Velocity effects

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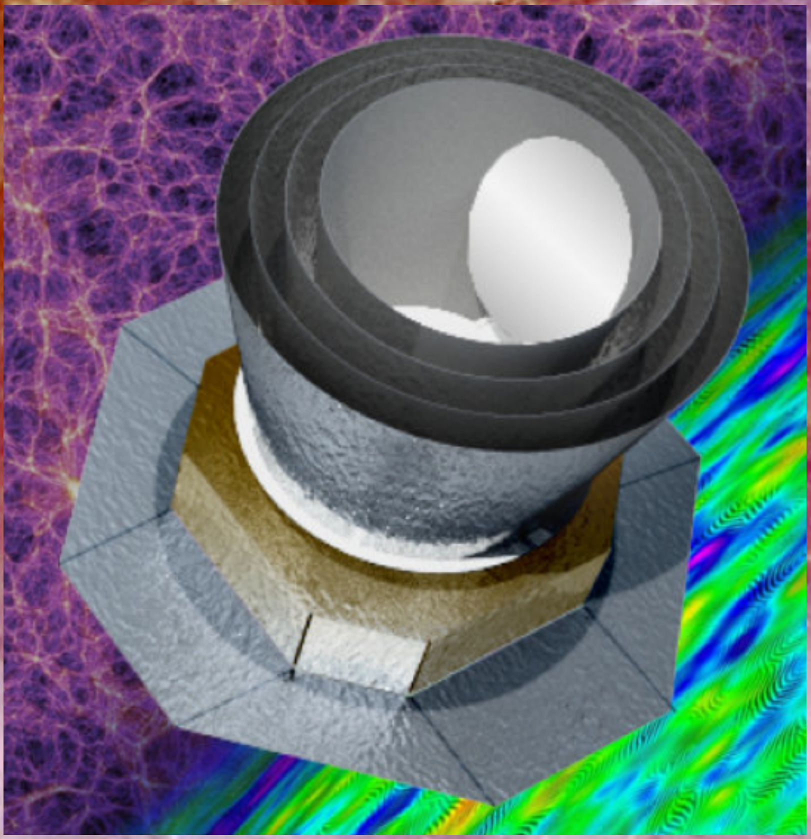
& the “peculiar motion” team



“Towards a next space probe for CMB observations and cosmic origins exploration”

Geneve, CERN, 17-20 May 2016

Peculiar motion team

C.B., Alessandro Buzzelli, Paolo Cabella, Sofia Carvalho, Jens Chluba, Luigi Danese, Paolo de Bernardis, Giancarlo de Gasperis, Gianfranco de Zotti, Alessandro di Marco, Andrea Lapi, Pasquale Mazzotta, Alessio Notari, Tiziana Trombetti, Nicola Vittorio

if you are interested to join, please let me know

EXPLORING COSMIC ORIGINS: Effects of the observer peculiar motion

- ## I- Introduction

This paper adresses the consequences of the peculiar motion which induces dipoles and boosting effects.

- **Brief description of:**
  - i) problem, probes and implications;
  - ii) synergy with other ECO papers/works;

    e.g. Mission, Instrument, Scan Strategy, Simulations, Clusters, CIB
  - iii) information and synergy with other frequency bands;
  - iv) main goals of the various sections of the paper.

- ## II- Review of current status
- ## III- Forecasts for COrE-M5
- ## IV- Boosting effects (temperature and polarization)
- ## V- Differential approach to CMB spectral distortions
- ## VI- Conclusion: summary of main results.

II - Review of current status

- **CMB dipole:**
  - review of current status from COBE, WMAP, Planck: results, criticalities;
  - interplay with calibration; interplay with data analysis (e.g. map-making/destriping);
  - limitation by foregrounds;
  - lessons learned.
- **CIB dipole:** e.g. Fixsen & Kashlinsky 2011 ApJ 734, 61
  - review of current status from COBE/FIRAS and *Planck*: results, criticalities;
  - interplay with calibration and data analysis;
  - limitation by foregrounds and synergy with far-IR data (e.g. IRIS maps);
  - Zodiacal Light implication;
  - lessons learned.
- **Galaxy clusters dipole:** e.g. Atrio-Barandela et al. 2015, ApJ 810, id143
  - review of current status from *Planck*:
  - extracting information from *Planck* catalog;
  - information available from other microwave/SZ surveys;
  - information available from other frequency bands (X-rays, optical).

Table 1. Dipole characterization from 70 GHz radiometers.

Radiometer	Amplitude [μK_{CMB}]	Galactic Coordinates [deg] l	b
18M	3371.89 ± 0.15	264°.014 ± 0°.008	48°.268 ± 0°.004
18S	3373.03 ± 0.15	263°.998 ± 0°.008	48°.260 ± 0°.004
19M	3368.02 ± 0.17	263°.981 ± 0°.009	48°.262 ± 0°.004
19S	3366.80 ± 0.16	264°.019 ± 0°.009	48°.262 ± 0°.004
20M	3374.08 ± 0.17	264°.000 ± 0°.010	48°.264 ± 0°.005
20S	3361.75 ± 0.17	263°.979 ± 0°.010	48°.257 ± 0°.005
21M	3366.96 ± 0.16	264°.008 ± 0°.008	48°.262 ± 0°.004
21S	3364.19 ± 0.16	264°.022 ± 0°.009	48°.266 ± 0°.004
22M	3366.61 ± 0.14	264°.014 ± 0°.008	48°.266 ± 0°.004
22S	3362.09 ± 0.16	264°.013 ± 0°.009	48°.264 ± 0°.004
23M	3354.17 ± 0.16	264°.027 ± 0°.009	48°.266 ± 0°.004
23S	3358.55 ± 0.18	263°.989 ± 0°.009	48°.268 ± 0°.004
Statistical . . .	3365.87 ± 0.05	264°.006 ± 0°.003	48°.264 ± 0°.001
Systematic . . .	3365.5 ± 3.0	264°.01 ± 0°.05	48°.26 ± 0°.02
Nominal[a]	3364.5 ± 2.0	264°.00 ± 0°.03	48°.24 ± 0°.02

[a] This estimate was produced combining the LFI and HFI dipoles, and it is the one used to calibrate the LFI data delivered in the 2015 data release.

Dipole from *Planck* 2015 results, A&A, available on line

LFI:
***Planck* 2015 results. V, arXiv:1505.08022**
HFI:
***Planck* 2015 results. VIII, arXiv:1502.01587**

Table 2. CMB solar dipole measurements for the 100 and 143 GHz channels estimated for different sky coverage levels (37, 50, and 58 %) corresponding to three thresholds in 857 GHz amplitude (2, 3, and 4 MJy sr^{-1}). Uncertainties include only statistical errors. Systematic errors are 0.8 μK for the amplitude, and (0°.024, 0°.0034) in Galactic (longitude, latitude).

