Impact on science: handling the systematic effects budget

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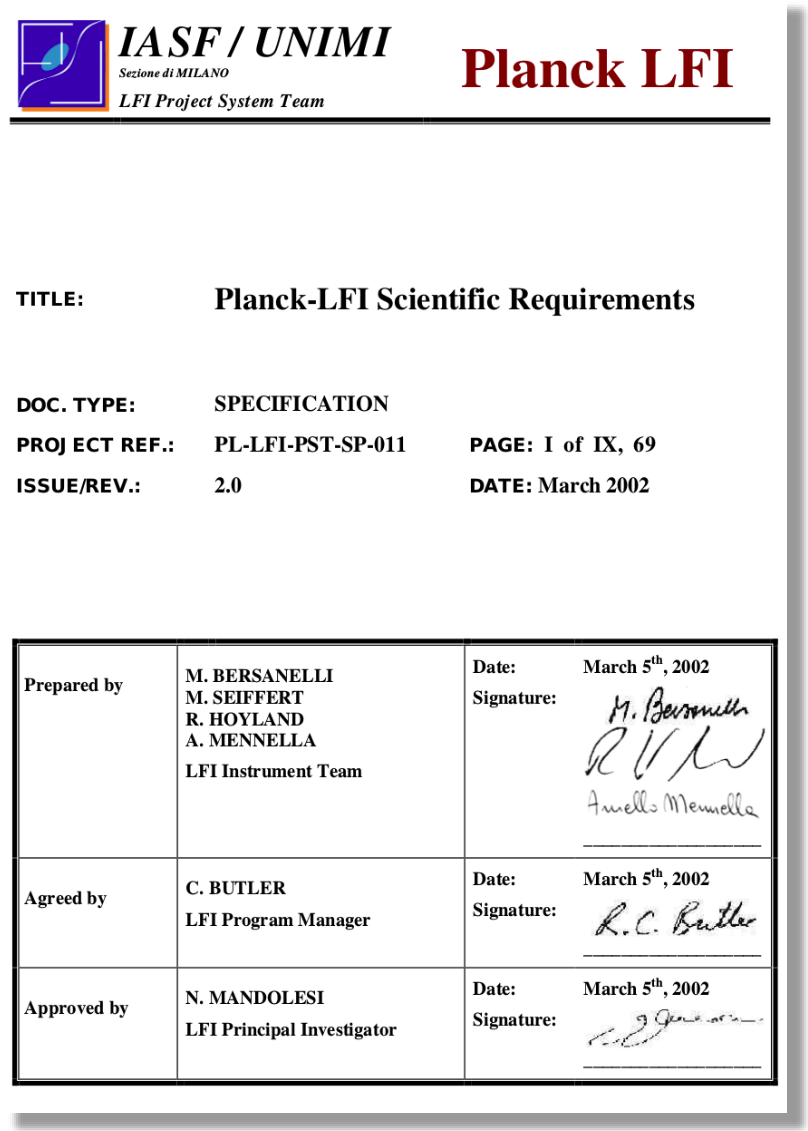
Back to 2002



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Planck LFI

TITLE: Planck-LFI Scientific Requirements

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Prepared by	M. BERSANELLI M. SEIFFERT R. HOYLAND A. MENNELLA LFI Instrument Team	Date: Signature:	March 5th, 2002
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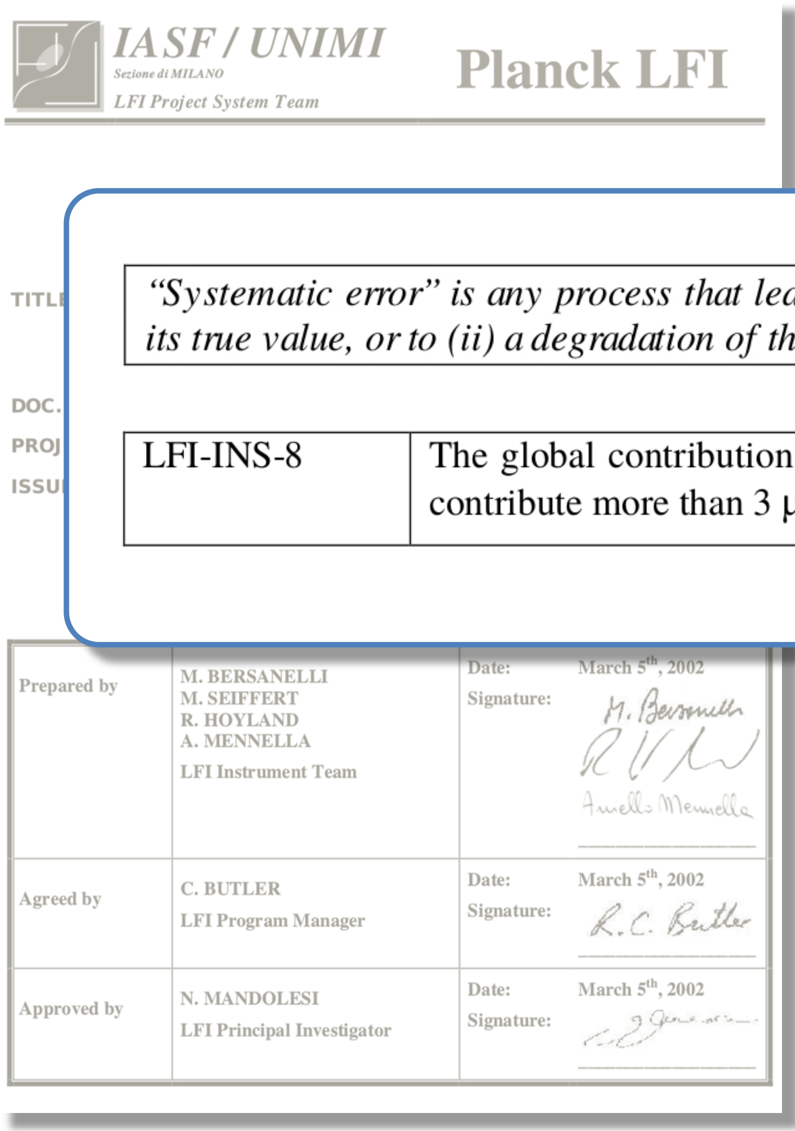
Approved by	N. MANDOLESI LFI Principal Investigator	Date: Signature:	March 5th, 2002

