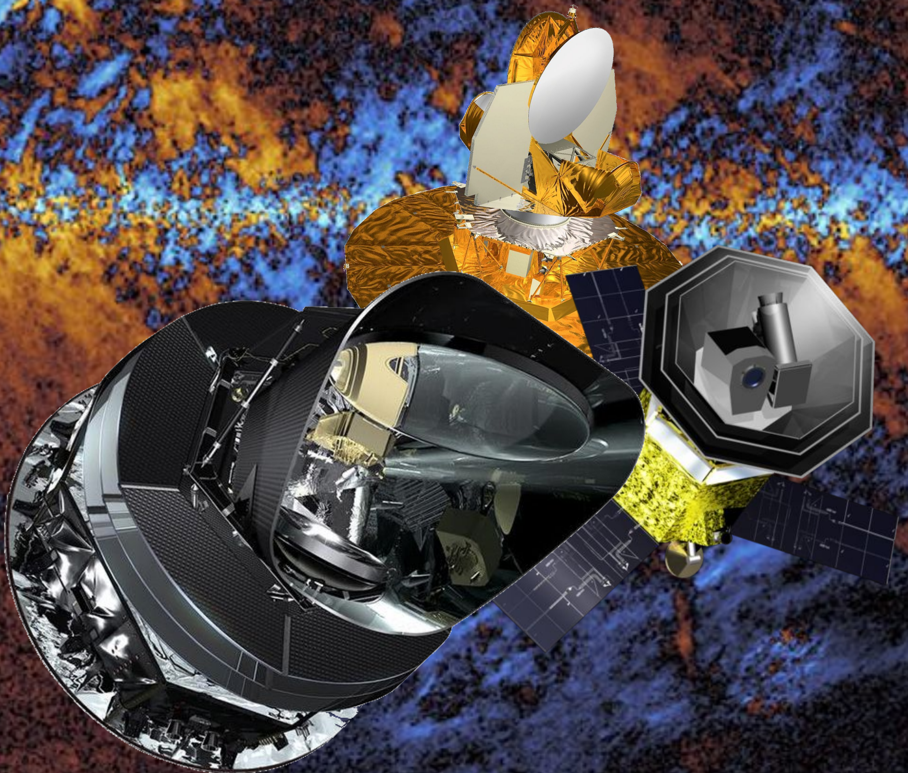
BeyondPlanck frequency maps

Anna-Stiina Suur-Uski



BeyondPlanck online release conference, November 18-20, 2020

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Introduction

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November 13, 2020

BeyondPlanck X. *Planck* LFI frequency map posteriors and sample-based error propagation

A.-S. Suur-Uski[3,7*], K. J. Andersen[11], R. Aurlien[11], R. Banerji[11], M. Bersanelli[4,9,10], S. Bertocco[8], M. Brilenkov[11], M. Carbone[14], L. P. L. Colombo[4], H. K. Eriksen[11], J. R. Eskilt[11], M. K. Foss[11], C. Franceschet[4,10], U. Fuskeland[11], S. Galeotta[8], M. Galloway[11], S. Gerakakis[14], E. Gjerløw[11], B. Hensley[2], D. Herman[11], M. Iacobellis[14], M. Ieronymaki[14], H. T. Ihle[11], J. B. Jewell[12], A. Karakci[11], E. Keihänen[3], R. Keskitalo[1], G. Maggio[8], D. Maino[4,9,10], M. Maris[8], A. Mennella[4,9,10], S. Paradiso[4,9], B. Partridge[6], M. Reinecke[13], M. San[11], T. L. Svalheim[11], D. Tavagnacco[8,5], H. Thommesen[11], D. J. Watts[11], I. K. Wehus[11], and A. Zacchei[8]

[1] Computational Cosmology Center, Lawrence Berkeley National Laboratory, Berkeley, California, U.S.A.
[2] Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, U.S.A.
[3] Department of Physics, Gustaf Hällströmin katu 2, University of Helsinki, Helsinki, Finland
[4] Dipartimento di Fisica, Università degli Studi di Milano, Via Celoria, 16, Milano, Italy
[5] Dipartimento di Fisica, Università degli Studi di Trieste, via A. Valerio 2, Trieste, Italy
[6] Haverford College Astronomy Department, 370 Lancaster Avenue, Haverford, Pennsylvania, U.S.A.
[7] Helsinki Institute of Physics, Gustaf Hällströmin katu 2, University of Helsinki, Helsinki, Finland
[8] INAF - Osservatorio Astronomico di Trieste, Via G.B. Tiepolo 11, Trieste, Italy
[9] INAF/IASF Milano, Via E. Bassini 15, Milano, Italy
[10] INFN, Sezione di Milano, Via Celoria 16, Milano, Italy
[11] Institute of Theoretical Astrophysics, University of Oslo, Blindern, Oslo, Norway
[12] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California, U.S.A.
[13] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85741 Garching, Germany
[14] Planetek Hellas, Leoforos Kifisias 44, Marousi 151 25, Greece

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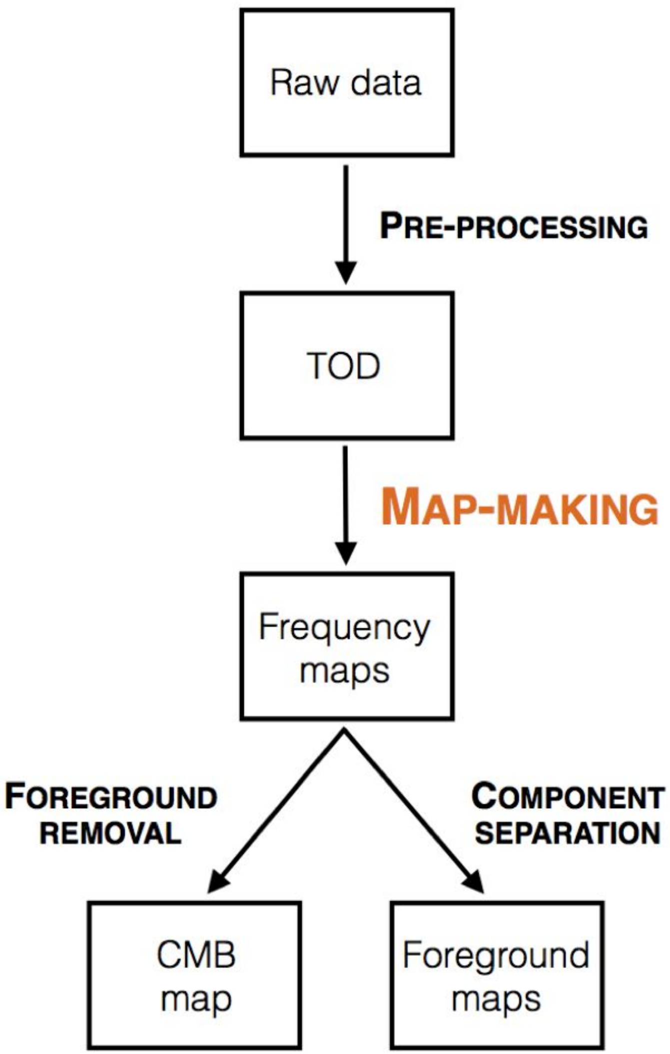
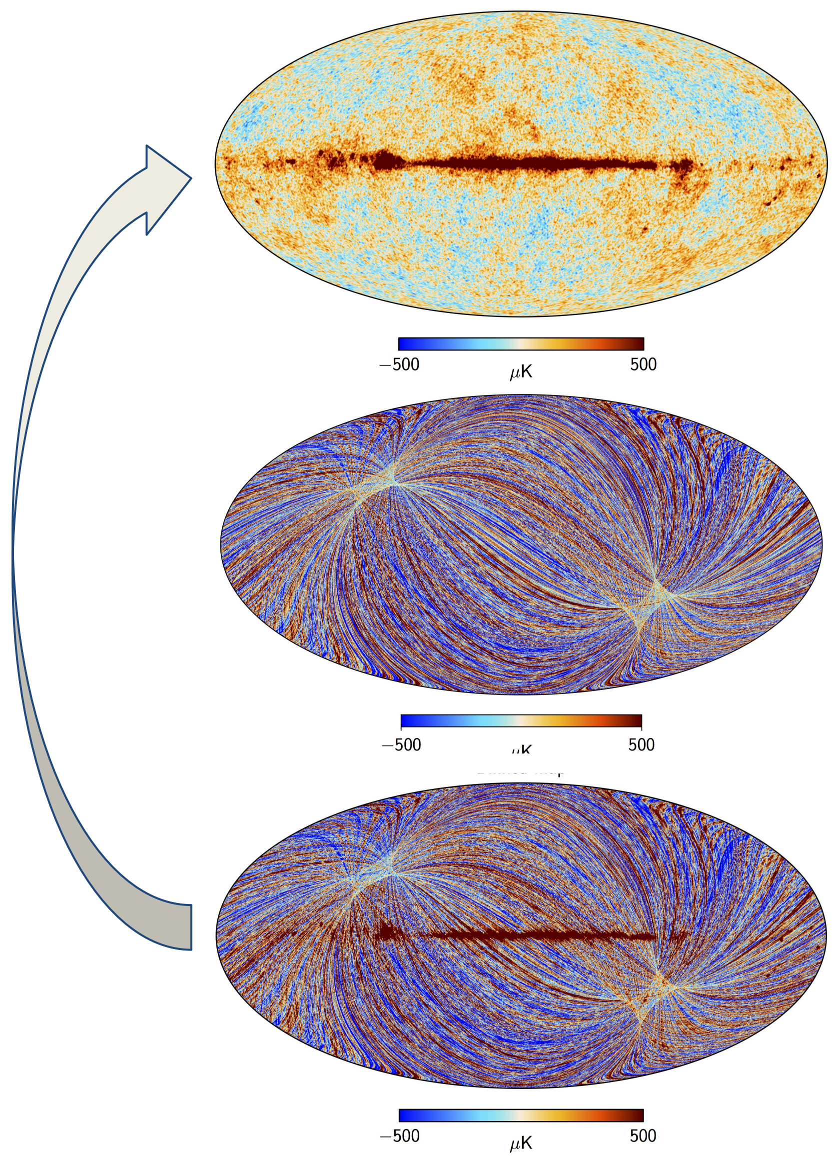
Beyond PLANCK

