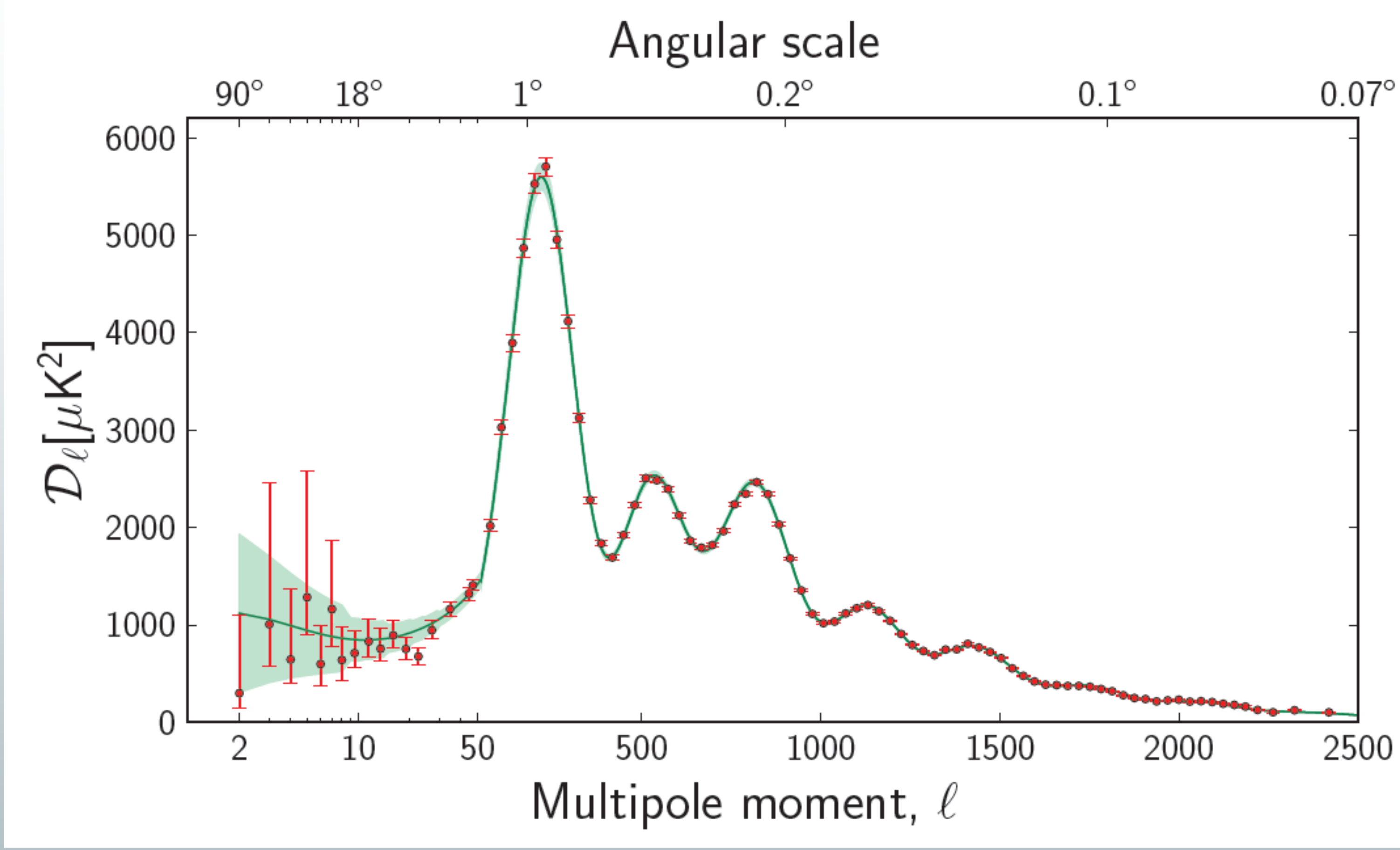
Questions to be tackled by Planck with the next release

Planck Collaboration, 2013

van Gogh – Starry night (Arles, 1888)

Marco Bersanelli – Physics Department, University of Milano
On behalf of the Planck Collaboration

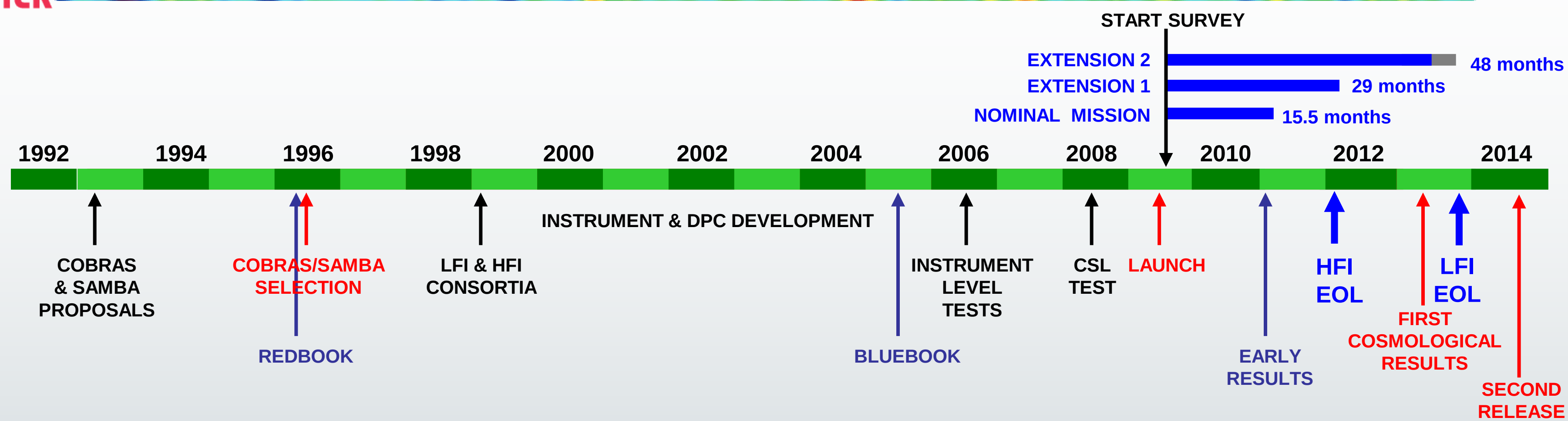
Can we improve over this?



Can we achieve comparable accuracy in polarization?

What's the scientific gain?

The Planck lifetime



- In-flight performance of Planck cooling chain surpassed optimistic expectations
  - 0.1K dilution: Low pressure operation doubled lifetime. Fantastic stability (~10μK/yr)
  - 4K Stirling cooler: stable and uninterrupted functionality
  - 20K sorption cooler: FM1 (second unit) outstanding duration and performance
- No sign of degradation from LFI and HFI instruments (100% functional since start)
- Mission extensions proposed by PST and approved by ESA, leading to full exploitation of HFI and LFI lifetimes:

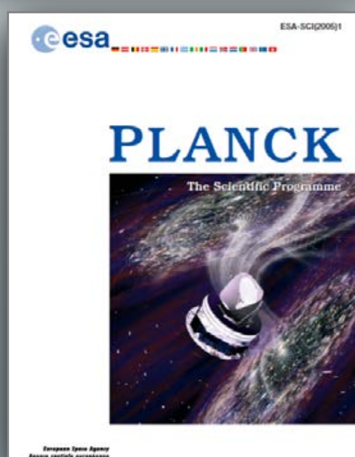
  HFI: 29 months, ~5 sky surveys

  LFI: 48 months, ~8 sky surveys
- Second release in 2014, followed by a third and final release in 2015

Ultimate Planck sensitivity

Noise measured on maps, extrapolated to full mission (CMB channels)

	30GHz	44GHz	70GHz	100GHz	143GHz	217GHz	353GHz
Angular resolution [arcmin]	33.2	28.1	13.1	9.7	7.3	5.0	4.9
Noise sensitivity [μK_{CMB} $s^{1/2}$]	148.5	173.2	151.9	41.3	17.4	23.8	78.8
NOISE/PIXEL							
Nominal mission [months]	*15.5*	*15.5*	*15.5*	*15.5*	*15.5*	*15.5*	*15.5*
From detector sensitivity [μK_{CMB}]	9.2	12.7	23.9	9.6	5.4	10.7	36.5
Measured from maps [μK_{CMB}]	9.2	12.5	23.2	11.2	6.6	12.0	43.2
Extended mission [months]	*48*	*48*	*48*	*29*	*29*	*29*	*29*
Expected [μK_{CMB}]	5.2	7.1	13.2	8.2	4.8	8.8	31.6
Expected [$\Delta T/T$]	**1.9**	**2.6**	**4.8**	**3.0**	**1.8**	**3.2**	**11.6**
Blue book [$\Delta T/T$]	**2.0**	**2.7**	**4.7**	**2.5**	**2.2**	**4.8**	**14.7**

