The problem of Galactic **Foregrounds** in **CMB** observations

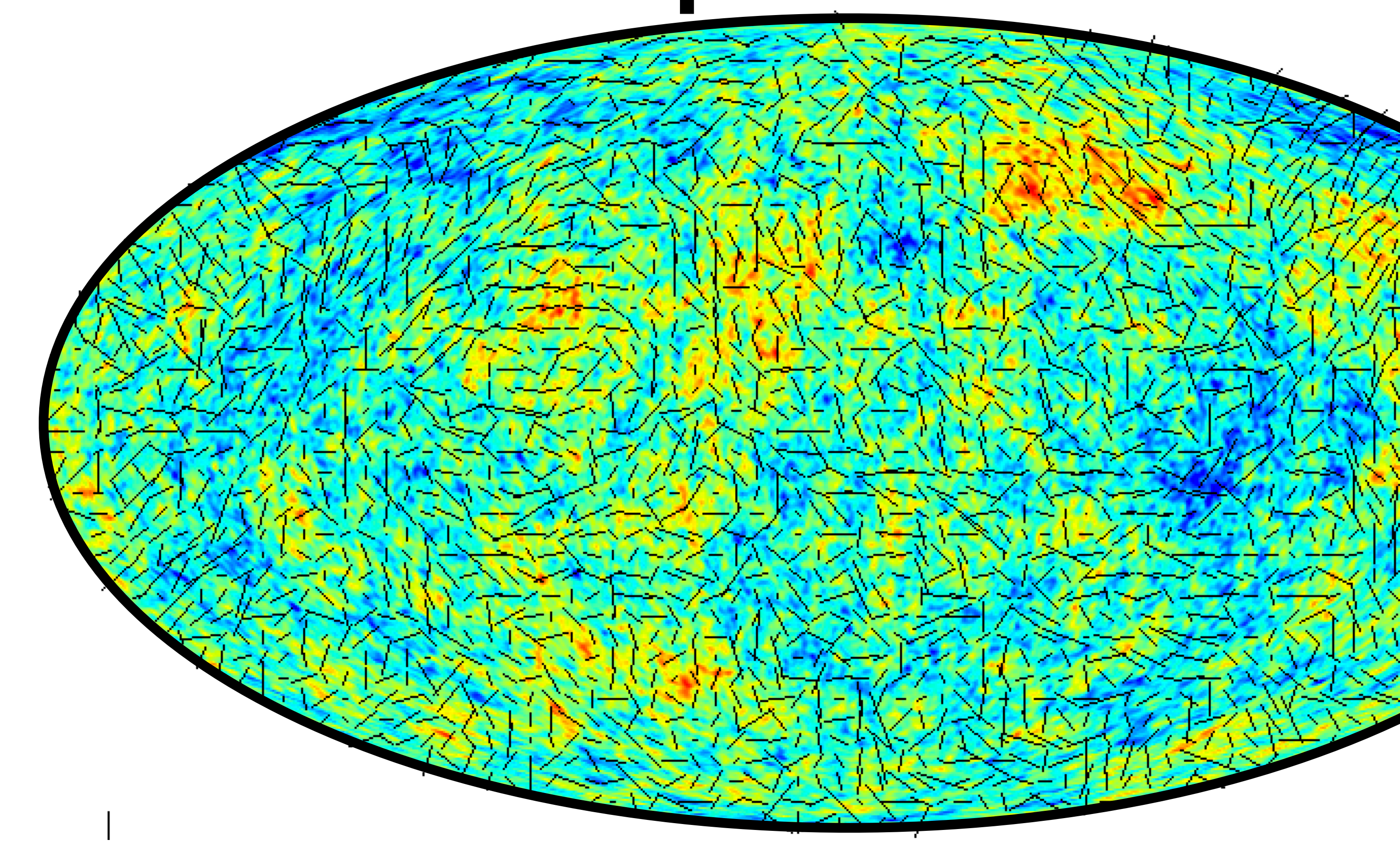
SISSA

Nicoletta Krachmalnicoff

EXPERIMENTAL CHALLENGE

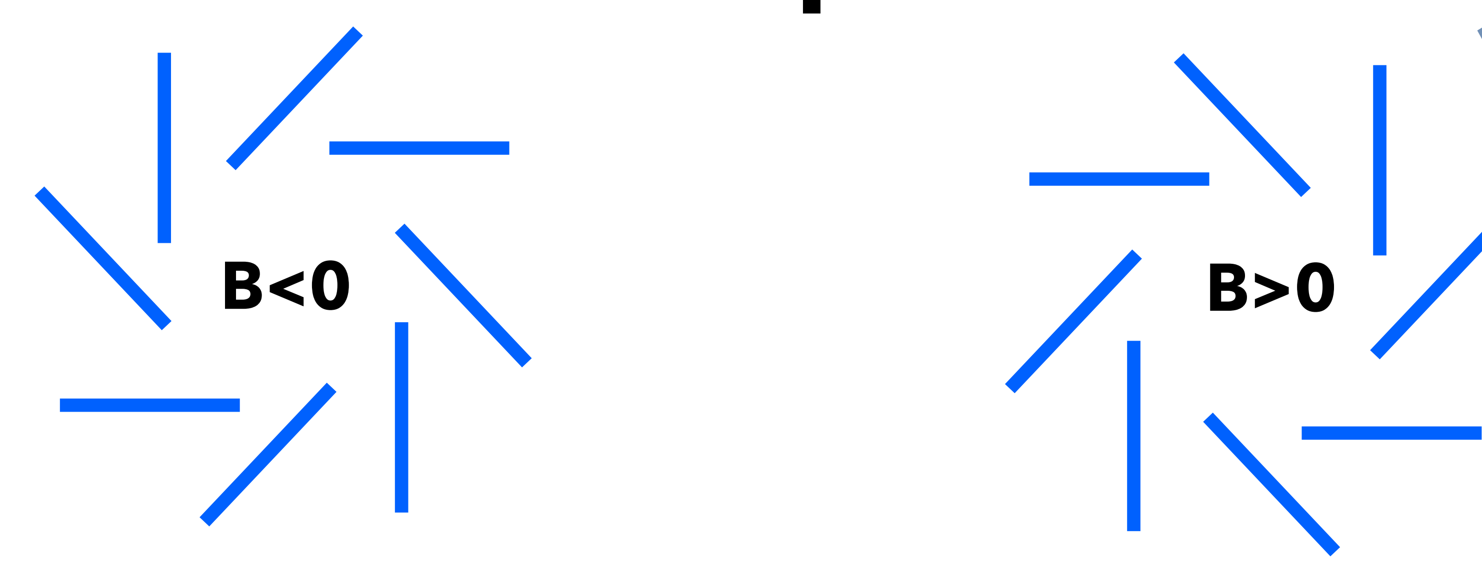
Quantum fluctuations

CMB polarization



Primordial Gravitational Waves

B-mode pattern



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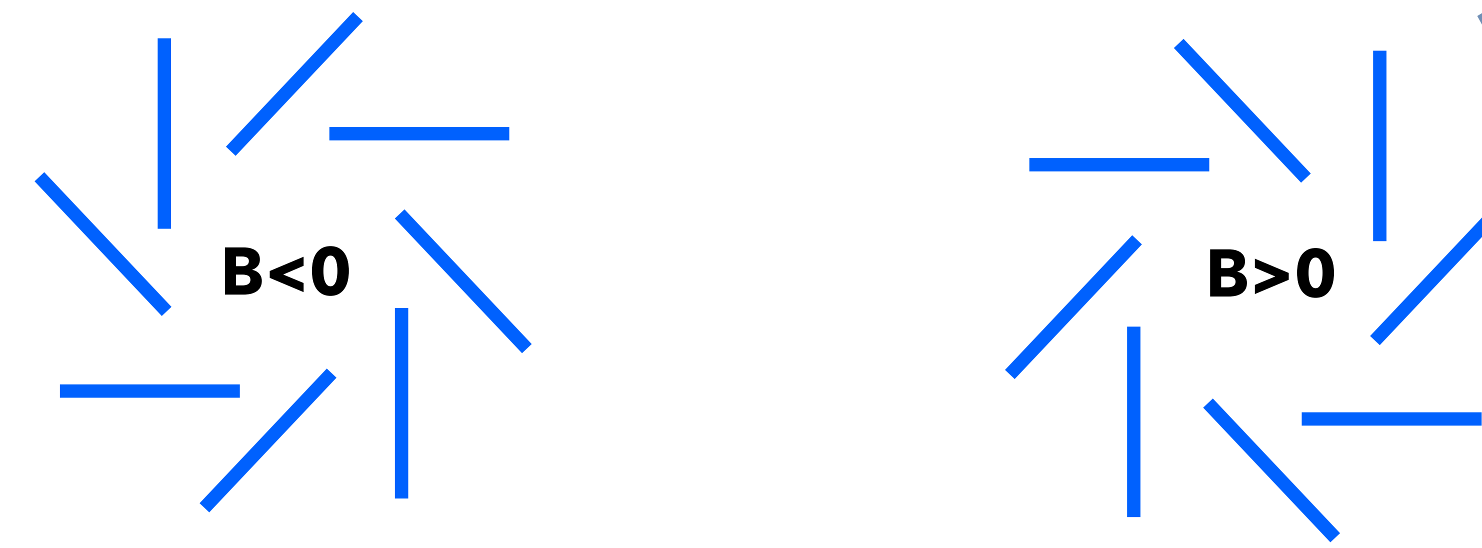
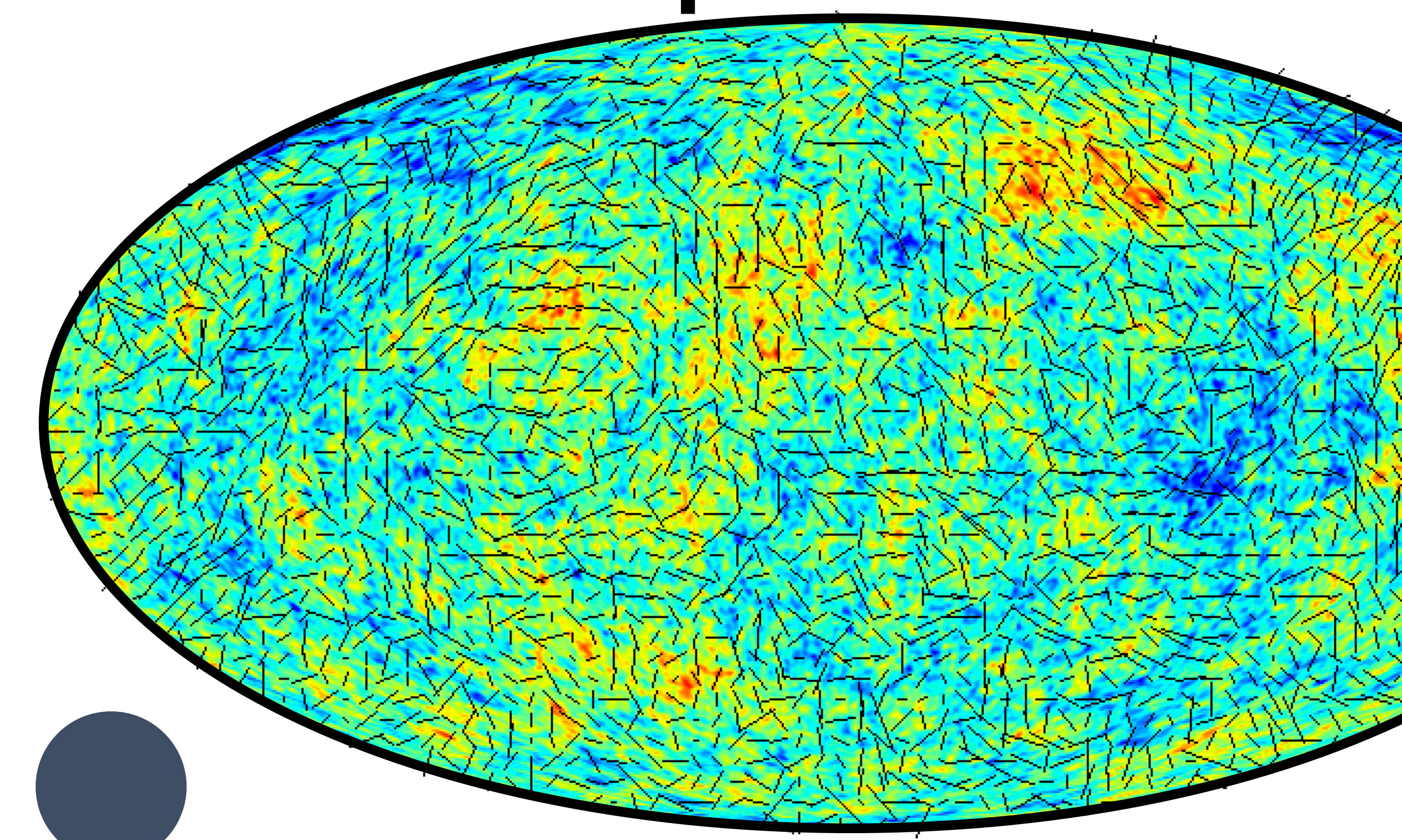