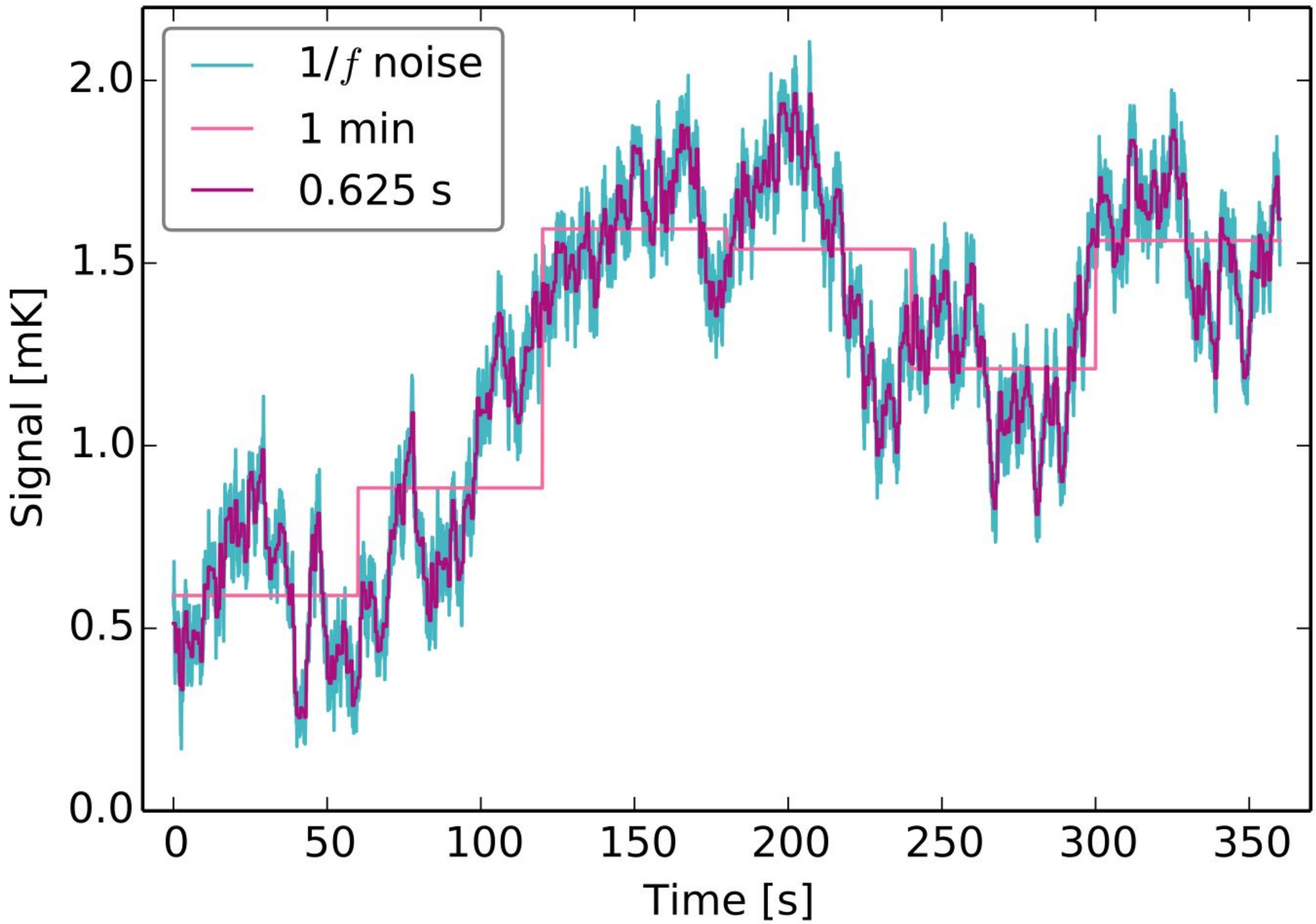
Map-making introduction



SIMULATED DATA



Destriping



SIMULATED DATA

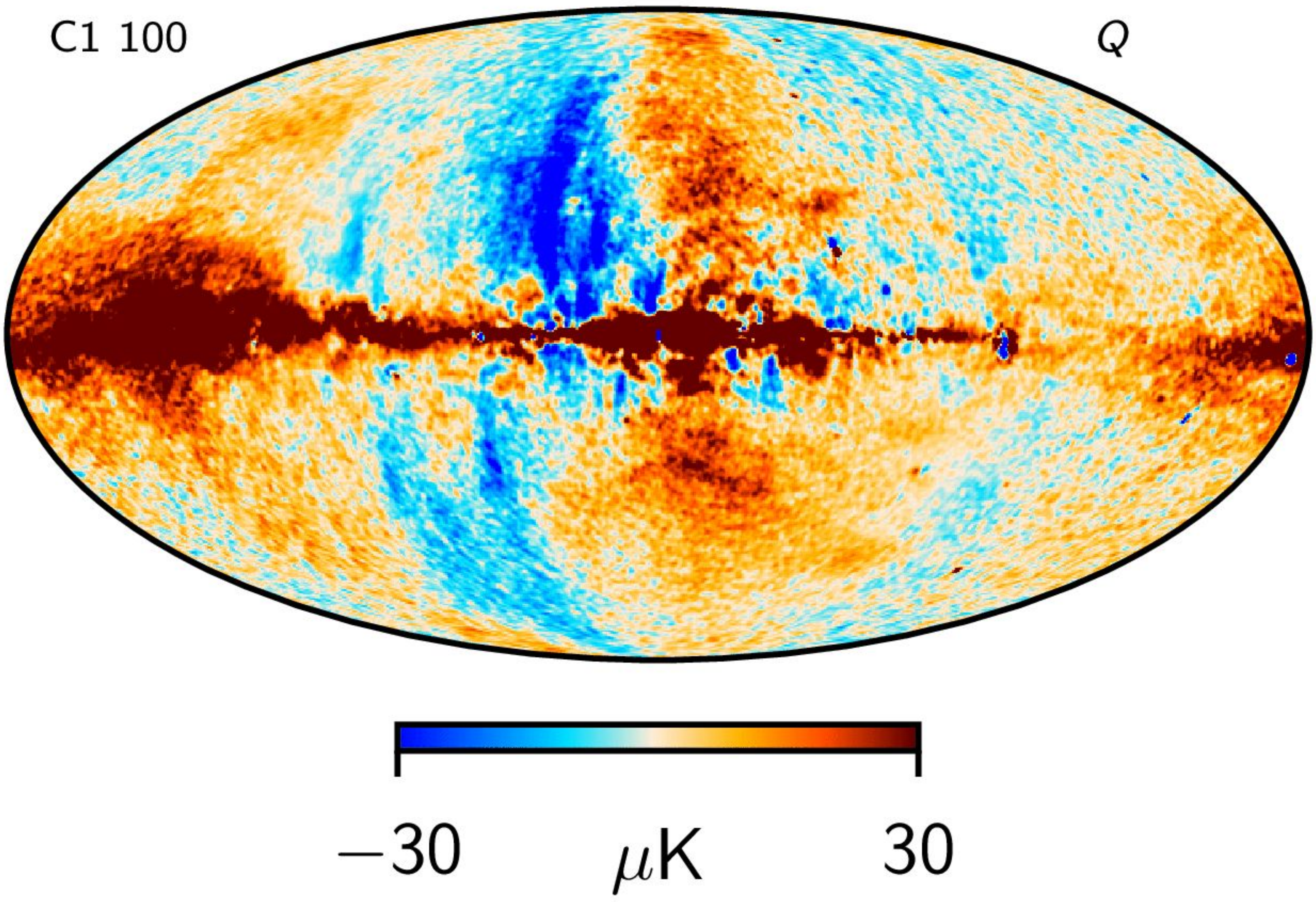
BeyondPlanck map-making

BeyondPlanck data model

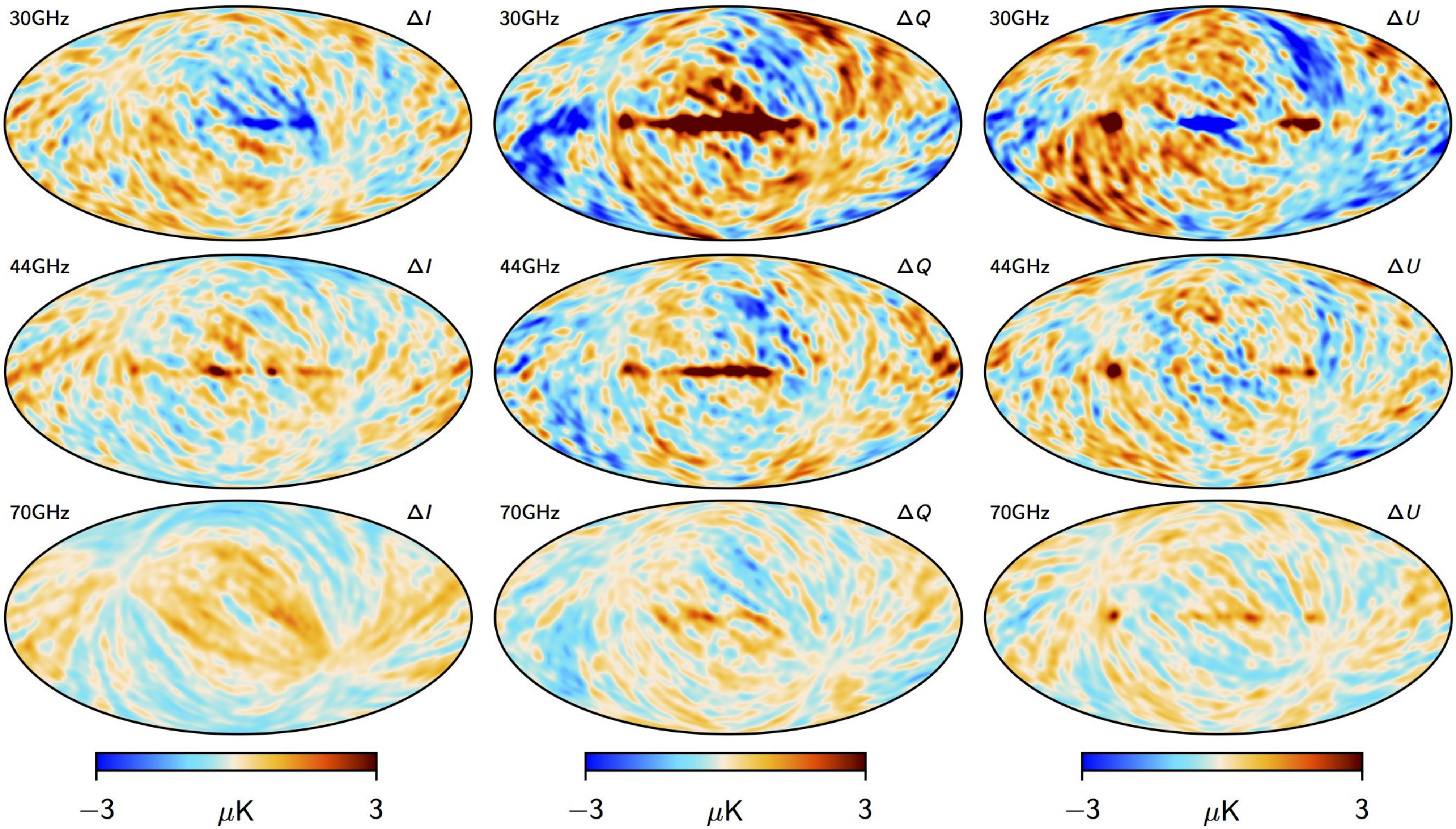
$$d_{j,t} = g_{j,t} \mathsf{P}_{tp,j} \left[\mathsf{B}^{\mathrm{symm}}_{pp',j} \sum_{c} \mathsf{M}_{cj}(\beta_{p'}, \Delta^{j}_{\mathrm{bp}}) a^{c}_{p'} + \mathsf{B}^{\mathrm{asymm}}_{j,t} \left(\boldsymbol{s}^{\mathrm{orb}}_{j} + \boldsymbol{s}^{\mathrm{fsl}}_{t} \right) \right] + n^{\mathrm{corr}}_{j,t} + n^{\mathrm{w}}_{j,t}.$$

Map is a derived quantity!