Back to 2002



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> *"Systematic error" is any process that leads to (i) a measurement of a point on the sky that is different than its true value, or to (ii) a degradation of the instrument angular resolution[1].*

LFI-INS-8	The global contribution from all systematic effects in a pixel at the end of mission will not contribute more than 3 μK (TBC).

Back to 2002

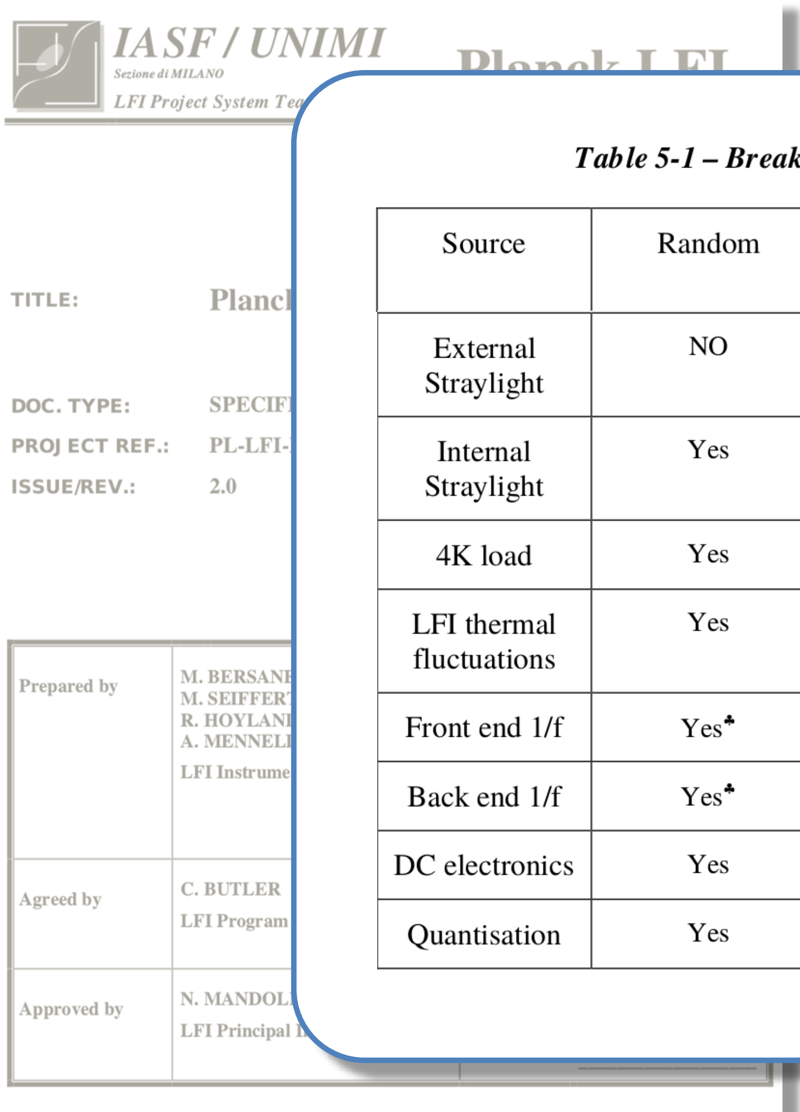
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Table 5-1 – Breakdown of systematics that impact on the measured signal