Frequency [GHz]	Threshold [MJy sr^{-1}]	d [μK]	lon [°]	lat [°]
100	2	3364.81 ± 0.06	263.921 ± 0.002	48.2642 ± 0.0008
100	3	3364.76 ± 0.05	263.922 ± 0.002	48.2640 ± 0.0006
100	4	3364.99 ± 0.04	263.928 ± 0.002	48.2631 ± 0.0006
143	2	3364.05 ± 0.03	263.908 ± 0.001	48.2641 ± 0.0004
143	3	3363.72 ± 0.02	263.903 ± 0.001	48.2653 ± 0.0003
143	4	3363.39 ± 0.02	263.905 ± 0.001	48.2668 ± 0.0003

III - Forecasts for COrE-M5

- **CMB dipole:**
  - **improvement from better sensitivity;**
  - **improvement from wider frequency coverage and increased frequency channels;**
  - **masking and improved large scale component separation;**
  - **implication of survey strategy and COrE-M5 (relative/absolute) calibration strategy and data analysis**
- **CIB dipole:**
  - **improvement from COrE-M5;**
  - **analysis of contributions in shells of redshift;**
  - **synergy with future far-IR and IR surveys.**
- **Galaxy clusters dipole:**
  - **expectations from COrE-M5 catalog;**
  - **synergy with future surveys in other frequency bands (X-rays, optical).**
  - **NB:** Link/sinergy with cluster project: one of the aims of that project is to map velocity distribution of clusters, the aim of this project is to map our peculiar velocity, so link in term of data/methods but goals clearly different/identified.

IV- Boosting effects (temperature and polarization)

- How well can we measure the peculiar motion of the Milky Way with various probes? and check their compatibility? And check whether the CMB "dipole" is purely Doppler?
- Primordial amplitude expected to be of the order of quadrupole
  - primary dipole versus Doppler dipole
  - dipole from CMB versus dipole from other probes

  Classical problem in cosmology, maybe, we have a chance to really measure it for the first time

  - multipole analysis (including correlation between multipole)
    - ✓ Challinor & van Leeuwen 2002, Phys. Rev. D 65, 103001
    - ✓ Kosowsky & Kahniashvili 2011, PRL 106, 191301
    - ✓ Amendola et al. 2011, JCAP 07, 027
    - ✓ *Planck* 2013 results. XXVII. A&A 571, A27:

      $v = 384\ \mathrm{km\ s^{-1}} \pm 78\ \mathrm{km\ s^{-1}}$ (stat.) $\pm\ 115\ \mathrm{km\ s^{-1}}$ (syst.) if $(l, b) = (264^\circ, 48^\circ)$.

Measuring our peculiar velocity β=v/c

- Our velocity produces a large (10^{-3}) DIPOLE (ℓ=1) BUT ALSO (10^{-8}) correlations
  - Breaks statistical isotropy of the CMB

$$\langle a_{\ell m}\, a_{\ell+1 m}\rangle = \beta(c^{-}_{\ell m} C_\ell + c^{+}_{\ell m} C_{\ell+1}) \neq 0$$

  - Planck measured β using such correlations

$$384\,\mathrm{km\,s^{-1}} \pm 78\,\mathrm{km\,s^{-1}}\ (\mathrm{stat.}) \pm 115\,\mathrm{km\,s^{-1}}\ (\mathrm{syst.})$$

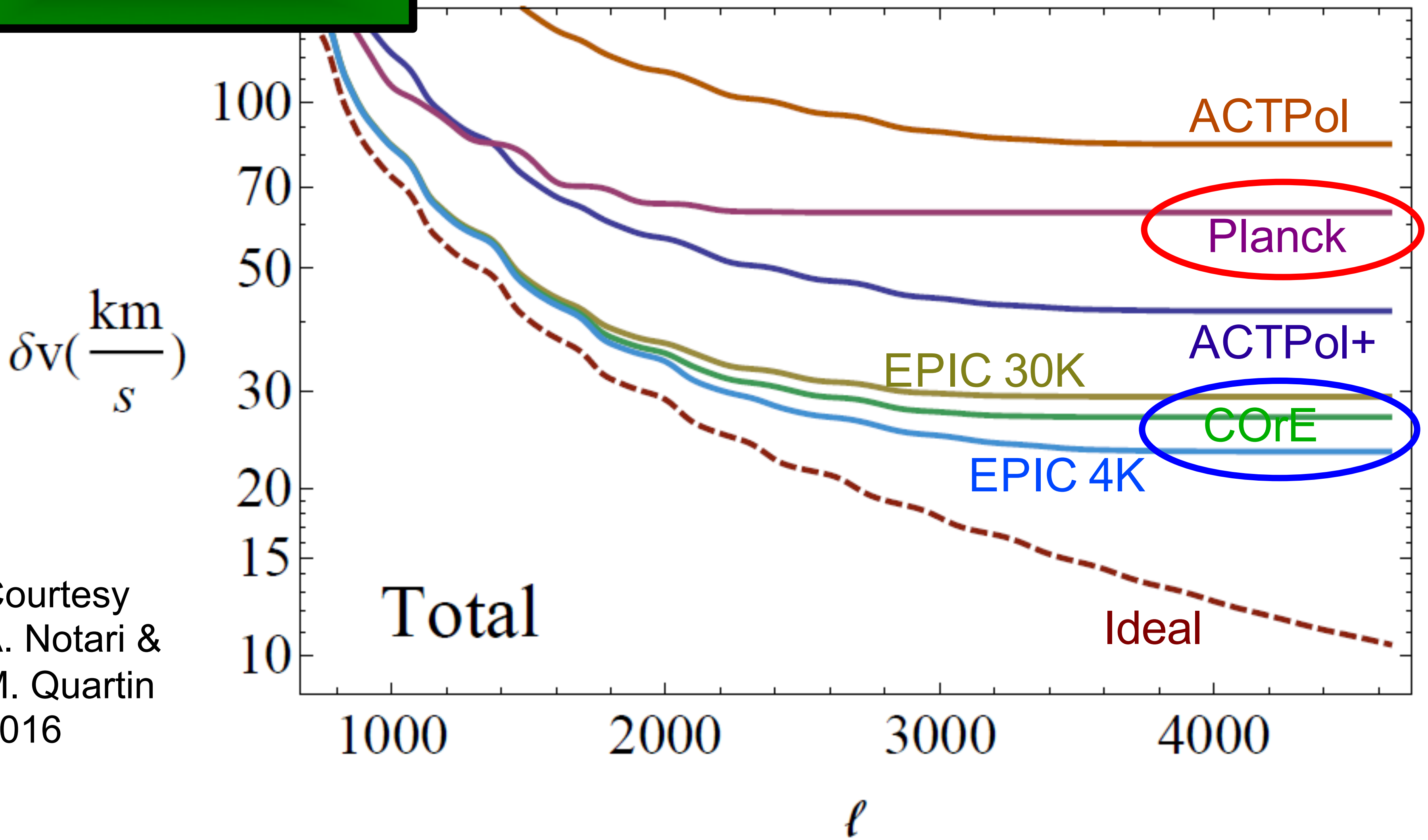
  - All ℓ's are affected: more ℓ measured → better S/N
  - Measuring EE, ET, TE and BB → better S/N