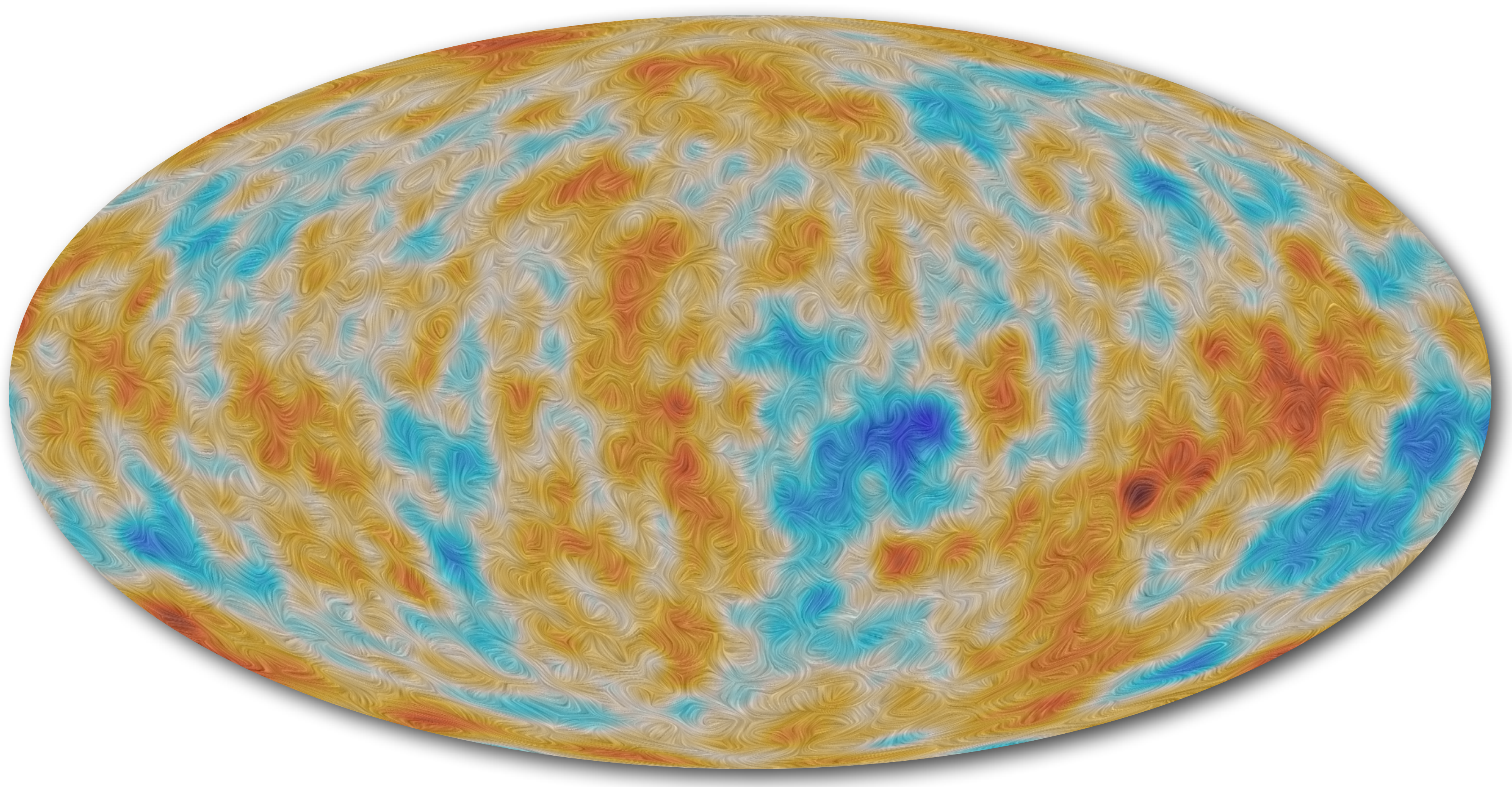
CMB polarization



Detection of B-mode pattern in CMB polarization as **imprint of primordial gravitational waves** and **Inflation**

