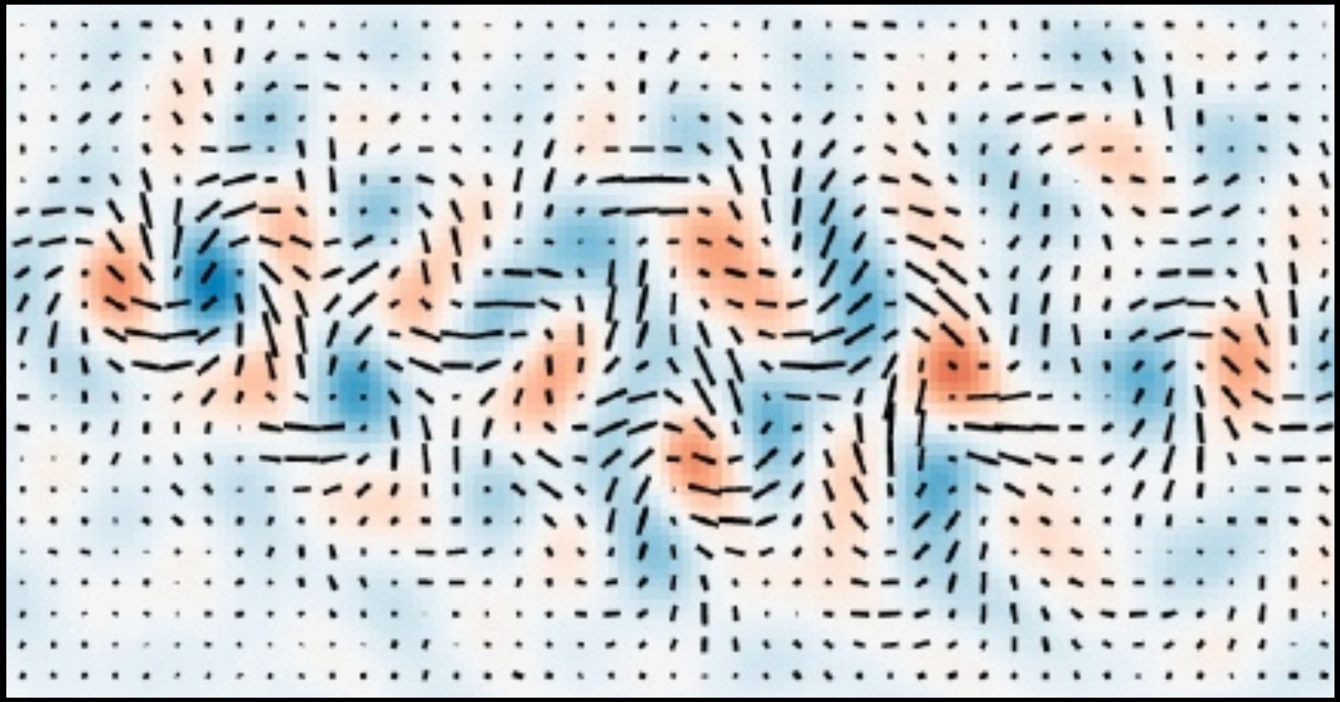
Galactic dust polarization foregrounds for current and future CMB experiments:

Learning from the BICEP2/Keck/Planck experience



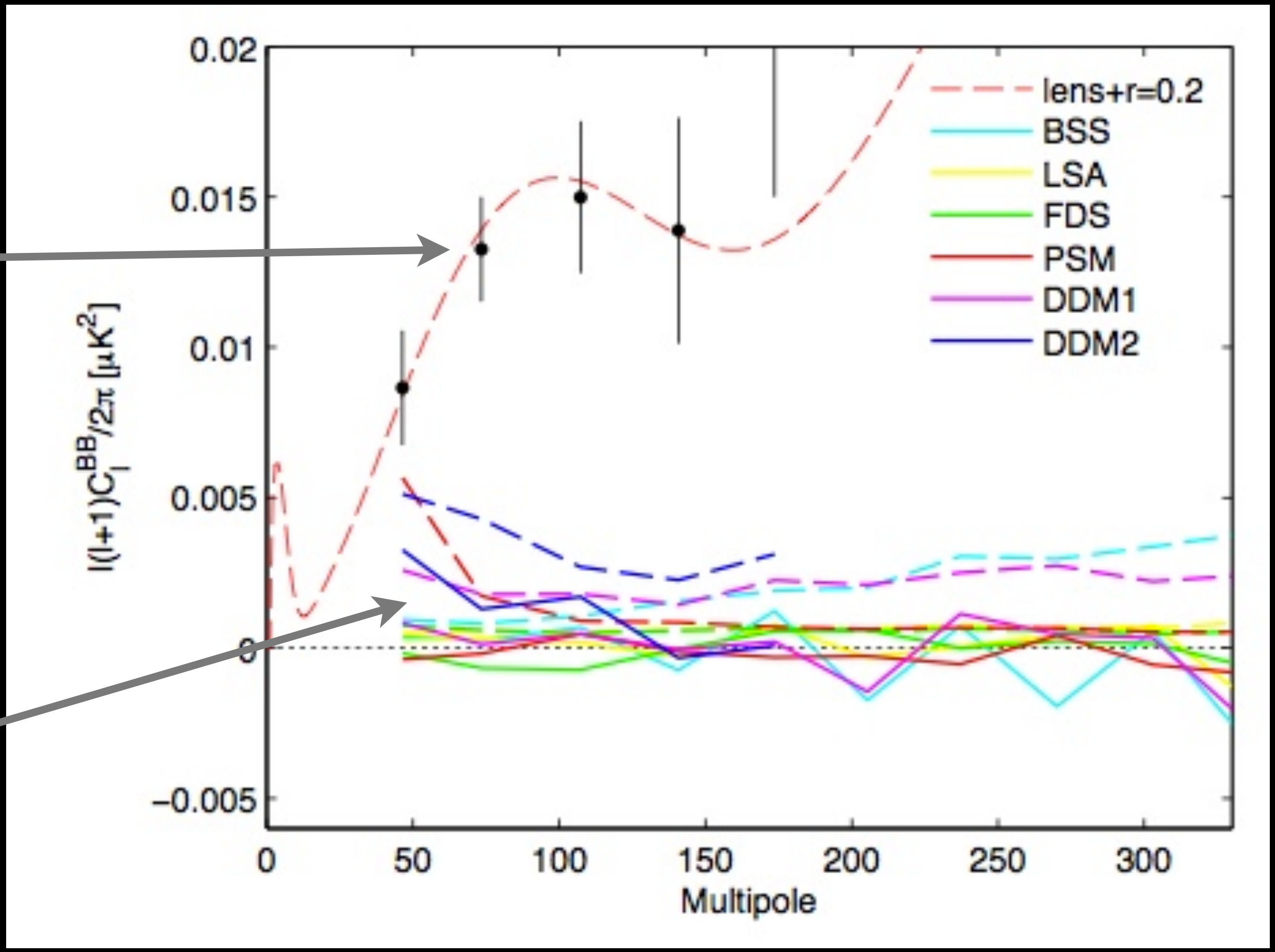
Ludovic Montier

on behalf on Planck Collaboration

The BICEP2 preliminary analysis

The BICEP2 results

Primordial Gravitational waves signal ?



