# Component Separation at B-modes from Space

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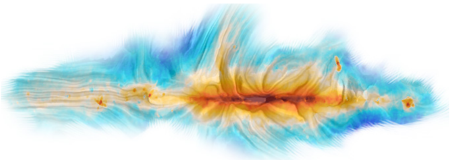
The International School for Advanced Studies (SISSA), Trieste

Berkeley, December 6th, 2017

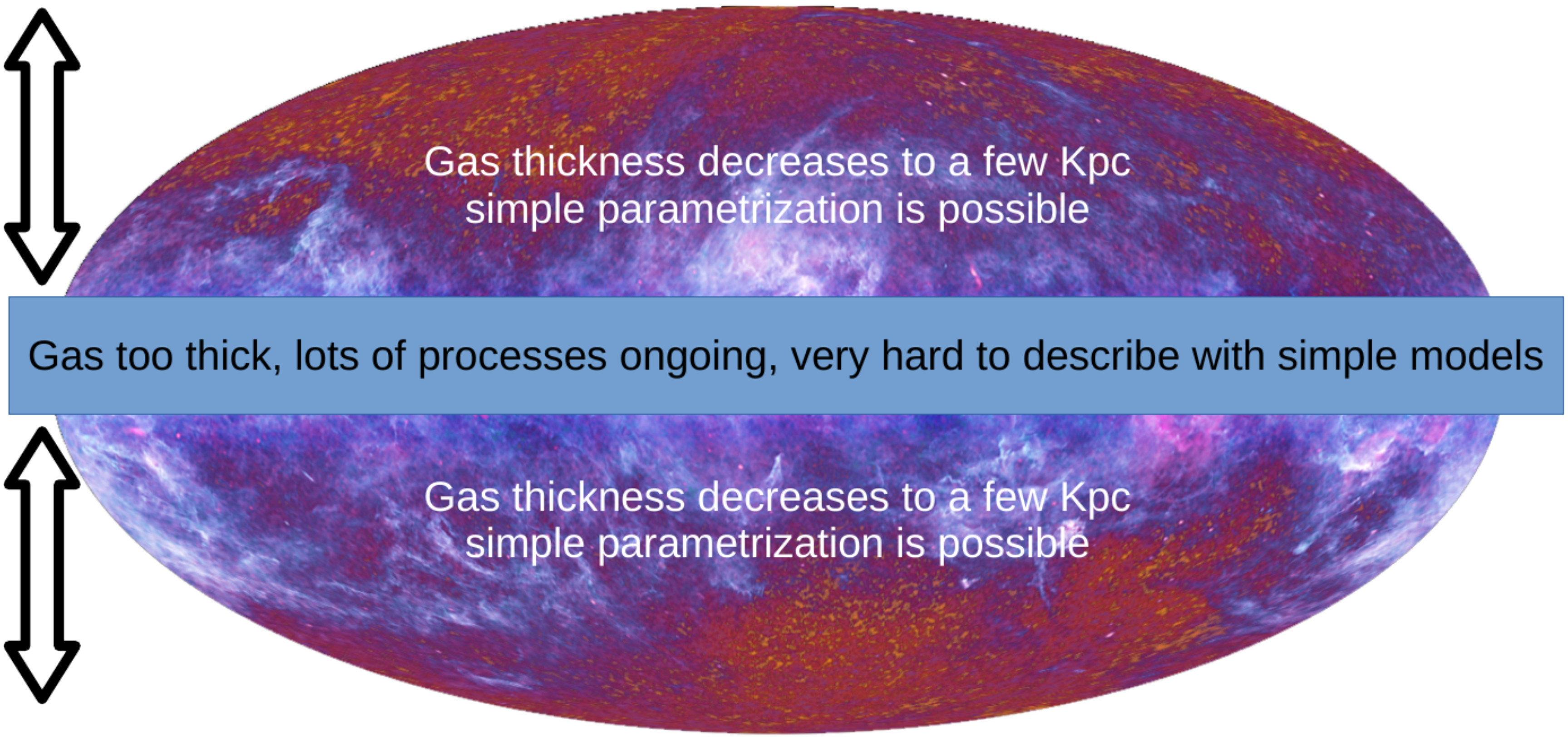


# Outline

- Planck Component Separation
- The relevance of Simulations
- Updated Contamination on B-modes from Galactic foregrounds
- B-mode Component Separation
- Conclusions

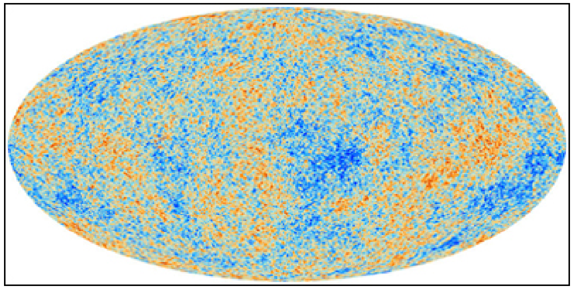
# Planck Component Separation

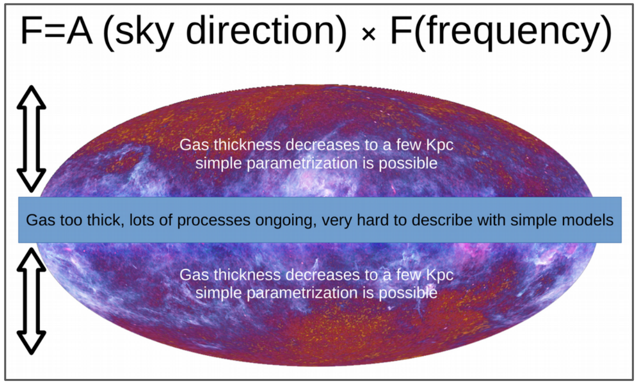
F=A (sky direction) × F(frequency)



# Component separation

$$X = A\,S + N$$

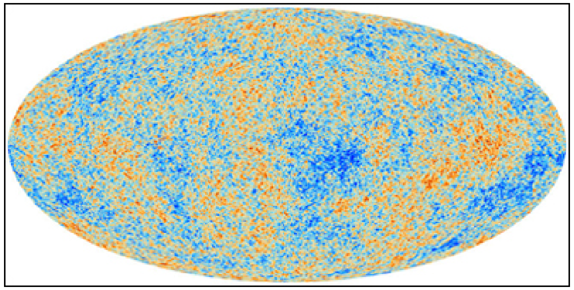




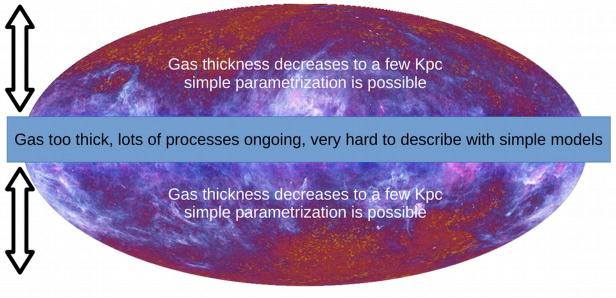
# Component separation

data — frequency scaling — amplitudes — noise

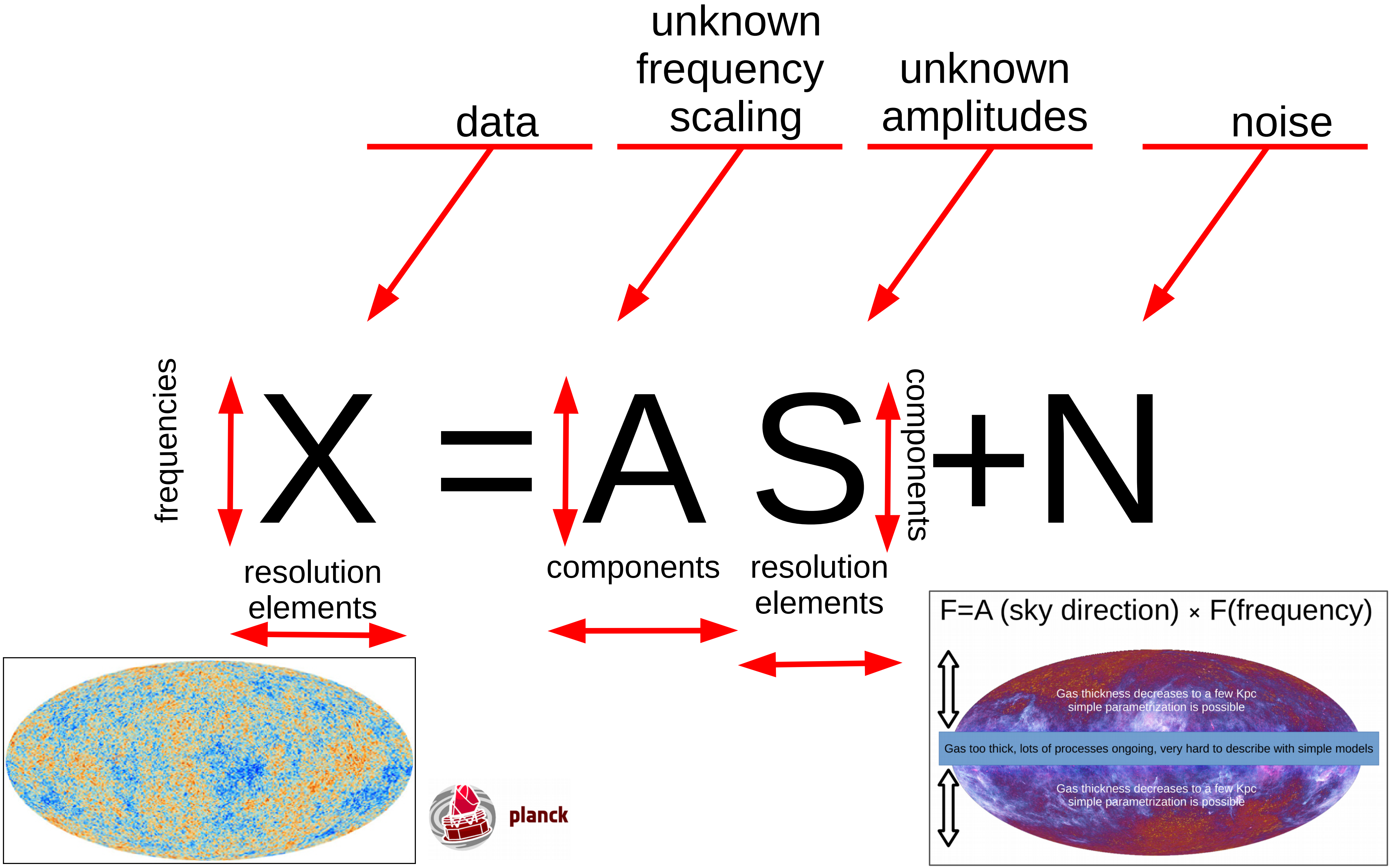
$$X = A\,S + N$$



F=A (sky direction) × F(frequency)



# Component separation



# Component separation

- On foregrounds you...
  - Know nothing
  - Know something

# Component separation

- Thus if you...
  - Know nothing, you
    - Look for minimum variance internal linear combination
  - Know something, you
    - Model foreground unknowns and fit

# Component separation

- Opearting domains: you can choose to cast your minimum variance search, or your fit, in
  - Pixel domain
  - Harmonic domain
  - Intermediate (needlets, wavelets) domain

# Component separation

- Thus if you...
  - Know nothing, you
    - Look for minimum variance internal linear combination
      - In the pixel domain
      - In the needlet domain
  - Know something, you
    - Model foreground unknowns and fit
      - In the pixel domain
      - In the needlet domain

# Component separation

- Thus if you...
  - Know nothing, you
    - Look for minimum variance internal linear combination
      - In the pixel domain – SEVEM
      - In the needlet domain – NILC
  - Know something, you
    - Model foreground unknowns and fit
      - In the pixel domain – COMMANDER
      - In the needlet domain – SMICA

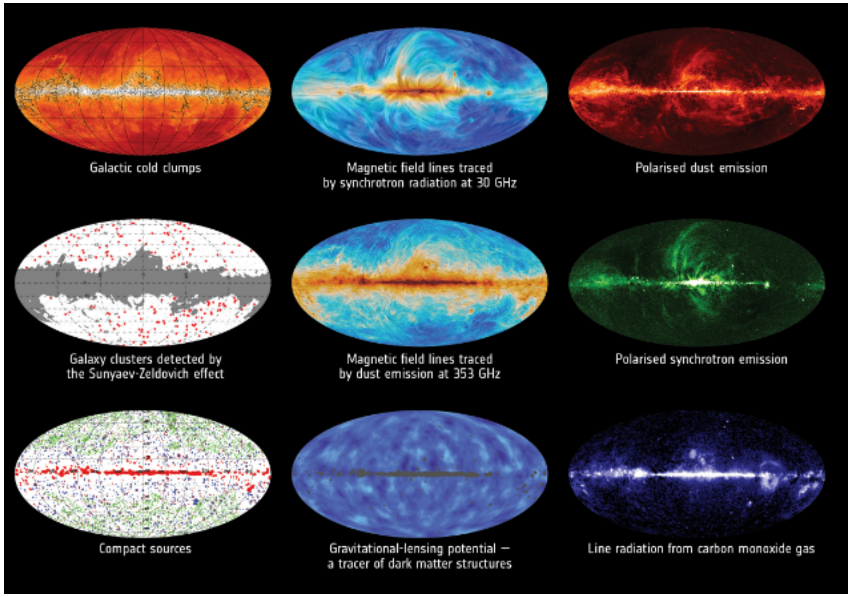
Planck 2013, XII, 2015, IX, X, 2017, in preparation