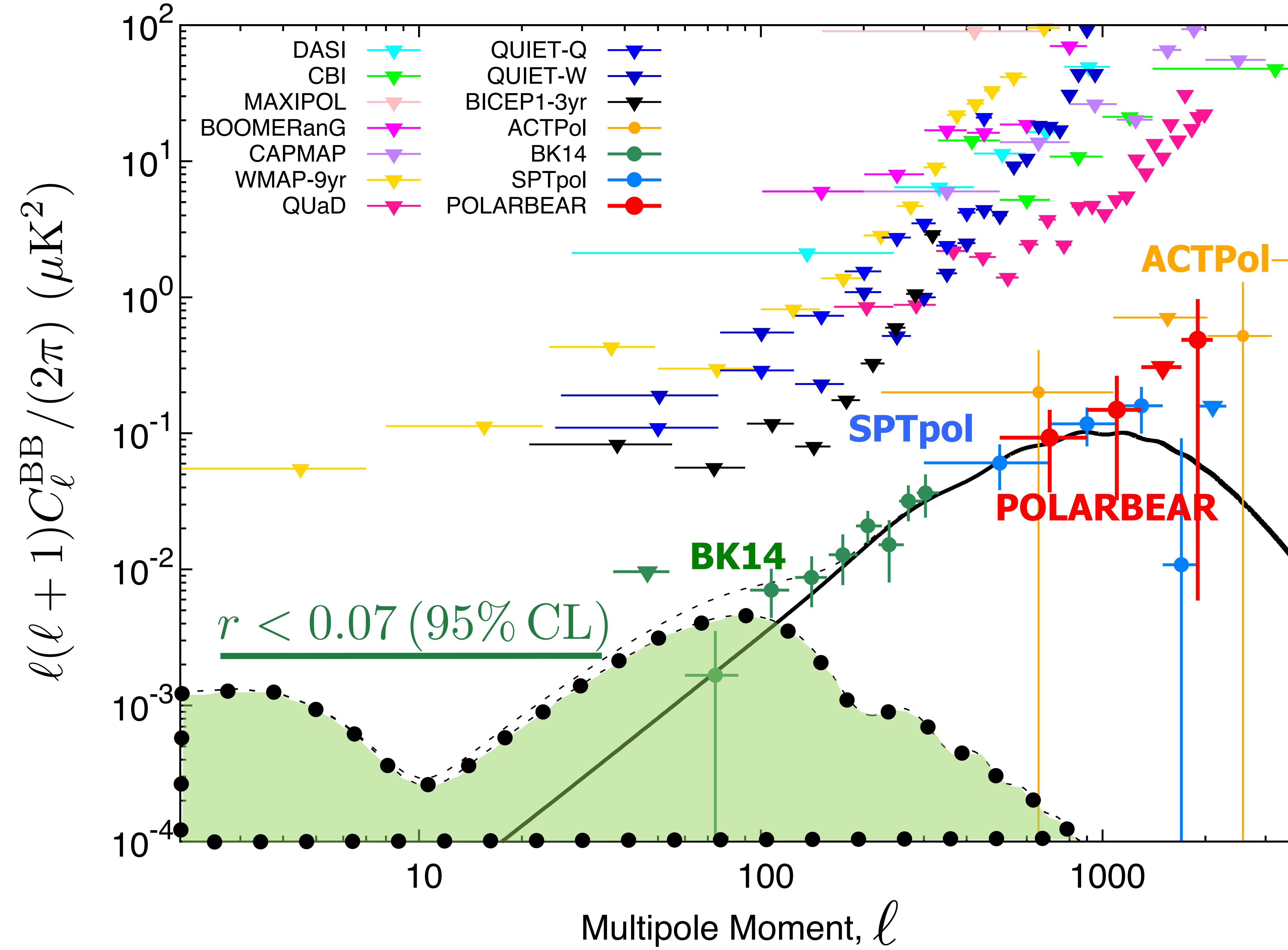
Nicoletta Krachmalnicoff

B-modes & Forgegrounds



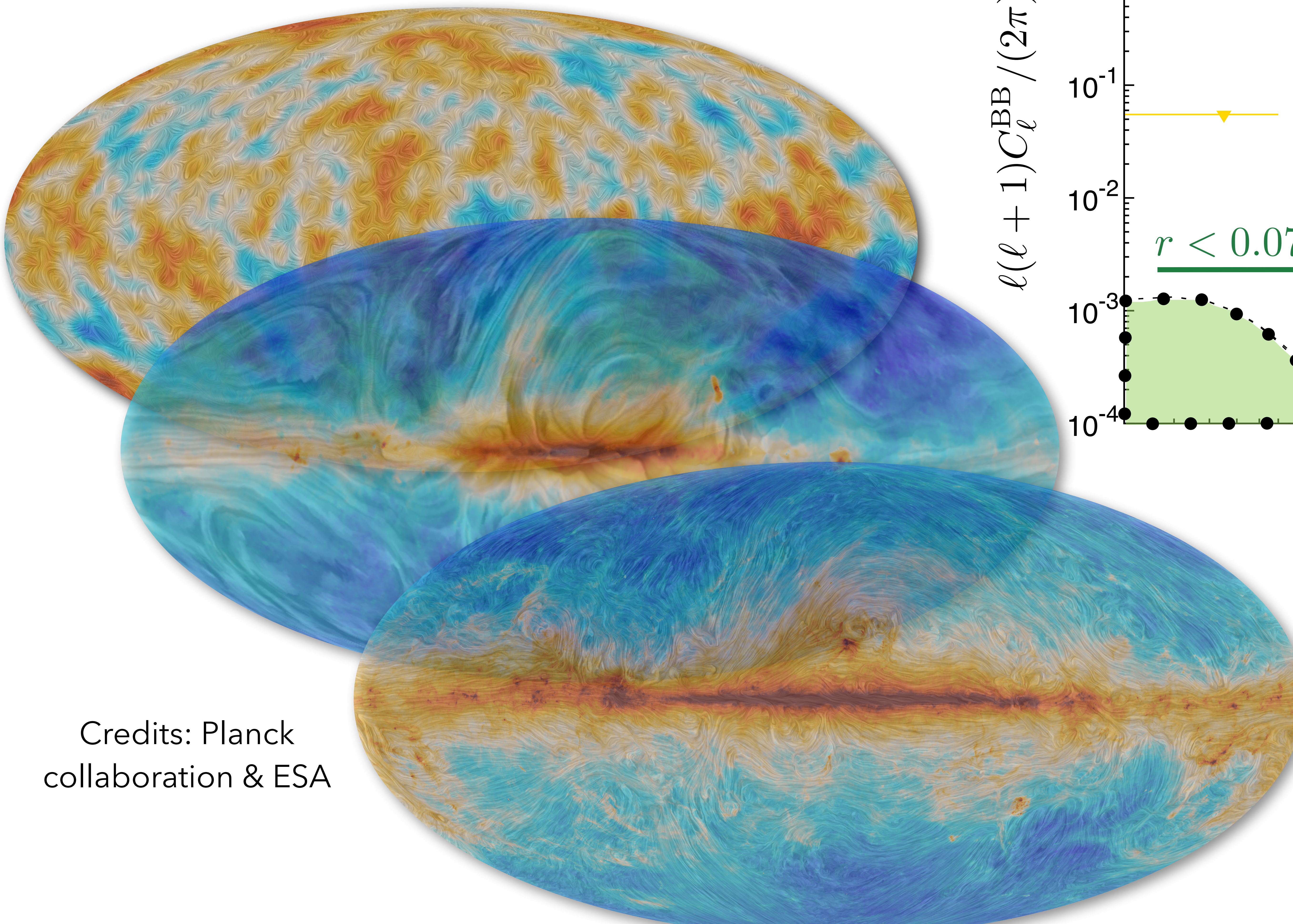
Credits: Planck collaboration & ESA

Status-of-art of CMB B-modes observations



Credits: POLARBEAR collaboration

B-modes & Forgegrounds



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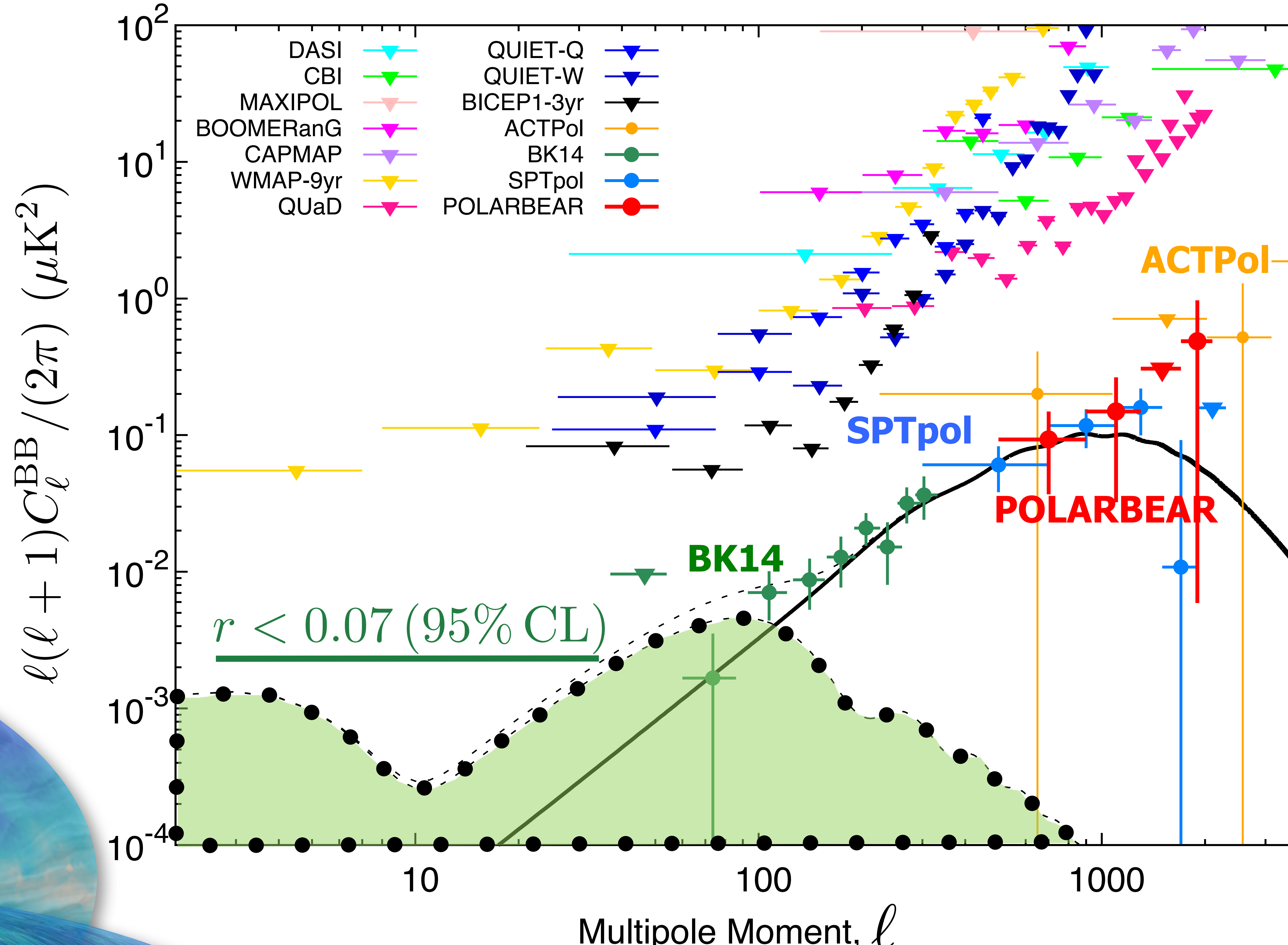
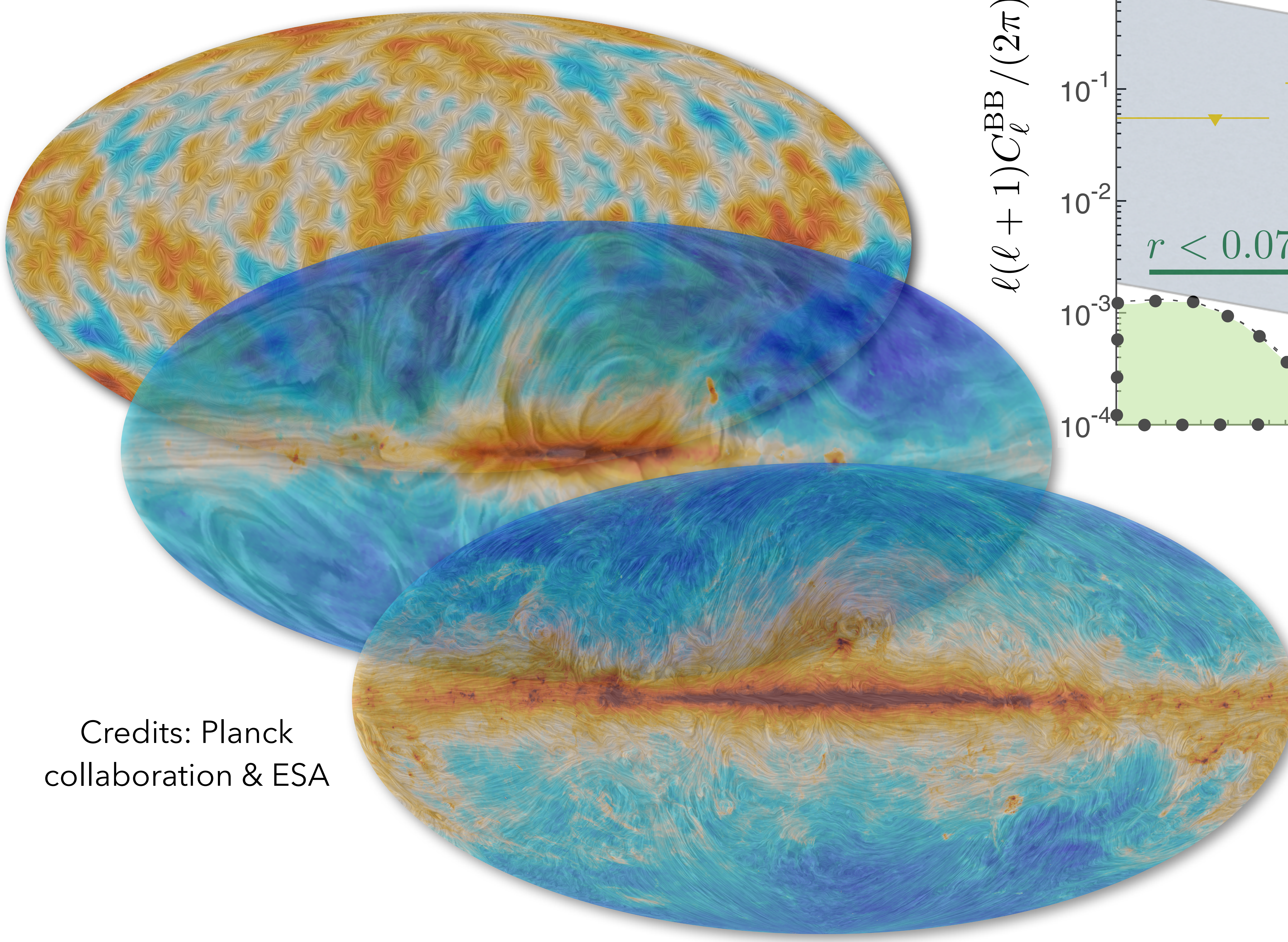


Credits: POLARBEAR collaboration

B-modes & Forgegrounds



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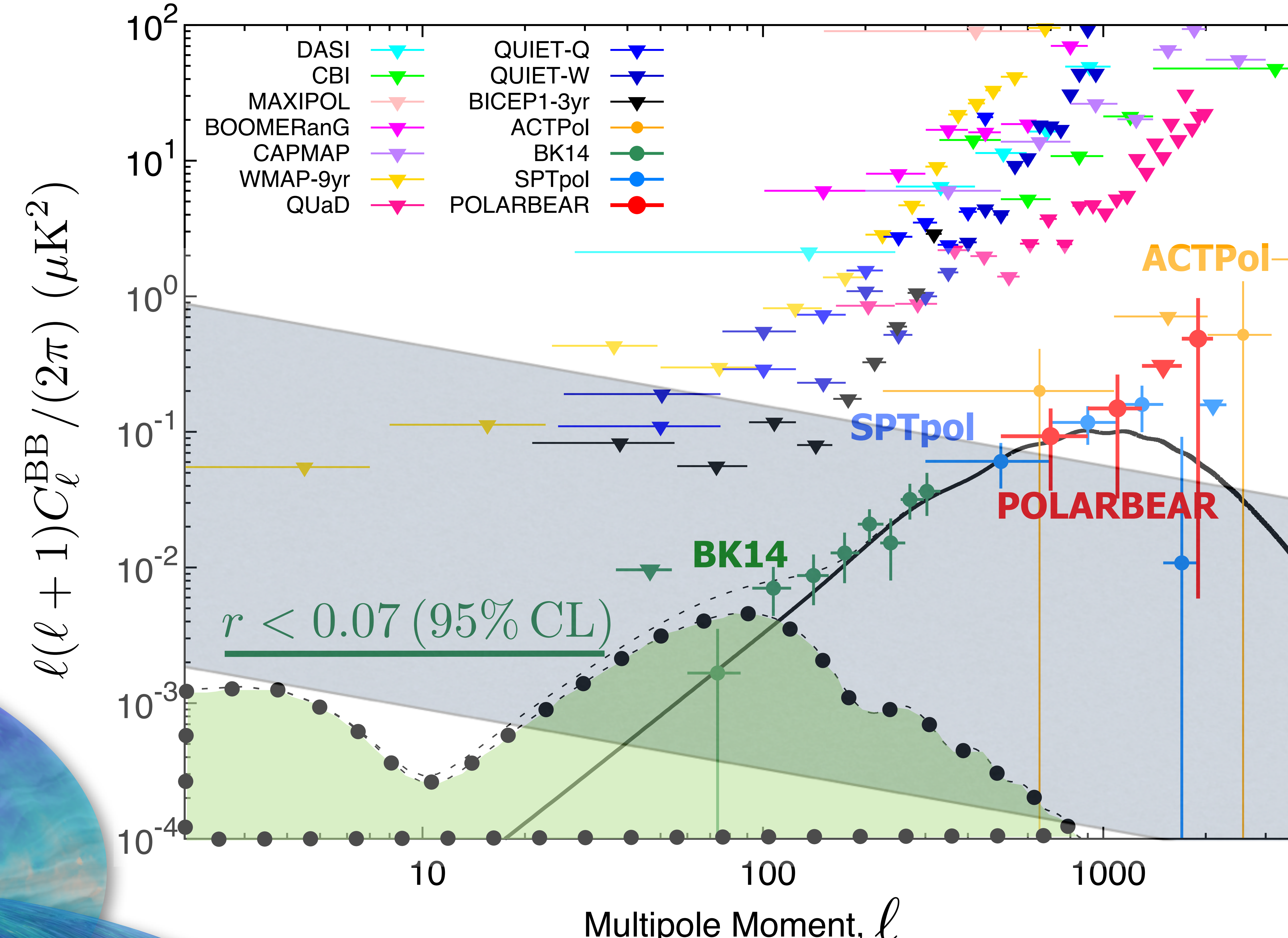
Status-of-art of CMB B-modes observations