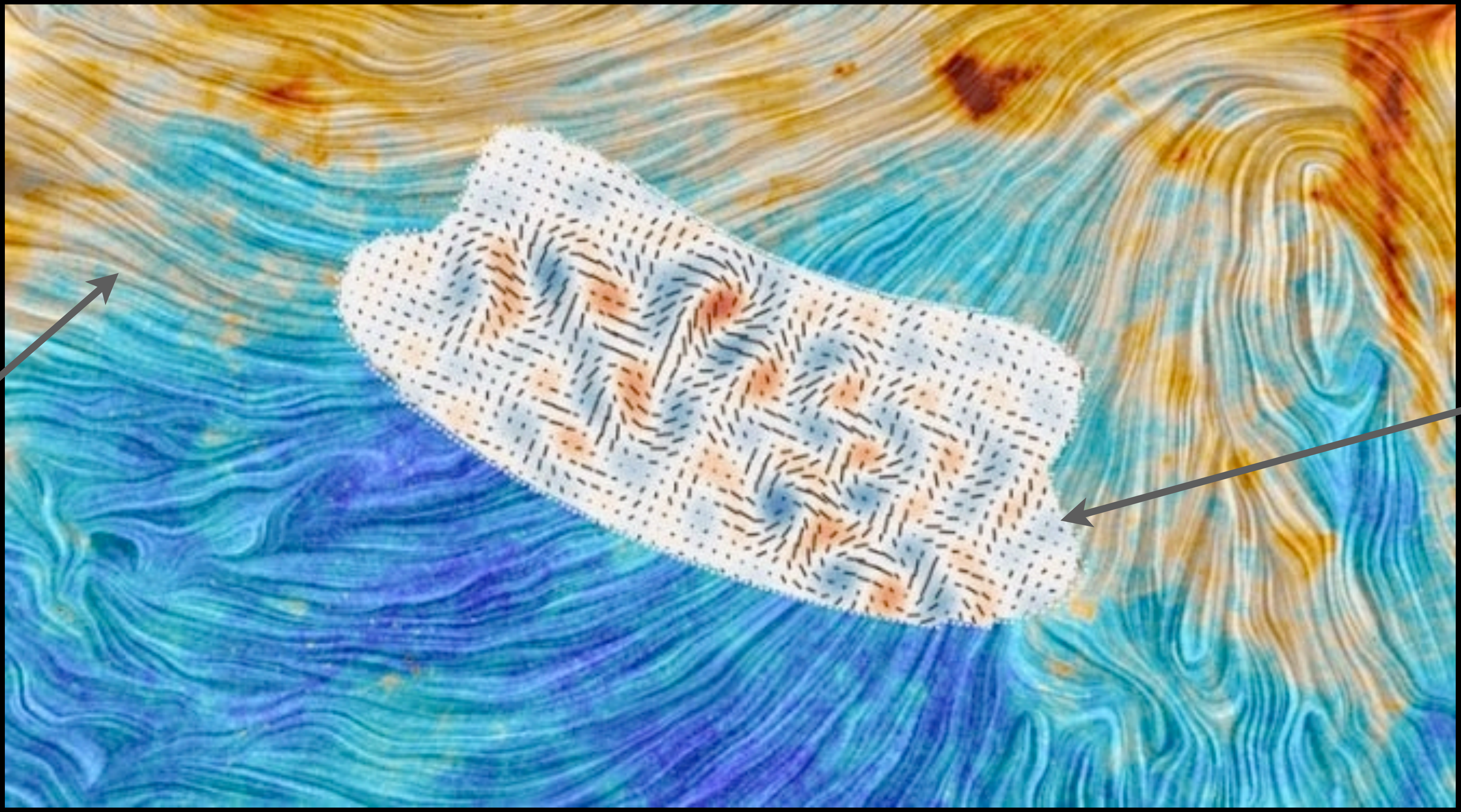
Galactic Foregrounds predictions

BICEP2 Collaboration ArXiv March 2014

The *Planck* view of the dust B-Modes

Clean from Galactic contamination ?

353GHz Intensity
+
Magnetic field structure



BICEP2
B-Mode Signal

The *Planck* view of the dust B-Modes

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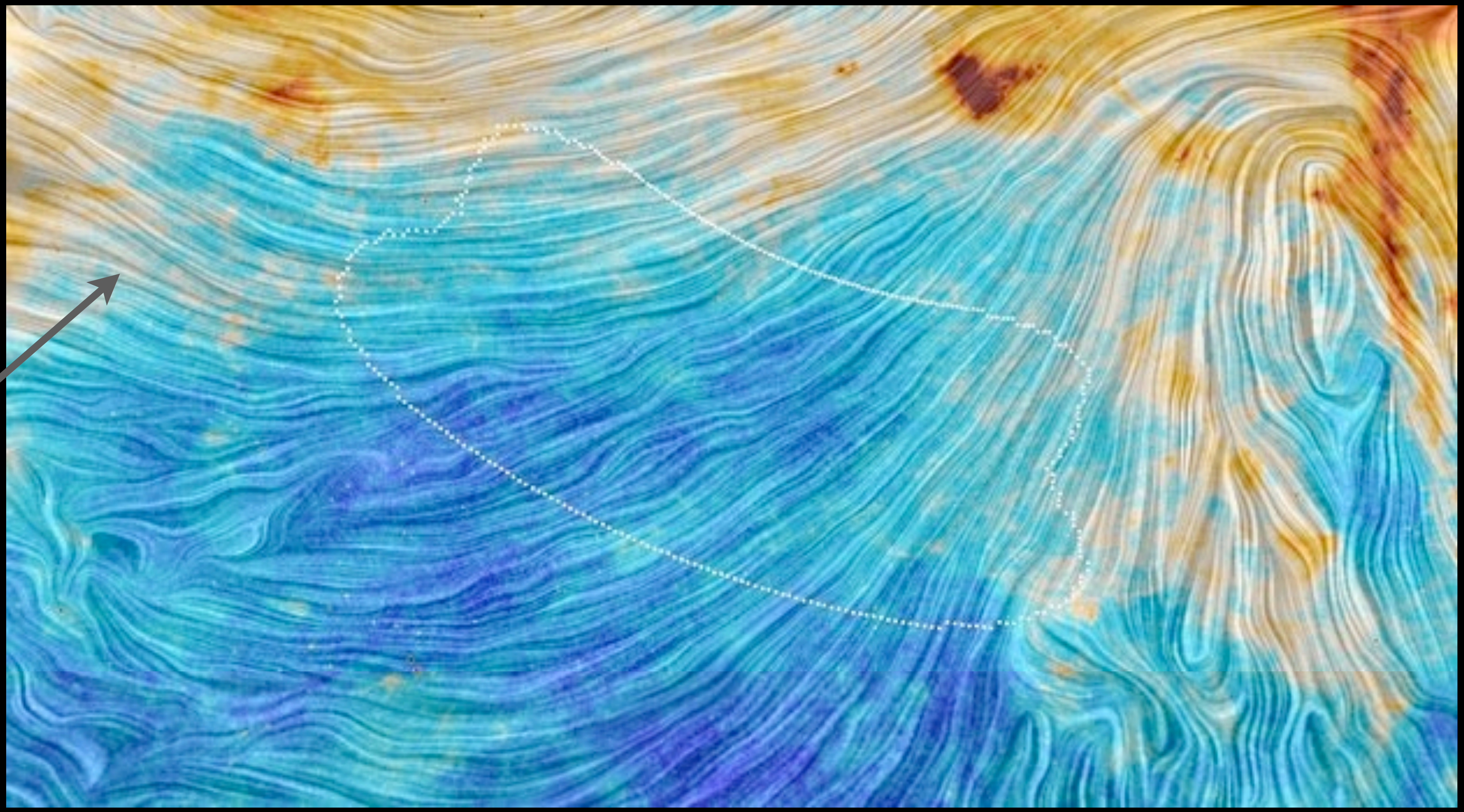

The *Planck* view of the dust B-Modes

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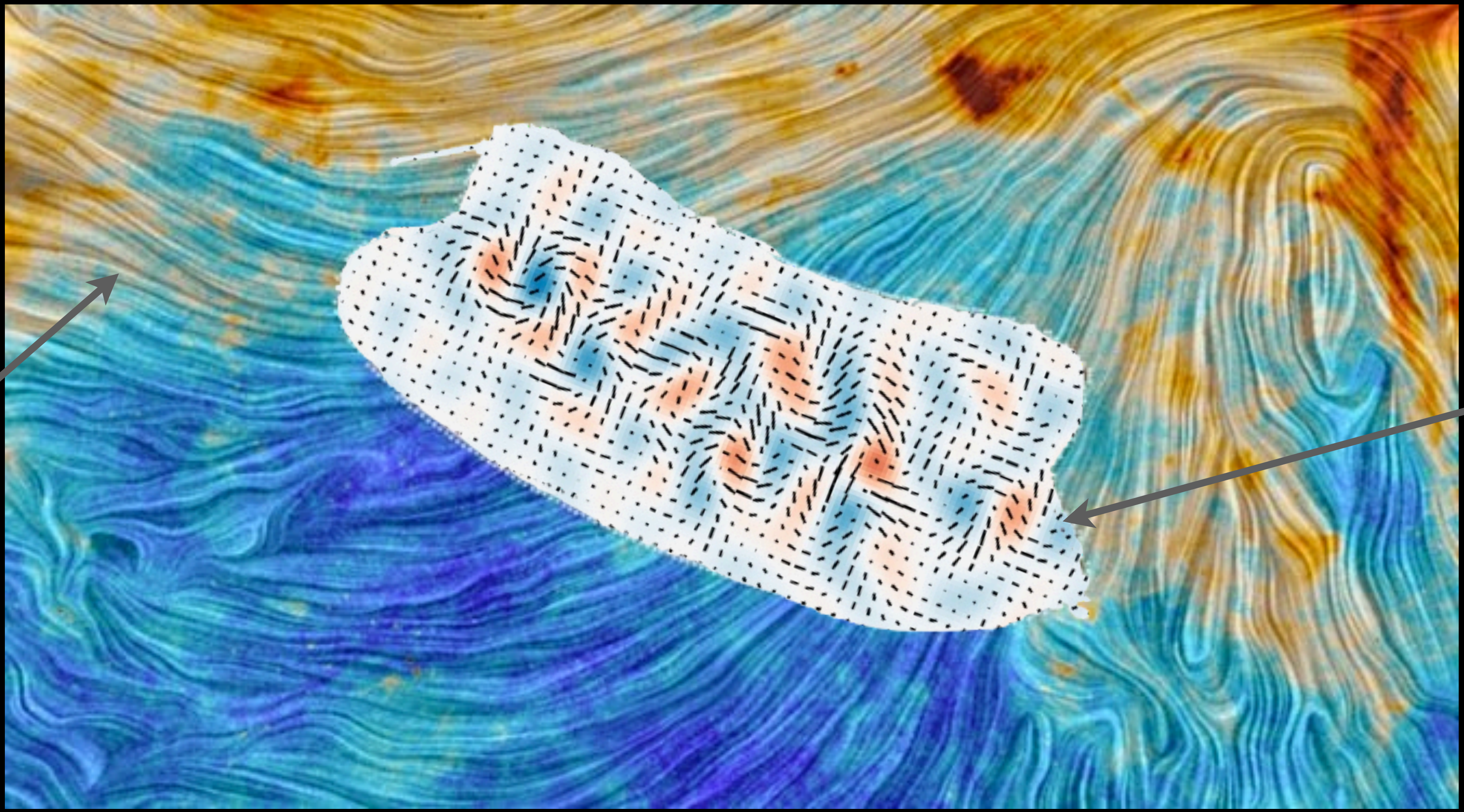