Ensemble of frequency maps

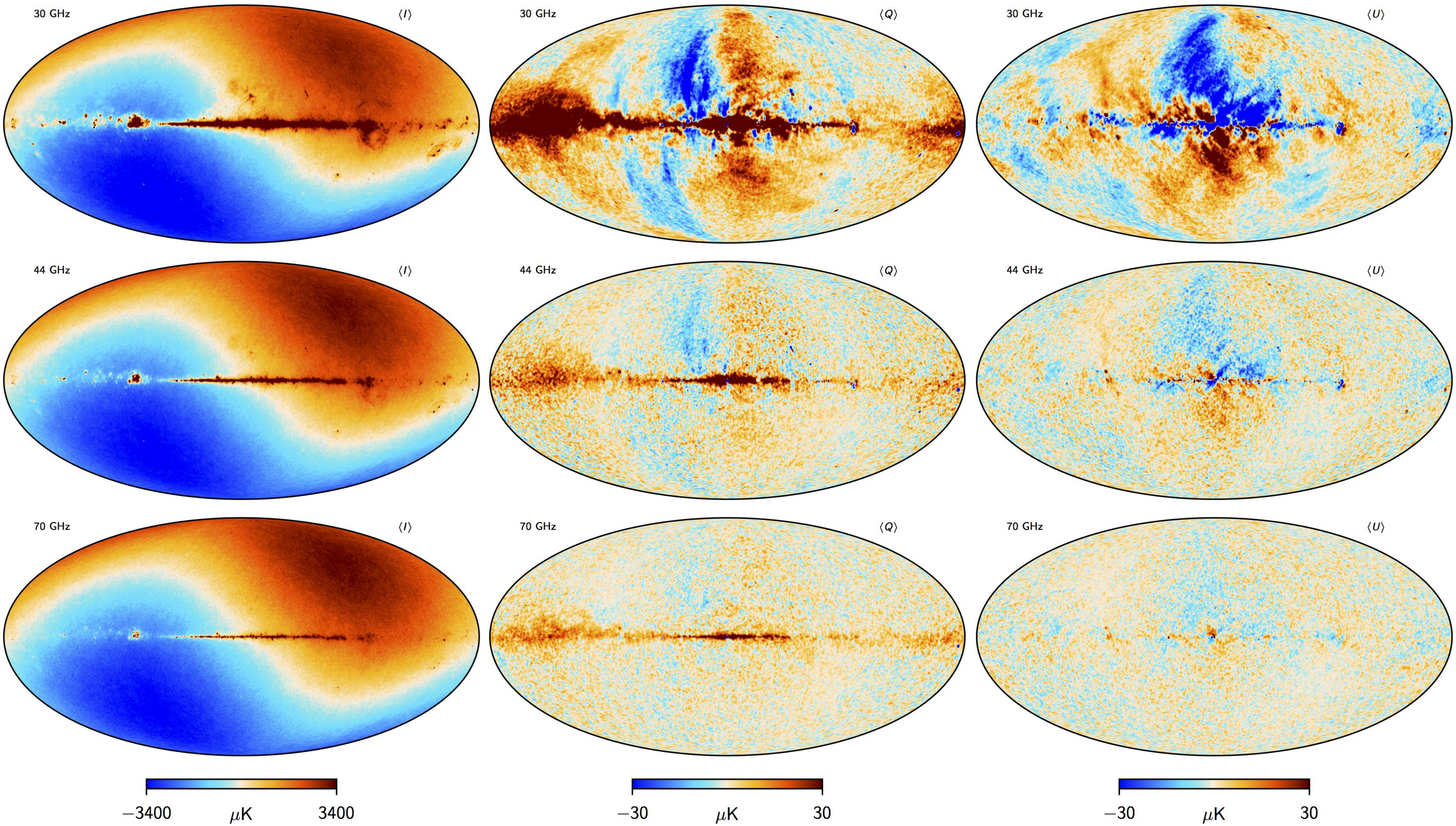


Sample difference



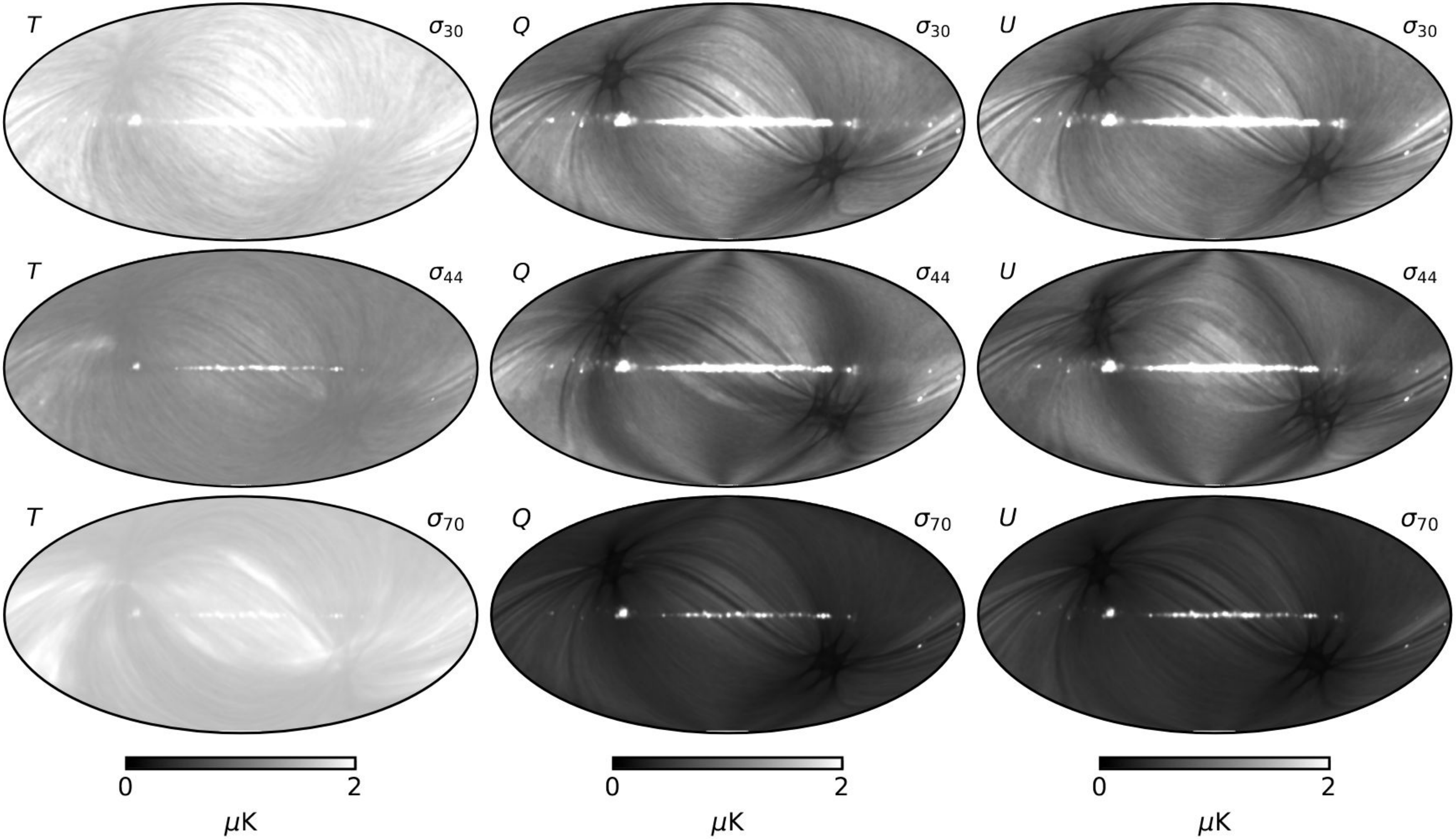
Frequency maps: Posterior means

$$\hat{\boldsymbol{m}}_\nu = \left\langle \boldsymbol{m}_\nu^i \right\rangle$$

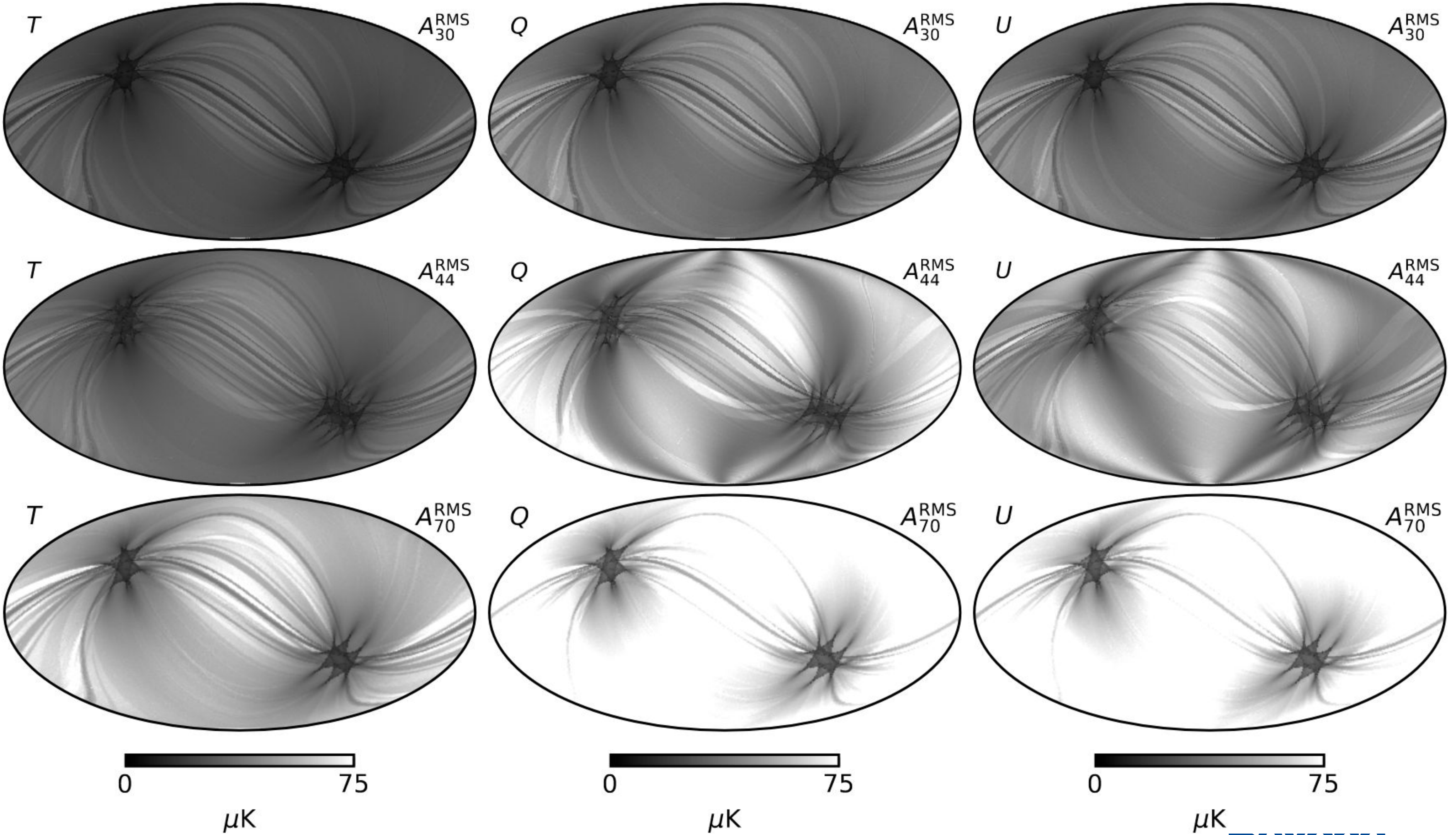


Frequency maps: Posterior RMS

$$\sigma_\nu(p) = \sqrt{\left\langle \left(m_\nu^i(p) - \hat{m}_\nu(p) \right)^2 \right\rangle}$$



Frequency maps: White noise



Planck 2018 and NPIPE

Astronomy & Astrophysics manuscript no. L02˙LFI˙Data˙Processing˙combined
September 12, 2018

Planck 2018 results. II. Low Frequency Instrument data processing

Planck Collaboration: Y. Akrami[54,56], F. Argüeso[14], M. Ashdown[63,4], J. Aumont[87], C. Baccigalupi[74], M. Ballardini[18,41], A. J. Banday[87,6], R. B. Barreiro[58], N. Bartolo[24,59], S. Basak[51], K. Benabed[53,86], J.-P. Bernard[87,6], M. Bersanelli[27,42], P. Bielewicz[71,6,74], L. Bonavera[12], J. R. Bond[5], J. Borrill[9,84], F. R. Bouchet[53,82], F. Boulanger[52], C. Burigana[40,25,44], R. C. Butler[41], E. Calabrese[78], J.-F. Cardoso[53], L. P. L. Colombo[19,60], B. P. Crill[60,8], F. Cuttaia[41], P. de Bernardis[26], A. de Rosa[41], G. de Zotti[37,74], J. Delabrouille[1], E. Di Valentino[53,82], C. Dickinson[61], J. M. Diego[58], A. Ducout[53,50], X. Dupac[30], G. Efstathiou[63,55], F. Elsner[69], T. A. Enßlin[69], H. K. Eriksen[56], Y. Fantaye[2,16], F. Finelli[41,44], M. Frailis[38], E. Franceschi[41], A. Frolov[81], S. Galeotta[38], S. Galli[62], K. Ganga[1], R. T. Génova-Santos[57,11], M. Gerbino[85,72,26], T. Ghosh[77,7], J. González-Nuevo[12], K. M. Górski[60,88], S. Gratton[63,55], A. Gruppuso[36,44], J. E. Gudmundsson[85,21], W. Handley[63,4], F. K. Hansen[56], D. Herranz[58], E. Hivon[53,86], Z. Huang[79], A. H. Jaffe[50], W. C. Jones[21], A. Karakci[1], E. Keihänen[20], R. Keskitalo[9], K. Kiiveri[20,35], J. Kim[69], T. S. Kisner[67], N. Krachmalnicoff[74], M. Kunz[10,52,2], H. Kurki-Suonio[20,35], J.-M. Lamarre[64], A. Lasenby[4,63], M. Lattanzi[25,45], C. R. Lawrence[60], J. P. Leahy[61], F. Levrier[64], M. Liguori[24,59], P. B. Lilje[56], V. Lindholm[20,35], M. López-Caniego[30], Y.