Source	Random	Spin synchronous	Periodic (non spin-synch.)	1/*f* correlation	% of sky affected
External Straylight	NO	Yes	No	No	20
Internal Straylight	Yes	Yes	Yes	No	100
4K load	Yes	Yes	Yes	No	100
LFI thermal fluctuations	Yes	Yes	Yes	No	100
Front end 1/f	Yes♣	No	No	Yes	100
Back end 1/f	Yes♣	No	No	Yes	100
DC electronics	Yes	No	No	No	100
Quantisation	Yes	No	No	No	100

Back to 2002

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Approved by	N. MANDOLESI LFI Principal Investigator

Table 5-2 – Budget of systematics that impact on the measured signal

Source	% of $\delta T_{1\text{-}sec}$	Error from spin synch. signals (μK)	Error from periodic signals (μK)
External Straylight	N/A	1[♣]	N/A
Internal Straylight	4.5%	1	0.9
4K load	2.6%	1	0.6
LFI thermal fluctuations	3.1%	0.8	1.1
Front end $1/f$	21.7%	N/A	N/A
Back end $1/f$	45.3%	N/A	N/A
DC electronics	4%	N/A	N/A
Quantisation	1%	N/A	N/A
Total	***50.7%***	***1.9***	***1.5***
Noise increase	***12.1%***		

How did we do?

Astronomy & Astrophysics manuscript no. Planck2014_systematics
February 29, 2016

Planck 2015 results. III. LFI systematic uncertainties

Planck Collaboration: P. A. R. Ade[77], J. Aumont[53], C. Baccigalupi[75], A. J. Banday[82,8], R. B. Barreiro[58], N. Bartolo[27,59], S. Basak[75], P. Battaglia[29,31], E. Battaner[83,84], K. Benabed[54,81], A. Benoit-Lévy[21,54,81], J.-P. Bernard[82,8], M. Bersanelli[30,45], P. Bielewicz[73,8,75], A. Bonaldi[61], L. Bonavera[58], J. R. Bond[7], J. Borrill[11,78], C. Burigana[44,28,46], R. C. Butler[44], E. Calabrese[80], A. Catalano[68,66], P. R. Christensen[74,33], L. P. L. Colombo[20,60], M. Cruz[17], A. Curto[58,5,63], F. Cuttaia[44], L. Danese[75], R. D. Davies[61], R. J. Davis[61], P. de Bernardis[29], A. de Rosa[44], G. de Zotti[41,75], J. Delabrouille[1], C. Dickinson[61], J. M. Diego[58], O. Doré[60,9], A. Ducout[54,51], X. Dupac[34], F. Elsner[21,54,81], T. A. Enßlin[71], H. K. Eriksen[56], F. Finelli[44,46], M. Frailis[43], C. Franceschet[30], E. Franceschi[44], S. Galeotta[43], S. Galli[62], K. Ganga[1], T. Ghosh[53], M. Giard[82,8], Y. Giraud-Héraud[1], E. Gjerløw[56], J. González-Nuevo[16,58], K. M. Górski[60,85], A. Gregorio[31,43,49], A. Gruppuso[44], F. K. Hansen[56], D. L. Harrison[55,63], C. Hernández-Monteagudo[10,71], D. Herranz[58], S. R. Hildebrandt[60,9], E. Hivon[54,81], M. Hobson[5], A. Hornstrup[13], W. Hovest[71], K. M. Huffenberger[22], G. Hurier[53], A. H. Jaffe[51], T. R. Jaffe[82,8], E. Keihänen[23], R. Keskitalo[11], K. Kiiveri[23,39], T. S. Kisner[70], J. Knoche[71], N. Krachmalnicoff[30], M. Kunz[14,53,2], H. Kurki-Suonio[23,39], G. Lagache[4,53], J.-M. Lamarre[66], A. Lasenby[5,63], M. Lattanzi[28], C. R. Lawrence[60], J. P. Leahy[61], R. Leonardi[6], F. Levrier[66], M. Liguori[27,59], P. B. Lilje[56], M. Linden-Vørnle[13], V. Lindholm[23,39], M. López-Caniego[34,58], P. M. Lubin[25], J. F. Macías-Pérez[68], B. Maffei[61], G. Maggio[43], D. Maino[30,45], N. Mandolesi[44,28], A. Mangilli[53,65], M. Maris[43], P. G. Martin[7], E. Martínez-González[58], S. Masi[29], S. Matarrese[27,59,36], P. R. Meinhold[25], A. Mennella[30,45], M. Migliaccio[55,63], S. Mitra[50,60], L. Montier[82,8], G. Morgante[44], D. Mortlock[51], D. Munshi[77], J. A. Murphy[72], F. Nati[24], P. Natoli[28,3,44], F. Noviello[61], F. Paci[75], L. Pagano[29,47], F. Pajot[53], D. Paoletti[44,46], B. Partridge[38], F. Pasian[43], T. J. Pearson[9,52], O. Perdereau[65], V. Pettorino[37], F. Piacentini[29], E. Pointecouteau[82,8], G. Polenta[3,42], G. W. Pratt[67], J.-L. Puget[53], J. P. Rachen[18,71], M. Reinecke[71], M. Remazeilles[61,53,1], A. Renzi[32,48], I. Ristorcelli[82,8], G. Rocha[60,9], C. Rosset[1], M. Rossetti[30,45], G. Roudier[1,66,60], J. A. Rubiño-Martín[57,15], B. Rusholme[52], M. Sandri[44], D. Santos[68], M. Savelainen[23,39], D. Scott[19], V. Stolyarov[5,79,64], R. Stompor[1], A.-S. Suur-Uski[23,39], J.-F. Sygnet[54], J. A. Tauber[35], D. Tavagnacco[43,31], L. Terenzi[76,44], L. Toffolatti[16,58,44], M. Tomasi[30,45], M. Tristram[65], M. Tucci[14], G. Umana[40], L. Valenziano[44], J. Valiviita[23,39], B. Van Tent[69], T. Vassallo[43], P. Vielva[58], F. Villa[44], L. A. Wade[60], B. D. Wandelt[54,81,26], R. Watson[61], I. K. Wehus[60,56], D. Yvon[12], A. Zacchei[43], J. P. Zibin[19], and A. Zonca[25]