# Component separation

- Thus if you...
  - Know nothing, you
    - Look for minimum variance internal linear combination
      - In the pixel domain – SEVEM (CMB only)
      - In the needlet domain – NILC (CMB only)
  - Know something, you
    - Model foreground unknowns and fit
      - In the pixel domain – COMMANDER (CMB and foregrounds)
      - In the needlet domain – SMICA (CMB and foregrounds)

Planck 2013, XII, 2015, IX, X, 2017, in preparation

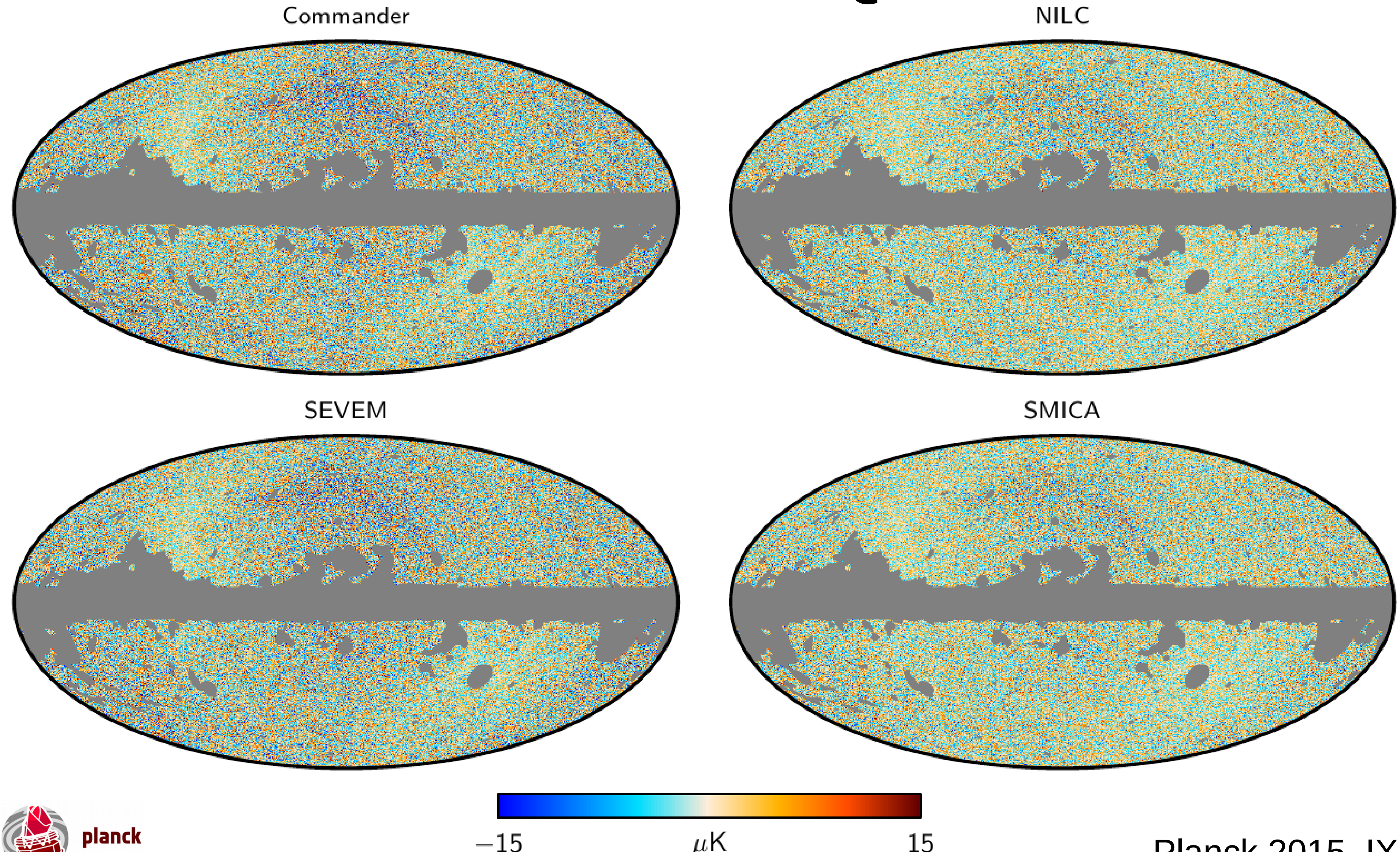
# Planck Foregrounds




- Main foreground monitor in present constraints on B-modes
- Guidance for current design study of forthcoming and long term probes
- New studies coming soon with the third data release, new dust analyses, new release of products,
- ...

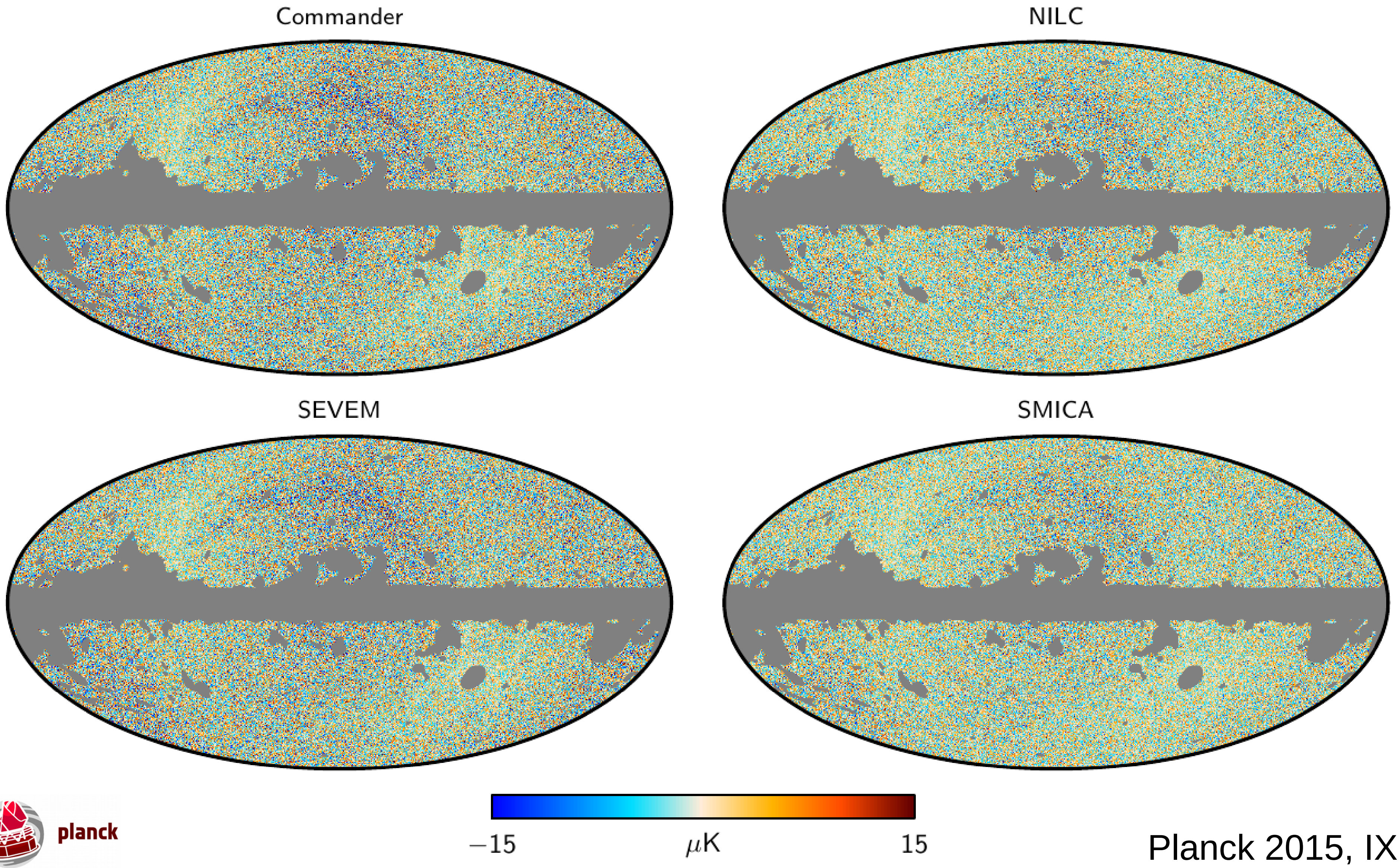
Planck 2013, XII, 2015, IX, X, 2017, in preparation