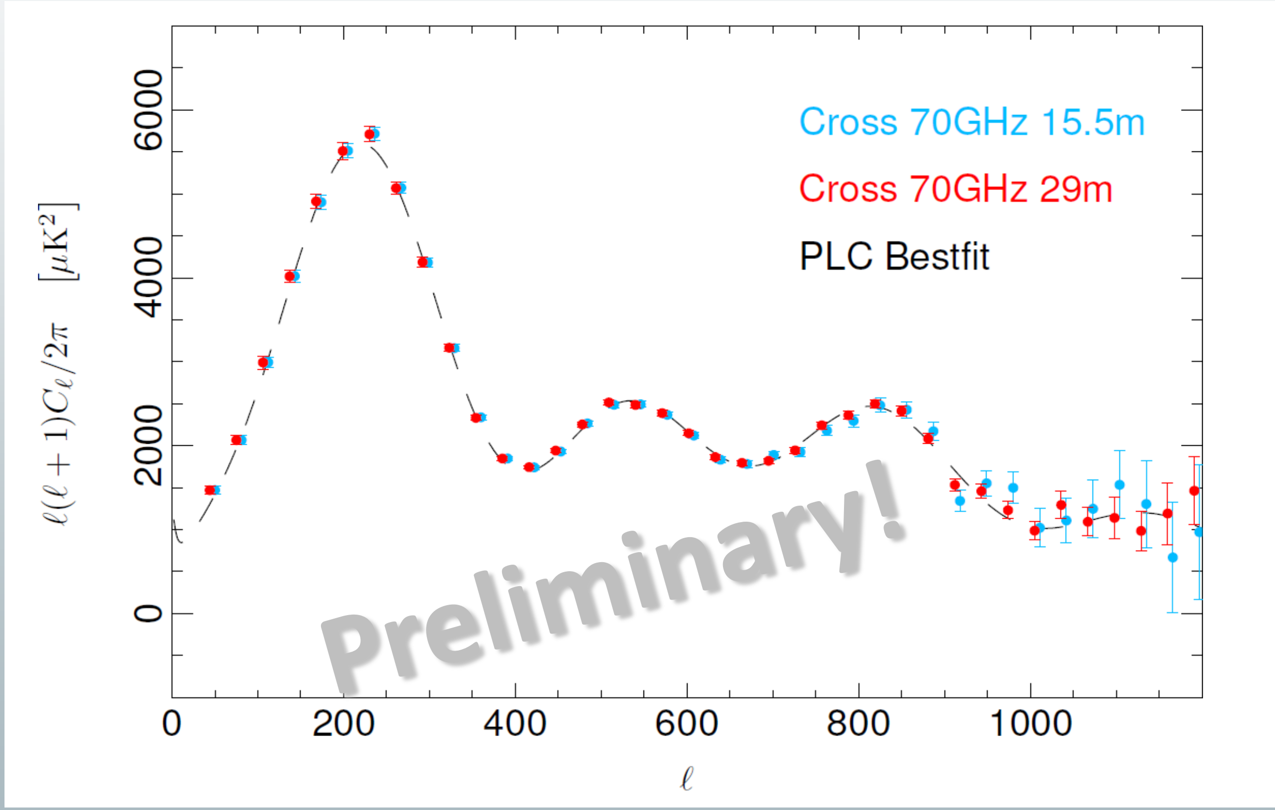


- At end of mission Planck fulfills the very ambitious sensitivity goals proposed in the design phase several years ago
- Next release has capability of reaching all scientific objectives described in Planck Bluebook
- Provided that...
  we properly tackle **systematics** and **foregrounds**

Reducing noise

- In most of the sky, HFI extreme sensitivity limited by astrophysical foregrounds already in nominal mission
- Significant improvement for LFI channels with extended mission

70 GHz TT



→ At end of mission: 48 months (+ 8% repointing TBC)

Exploiting redundancy

Nominal

SS1	SS2	SS3
yr1		
Phase $\phi = 340°$		

Extension 1 (LFI+HFI)

SS1	SS2	SS3	SS4	SS5
yr1		yr2		
Phase $\phi = 340°$				$\phi = 250°$

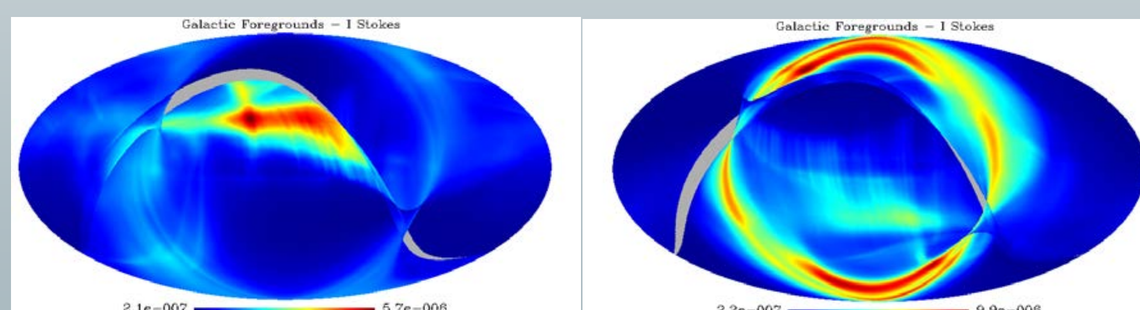
Extension 2 (LFI Only)

SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8
yr1		yr2		yr3		yr4	
Phase $\phi = 340°$				Phase $\phi = 250°$			

- Next release will take advantage of multiple full-sky redundancies (main motivation for extension)
- Due to Planck scanning strategy, odd and even surveys couple differently with global sky signal (straylight, beam ellipticity)
- Full Planck scan cycle is 1 year

Galactic straylight (simulation)