- Roughly equal signal in Doppler/Aberration
  - Consistent with Dipole (ℓ=1)
  - DOPPLER constant in ℓ, ABERRATION GROWS with ℓ
  - CORE can go to S/N = 15

Courtesy A. Notari & M. Quartin 2016

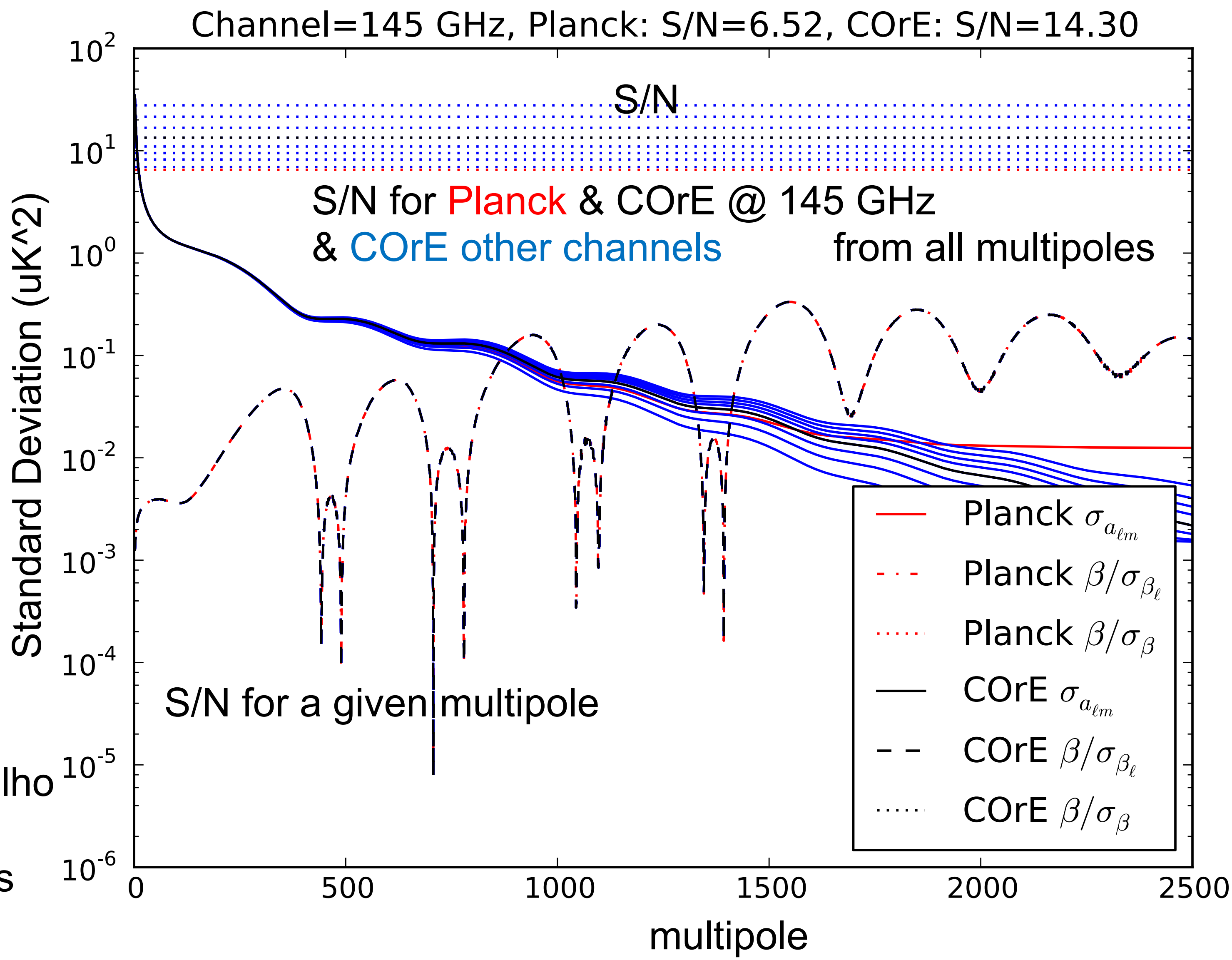
Results: Measuring β

$v_{CMB} \approx 370$ km/s



Courtesy
A. Notari &
M. Quartin
2016

Preliminary analysis with TT only



Courtesy C.S.Carvalho 2016, in progress

Velocity and Dipolar modulation

- A possible anomalous dipolar modulation of the spectrum is seen in WMAP/PLANCK at ~3σ
- (Amplitude: 0.07 at ℓ<60, O(0.01) at ℓ<500, absent at high ℓ)

- IS THE UNIVERSE ISOTROPIC? [see also aligments of multipoles, parity asymmetry...]

- The Doppler estimator is 100% degenerate with it (in fact planck did not use ℓ<500 for measuring β)

- CORE can measure:
  - Modulation/Doppler also in polarization (ℓ<500, $\Delta\beta$ of about 10^{-3}) SYSTEMATICS?
  - Aberration at high ℓ much better: test consistency with LCDM+local velocity picture

Courtesy A. Notari & M. Quartin 2016

Interpretation?

- Testing these 3 observables: a consistency check of Isotropic ΛCDM + Gaussianity + local velocity
- ….What if they will not agree?
- Alternative possibilities?
  - (Large scale dipolar gravitational potential?)