(Affiliations can be found after the references)

February 29, 2016

ABSTRACT

We present the current accounting of systematic effect uncertainties for the Low Frequency Instrument (LFI) that are relevant to the 2015 release of the *Planck* cosmological results, showing the robustness and consistency of our data set, especially for polarization analysis. We use two complementary approaches: (i) simulations based on measured data and physical models of the known systematic effects; and (ii) analysis of difference maps containing the same sky signal ("null-maps"). The LFI temperature data are limited by instrumental noise. At large angular scales the systematic effects are below the cosmic microwave background (CMB) temperature power spectrum by several orders of magnitude. In polarization the systematic uncertainties are dominated by calibration uncertainties and compete with the CMB E-modes in the multipole range 10–20. Based on our model of all known systematic effects, we show that these effects introduce a slight bias of around 0.2 σ on the reionization optical depth derived from the 70 GHz EE spectrum using the 30 and 353 GHz channels as foreground templates. At 30 GHz the systematic effects are smaller than the Galactic foreground at all scales in temperature and polarization, which allows us to consider this channel as a reliable template of synchrotron emission. We assess the residual uncertainties due to LFI effects on CMB maps and power spectra after component separation and show that these effects are smaller than the CMB amplitude at all scales. We also assess the impact on non-Gaussianity studies and find it to be negligible. Some residuals still appear in null maps from particular sky survey pairs, particularly at 30 GHz, suggesting possible straylight contamination due to an imperfect knowledge of the beam far sidelobes.

Key words. Cosmology: cosmic background radiation – observations – Space vehicles: instruments – Methods: data analysis

1. Introduction

This paper, one in a set associated with the 2015 release of data from the *Planck*[1] mission, describes the Low Frequency Instrument (LFI) systematic effects and their related uncertainties in cosmic microwave background (CMB) temperature and polarization scientific products. Systematic effects in the High Frequency Instrument data are discussed in Planck Collaboration VII (2016) and Planck Collaboration VIII (2016).

The 2013 *Planck* cosmological data release (Planck Collaboration I 2014) exploited data acquired during the first 14 months of the mission to produce the most accurate (to date) all-sky CMB temperature map and power spectrum in terms of sensitivity, angular resolution, and rejection of astrophysical and instrumental systematic effects. In Planck Collaboration III (2014), we showed that known and unknown systematic uncertainties are at least two orders of magnitude below the CMB temperature power spectrum, with residuals dominated by Galactic straylight and relative calibration uncertainty.

The 2015 release (Planck Collaboration I 2016) is based on the entire mission (48 months for LFI and 29 months for HFI). For LFI, the sensitivity increase compared to the 2013 release is a approximately a factor of two on maps. This requires a thor-

[1] *Planck* (http://www.esa.int/Planck) is a project of the European Space Agency (ESA) with instruments provided by two scientific consortia funded by ESA member states and led by Principal Investigators from France and Italy, telescope reflectors provided through a collaboration between ESA and a scientific consortium led and funded by Denmark, and additional contributions from NASA (USA).

How did we do?