Credits: POLARBEAR collaboration

Synchrotron

Acceleration of cosmic rays electrons in the Galactic magnetic field

Highly linearly polarized with polarization fraction up to ~20% for high Galactic latitudes

Power law frequency dependence with spectral index $\beta_s \sim -3$

Dominates sky emissions at low frequencies (< 70 GHz)

Thermal Dust

Thermal emission from interstellar dust grains

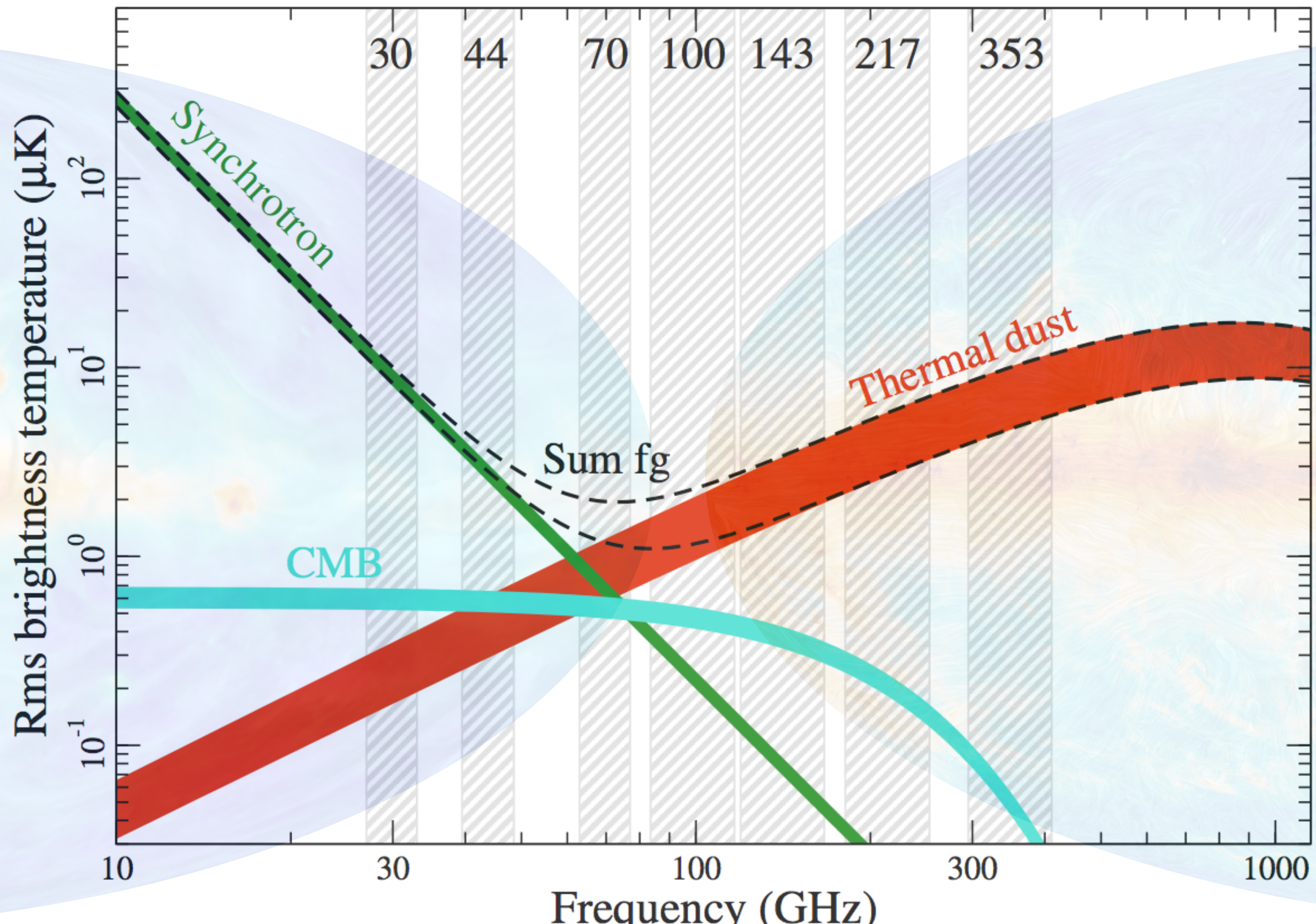
Asymmetries in the dust grains and alignment with the Galactic magnetic field lead to linearly polarized emission up to ~20%

Modified Blackbody frequency dependence with $T_d \sim 20$ K and $\beta_d \sim 1.6$

Dominates sky emissions at high frequencies (> 100 GHz)

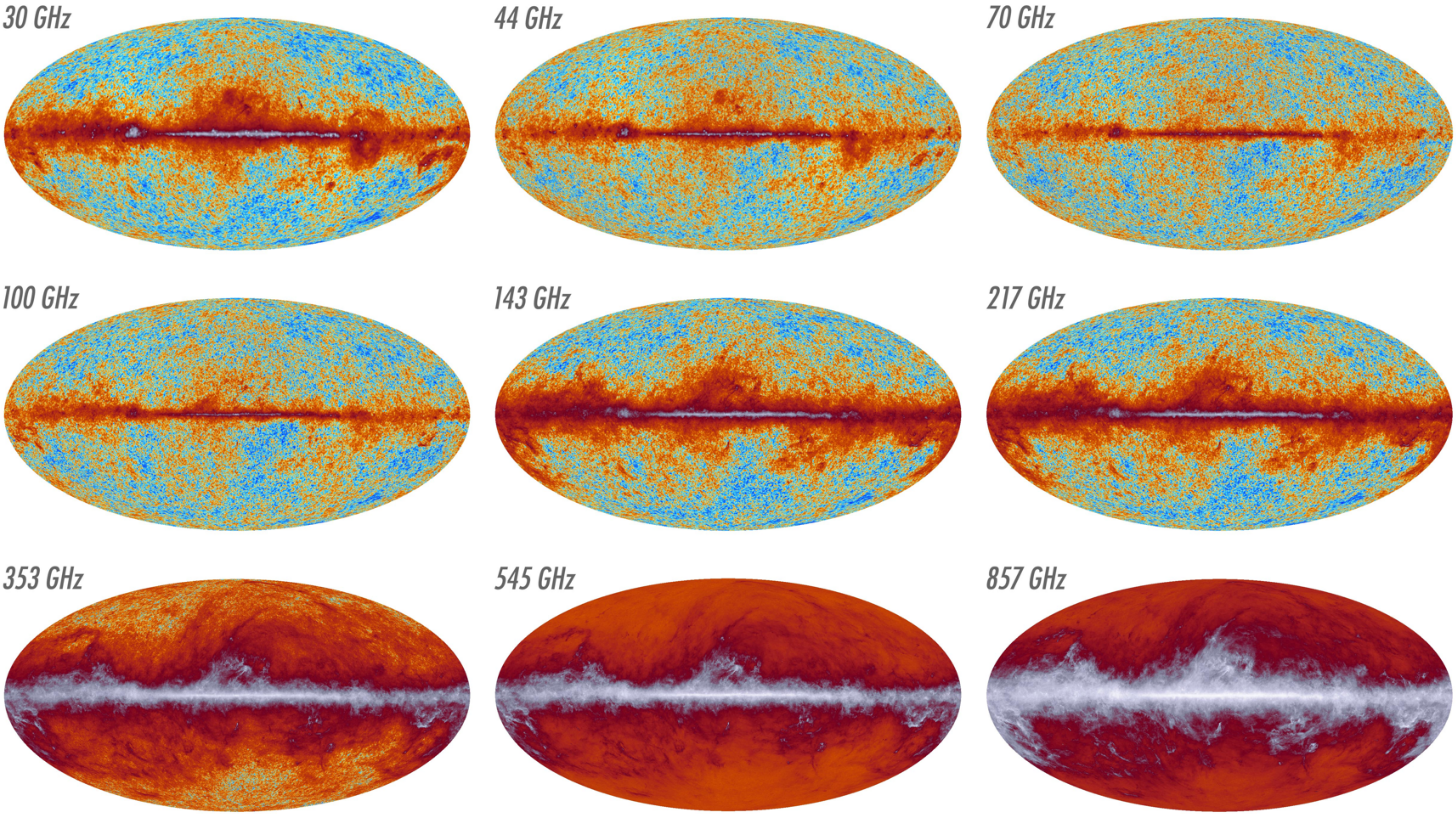
Synchrotron Thermal Dust

Planck 2015 results X



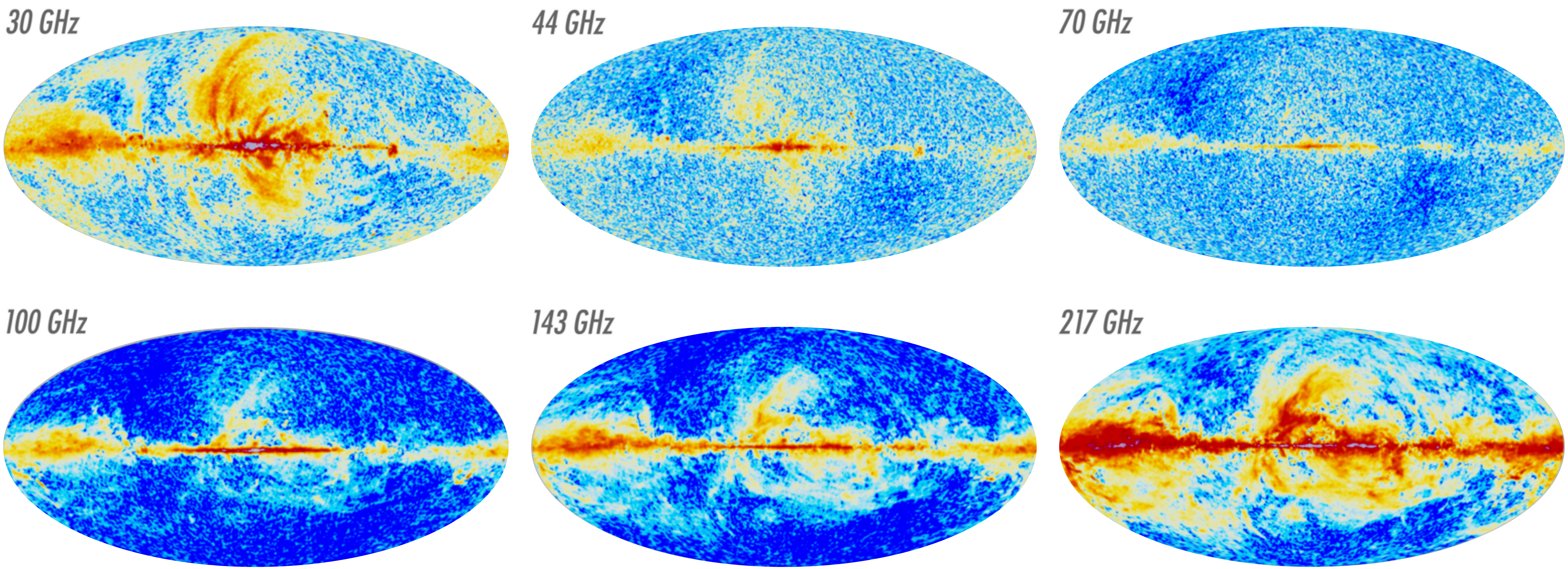
The Planck view of the sky in **Total intensity**