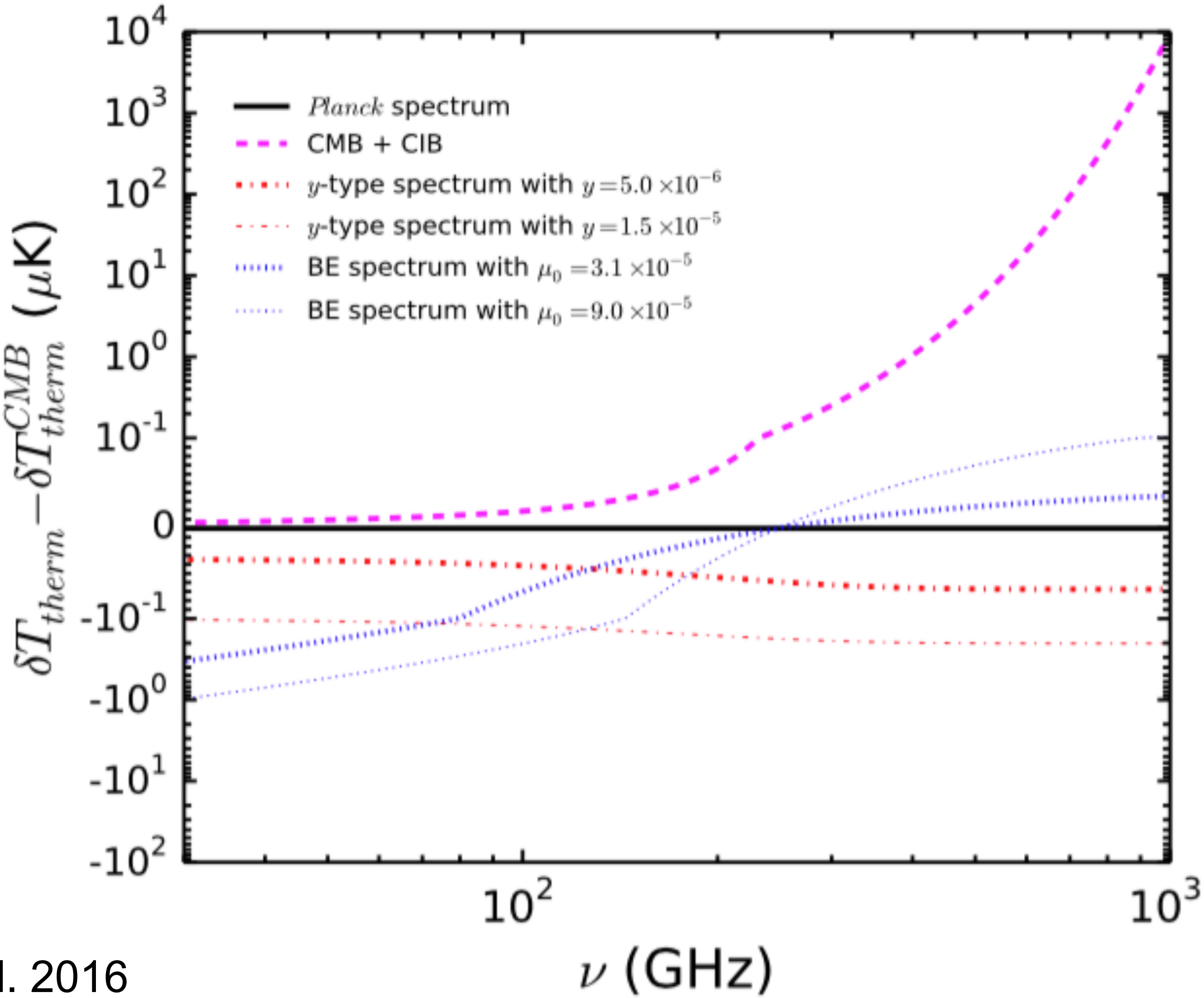
O. Roldan, A. Notari, M. Quartin, 2016

	10^{-3} dipole	10^{-8} Doppler-like couplings	10^{-8} aberration-like couplings
Peculiar Velocity	yes	yes	yes
Dipolar Potential	yes	yes	different, unless fine-tuned
Non-Gaussian Dipolar Potential	yes	different	different, unless fine-tuned

V- Differential approach to CMB spectral distortions

- ✧ Original idea of Danese & de Zotti 1981, A&A L33 of application of Compton-Getting effect (1935, Phys. Rev. 47, 817)
- ➢ brief overview of observational status
- ➢ relaxing blackbody assumption in calibration
- ➢ joint analysis of calibration and spectral distortions
- ➢ differential approach for early type distortions
- ➢ differential approach for intermediate type distortions
- ➢ differential approach for late type distortions
  - ➢ motion-induced y-dipole (from the y-monopole)
- ➢ spectra of the dipole, quadrupole and higher anisotropies to probe the temperature redshift relation between $z=10^3$ and today, as well as give additional limits on the primordial dipole (see also Balashev et al. 2015)

