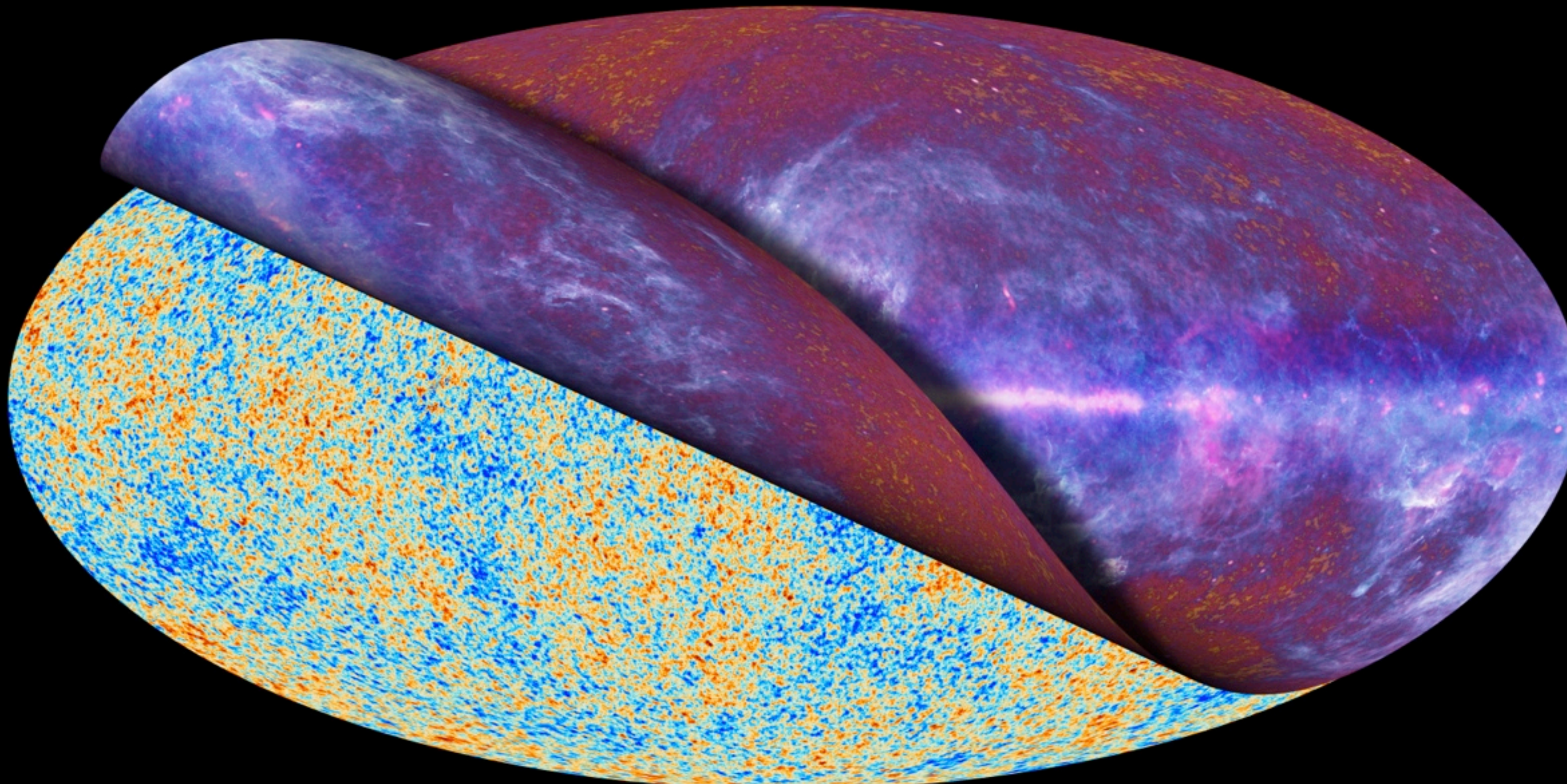


Planck unveils the Cosmic Microwave Background

CONSISTENCY OF THE PLANCK DATA

C. R. Lawrence, JPL
on behalf of the Planck Collaboration

ESLAB 47
ESTEC, 2013 April 2

The Role of Consistency Tests*

Planck has greater capability than previous CMB experiments. Must demonstrate lower systematics.

How do we demonstrate correctness of the results?