-Z. Ma[61,76,73], J. F. Macías-Pérez[65], G. Maggio[38], D. Maino[27,42,46] ⋆, A. Mangilli[6], M. Maris[38], P. G. Martin[5], E. Martínez-González[58], S. Matarrese[24,59,32], N. Mauri[44], J. D. McEwen[70], P. R. Meinhold[22], A. Melchiorri[26,47], A. Mennella[27,42], M. Migliaccio[83,48], D. Molinari[25,41,45], L. Montier[87,6], G. Morgante[41], A. Moss[80], P. Natoli[25,83,45], L. Pagano[52,64], D. Paoletti[41,44], B. Partridge[34], G. Patanchon[1], L. Patrizii[44], M. Peel[13,61], V. Pettorino[33], F. Piacentini[26], G. Polenta[3], J.-L. Puget[52,53], J. P. Rachen[15], B. Racine[56], M. Reinecke[69], M. Remazeilles[61,52,1], A. Renzi[74,49], G. Rocha[60,8], G. Roudier[1,64,60], J. A. Rubiño-Martín[57,11], L. Salvati[52], M. Sandri[41], M. Savelainen[20,35,68], D. Scott[17], D. S. Seljebotn[56], C. Sirignano[24,59], G. Sirri[44], L. D. Spencer[78], A.-S. Suur-Uski[20,35], J. A. Tauber[31], D. Tavagnacco[38,28], M. Tenti[43], L. Terenzi[41], L. Toffolatti[12,41], M. Tomasi[27,42], T. Trombetti[25,39,45], J. Valiviita[20,35], F. Vansyngel[52], F. Van Tent[66], P. Vielva[58], F. Villa[41], N. Vittorio[29], B. D. Wandelt[53,86,23], R. Watson[61], I. K. Wehus[60,56], A. Zacchei[38], and A. Zonca[75]

(Affiliations can be found after the references)

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ABSTRACT

We present a final description of the data-processing pipeline for the *Planck* Low Frequency Instrument (LFI), implemented for the 2018 data release. Several improvements have been made with respect to the previous release, especially in the calibration process and in the correction of instrumental features such as the effects of nonlinearity in the response of the analogue-to-digital converters. We provide a brief pedagogical introduction to the complete pipeline, as well as a detailed description of the important changes implemented. Self-consistency of the pipeline is demonstrated using dedicated simulations and null tests. We present the final version of the LFI full sky maps at 30, 44, and 70 GHz, both in temperature and polarization, together with a refined estimate of the solar dipole and a final assessment of the main LFI instrumental parameters.