# Planck Q



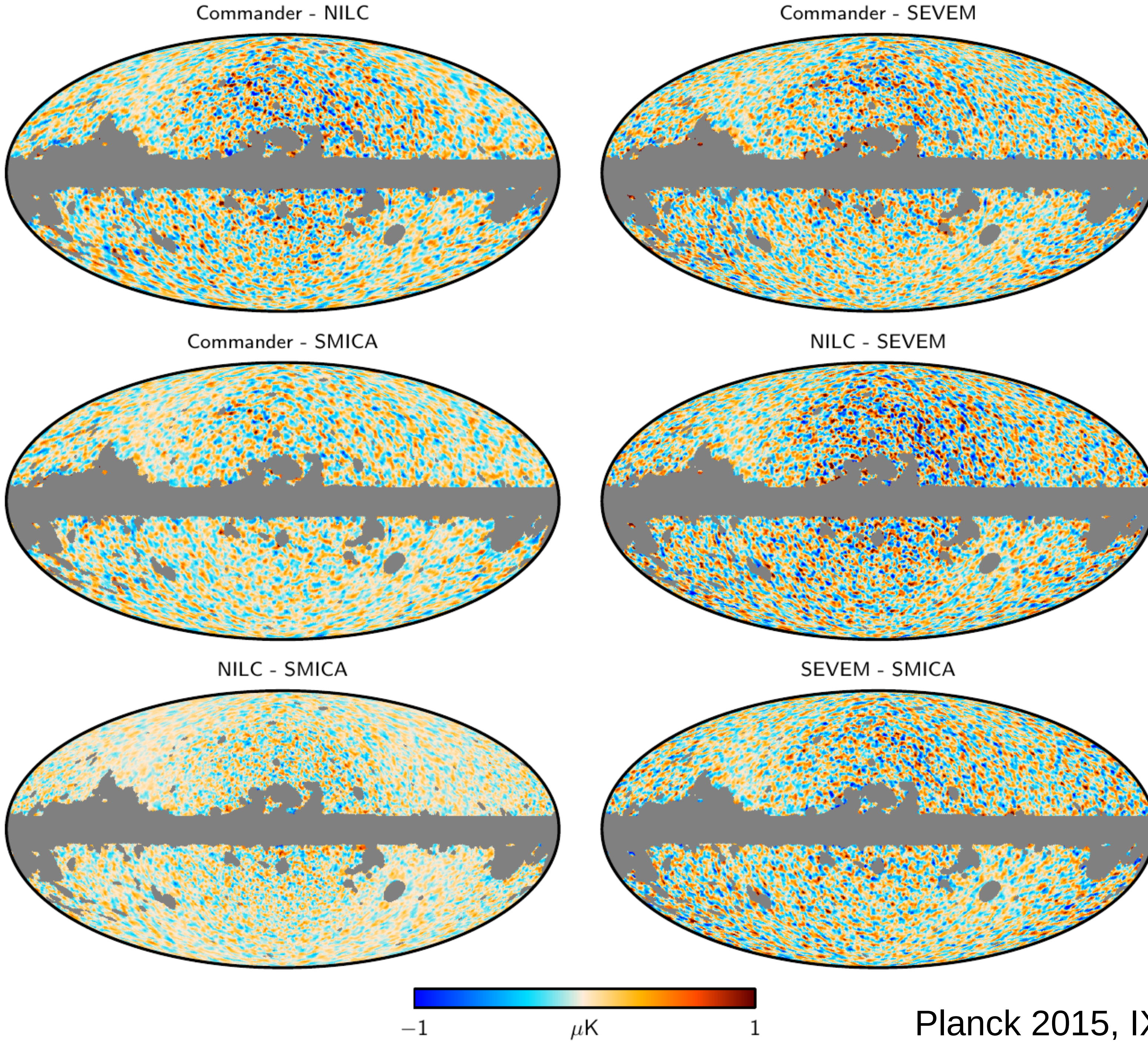

Planck 2015, IX

# Planck U



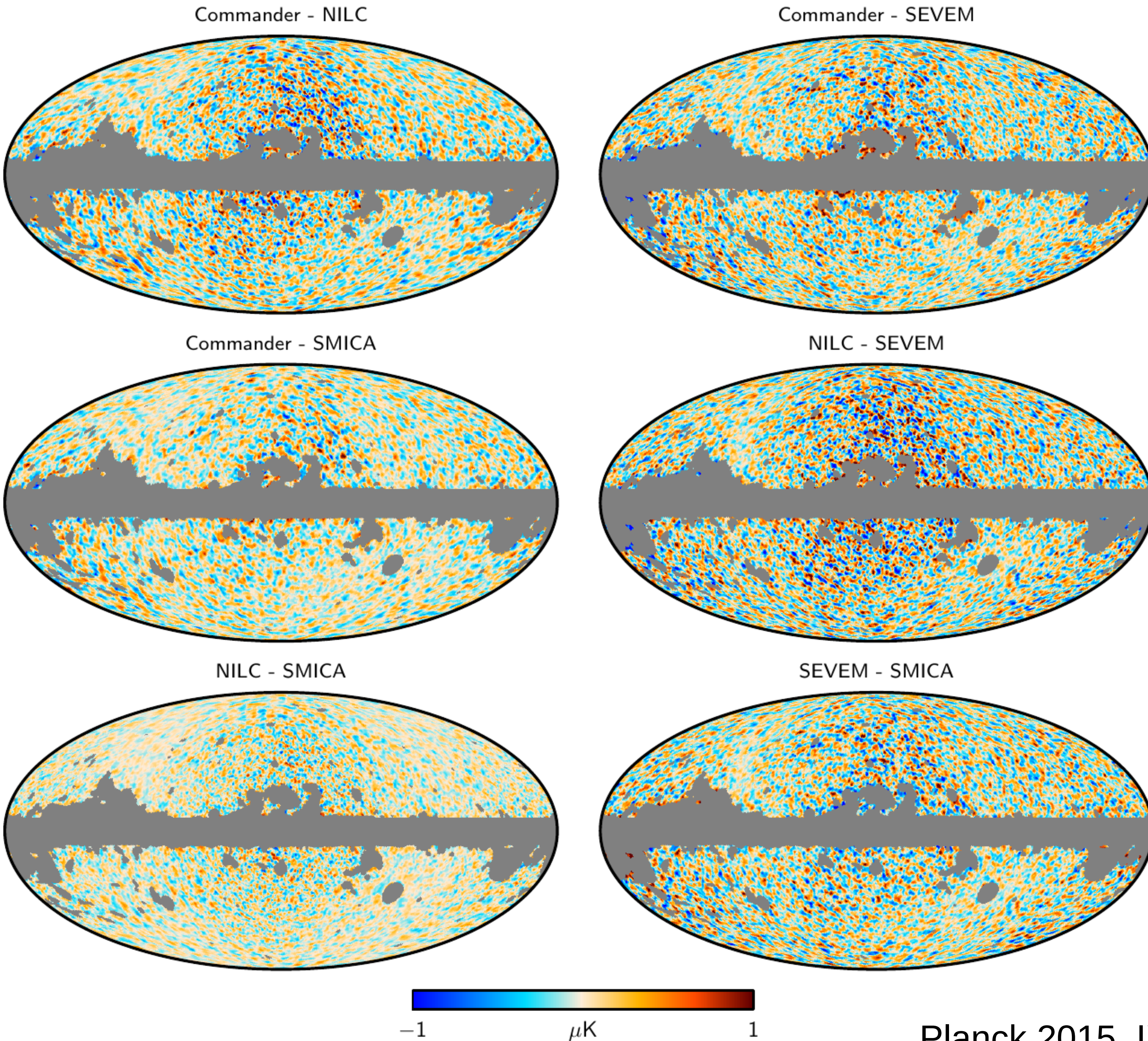

Planck 2015, IX

# Solution differences, Q




Planck 2015, IX

# Solution differences, U

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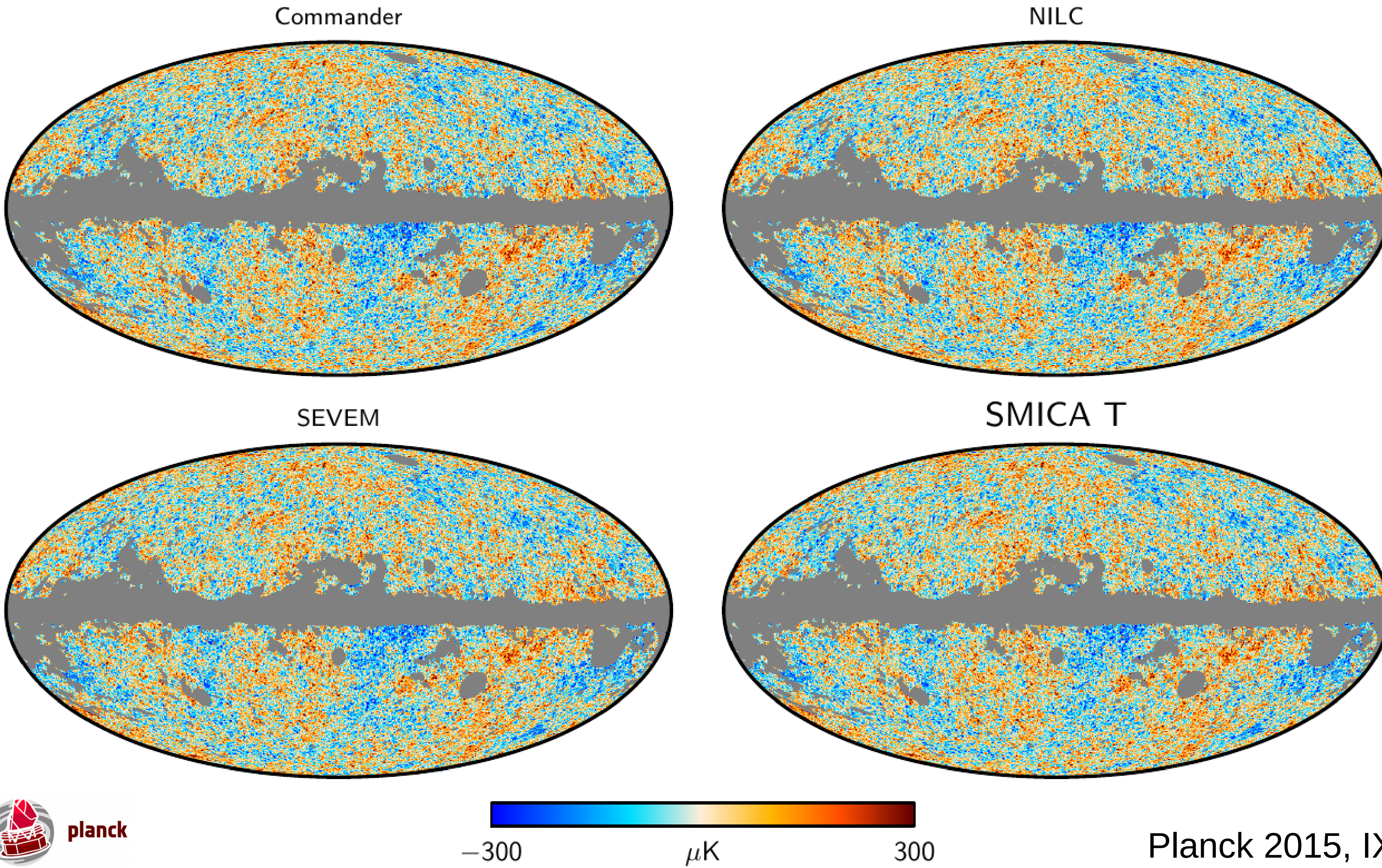
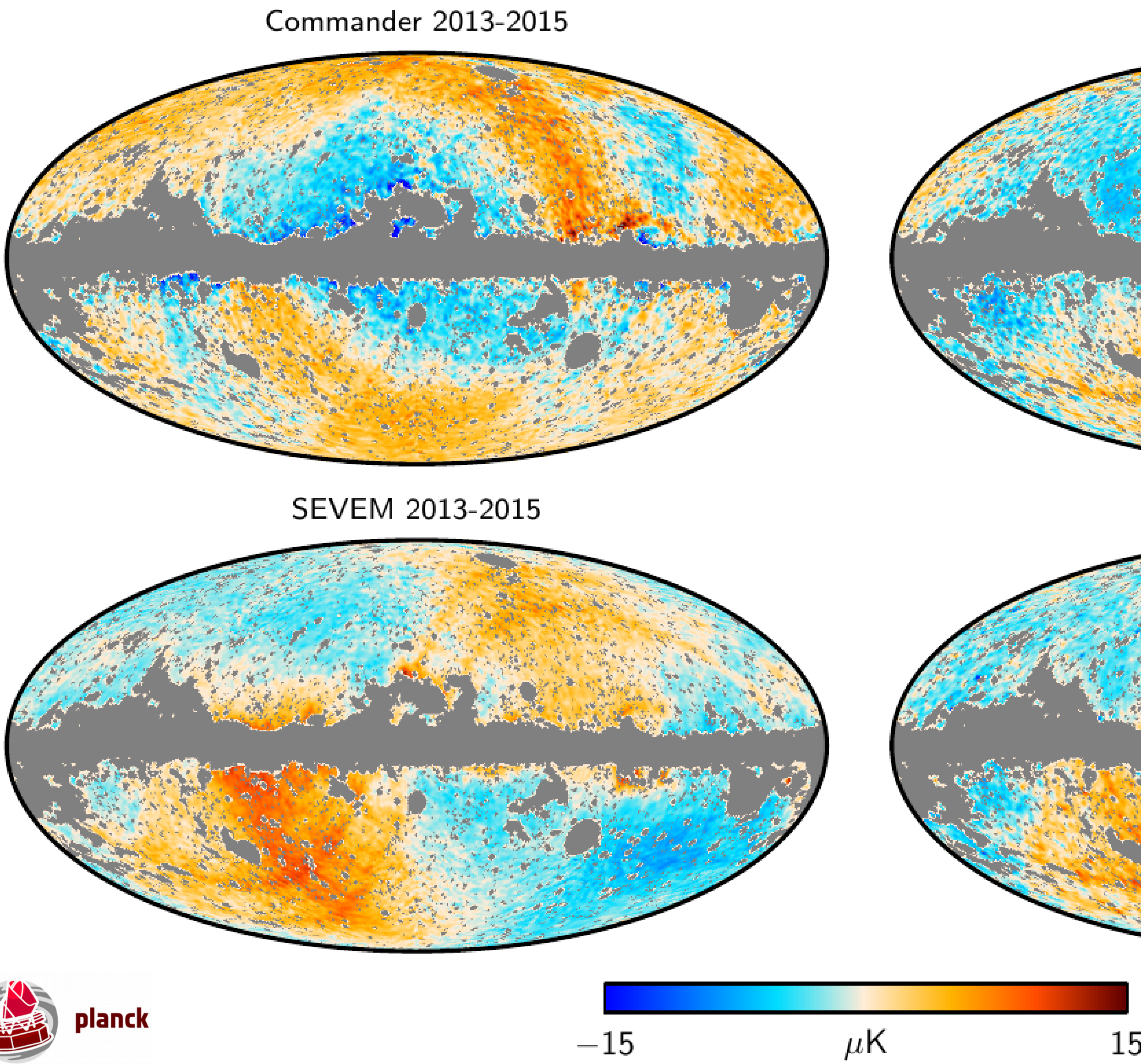
Planck 2015, IX