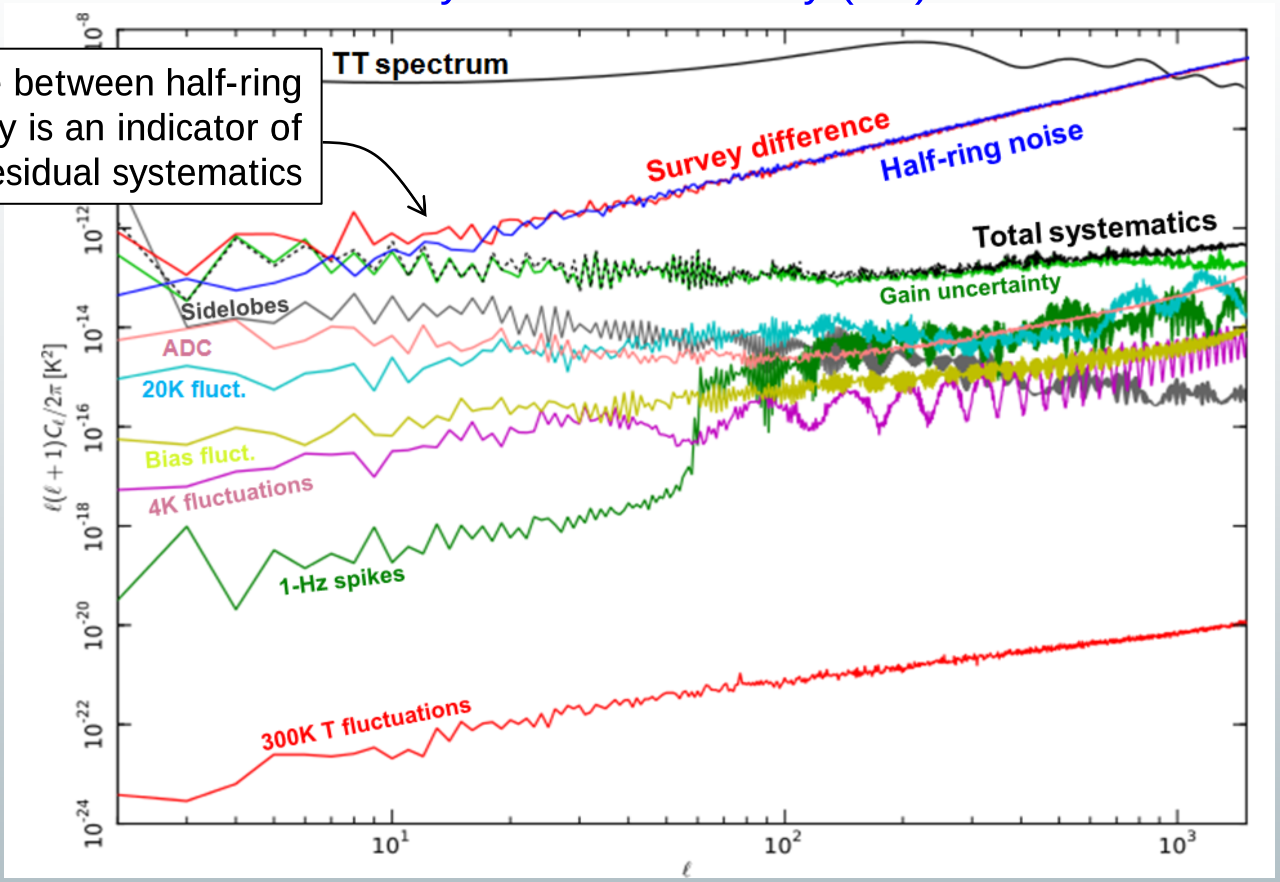
Odd survey **Even survey**



Main challenge: systematic effetcs

Systematics summary (LFI)

Difference between half-ring and Survey is an indicator of residual systematics



[Planck Collaboration III. LFI Systematics, 2013]

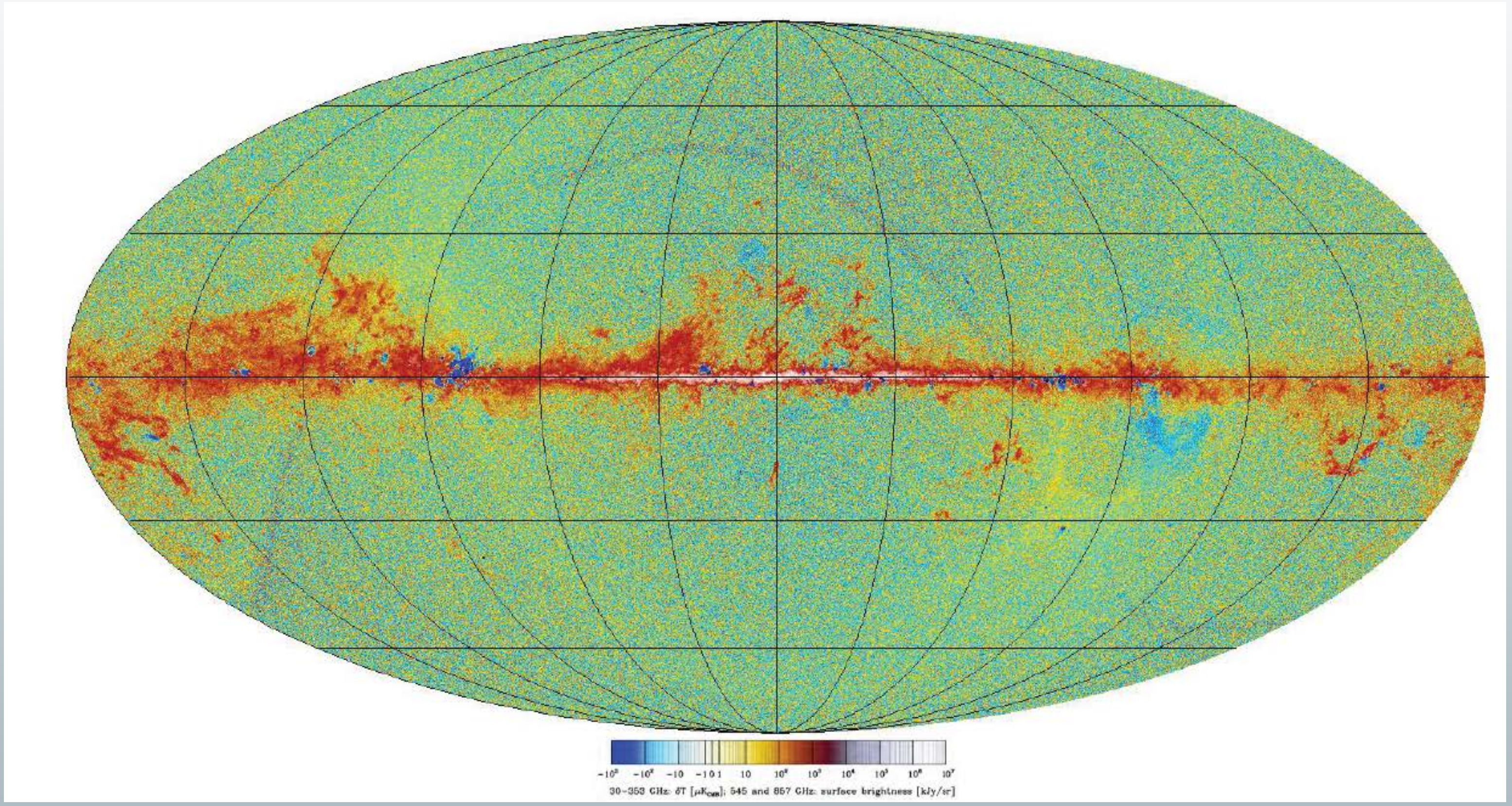
- Systematics are well under control for TT
- True for both LFI and HFI, with different effects

Challenge: can we reach comparable confidence for polarization?

Systematics crosschecks & calibration

Unique capability of Planck: compare two technologies over large multipole space and at nearby frequencies

[LFI 70 GHz – HFI 100 GHz]

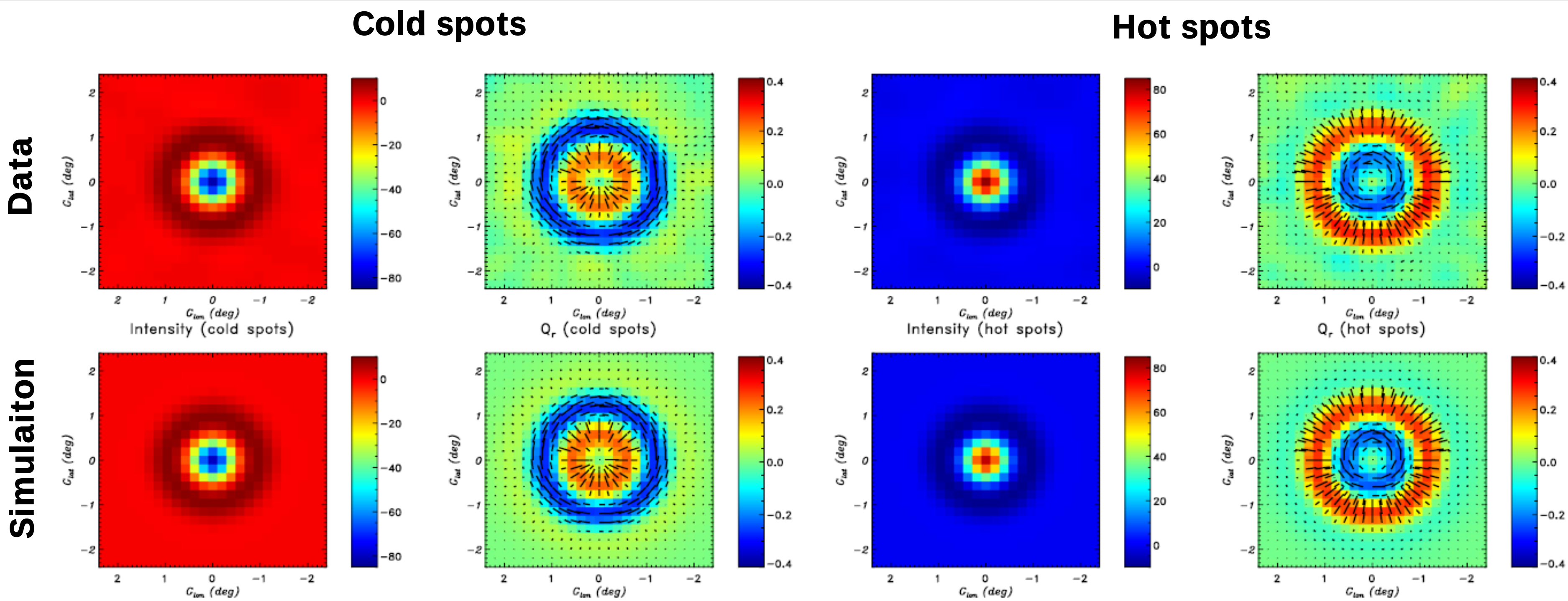


Powerful tool for Polarization analysis

Planck CMB polarization

- Scientific analysis on polarisation not yet ready
- Both HFI and LFI in rapid progress
- Preliminary Planck polarization already show spectacular performance