Key words. Space vehicles: instruments – Methods: data analysis – cosmic microwave background

Contents

⋆ Corresponding author: D.Maino, davide.maino@mi.infn.it

1

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July 13, 2020

Planck intermediate results. LVII. Joint *Planck* LFI and HFI data processing

Planck Collaboration: Y. Akrami[11,49,50], K. J. Andersen[50], M. Ashdown[56,3], C. Baccigalupi[65], M. Ballardini[16,33], A. J. Banday[78,6], R. B. Barreiro[52], N. Bartolo[20,53], S. Basak[71], K. Benabed[48,73], J.-P. Bernard[78,6], M. Bersanelli[23,38], P. Bielewicz[64,65], J. R. Bond[5], J. Borrill[9,76], C. Burigana[37,21,40], R. C. Butler[33], E. Calabrese[68], B. Casaponsa[52], H. C. Chiang[18,4], L. P. L. Colombo[23], C. Combet[58], B. P. Crill[54,8], F. Cuttaia[33], P. de Bernardis[22], A. de Rosa[33], G. de Zotti[34], J. Delabrouille[1], E. Di Valentino[55], J. M. Diego[52], O. Doré[54,8], M. Douspis[47], X. Dupac[26], H. K. Eriksen[50], R. Fernandez-Cobos[52], F. Finelli[33,40], M. Frailis[35], A. A. Fraisse[18], E. Franceschi[33], A. Frolov[72], S. Galeotta[35], S. Galli[48,73], K. Ganga[1], M. Gerbino[29], T. Ghosh[67,7], J. González-Nuevo[13], K. M. Górski[54,79], A. Gruppuso[33,40], J. E. Gudmundsson[77,18], W. Handley[56,3], G. Helou[8], D. Herranz[52], S. R. Hildebrandt[54,8], E. Hivon[48,73], Z. Huang[69], A. H. Jaffe[45], W. C. Jones[18], E. Keihänen[17], R. Keskitalo[9] ⋆, K. Kiiveri[17,31], J. Kim[62], T. S. Kisner[60], N. Krachmalnicoff[65], M. Kunz[10,47,2], H. Kurki-Suonio[17,31], A. Lasenby[3,56], M. Lattanzi[41,21], C. R. Lawrence[54], M. Le Jeune[1], F. Levrier[74], M. Liguori[20,53], P. B. Lilje[50], M. Lilley[48,73], V. Lindholm[17,31], M. López-Caniego[26], P. M. Lubin[19], J. F. Macías-Pérez[58], D. Maino[23,38,42], N. Mandolesi[33,21], A. Marcos-Caballero[52], M. Maris[35], P. G. Martin[5], E. Martínez-González[52], S. Matarrese[20,53,28], N. Mauri[40], J. D. McEwen[63], P. R. Meinhold[19], A. Mennella[23,38], M. Migliaccio[25,43], S. Mitra[44,54], D. Molinari[21,33,41], L. Montier[78,6], G. Morgante[33], A. Moss[70], P. Natoli[21,75,41], D. Paoletti[33,40], B. Partridge[30], G. Patanchon[1], D. Pearson[54], T. J. Pearson[8,46], F. Perrotta[65], F. Piacentini[22], G. Polenta[75], J. P. Rachen[14], M. Reinecke[62], M. Remazeilles[55], A. Renzi[53], G. Rocha[54,8], C. Rosset[1], G. Roudier[1,74,54], J. A. Rubiño-Martín[51,12], B. Ruiz-Granados[51,12], L. Salvati[32,36], M. Savelainen[17,31,61], D. Scott[15], C. Sirignano[20,53], G. Sirri[40], L. D. Spencer[68], A.-S. Suur-Uski[17,31], T. L. Svalheim[50], J. A. Tauber[27], D. Tavagnacco[35,24], M. Tenti[39], L. Terenzi[33], H. Thommesen[50], L. Toffolatti[13,33], M. Tomasi[23,38], M. Tristram[57], T. Trombetti[37,41], J. Valiviita[17,31], B. Van Tent[59], P. Vielva[52], F. Villa[33], N. Vittorio[25], B. D. Wandelt[48,73], I. K. Wehus[50], A. Zacchei[35], and A. Zonca[66]

(Affiliations can be found after the references)

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ABSTRACT

We present the `NPIPE` processing pipeline, which produces calibrated frequency maps in temperature and polarization from data from the *Planck* Low Frequency Instrument (LFI) and High Frequency Instrument (HFI) using high-performance computers. `NPIPE` represents a natural evolution of previous *Planck* analysis efforts, and combines some of the most powerful features of the separate LFI and HFI analysis pipelines. For example, following the LFI 2018 processing procedure, `NPIPE` uses foreground polarization priors during the calibration stage in order to break scanning-induced degeneracies. Similarly, `NPIPE` employs the HFI 2018 time-domain processing methodology to correct for bandpass mismatch at all frequencies. In addition, `NPIPE` introduces several improvements, including, but not limited to: inclusion of the 8 % of data collected during repointing manoeuvres; smoothing of the LFI reference load data streams; in-flight estimation of detector polarization parameters; and construction of maximally independent detector-set split maps. For component-separation purposes, important improvements include: maps that retain the CMB Solar dipole, allowing for high-precision relative calibration in higher-level analyses; well-defined single-detector maps, allowing for robust CO extraction; and HFI temperature maps between 217 and 857 GHz that are binned into 0.′9 pixels ($N_{\rm side} = 4096$), ensuring that the full angular information in the data is represented in the maps even at the highest *Planck* resolutions. The net effect of these improvements is lower levels of noise and systematics in both frequency and component maps at essentially all angular scales, as well as notably improved internal consistency between the various frequency channels. Based on the `NPIPE` maps, we present the first estimate of the Solar dipole determined through component separation across all nine *Planck* frequencies. The amplitude is $(3366.6 \pm 2.7)\,\mu$K, consistent with, albeit slightly higher than, earlier estimates. From the large-scale polarization data, we derive an updated estimate of the optical depth of reionization of $\tau = 0.051 \pm 0.006$, which appears robust with respect to data and sky cuts. There are 600 complete signal, noise and systematics simulations of the full-frequency and detector-set maps. As a *Planck* first, these simulations include full time-domain processing of the beam-convolved CMB anisotropies. The release of `NPIPE` maps and simulations is accompanied with a complete suite of raw and processed time-ordered data and the software, scripts, auxiliary data, and parameter files needed to improve further on the analysis and to run matching simulations.

Key words. cosmology: cosmic background radiation – cosmology: observations – methods: data analysis – methods: high-performance computing

Contents

⋆ Corresponding author: R. Keskitalo, `rtkeskitalo@lbl.gov`

1

Planck 2018 and NPIPE

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September 12, 2018

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- Madam
- N_{side}=1024
- 0.25 - 1.0 s baselines
- Dipole removed
- Missing beam power
- Available from PLA

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Planck intermediate results. LVII. Joint *Planck* LFI and HFI data processing

Planck Collaboration: Y. Akrami[11,49,50], K. J. Andersen[50], M. Ashdown[56,3], C. Baccigalupi[65], M. Ballardini[16,33], A. J. Banday[78,6], R. B. Barreiro[52], N. Bartolo[20,53], S. Basak[71], K. Benabed[48,73], J.-P. Bernard[78,6], M. Bersanelli[23,38], P. Bielewicz[64,65], J. R. Bond[5], J. Borrill[9,76], C. Burigana[37,21,40], R. C. Butler[33], E. Calabrese[68], B. Casaponsa[52], H. C. Chiang[18,4], L. P. L. Colombo[23], C. Combet[58], B. P. Crill[54,8], F. Cuttaia[33], P. de Bernardis[22], A. de Rosa[33], G. de Zotti[34], J. Delabrouille[1], E. Di Valentino[55], J. M. Diego[52], O. Doré[54,8], M. Douspis[47], X. Dupac[26], H. K. Eriksen[50], R. Fernandez-Cobos[52], F. Finelli[33,40], M. Frailis[35], A. A. Fraisse[18], E. Franceschi[33], A. Frolov[72], S. Galeotta[35], S. Galli[48,73], K. Ganga[1], M. Gerbino[29], T. Ghosh[67,7], J. González-Nuevo[13], K. M. Górski[54,79], A. Gruppuso[33,40], J. E. Gudmundsson[77,18], W. Handley[56,3], G. Helou[8], D. Herranz[52], S. R. Hildebrandt[54,8], E. Hivon[48,73], Z. Huang[69], A. H. Jaffe[45], W. C. Jones[18], E. Keihänen[17], R. Keskitalo[9] ⋆, K. Kiiveri[17,31], J. Kim[62], T. S. Kisner[60], N. Krachmalnicoff[65], M. Kunz[10,47,2], H. Kurki-Suonio[17,31], A. Lasenby[3,56], M. Lattanzi[41,21], C. R. Lawrence[54], M. Le Jeune[1], F. Levrier[74], M. Liguori[20,53], P. B. Lilje[50], M. Lilley[48,73], V. Lindholm[17,31], M. López-Caniego[26], P. M. Lubin[19], J. F. Macías-Pérez[58], D. Maino[23,38,42], N. Mandolesi[33,21], A. Marcos-Caballero[52], M. Maris[35], P. G. Martin[5], E. Martínez-González[52], S. Matarrese[20,53,28], N. Mauri[40], J. D. McEwen[63], P. R. Meinhold[19], A. Mennella[23,38], M. Migliaccio[25,43], S. Mitra[44,54], D. Molinari[21,33,41], L. Montier[78,6], G. Morgante[33], A. Moss[70], P. Natoli[21,75,41], D. Paoletti[33,40], B. Partridge[30], G. Patanchon[1], D. Pearson[54], T. J. Pearson[8,46], F. Perrotta[65], F. Piacentini[22], G. Polenta[75], J. P. Rachen[14], M. Reinecke[62], M. Remazeilles[55], A. Renzi[53], G. Rocha[54,8], C. Rosset[1], G. Roudier[1,74,54], J. A. Rubiño-Martín[51,12], B. Ruiz-Granados[51,12], L. Salvati[32,36], M. Savelainen[17,31,61], D. Scott[15], C. Sirignano[20,53], G. Sirri[40], L. D. Spencer[68], A.-S. Suur-Uski[17,31], T. L. Svalheim[50], J. A. Tauber[27], D. Tavagnacco[35,24], M. Tenti[39], L. Terenzi[33], H. Thommesen[50], L. Toffolatti[13,33], M. Tomasi[23,38], M. Tristram[57], T. Trombetti[37,41], J. Valiviita[17,31], B. Van Tent[59], P. Vielva[52], F. Villa[33], N. Vittorio[25], B. D. Wandelt[48,73], I. K. Wehus[50], A. Zacchei[35], and A. Zonca[66]