- Show that methods work in realistic simulations
- Show internal consistency

PLANCK HAS REDUNDANCY IN MANY WAYS, EACH OF WHICH PROVIDES ITS OWN TESTS

*Based on Planck Collaboration I and XI, 2013

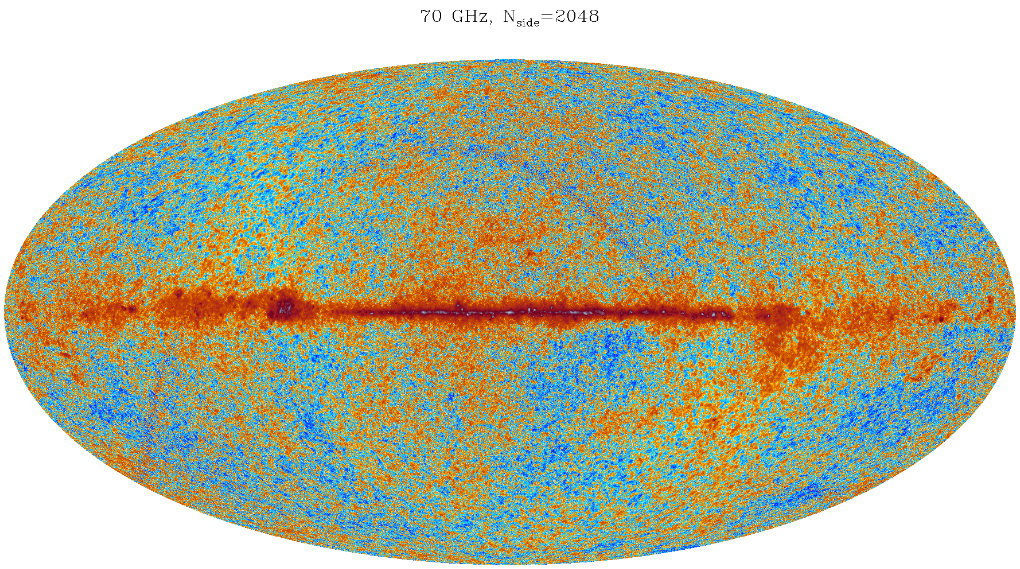
Redundancy and Related Tests

Examples in Zacchei/Bouchet Overview of LFI & HFI frequency maps today

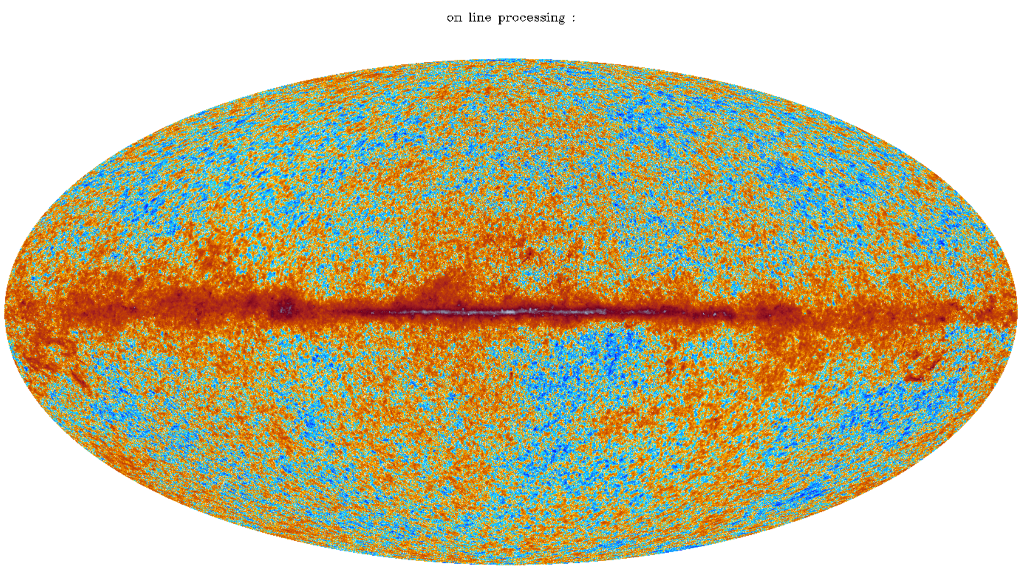
- Multiple detectors at a given frequency
  - Compare the output from one detector to that of another
- Spins at 1 rpm with axis fixed for 39–65 rotations (a "ring")
  - Compare data from the first and second halves of a ring
  - In "half-ring difference" maps, the sky signal subtracts out, leaving noise and possibly other systematic residuals
  - Half-ring differences can be constructed for single or multiple detectors, and for any period of time
- Multiple frequencies
  - Foregrounds change, but (in appropriate units) the CMB doesn't
- Multiple sky coverages
  - In six months (one "survey") Planck covers most of the sky once
  - In "survey difference" maps, the sky signal subtracts out, but the effects of different beam orientations and sidelobes, etc. leave residuals
  - In twelve months Planck covers the sky twice, exactly (Bersanelli on Friday)
- LFI and HFI. Different technologies, different systematics.