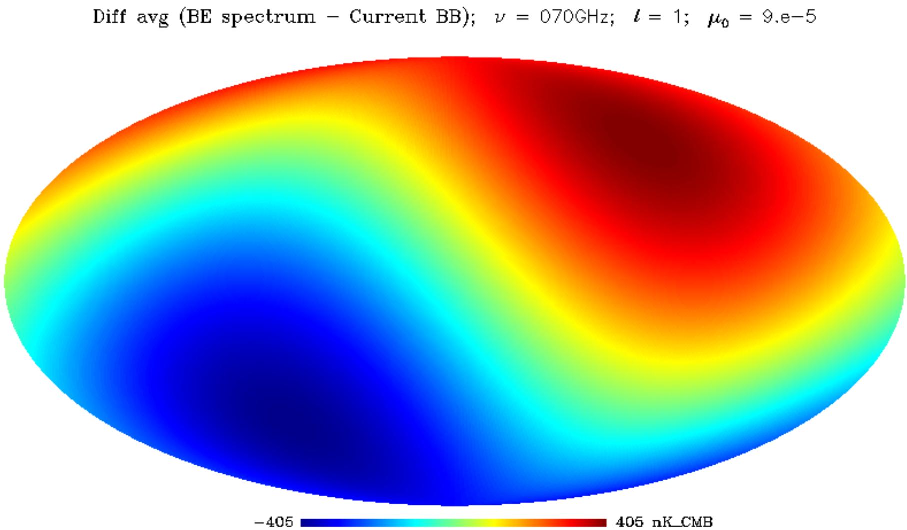
Dipole spectrum: CMB distortions vs CIB

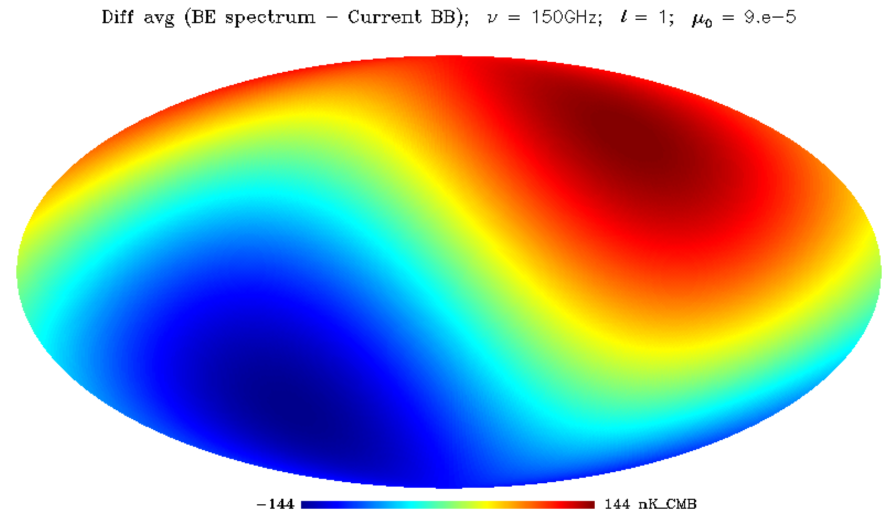


de Zotti et al. 2016

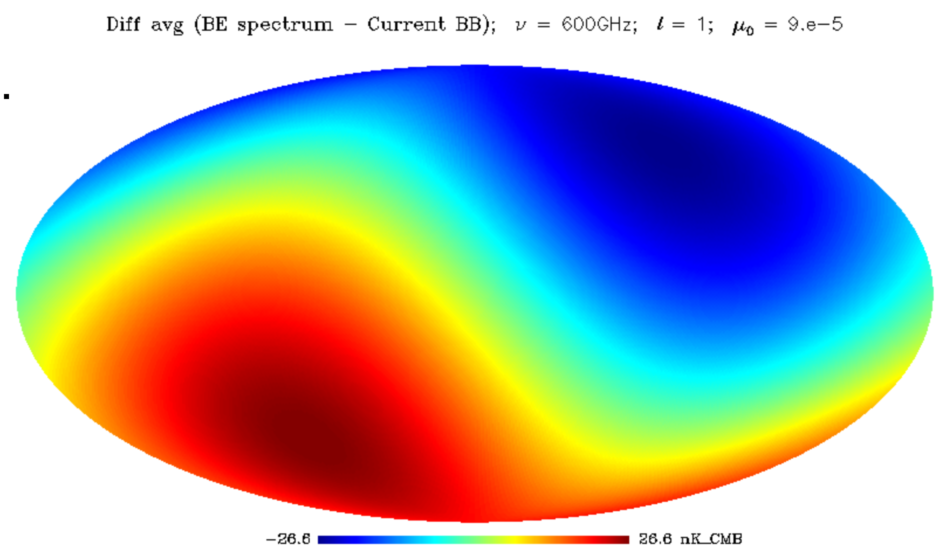
Extension to all (low) multipoles

BE dist. freq. dep. - Maps @ multipole = 1



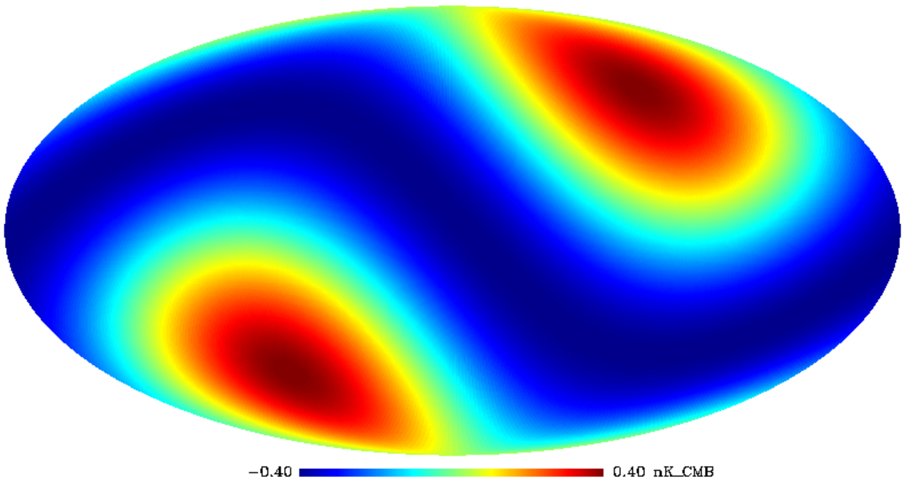


Courtesy
T. Trombetti & C.B.
2016

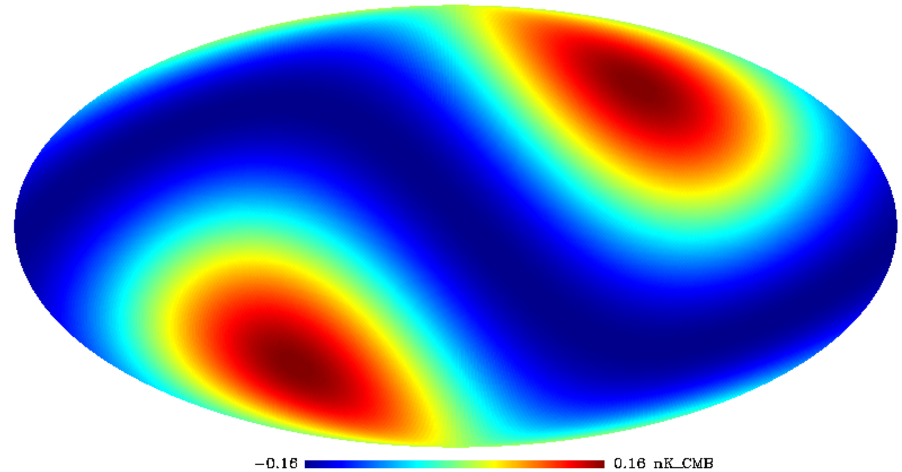


BE dist. freq. dep. - Maps @ multipole = 2

Diff avg (BE spectrum − Current BB); ν = 070GHz; ℓ = 2; μ_0 = 9.e−5



Diff avg (BE spectrum − Current BB); ν = 150GHz; ℓ = 2; μ_0 = 9.e−5