Stacked maps for I and polarization Q_r (30' resolution)



Planck 70 to 353 GHz channels

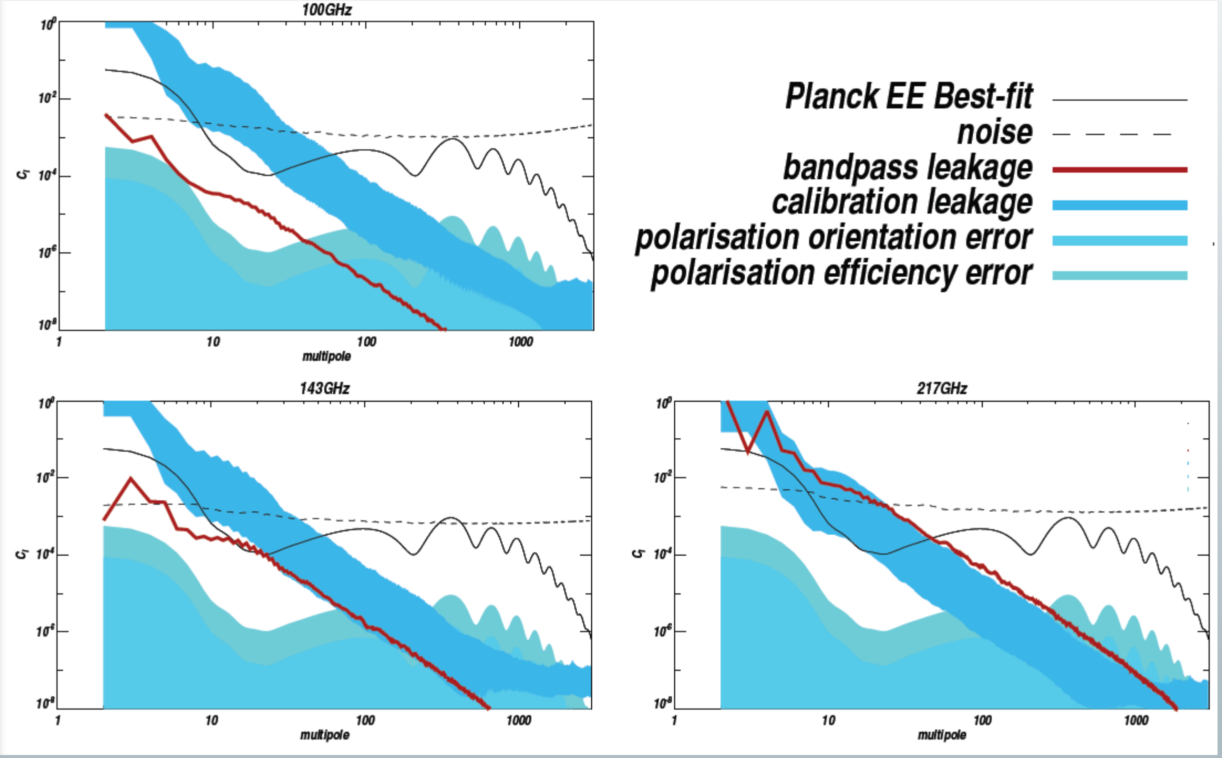
[Planck 2013 results. I. Mission paper]

Polarization systematics: HFI

Current HFI status

- Low ell affected by gain leakage: much work in progress, high priority for 2014
- At high multipoles systematics are sub-dominant

→ Quantitative assessment on-going



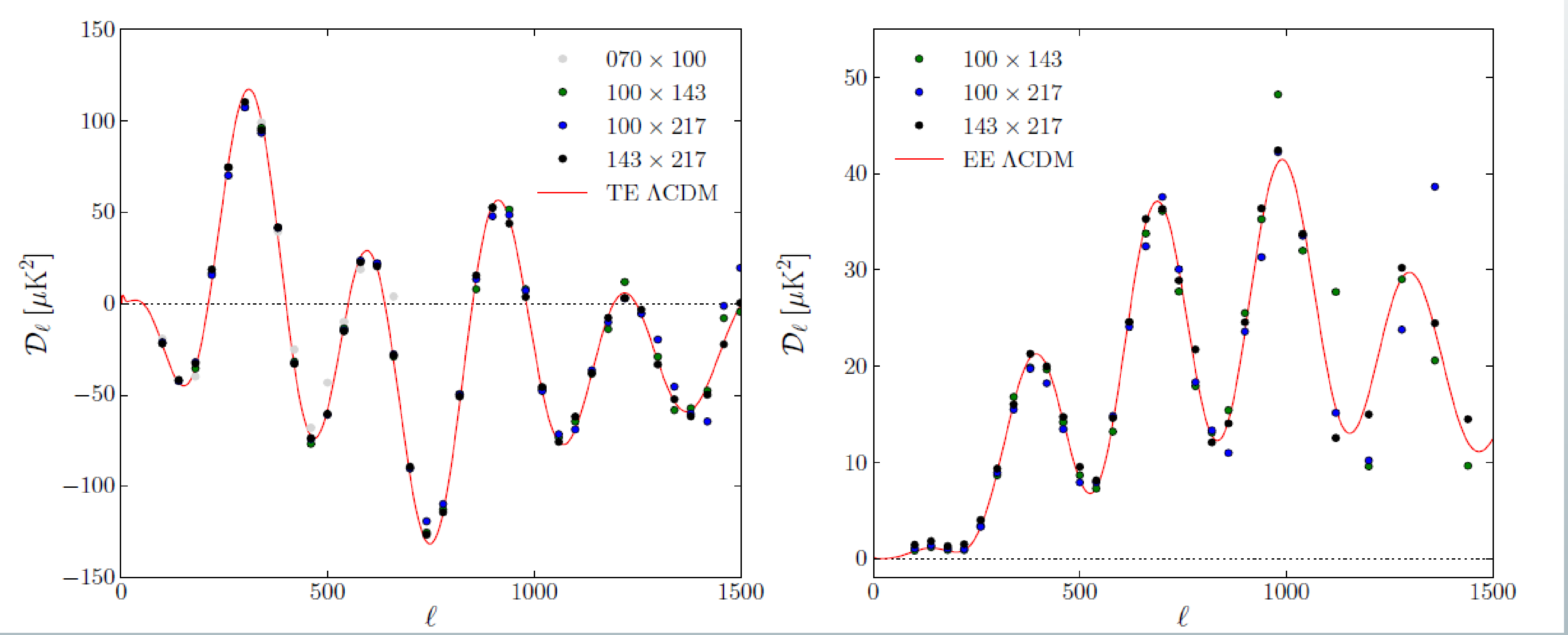
[Planck 2013 results. VI. HFI data processing]

Estimation based on dedicated MC simulations at ring level

Polarization systematics: HFI

Current HFI status

• High ell HFI polarization TE and EE (preliminary!) spectra demonstrate the excellent quality of the data (note: red line is not a fit!)
• Foregrounds and systematics are not dominant