LFI & HFI: Map Level Consistency 1

- Make initial comparison on the observed sky, before foreground separation.
- Foreground minimum at 70 GHz
- Compare LFI 70 GHz with HFI 100 GHz
- Different technologies, different systematics



70 GHz, $N_{\rm side} = 2048$



100 GHz, $N_{\rm side} = 2048$

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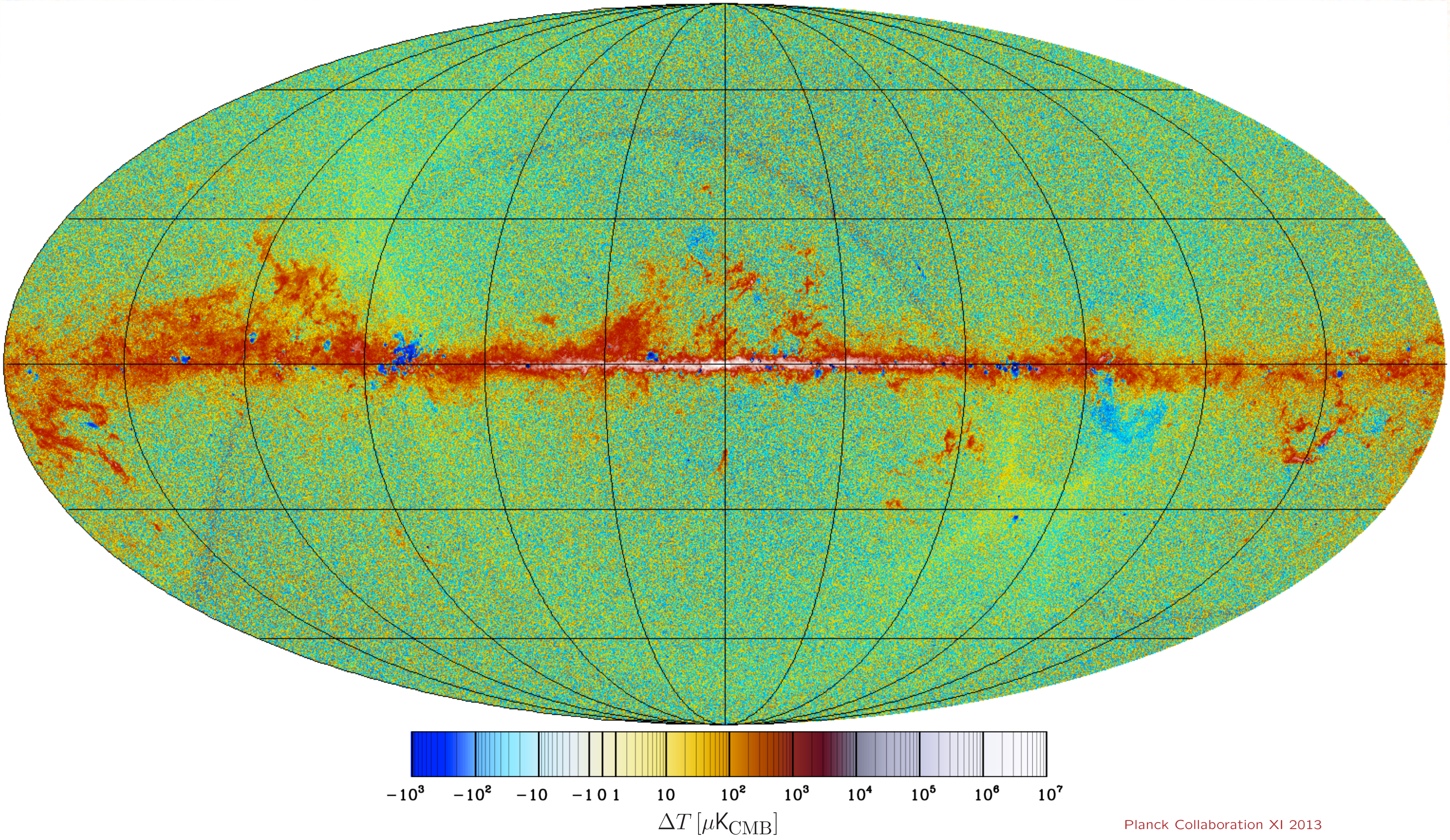
LFI & HFI: Map Level Consistency 2

- 100 GHz − 70 GHz. Red is mostly CO, blue is mostly free-free. CMB is gone!