Astronomy & Astrophysics manuscript no. Planck2014_s
February 29, 2016

Planck 2015 results. II

1. Introduction

Table 1: List of known instrumental systematic effects in *Planck*-LFI.

Effect	Source	Control/Removal	Reference
Effects independent of the sky signal (temperature and polarization)			
White noise correlation	Phase switch imbalance	Diode weighting	Planck Collaboration III (2014)
$1/f$ noise	RF amplifiers	Pseudo-correlation and destriping	Planck Collaboration III (2014)
Bias fluctuations	RF amplifiers, back-end electronics	Pseudo-correlation and destriping	3.2.5
Thermal fluctuations	4-K, 20-K and 300-K thermal stages	Calibration, destriping	3.2.4
1-Hz spikes	Back-end electronics	Template fitting and removal	3.2.6
Effects dependent on the sky signal (temperature and polarization)			
Main beam ellipticity	Main beams	Accounted for in window function	Planck Collaboration III (2016)
Near sidelobe pickup	Optical response at angles $< 5°$ from the main beam	Masking of Galaxy and point sources	Planck Collaboration II (2016), 2.1.2, 3.2.1
Far sidelobe pickup	Main and sub-reflector spillover	Model sidelobes removed from timelines	2.1.1, 3.2.1
Analogue-to-digital converter nonlinearity	Back-end analogue-to-digital converter	Template fitting and removal	3.2.3
Imperfect photometric calibration	Sidelobe pickup, radiometer noise temperature changes, and other non-idealities	Adaptive smoothing algorithm using 4π beam, 4-K reference load voltage output, temperature sensor data	Planck Collaboration II (2016), 2.2, 3.2.2
Pointing	Uncertainties in pointing reconstruction, thermal changes affecting focal plane geometry	Negligible impact on anisotropy measurements	2.1, 3.2.1
Effects specifically impacting polarization			
Bandpass asymmetries	Differential orthomode transducer and receiver bandpass response	Spurious polarization removal	2.3
Polarization angle uncertainty	Uncertainty in the polarization angle in-flight measurement	Negligible impact	2.1.3, 3.2.1
Orthomode transducer cross-polarization	Imperfect polarization separation	Negligible impact	Leahy et al. (2010)

How did we do?

Astronomy & Astrophysics manuscript no. Planck2014_systematics ©ESO 2016
February 29, 2016

LFI-INS-8	The global contribution from all systematic effects in a pixel at the end of mission will not contribute more than 3 μK (TBC).

Total < 3 μK p-p

30 GHz

	I		Q		U	
	p-p	rms	p-p	rms	p-p	rms
Near sidelobes	0.72	0.13	0.05	0.01	0.05	0.01
Pointing	0.37	0.07	0.02	0.01	0.02	0.00
Polarization angle	0.02	0.00	0.53	0.11	0.64	0.15
1-Hz spikes	0.54	0.11	0.11	0.02	0.09	0.02
Bias fluctuations	0.07	0.01	0.07	0.01	0.06	0.01
ADC nonlinearity	0.42	0.09	0.54	0.11	0.56	0.11
Calibration	2.43	0.55	2.53	0.46	2.34	0.43
Thermal fluct. (300 K)	0.00	0.00	0.00	0.00	0.00	0.00
Thermal fluct. (20 K)	0.12	0.03	0.06	0.02	0.06	0.02
Thermal fluct. (4 K)	0.29	0.06	0.06	0.01	0.05	0.01
Total[b]	2.72	0.61	2.79	0.52	2.42	0.49

Near sidelobes	0.09	0.02	0.00	0.00	0.00	0.00
Pointing	0.30	0.06	0.01	0.00	0.01	0.00
Polarization angle	0.04	0.01	0.35	0.07	0.38	0.10
1-Hz spikes	1.99	0.40	0.88	0.18	1.04	0.21
Bias fluctuations	0.04	0.01	0.05	0.01	0.05	0.01
ADC nonlinearity	0.30	0.06	0.36	0.07	0.34	0.07
Calibration	1.05	0.18	1.57	0.29	1.31	0.26
Thermal fluct. (300 K)	0.00	0.00	0.00	0.00	0.00	0.00
Thermal fluct. (20 K)	0.04	0.02	0.06	0.01	0.05	0.01
Thermal fluct. (4 K)	0.23	0.05	0.05	0.01	0.06	0.01
Total	2.29	0.45	1.95	0.37	1.76	0.37