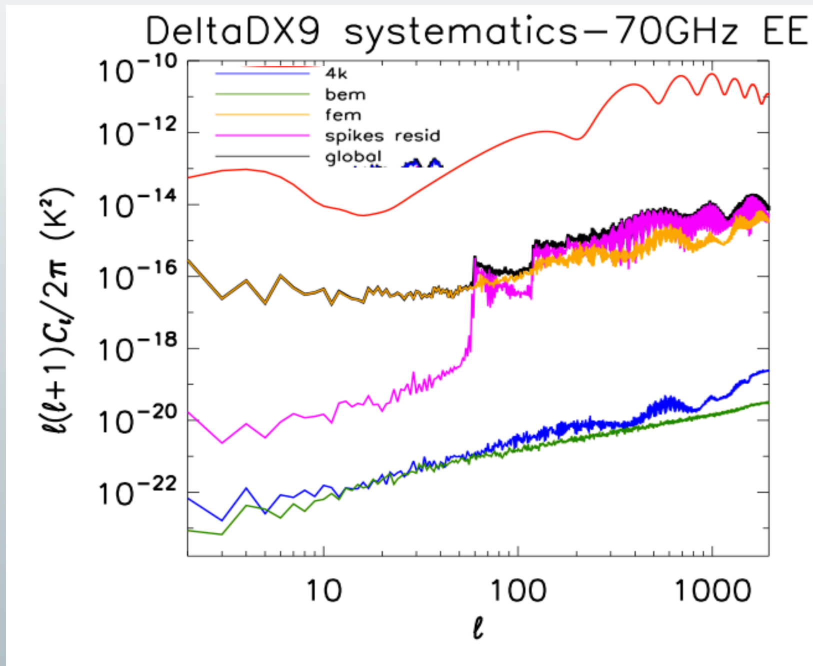


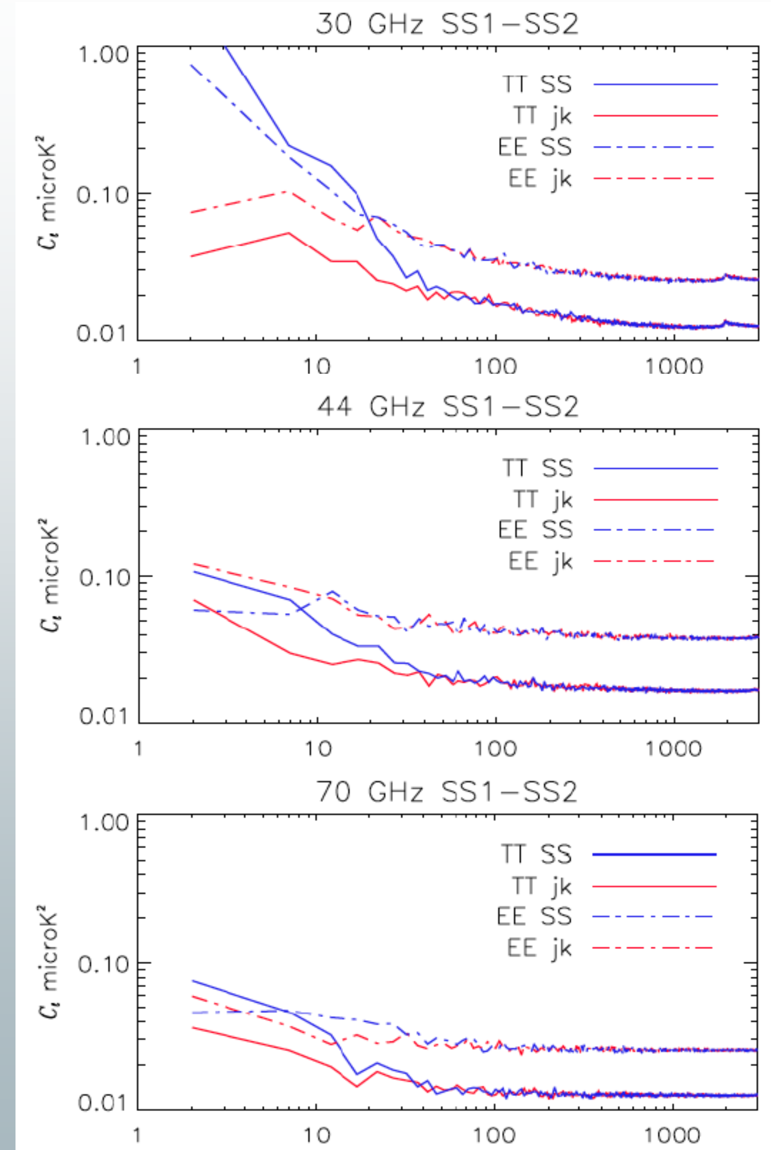
• Large and intermediate scales common to LFI and HFI

Polarization systematics: LFI

Current LFI status

- Low ell thermal effects & spikes below significance for EE
- Analysis not yet complete



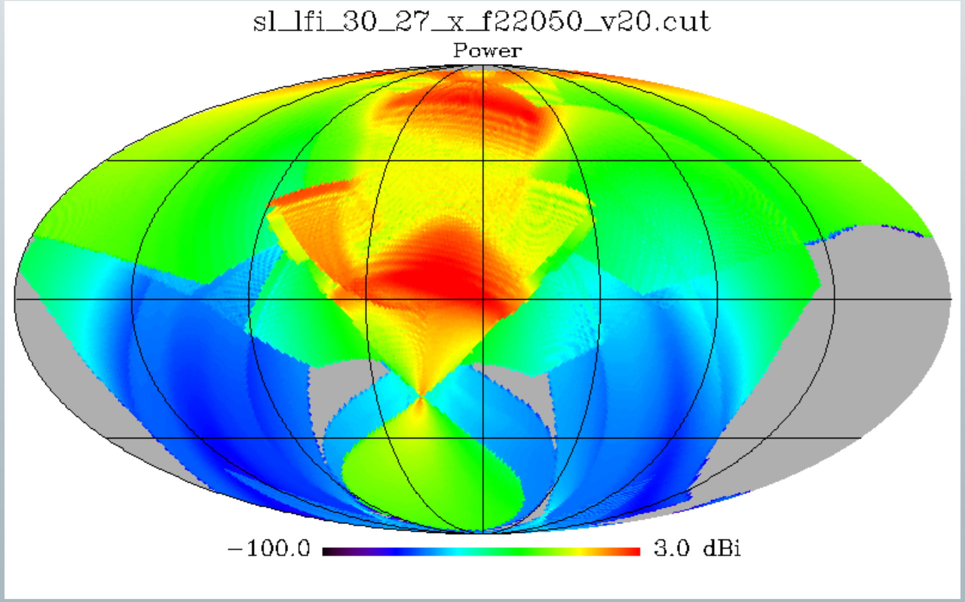


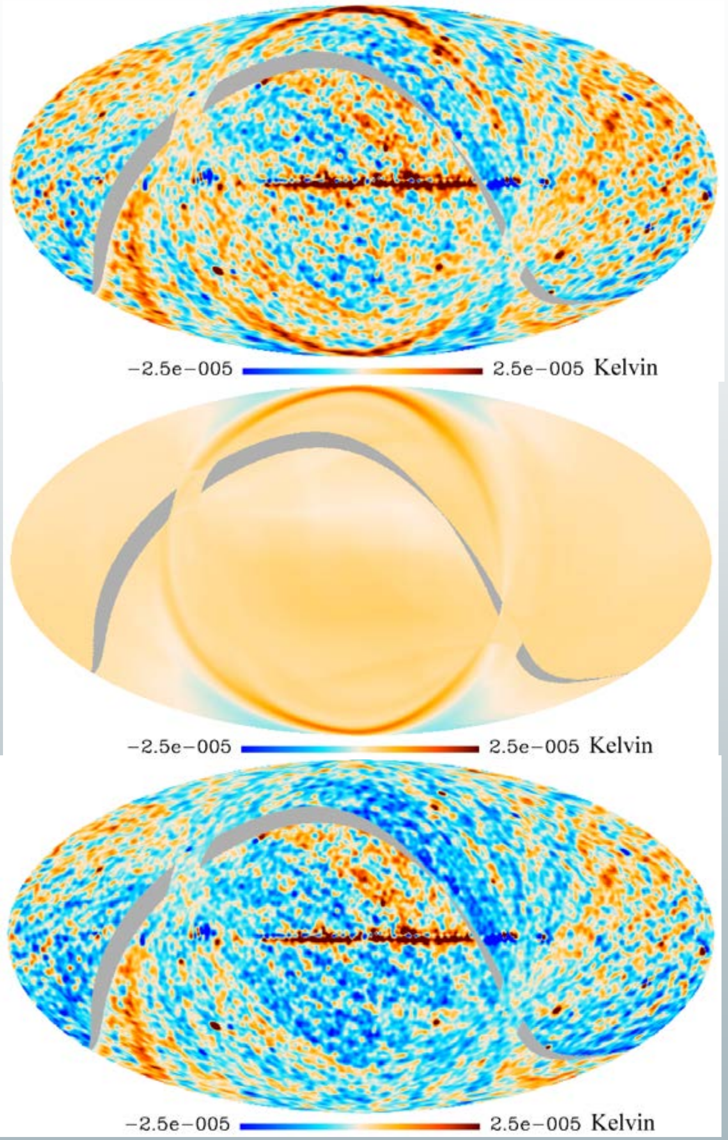
Difference between half-ring and Survey-Survey reveals residual systematics