Planck 353GHz
B-Mode Signal

The *Planck* view of the dust B-Modes

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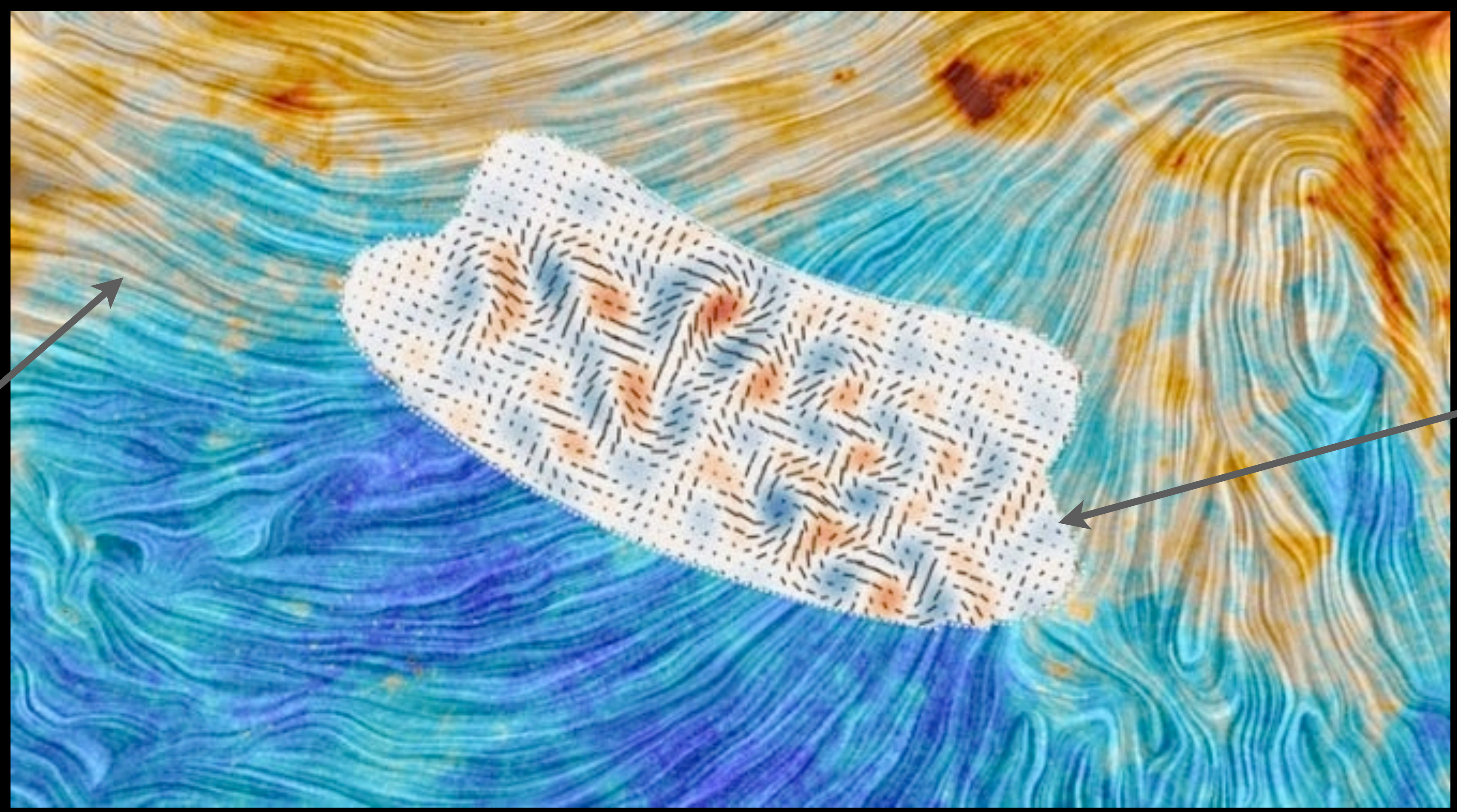
Magnetic field structure



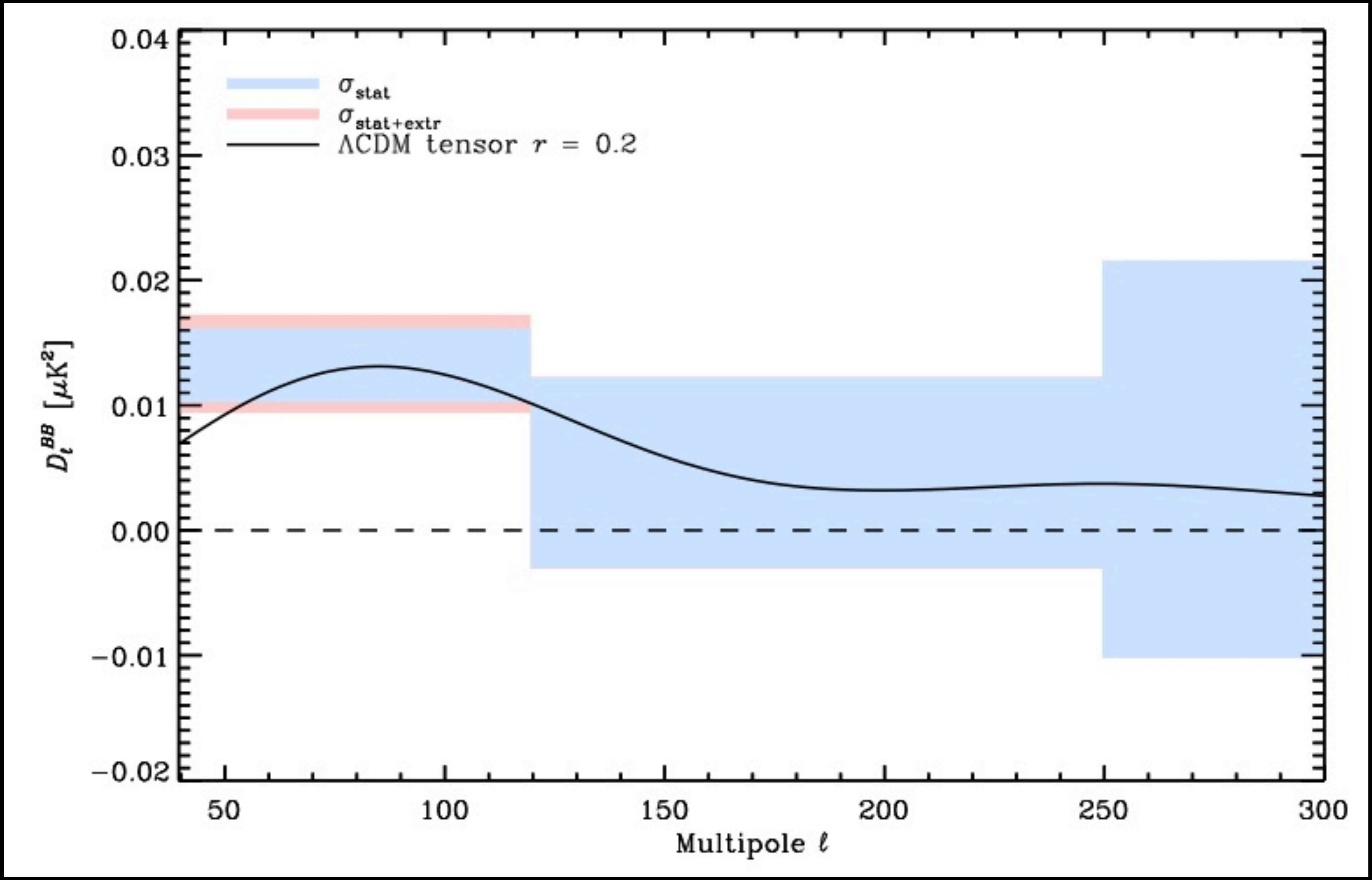
BICEP2
B-Mode Signal

The *Planck* view of the dust B-Modes

The *Planck* warning...