70 GHz

	I		Q		U	
	p-p	rms	p-p	rms	p-p	rms
Near sidelobes	0.30	0.07	0.01	0.00	0.01	0.00
Pointing	0.60	0.11	0.03	0.01	0.03	0.01
Polarization angle	0.02	0.00	0.08	0.02	0.08	0.02
1-Hz spikes	0.39	0.08	0.17	0.03	0.15	0.03
Bias fluctuations	0.68	0.14	0.84	0.17	0.95	0.18
ADC nonlinearity	1.56	0.33	1.92	0.39	2.05	0.41
Calibration	1.06	0.23	0.98	0.18	0.77	0.16
Thermal fluct. (300 K)	0.00	0.00	0.00	0.00	0.00	0.00
Thermal fluct. (20 K)	0.44	0.08	0.07	0.01	0.08	0.02
Thermal fluct. (4 K)	0.38	0.08	0.04	0.01	0.05	0.01
Total	2.24	0.47	2.27	0.46	2.38	0.48

gators from France and Italy, telescope reflectors provided through a collaboration between ESA and a scientific consortium led and funded by Denmark, and additional contributions from NASA (USA).

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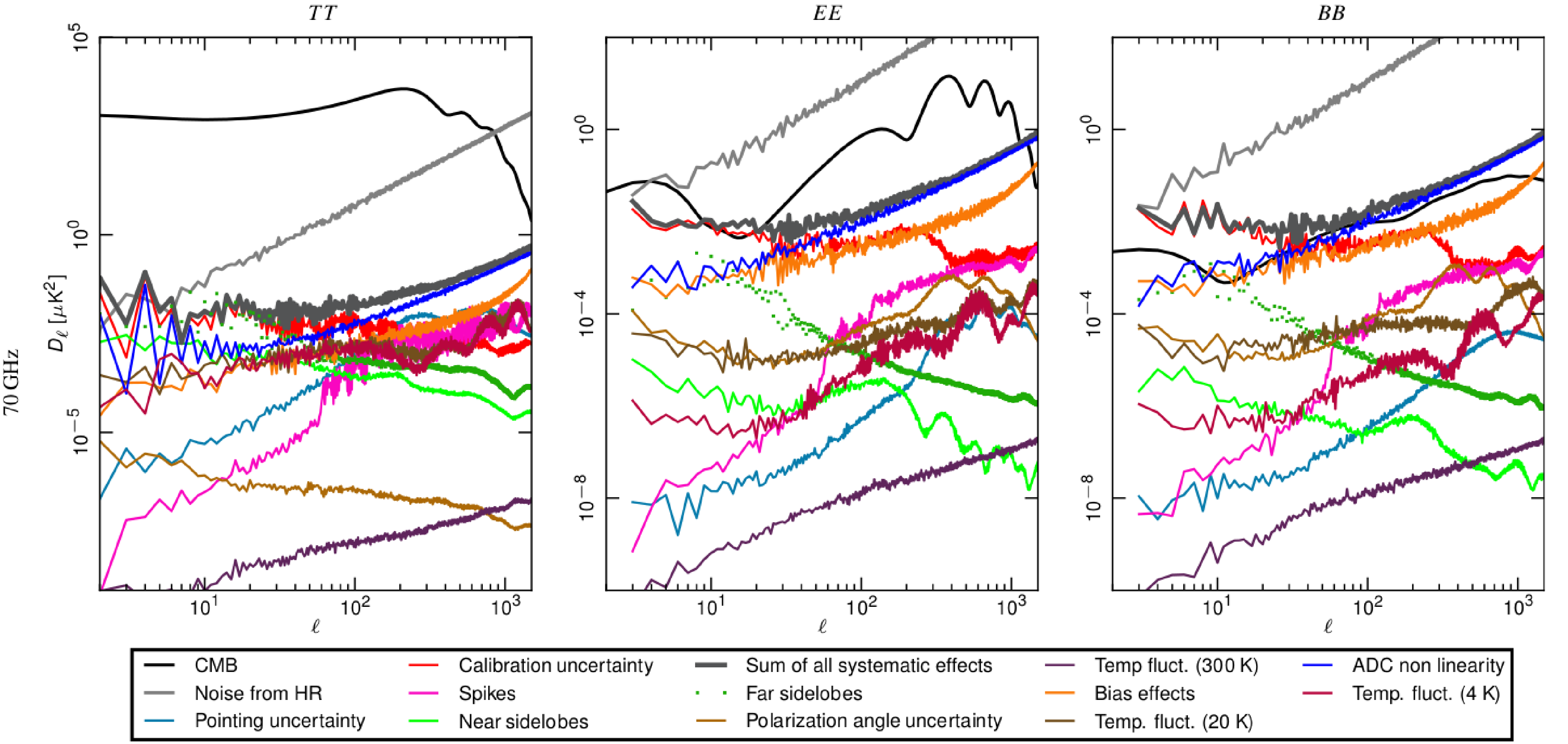
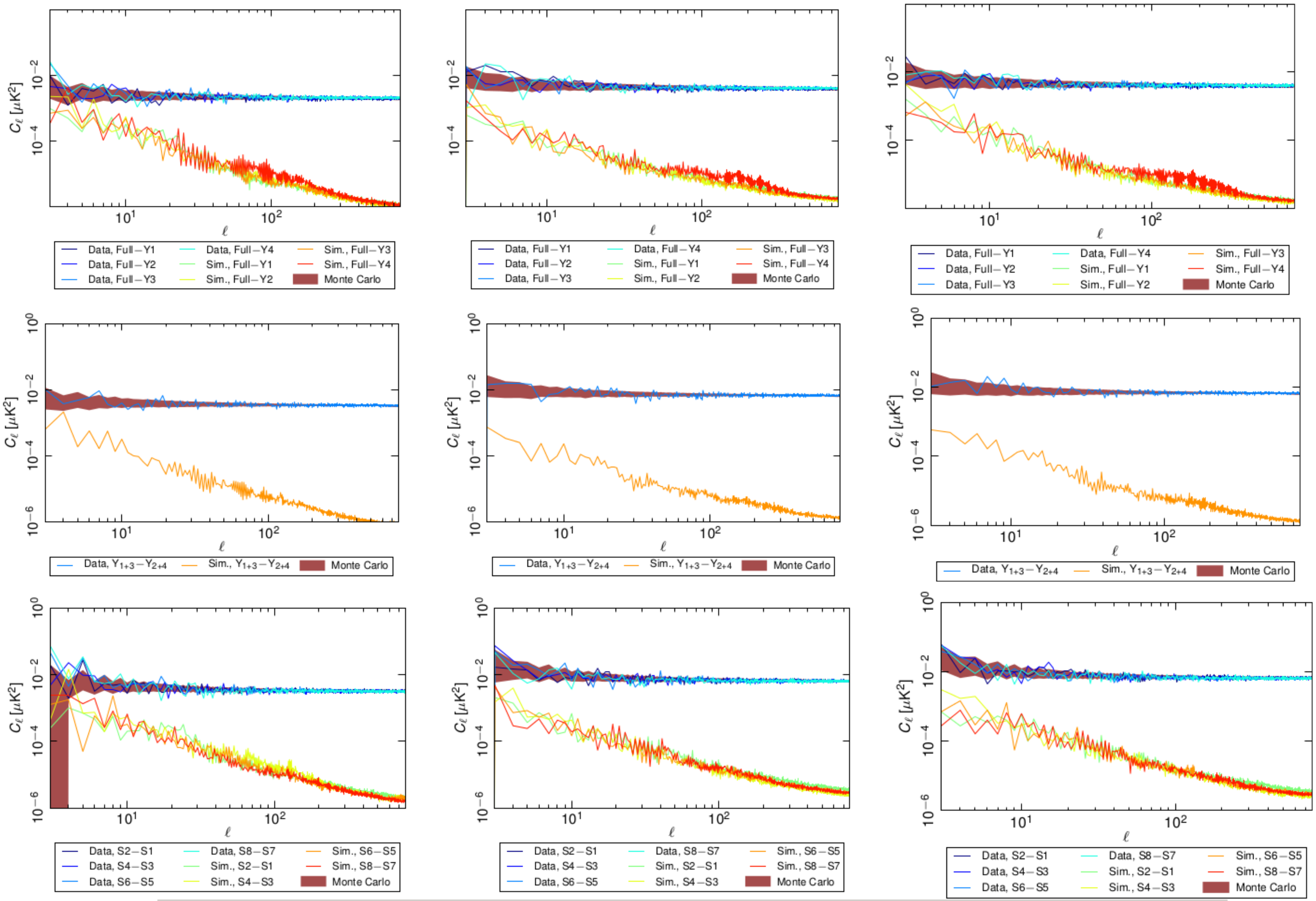
Impact on power spectra(70 GHz)