Polarization systematics: LFI

Beam integration across the band

- Full beams (main beam + sidelobes) at >20 frequencies within band computed for each LFI radiometer (GRASP10).
- Integrated beams: weighted mean taking into account radiometer bandshape
- Will be used in next release to improve **calibration** pipeline and **removal of Galactic straylight**

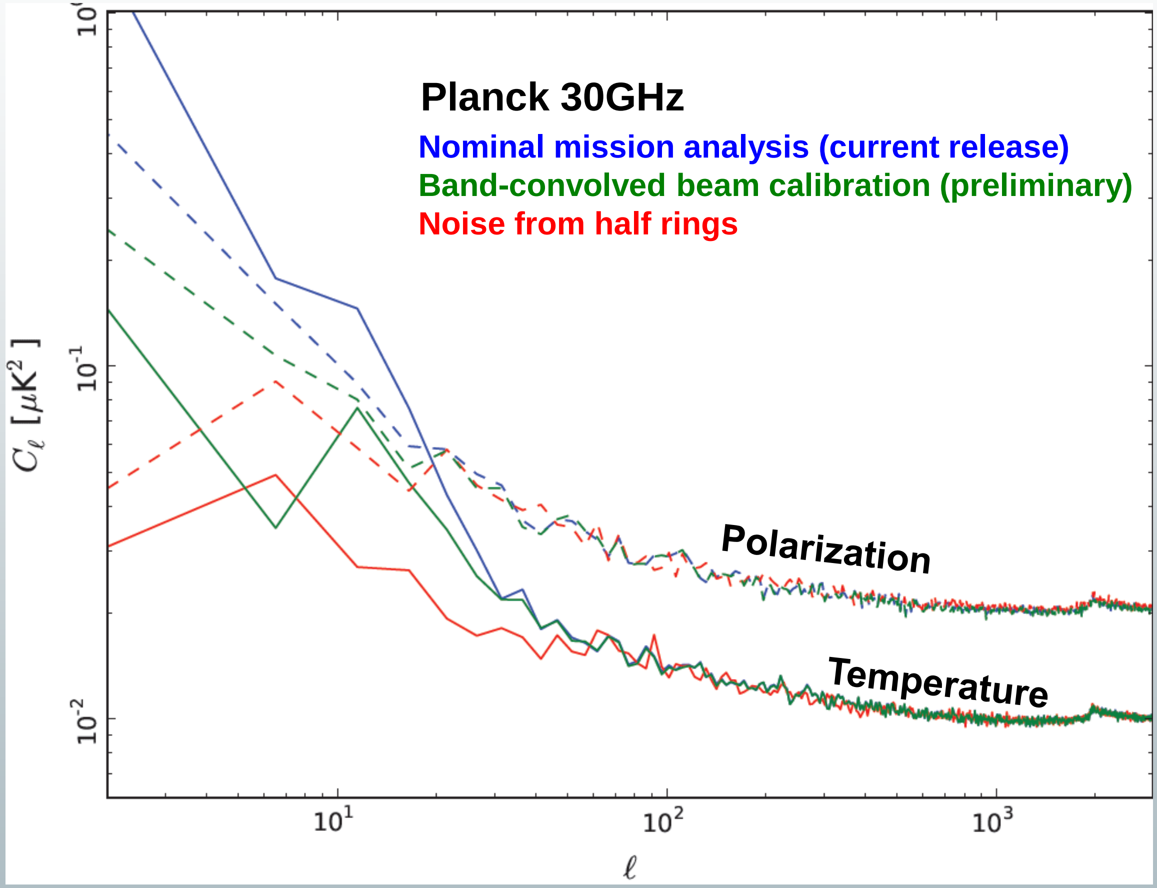




Polarization systematics: LFI

Beam integration across the band

Null-test spectra (Survey 1 – Survey 2)



- Promising results
- Being optimized & extended to 44GHz and 70GHz channels

Component separation challenges

Planck has entered a new era!

Full mission data

- Next release: Total intensity and Polarization products
- Increased specialization of foreground cleaning and astrophysical investigation
- Use of independent methods for complementarity and cross-checking between
- Use of ancillary datasets for foreground recovery and astrophysical studies
- Stronger link between component separation products and Planck likelihood, in particular for polarization analysis

Polarization highlights

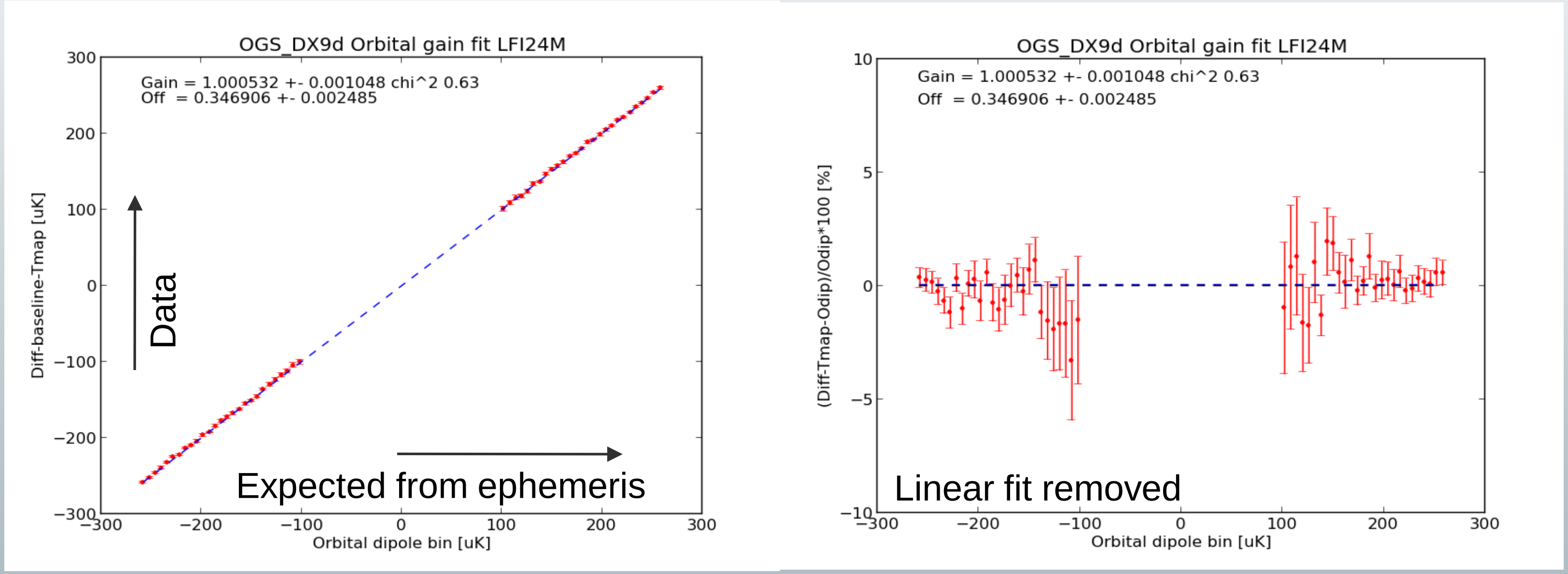
- Decreased signal to noise ratio at high Galactic latitudes
- Increased foreground-to-CMB ratio wrt total intensity
- Foreground minimum near 70 GHz (depending on scale)
- Very little ancillary data
- Impact of systematic effects (e.g. bandpass leakage, both LFI and HFI)

More issues to be tackled

- **Beam handling**, both for calibration and for scientific analysis
- In-flight recovery of the **telescope geometry**
- **Absolute calibration** using orbital dipole (both LFI and HFI)

