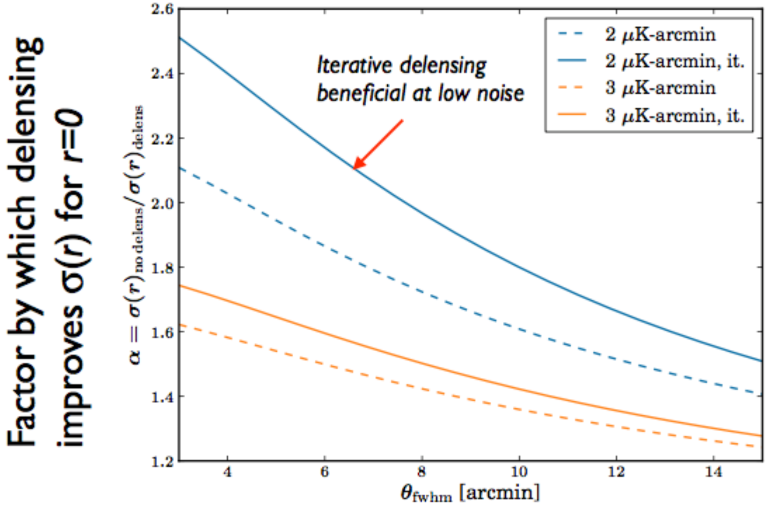


Figure by Josquin Errard

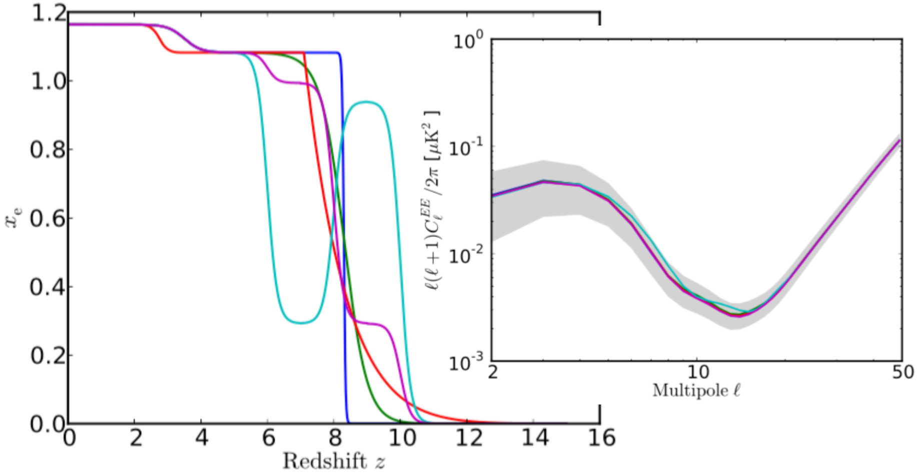


Courtesy Feeney & Errard
and Challinor

- ➢ **Internal delensing improves σ(*r*) by factor 1.6-2.3 (for low *r*) at few arcmin resolution**
- ➢ **See Finelli's talk**
- ➢ **CMB lensing power spectrum helps cosmology**
- ✓ ***- E.g., at least 4σ detection of neutrino mass (with DESI/Euclid BAO)***
- ✓ ***CORE alone* σ (M_n)~44meV + *Euclid* ~15-20meV**

Courtesy J. Lesgourgues

Reionization beyond $\tau = \int \chi_e n_e \sigma_T c\,dt$ approximation
Extension to all modes – EE & BB modes



