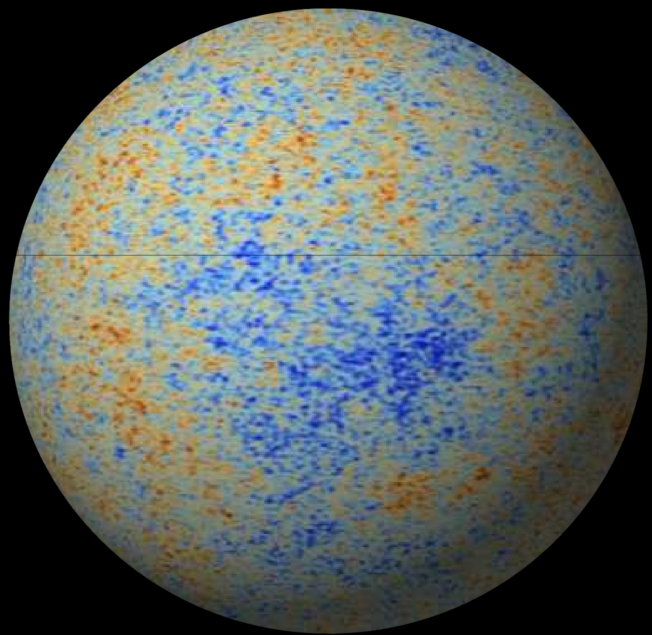
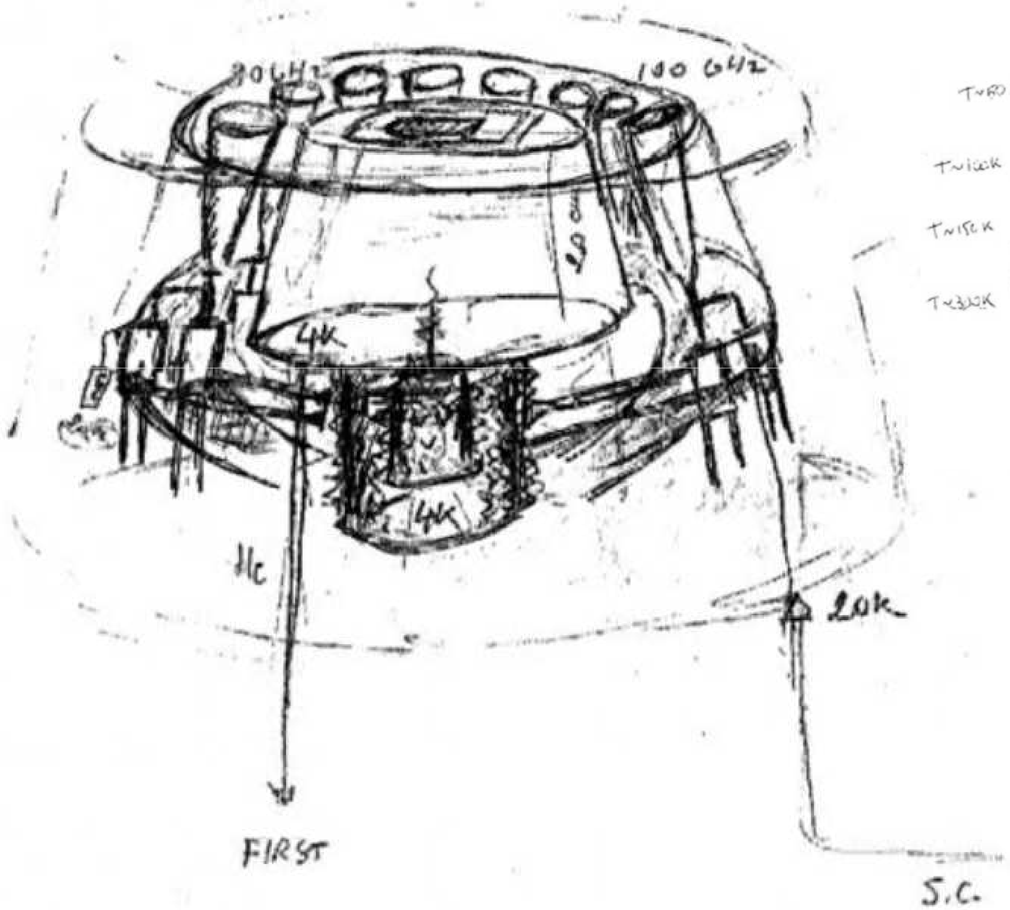
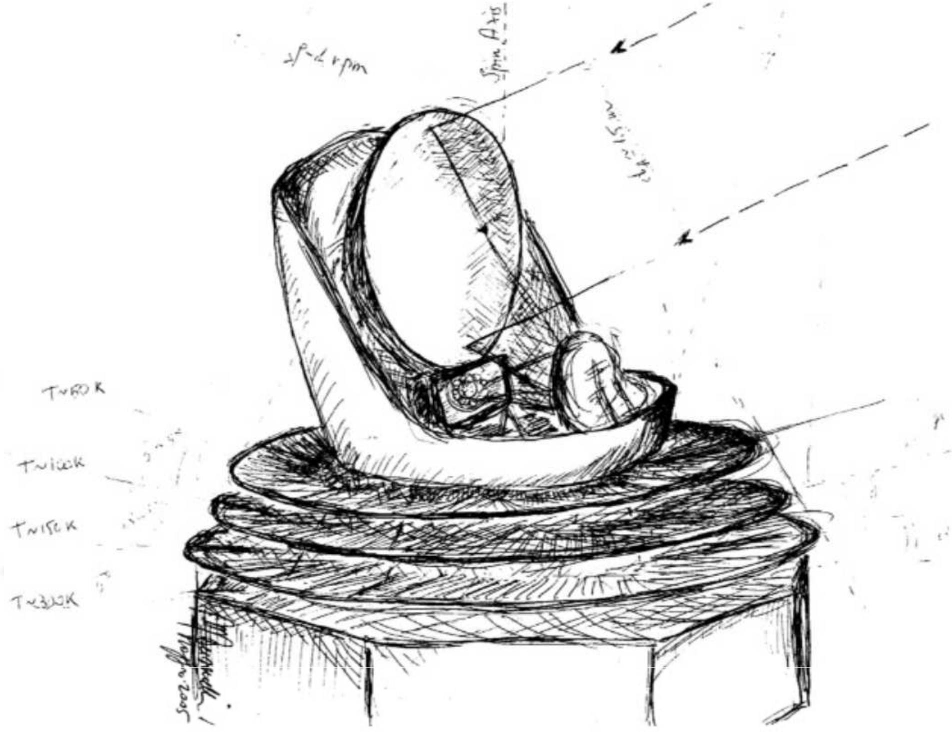
ISSS Course
"Observing the Universe with the Cosmic Microwave Background"
L'Aquila, Italy – April 22-26, 2014

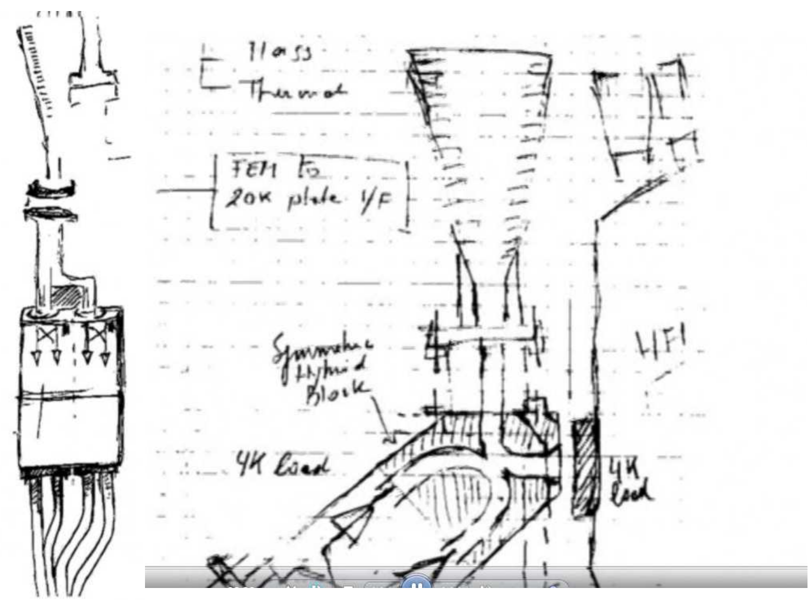
# The next Planck release



Marco Bersanelli
Physics Department, University of Milano

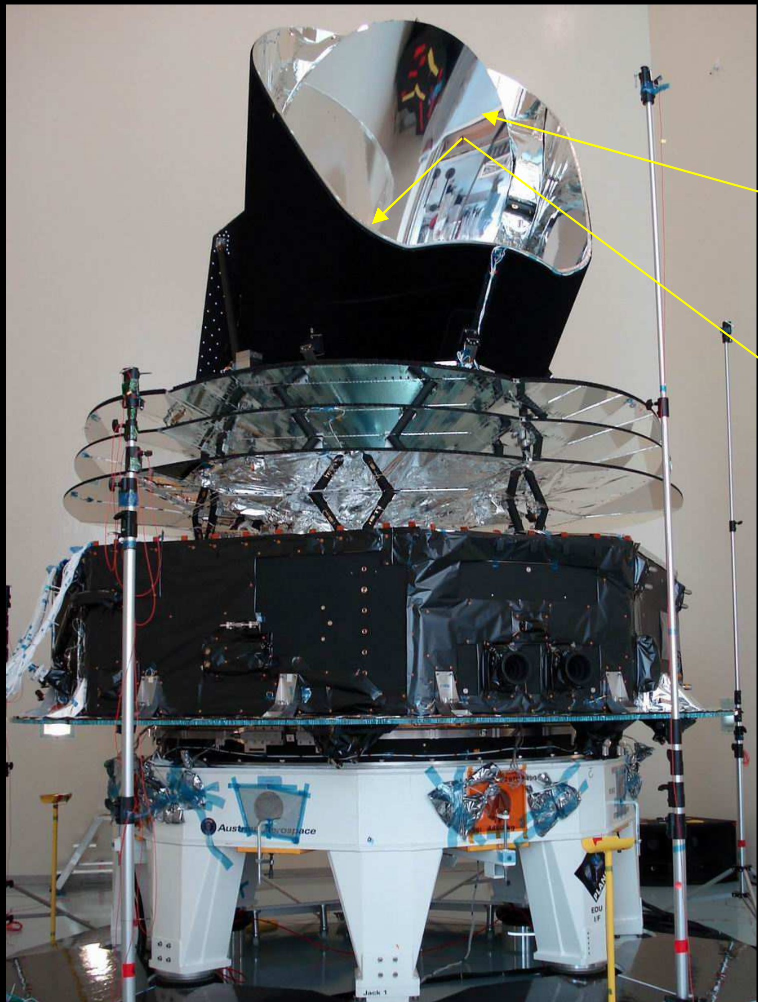

30GHz
100 GHz
4K
4K
He
20K
FIRST
S.C.


Spin Axis
T~50K
T~100K
T~150K
T~300K


Mass
Thermal
FEM to
20K plate I/F
Symmetric
Hybrid
Block
4K Load
4K
load
LFI

# PLANCK

## *Looking back to the dawn of time*



**Planck Telescope**
1.5x1.9m off-axis
Gregorian
T = 50 K

**LFI Radiometers**
27-77 GHz, T = 20 K

**HFI Bolometers**
100-850 GHz, T = 0.1 K

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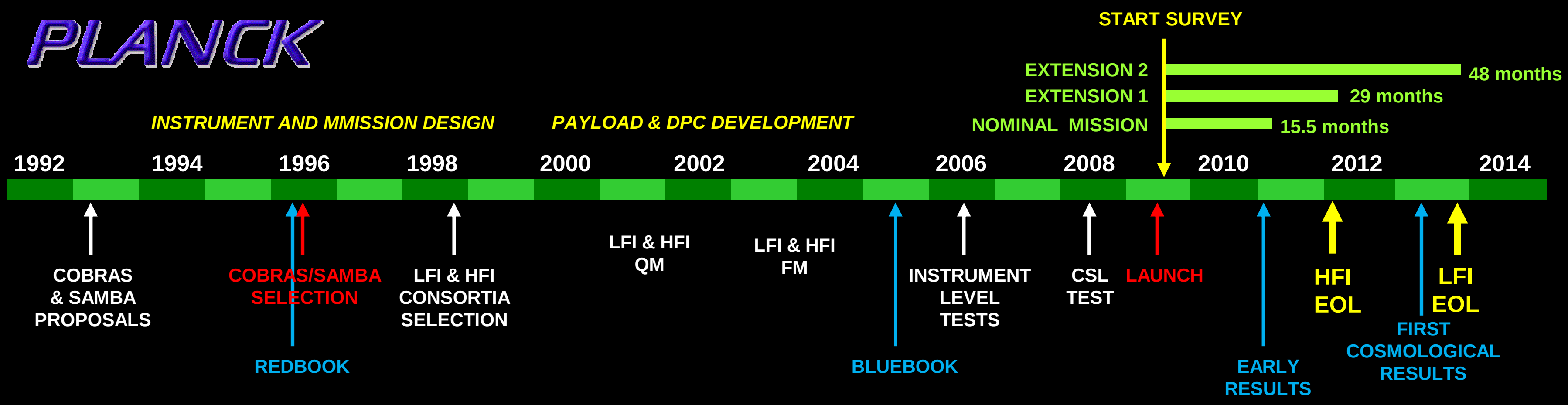


# The Planck Collaboration

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Ciancietta, M. Cibrario, R. Cizeron, D. Clements, B. Collaudin, J.-M. Colley, S. Colombi, A. Colombo, F. Colombo, O. Corre, F. Couchot, B. Cougrand, A. Coulais, P. Couzin, B. Crane, B. Crill, M. Crook, D. Crumb, F. Cuttaia, U. D¨orl, P. da Silva, R. Daddato, C. Damasio, L. Danese, G. d'Aquino, O. D'Arcangelo, K. Dassas, R. D. Davies, W. Davies, R. J. Davis, P. De Bernardis, D. de Chambure, G. de Gasperis, M. L. De la Fuenta, P. De Paco, A. De Rosa, G. De Troia, G. De Zotti, M. Dehamme, J. Delabrouille, J.-M. Delouis, F.-X. D´esert, G. di Girolamo, C. Dickinson, E. Doelling, K. Dolag, I. Domken, M. Douspis, D. Doyle, S. Du, D. Dubruel, C. Dufour, C. Dumesnil, X. Dupac, P. Duret, C. Eder, A. Elfving, T. A. Enßlin, P. Eng, K. English, H. K. Eriksen, P. Estaria, M. C. Falvella, F. Ferrari, F. Finelli, A. Fishman, S. Fogliani, S. Foley, A. Fonseca, G. Forma, O. Forni1, P. Fosalba, J.-J. Fourmond, M. Frailis, E. Franceschi, S. Franois, M. Frerking, M. F. Gomez-Renasco, K. M. Gorski, T. C. 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. 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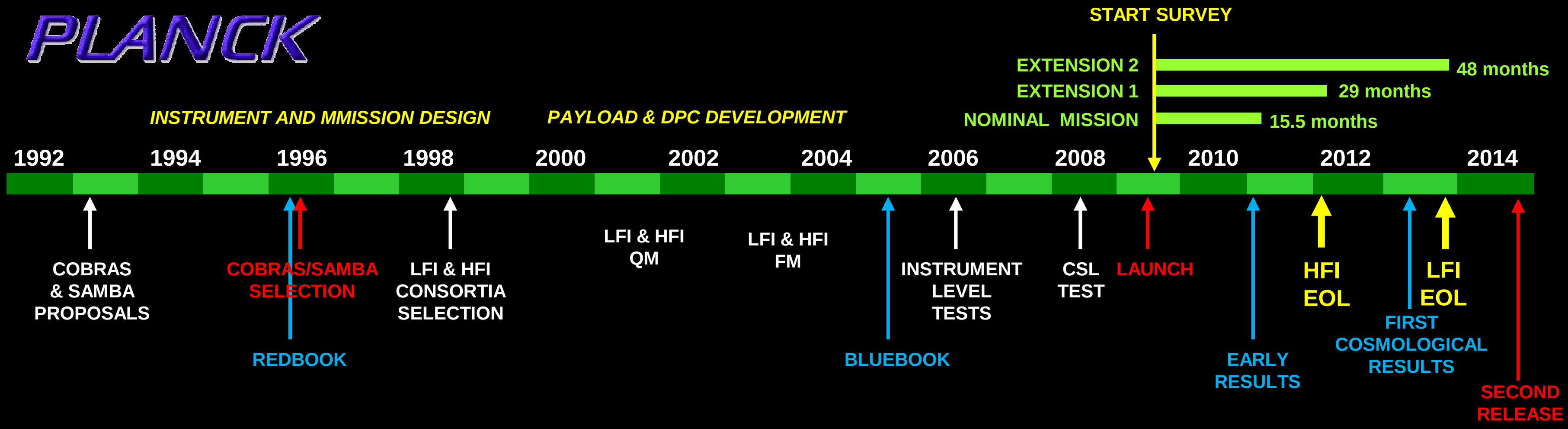
Nielsen, N. Ninane, F. Noviello, D. Novikov, I. Novikov, I. J. O'Dwyer, P. Oldeman, P. Olivier, L. Ouchet, C. A. Oxborrow, L. Perez-Cuevas, L. Pagan, C. Paine, F. Pajot, R. Paladini, F. Pancher, J. Panh, G. Parks, P. Parnaudeau, B. Partridge, B. Parvin, J. P. Pascual, F. Pasian, D. P. Pearson, T. Pearson, 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

PLANCK




- 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 significant of degradation in LFI and HFI (100% functional since start)
- Two mission extension proposals by PST, approved by ESA, leading to full exploitation of HFI and LFI lifetimes:

HFI: 29 months, ~5 sky surveys

LFI: 48 months, ~8 sky surveys

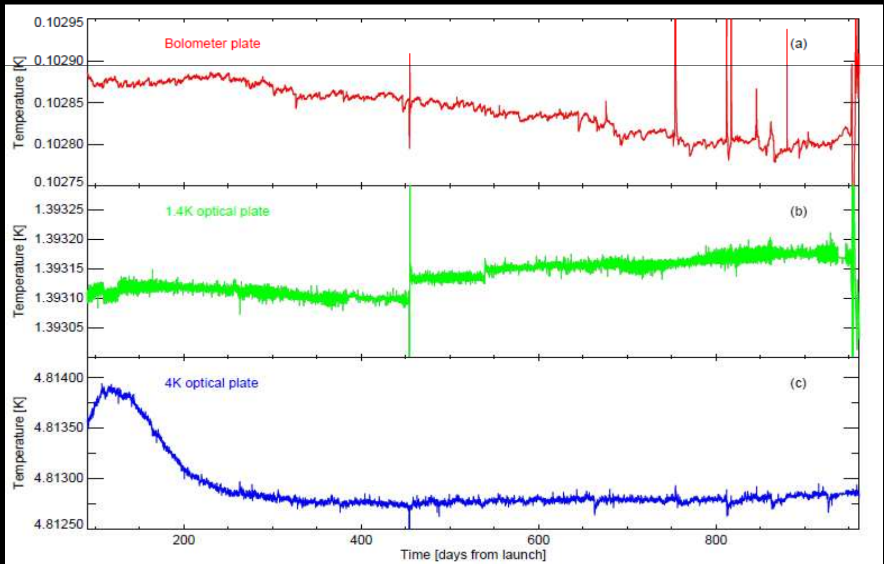
- Second cosmological release in 2014: Full-mission Temperature and Polarisation
- Followed by a third and final release in 2015

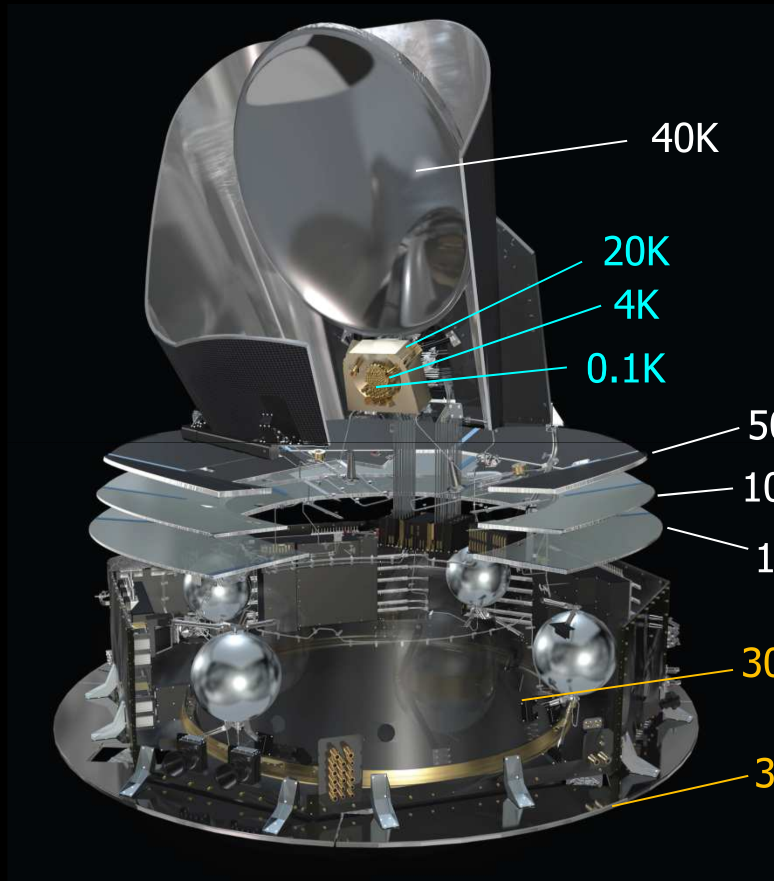
# In-flight cryo-chain performance & mission lifetime

## Excellent in-flight thermal performance

– Bolometer plate = 103mK
– LFI reference loads = 4.4-4.6 K
– LFI focal plane = 19.8–20.8 K
– Secondary mirror = 39.6 K
– Primary mirror = 36.5 K
– V-groove 3 (final radiative pre-cool) = 45-47 K