# Planck T




Planck 2015, IX

# Planck T: 2013-2015 differences

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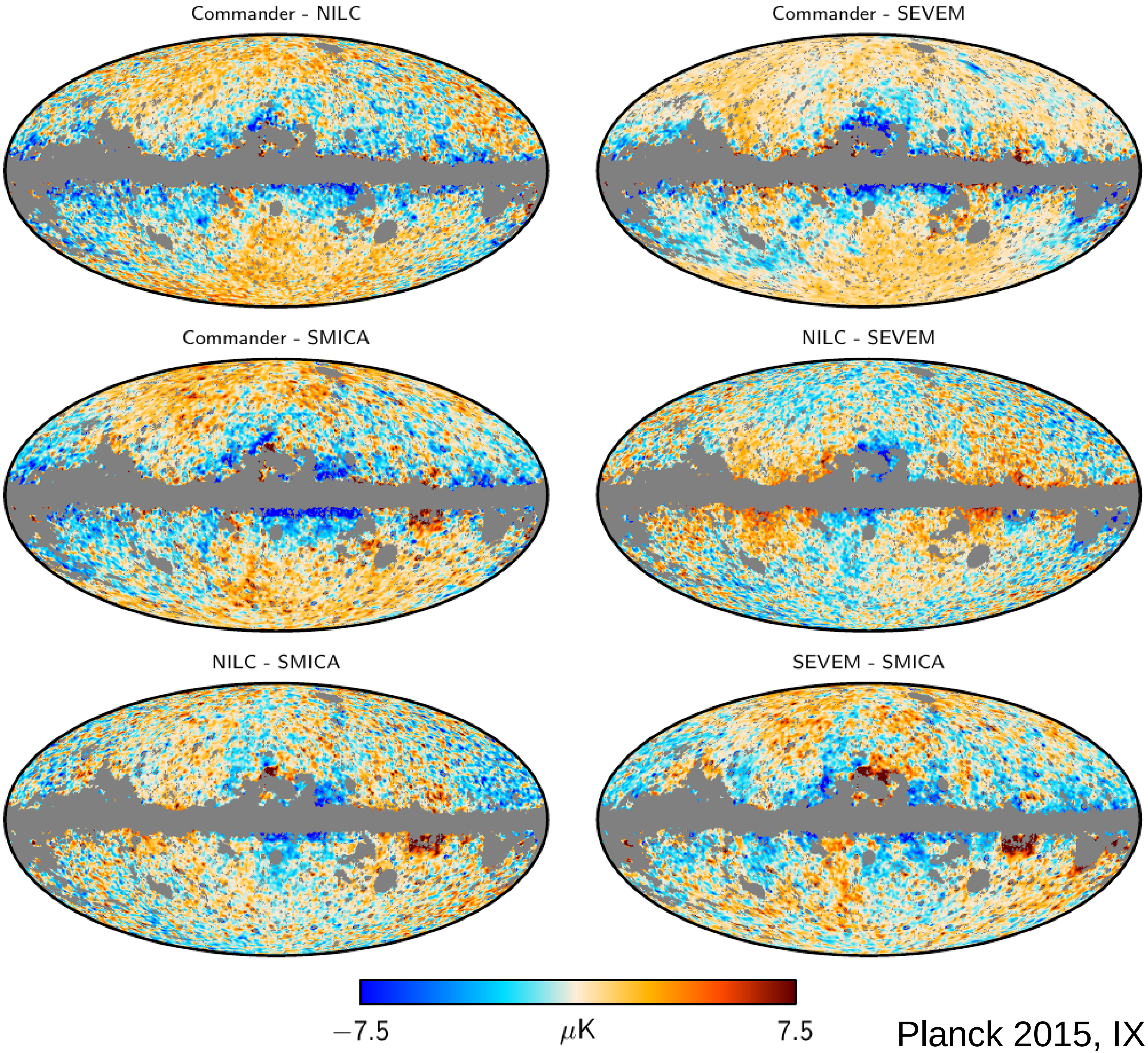
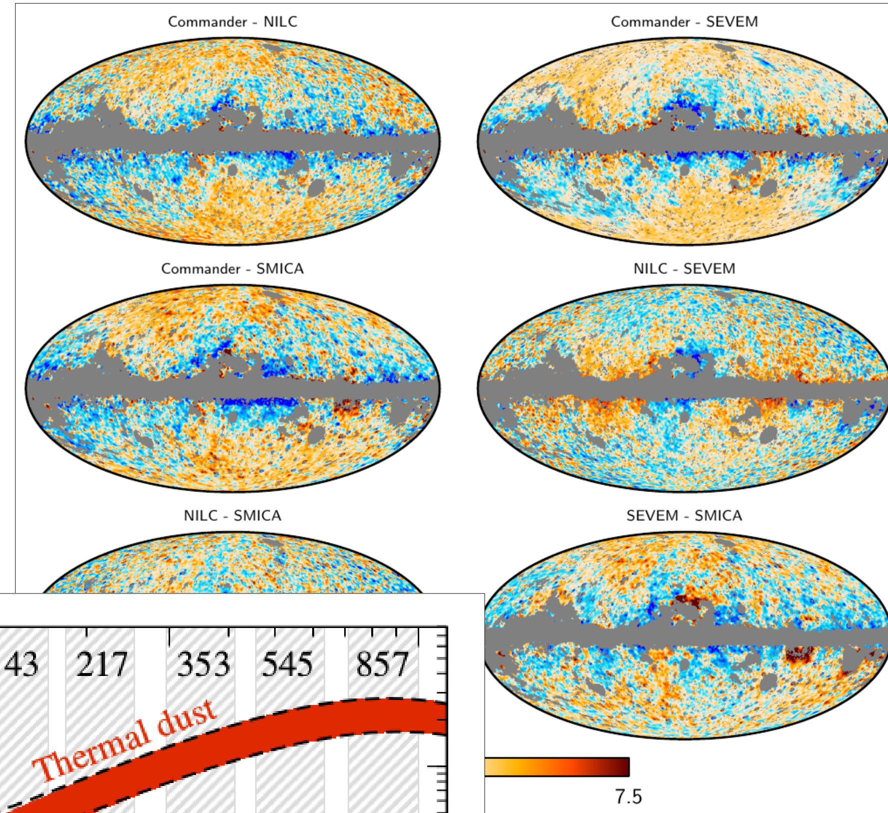
Planck 2015, IX

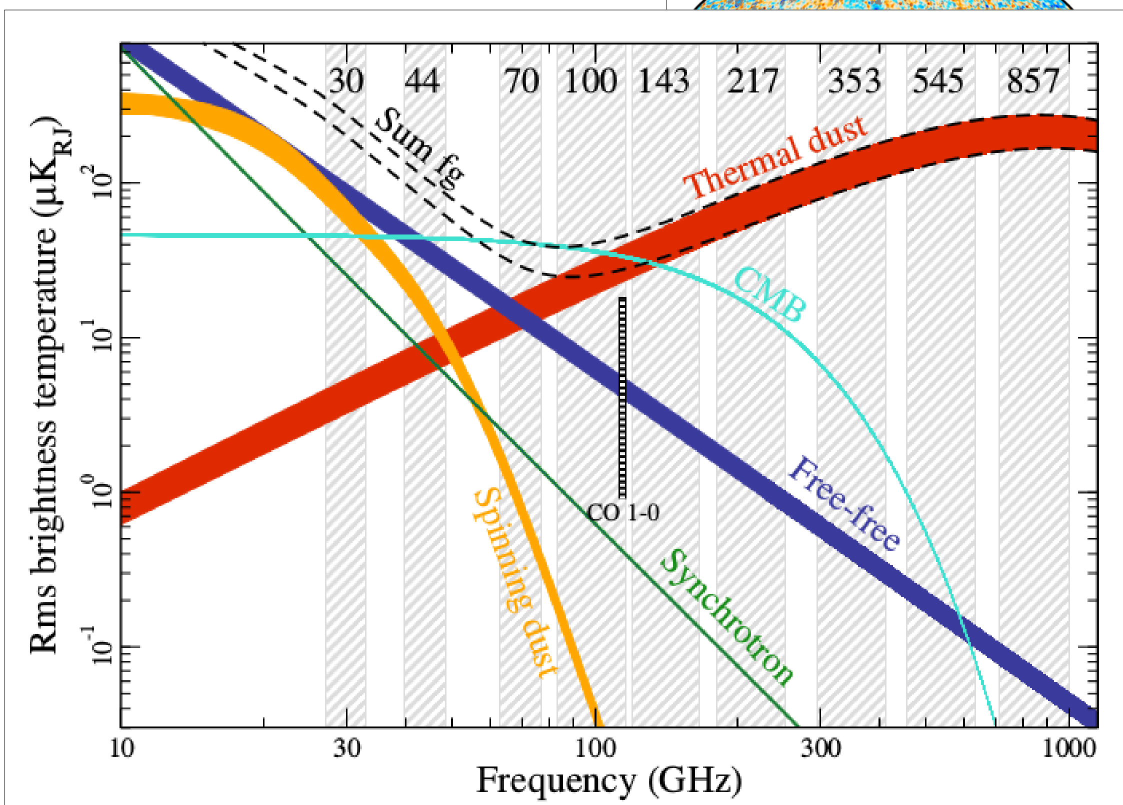
# Solution differences, T




Planck 2015, IX

# Solution differences, T

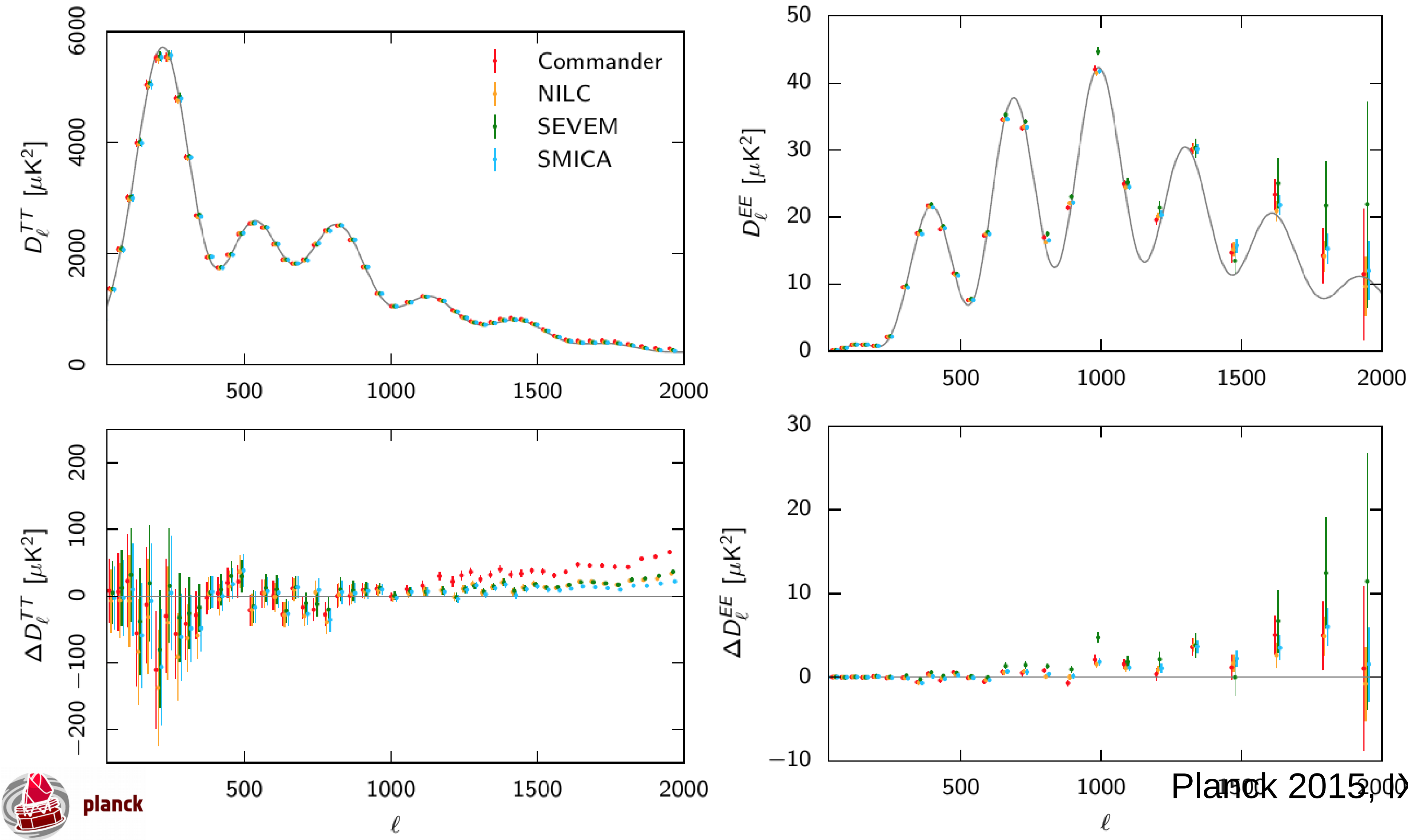



Planck 2015, IX

# Angular Power Spectra

## see Graca's talk next

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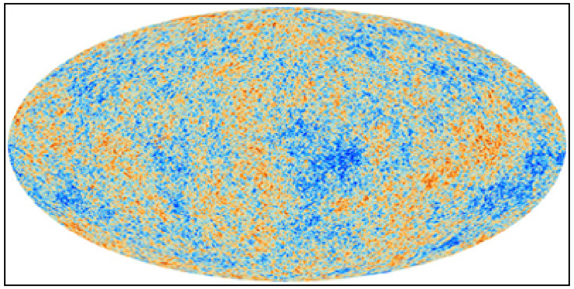
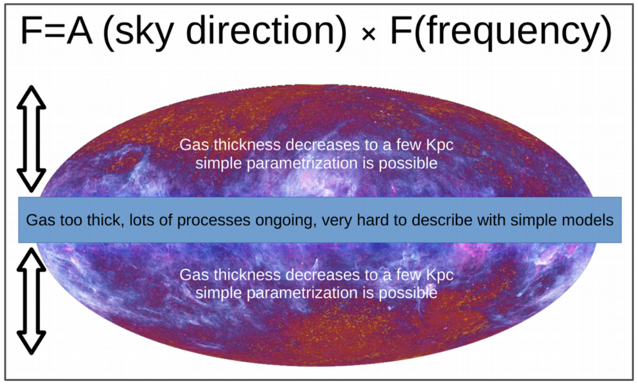
Planck 2015, IX

# Relevance of Simulations

- Exploitation of Full Focal Plane Simulation in Component Separation:
  - Validation,
  - Diagnostics