Planck Collaboration: Planck constraints on reionization history

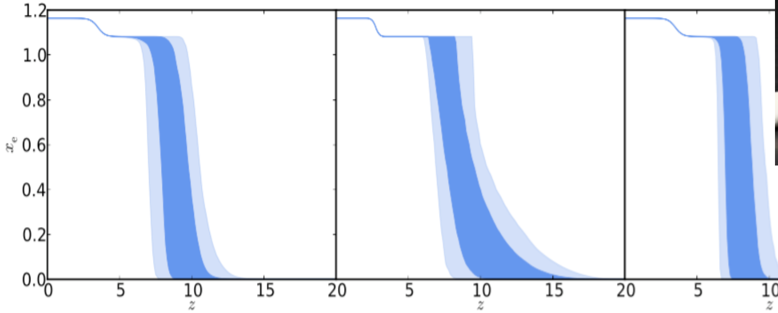
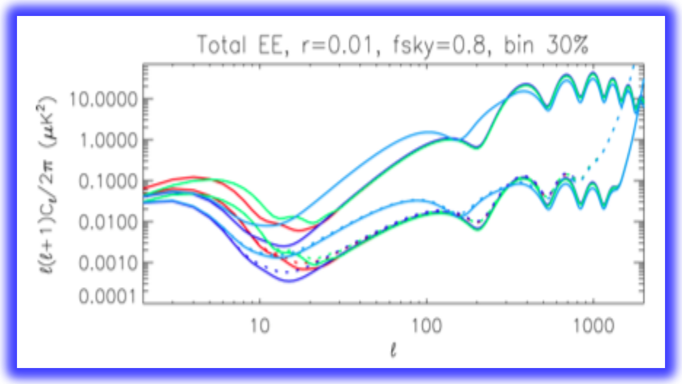
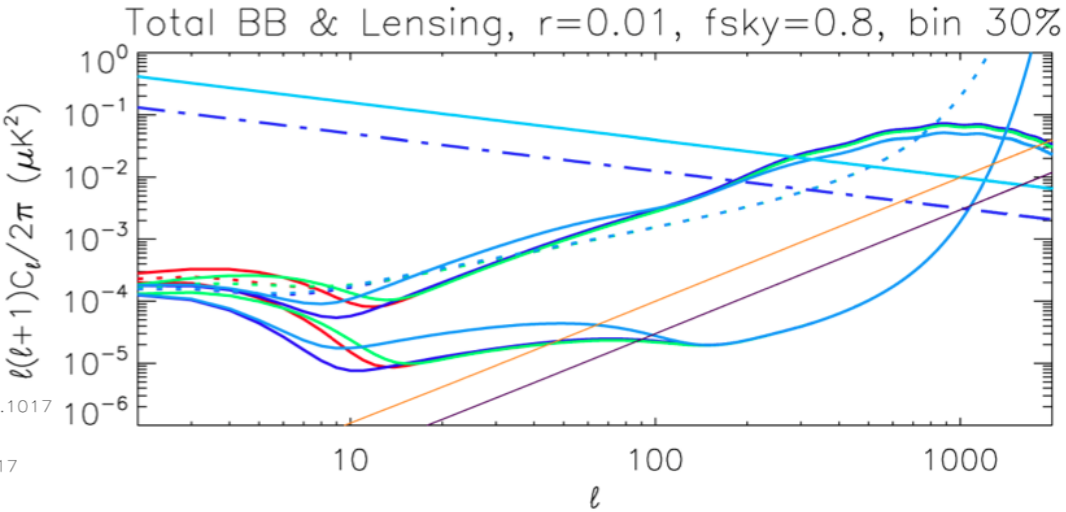


Fig. 18. Constraints on ionization fraction during reionization. The allowed models, in terms of z_{re} and Δz, translate into an allowed region in $x_e(z)$ (68 % and 95 % in dark blue and light blue, respectively), including the $z_{end} > 6$ prior here. *Left*: Constraints from CMB data using a redshift-symmetric function ($x_e(z)$ as a hyperbolic tangent with $\delta z = 0.5$). *Centre*: Constraints from CMB data using a redshift-asymmetric parameterization ($x_e(z)$ as a power law). *Right*: Constraints from CMB data using a redshift-symmetric parameterization with additional constraints from the kSZ effect.