  2013 release – Main calibrator: WMAP solar dipole
  2014 release – Absolute calibration based on Planck satellite orbital velocity

Preliminary results from Planck 44 GHz channel



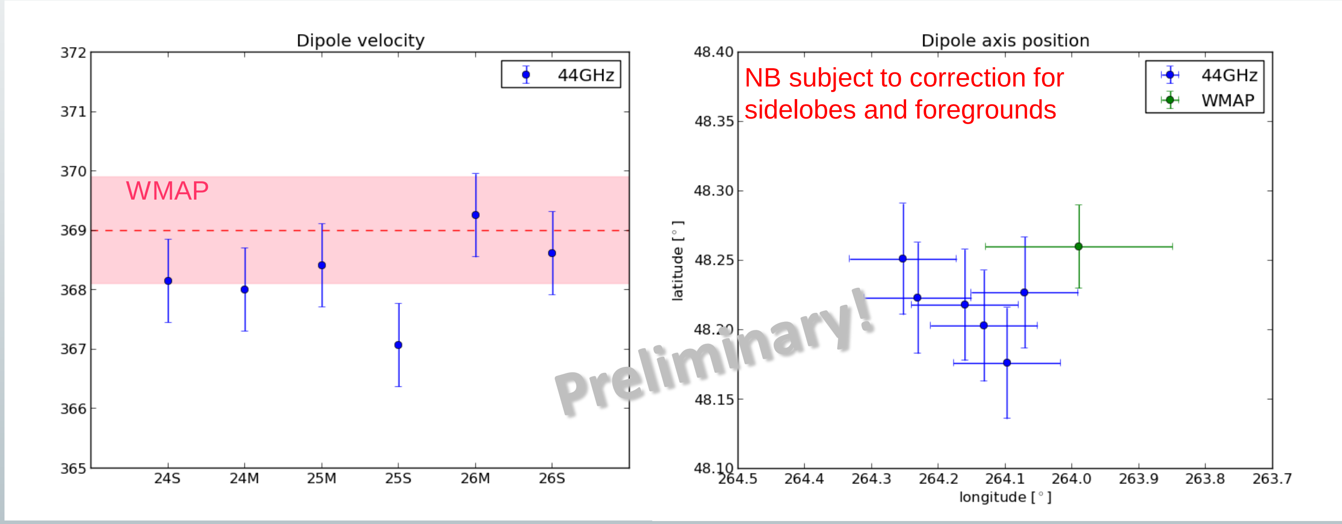
- Data visiting same spot 6 months apart with opposite velocity is used to separate orbital velocity effect from intrinsic sky signal
- Relative calibration scheme based on solar dipole or house-keeping data

Orbital dipole calibration

Limitations:

Relative gain variations ~0.2% (extra noise component)
Far-sidelobes ~0.2% (biases 6 month differences)

Current best results are at 44 GHz where the far-sidelobes are 4 times smaller



- Very good agreement with WMAP
- With improved relative calibration and far-sidelobe correction, simulations suggest we should achieve 0.04% absolute calibration

→ **Unprecedented accuracy on absolute dipole measurement**

Cosmological parameters

6-parameters model

Parameter		2013 uncertainty (Planck+WP)	Expected 2014 (Planck T+P)
Baryon density today	$\Omega_b h^2$	0.00028	0.00013
Cold dark matter density today	$\Omega_c h^2$	0.0027	0.0010
Thomson scattering optical depth	τ	0.013	0.0042
Hubble constant [km/s/Mpc]	H_0	1.2	0.53
Scalar spectrum power-law index	n_S	0.007	0.0031

Constraints on other parameters

Parameter		2013 uncertainty (Planck+WP)	Expected 2014 (Planck T+P)
Effective number of neutrino species	N_{eff}	0.42	0.18
Fraction of baryonic mass in helium	Y_p	0.035	0.010
Dark energy equation of state	w	0.32	0.20
Varying fine-structure constant	α/α_0	0.0043	0.0018

→ Expected reduction in error bars by factors of 2 or more

f_{NL} with polarization data

Expected benefits from full mission

• Planck to achieve first measurement of primordial NG parameters using CMB polarization

• f_{NL} expected improvement on error bars ≈20% when TTE, TEE, EEE bispectra are included in the analysis

• EEE bispectrum *alone* should produce error bars comparable to WMAP TTT bispectrum constraints ($Df_{NL} \approx 20$) → interesting cross-check

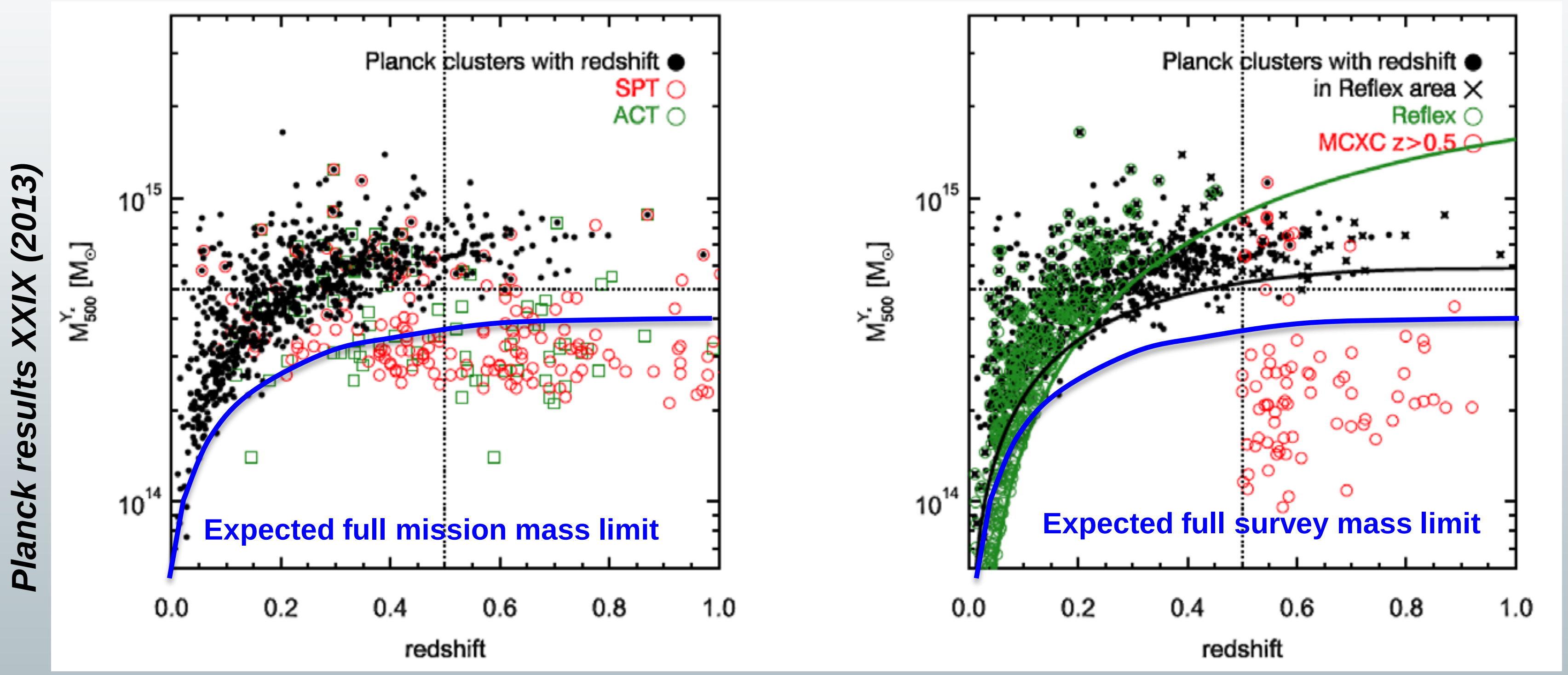
• Removing low-l multipoles from polarized component of the KSW bispectrum estimator does not degrade S/N significantly (Yadav et al. 2007)
If foreground limited at low ell → robustness of the result should be preserved in presence of polarized foregrounds

• Interesting constraints expected on isocurvature modes from polarized bispectra (Langlois & Van Tent 2012)

Improved SZ studies

Mass redshift distribution: expectations for the full survey

- Lower mass limits ($M_{500} \sim 4\times10^{14} M_{\odot}$ at z=1)
- Possibility of finding clusters at z>1