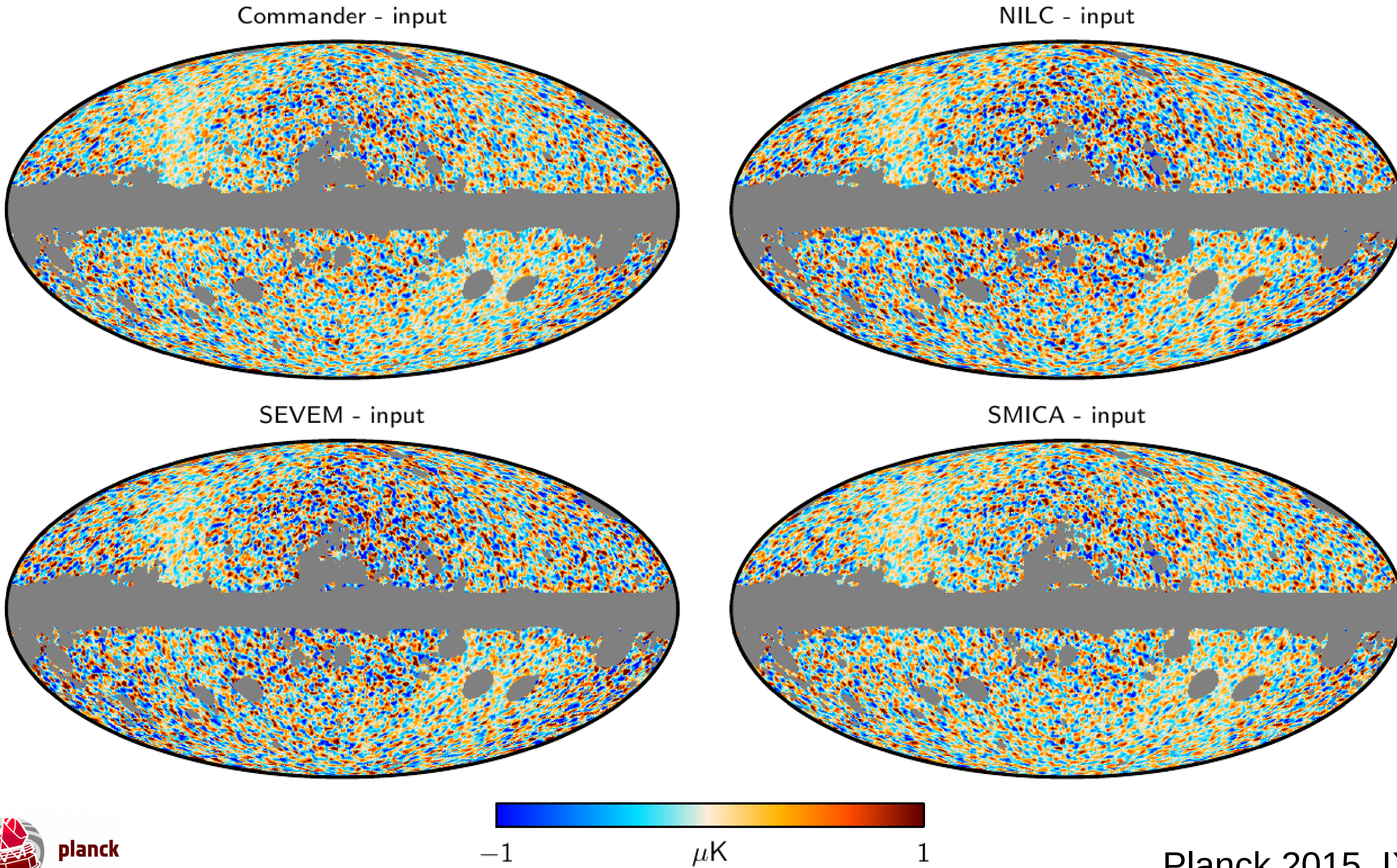




# Full Focal Plane Simulations from a Component Separation Perspective

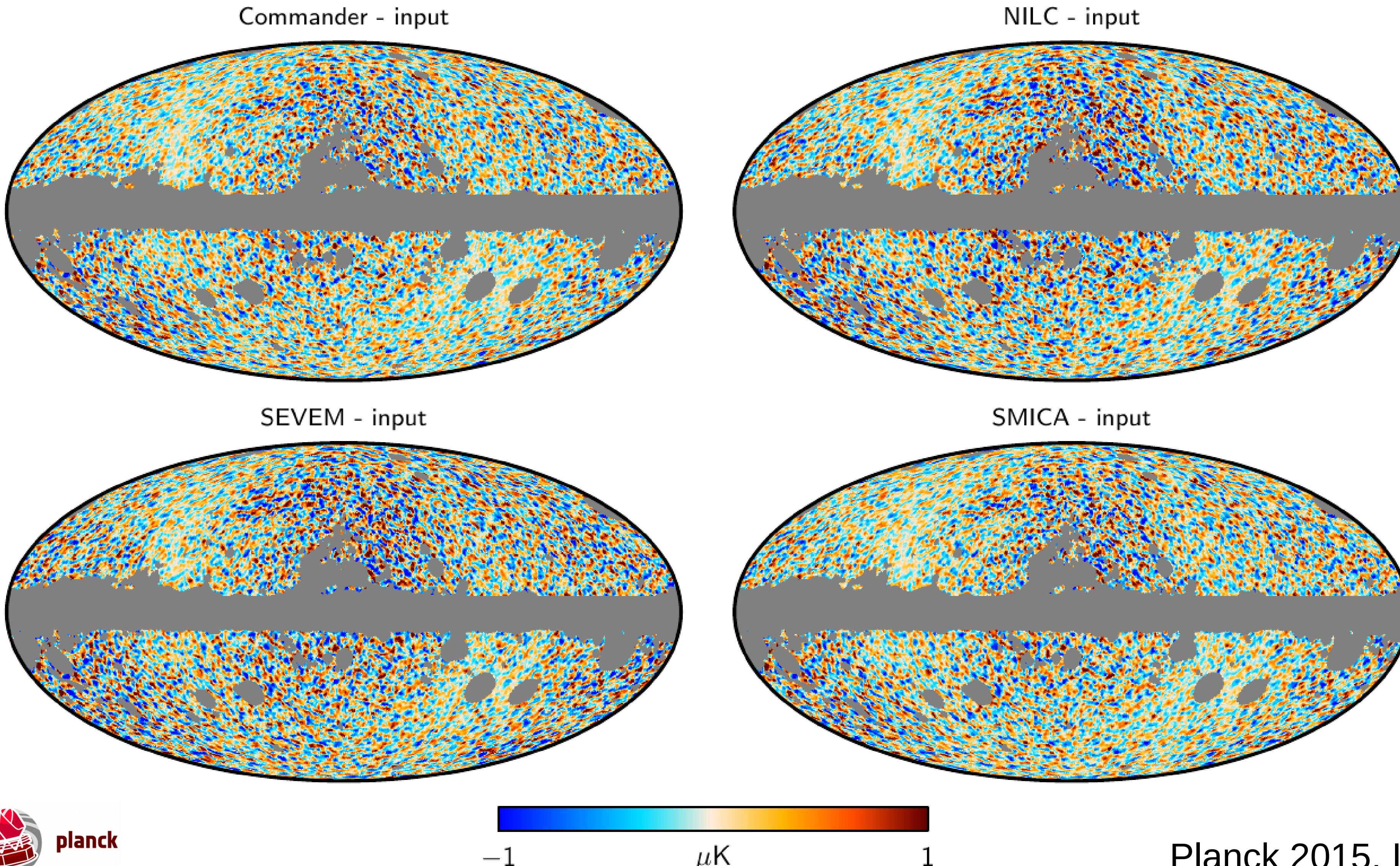
- The Full Focal Plane Simulations (Planck 2015, XII) consist of
  - 10000 CMB and noise realizations
  - Anomalous dust, CIB, CO lines, dust, extra-Galactic infrared and radio sources, free-free, synchrotron, Sunyaev Zel'dovich from the Planck Sky Model
  - Main systematics effects: intermediate and far sidelobe, bandpass leakage, ...
- Widely used in Planck analyses, exploited in component separation used as most important diagnostics & validation, based on:
  - Overall study of separation performance by direct I/O comparisons
  - Propagation of CMB and noise realizations through pipelines, for assessing overall uncertainties on products,
  - Propagation of foregrounds templates through pipelines, for assessing foreground residuals,
- FFP8 exploited in Planck 2015, X, currently analysis is based on FFP10