(Affiliations can be found after the references)

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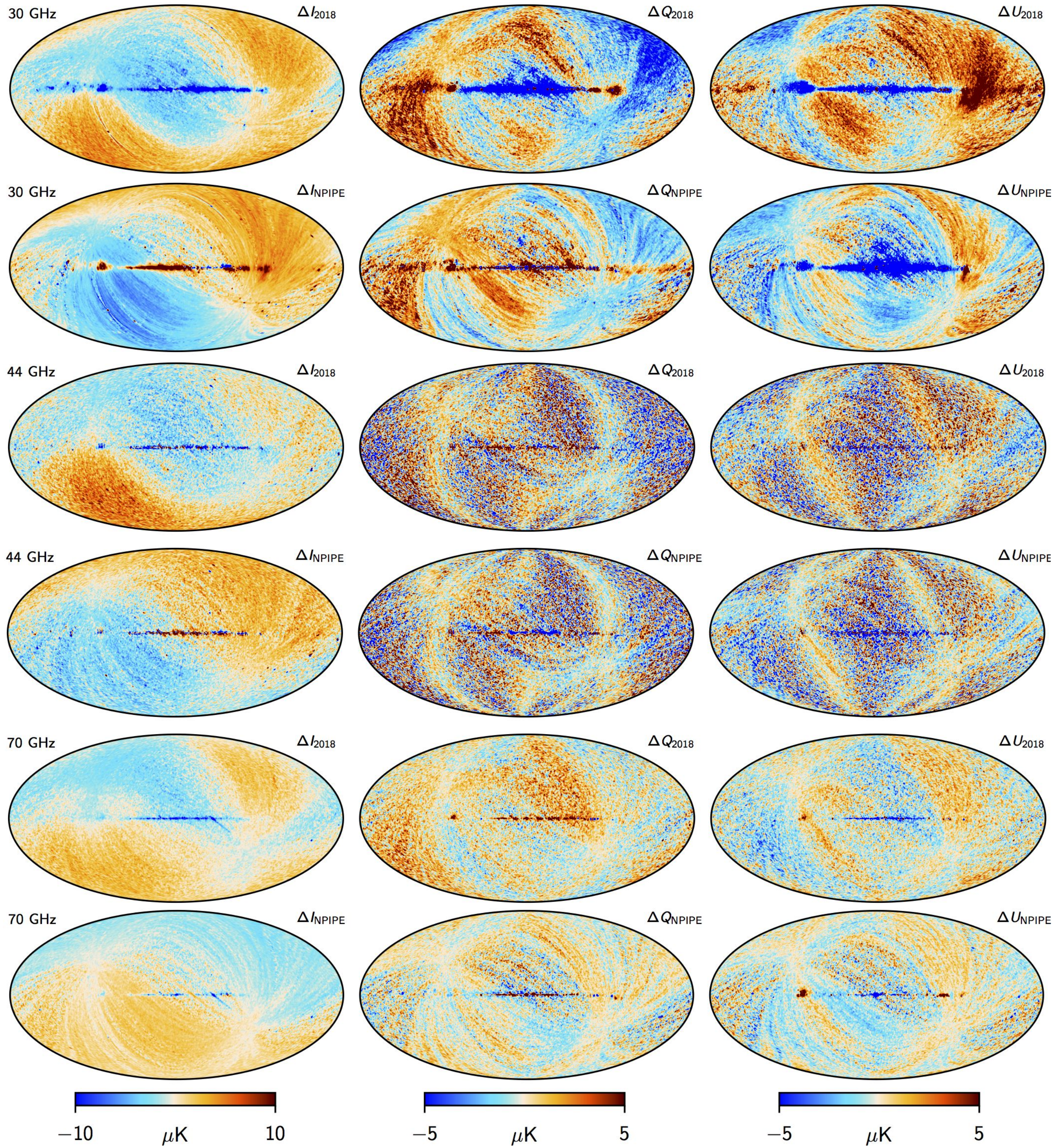
ABSTRACT

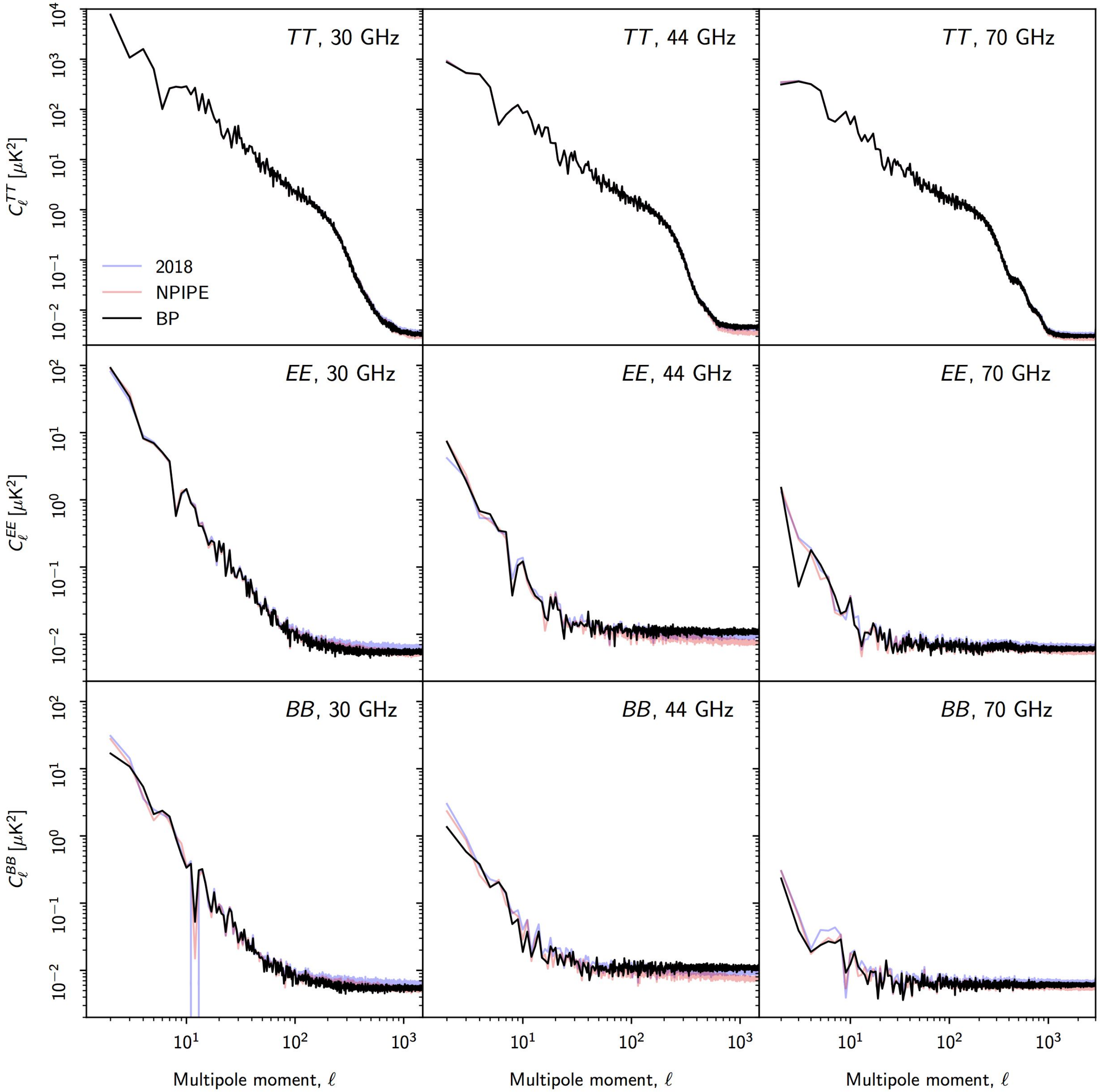
- libMadam
- N_{side}=1024
- 167 ms baselines
- Contains dipole
- Beams normalized
- Available from Nersc