Planck Int. XXX 2014

Foregrounds !



So what ? Is BICEP2 signal primordial or Galactic, or both ?

The *Planck* view of the dust B-Modes

The *Planck* 353 GHz polarization modelling

EE/BB power spectra of dust follow a power law:

$D_{\ell\ell} \propto \ell^{-0.42}$

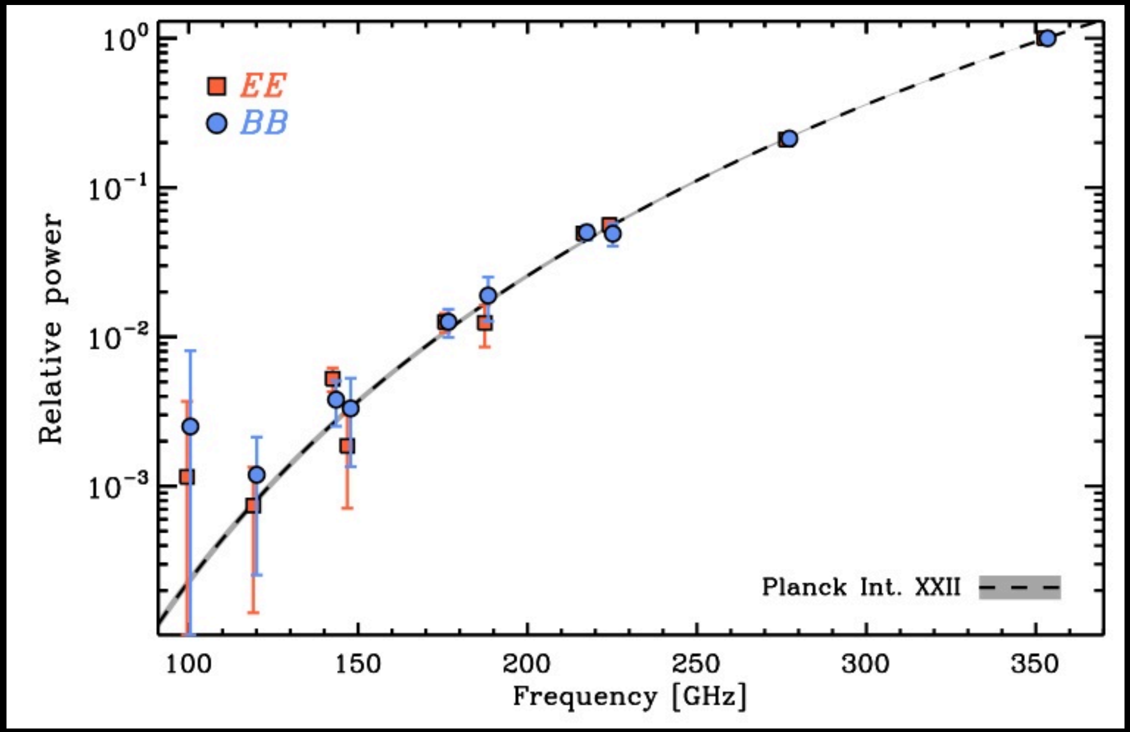
SED = Modified blackbody emission :

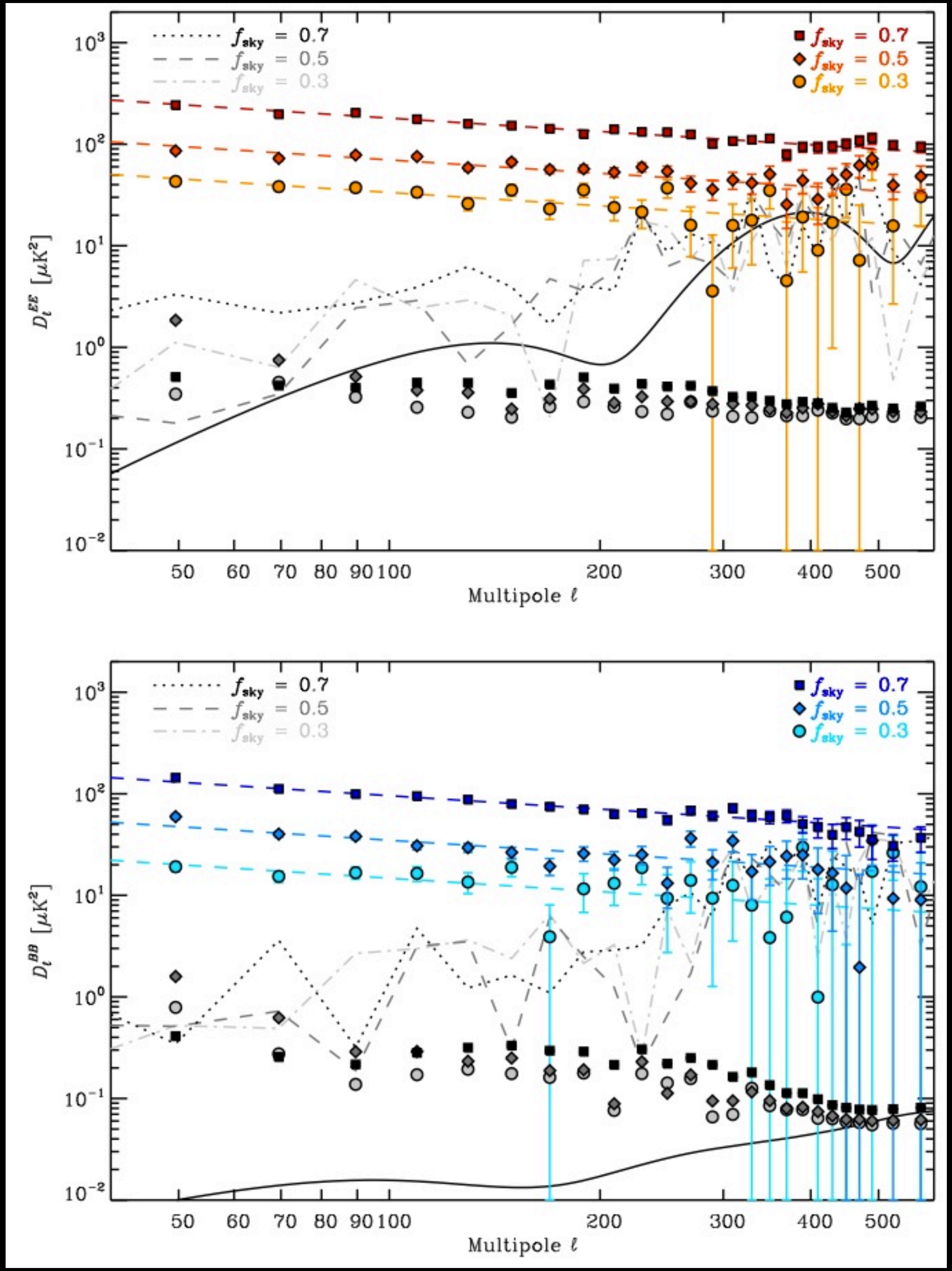
$T_D = 19.6$ K
$\beta_D = 1.59 \pm 0.11$

E/B Modes ratio:

E / B ~ 2

Planck Int. XXII, XXX 2014

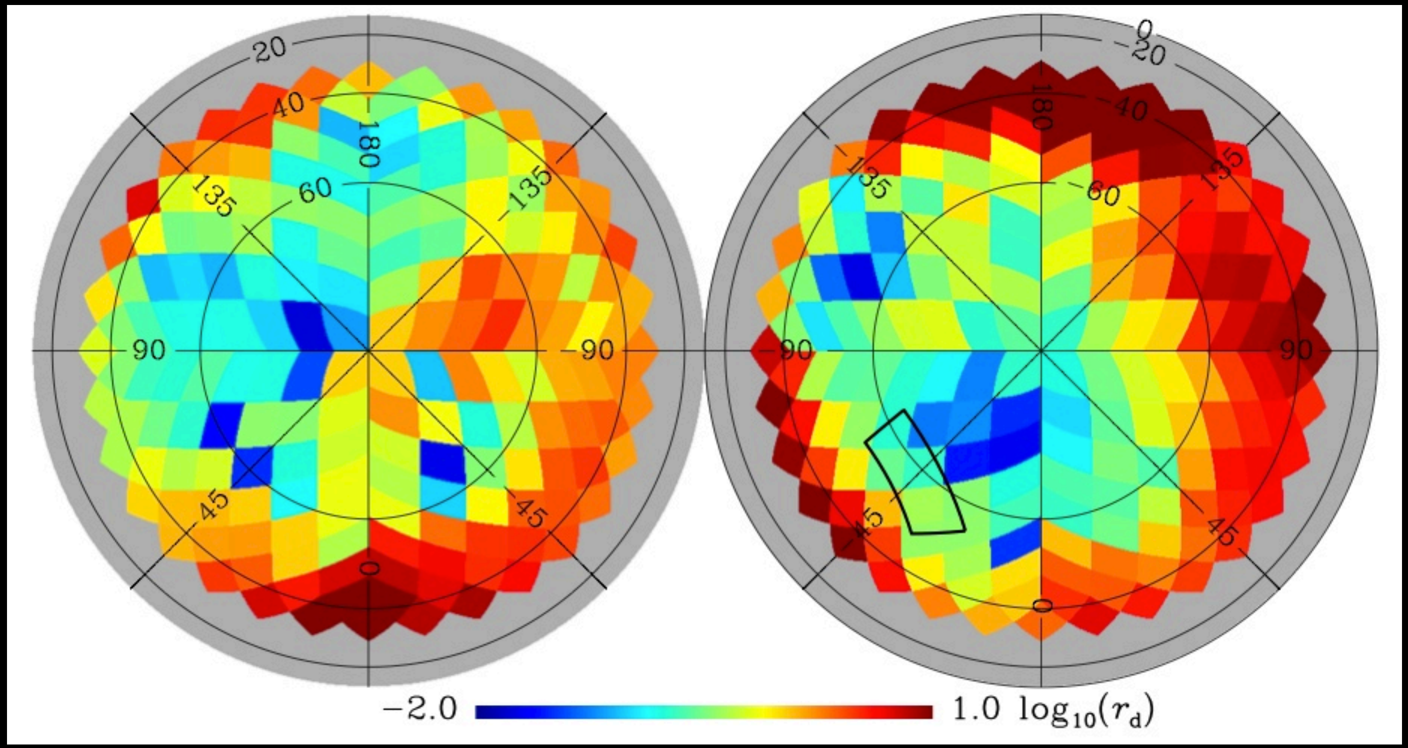




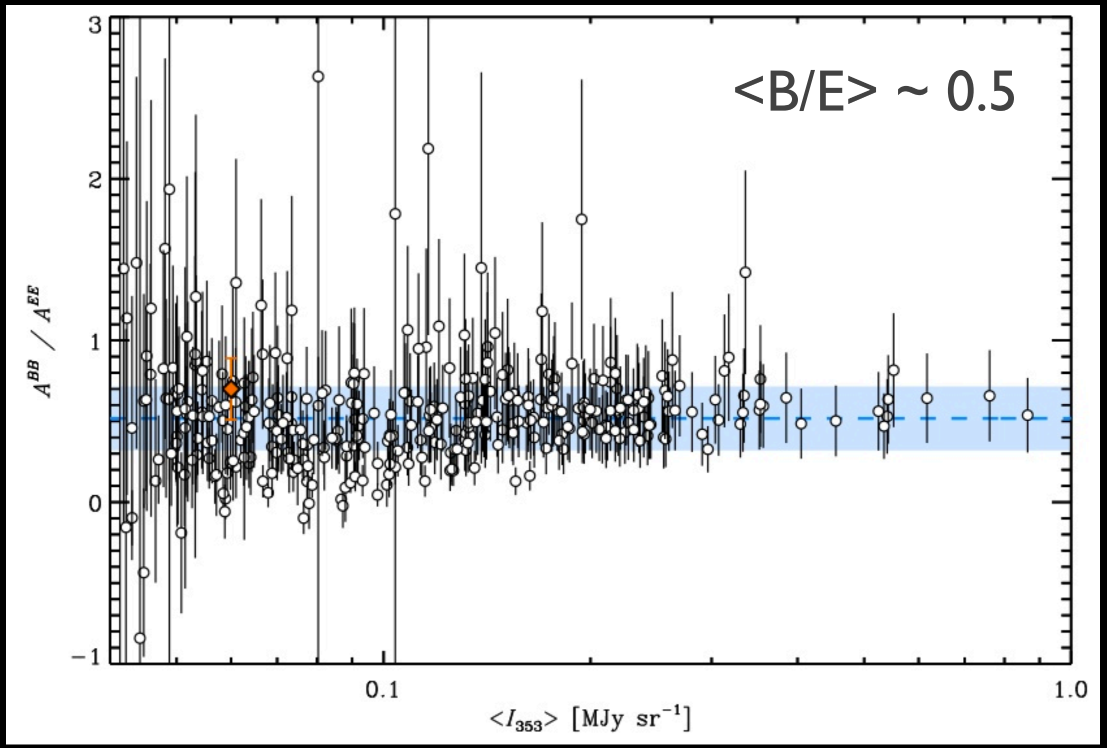
The *Planck* view of the dust B-Modes

The *Planck* 353 GHz polarization modelling

Dust contamination level in units of r



Spatial variations of the B/E ratio

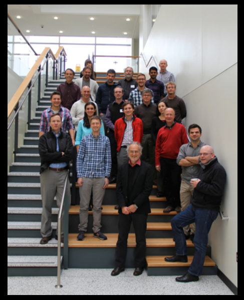


- Polarization fraction of dust ~10% at high latitude
- Dust is not homogeneously distributed
- E/B ratio depends on local filamentary structures

Planck Int. XXXVIII 2015

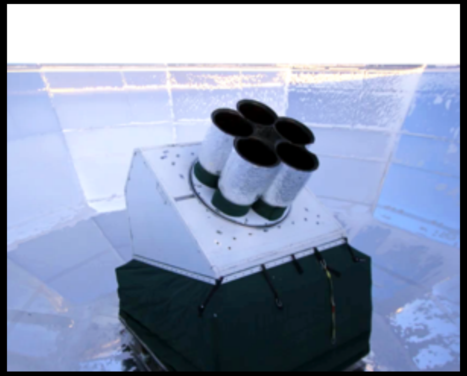
→ Dust modelling valid on large scales but non constrained on local fields to reach high accuracy on r