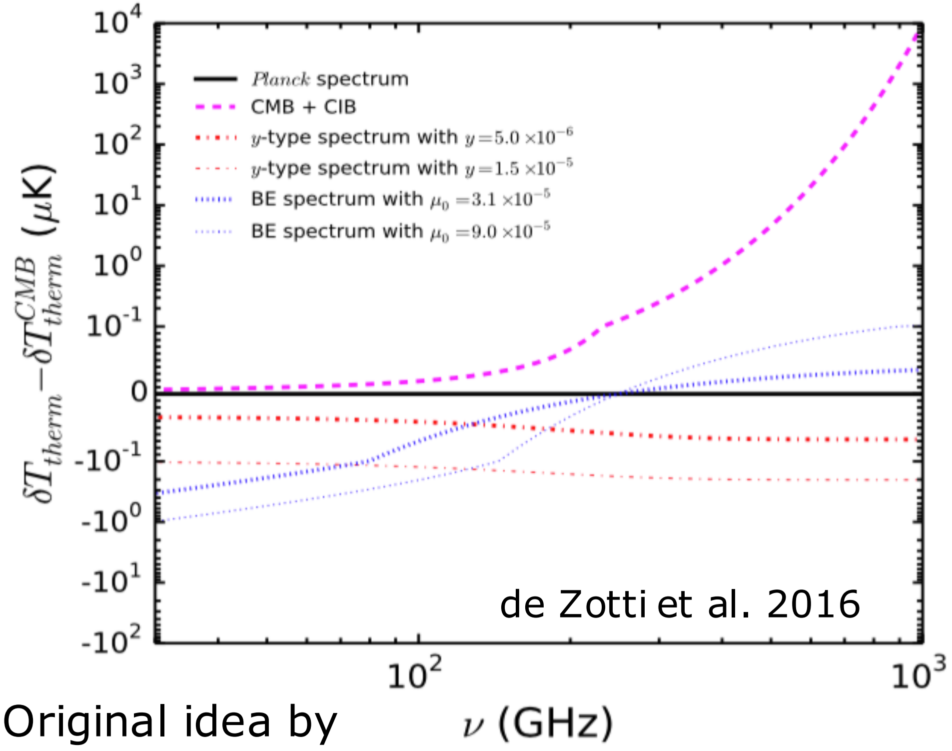


Suppression, τ=0.1017
Planck CV+N
COrE CV+N
Filtering, τ=0.0631
Planck CV+N
COrE CV+N
Synchrotron, ν_{cmb}=70 GHz
Radiosources

Late Double Peaked, τ=0.1017
Planck CV+N
COrE CV+N
Early & Filtering, τ=0.1017
Planck CV+N
COrE CV+N
Dust, ν_{cmb}=70 GHz
Radiosources 30%