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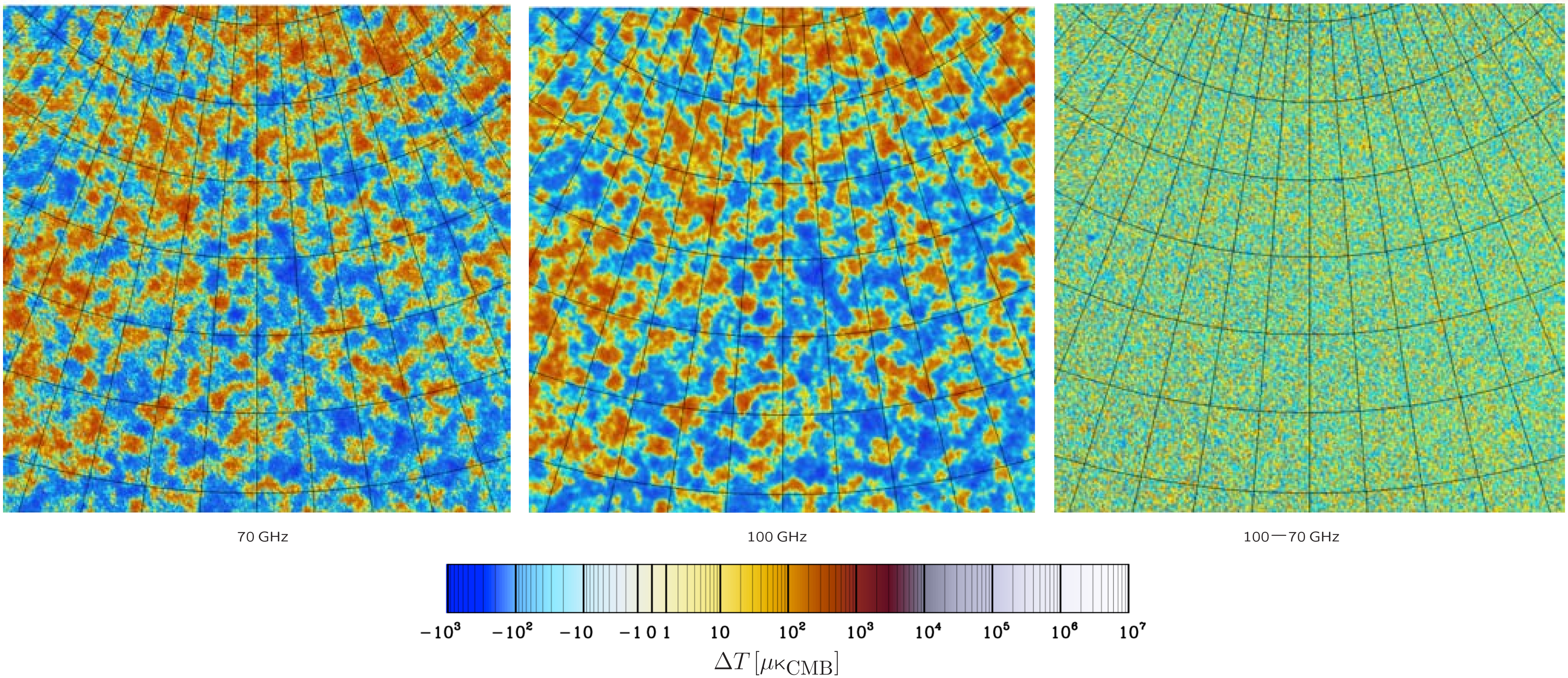
LFI & HFI: Map Level Consistency 3

- Low-foreground patch of sky near the NEP



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- Difference dominated by 70 GHz noise (at $N_{\rm side} = 2048$)