BICEP2 / Keck / *Planck* MoU

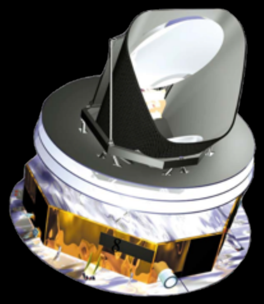


BICEP2

Keck



Planck



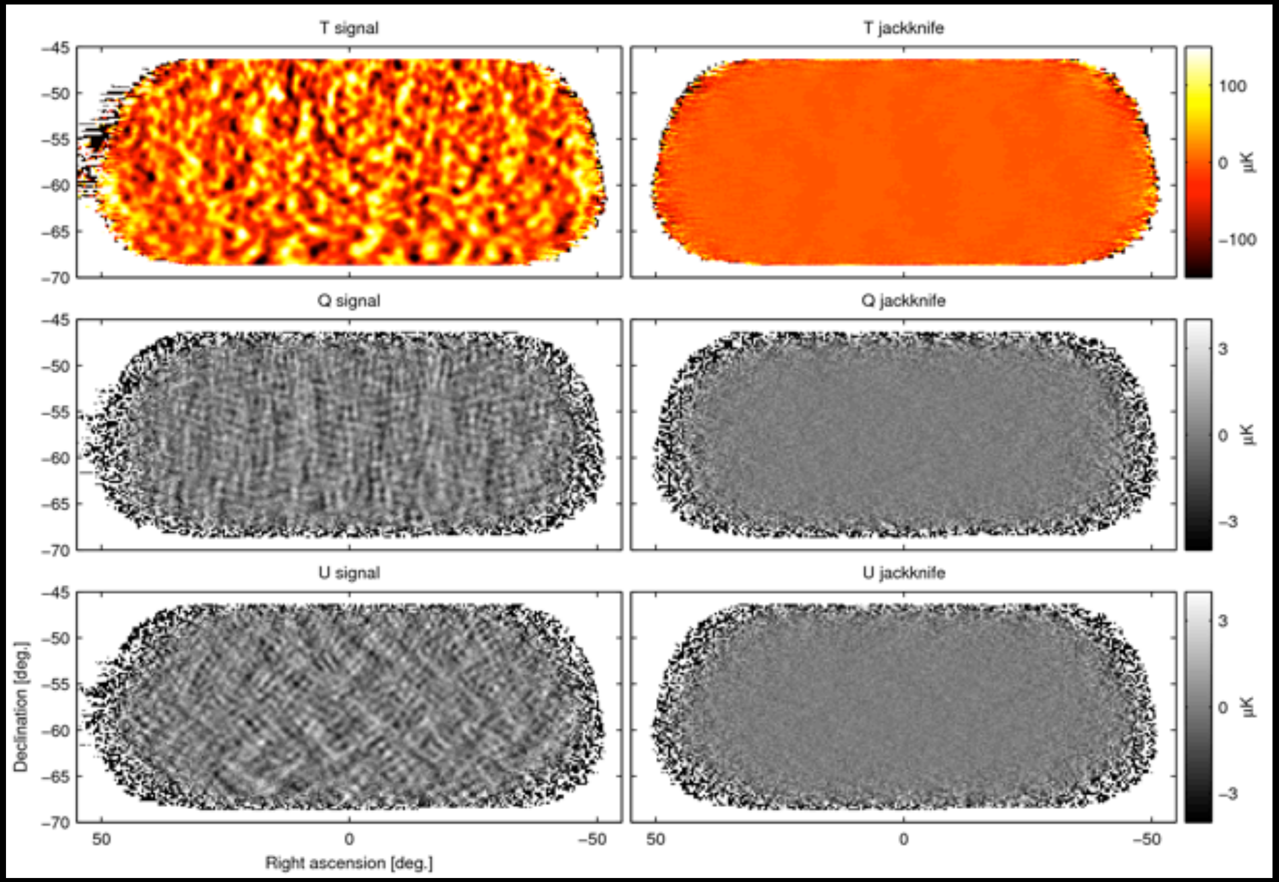
150 GHz - 400 deg^2 - 57nK.deg

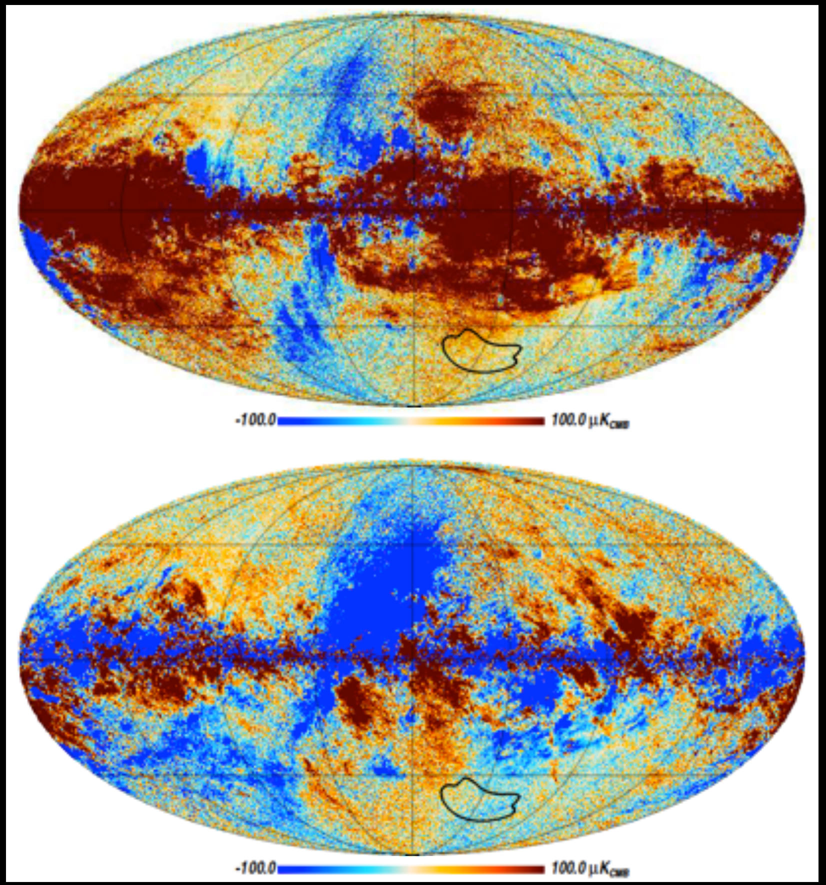
353 GHz all-sky - 7.31µK.deg

T

Q

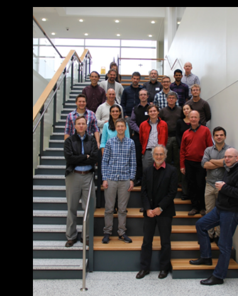
U



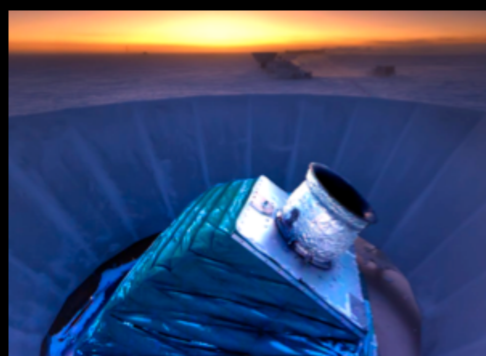


The BICEP2 / Keck / *Planck* analysis

BICEP2 / Keck / *Planck* MoU

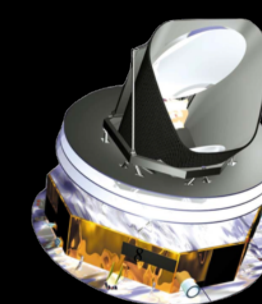


BICEP2



Keck

Planck



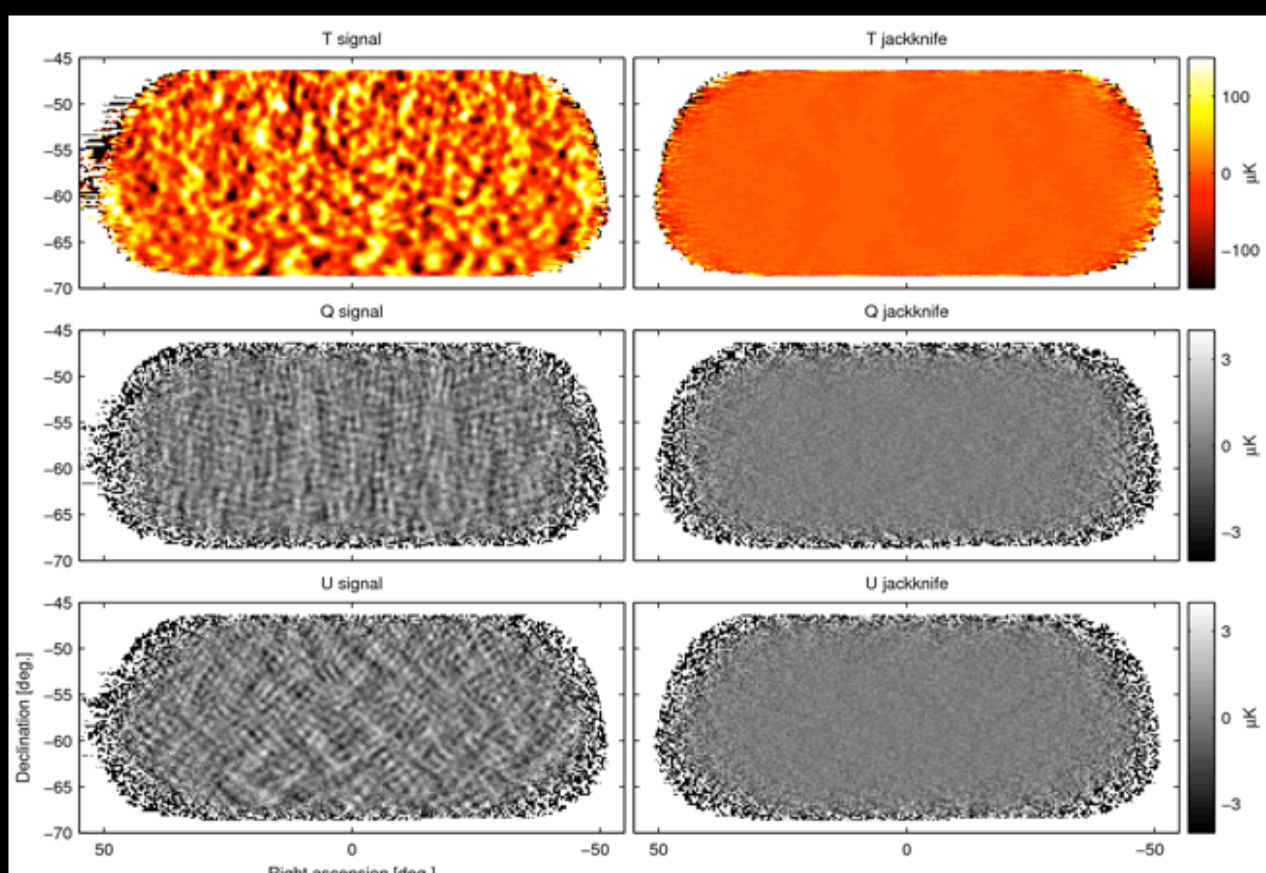