Beyond PLANCK

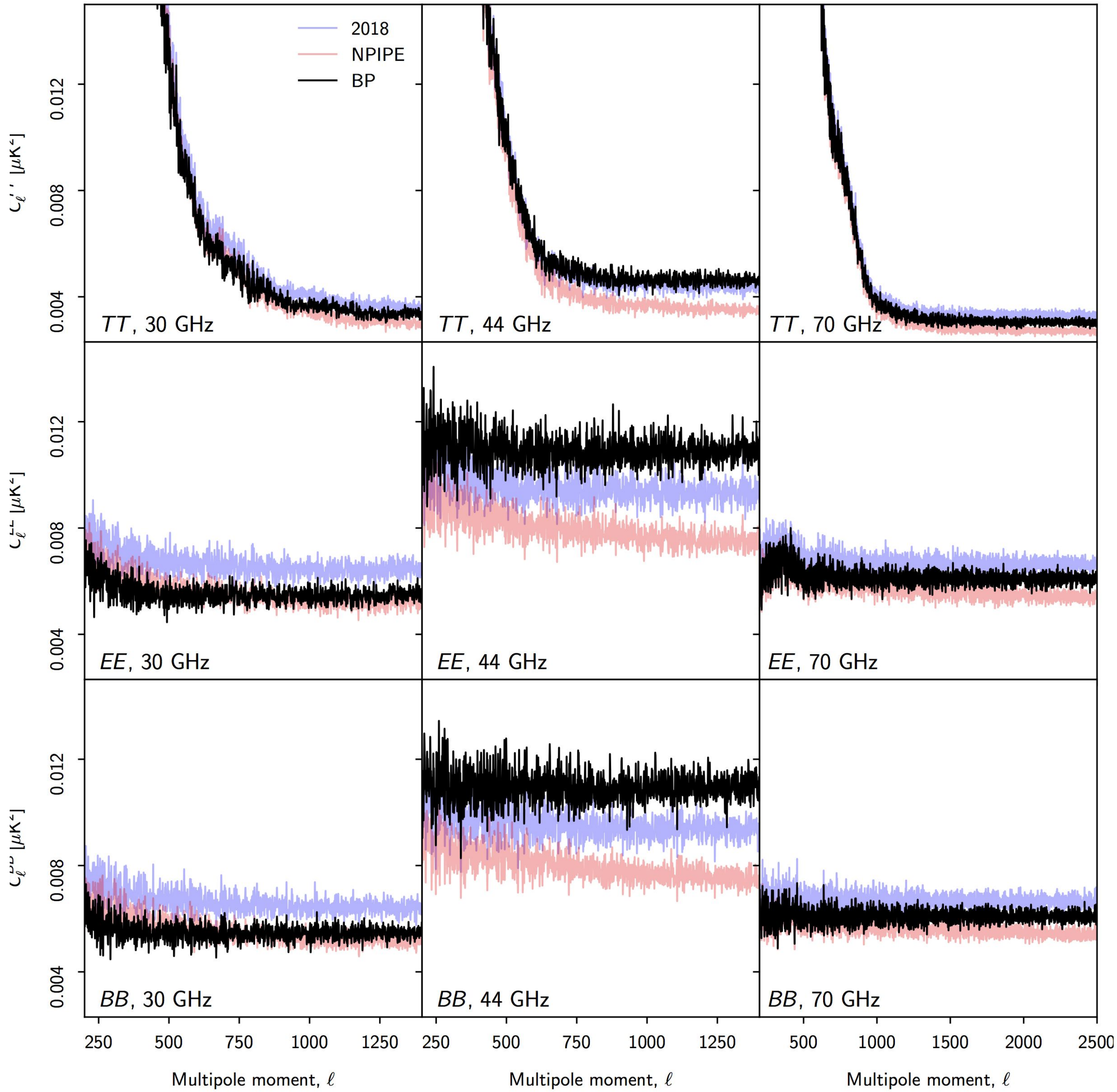
BeyondPlanck maps versus Planck 2018 & NPIPE



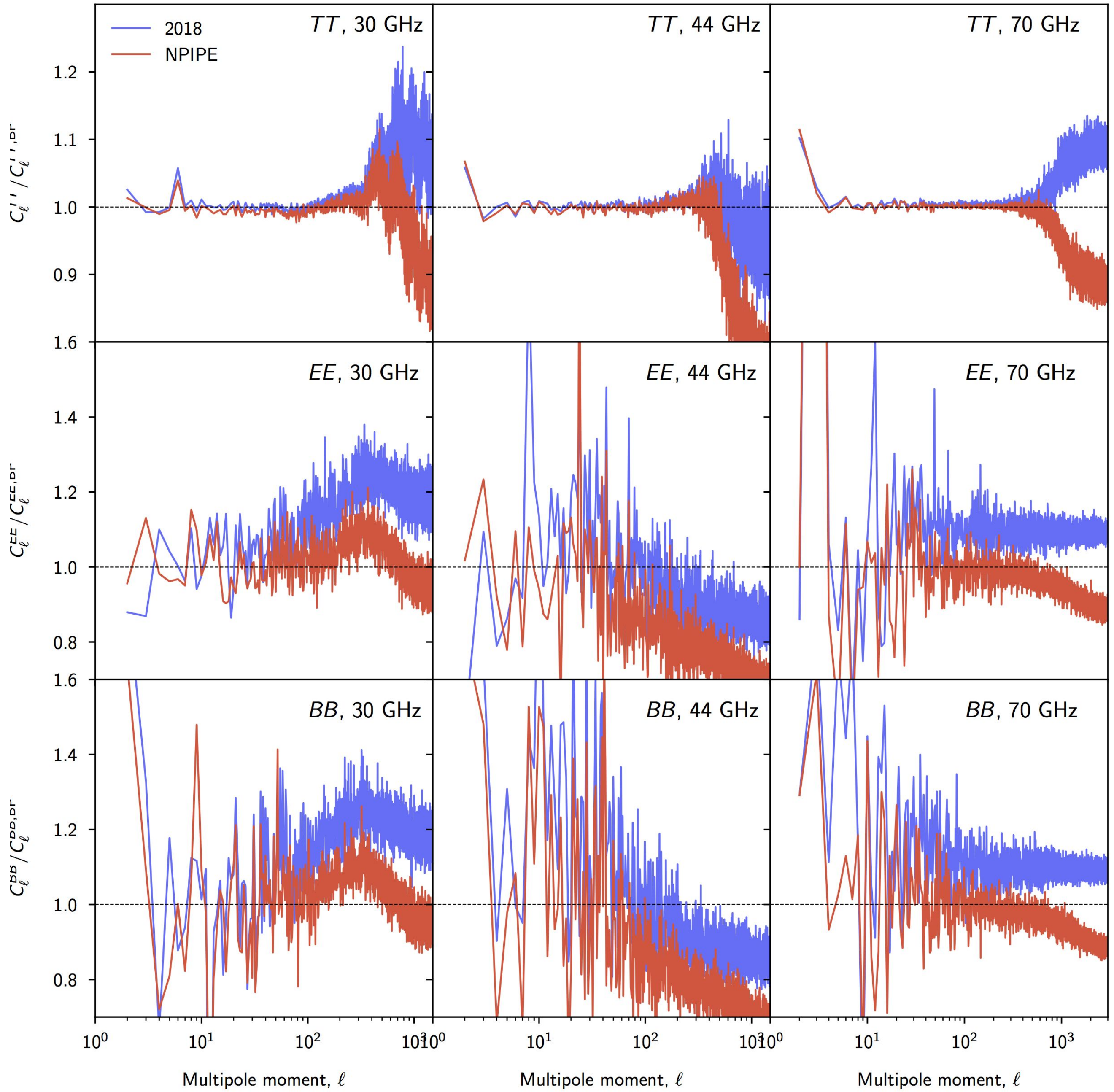
BeyondPlanck maps versus Planck 2018 & NPIPE



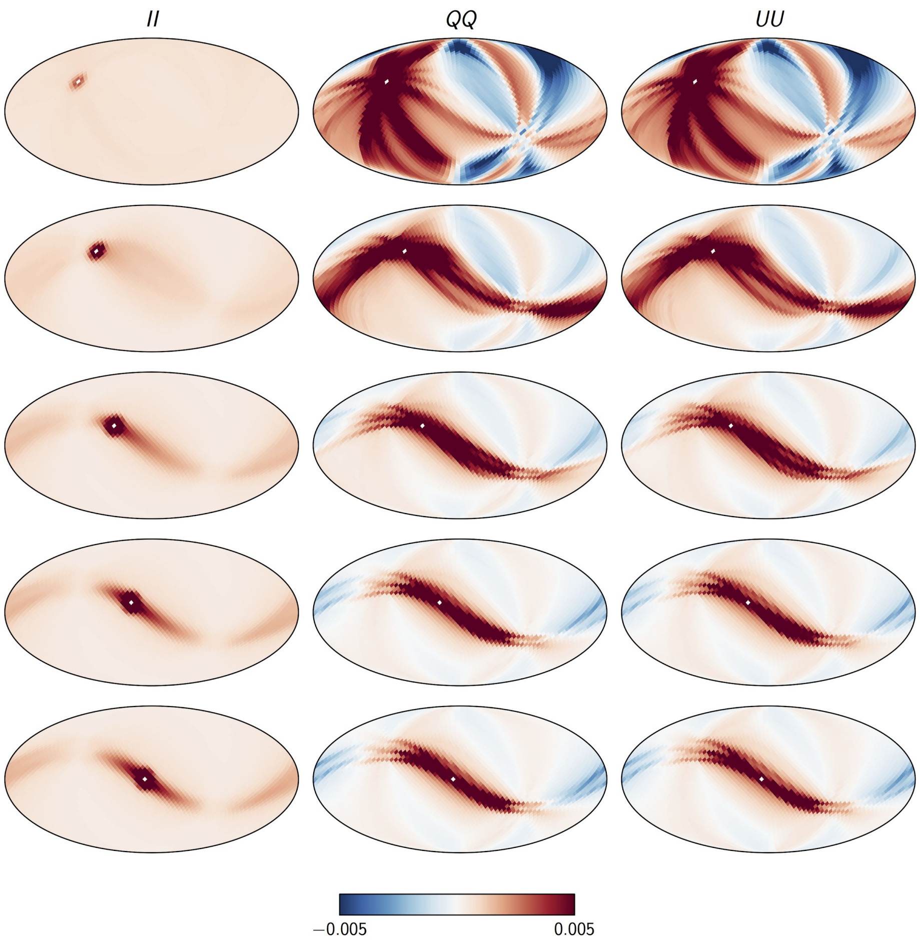
BeyondPlanck maps versus Planck 2018 & NPIPE