All sky thermal SZ maps

- Improved statistics and higher control on systematics will benefit SZ power spectrum and cosmological parameters estimation

Diffuse astrophysical components

Expected benefits from full mission

Galactic diffuse emissions

- In polarization, additional data are extremely important: noise, systematics
- Unprecedented characterization of dust polarization
- More accurate spectral indices of all components at high Galactic latitudes
    - E.g.: Long wavelength sub-mm value of dust spectral index: ~50% more accurate

      → improve high frequency spectrum of AME
- Polarization of the “haze”
- Separation of synchrotron/free-free/AME

CIB

- Full mission to improve substantially 217, 143 GHz

  (≥ 353 already signal-dominated)
- Perform joined SZ-CIB analysis (including tSZ-CIB correlation)

Planck Catalogue of Compact Sources

Expected benefits from full mission

- **Polarization information will be added in next release**

Multi-frequency catalogues:
-- multi-frequency detection methods (thermal and non-thermal sources)
-- band-merging information (if a source has been detected in the neighbouring channels)

- **Variability**

With 5—8 surveys it will be possible to analyze variability behaviour of the Planck sources

- **Scientific outputs:**

-- Update statistical properties of the PCCS sources with better accuracy and toward fainter flux density levels allowed by 5—8 surveys
-- Simultaneous analysis both in total intensity and polarization will provide unprecedented information about emission physics of non-thermal sources

Conclusions

• The excellent performance of Planck instruments and coolers allows for major extensions of the Planck survey (5 surveys for HFI, 8 surveys for LFI)

• Increased observing time and multiple redundancy will lead to higher sensitivity and more stringent control of systematic effects and calibration:

→ *the key for more science results!*

• The Planck full mission and new polarization data will bring Cosmology in yet unmatched precision levels

→ parameters, non-G, lensing, anomalies (vs. polarization!), …

• Significant advances in several aspects of mm-wave astrophysics, including Galactic diffuse components, sources catalogs, SZ studies

• Polarization will require working at the very limit of our instrument and (perhaps more critical) of our knowledge of the instruments themselves

The work of many people has to be greeted!

Planck Collaboration

Planck Core Team

Planck Collaboration

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Gaier, S. Galeotta, J. Gallegos, K. Ganga, J. Garcıa Lazaro, A. Garnica, M. Gaspard, E. Gavila, M. Giard1, G. Giardino, G. Gienger, Y. Giraud-Heraud, J.-M. Glorian, M. Grin, A. Gruppuso, L. Guglielmi, D. Guichon, B. Guillaume, P. Guillouet, J. Haissinski, F. K. Hansen, J. Hardy, D. Harrison, A. Hazell, M. Hechler, V. Heckenauer, D. Heinzer, R. Hell, S. Henrot-Versille, C. Hernandez-Monteagudo, D. Herranz, J. M. Herreros, V. Hervier, A. Heske, A. Heurtel, S. R. Hildebrandt, R. Hills, E. Hivon, M. Hobson, D. Hollert, W. Holmes, A. Hornstrup, W. Hovest, R. J. Hoyland, G. Huey, K. M. Huenberger, N. Hughes, U. Israelsson, B. Jackson, A. Jae, T. R. Jae, T. Jagemann, N. C. Jessen, J. Jewell, W. Jones, M. Juvela, J. Kaplan, P. Karlman, F. Keck, E. Keihanen, M. King, T. S. Kisner, P. Kletzkine, R. Kneissl, J. Knoche, L. Knox, T. Koch, M. Krassenburg, H. Kurki-Suonio, A. Lahteenmaki, G. Lagache, E. Lagorio, P. Lami, J. Lande, A. Lange, F. Langlet, R. Lapini, M. Lapolla, A. Lasenby, M. Le Jeune, J. P. Leahy, M. Lefebvre, F. Legrand, G. Lemeur, R. Leonardi, B. Leriche, C. Leroy, P. Leutenegger, S. M. Levin, P. B. Lilje, C. Lindensmith, M. Linden-Vørnle, A. Loc, Y. Longval, P. M. Lubin, T. Luchik, I. Luthold, J. F. Macias-Perez, T. Maciaszek, C. MacTavish, S. Madden, B. Maei, C. Magnevile, D. Maino, A. Mambretti, B. Mansoux, D. Marchioro, M. Maris, F. Marliani, J.-C. Marrucho, J. Martı-Canales, E. Martınez-Gonzalez, A. Martın-Polegre, P. Martin, C. Marty, W. Marty, S. Masi, M. Massardi, S. Matarrese, F. Matthai, P. Mazzotta, A. McDonald, P. McGrath, A. Mediavilla, P. R. Meinhold, J.-B. Melin, F. Melot, L. Mendes, A. Mennella, C. Mervier, L. Meslier, M. Miccolis, M.-A. Miville-Deschenes, A. Moneti, D. Montet, L. Montier, J. Mora, G. Morgante, G. Morigi, G. Morinaud, N. Morisset, D. Mortlock, S. Mottet, J. Mulder, D. Munshi, A. Murphy, P. Murphy, P. Musi, J. Narbonne, P. Naselsky, A. Nash, F. Nati, P. Natoli, B. Netterfield, J. Newell, M. Nexon, C. Nicolas, P. H. Nielsen, N. Ninane, F. Noviello, D. Novikov, I. Novikov, I. J. O'Dwyer, P. Oldeman, P. Olivier, L. Ouchet, C. A. Oxborrow, L. Perez-Cuevas, L. Pagan, C. Paine, F. Pajot, R. Paladini, F. Pancher, J. Panh, G. Parks, P. Parnaudeau, B. Partridge, B. Parvin, J. P. Pascual, F. Pasian, D. P. Pearson, T. Pearson, M. Pecora, O. Perdereau, L. Perotto, F. Perrotta, F. Piacentini, M. Piat, E. Pierpaoli, O. Piersanti, E. Plaige, S. Plaszczynski, P. Platania, E. Pointecouteau, G. Polenta1, N. Ponthieu, L. Popa, G. Poulleau, T. Poutanen, G. Prezeau, L. Pradell, M. Prina, S. Prunet, J. P. Rachen, D. Rambaud, F. Rame, I. Rasmussen, J. Rautakoski, W. T. Reach, R. Rebolo, M. Reinecke, J. Reiter, C. Renault, S. Ricciardi, P. Rideau, T. Riller, I. Ristorcelli, J. B. Riti, G. Rocha, Y. Roche, R. Roger Pons, R. Rohlfs, D. Romero, S. Roose, C. Rosset, S. Rouberol, M. Rowan-Robinson, J. A. Rubino-Martin, P. Rusconi, B. Rusholme, M. Salama, E. Salerno, M. Sandri, D. Santos, J. L. Sanz, L. Sauter, F. Sauvage, G. Savini, M. Schmelzel, A. Schnorhk, W. Schwarz, D. Scott, M. D. Seiert, P. Shellard, C. Shih, M. Sias, J. I. Silk, R. Silvestri, R. Sippe, G. F. Smoot, J.-L. Starck, P. Stassi, J. Sternberg, F. Stivoli, V. Stolyarov, R. Stompor, L. Stringhetti, D. Strommen, T. Stute, R. Sudiwala, R. Sugimura, R. Sunyaev, J.-F. Sygnet, M. Turler, E. Taddei, J. Tallon, C. Tamiatto, M. Taurigna, D. Taylor, L. Terenzi, S. Thuerey, J. Tillis, G. Tofani, L. Toolatti, E. Tommasi, M. Tommasi, E. Tonazzini, J.-P. Torre, S. Tosti, F. Touze, M. Tristram, J. Tuovinen, M. Tuttlebee, G. Umana, L. Valenziano, D. Vallee, M. van der Vlis, F. Van Leeuwen, J.-C. Vanel, B. VanTent, J. Varis, E. Vassallo, C. Vescovi, F. Vezzu, D. Vibert, P. Vielva, J. Vierra, F. Villa, N. Vittorio, C. Vuerli, L. A. Wade, A. R. Walker, B. D. Wandelt, C. Watson, D. Werner, M. White, S. D. M. White, A. Wilkinson, P. Wilson, A. Woodcraft, B. Yoo, M. Yun, V. Yurchenko, D. Yvon, B. Zhang, O. Zimmermann, A. Zonca, and D. Zorita

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

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