# I/O for Full Focal Plane Simulations: Q



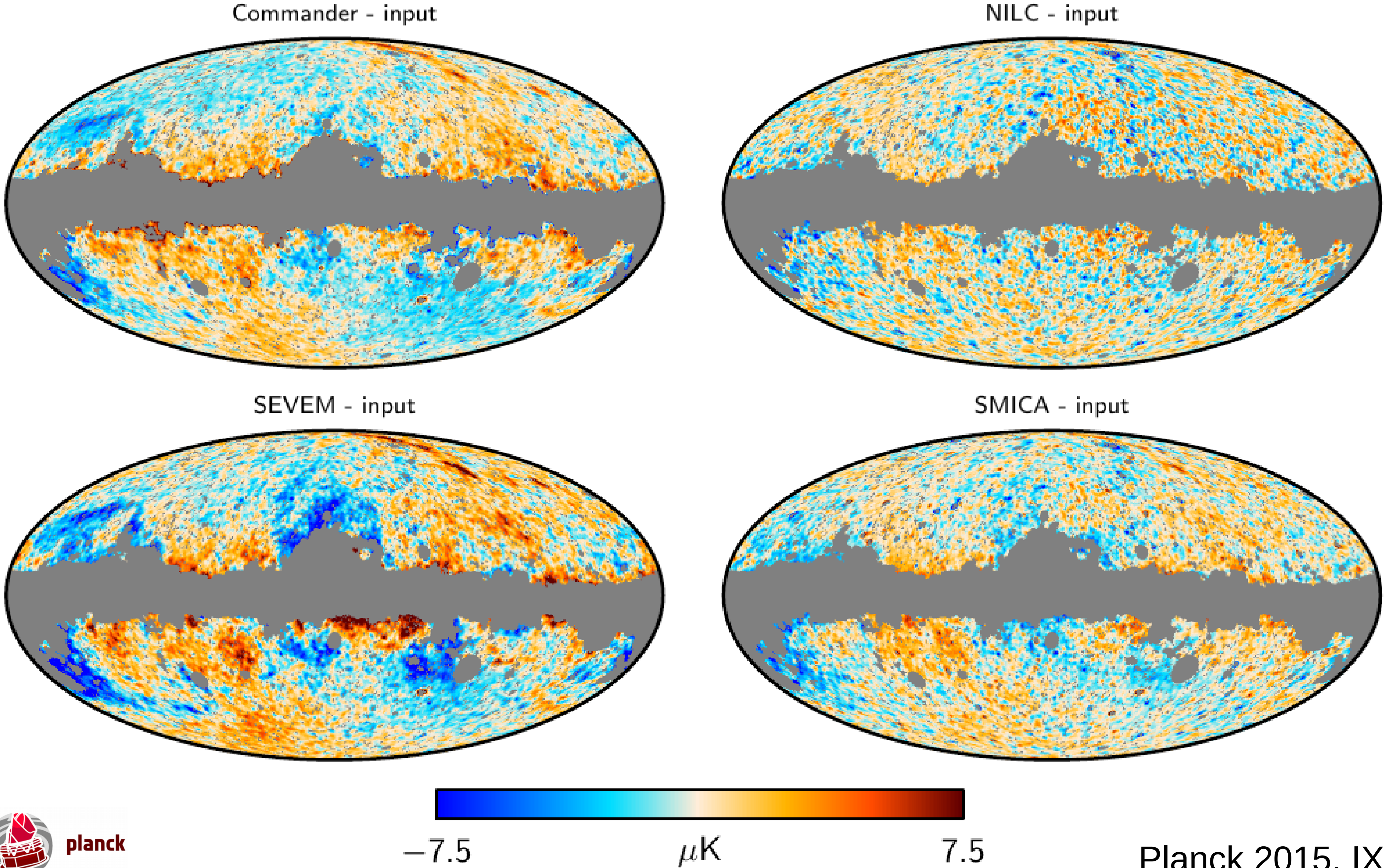

Planck 2015, IX

# I/O for Full Focal Plane Simulations: U




Planck 2015, IX

# I/O for Full Focal Plane Simulations: T

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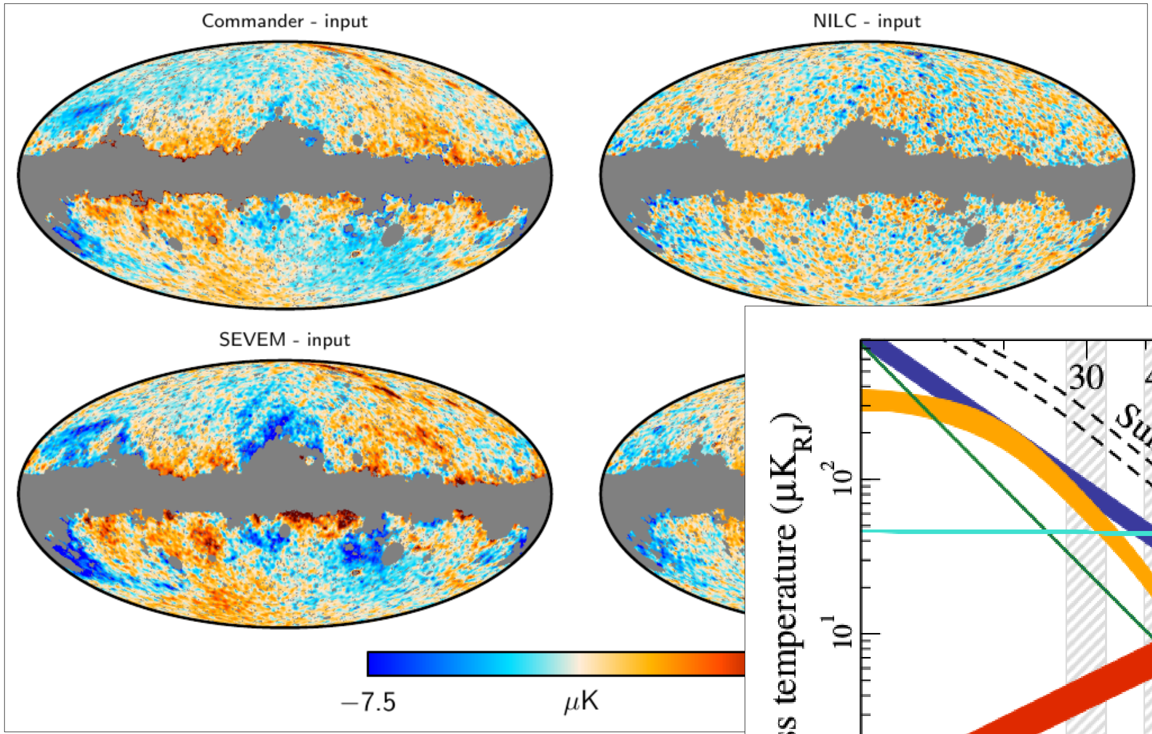
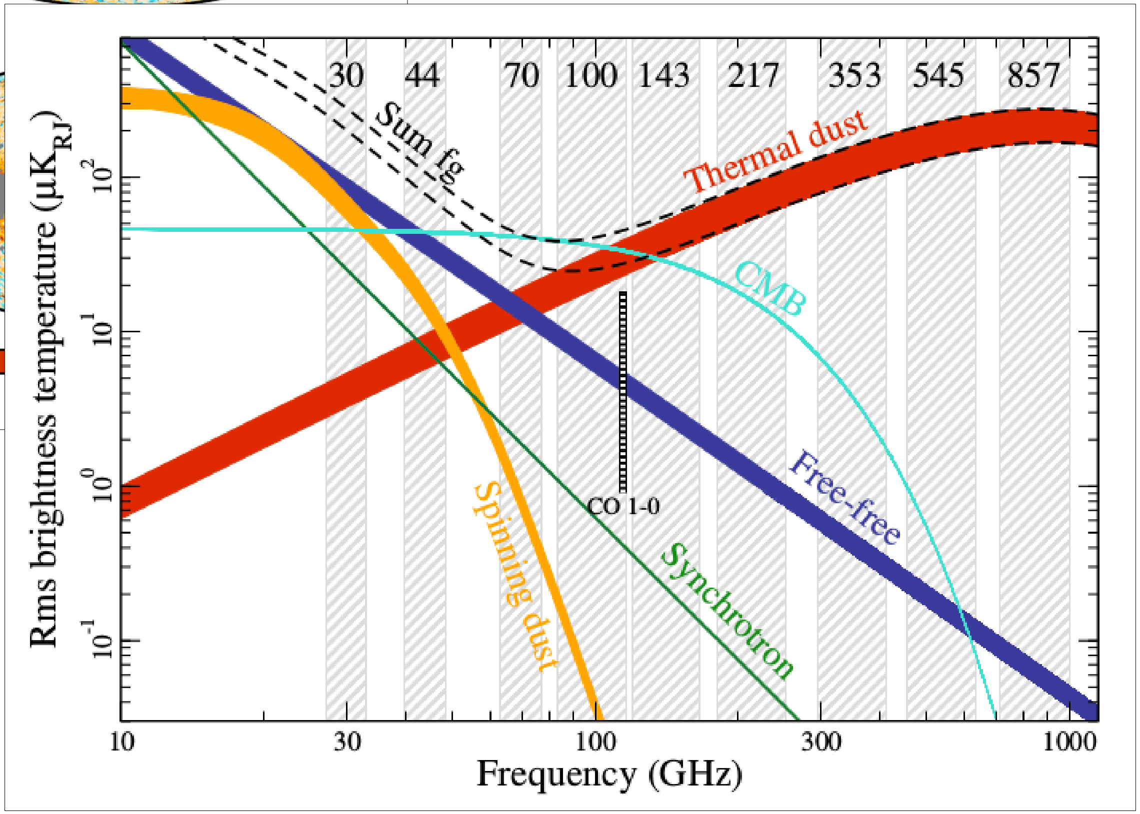
Planck 2015, IX