## Thermal stability



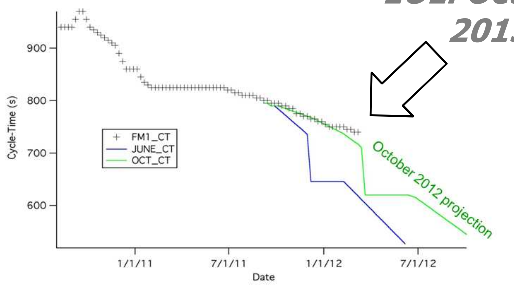

**Excellent Planck cryo-chain performance**
**more-than-doubled mission lifetime**

# Sorption Cooler & Planck lifetime

## Sorption Cooler & LFI lifetime

G.L. Morgante & D. Pearson

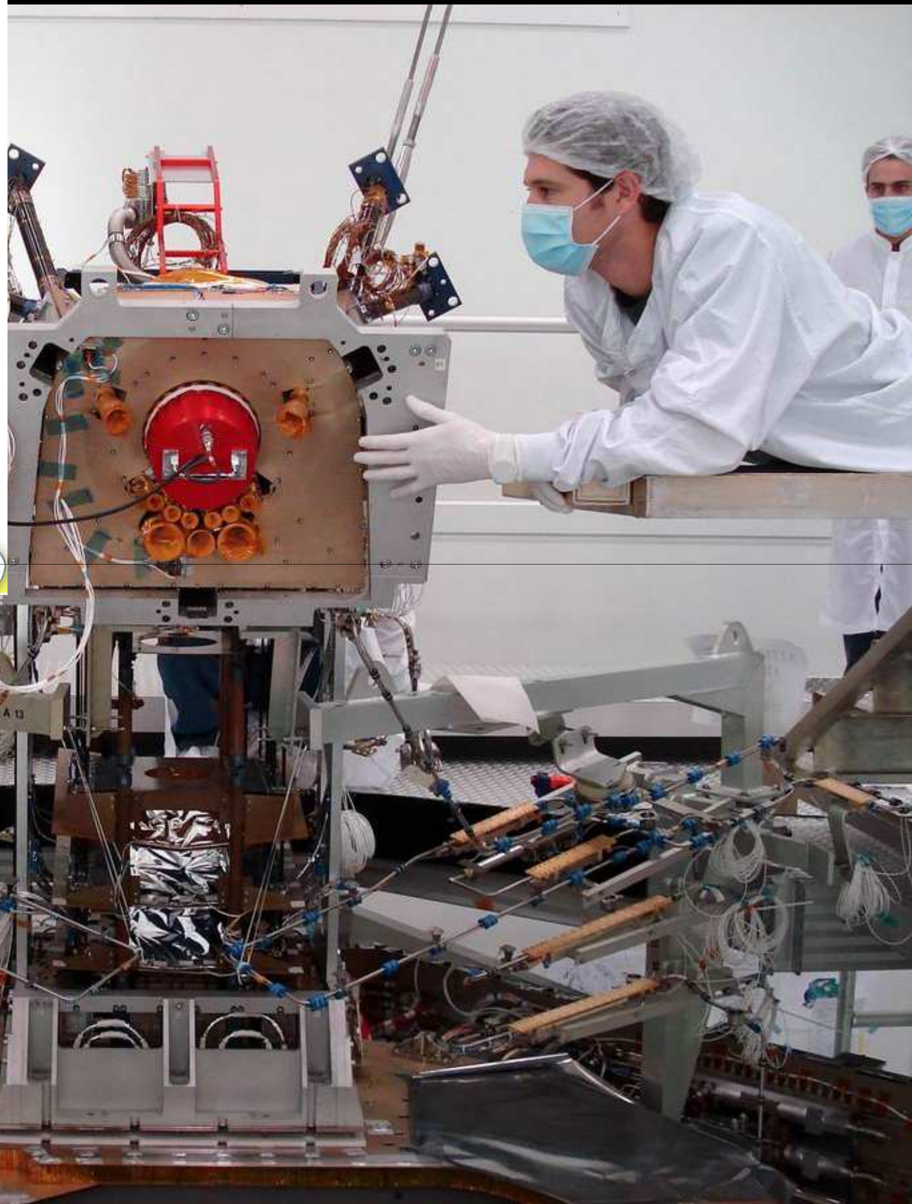
*EOL: October 2013*




- FM1 continues to outperform projections
- Recent experiments at JPL (Bob Bowman) indicate that regeneration is effective at 30 Bar (~in-flight pressure)

→ Possibility of extending "LFI-only" phase beyond January 2013

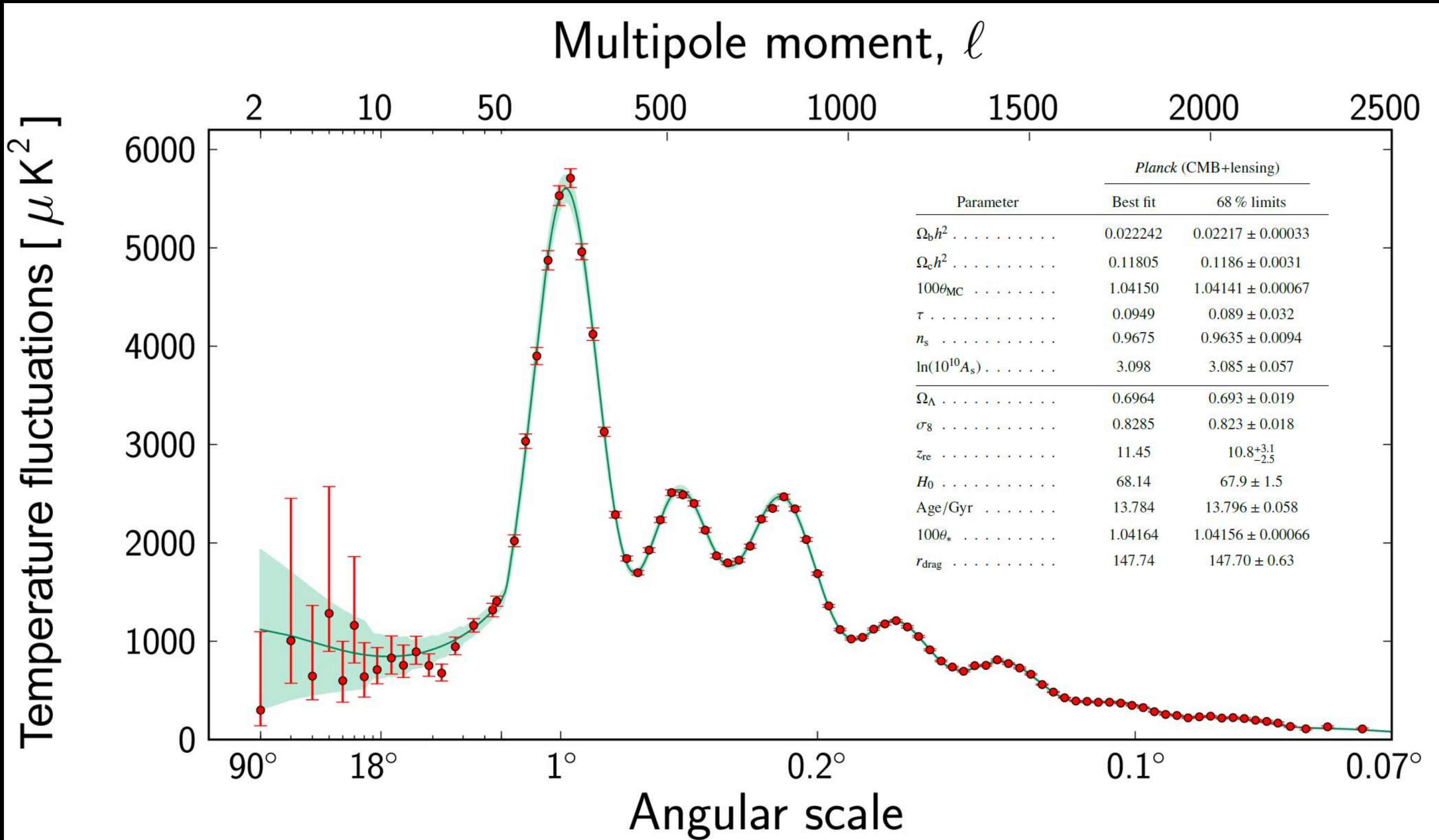




# Good bye Planck!

## Darmstadt, 23 October 2013

# Can we improve over this?




**Can we achieve comparable accuracy in polarization?**
**What's the scientific gain?**

# Aiming at ultimate $\frac{\delta T}{T}$ CMB measurement

$$\Delta T_{\min}(f) = k_R T_{\text{sys}} \sqrt{\frac{1}{n_{\text{det}} n_{\text{mod}} \Delta\nu \cdot \tau} + \left(\frac{\delta G_T(f)}{< G_T >}\right)^2} + \delta T_{\text{Systmatics}}(f)$$

**White noise**

- → Push detector sensitivity to fundamental limits
- → Cool to cryogenic temperatures
- → Make large arrays of detectors

**Stability (1/f noise)**

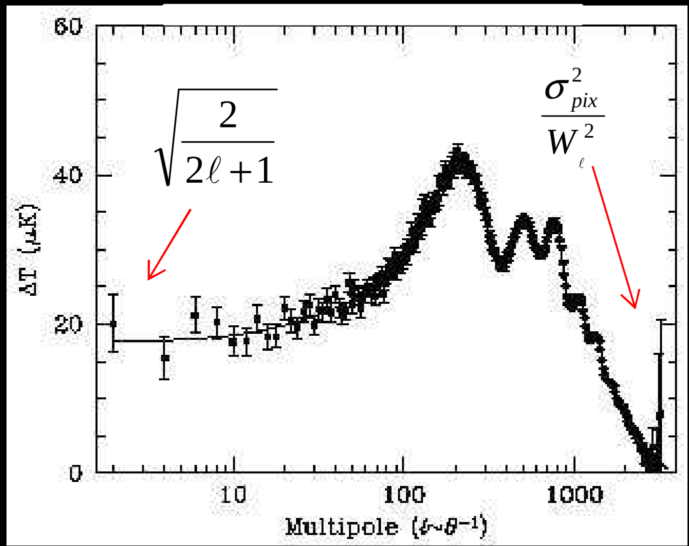
- → Differential systems
- → Internal or sky reference
- → Modulate bolometer reedout

## Power spectrum accuracy

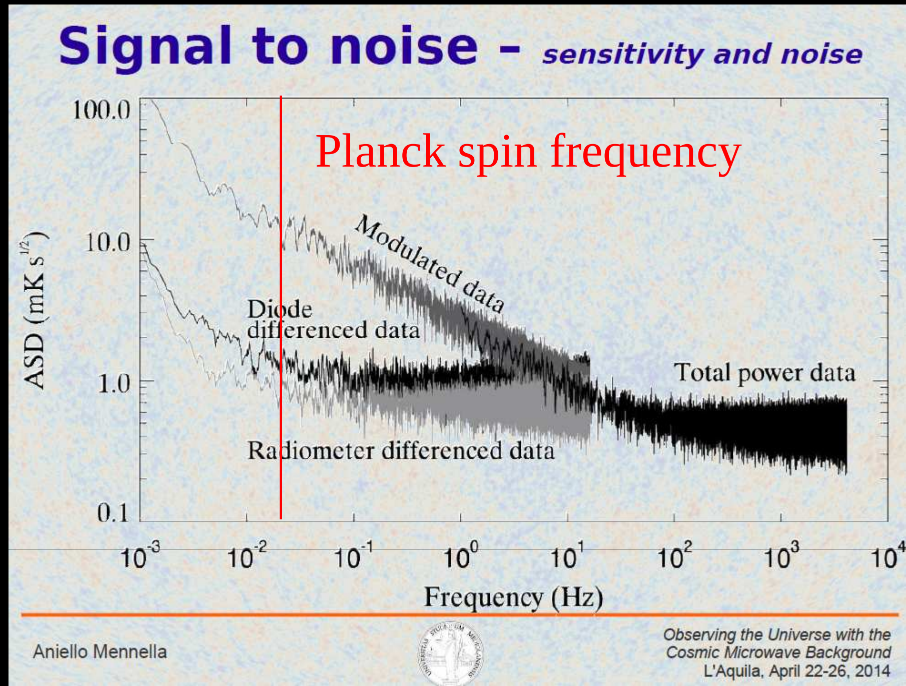
$$\frac{\delta C_\ell}{C_\ell} = f_{sky}^{-1/2} \sqrt{\frac{2}{2\ell+1}} \left[1 + \frac{A\sigma_{pix}^2}{N_{pix} C_\ell W_\ell^2}\right]$$

*Sky coverage* — *Cosmic variance* — *Instrument noise and beams*

Simulated T power spectrum



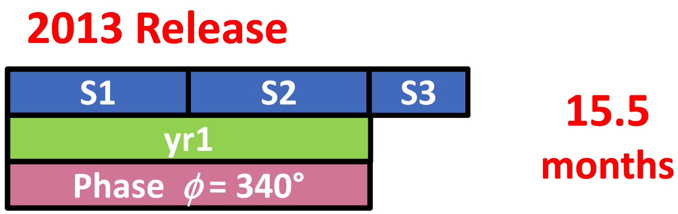
# Planck scanning strategy

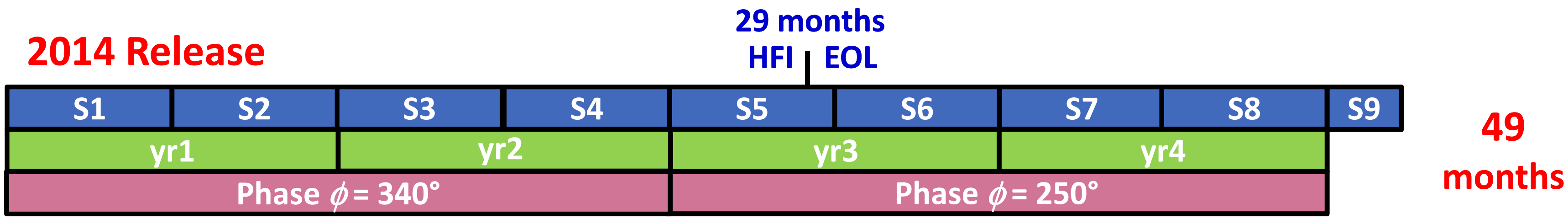



- Noise power spectrum has knee frequency 10-50 mHz
- Spin frequency needs to be comparable or higher
  - → Planck: 1rpm = 16mHz

# Full Mission data release

## "LFI-only" extension: 8 full sky surveys

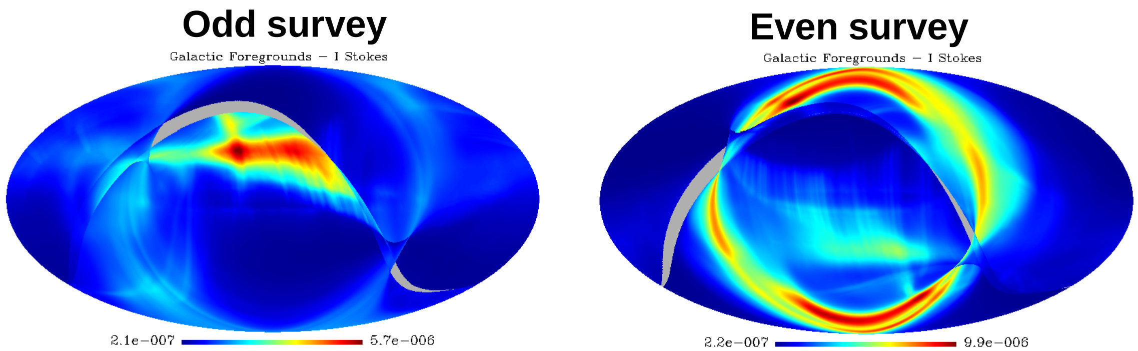



- Multiple full-sky redundancy: powerful tool to test systematics
- Planck scanning strategy: odd and even surveys couple differently with global sky signal (straylight, beam ellipticity)

**Galactic straylight (simulation)**

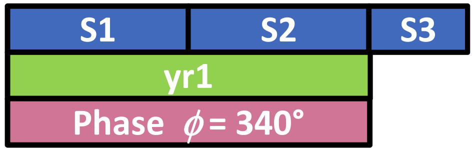
**Full Planck scan cycle is 1 year**



# Full Mission data release

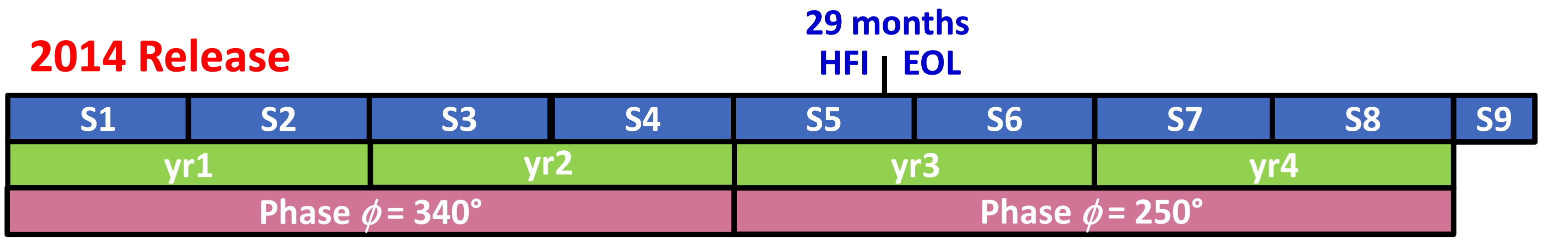
## “LFI-only” extension: 8 full sky surveys

**2013 Release**




**15.5 months**

**2014 Release**




**49 months**

Next release will take advantage of multiple full-sky redundancies
(main motivation for extension)

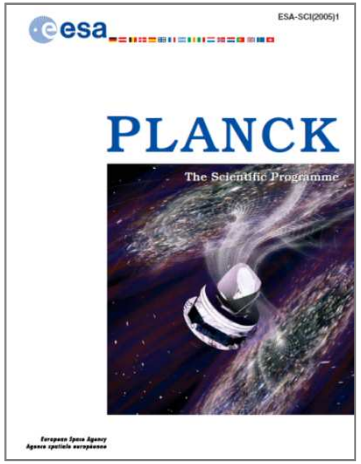
### Planck scanning strategy: time scales

| | |
|---|---|
| • **“Sky cirlce”:** subsequent 1-min scans in the sky | **1 min** |
| • **“Half-ring”:** 1st – 2nd half of data acquired in each pointing period | **45 min** |
| • **“Survey”:** Full sky (Even/odd have different orientations) | **6 months** |
| • **“Year”:** Full scanning period | **1 year** |
| • **“Phase”:** Opposite phase of 7° precession | **2 years** |

# Full mission: LFI and HFI sensitivity

## Noise measured on maps at 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 [$\mu K_{CMB}$ $s^{1/2}$]** | 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 [$\mu K_{CMB}$ ] | 9.2 | 12.7 | 23.9 | 9.6 | 5.4 | 10.7 | 36.5 |
| Measured from maps [$\mu K_{CMB}$ ] | 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 [$\mu K_{CMB}$ ] | 5.2 | 7.1 | 13.2 | 8.2 | 4.8 | 8.8 | 31.6 |
| **Expected [ΔT/T]** | **1.9** | **2.6** | **4.8** | **3.0** | **1.8** | **3.2** | **11.6** |
| **Blue book [ΔT/T]** | **2.0** | **2.7** | **4.7** | **2.5** | **2.2** | **4.8** | **14.7** |

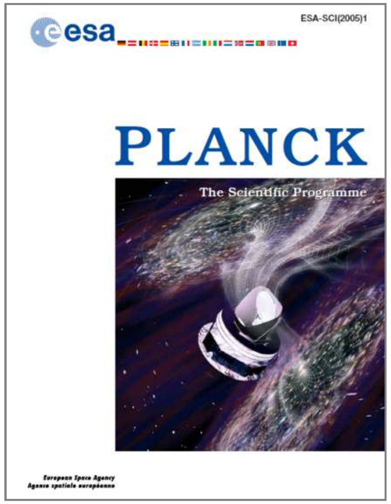



- At end of mission both LFI and HFI fulfill the "Blue Book" sensitivity goals
- 2014 release has capability of reaching all scientific objectives described in Planck Bluebook
- Provided that…

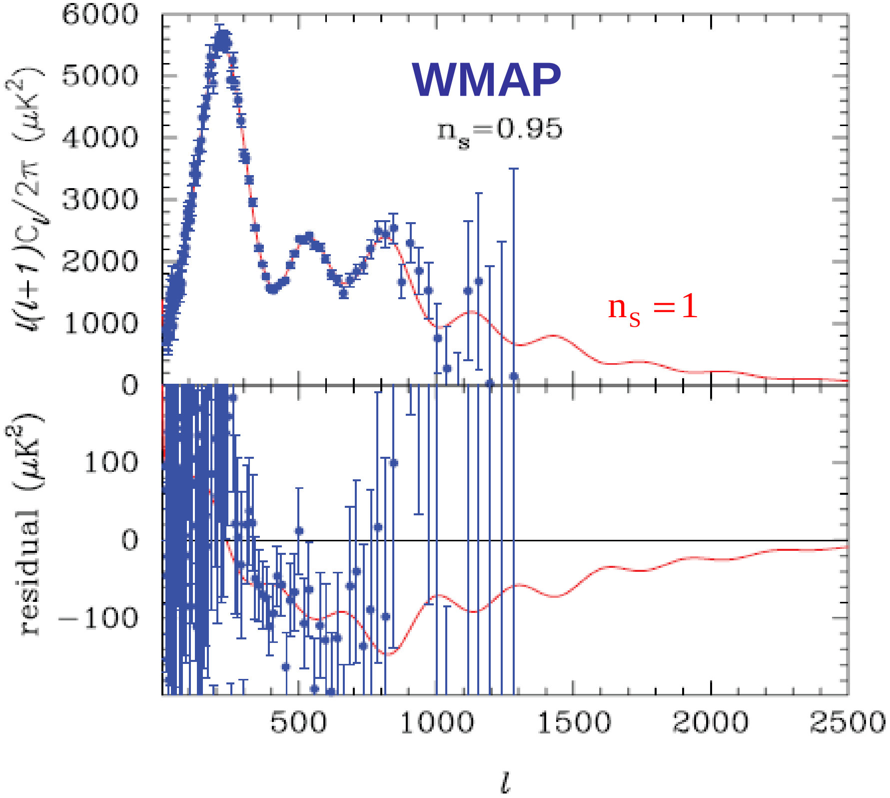
  we properly tackle **systematics** and **foregrounds**