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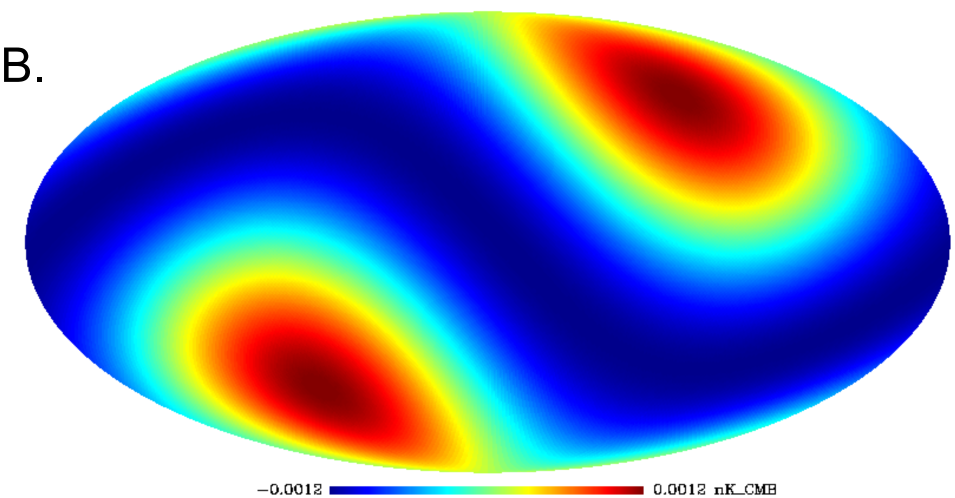
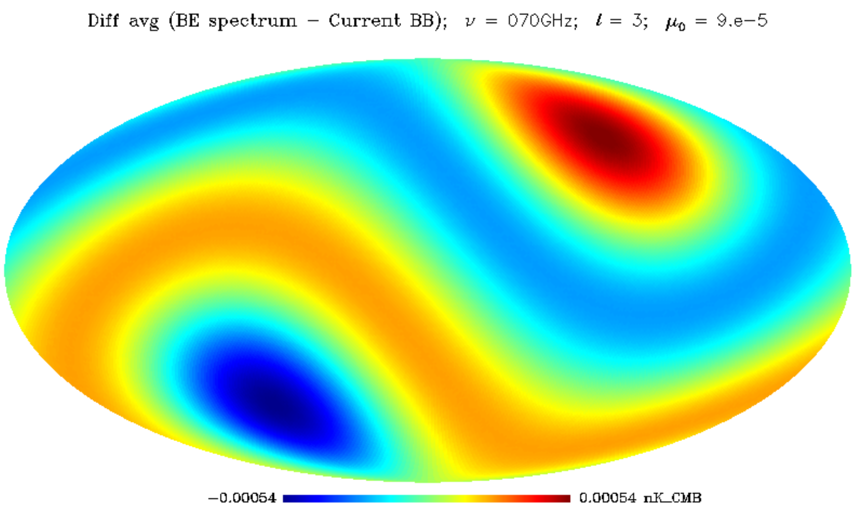
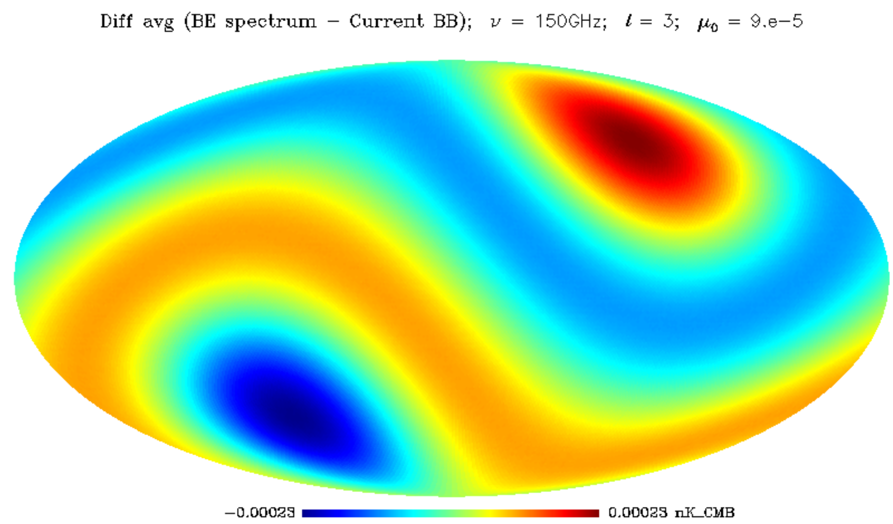
Diff avg (BE spectrum − Current BB); ν = 600GHz; ℓ = 2; μ_0 = 9.e−5



BE dist. freq. dep. - Maps @ multipole = 3





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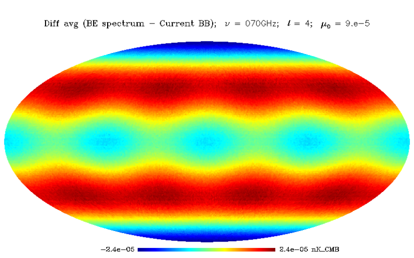
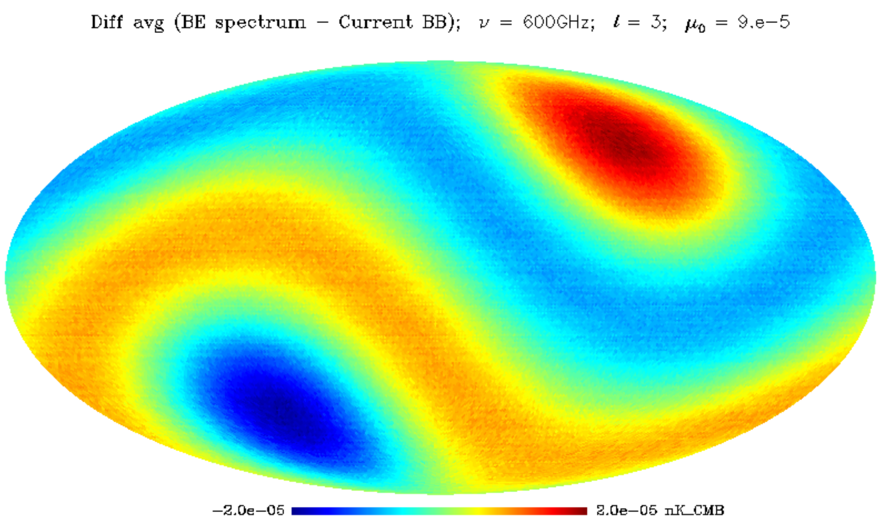
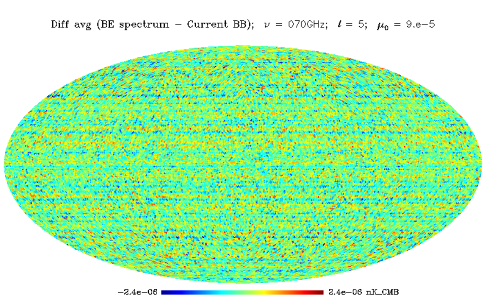
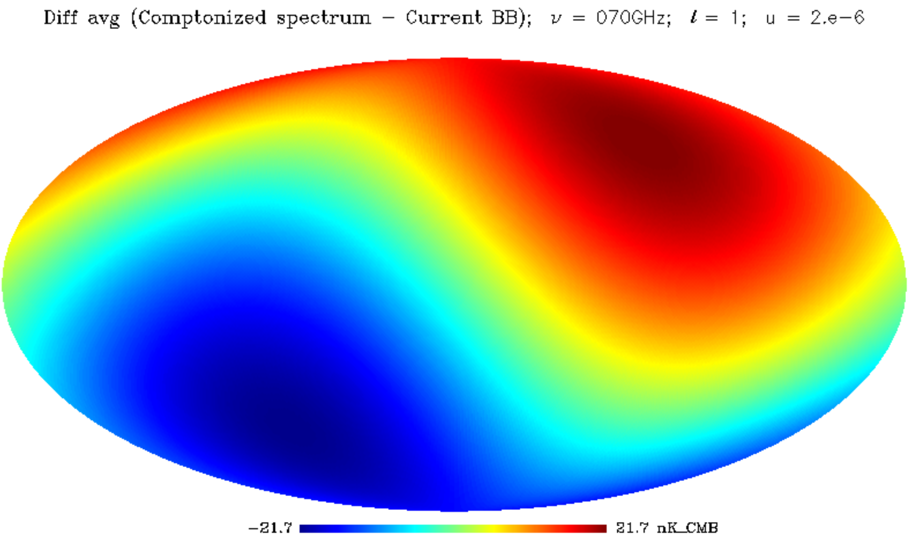
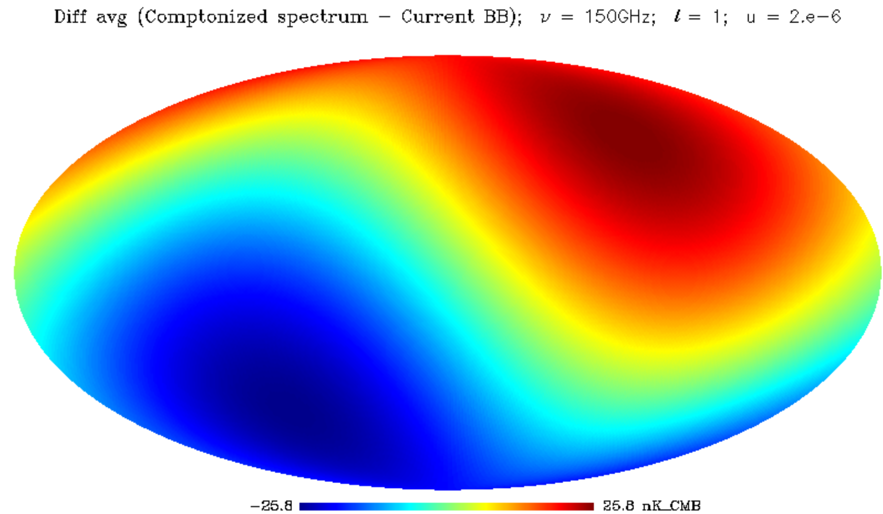