# I/O for Full Focal Plane Simulations: T

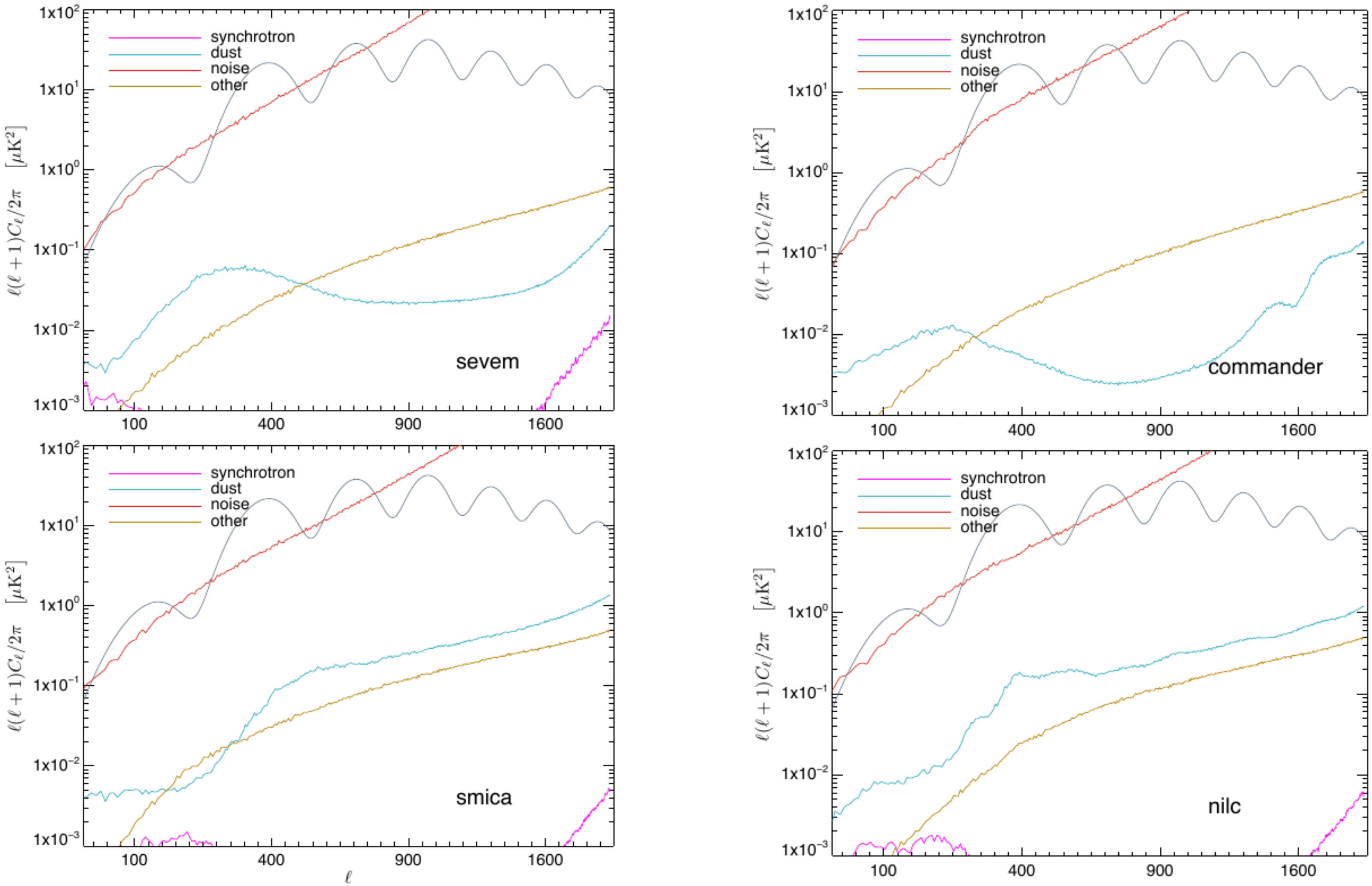



Planck 2015, IX

# FFP diagnostics on outputs: E

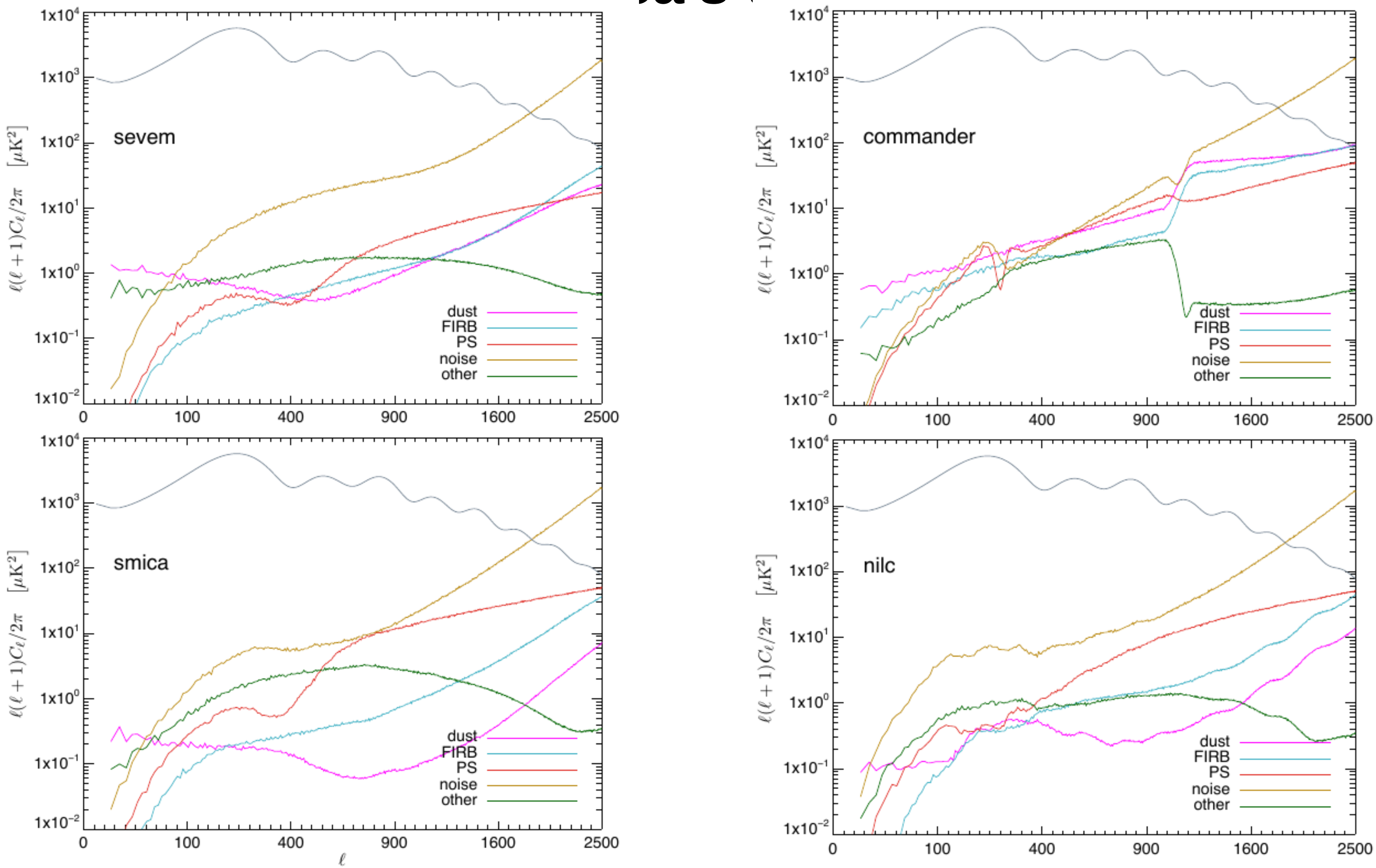
## see Graca's talk next




Planck 2015, X

# FFP diagnostics on outputs: T

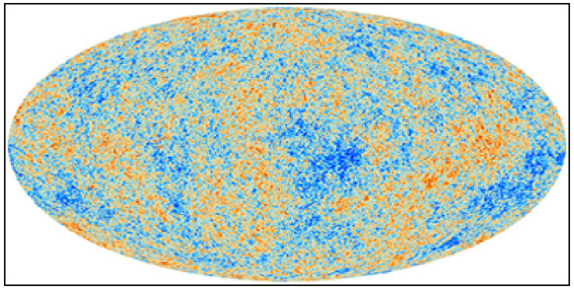
see Graca's talk next

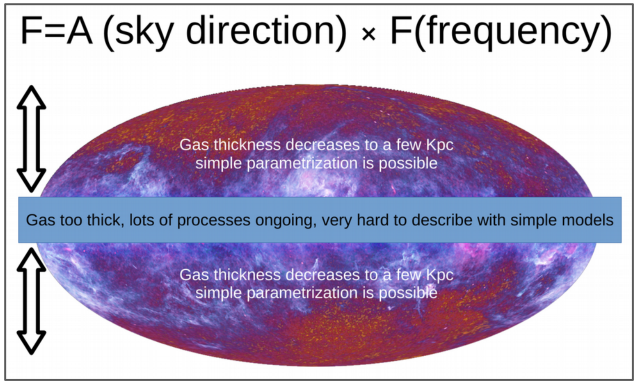



Planck 2015, X

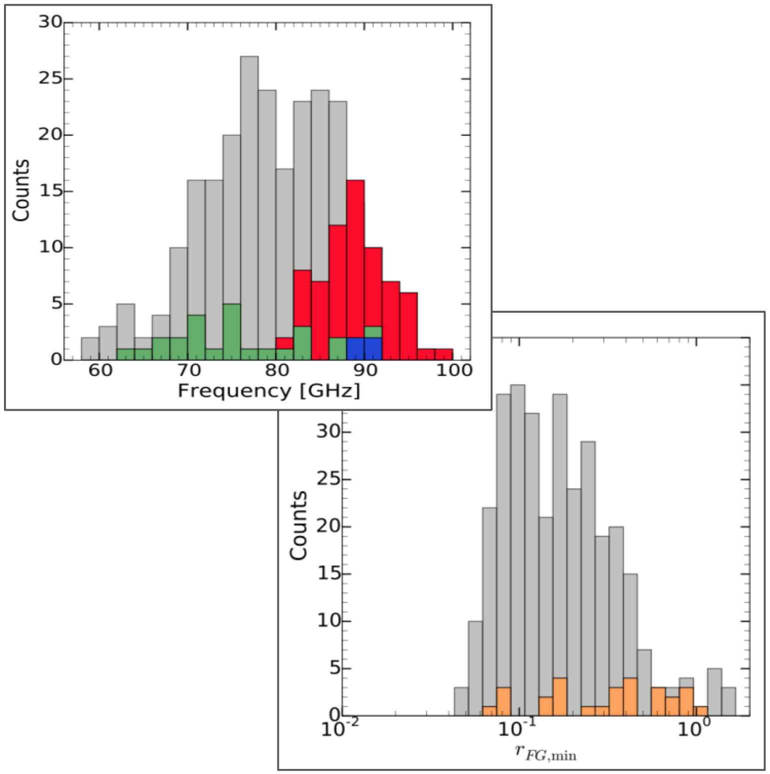
# Contamination to B-modes

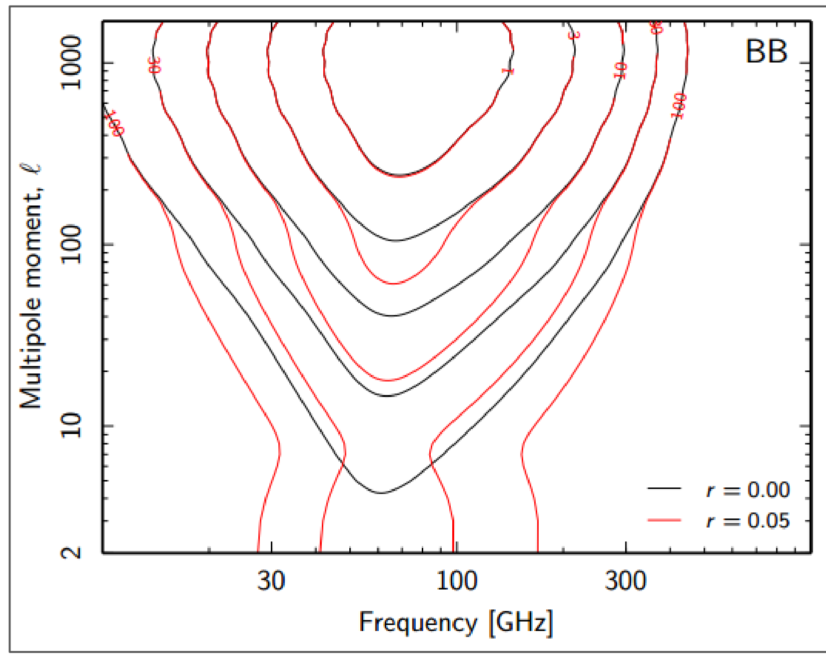
- B-modes from diffuse Galactic emissions:
  - Status of normalization of the contamination
  - Preliminary results from S-PASS





# Diffuse Galactic Contamination on B-modes



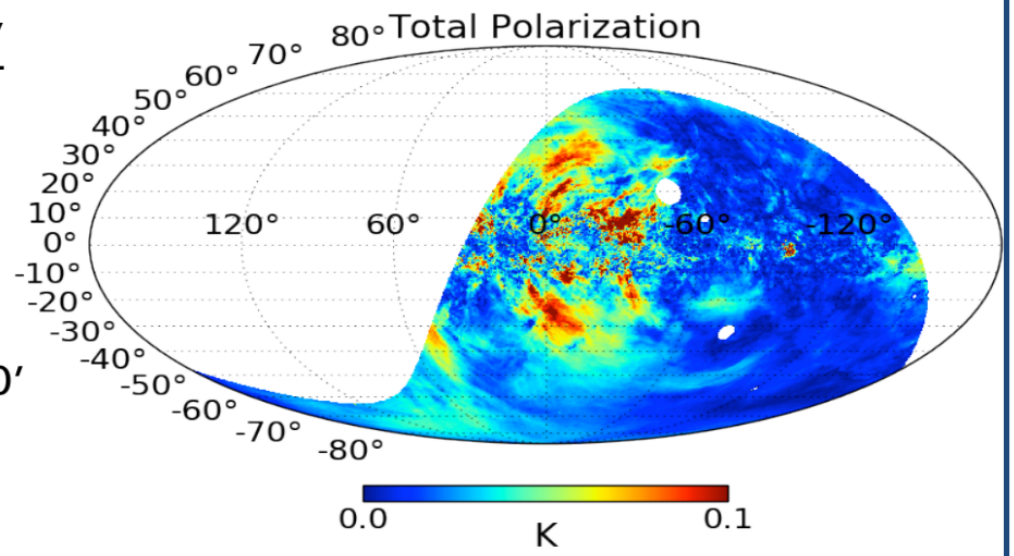

$$f(\ell,\nu) = [C_\ell^{\rm fg}(\nu)/C_\ell^{\rm CMB}]^{1/2}$$

Krachmalnicoff et al. 2016, Planck 2015, X

# Diffuse Galactic Contamination on B-modes

## SPASS survey

Carretti et al. 2013
Carretti et al. in prep




**Frequency:** 2.3 GHz
**Angular resolution:** 10′
**Sky coverage:** ~50%
**S/N:** >3 everywhere

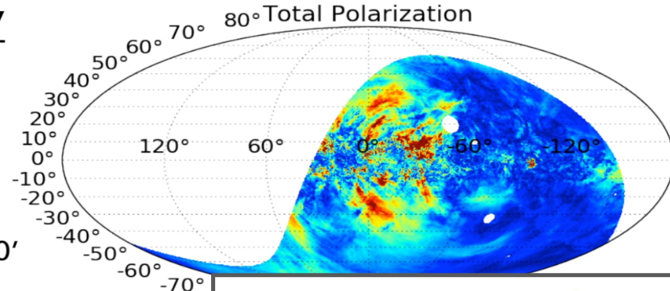
**Diffuse Synchrotron emission as CMB contaminant:**
(Krachmalnicoff et al. in prep)

- Angular power spectra at different Galactic latitudes up to ell~500
- Contamination to CMB B-modes in small sky regions at high Galactic latitude
- Correlation with other data (WMAP-Planck): SED, spectral index variation, correlation with dust emission

# Diffuse Galactic Contamination on B-modes

## SPASS survey

Carretti et al. 2013
Carretti et al. in prep

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**Diffuse Synchrotron emission as CMB**
(Krachmalnicoff et al. in prep)

- Angular power spectra at different Gala
- Contamination to CMB B-modes in sma latitude
- Correlation with other data (WMAP-Plar correlation with dust emission

*Instituto de Astrofísica de Canarias*
*Universidad de Cantabria*
*University of Cambridge*
*University of Manchester*
*SISSA*
*CNRS Grenoble*

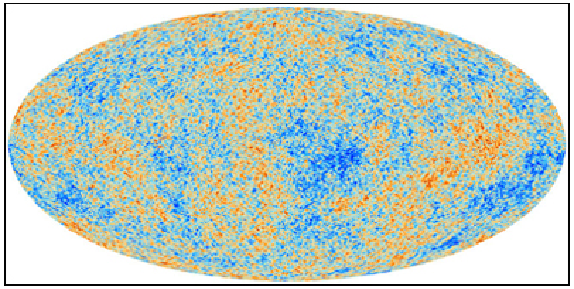
RADIO FOREGROUNDS

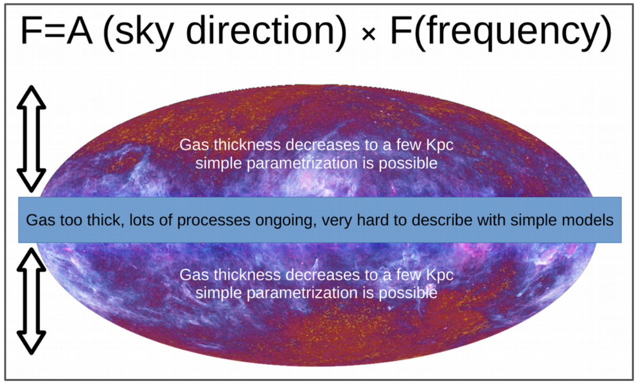
“ The aim of the project is to combine **Planck** (30-353 GHz) and **QUIJOTE** (10-20 GHz) data to provide a best possible **characterization of the physical properties of polarized emissions** in the microwave domain. ”

**DATA ANALYSIS** **MODELIZATION** **ALGORITHMS**

# B-modes foreground estimates and cleaning

- See Errard's and Remazeilles's talks for simulations concerning design of forthcoming and long term probes
- Here we give examples of B-modes data analysis concerning the control of foregrounds:
  - Upper limits on PolarBear Fields
  - BICEP2 x Planck cleaning