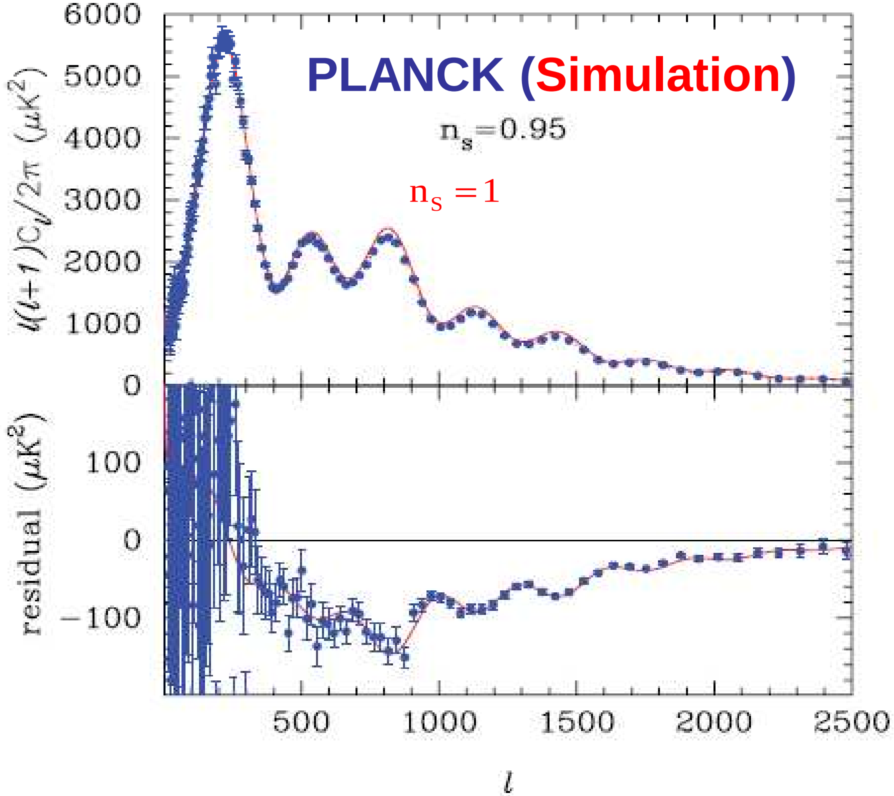
# PLANCK

## Temperature anisotropies

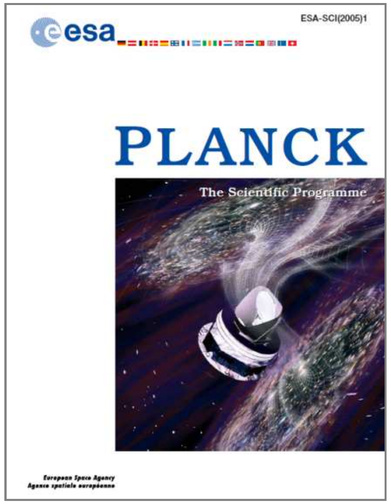



$$C_\ell = \left\langle \left| a_{\ell m} \right|^2 \right\rangle = \frac{1}{2\ell + 1} \sum_{m=-\ell}^{\ell} a_{\ell m}^2$$

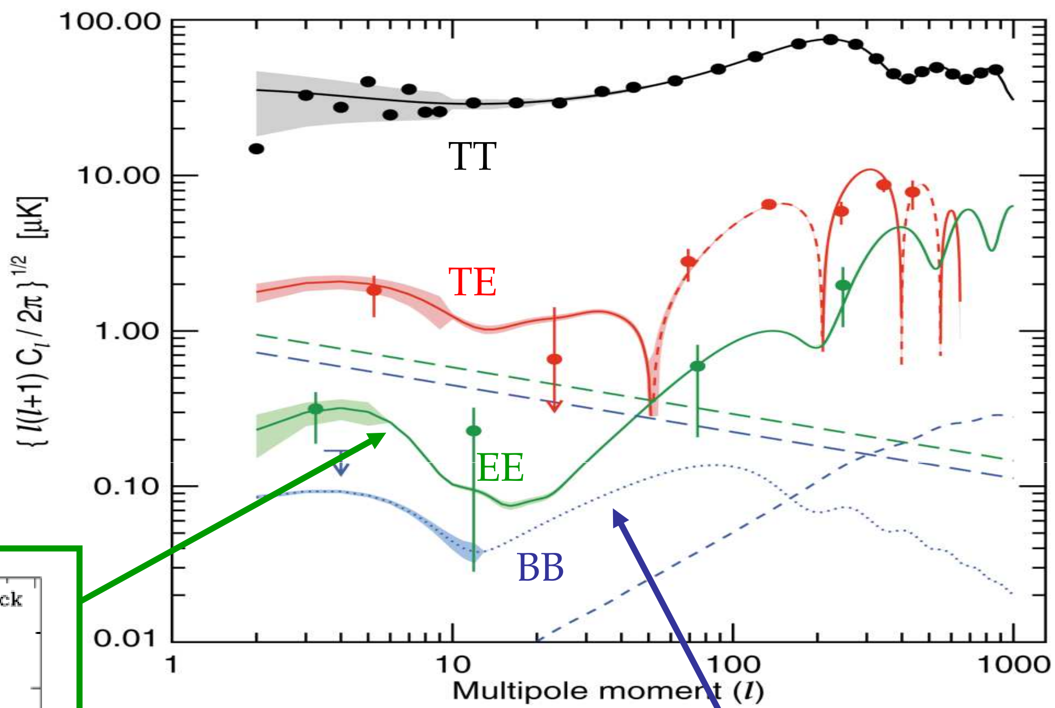


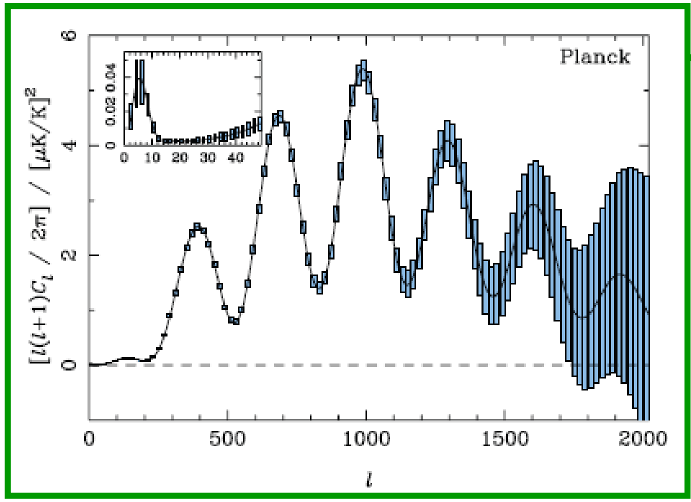
# PLANCK



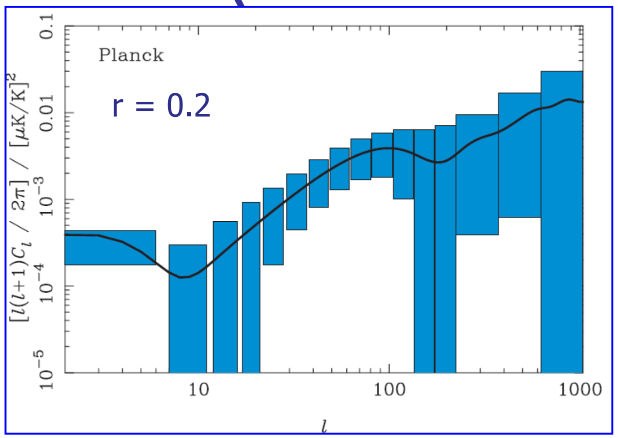

## Polarization anisotropies




"E-mode" from last scattering surface




"B-mode" polarisation from primordial gravitational waves



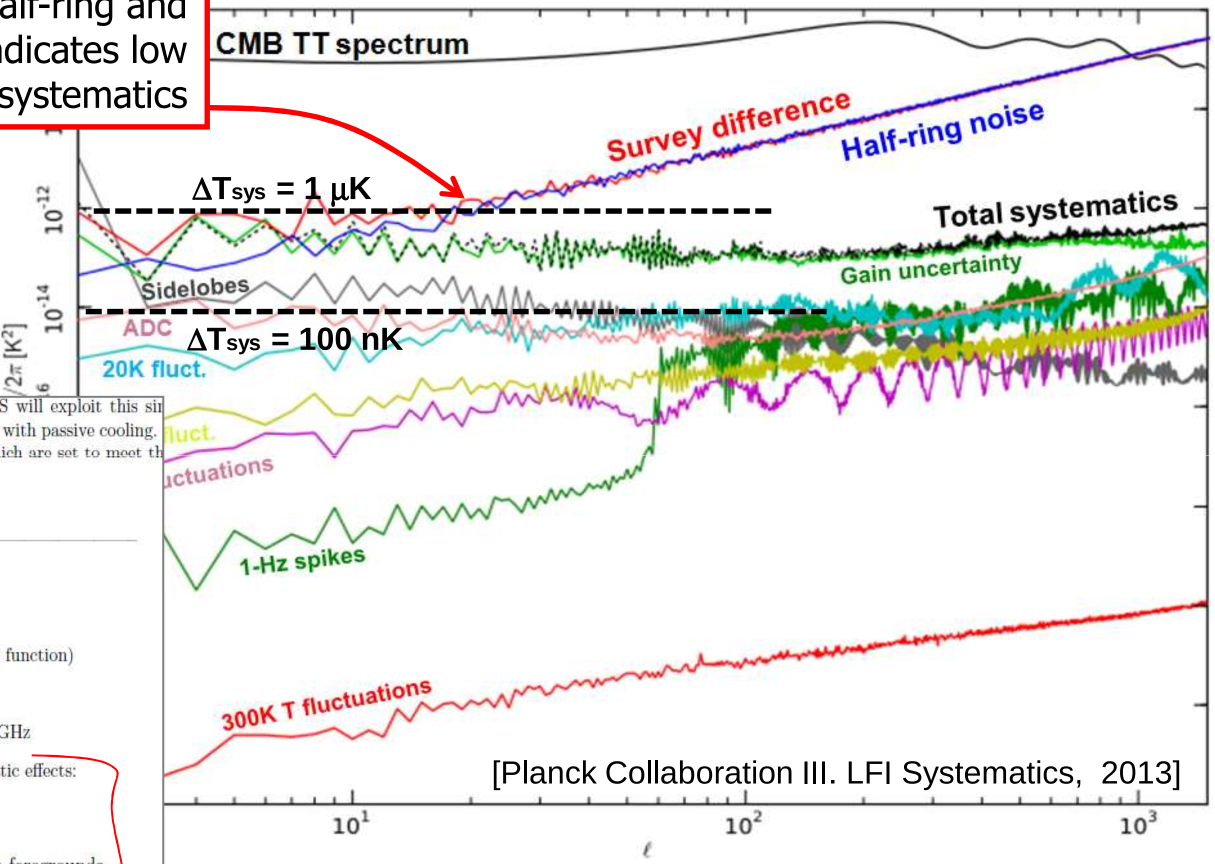
# Main challenge: systematic effects

## LFI Systematics summary (Mennella et al)

"TOP DOWN"

Match between half-ring and S-S differences indicates low residual systematics

**2013**




"BOTTOM UP"

**1993**

mobility transistor) amplifiers. COBRAS will exploit this si
which can achieve the required sensitivity with passive cooling.
COBRAS observational requirements, which are set to meet th

Table 1

- Angular resolution: $\theta \sim 20'$-$30'$
- Sensitivity: $\frac{\Delta T}{T} \sim 10^{-6}$
- Imaging observations (wide window function)
- Large sky coverage (> 40% )
- Spectral range: 30 GHz < $\nu$ < 140 GHz
- High control over potential systematic effects:
  - Off-axis optics
  - Multifrequency observations
  - Minimum, frequency-dependent foregrounds
  - Observation strategy (redundancy, closure)
  - Frequent calibration

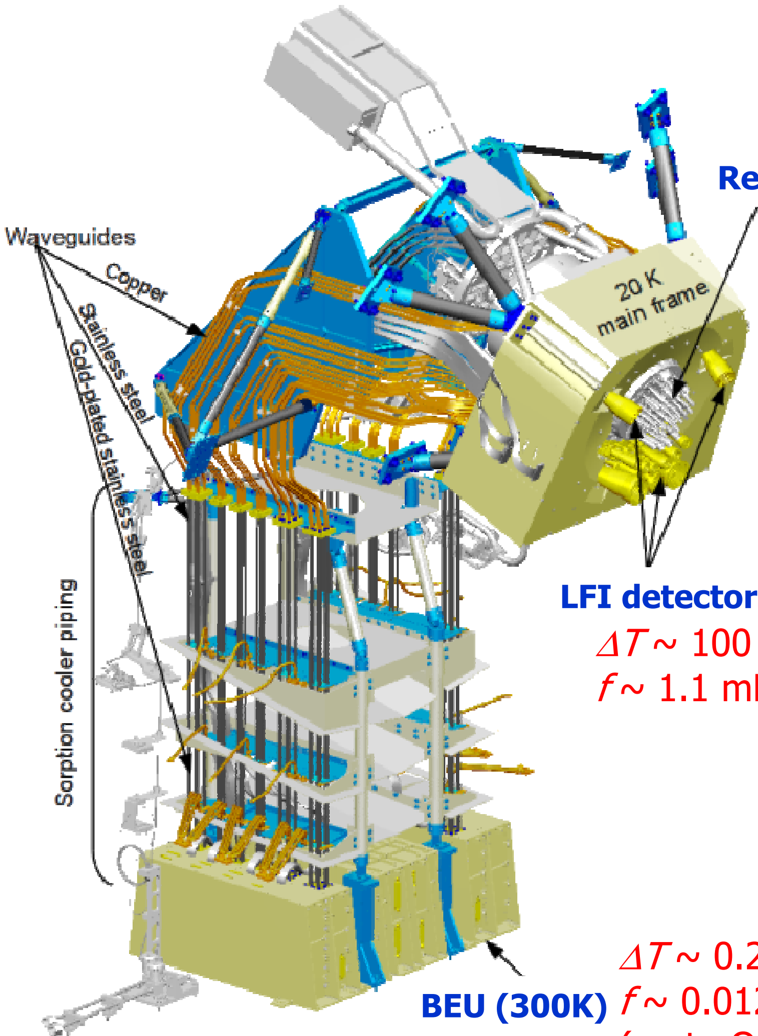
2 The COBRAS payload

In order for the observations to be confusion-limited very accur
instrument is required. The main goal of the payload design is
metric performances while reducing below significance level all

# Systematic effects: Thermal fluctuations

**(Terenzi, Morgante , Tomasi et al)**

Temperature changes are "slow" compared to spin rate: $f_{\mathrm{Thermal}} << f_{\mathrm{Spin}} \simeq 16\ \mathrm{mHz}$




**Ref Loads (4K)**
$\Delta T \sim$ 0.9 mK
$f \sim$ 1.1 mHz (15min)
$f \sim$ 0.2 mHz (90min)

**LFI detectors (20K)**
$\Delta T \sim$ 100 mK
$f \sim$ 1.1 mHz (15min)

**BEU (300K)**
$\Delta T \sim$ 0.2 K
$f \sim$ 0.012 mHz (24h)
(up to OD 258)

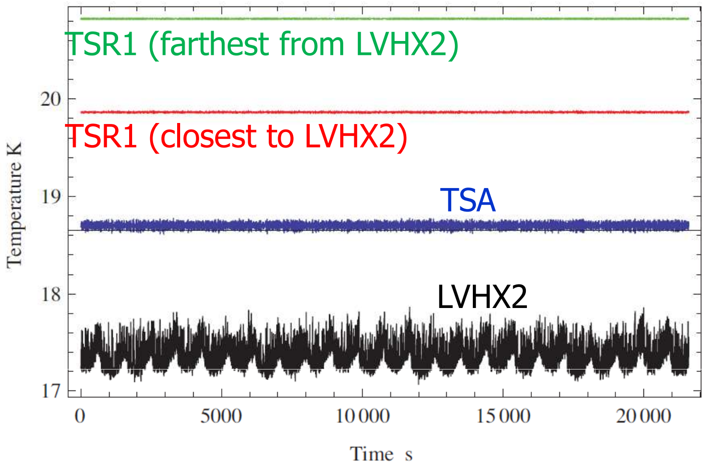
## How can we quantify these effects?

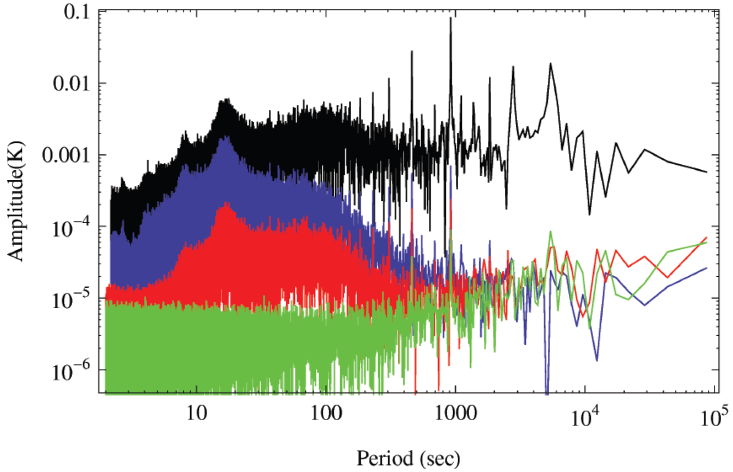
- Representative Temperature Sensors data (4-yr streams )
- Apply thermal transfer functions
- Apply radiometric transfer
- Re-sample and build differenced time ordered data
- Build destriped map
- Compute power spectrum

# Systematic effects: Thermal fluctuations

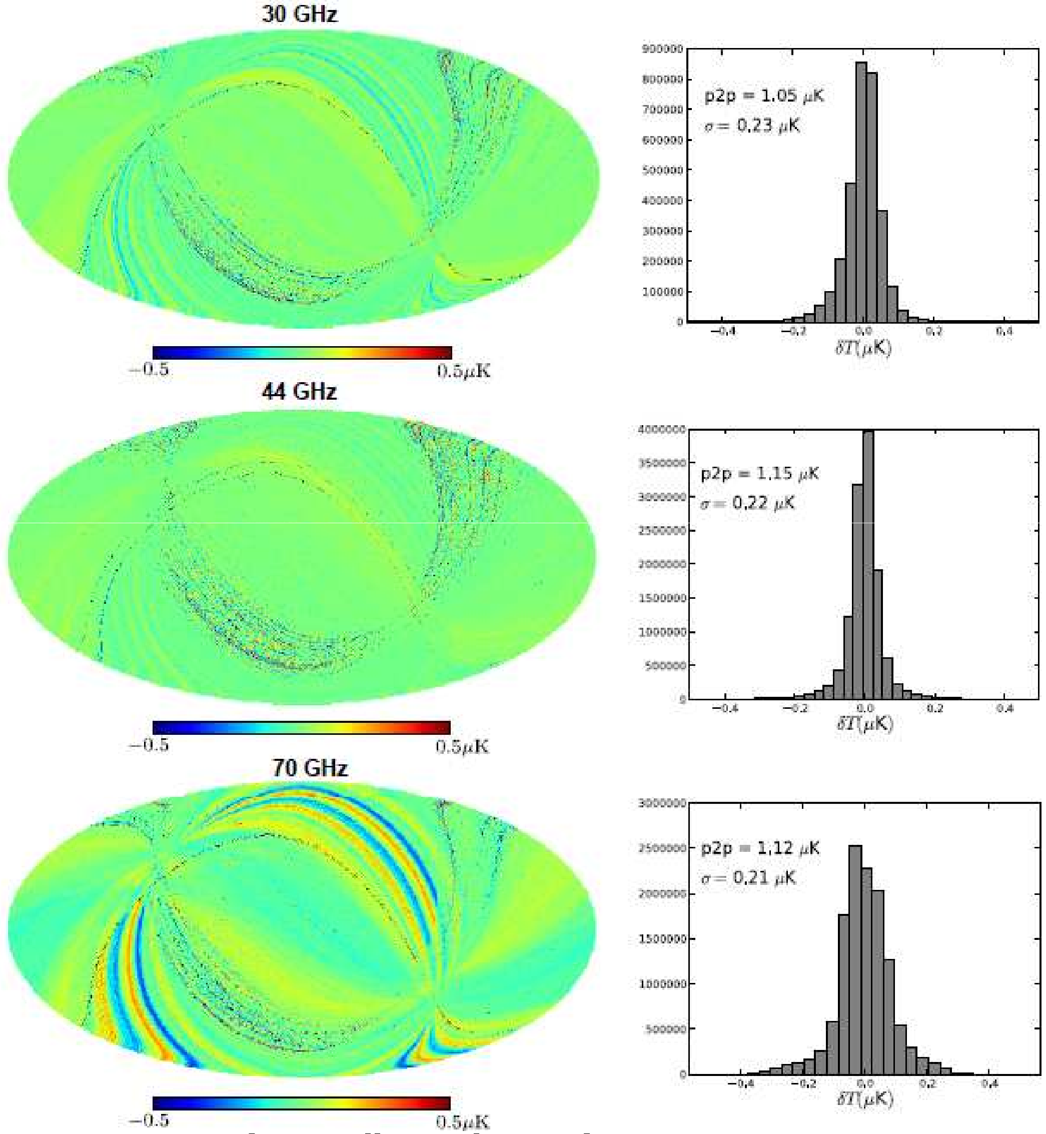
## Front-end fluctuations (20K)

LFI focal plane
Temperature Sensors
(24h, Oct 09)