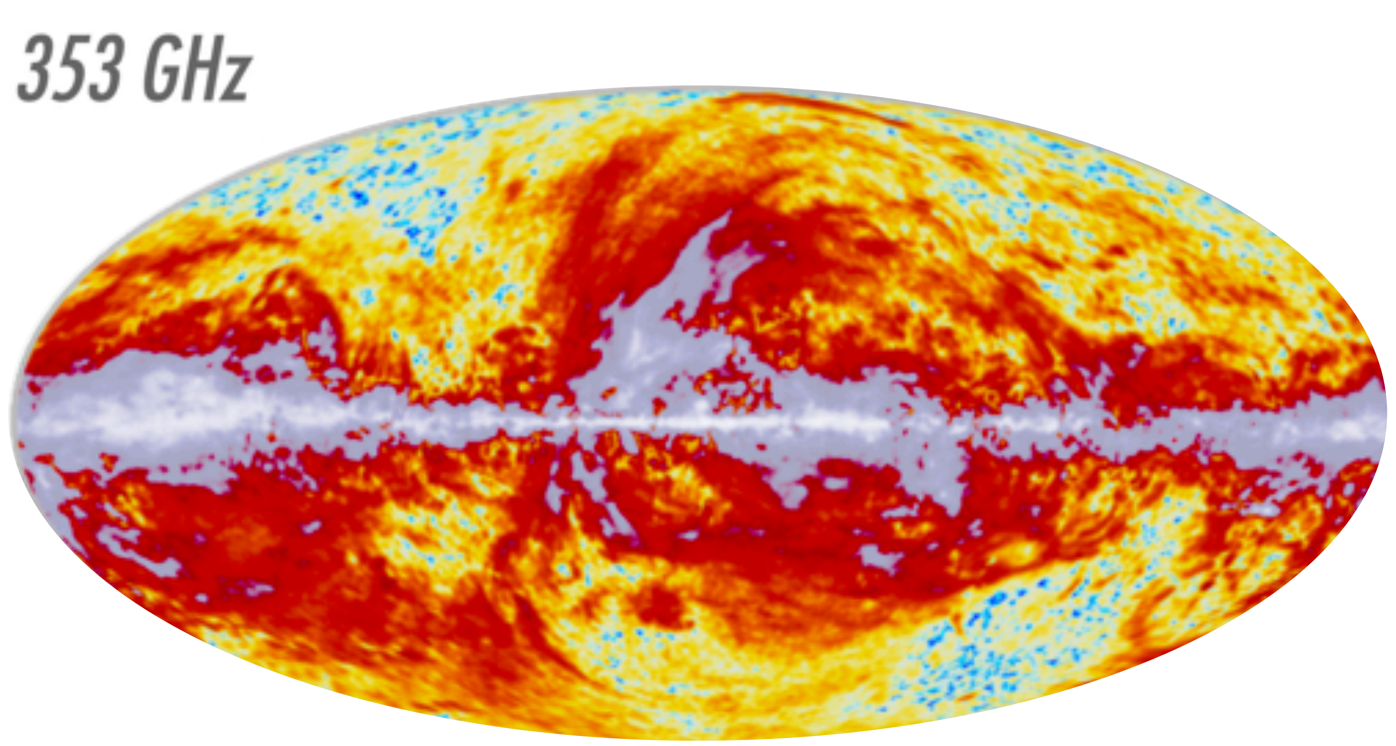
Credits: Planck collaboration & ESA



The Planck view of the sky in **Polarization**

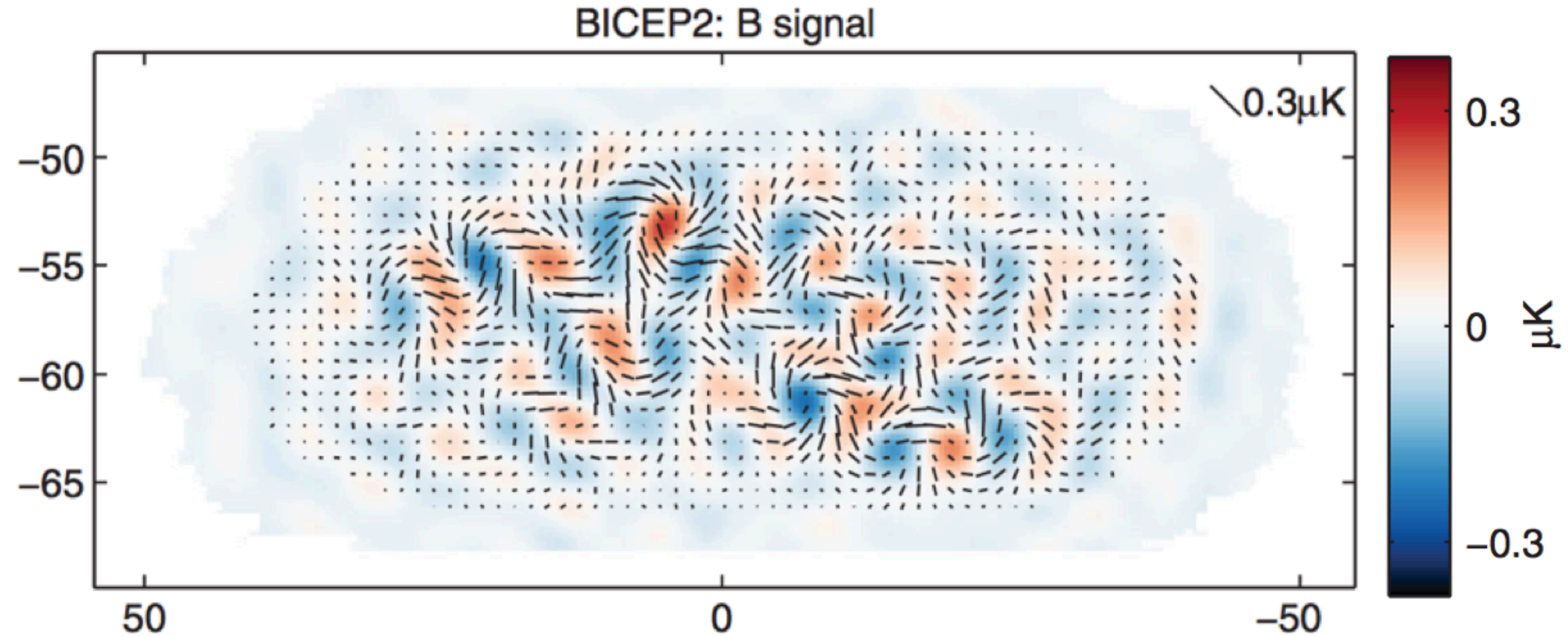
Credits: Planck collaboration & ESA



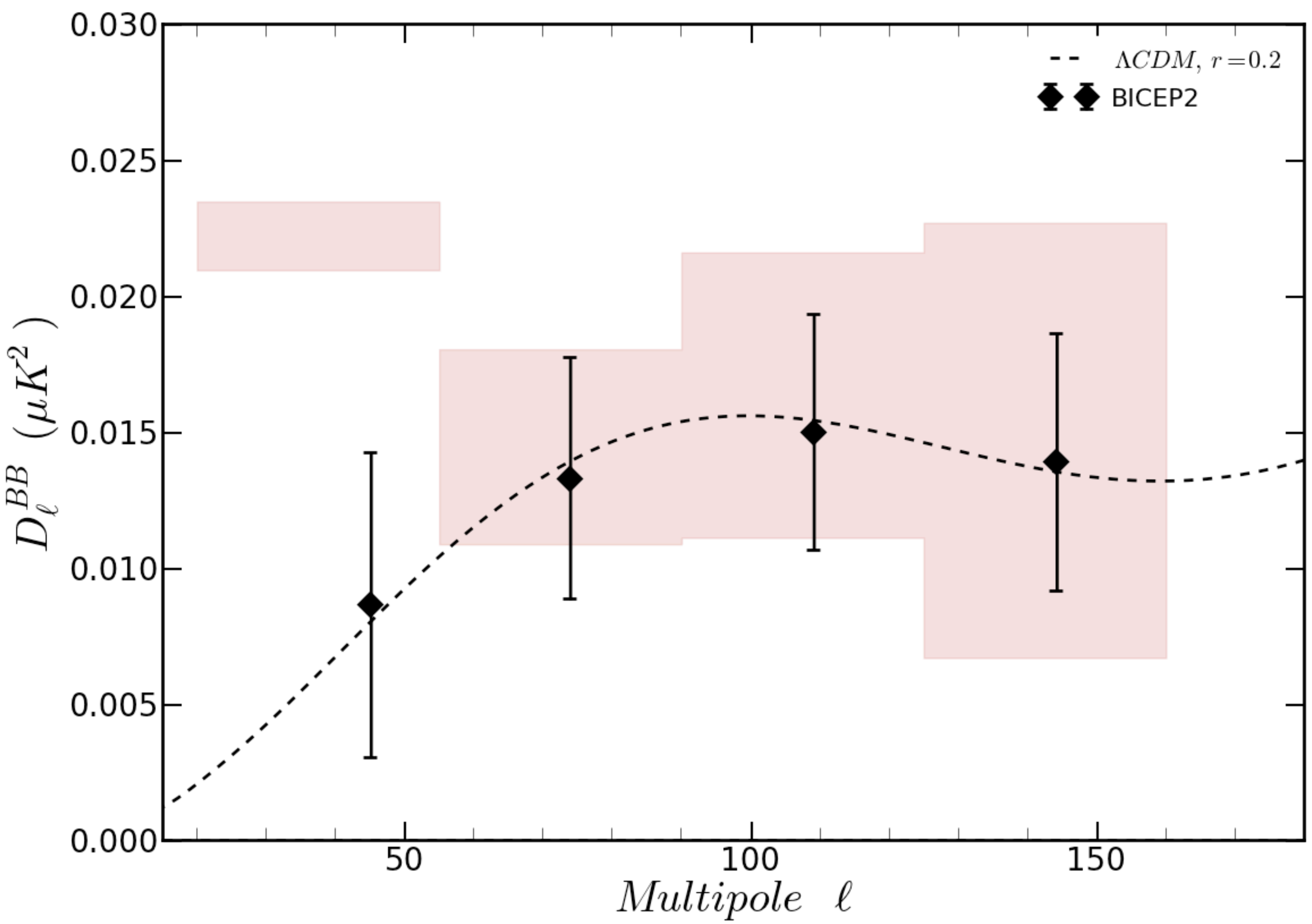


Is there any region of the sky where, at a certain frequency, the CMB B-mode signal dominates over foreground emission?