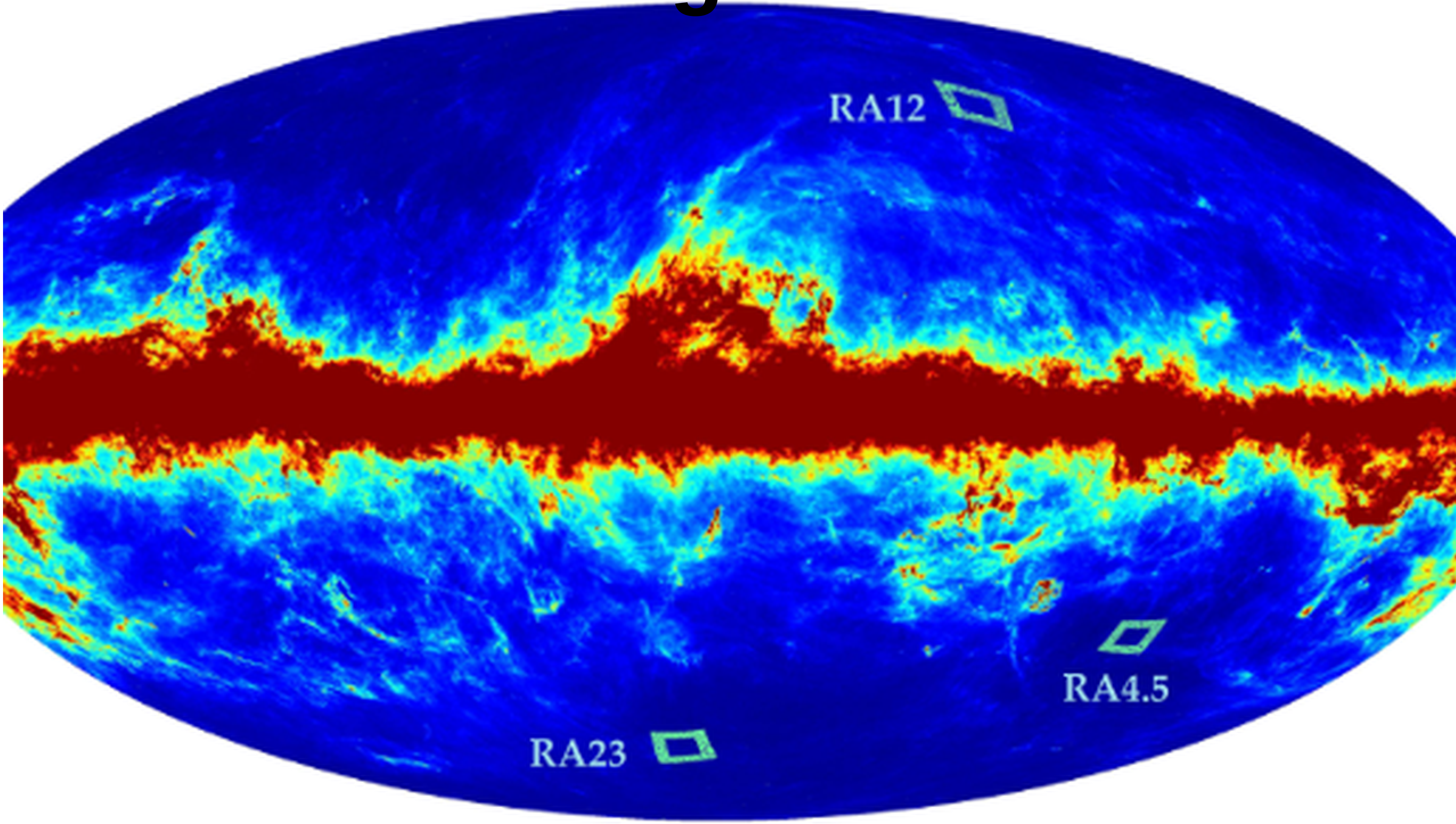




# Bibliography for B-mode Component Separation

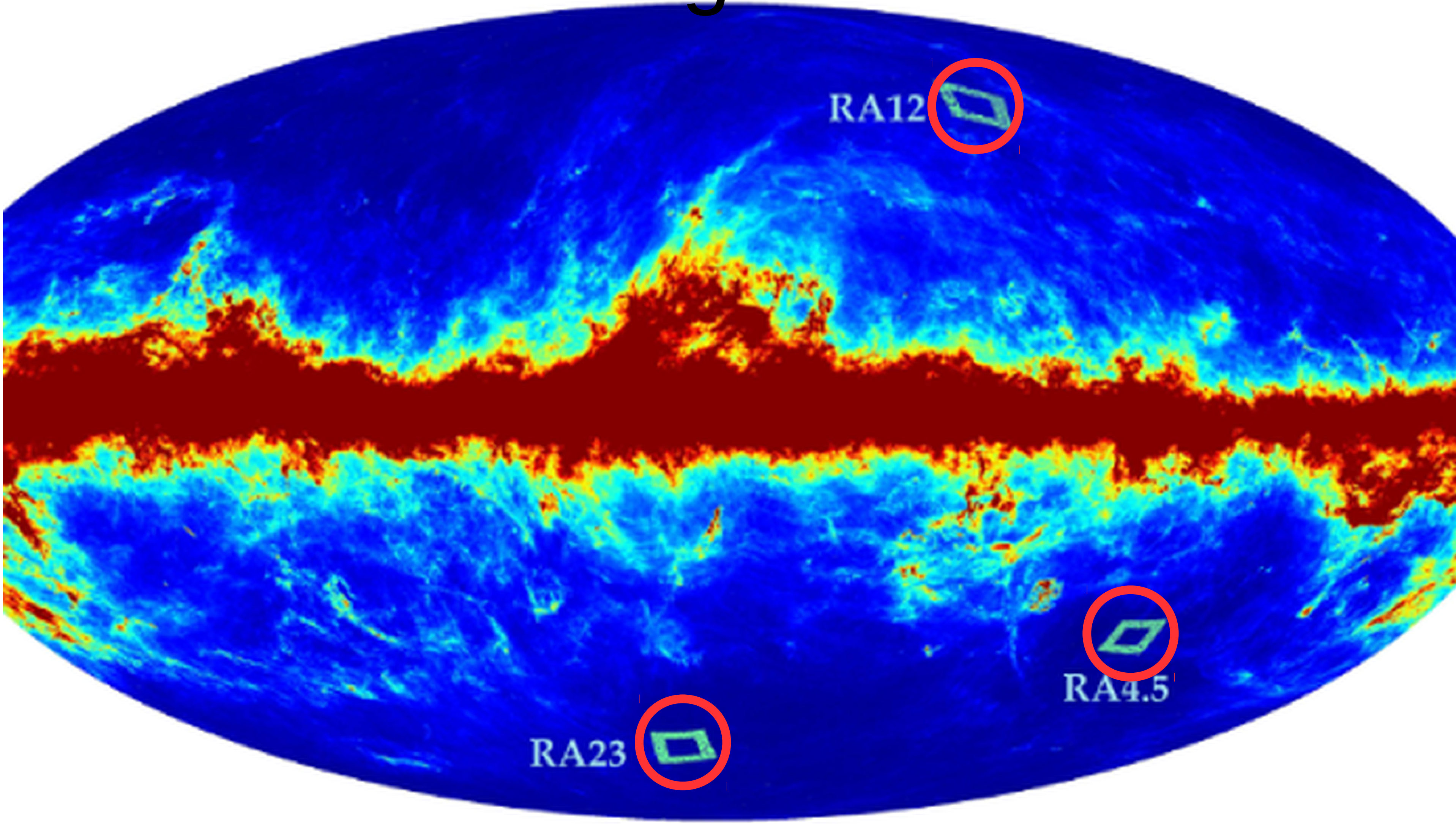

- Maximum likeihood casting, Stompor et al. 2009
- Implementation, Leach e al., 2010
- Simulations of sub-orbitals, Stivoli et al. 2010
- Parameter estimation, Fantaye et al. 2011
- Power spectrum estimation through the Xpure code, Grain et al. 2012
- Foreground cleaning and lensing reconstruction, Fantaye et al. 2012
- Linearized system for forecasts, Errard and Stompor 2012
- Fisherization, Errard et al. 2016
- Control of Foreground biases at, Stompor et al. 2016

# PolarBear Foreground Estimates



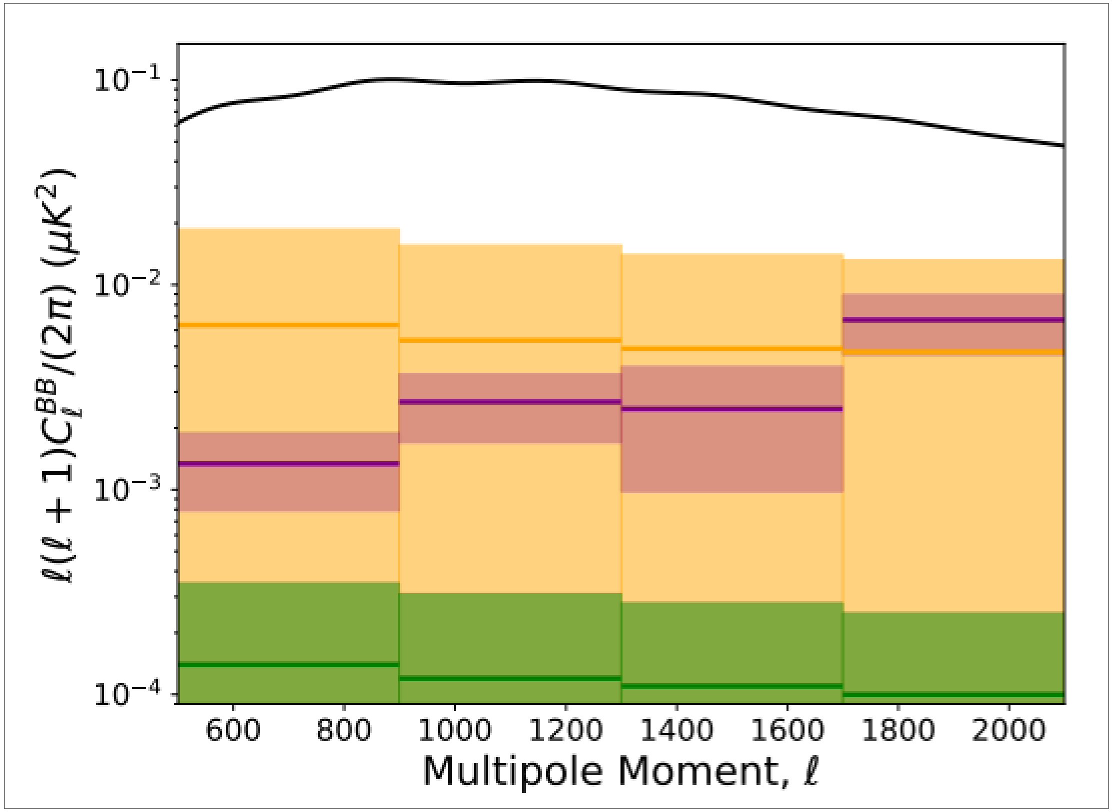

PolarBear Collaboration, 2017

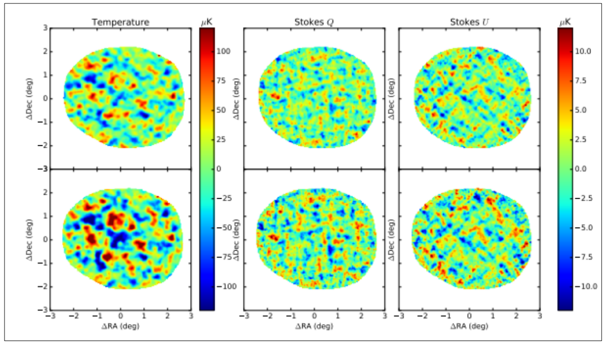
# PolarBear Foreground Estimates




PolarBear Collaboration, 2017

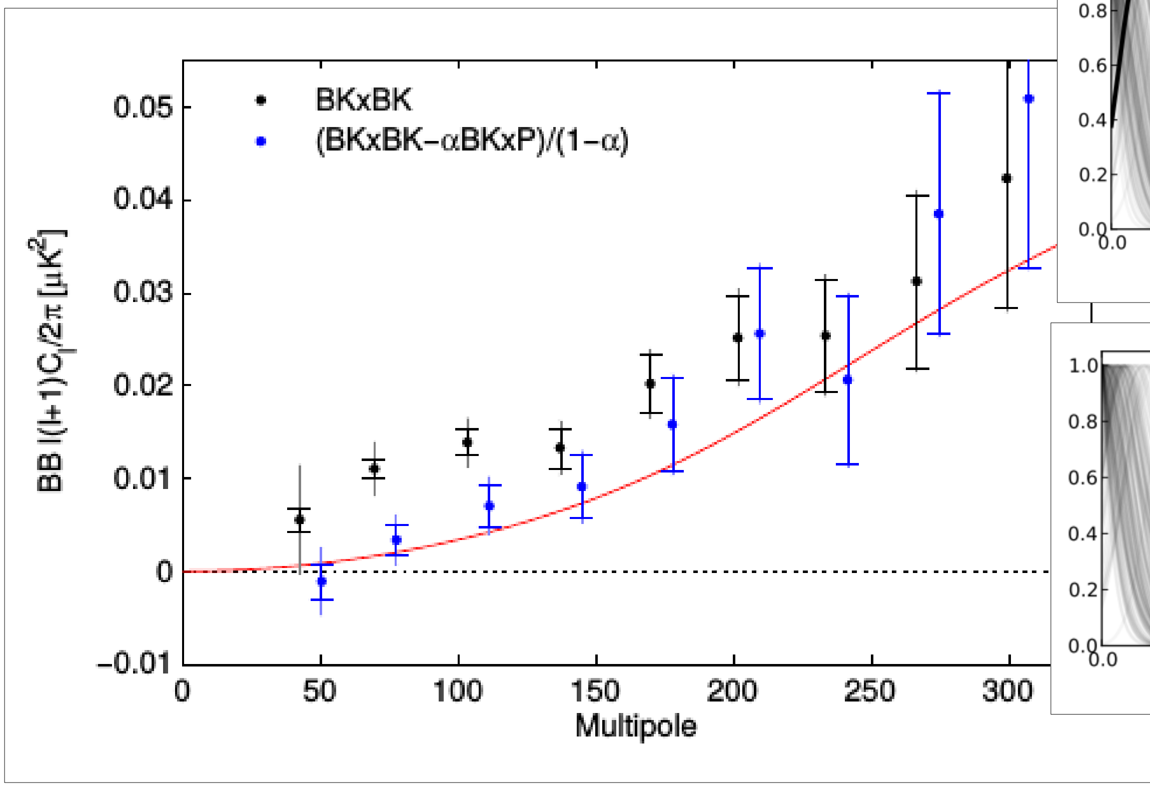
# PolarBear Foreground Estimates

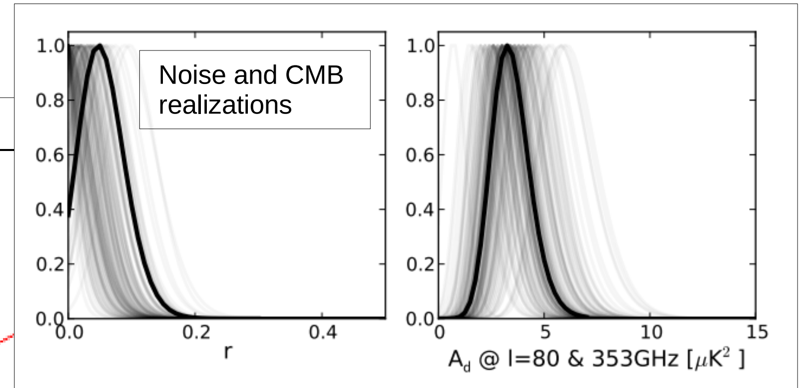


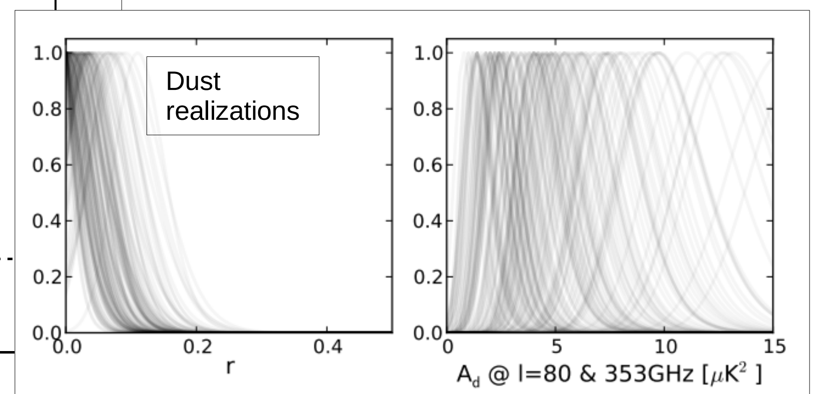




PolarBear Collaboration, 2017

# B-mode foreground cleaning: Planck × Bicep2 × KEcK




BKP 2015

# Conclusions

- Main foreground monitor in present constraints on B-modes
- Guidance for current design study of forthcoming and long term probes
- Planck component separation in polarization is presently noise dominated, hiding foreground biases and residuals which are visible in total intensity
- Large simulations are necessary, but not sufficient, to assess the level of residual contamination in foreground cleaned maps, likely to increase in importance for B-mode foreground cleaning
- B-mode foreground contamination unveiling the messages from polarized surveys in the radio band (S-PASS, C-BASS), which in combination with dust measurements reads:
  - Minimum $r_{FG}$ at the $10^{-2}$, larger than $10^{-3}$ everywhere
  - Flat prior on foreground minimum frequency between 60 and 90 GHz
- B-mode foreground cleaning driving instrumental configurations in simulations, ongoing applications to data concerning foreground upper limits, or cross-spectra based cleaning, dominating the present constraint on r