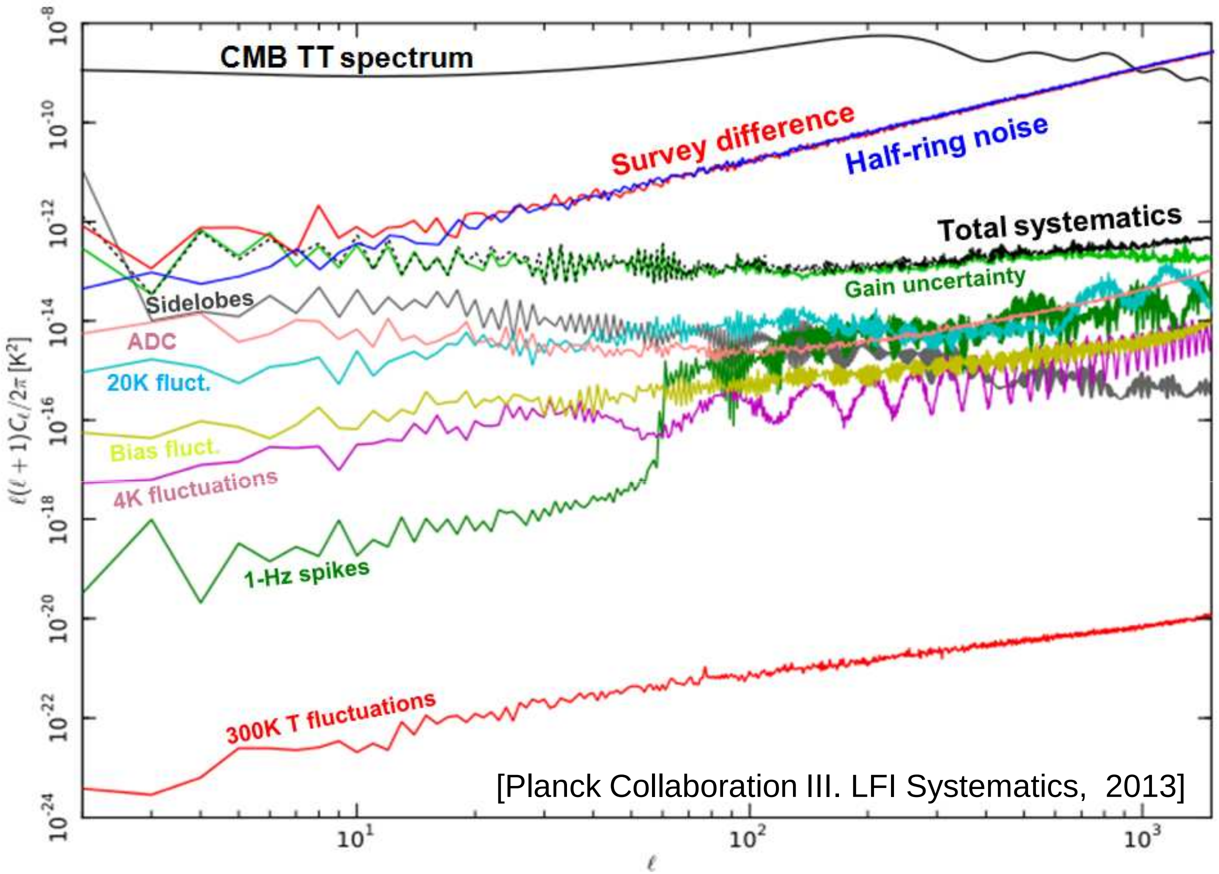

(Planck Collaboration 2011)




(Mennella et al. 2011)

# Main challenge: systematic effects

LFI Systematics summary (Mennella et al)




- Systematics are well under control for TT
- LFI and HFI have different dominant effects

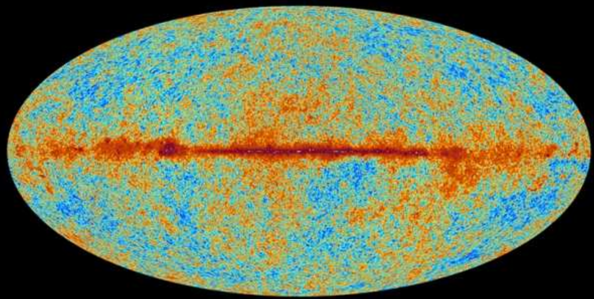
**Challenge: can we reach comparable confidence for polarization?**

# Systematics crosschecks & calibration

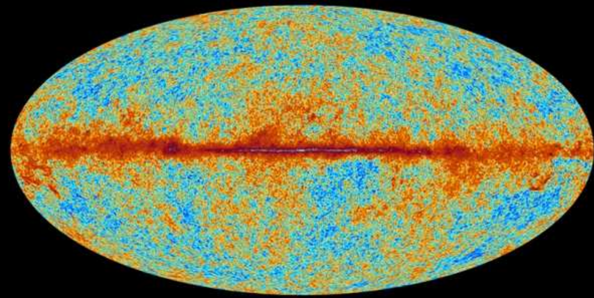
Unique capability of Planck: compare two technologies over large multipole space and at nearby frequencies

**LFI**

**HEMT amplifiers**



70 GHz

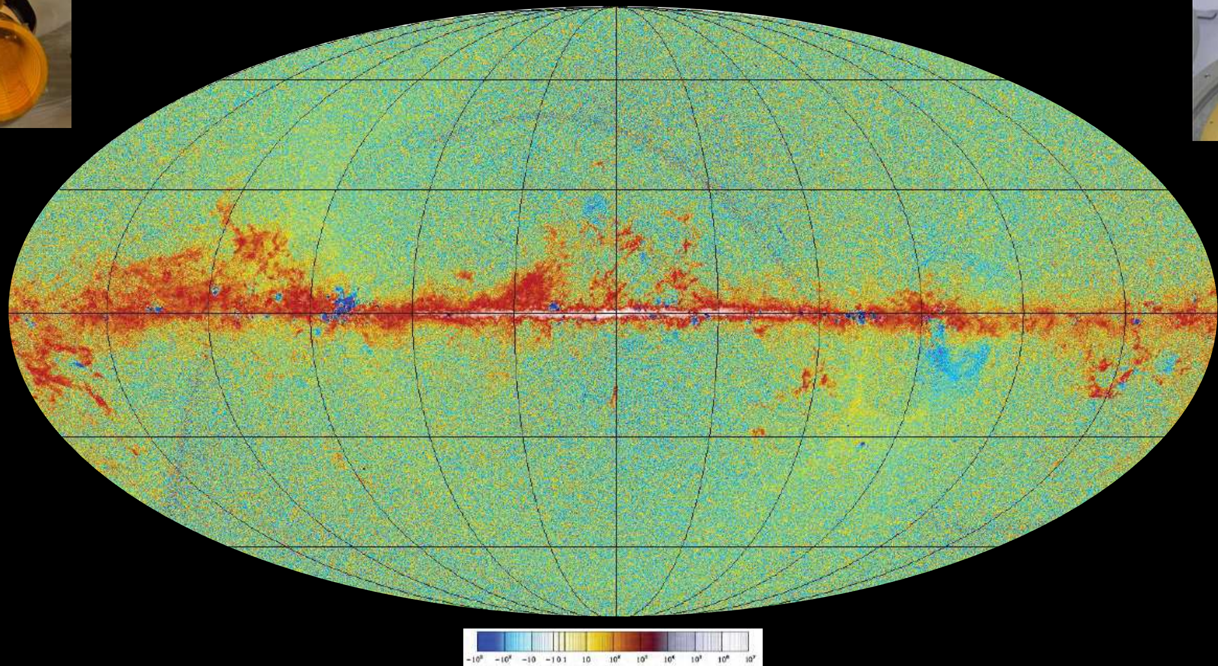


100 GHz

**HFI**

**Bolometers**

**[HFI 100 GHz – LFI 70 GHz]**

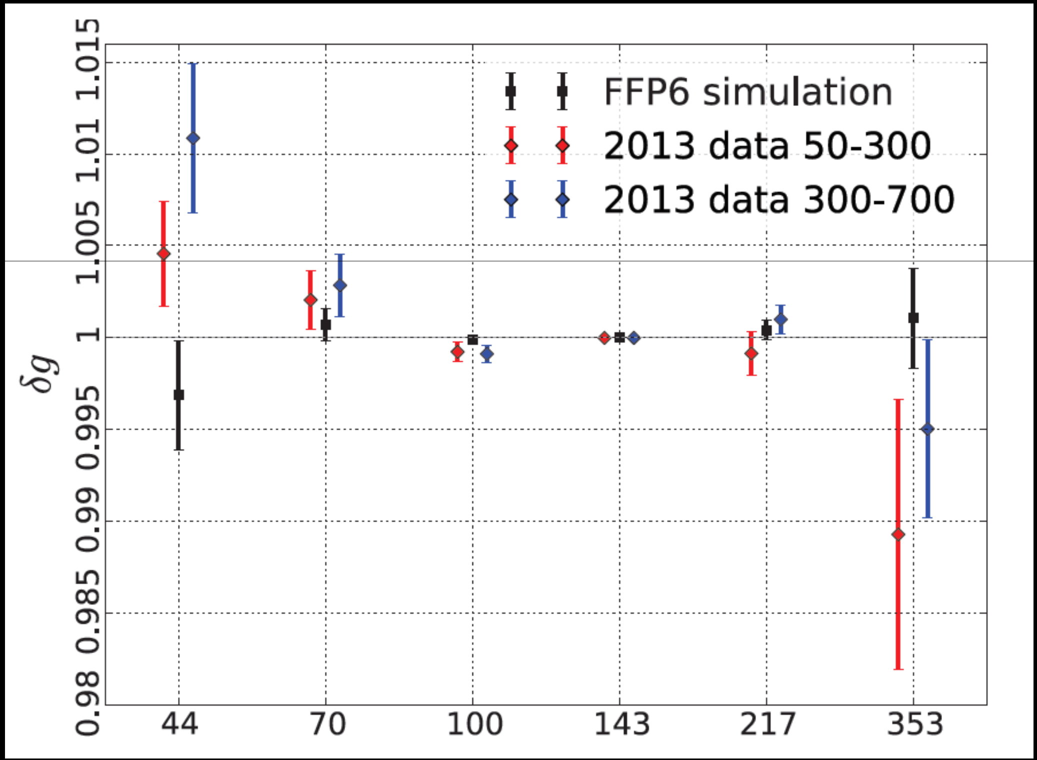


# Systematics crosschecks & calibration

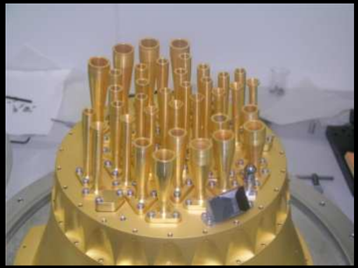
Unique capability of Planck: compare two technologies over large multipole space and at nearby frequencies

## Recalibration factor (wrt 143GHz) maximizing CMB consistency

**LFI**
**HEMT amplifiers**



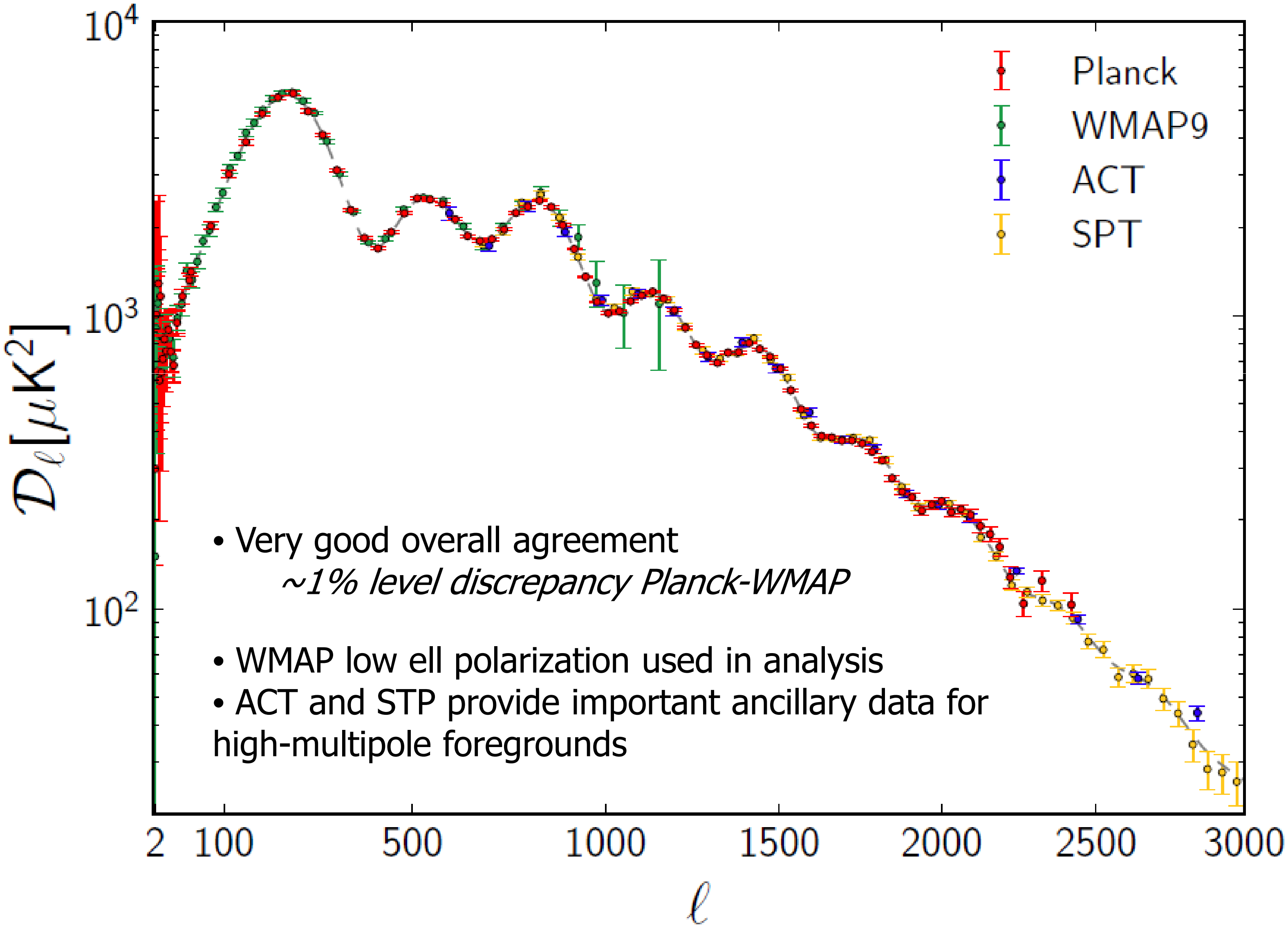

**HFI**
**Bolometers**



Agreement in CMB channels (70-217 GHz) maps <0.3%
Consistent with expectation from simulations

# Planck 2014: Dipole calibration

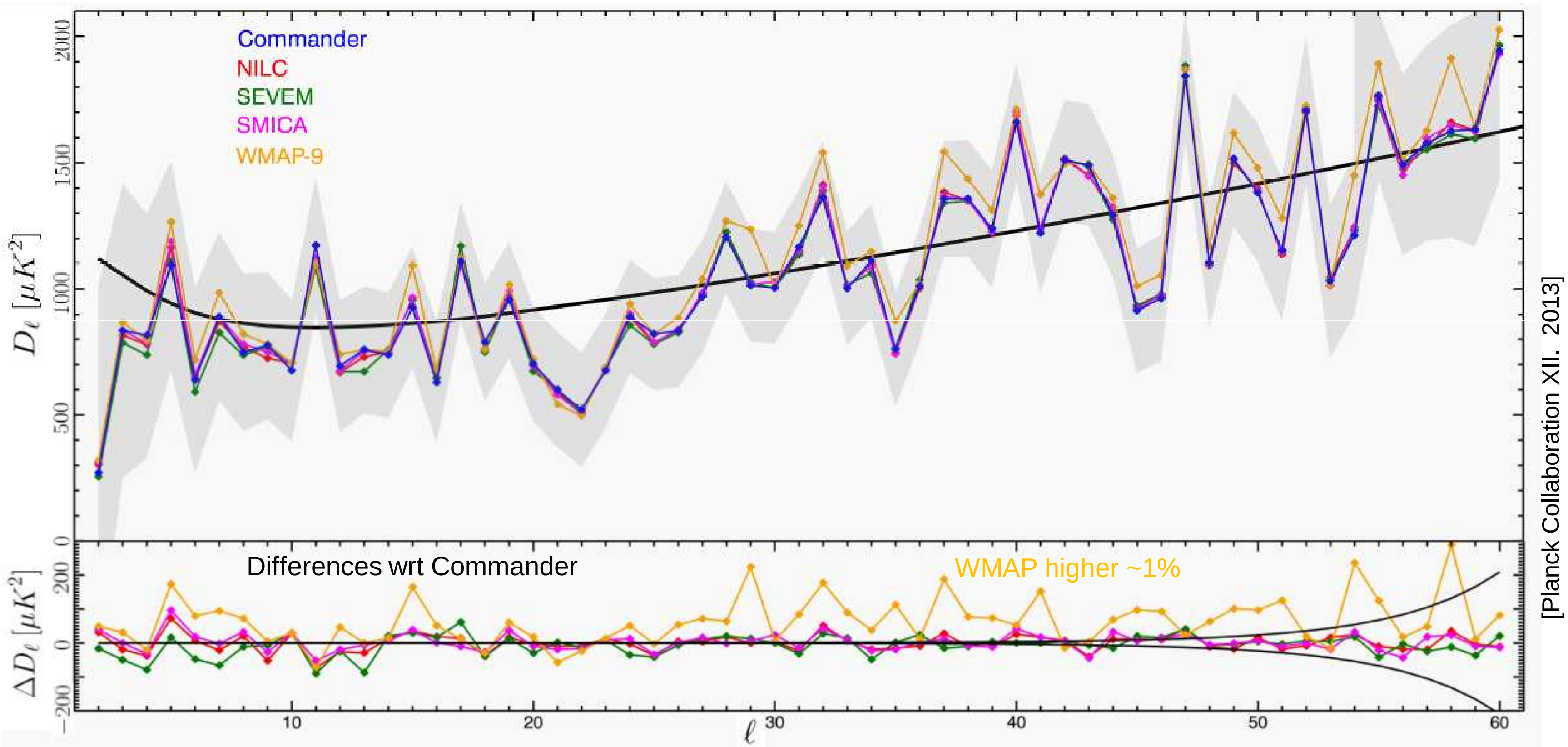
## Planck vs WMAP



# Planck 2014: Dipole calibration

## Planck vs WMAP

Consistency between CompSep methods at low multipoles



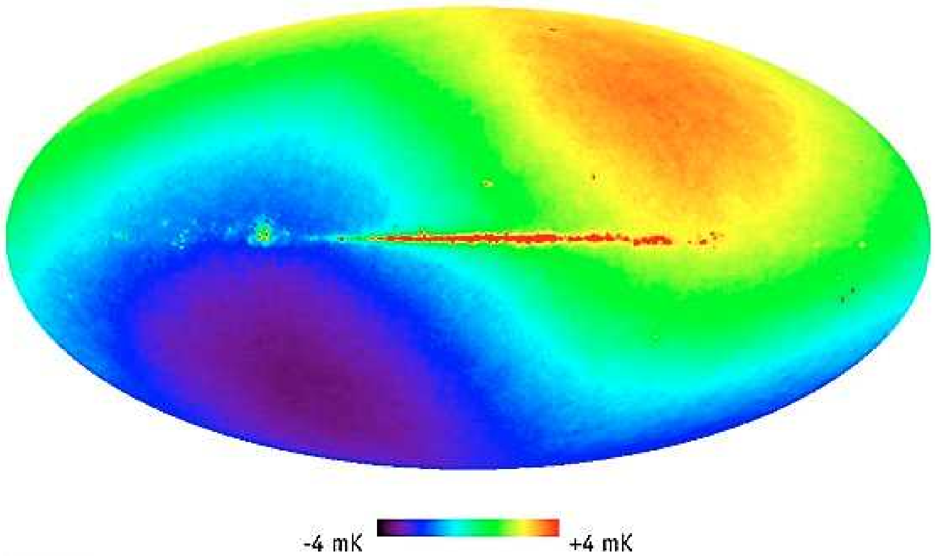
# Planck 2014: Dipole calibration

• The measured dipole is a combination of the "Solar" and "Orbital" components

$$\Delta T_D(\hat{x},t) = T_{CMB}\left(\frac{1}{\gamma(t)[1-\|\hat{\beta}\|\cos\theta(t)]}-1\right)\hat{\beta}\cdot\hat{x}$$

$$\hat{\beta} = \frac{\hat{v}_{\mathrm{Sun}}+\hat{v}_{\mathrm{Satellite}}}{c} \qquad \gamma = (1-\beta^2)^{-1/2}$$

• For 2013 release, all Planck detectors (LFI and HFI) were calibrated using as a reference the Solar Dipole as measured by WMAP