150 GHz - 400 deg^2 - 57nK.deg

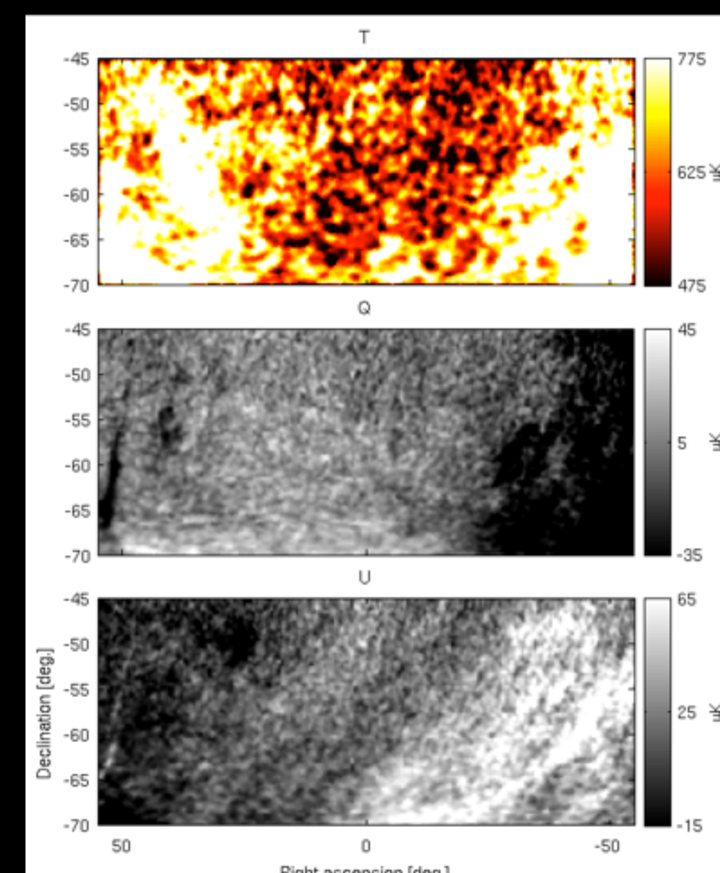
353 GHz on BICEP2/Keck Field

T

Q

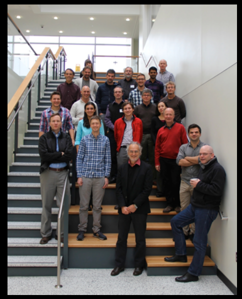
U





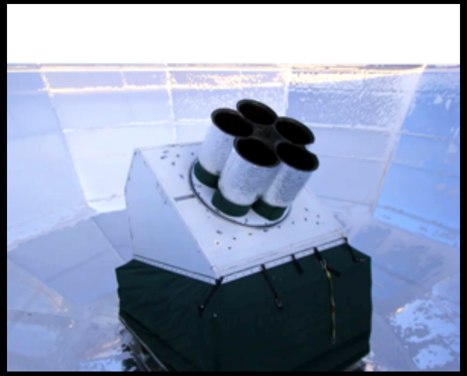
The BICEP2 / Keck / *Planck* analysis

BICEP2 / Keck / *Planck* MoU

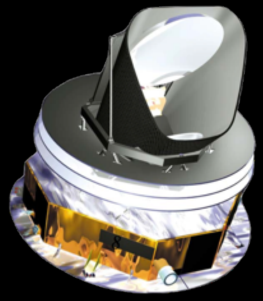


BICEP2

Keck



Planck

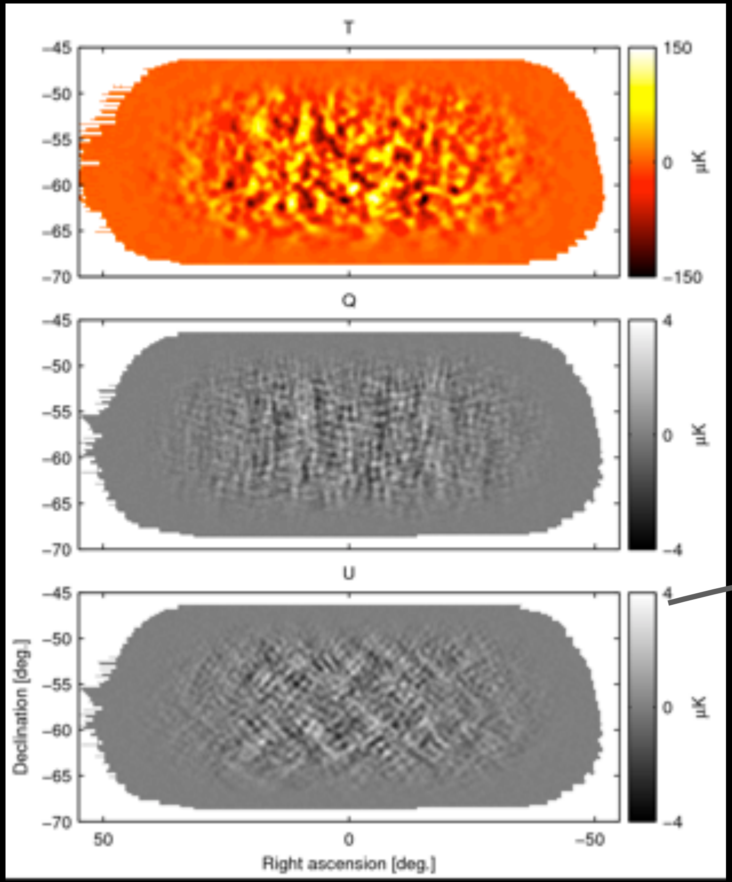


150 GHz - 400 deg^2 - 57nK.deg

T

Q

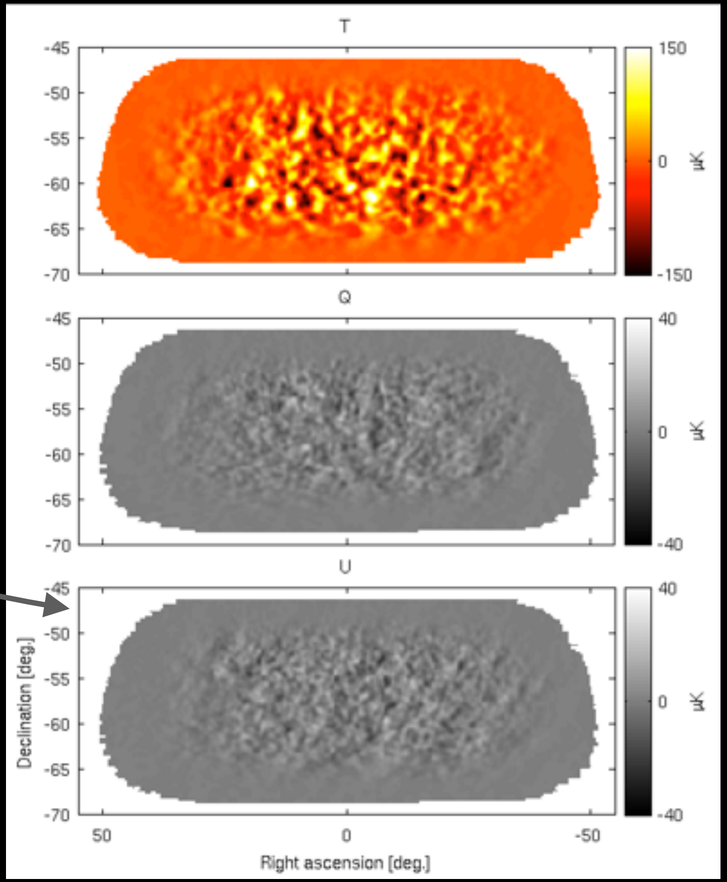
U



after filtering and apodization

Color scale x10

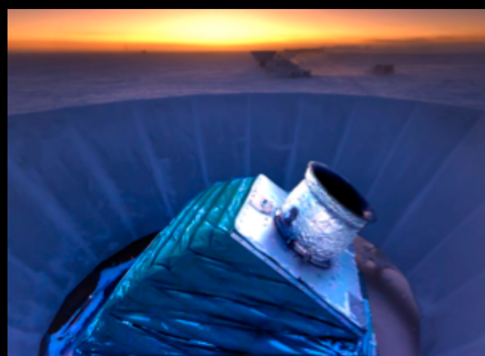