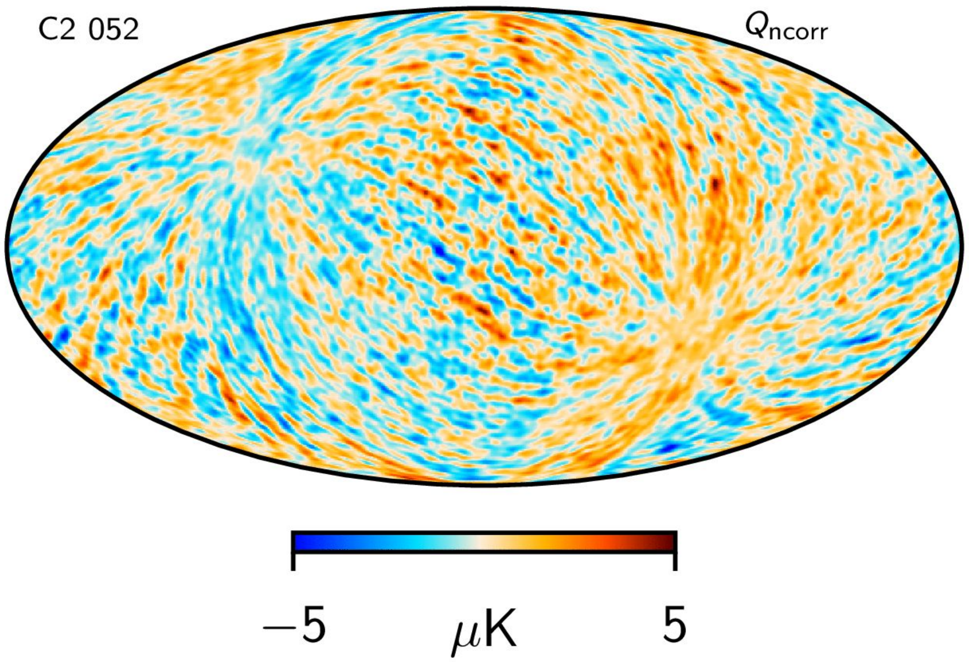


BeyondPlanck maps versus Planck 2018 & NPIPE



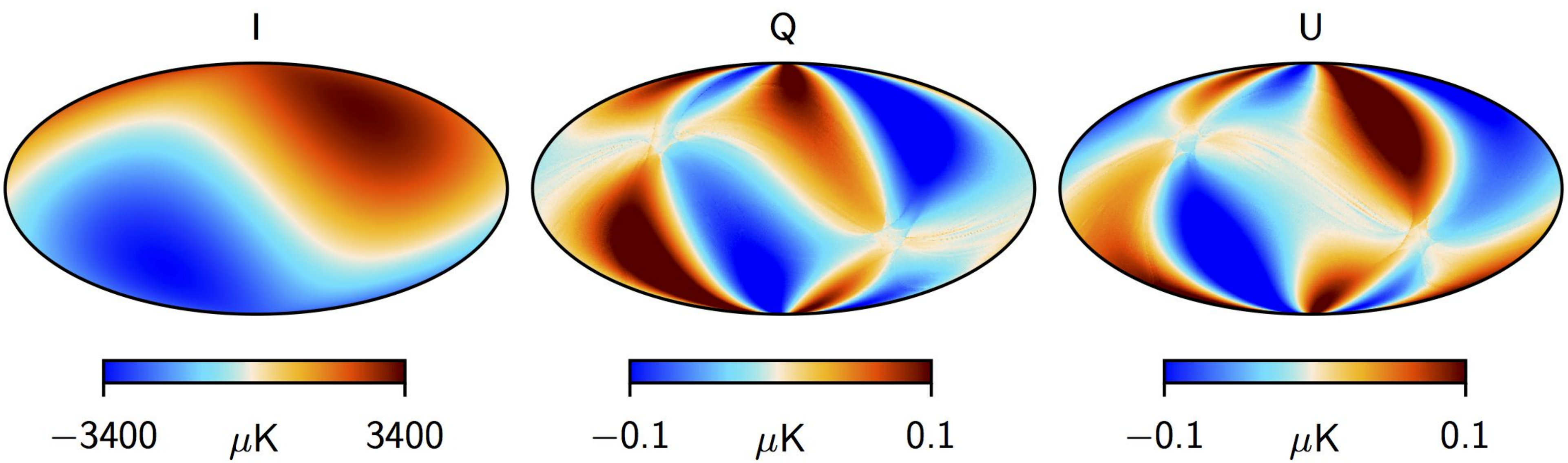
Error propagation





Beam deconvolution

- Removes effects of beam asymmetry
  - leakage of temperature signal to polarization through beam shape mismatch
  - deformed point source shapes
- Produces sky maps with effective symmetric beam



ArtDeco

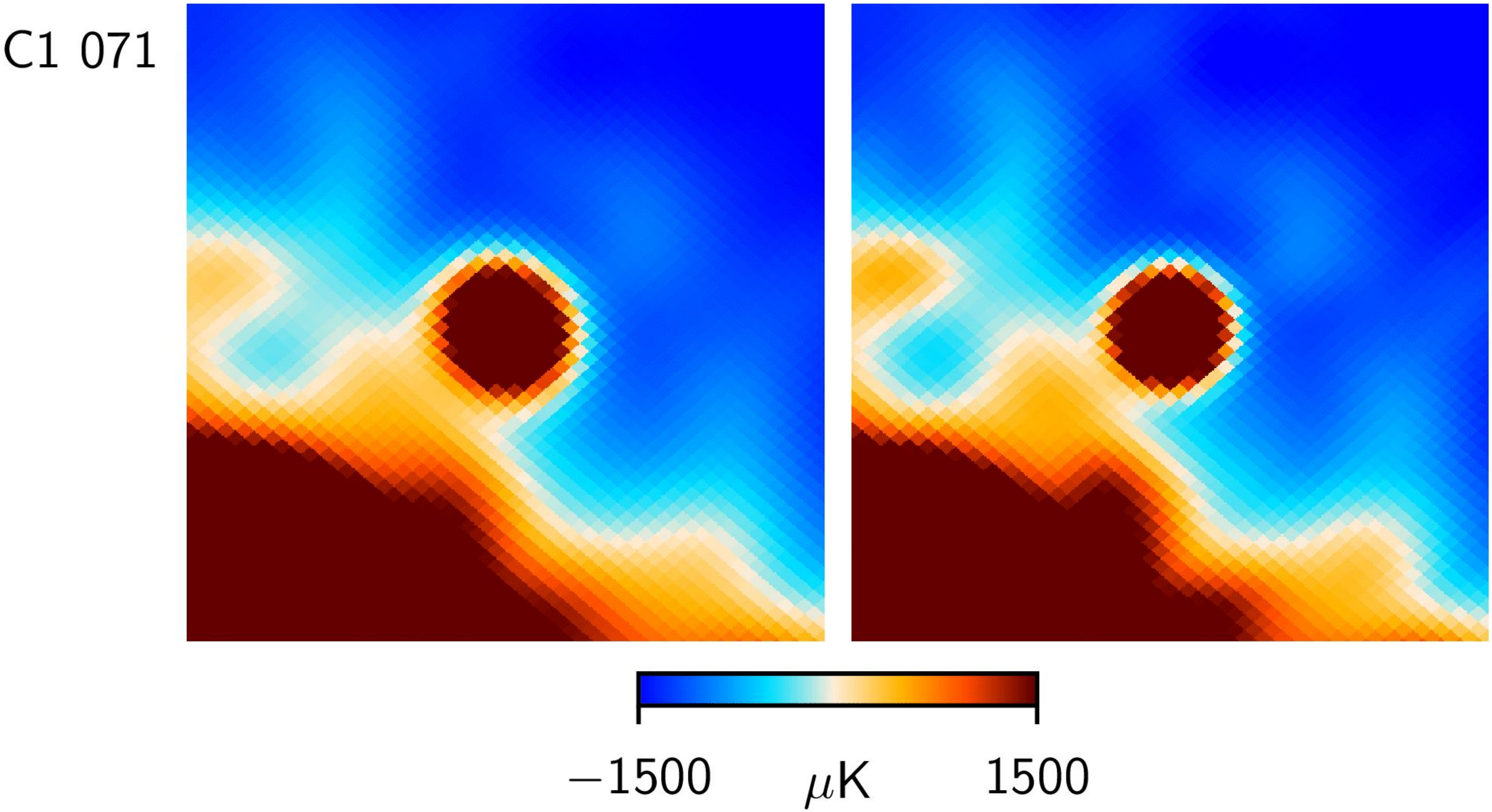
European Commission

- Deconvolver designed for Planck like data
  - Has been applied to Planck LFI data previously
- Required inputs
  - Cleaned TOD (destriped TOD)
  - Detector pointing
  - Beam model

  } Imported as “3D maps”
- Output
  - Harmonic coefficients a_{lm} , representing the beam-free sky
- References
  - ArtDeco: a beam-deconvolution code for absolute cosmic microwave background measurements
  - Impact of deconvolution on noise properties in CMB measurements: Application to Planck LFI

Beyond PLANCK

BP Deconvolution products



Conclusions

We have produced Planck LFI full-frequency maps with novel sample-based noise description:

- Full sky signal at 30, 44 and 70 GHz including CMB dipole
- Correlated noise propagation at full angular resolution with Monte Carlo sampling

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- "*BeyondPlanck*"
  - COMPET-4 program
  - PI: Hans Kristian Eriksen
  - Grant no.: 776282
  - Period: Mar 2018 to Nov 2020

Collaborating projects:

- "*bits2cosmology*"
  - ERC Consolidator Grant
  - PI: Hans Kristian Eriksen
  - Grant no: 772 253
  - Period: April 2018 to March 2023
- "*Cosmoglobe*"
  - ERC Consolidator Grant
  - PI: Ingunn Wehus
  - Grant no: 819 478
  - Period: June 2019 to May 2024

Questions?