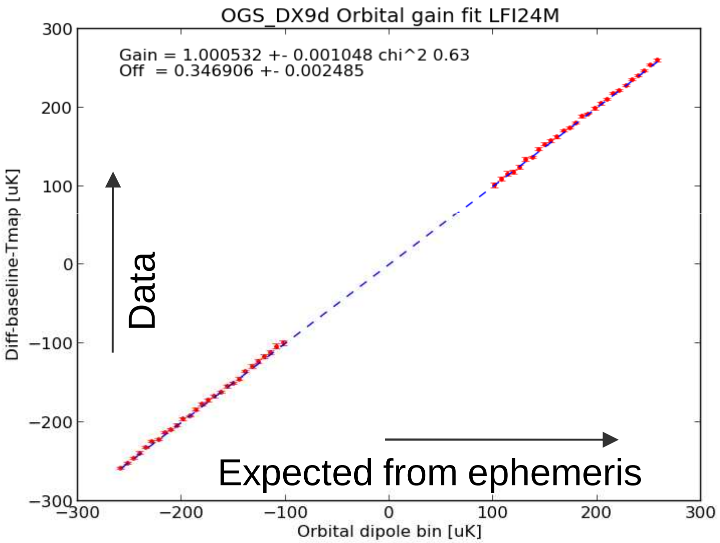


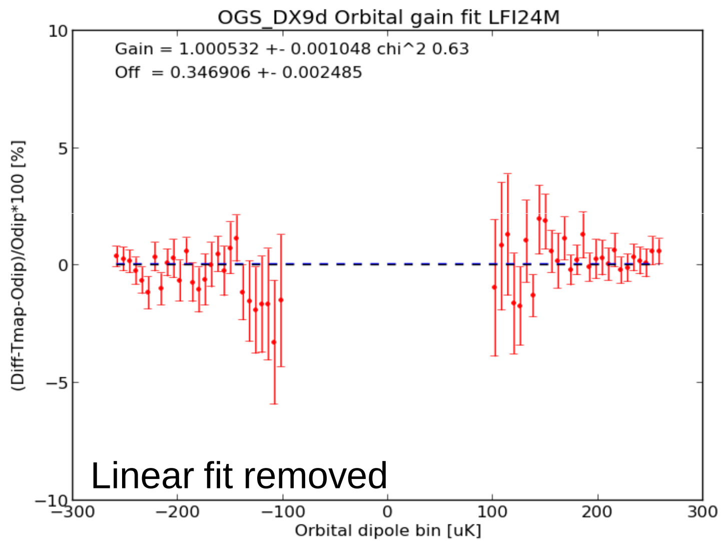
# 2014 Planck release: Dipole calibration

## Planck orbital dipole calibration

**For 2014 release – Planck calibration based on Planck satellite orbital velocity (Earth orbit + S/C orbit speed)**

### Preliminary results from Planck 44 GHz channel



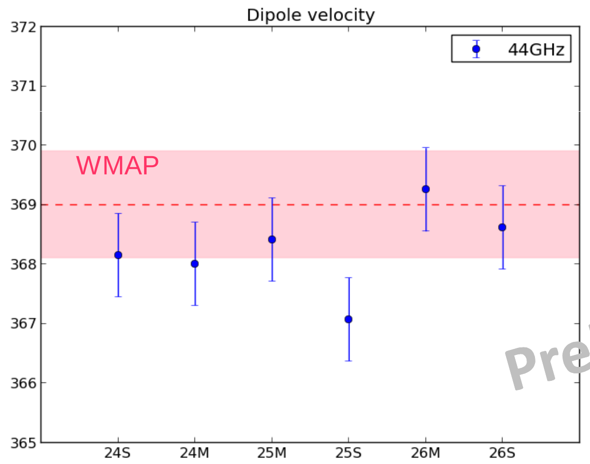

- Data visiting same spot 6 months apart with opposite velocity is used to separate orbital velocity effect from intrinsic sky signal
- Galaxy and other foregrounds need to be masked/removed
- Relative calibration scheme based on solar dipole or house-keeping data

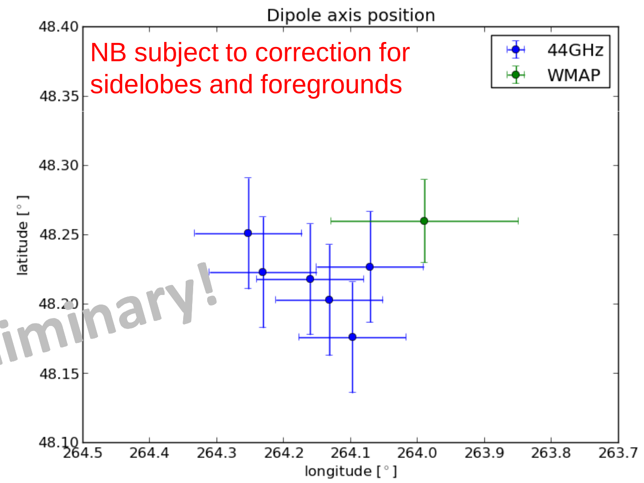
# 2014 Planck release: Dipole calibration

## Planck orbital dipole calibration

**Limitations:**
Relative gain variations ~0.2% (extra noise component)
Far-sidelobes ~0.2% (biases 6 month differences)
Foreground contamination

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




- Good agreement with WMAP
- With improved relative calibration and far-sidelobe correction, simulations suggest we should achieve 0.1% absolute calibration

→ **Unprecedented accuracy on absolute dipole measurement**

# Next Planck release: Polarization

Polarization data analysis is more complex than for temperature data:

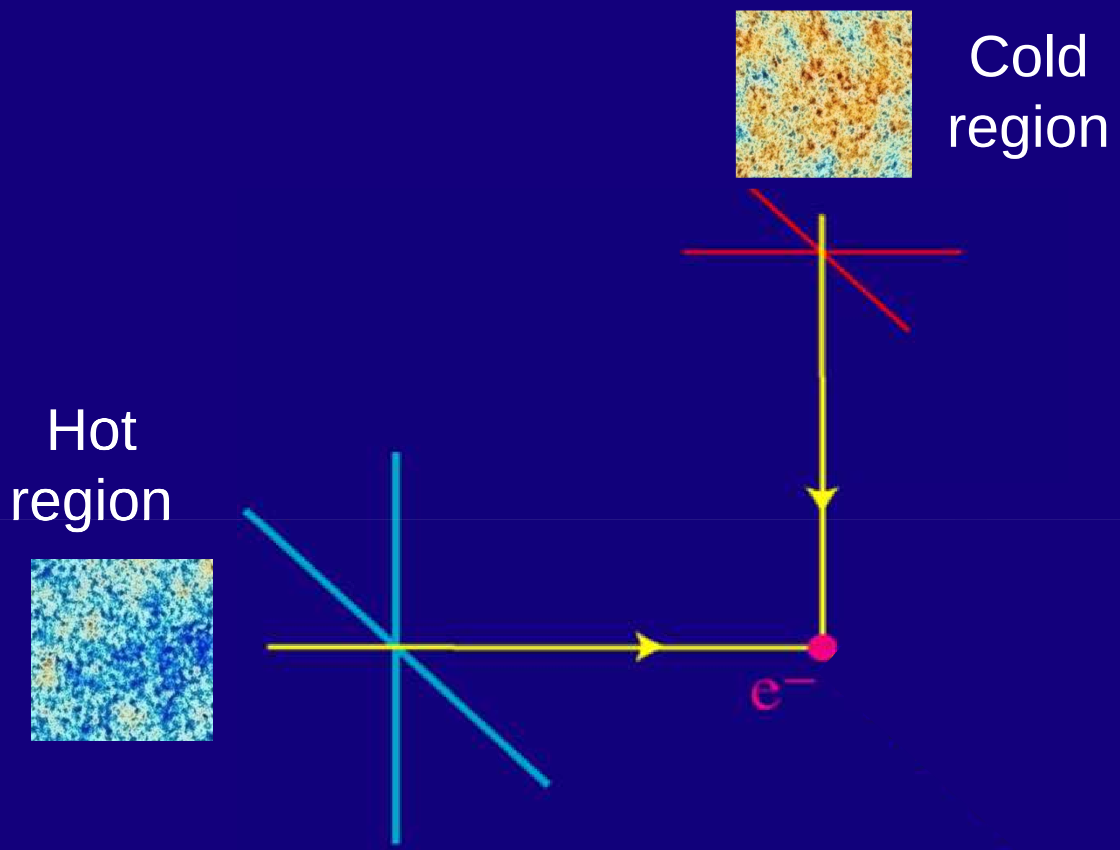
- No “good” celestial polarized calibrator (Crab)

- Amplitude of CMB signal is low (E-mode: few μK, B-mode: <0.1μK)

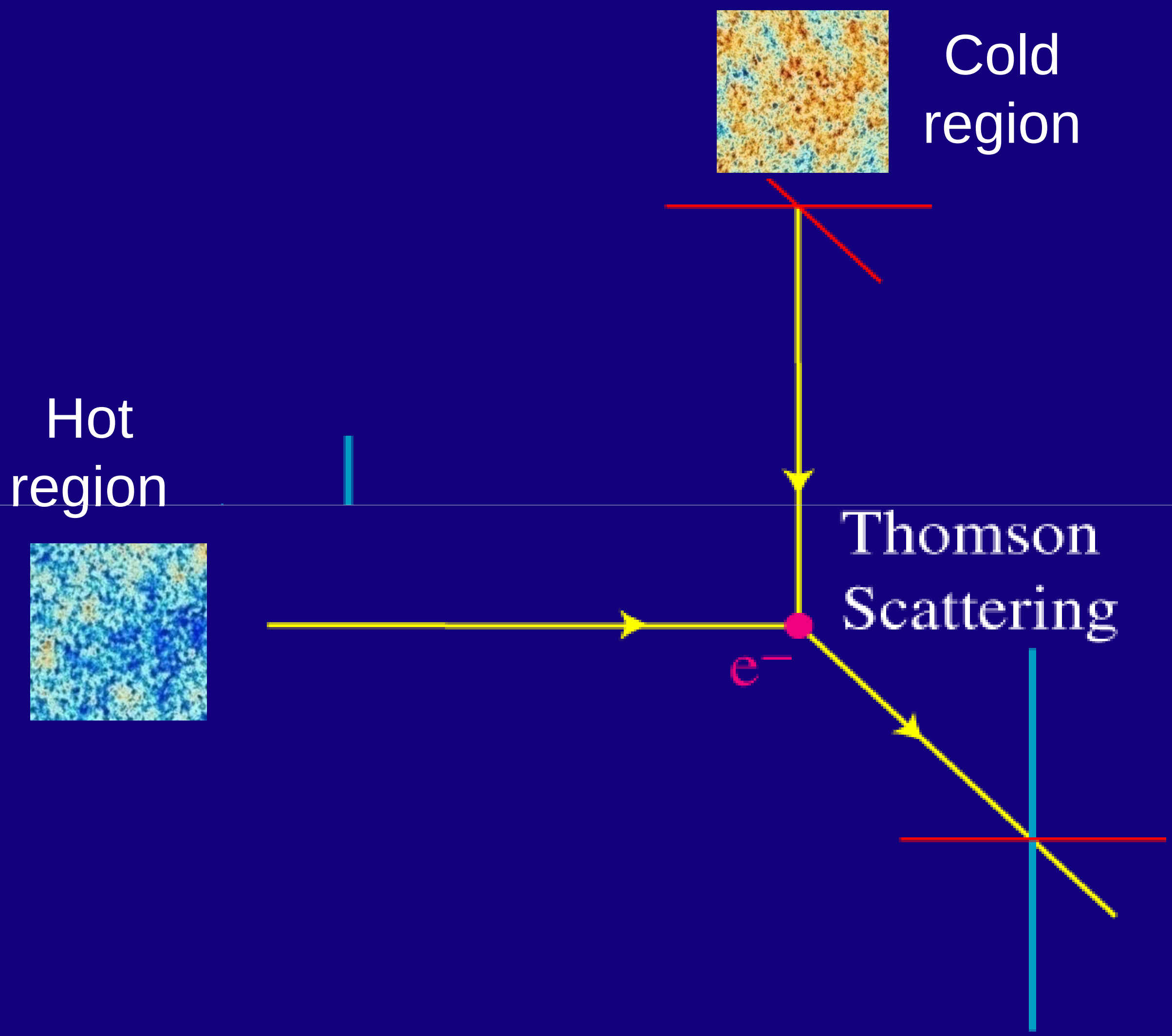
- Astrophysical foregrounds dominate over the most of the sky

- Specific systematic effects

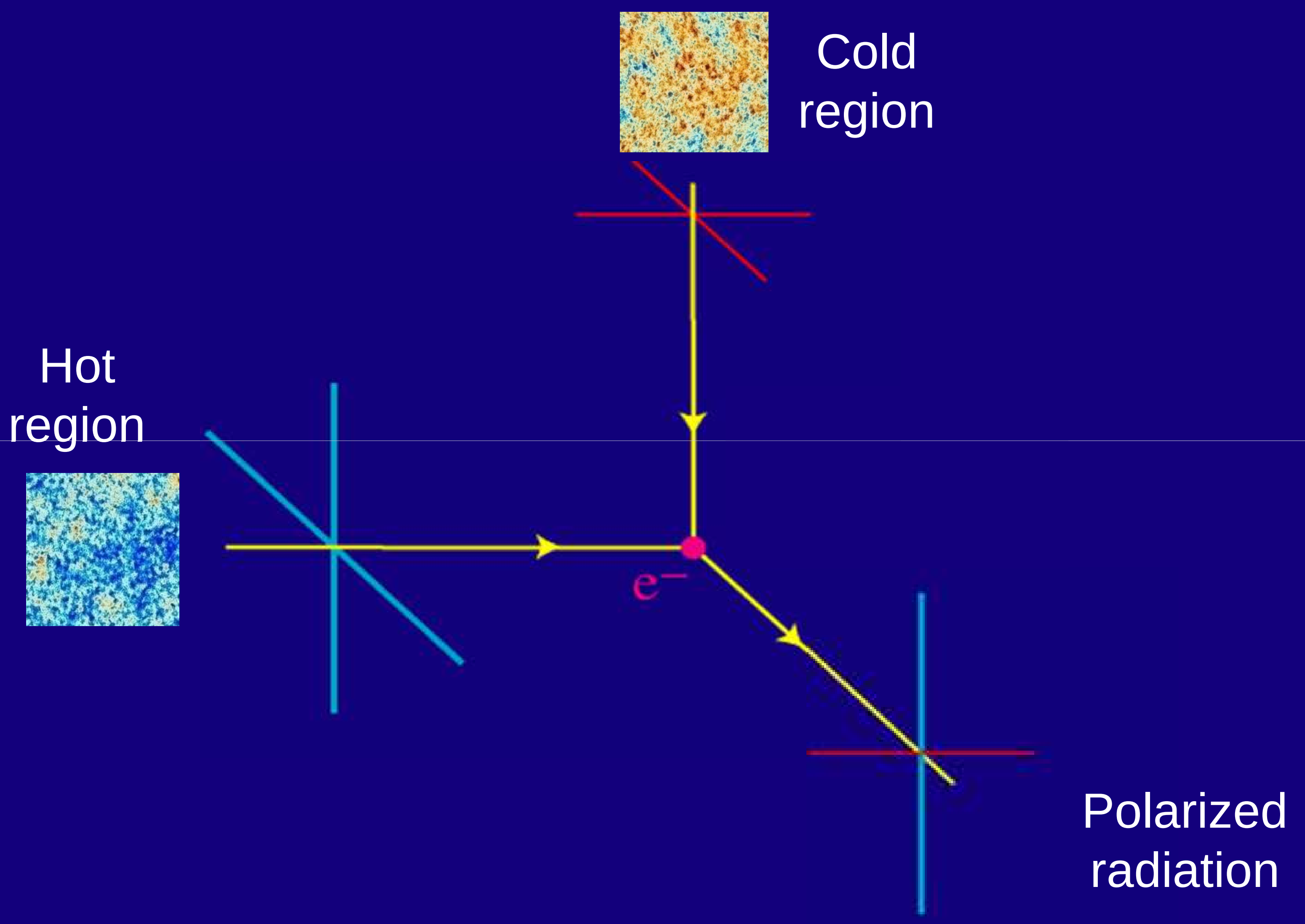
# Next Planck release: Polarization



# Next Planck release: Polarization



# Next Planck release: Polarization

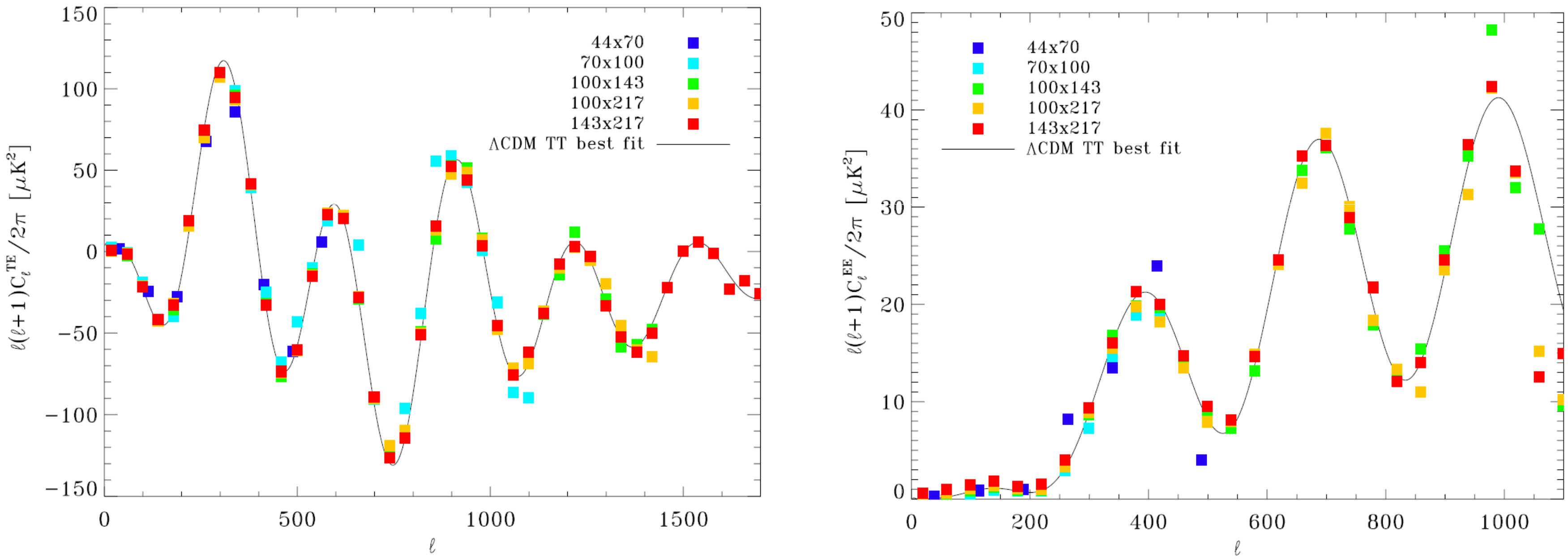


# Planck CMB polarization

- **Scientific analysis on polarisation on-going**
- **Both HFI and LFI in rapid progress**

**Preliminary Planck polarization already show spectacular performance**

TE Correlation, EE power spectrum (preliminary)



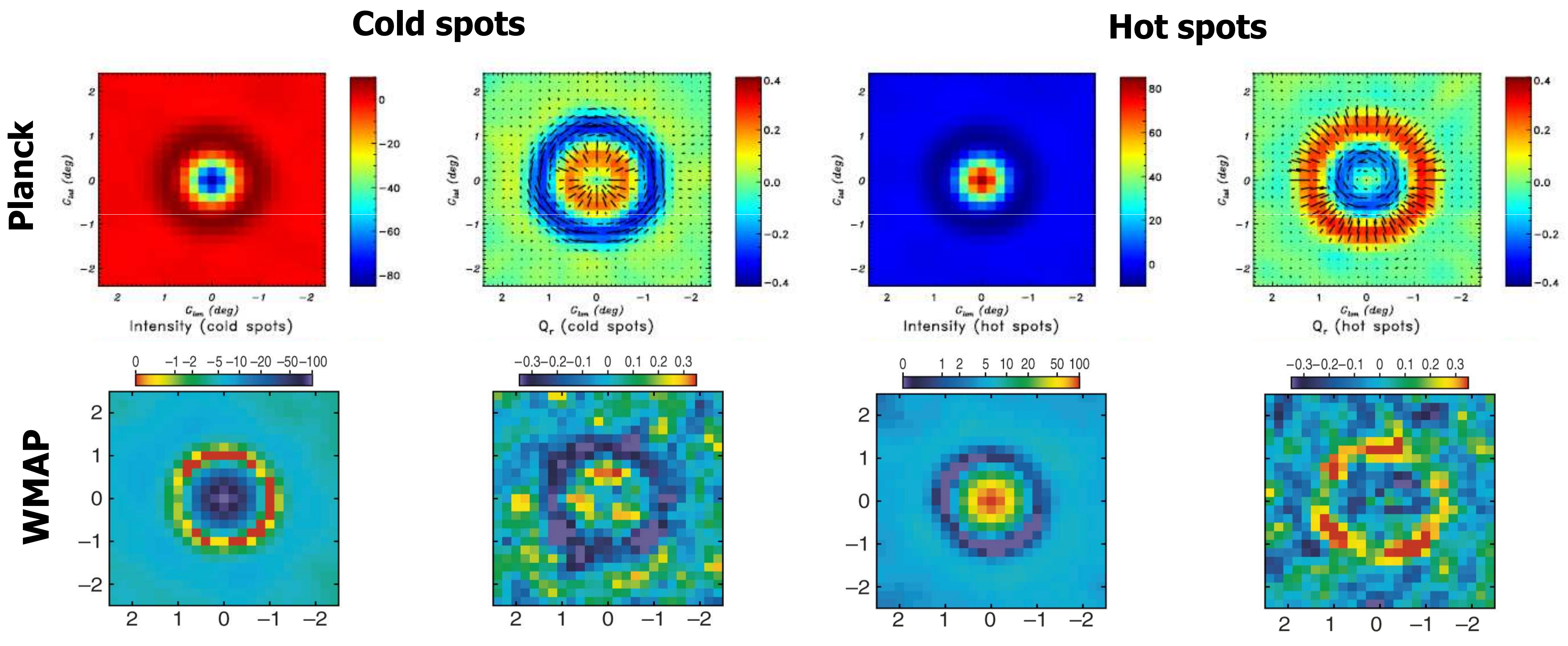

- High ell polarization TE and EE (preliminary!) spectra demonstrate the excellent quality of the data (note: solid line is best fit of TT 6-parameters model!)
- Foregrounds and systematics are not dominant at high multipoles

# Planck CMB polarization

- **Scientific analysis on polarisation on-going**
- **Both HFI and LFI in rapid progress**

**Preliminary Planck polarization already show spectacular performance**

Stacked maps for I and polarization $Q_r$ (30′ resolution)