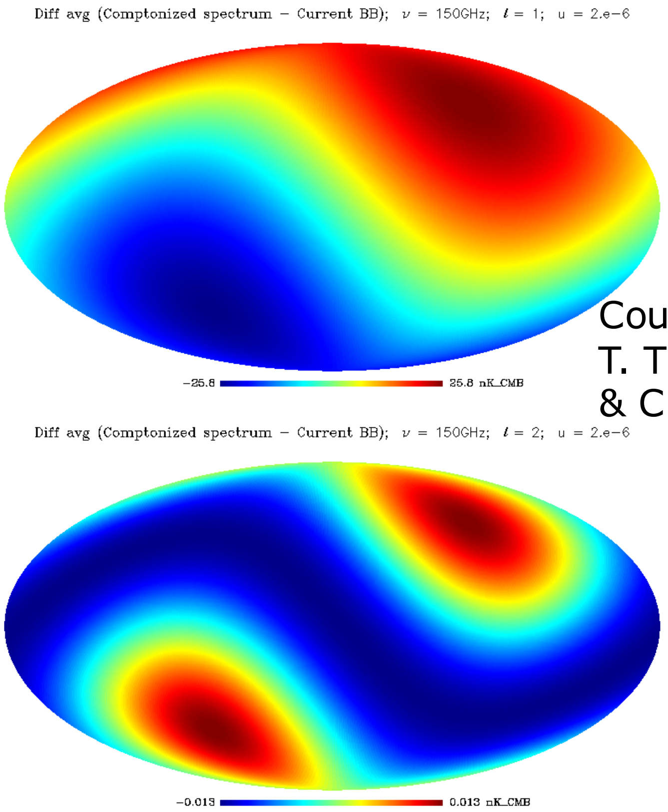
From Trombetti & Burigana, 2012

Dipole spectrum: CMB distortions and CIB



de Zotti et al. 2016

Original idea by
Danese & de Zotti 1981

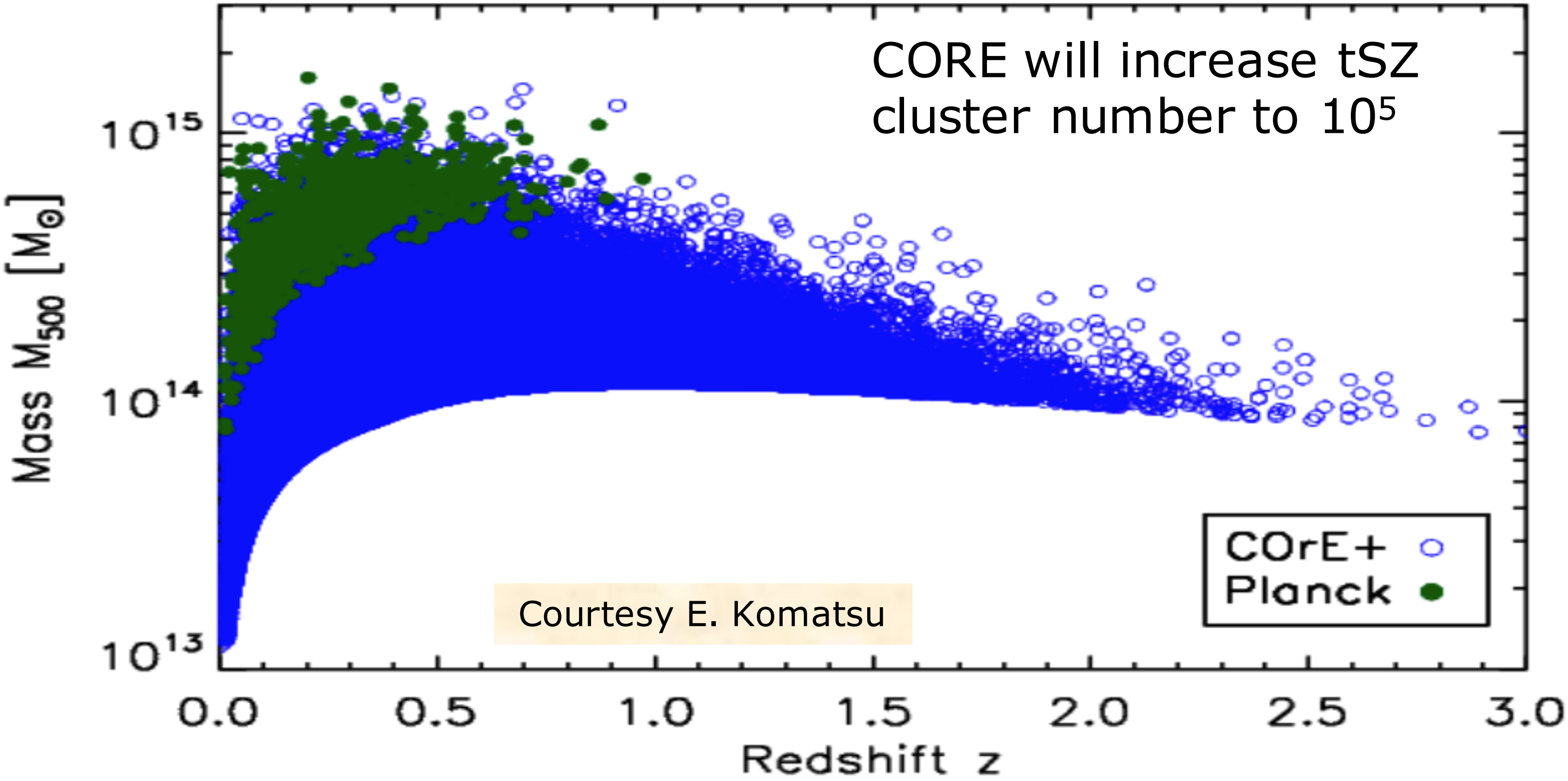


Courtesy
T. Trombetti
& C.B. 2016

- **Without absolute calibration, but with only accurate relative & interfrequency calibration CORE will have the chance to detect CIB & reonization (& others?) distortions (see also Liguori's talk) through low multipole pattern**