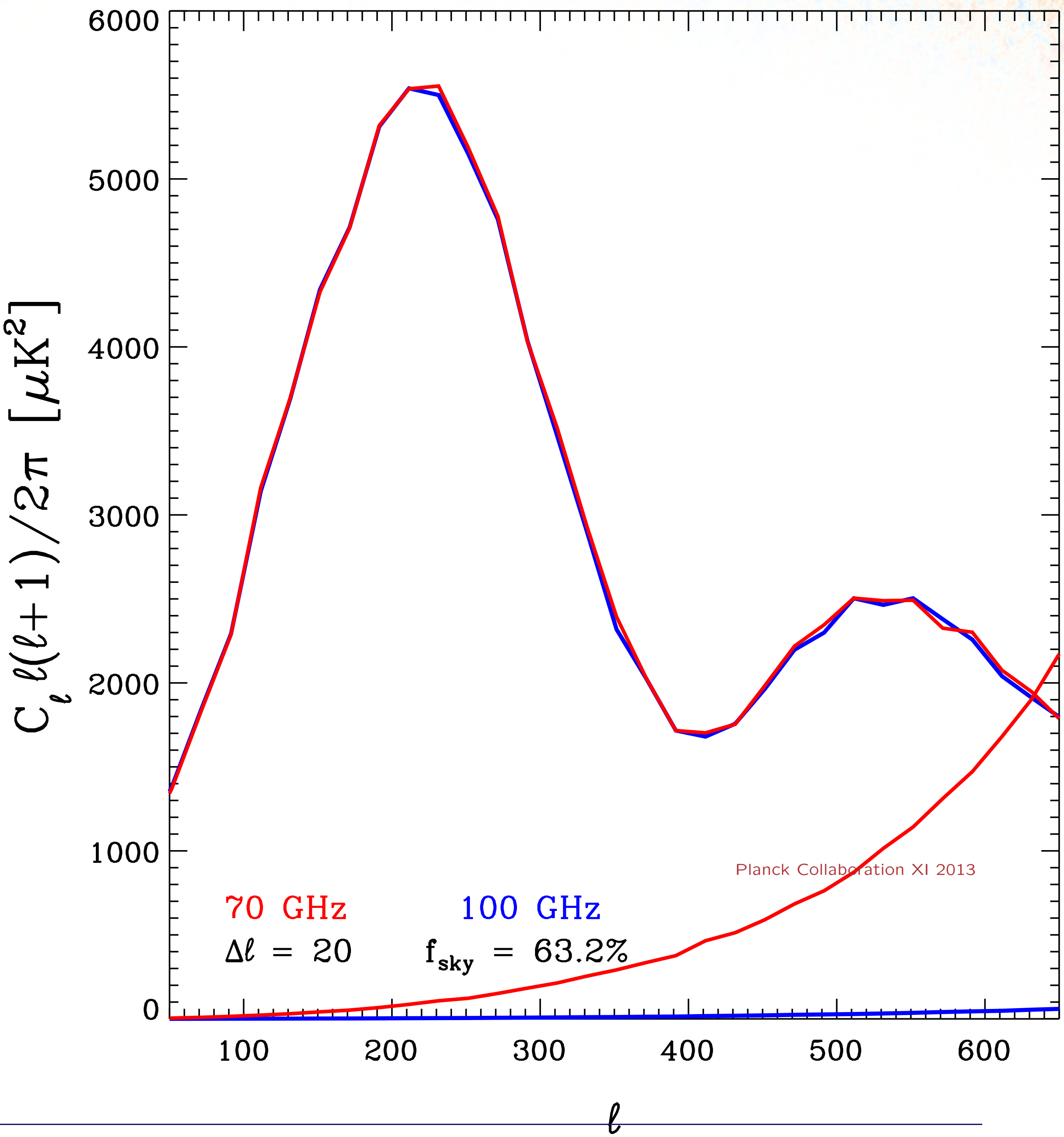
LFI & HFI: Power Spectrum Consistency 1

- Agreement between 70 and 100 GHz where foregrounds are weak is visually impressive at the map level.
- Look at power spectrum level. Must be extremely careful in the calculation.
  - Identical masks

    Mask = union of foreground masks used in diffuse component separation + PCCS
  - Appropriate beam and pixel window function corrections
  - Monopole and dipole removal

LFI & HFI: Power Spectrum 2

- Spectrum and noise
  - Red = 70 GHz
  - Blue = 100 GHz
  - Spectra mask-kernel-inverted to 4π amplitude and debeamed
- Small differences near peak, greater at $\ell = 350$, and where 70 GHz noise picks up
- To avoid noise bias, we want a metric that uses only cross-spectra.



LFI & HFI: Power Spectrum 3

Cross spectra: (relative to 100 GHz)

$(70_{\rm hr1} - 70_{\rm hr2})/2 \times (100_{\rm hr1} - 100_{\rm hr2})/2$

i.e., noise cross-correlations between frequencies.