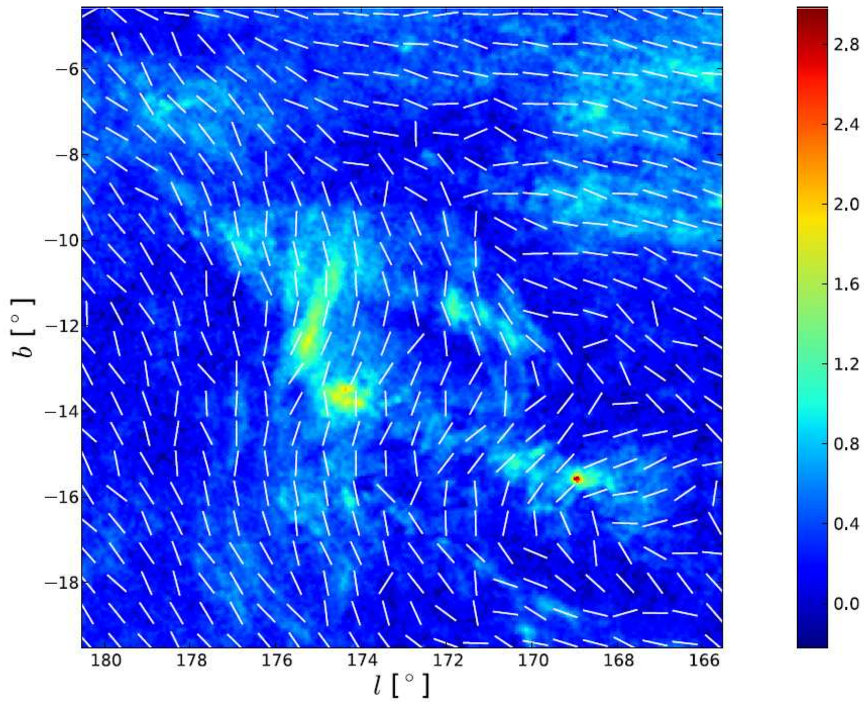
# E/B-mode challenges

- **Very low multipoles (ell < 20): "reionization bump"**
  - Measurement of optical depth Tau (E modes)
  - search for B-modes at very large scales

- **Intermediate ell (70 < ell < 100): "recombination bump"**
  - Verify polarized foregrouds impact on Bicep2 field
  - Independent measurement or upper limits of r

- **Chellenges:**
  - Systematic effects
  - Foregrounds

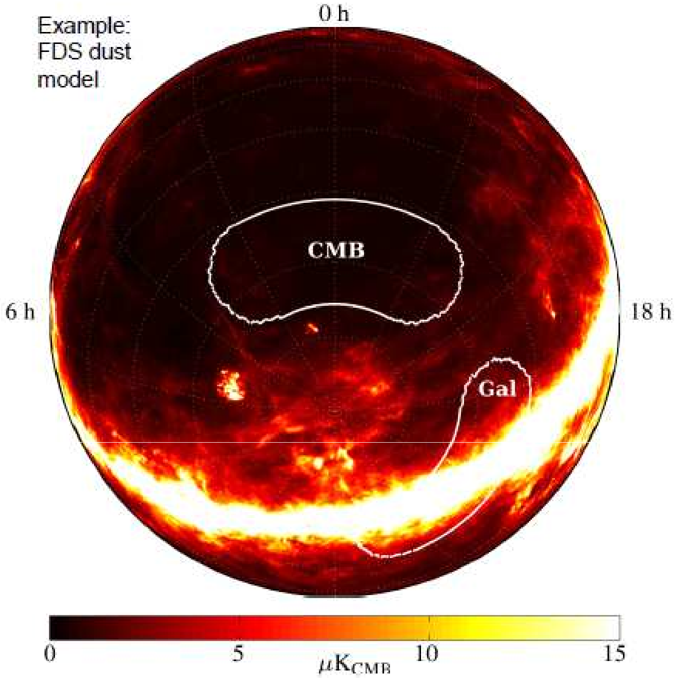
Planck polarisation at 353 GHz (Taurus region)

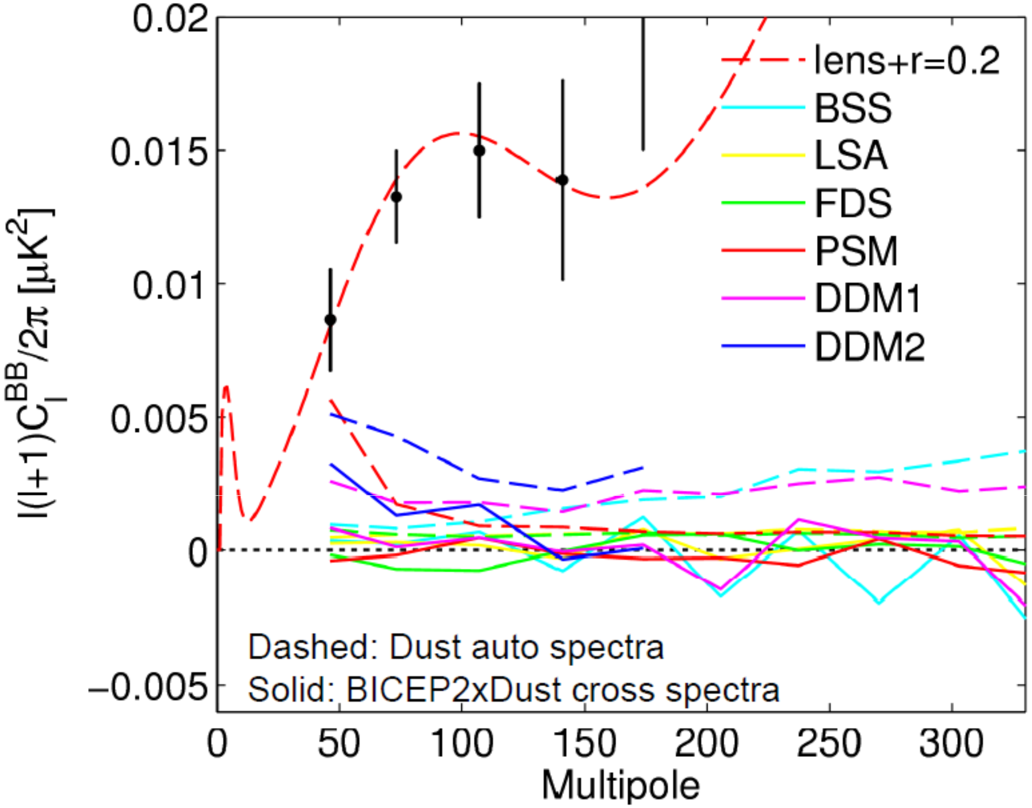



Polarised intensity at 353 GHz (in mK_CMB) and polarization orientation indicated as segments of uniform length,

# E/B-mode challenges

## B-modes and Bicep2 verification




- No foregrounds subtraction
- Single frequency, 150 GHz: near foraground minimum
- Very "clean" region
- Planck will verify poarised synchrotron and dust in Bicep2 region (30GHz, 353GHz, spectal index measurements)

# LFI systematic effects

Effects considered in 2013 analysis
(Will be extended to full 8-survey mission)

*New approach required for 2014 (polarization) analysis*

- Sidelobes effects → *Residual uncertainty after removal*
- Gain uncertainty → *Include uncertainty in relative calibration*
- Thermal effects
  - 4K Reference loads
  - Focal plane unit (20K)
  - Back end (300K)
- Bias fluctuations
- 1 Hz spykes

Effects to be included in 2014 analysis (not considered in 2013)

- Straylight from intermediate sidelobes
- Optics and OMT cross-polarization
- Uncertainty in polarisation angle
- Residual uncertainty after bandpass mismatch correction

---

**For each effect:**

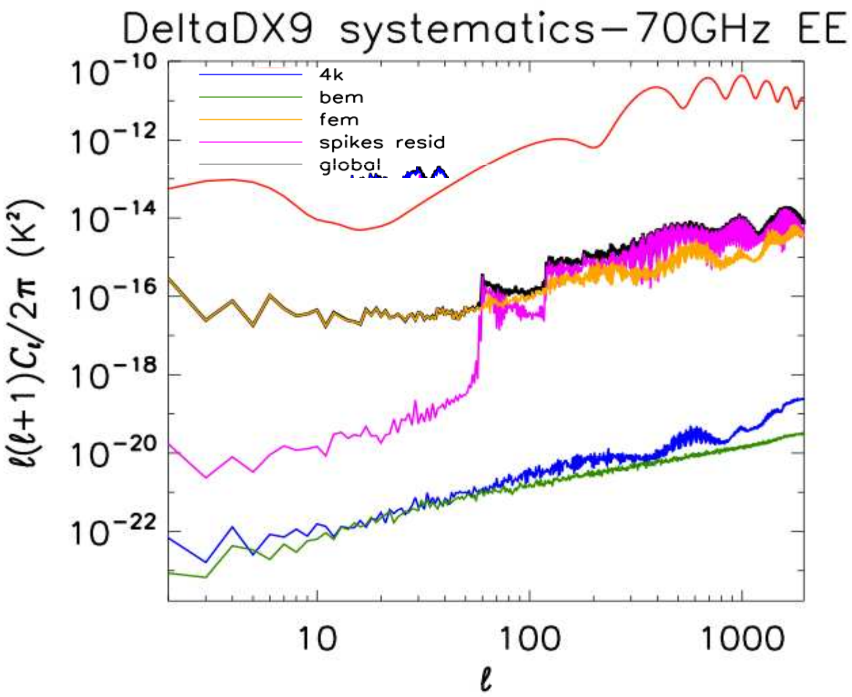
Basic codes/algorithms are (mostly) ready; Team & leader identified.
(Overall coordination: A. Mennella)

# Polarization systematics: LFI

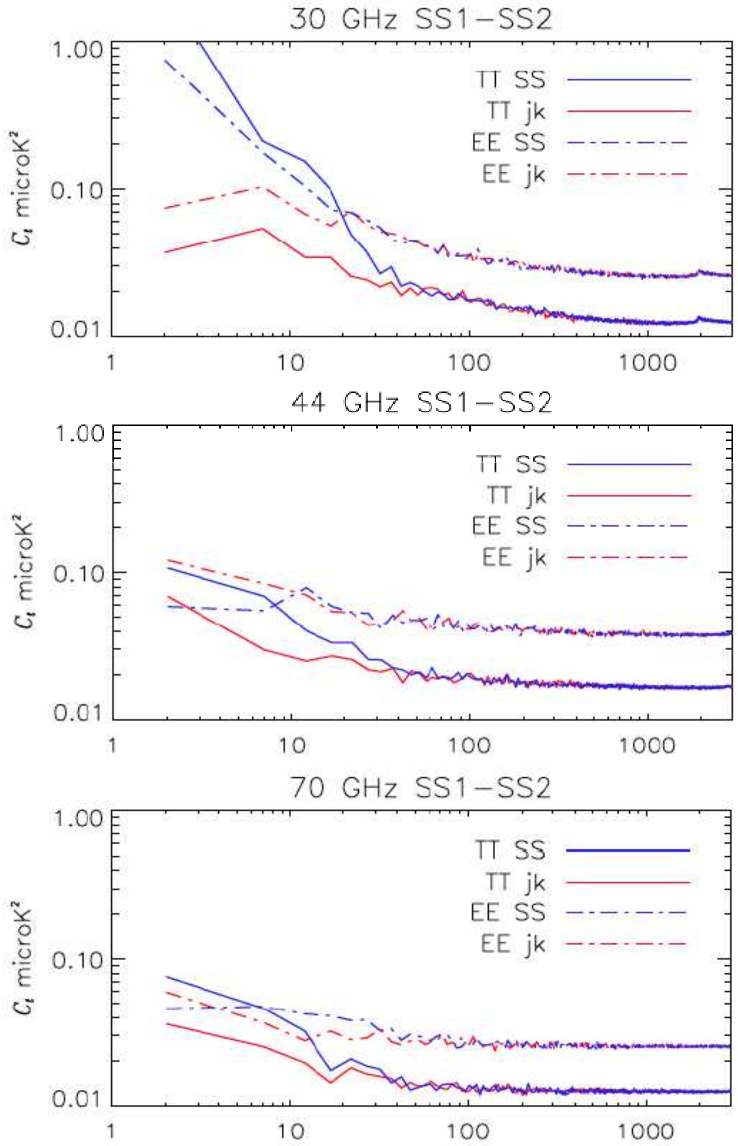
**From ESLAB Conference (Aapril 2013)**

**Much progress in LFI and JFI low-ell pol in past few months**

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




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



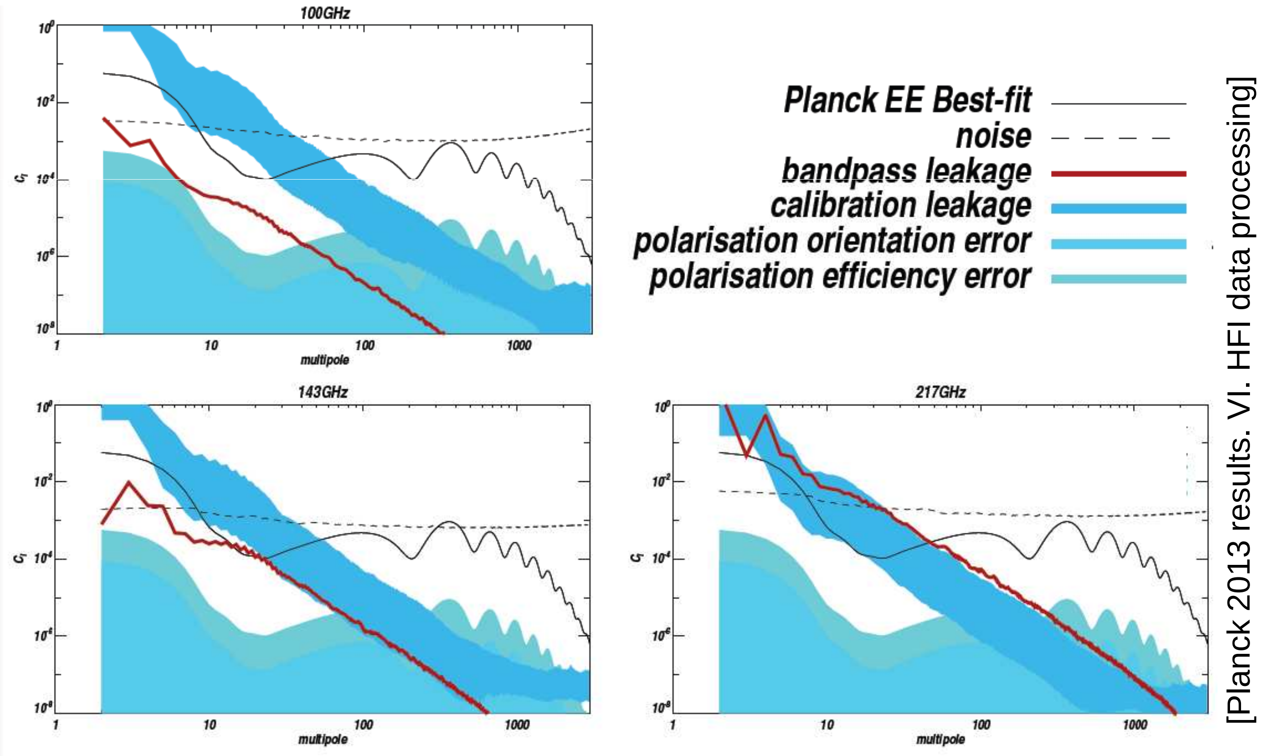
# Polarization systematics: HFI

**From ESLAB Conference (Aapril 2013)**

**Much progress in LFI and JFI low-ell pol in past few months**

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

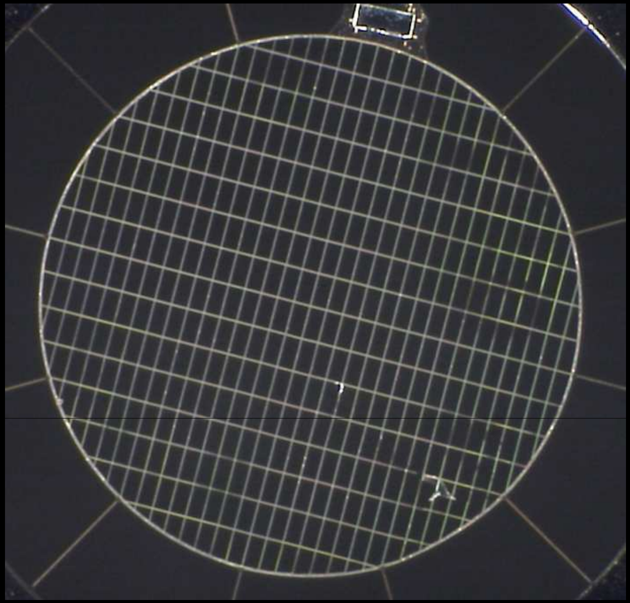
→ Quantitative assessment on-going

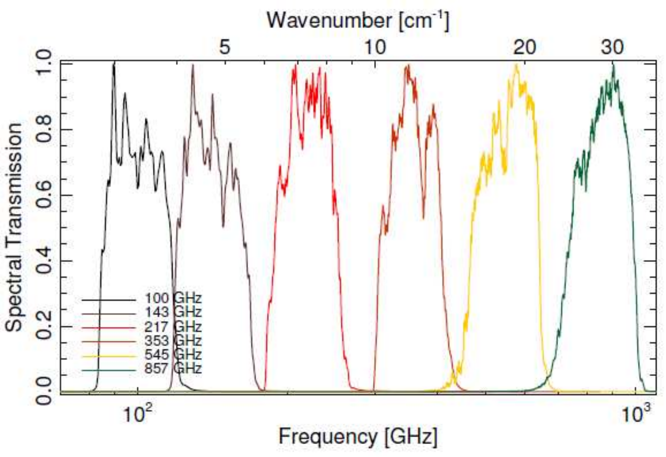



*Estimation based on dedicated MC simulations at ring level*

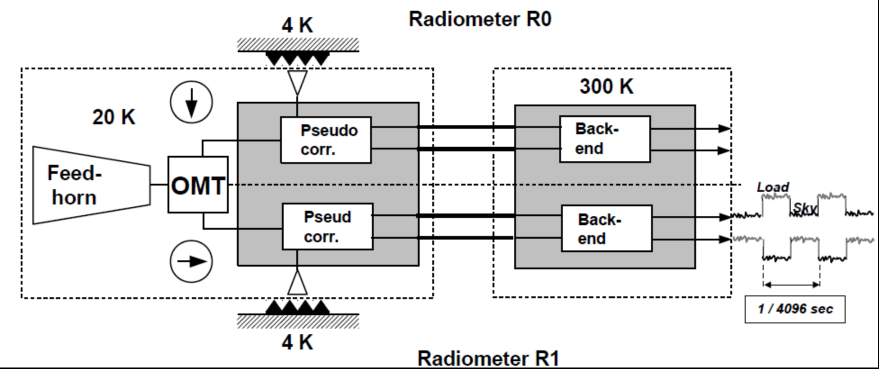
# Polarization specific effects: Bandpass mismatch

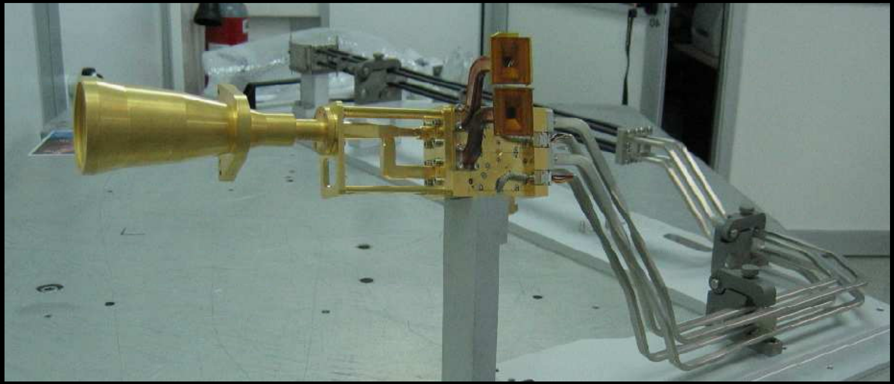
Polarization Sensitive Bolometer






Radiometer Chain Assembly (OMT)

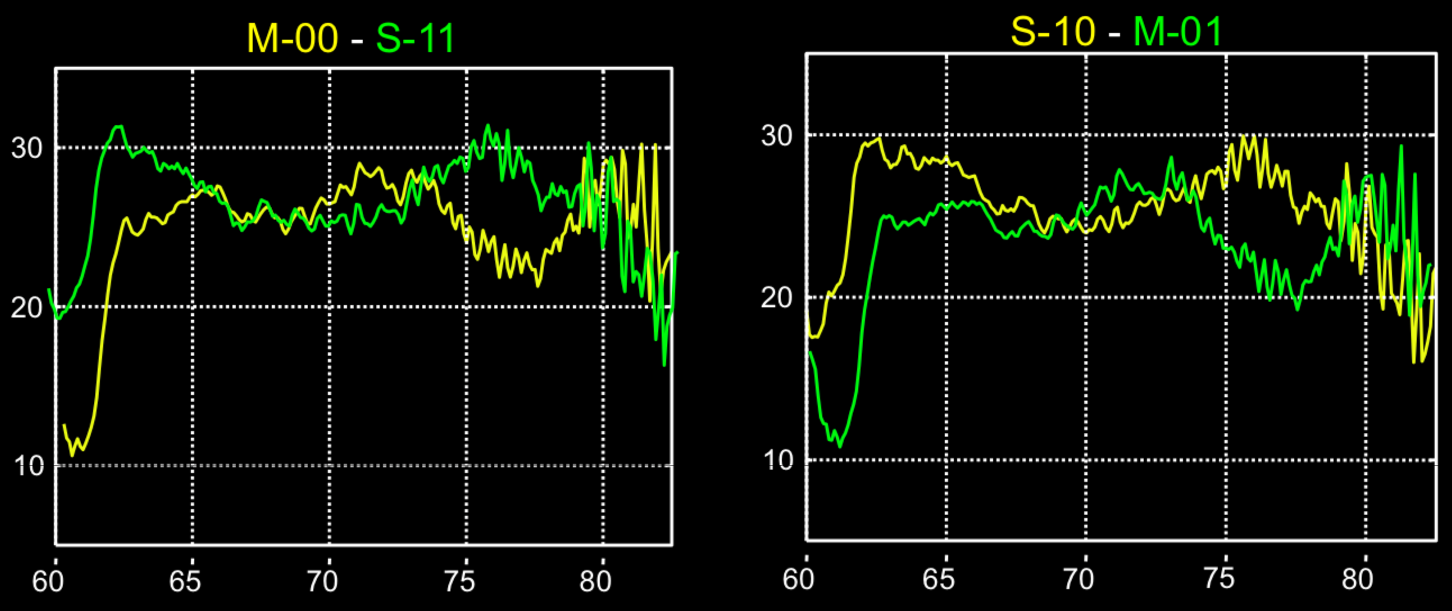


Mismatch between bandpasses in the two orthogonal polarizations produce leakage of I in Q and U