BICEP2 Collaboration I 2014; BICEP2 Collaboration II 2014

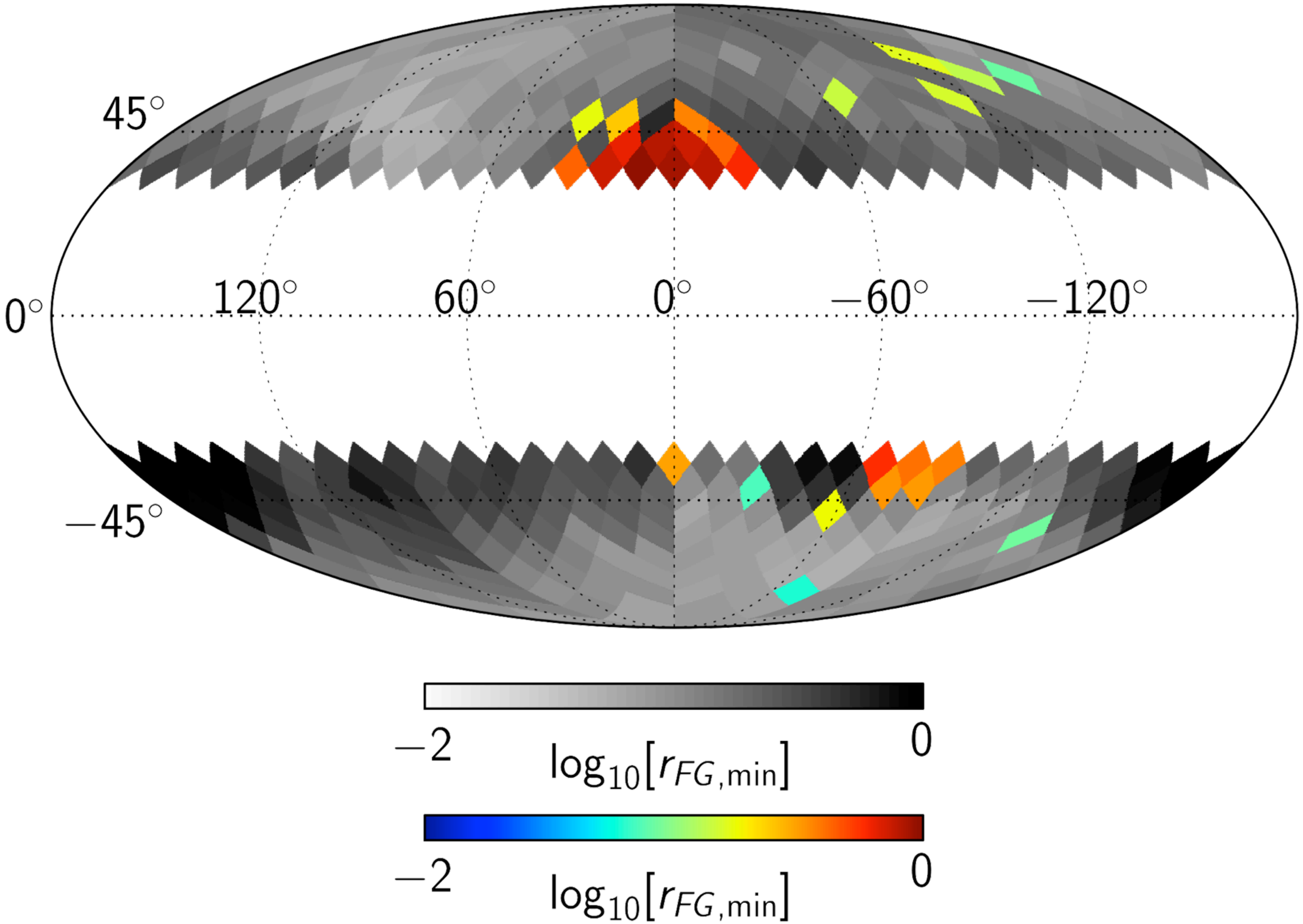


Krachmalnicoff N. PhD Thesis, 2015 & Planck Collaboration Int. XXX, 2016

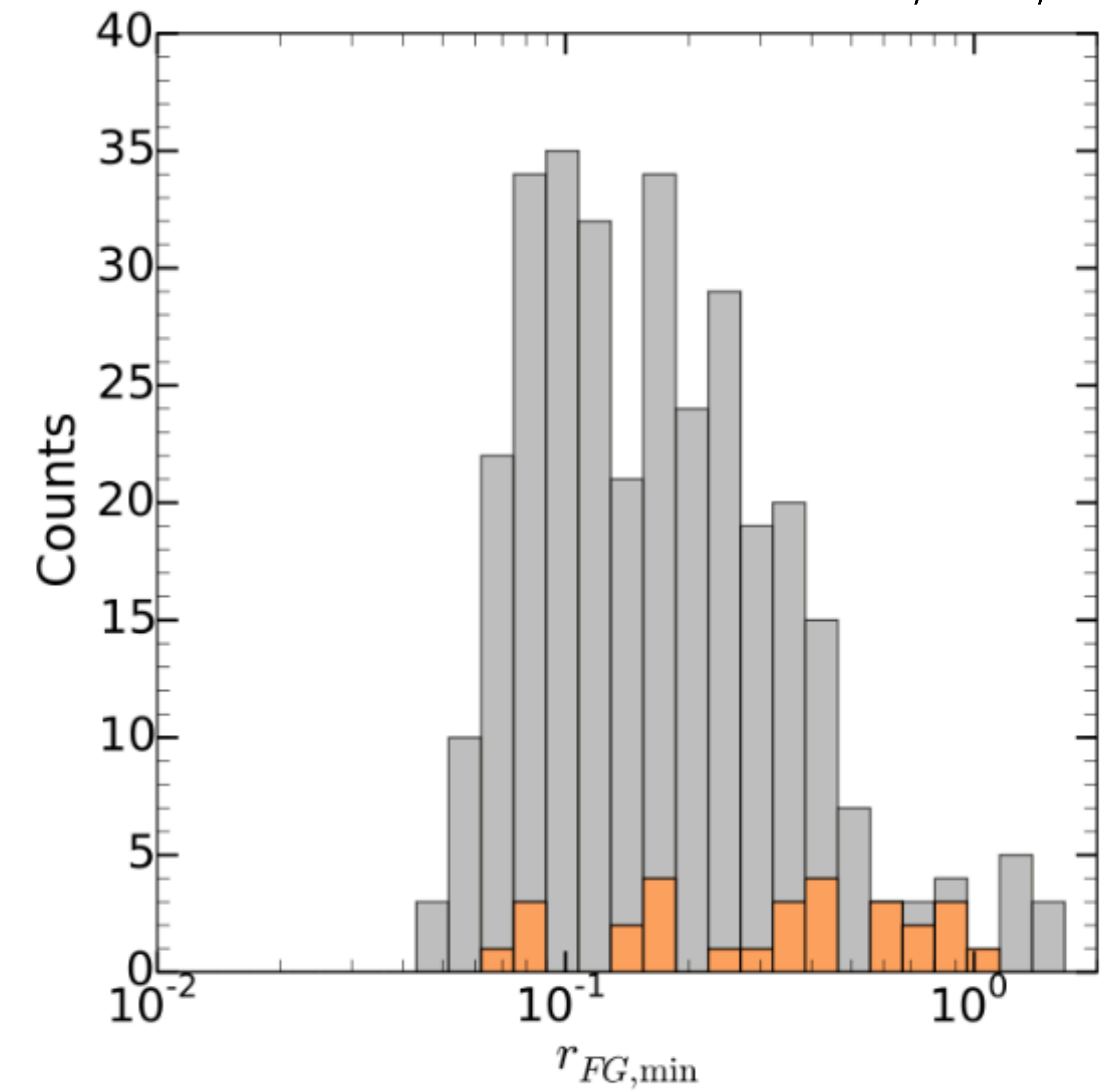


The **BICEP-2 case**, in late 2014, represented a **turning point in our awareness of the importance of foregrounds** as CMB contaminants

Estimate of the foreground minimum



Krachmalnicoff N. et al., A&A, 2016

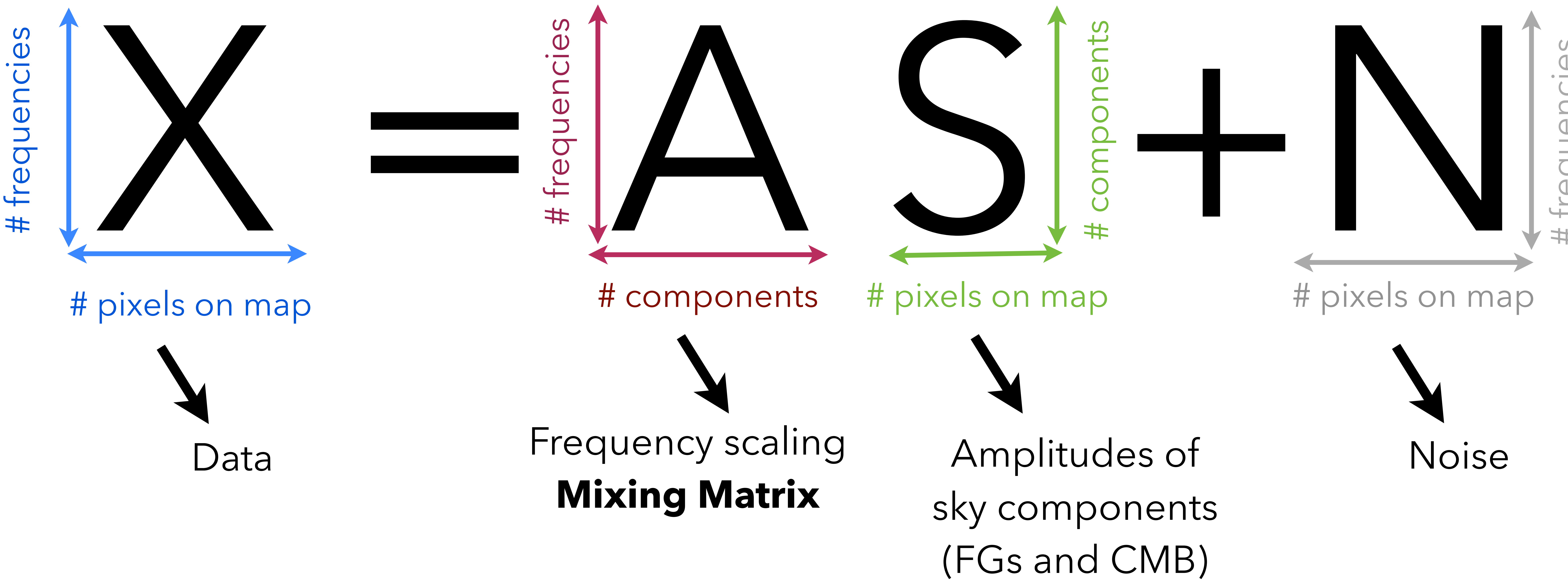


$$0.05 \lesssim r_{\rm FG} \lesssim 1.5$$

So…

- **Foregrounds are not negligible** anywhere and at any frequency (or at least we couldn't prove the contrary yet)
- **We need component separation**, to isolate the CMB signal with foreground residuals low enough
- **We need knowledge and characterization of foreground** emission in order to properly model them

Component Separation



Two approaches to perform Component Separation:

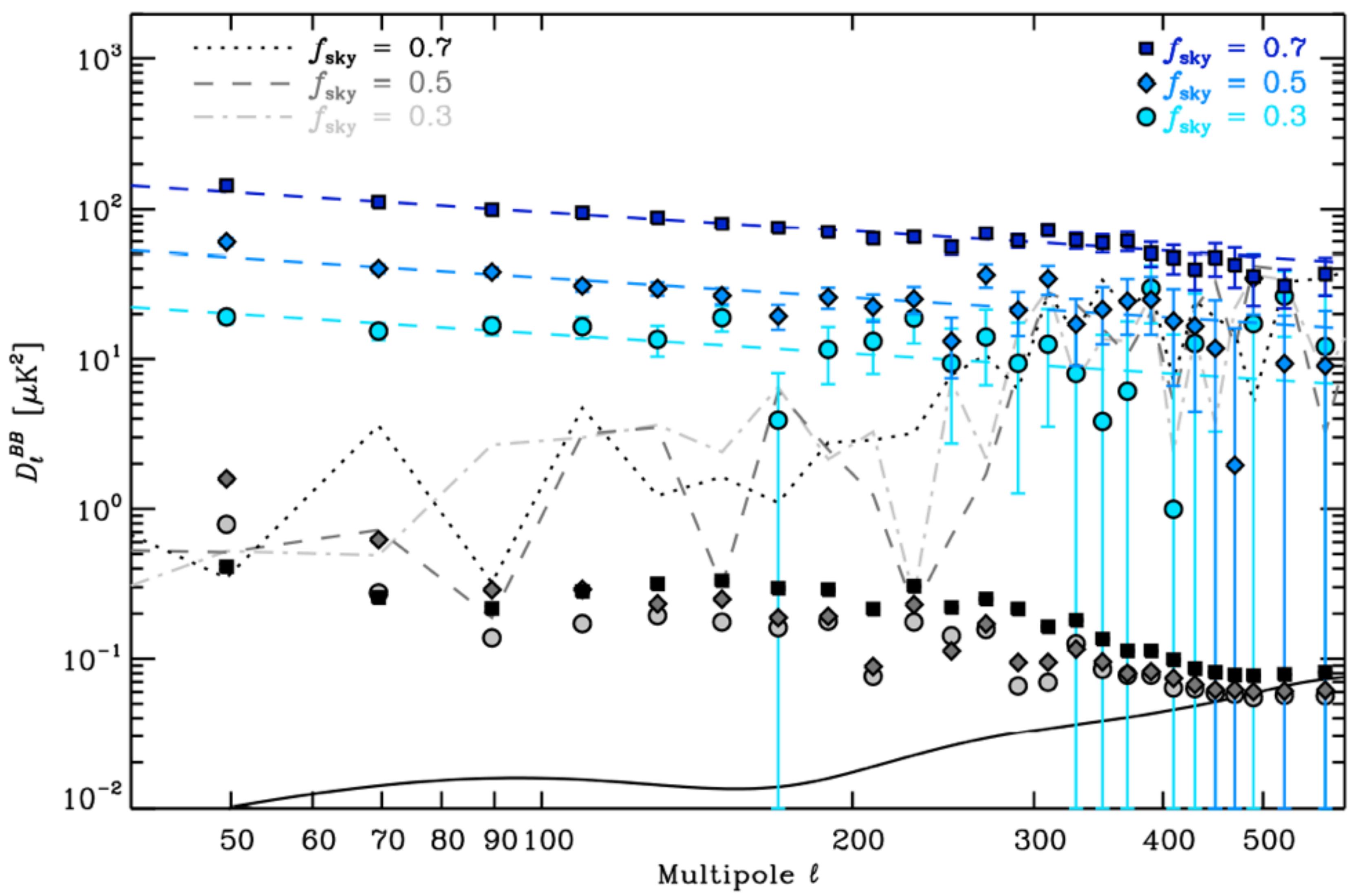
1) No knowledge on foreground emission:

- Estimate the **CMB signal as a linear combination of the data minimizing the output variance**
- ILC algorithms (Internal Linear Combination) broadly tested on total intensity data, less on polarization

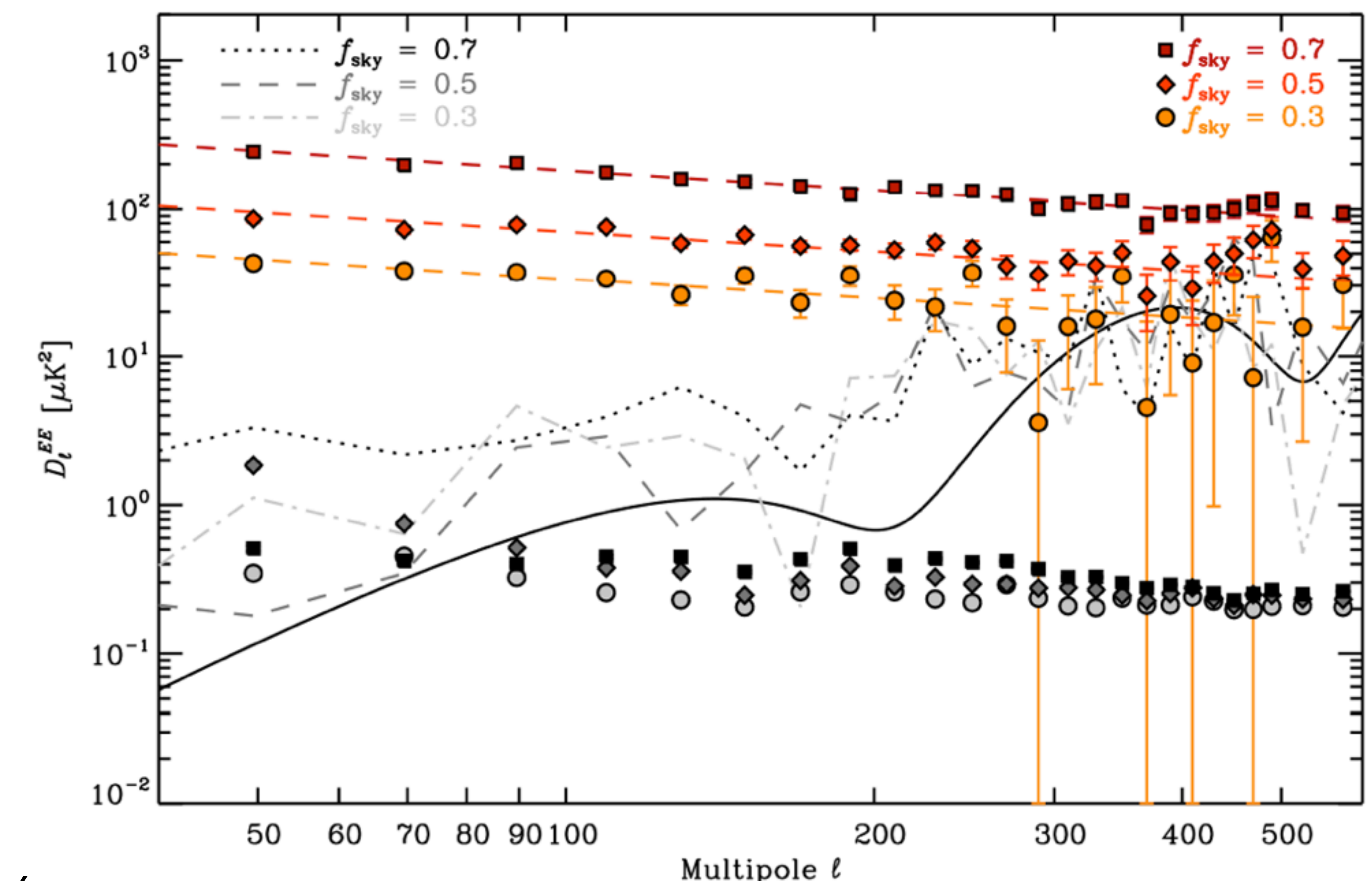
2) Some knowledge on the foreground emission

- **Parametrized the mixing matrix** with free parameters describing the frequency scaling of foreground emissions (typically spectral indices) and fit the data
- Currently great efforts to apply this kind of algorithms to existing data and simulations in polarization (Davide is on that)
- **Need accurate model of foreground emissions** the minimize residuals on CMB maps

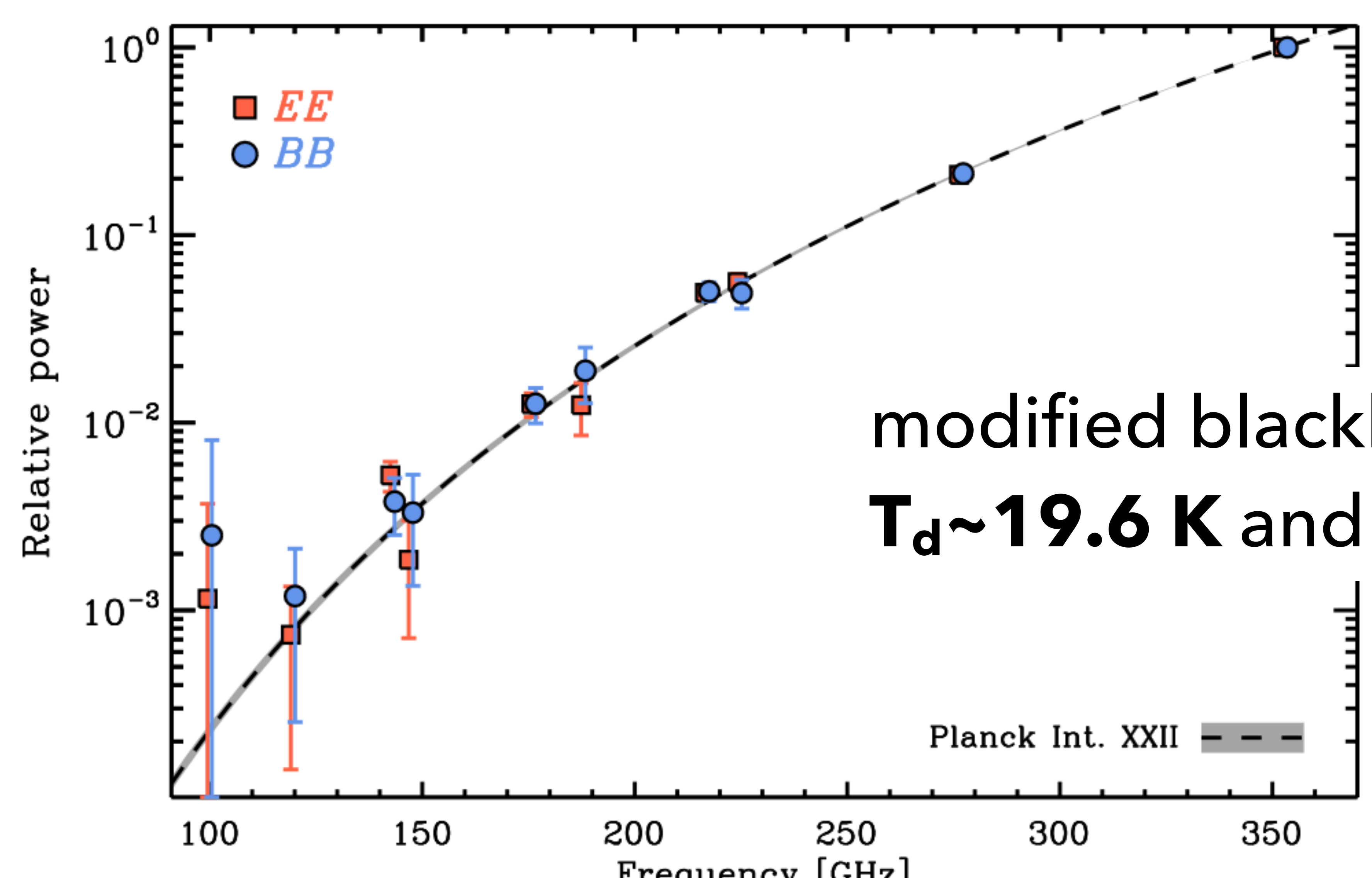
For **Thermal Dust** we can rely on Planck full-sky data at high frequency (217 - 353 GHz)