Compt. dist. freq. dep. - Maps @ multipole = 1





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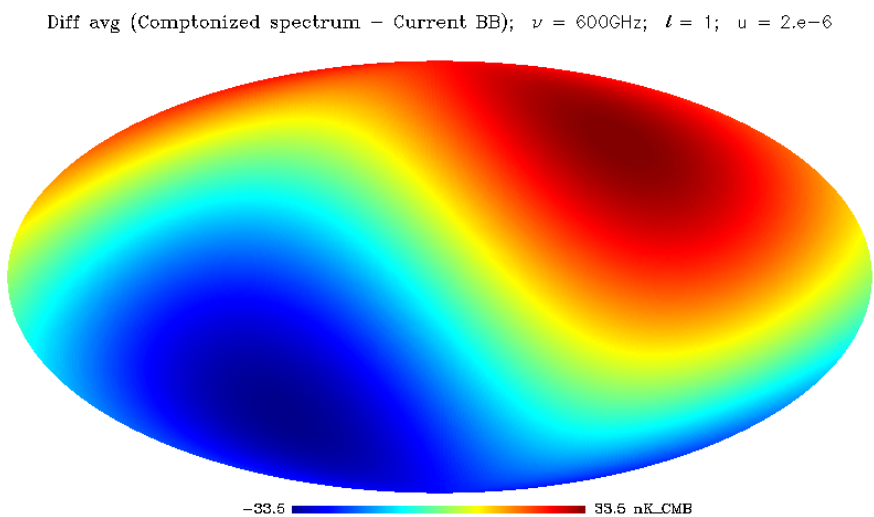

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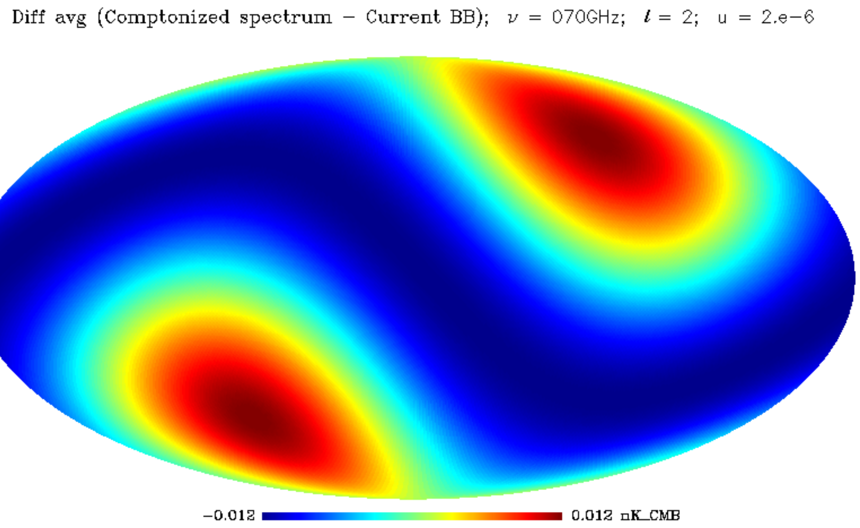

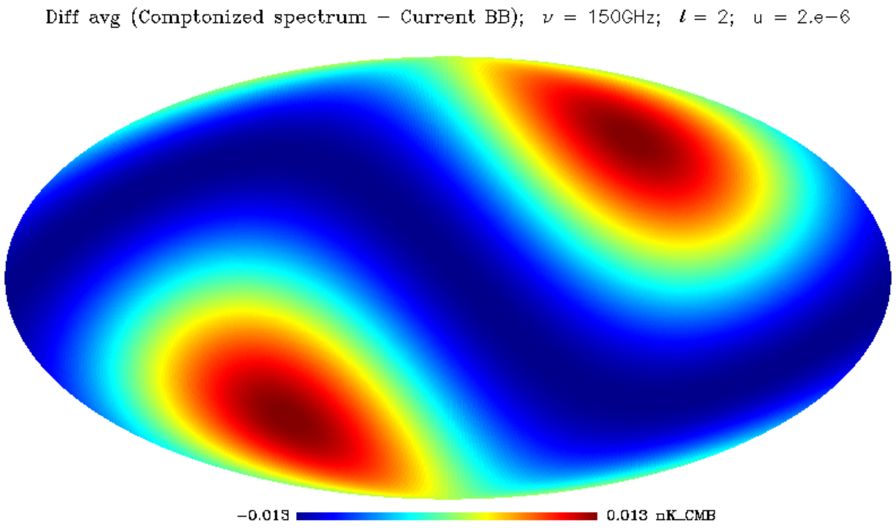

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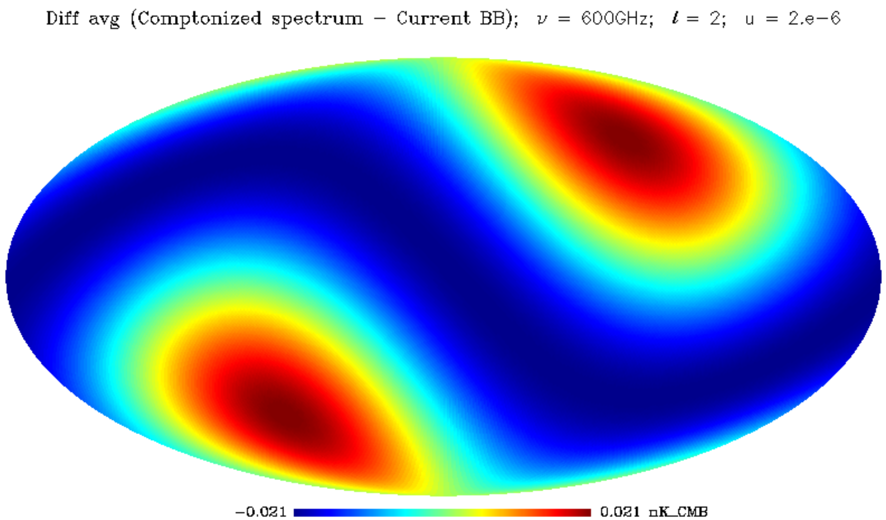