# Polarization specific effects: Bandpass mismatch

Frequency response is asymmetric on the two OMT arms




Effect expected on polarisation measurements that depend on the difference between the two OMT arms. Can be corrected if bandshape known within ~ 0.2% accuracy

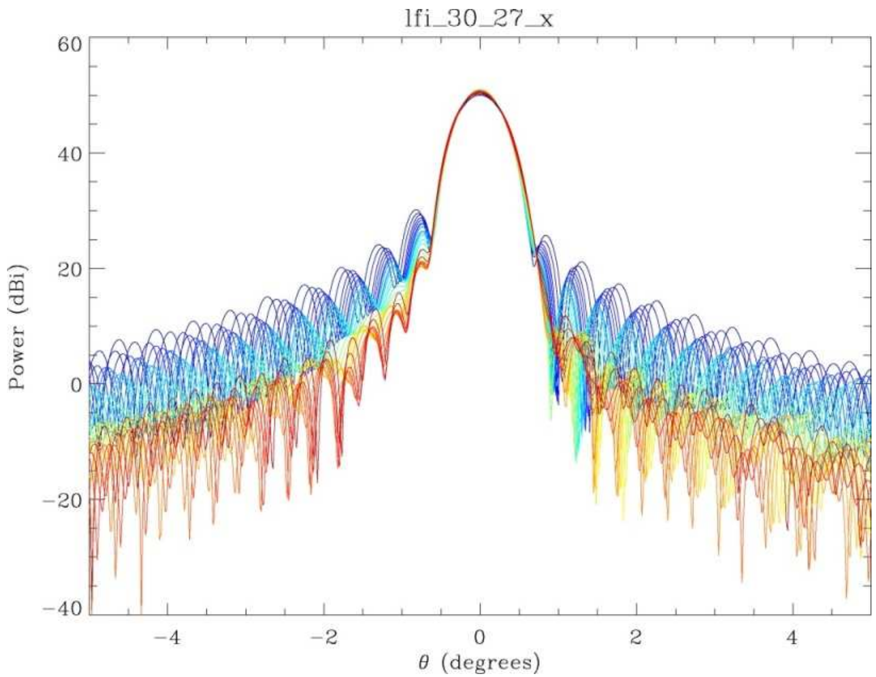
- Correction depends on nature and intensity of foregrounds in observed sky
- Most important in the galactic plane
- Requires knowledge of instrument response
- In-flight measures of polarized synchrotron and thermal dust sources
- Much improvement with Full Mission data set

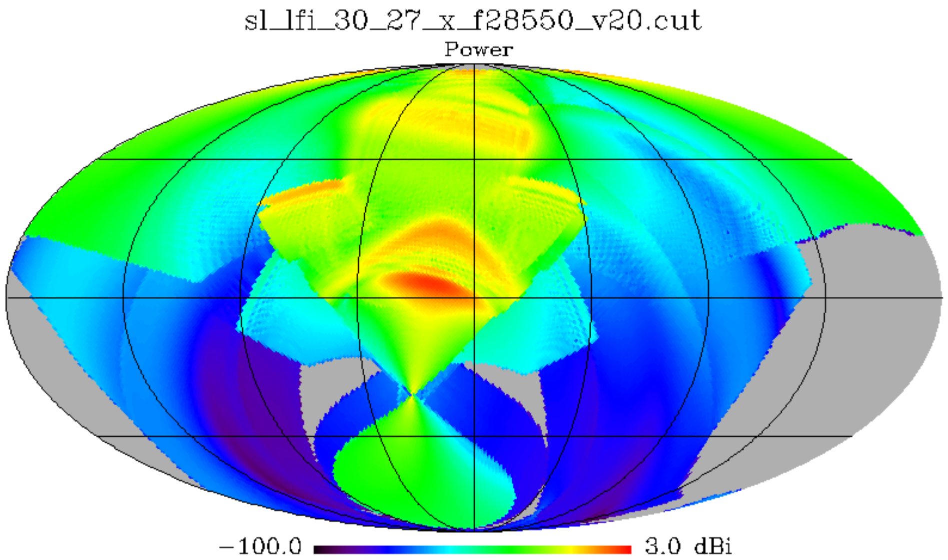
# Straylight removal

*(Maura Sandri et al)*

## 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**
- 2014 release will include **removal of Galactic straylight** from timelines

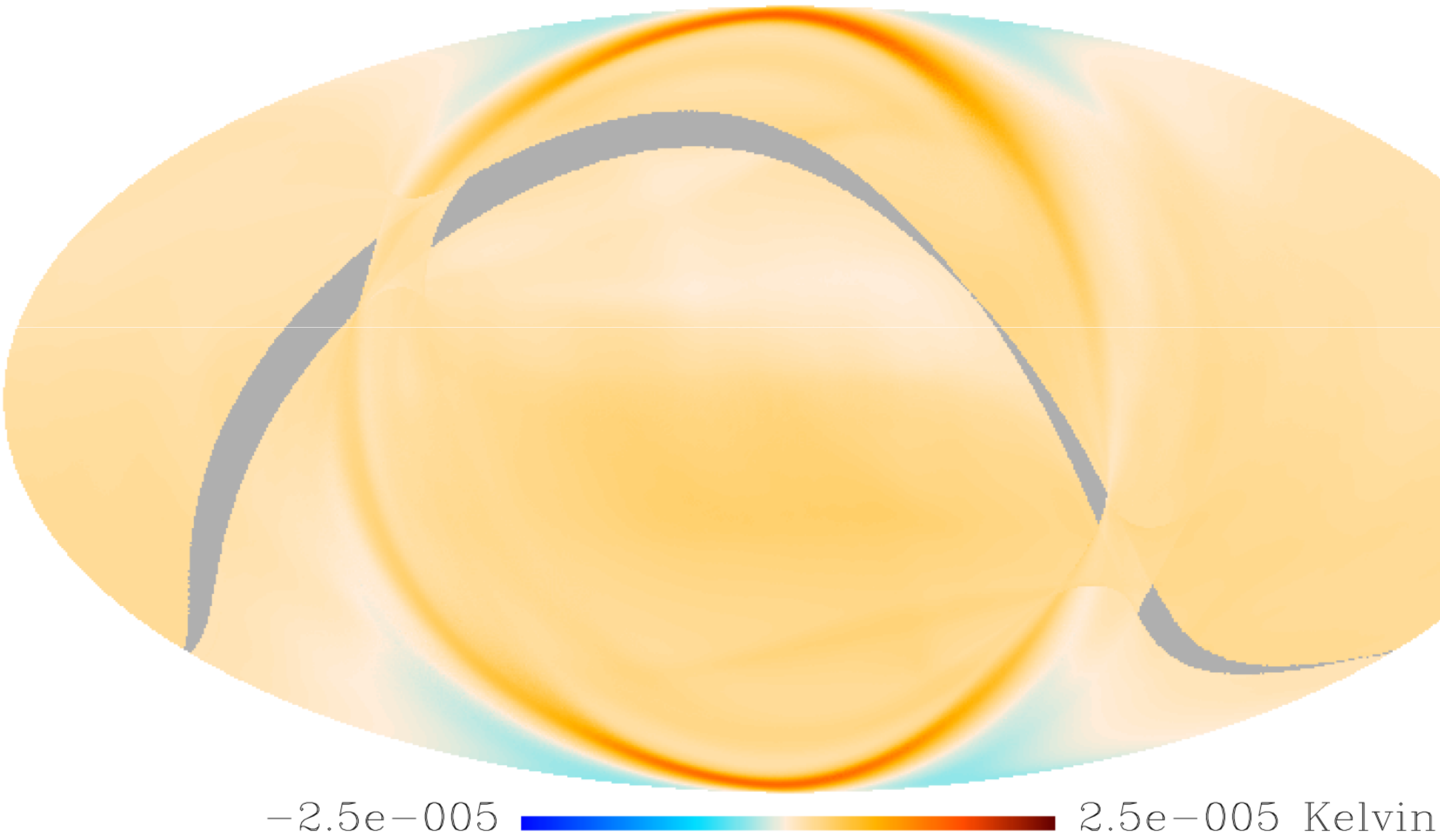


# Straylight removal

## 30 GHz, S2–S1

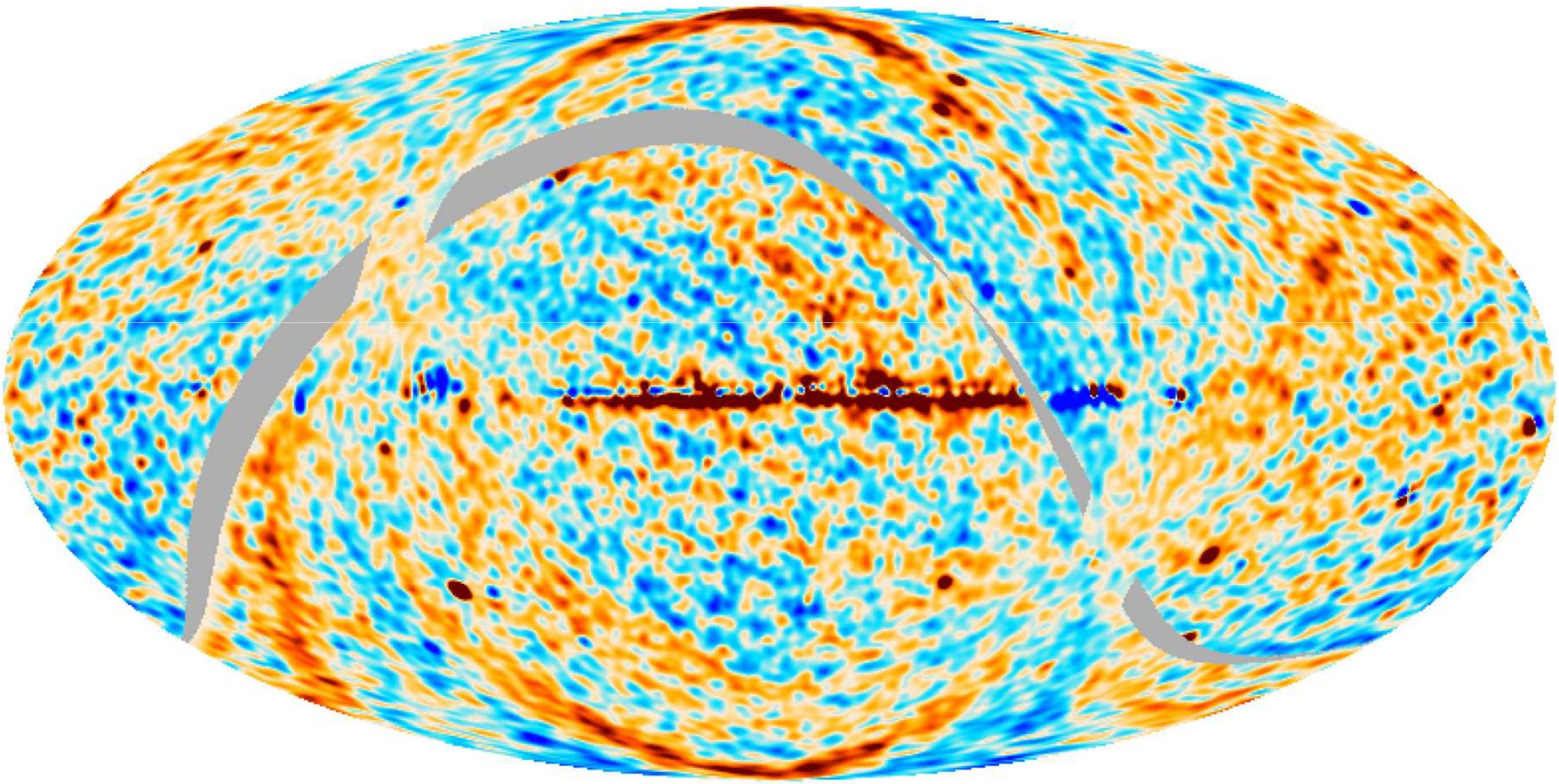
## Straylight simulation



# Straylight removal

## 30 GHz, S2–S1 (DX9 data)

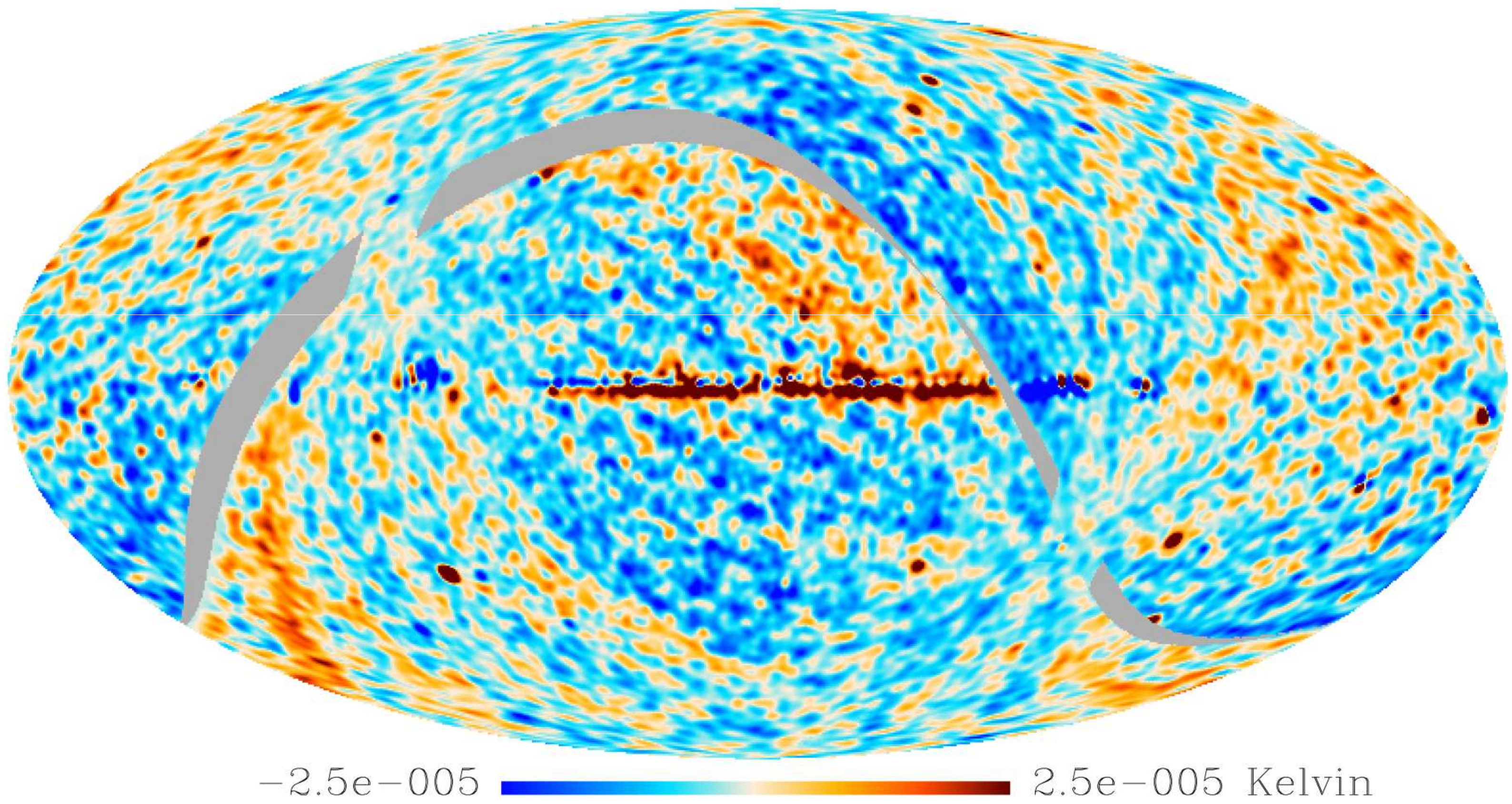
## Before correction



# Straylight removal

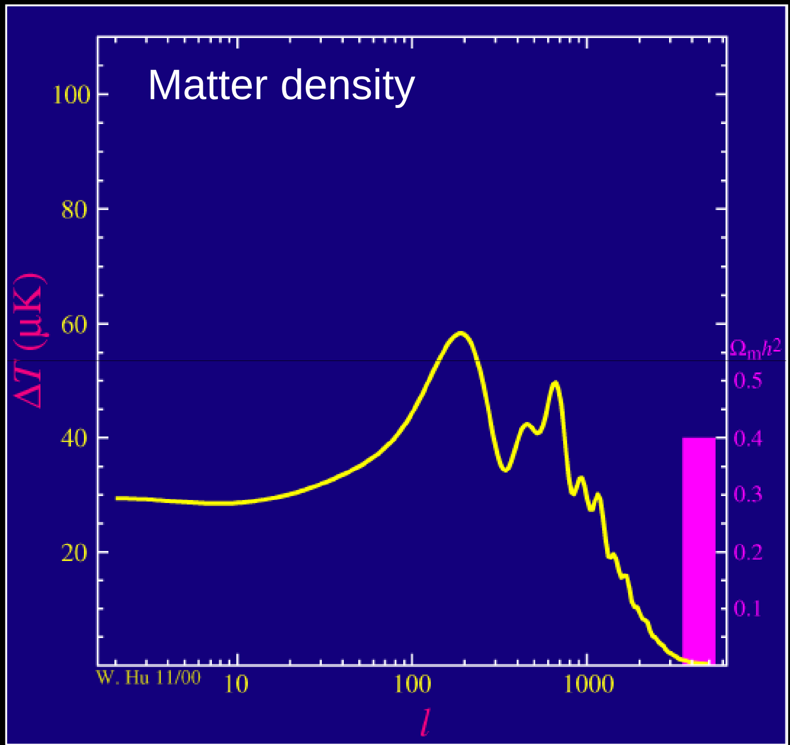
## 30 GHz, S2–S1 (DX9 data)

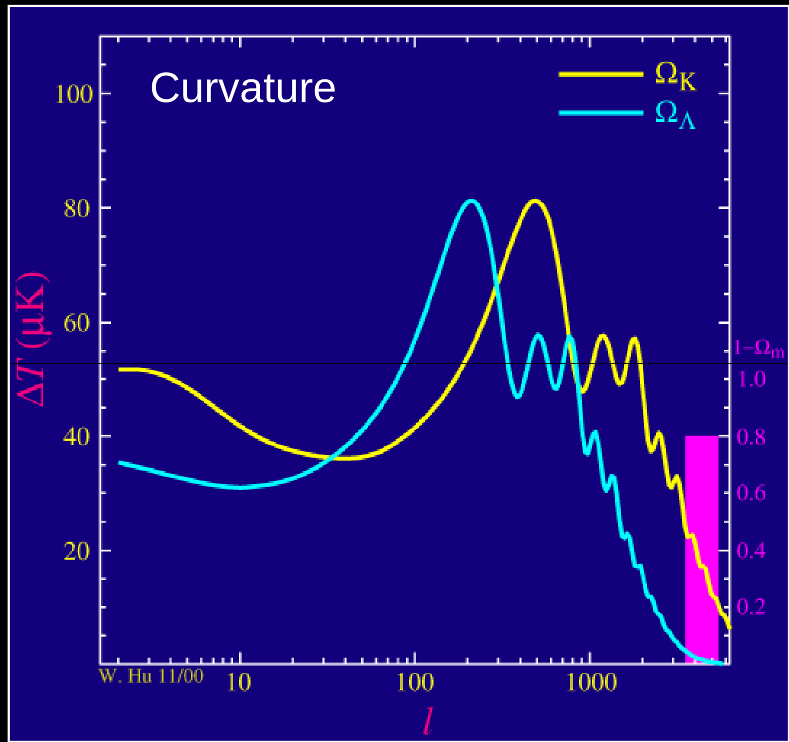
## After correction



# Planck Full Mission: Cosmological parameters

- Improved sensitivity on TT power spectrum
- Sumultaneous additional constraints from TE and EE




by Wayne Hu

→ Increased accuracy in cosmoloquical parameters

$$H_0, \Omega_M, \Omega_\Lambda, \Omega_B, \Omega_0, \sum m_\nu$$

# Planck Full Mission: 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 | $\tau$ | 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 |