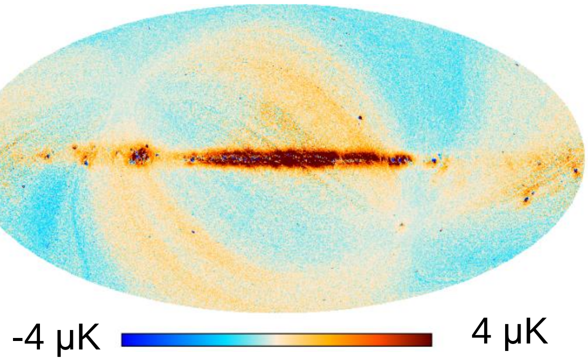


Null spectra

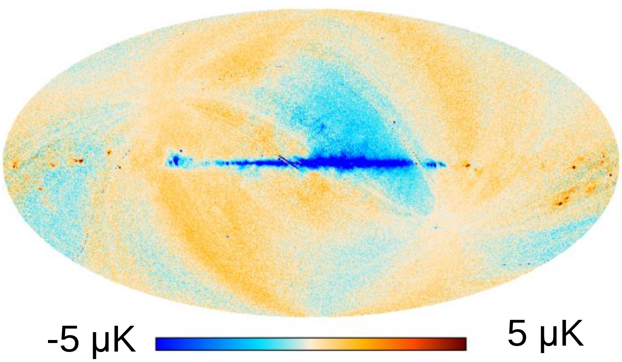


Bias on tau

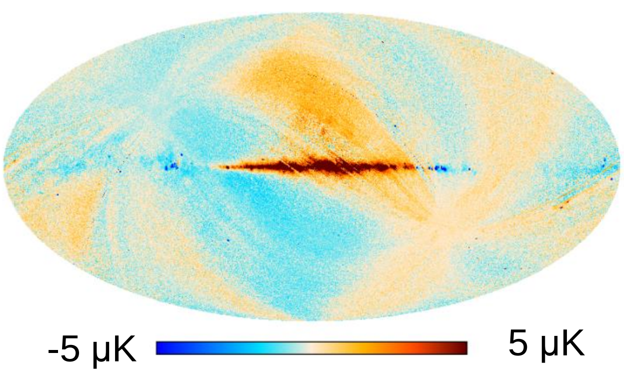
30 GHz I



30 GHz Q



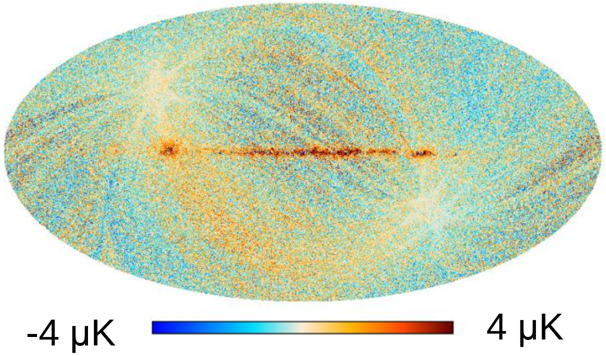
30 GHz U



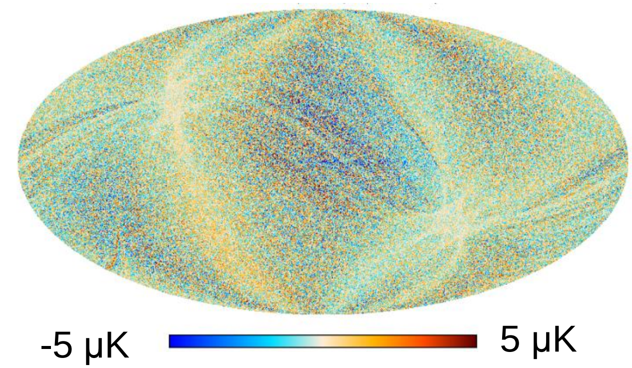
Systematic effects templates used in tau analysis

- Bias on tau derived from simulations of 1000 CMB+ noise and 1000 CMB + noise + systematic effects templates
- Found <Δτ> ~ 0.005

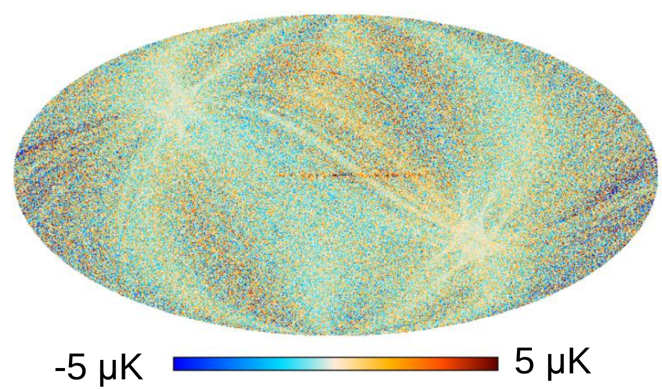
70 GHz I



70 GHz Q



70 GHz U



What we learned from Planck

- Systematic effects must be attacked, first of all, in hardware
- Know the instrument and simulate its behaviour using its physics
- Know the data and look for residuals
- Physically-based simulations and data-driven analysis must be combined to understand residual systematic uncertainties

How should we handle systematic effects budget for COrE?

A three-steps approach

1. Define the global budget

- Should come from scientific objectives
- At what level we define it? (Maps, power spectra, cosmological parameters?)

2. Break down the budget

- Define list of known sources of systematic uncertainties (*main categories: optics, detectors, electronics, thermal…*)
- Make a reasonable guess on how the global budget should be broken down $\rightarrow$ first guess on requirements

3. Assess performance

- Possible objective for phase A study
- Simulate residual effects coming from known systematic effects assuming a given mission design
- Assess impact on scientific products
- Iterate with payload and instrument design if necessary