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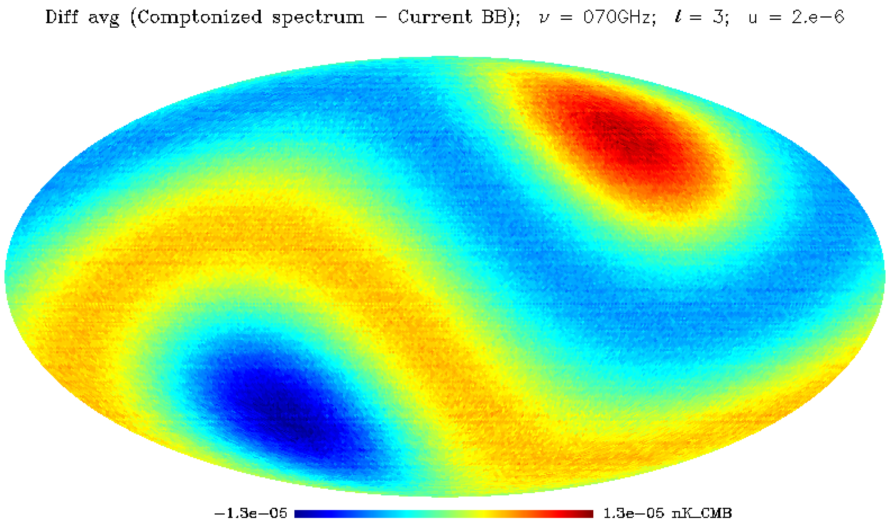

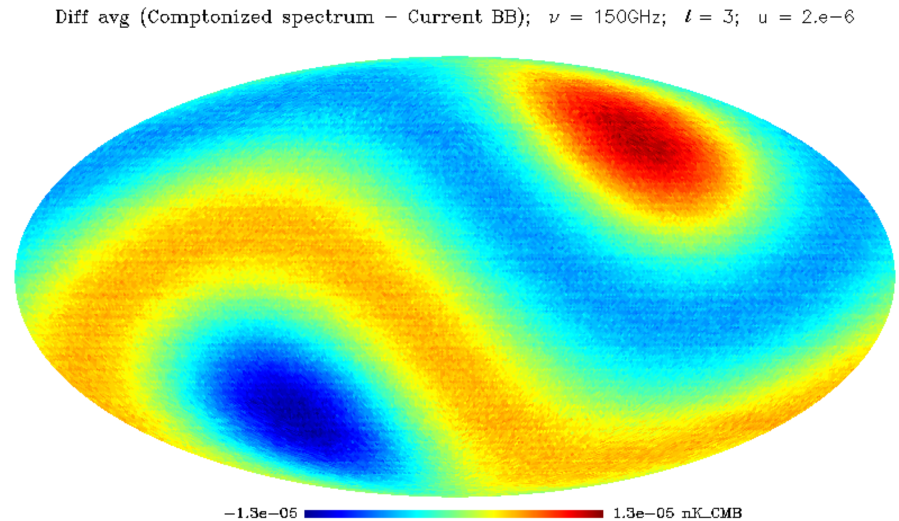

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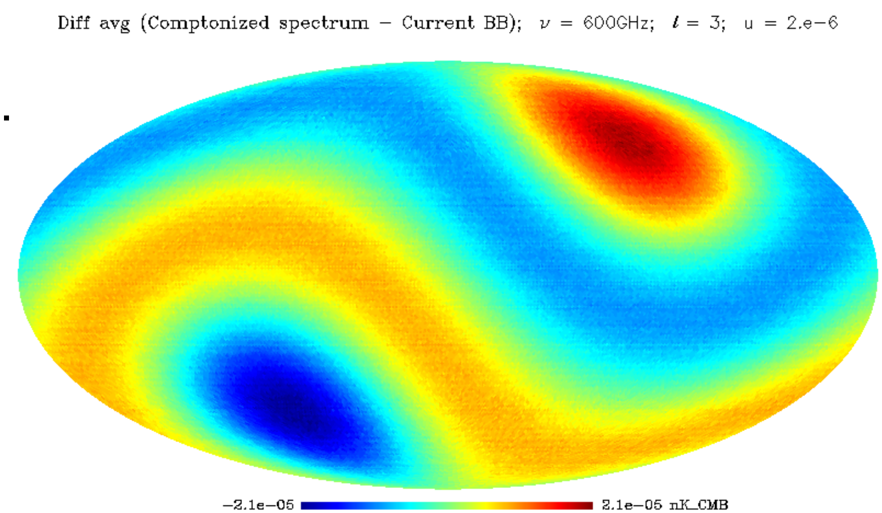

Spurious frequency dependence

- **NOTE: Using a linearized formula between Intensity & Temperature Introduces**
- **$O(\Delta T/T)^2 = O(\beta^2) + O(\beta * \Delta T/T)$ freq. dependent effect.**
- **A y-channel quadrupole+monopole ($O(10^{-6})$) and higher multipoles $O(10^{-8})$…**

SUGGESTION: Use the full blackbody equation for I-T conversion, easy to do

- **Otherwise introduces spurious y-signal affecting:**

1. calibration [O (solar dipole*earth dipole)]

2. y-maps [tSZ]

3. quadrupole measurements

4. spurious significance in the Doppler estimators

Courtesy
A. Notari &
M. Quartin
2016

Towards quantitative "realistic" forecasts

- **In general:**

- **for all the topics mentioned above we need/plan to quantify the improvement expected from COrE-M5**
- **→ obviously link to other ECO papers/projects**
- **various levels of forecast predictions according to specifications/details**
  - **masking vs separation**

Next activities & link with (simple?) simulations

- **Main issues**
- **For large scales analyses:**
  - Scanning strategy but linked with spacecraft velocity (input from Wallis et al. arXiv:1604.02290)
  - Input from inter/cross-frequency T calibration (absolute calibration of anisotropies)
    - calibration accuracy without dipole BB assumptions
    - assessment of uncertainty from systematics
  - Component separation at large scales, particularly for CIB analyses
- **At small scales:**
  - Analysis of extraction of clusters → expected catalogs
  - Polarized signal from clusters, relevant for tangential motion reconstruction – issue (?): resolution (1.2 m)