$(70_{\rm hr1} - 100_{\rm hr1})/2 \times (70_{\rm hr2} - 100_{\rm hr2})/2$

$(70_{\rm hr1} - 100_{\rm hr2})/2 \times (70_{\rm hr2} - 100_{\rm hr1})/2$

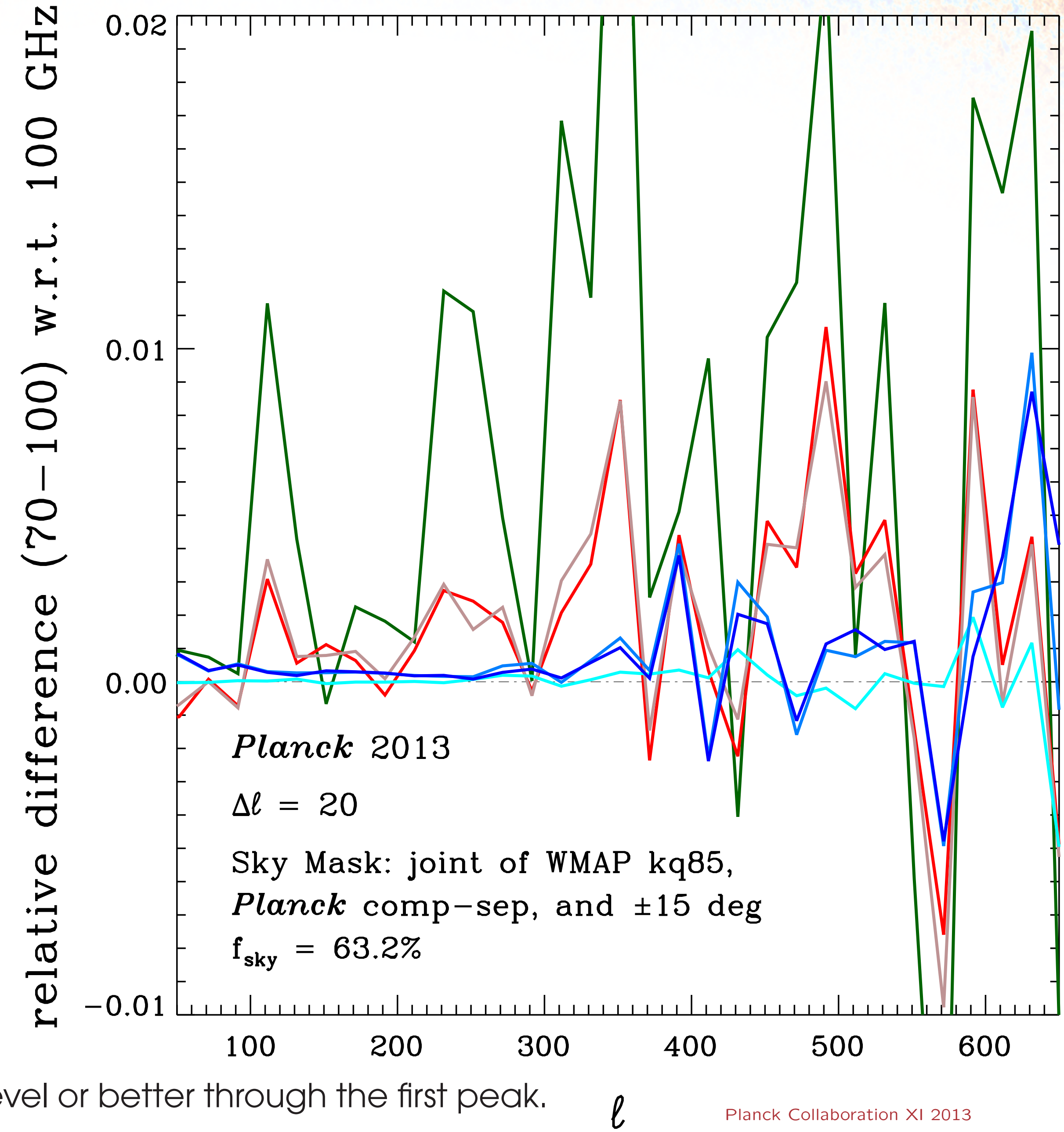
Scale quadratically with "gains"; are a cross-spectrum estimator of power mismatch.

$(70_{\rm hr1} + 100_{\rm hr1})/2 \times (70_{\rm hr2} - 100_{\rm hr2})/2$

$(70_{\rm hr1} + 100_{\rm hr2})/2 \times (70_{\rm hr2} - 100_{\rm hr1})/2$

Cross-spectra of frequency sum and frequency difference maps. Scale linearly with gain differences.

$(70_{\rm hr1} \times 70_{\rm hr2}) - (100_{\rm hr1} \times 100_{\rm hr2})$



Agreement is at the few tenths of a % level or better through the first peak.

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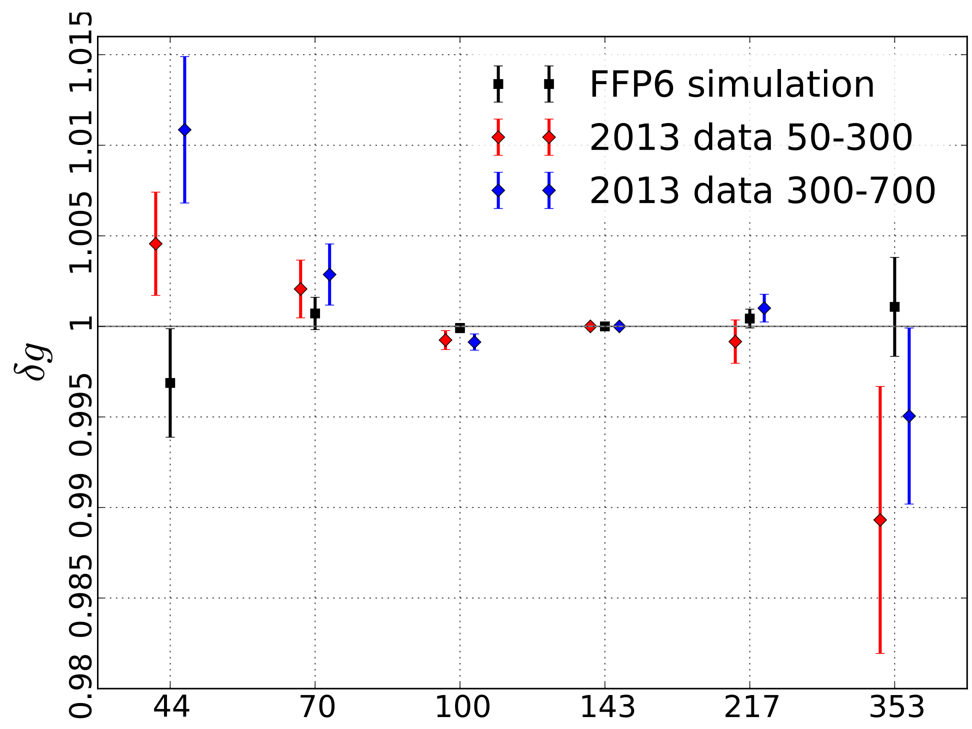
Intercalibration