→ Global & (almost) model independent constraints on energy dissipations

Y map gives us lots of clusters

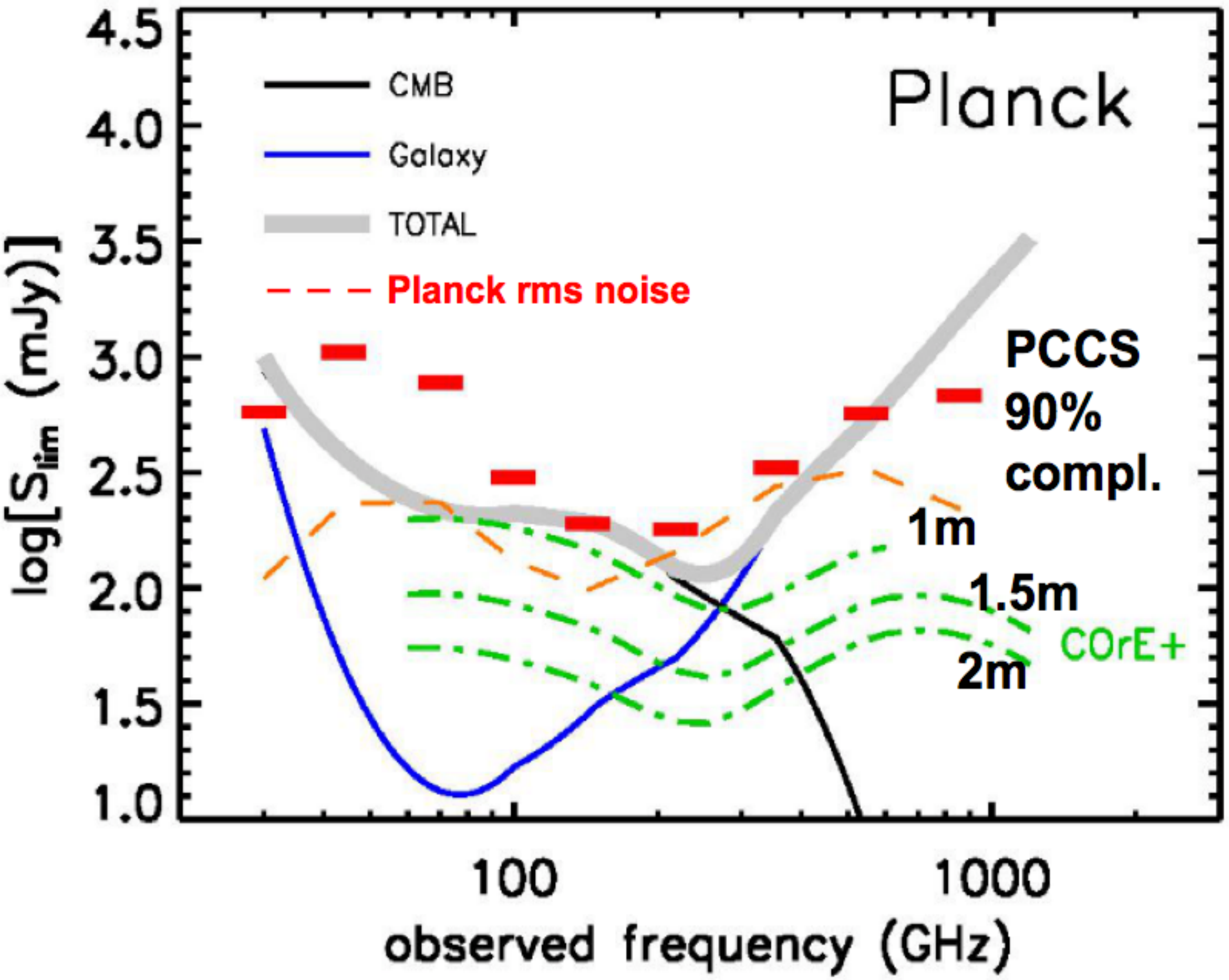


CORE will increase tSZ cluster number to 10^5

Courtesy E. Komatsu

- **3D reconstruction on very large volumes**
- **Synergy with other experiments (eROSITA,Euclid, LSST, WFIRST, Athena)**
- **Velocites (kSZ)** to 30,000 clusters with ≥ 5σ precision
- **Relativistic tSZ effect**

Detection limits for a diffraction-limited survey



In total intensity:

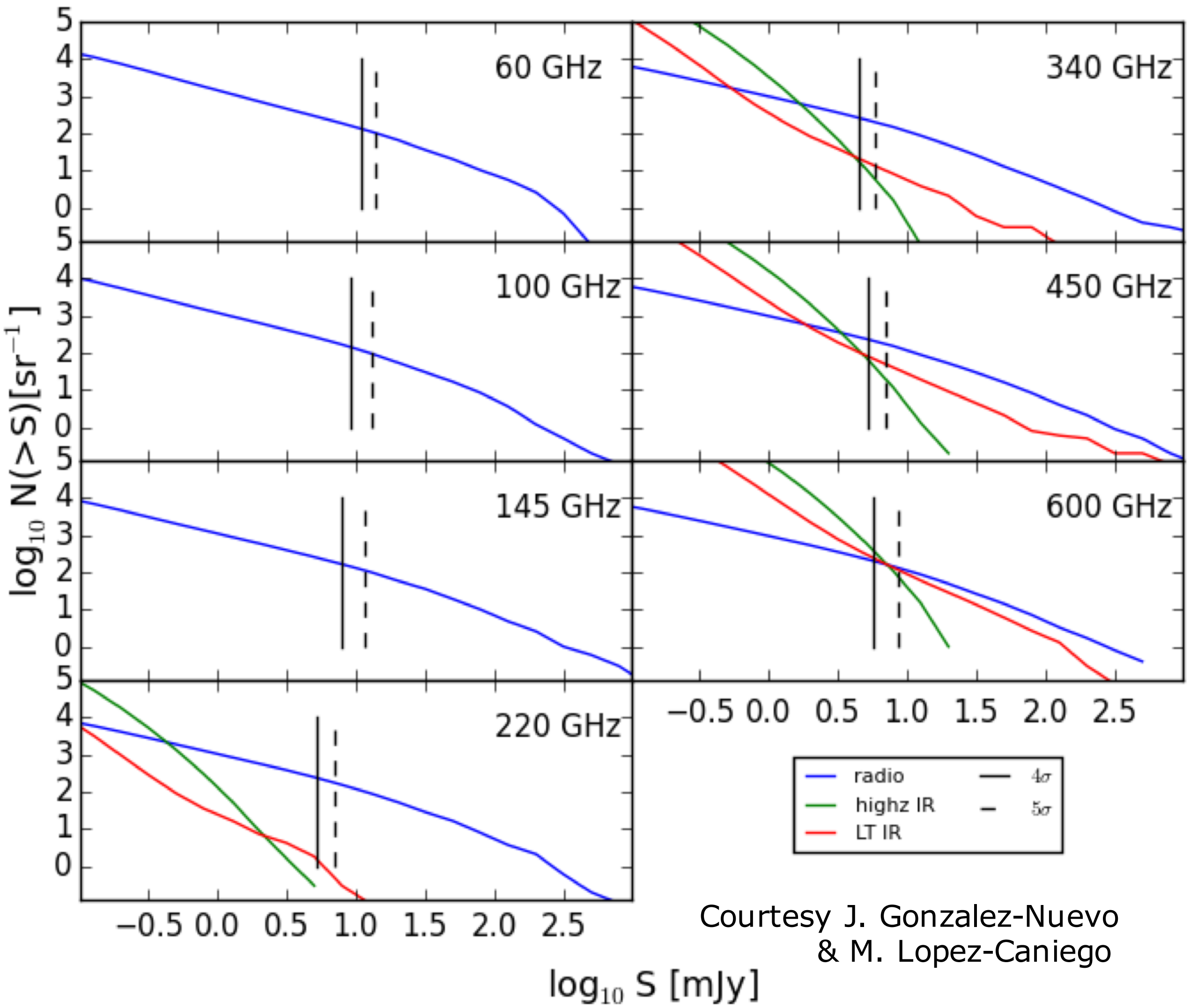
Given current sensitivities, confusion dominates detection limits

→ **Angular resolution critical**

Planck HFI worse than diffraction limited

Improvements expected even with *smaller telescope* but *diffraction-limited*

Predicted counts in polarization for a 1m telescope



Courtesy J. Gonzalez-Nuevo
& M. Lopez-Caniego

Complete samples in polarization are currently limited to:

- ✓ **some tens of radio-sources (microwaves/mm)**
- ✓ **negligible number (sub-mm)**

COrE-M5 high sensitivity in polarization open a new window

Simulations for COrE-M5 suggest:

- ❖ **detection of: thousands of sources in its whole frequency range**
- ❖ **for the first time: hundreds of galaxies with intense star formation with polarized signal by dust grains**

→ Unique information on:

- ➢ **their magnetic fields**
- ➢ **unknown origin of tight correlation between IR and radio luminosities of these objects**

Conclusions

1. ***Planck* legacy will set the scene for many years**
2. **Time is appropriate for starting with a new CMB mission**, from both scientific expertise and technological development
3. **CMB science** ("primary" & "secondary") **essential** for early Universe, cosmic evolution, fundamental physics (see also di Serego's talk)
4. **Crucial CMB science goals** can be achieved by a focussed **medium mission**
5. **Synergy between ground & space projects**
6. **Space necessary for frequency coverage above 200 GHz (dust!)**
7. **Resolution necessary for delensing (!)**
8. **CORE targeted to *characterize, not only detect,* B-modes down to $r \cong 10^{-3}$ or even lower ($r \cong 2x10^{-4}$)**
9. **Wide set of key scientific goals & potentially immense legacy science "automatically" assured by this aim**