$$C_\ell \propto \ell^{-2.42}$$

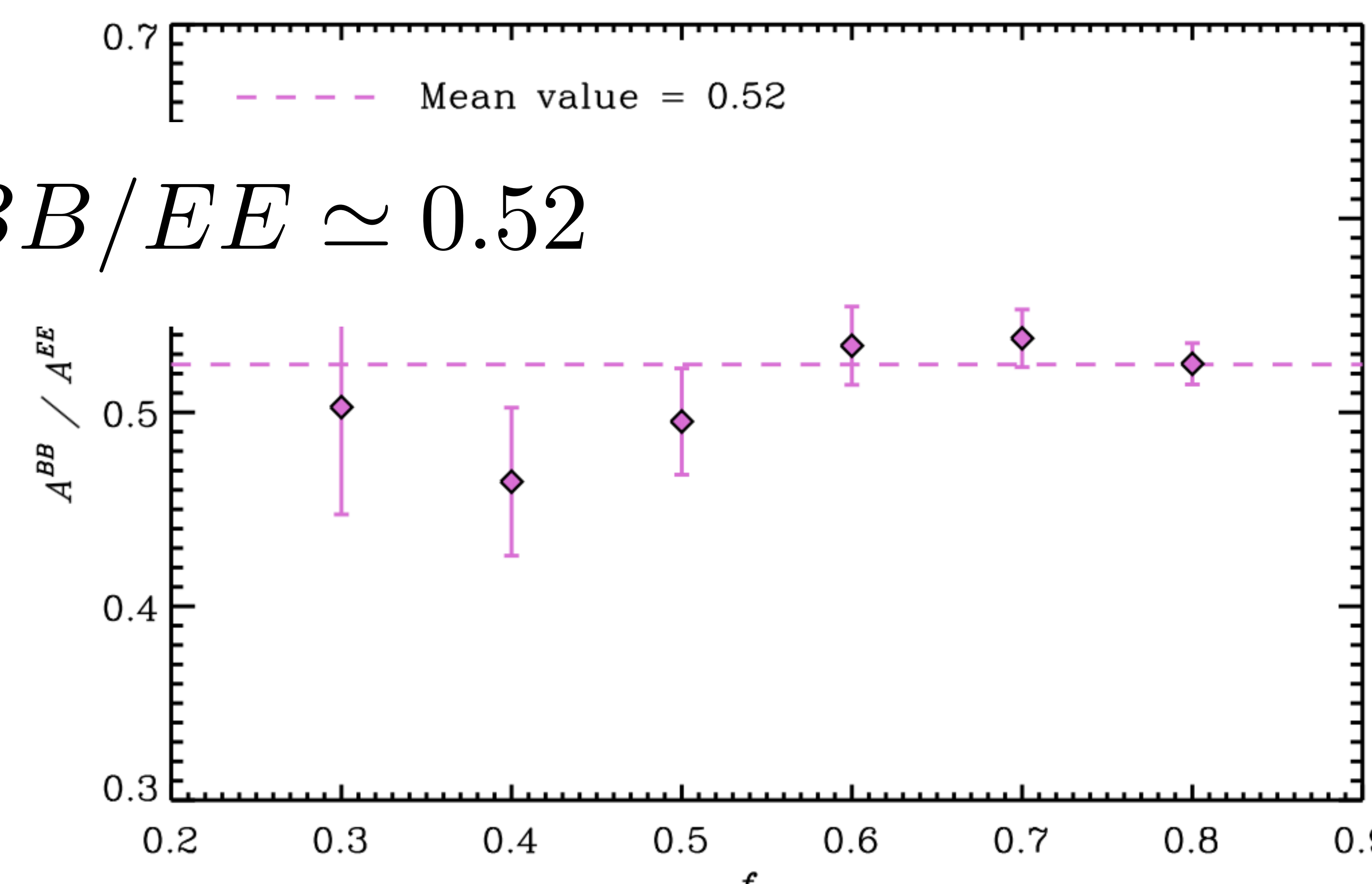


Planck Collaboration Int. XXX, 2016

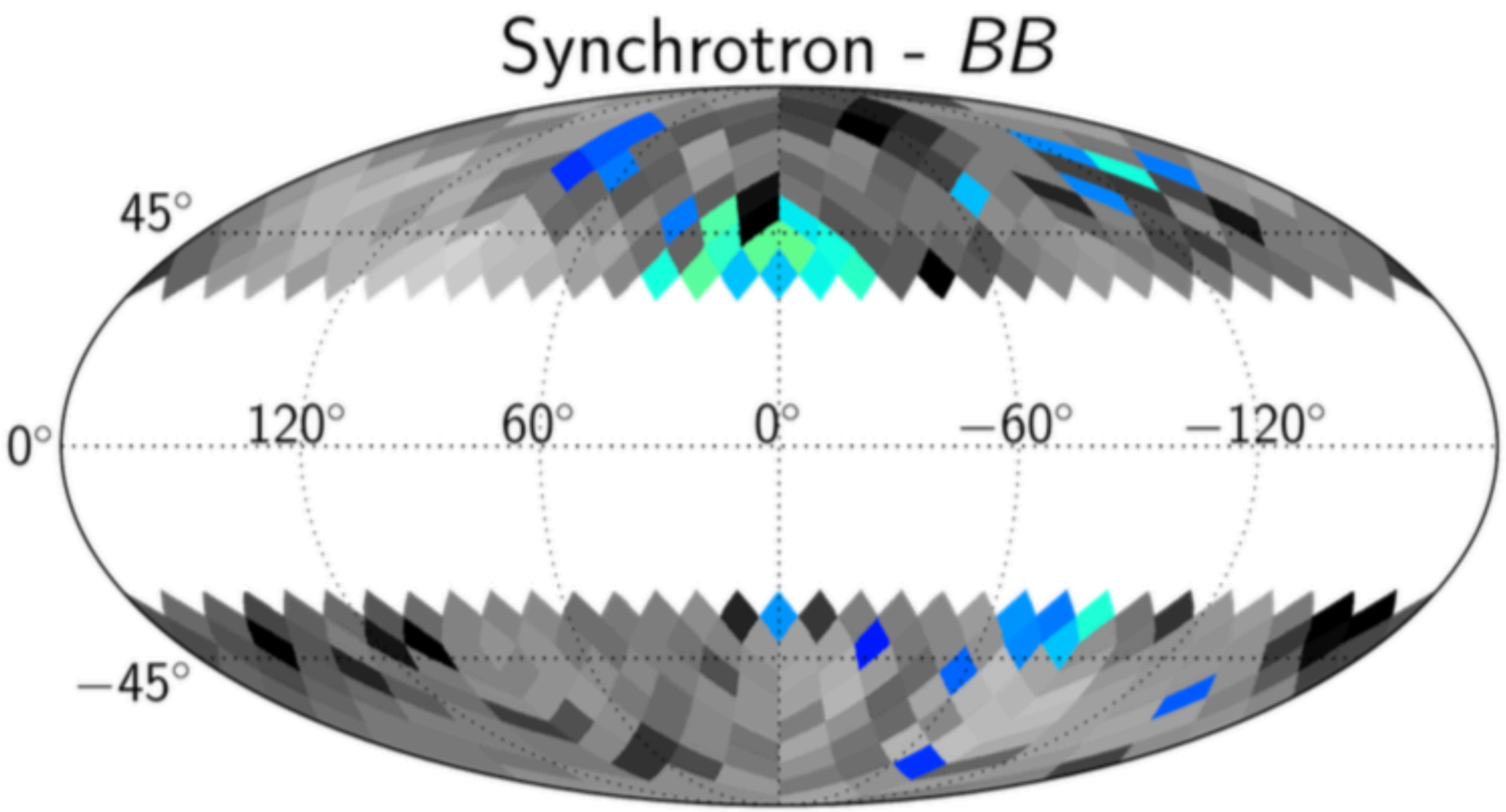


modified blackbody with **T_d~19.6 K** and **β_d~1.59**

$$BB/EE \simeq 0.52$$



What about **Synchrotron?**



Krachmalnicoff N. et al., A&A, 2016

Sensitivity of Planck and WMAP low frequency data (~20-30 GHz) **is not enough** with few detection at intermediate and high Galactic latitudes

Radio data (frequency < 10 GHz) can help in characterizing Synchrotron signal

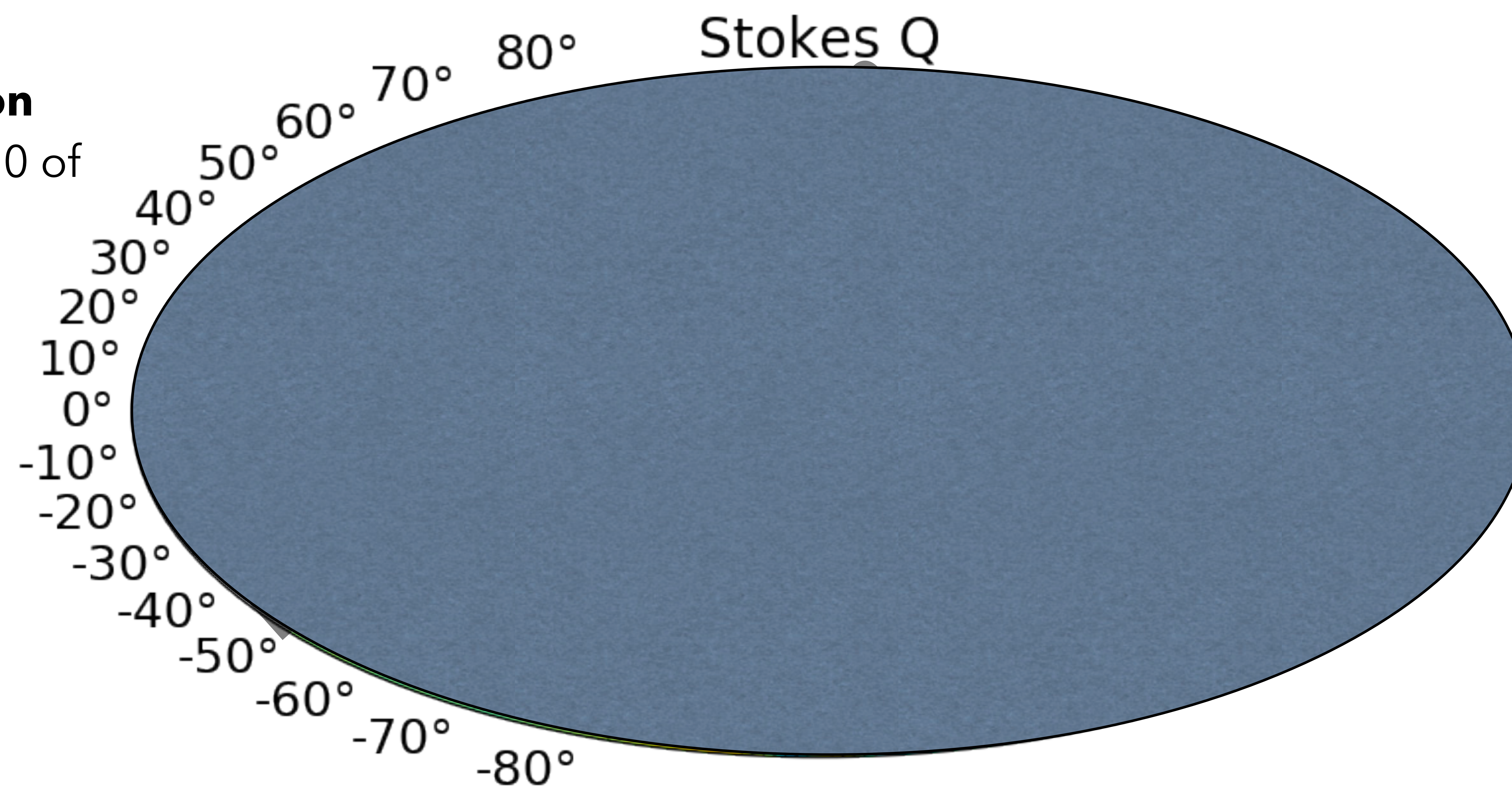
S-PASS survey (2.3 GHz)

PROs:

- **Much higher signal-to-noise ratio.** With signal 10^3 times stronger than at Planck and WMAP frequencies
- **Better angular resolution** (about 9 arc-mins vs 30-50 of Planck and WMAP)

CONs:

- **Depolarization due to Faraday rotation** on the Galactic Plane
- **Long extrapolation to CMB frequencies** (100-150 GHz)



SUMMARY

Detecting the primordial CMB B-mode signal is extremely challenging.

No detection can be claim at any frequency and in any region of the sky without a complete and precise analysis and removal of the FG emission.

Keep analyzing incoming data to update our FG understanding and modeling

We need high sensitivity and multi-frequency data for the next generation of experiments

Radio survey are major sources of information for Synchrotron emission and S-PASS is a unique dataset

Develop, optimize and test component separation algorithms