- Residual dipoles in the calibrated maps test the quality of calibration with respect to the dipole as measured by WMAP used in 2013.
- These are
  - $< 0.1\%$ for HFI
  - $< 0.3\%$ for LFI
- Recalibration factors maximizing CMB consistency are shown for simulations and for two multipole ranges in the data.
  - Over 40% of the sky
  - For 70–217 GHz, all are $\leq 0.3\%$



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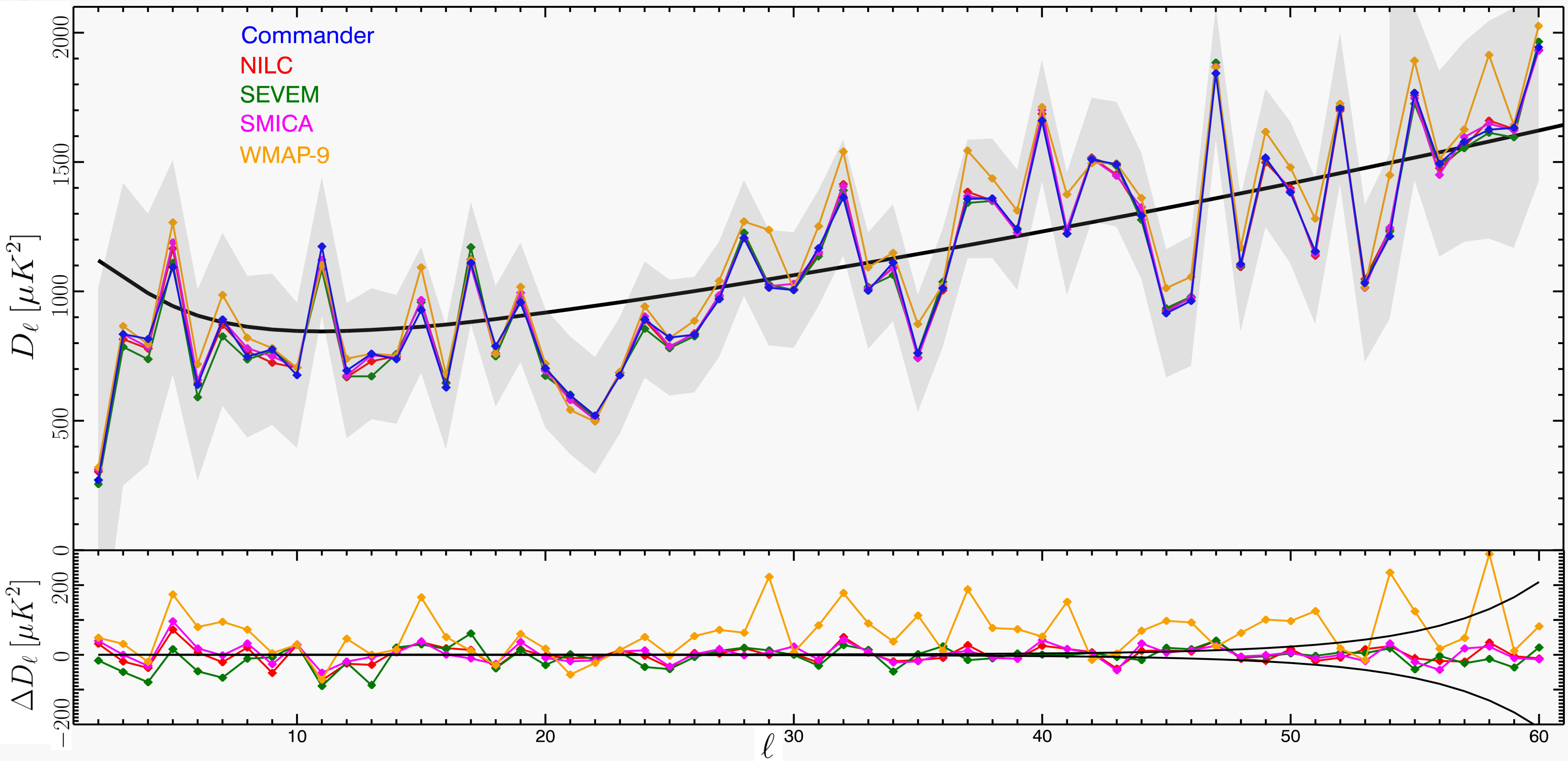
Low Multipoles, After Component Separation