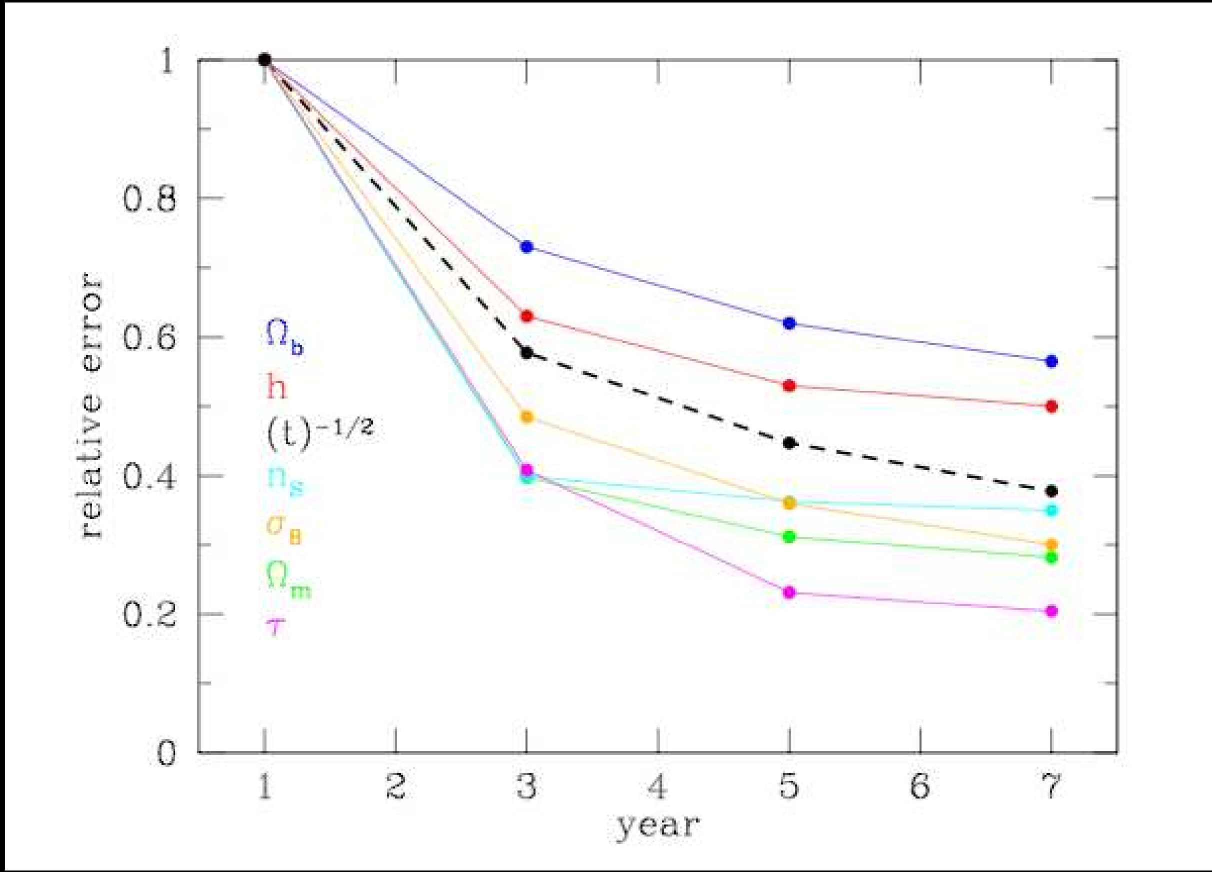
## Constraints on other parameters

| 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 | $\alpha/\alpha_0$ | 0.0043 | 0.0018 |

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

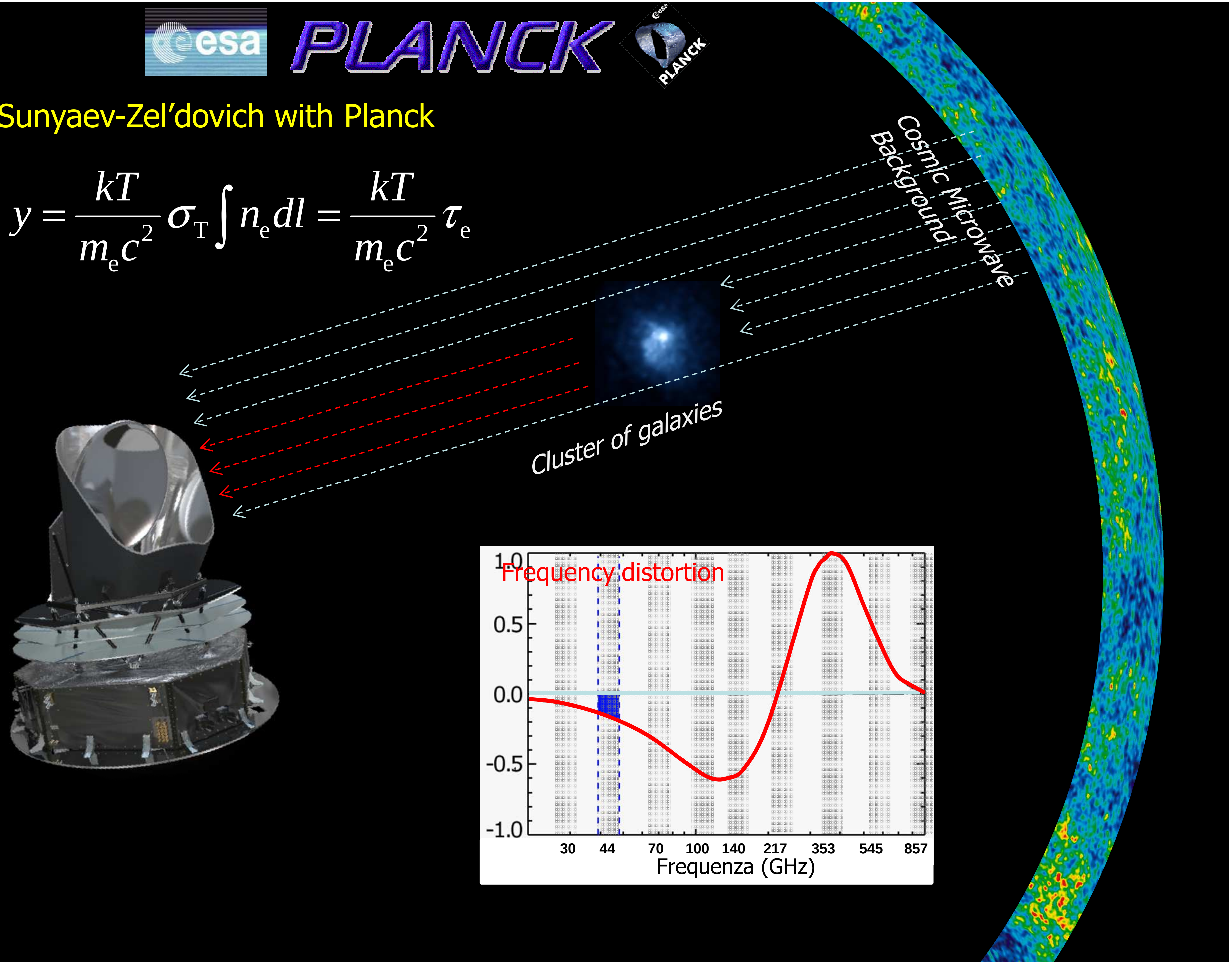
# Planck Full Mission: Cosmological parameters

*The WMAP experience*

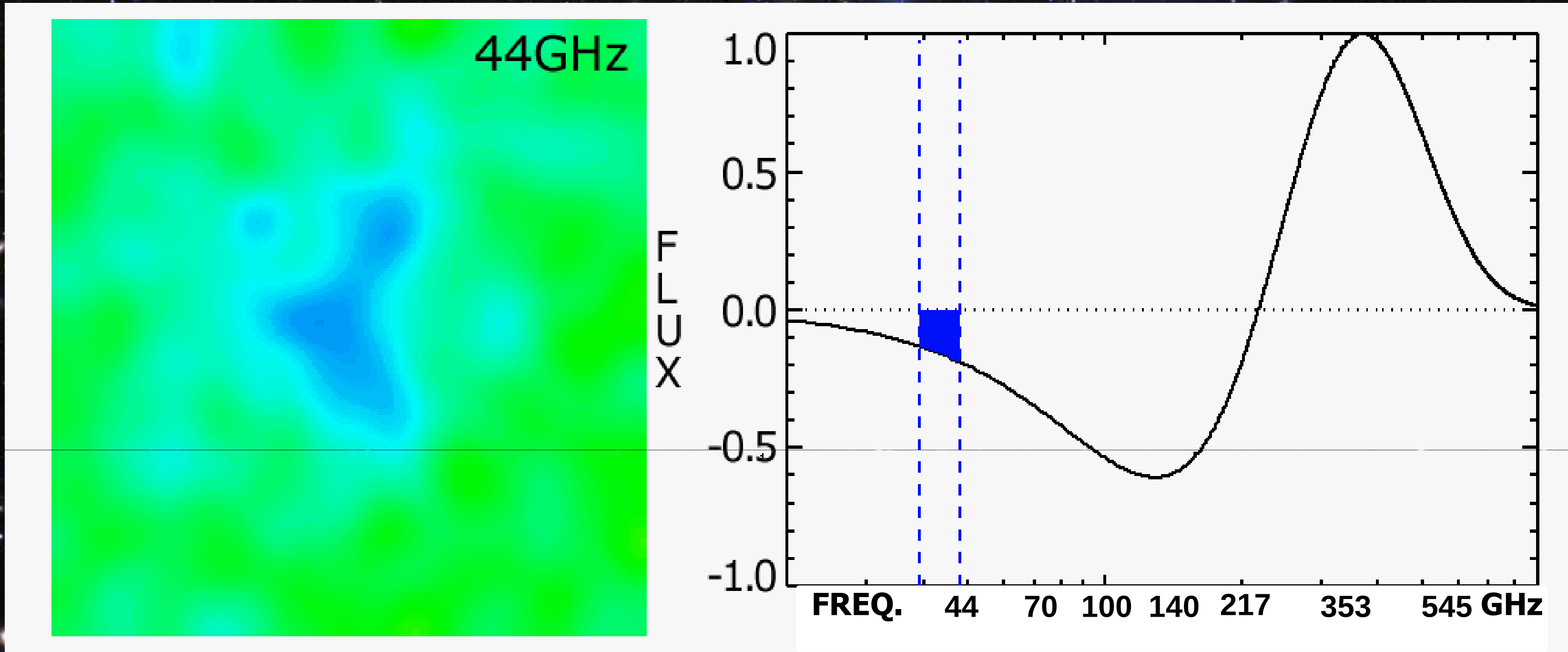



*Relative error in the basic six parameters of a standard cosmological model using four different data-sets based on 1, 3, 5 and 7 years of WMAP data. These are compared with the naïve expectation for improvement,* Sunyaev-Zel'dovich with Planck

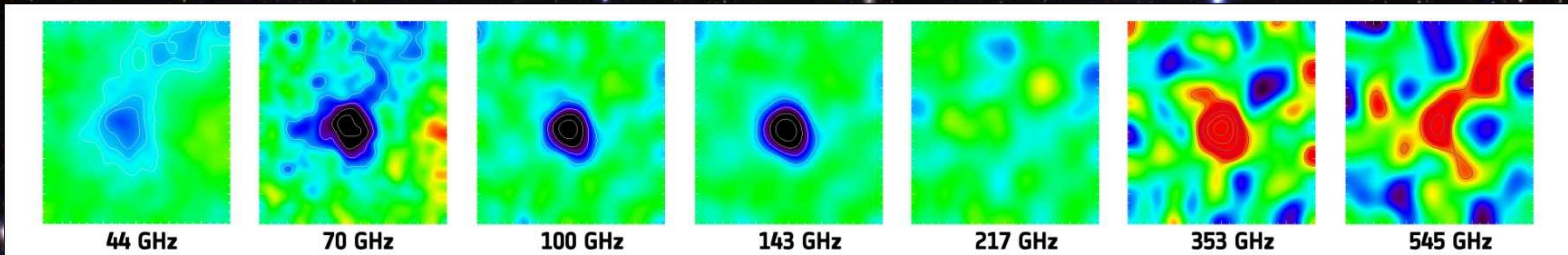
$$y = \frac{kT}{m_e c^2}\sigma_T \int n_e dl = \frac{kT}{m_e c^2}\tau_e$$



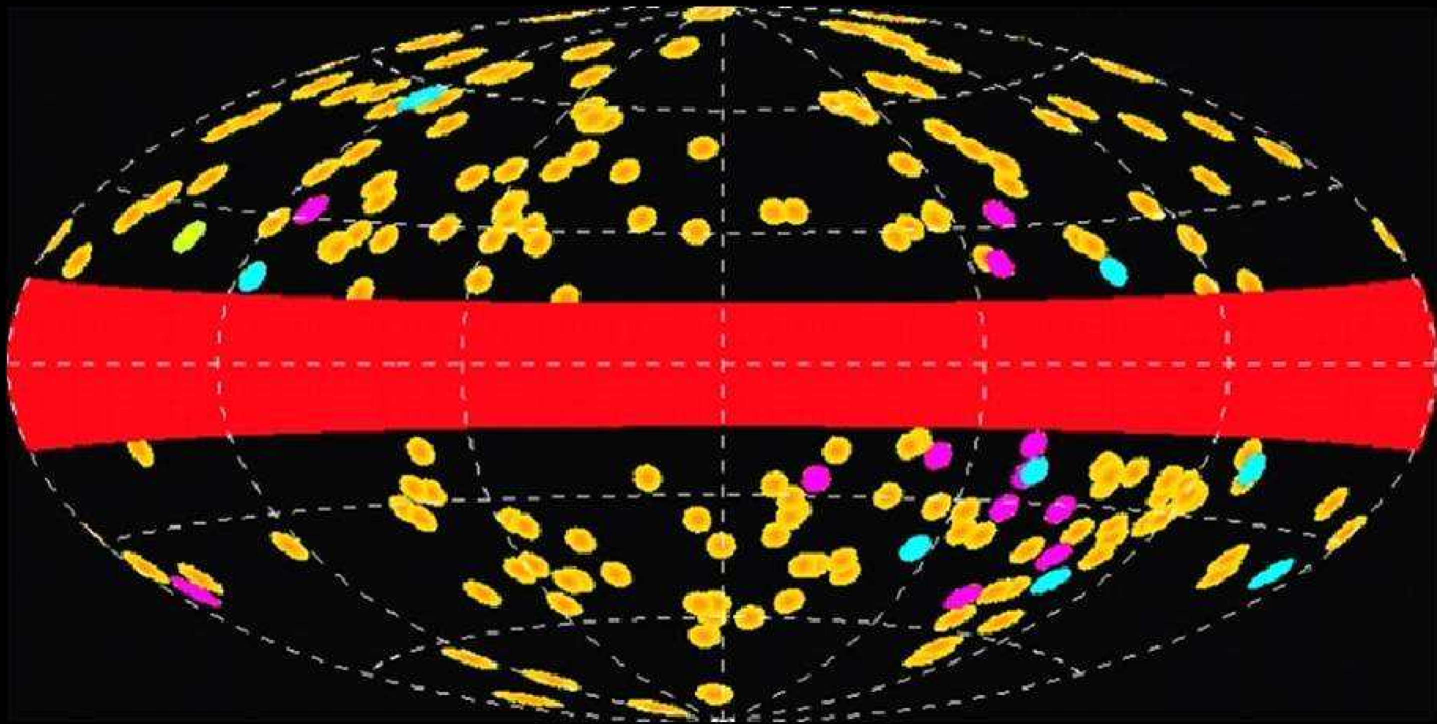
# Effetto Sunyaev-Zel’dovich (SZ)




**Galaxy Cluster: Abel 2319**



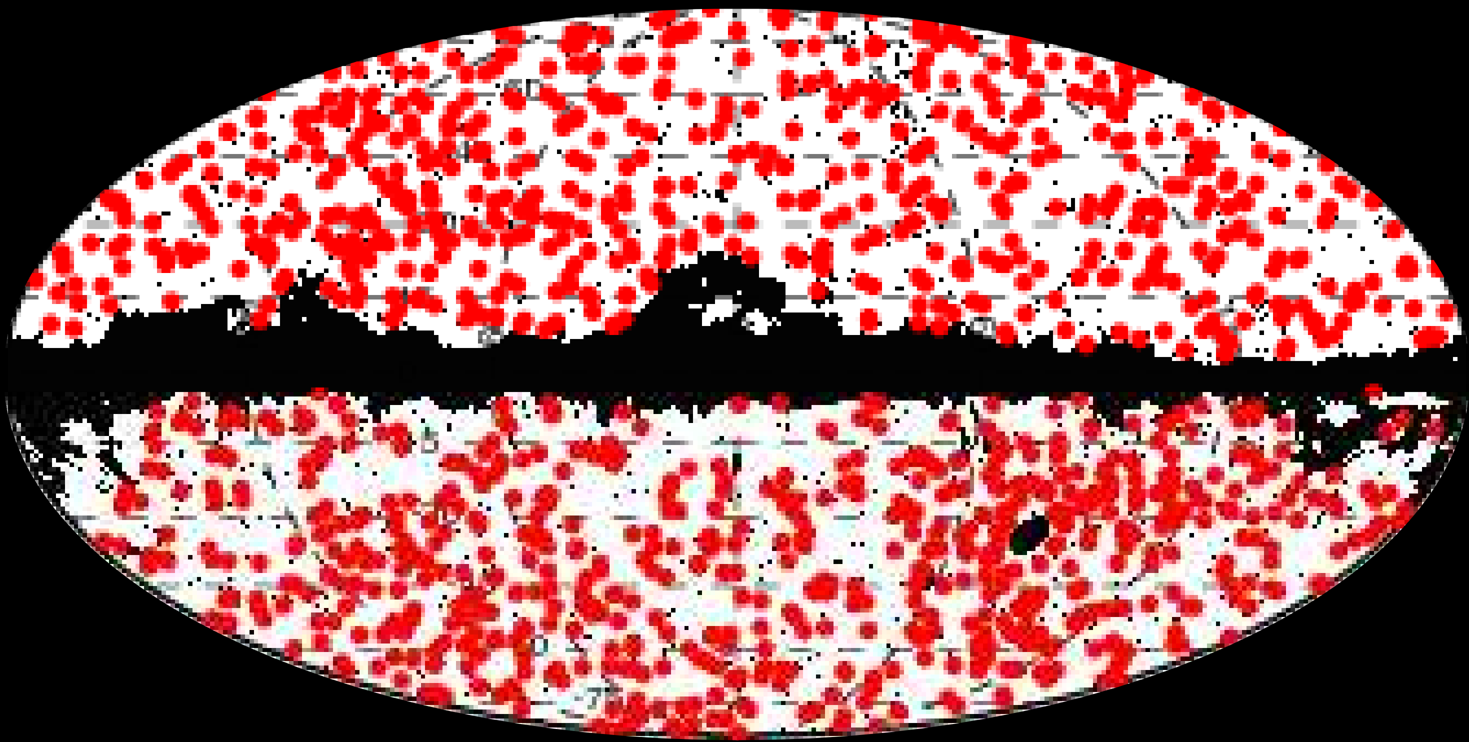
For the first time, Planck has measured the SZ effect on the full sky



Early Planck release: 187 galaxy clusters

PLANCK

For the first time, Planck has measured the SZ effect on the full sky



Early Planck release: 187 galaxy clusters

Planck 2013 release: 1227 galaxy clusters

For the first time, Planck has measured the SZ effect on the full sky

Planck 2013 release

| Category | N | n | | Source |
|---|---|---|---|---|
| **Previously known . . . . . . . . . . .** | **683** | | | |
| from: | | 472 | X-ray: | MCXC meta-catalogue |
| | | 182 | Optical: | Abell, Zwicky, SDSS |
| | | 16 | SZ: | SPT, ACT |
| | | 13 | Misc: | NED & SIMBAD |
| **New confirmed . . . . . . . . . . . . . .** | **178** | | | XMM, ENO, WFI, NTT, AMI, SDSS |
| **New candidate . . . . . . . . . . . . . .** | **366** | | | |
| reliability: | | 54 | High | |
| | | 170 | Medium | |
| | | 142 | Low | |
| **Total *Planck* SZ catalogue . . . . .** | **1227** | | | |

Early Planck release: 187 galaxy clusters

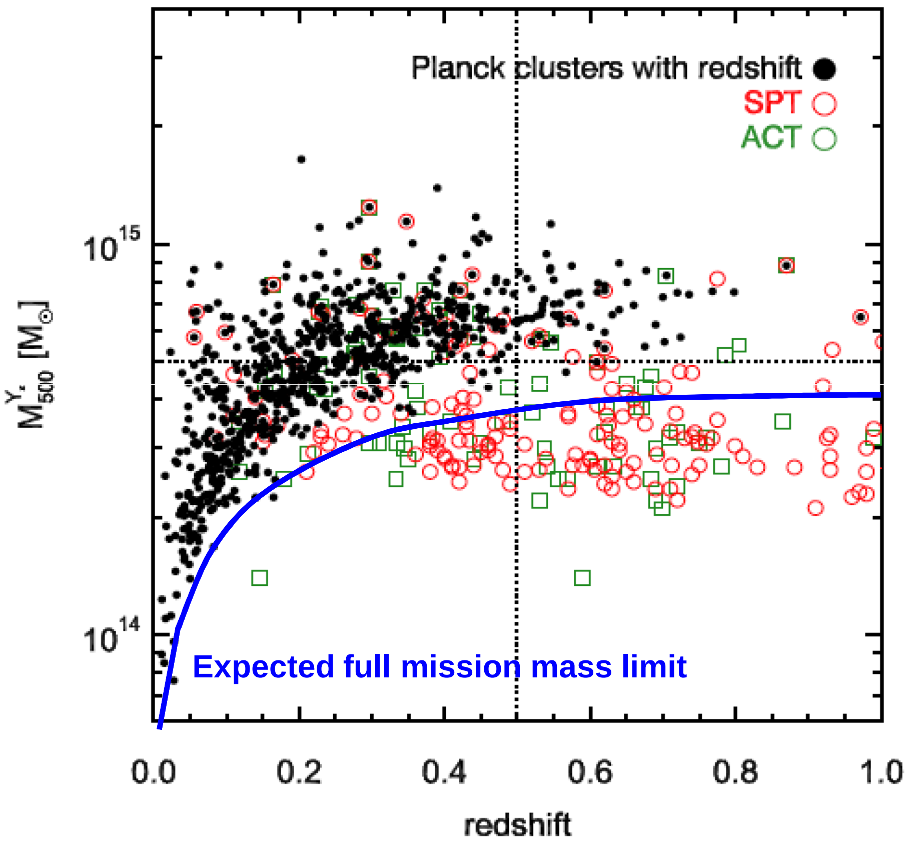
Planck 2013 release: 1227 galaxy clusters

Planck 2014 release: **...stay tuned!**

# Improved SZ studies

## Mass redshift distribution: expectations for the full survey

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




*Planck results XXIX (2013)*

## All sky thermal SZ maps

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

2014 Planck release

# Conclusions

• The excellent performance of Planck instruments and coolers allowed 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!), …

→ E/B modes at low ell, verification of Bicep2 results

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

• Polarization requires working at the very limit of our instruments and 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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