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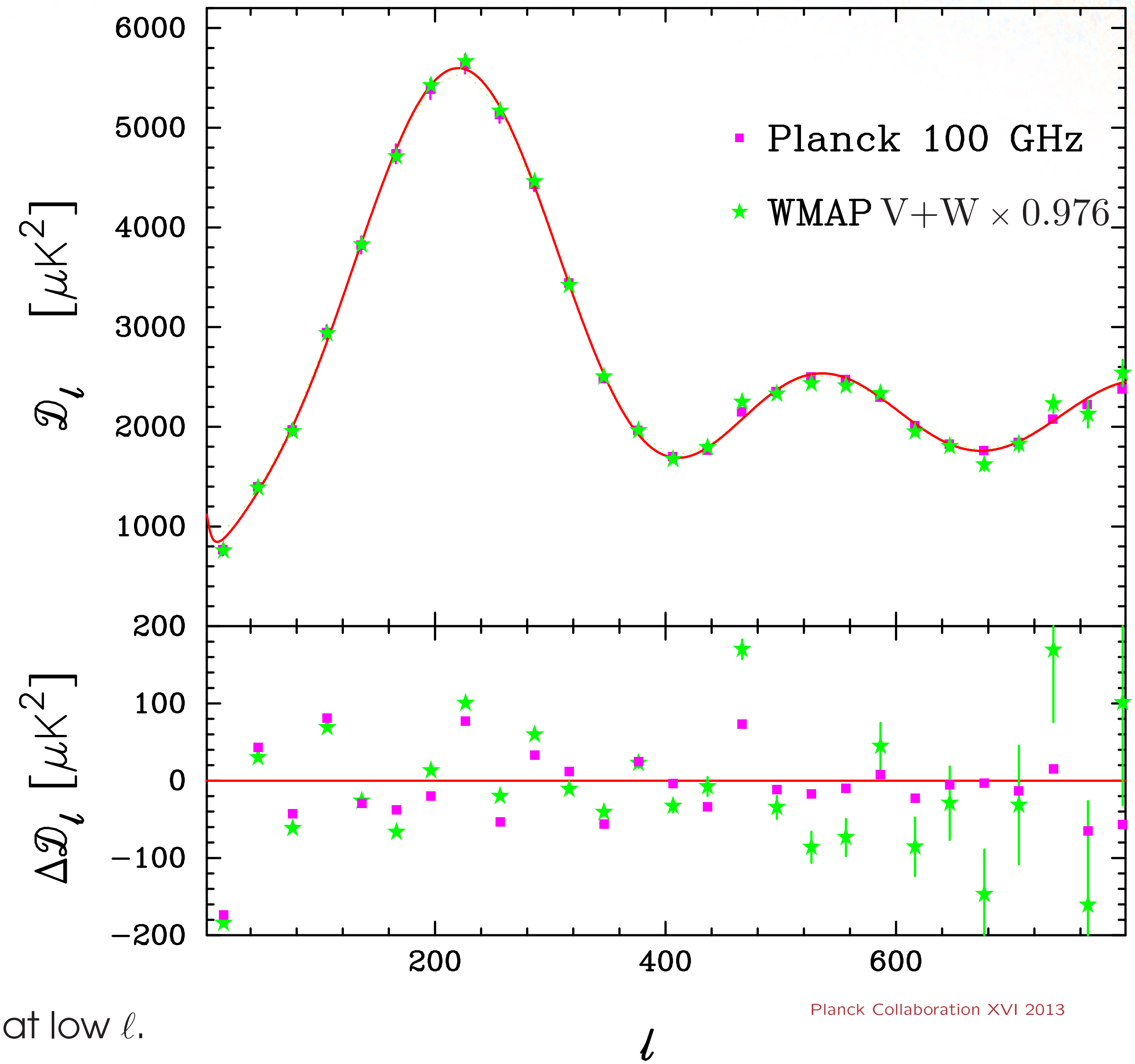
Top: Grey band shows 1σ Fisher errors. Solid line is Planck best-fit ΛCDM model. *Bottom*: Differences w.r.t. the Commander spectrum. Black lines are expected 1σ uncertainty due to (regularization) noise.

- Extremely good agreement between component separation methods
- WMAP is consistently higher than Planck by about 2.5%

Intermediate Multipoles, Planck & WMAP9

- Planck 100×100 GHz spectrum
- WMAP9 V+W spectrum scaled by 0.976.
- Red line is the best-fit Planck + WP + highL ΛCDM model.



- Residuals with respect to the model. The error bars on the WMAP points show errors from instrumental noise alone.

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- Same 2.5% difference as at low ℓ.

Summary

- The Planck hardware and scanning strategy afford a wide array of consistency tests.
- Planck's performance on these tests gives confidence that its unprecedented sensitivity is being realized, and that its scientific results are robust.
- A number of corrections and improved calibration and analysis procedures are known and will be implemented for the 2014 release. Everything we know suggests that these will only improve the consistency of the data, and bring HFI and LFI into even closer agreement.

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

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.