353 GHz on BICEP2/Keck Field



The BICEP2 / Keck / *Planck* analysis

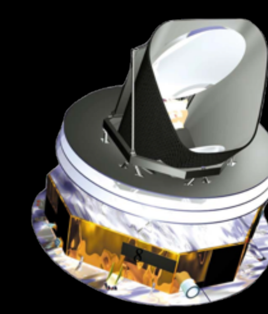
BICEP2 / Keck / *Planck* MoU

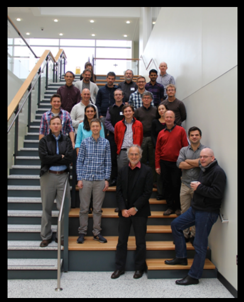
BICEP2



Keck

Planck



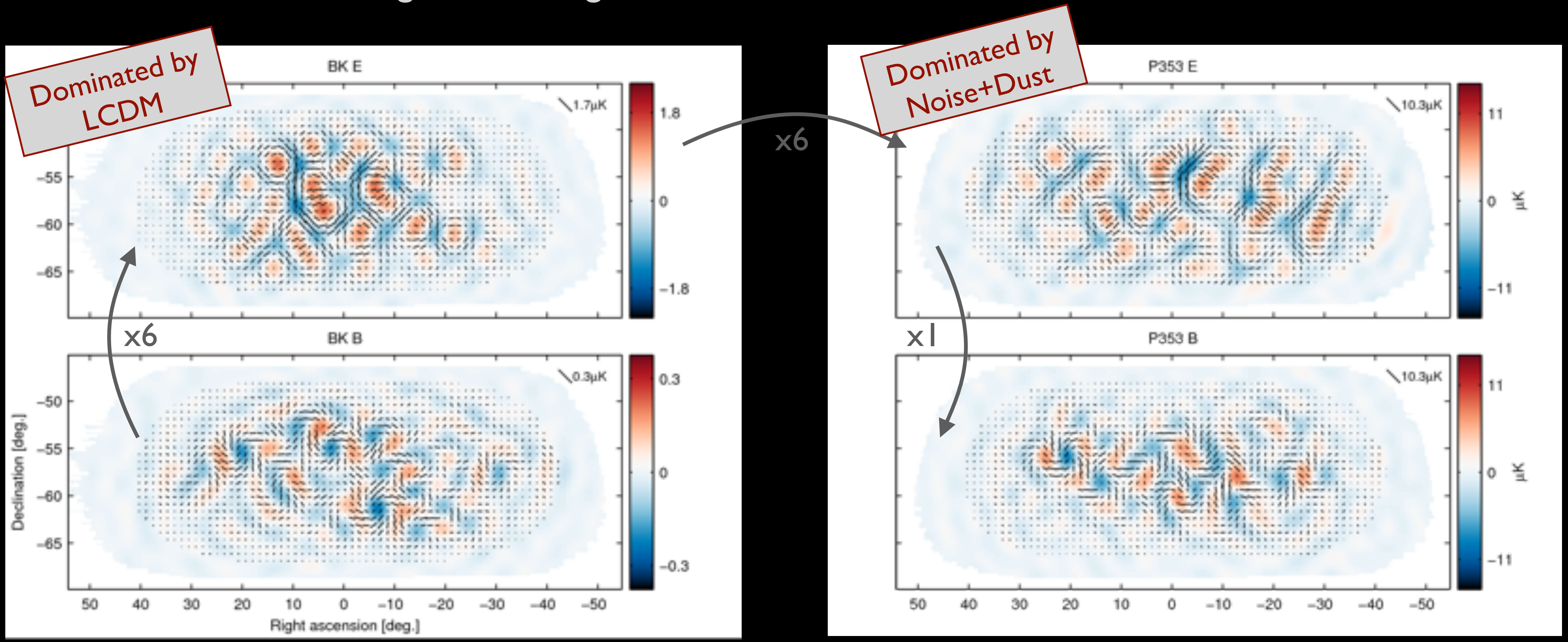


150 GHz - 400 deg^2 - 57nK.deg

353 GHz on BICEP2/Keck Field

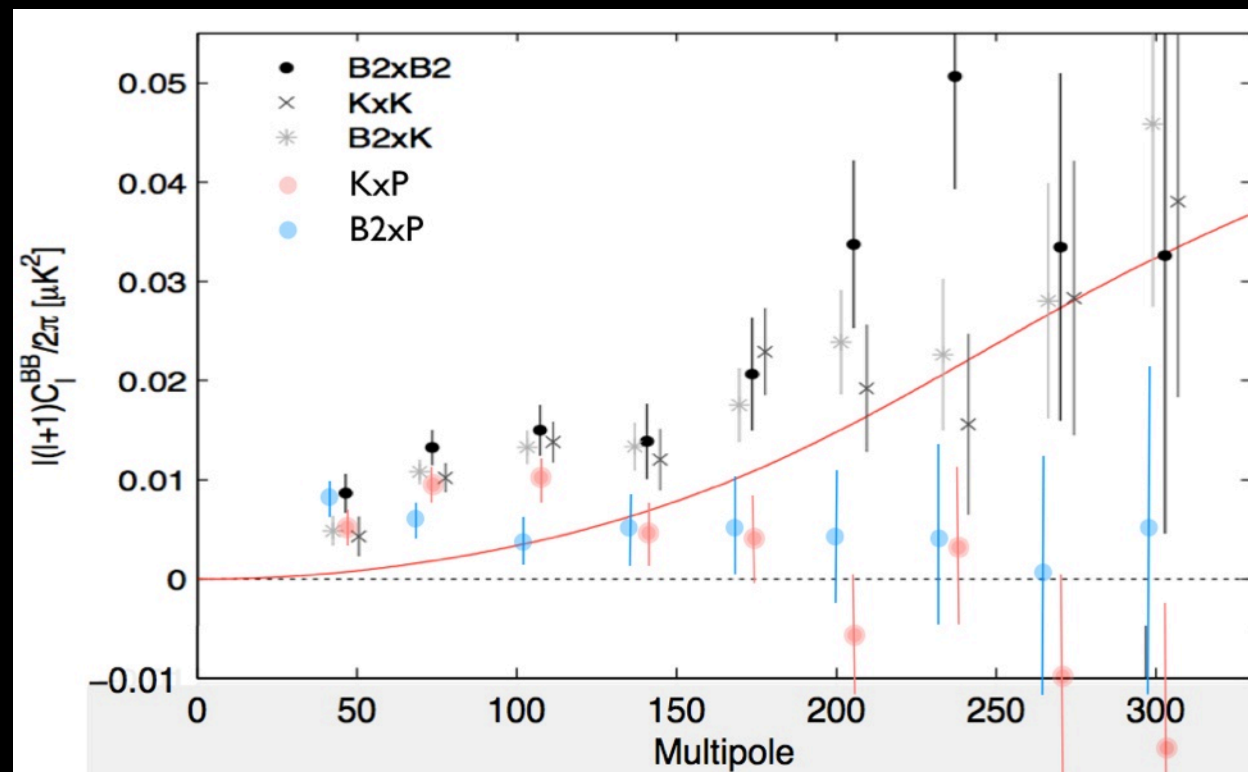
E

B



Multi-Component Multi-Spectral Likelihood analysis

Cross-Spectra between *Planck* 353GHz & BICEP2/Keck 150GHz between $20 < \ell < 200$



Fiducial Model:

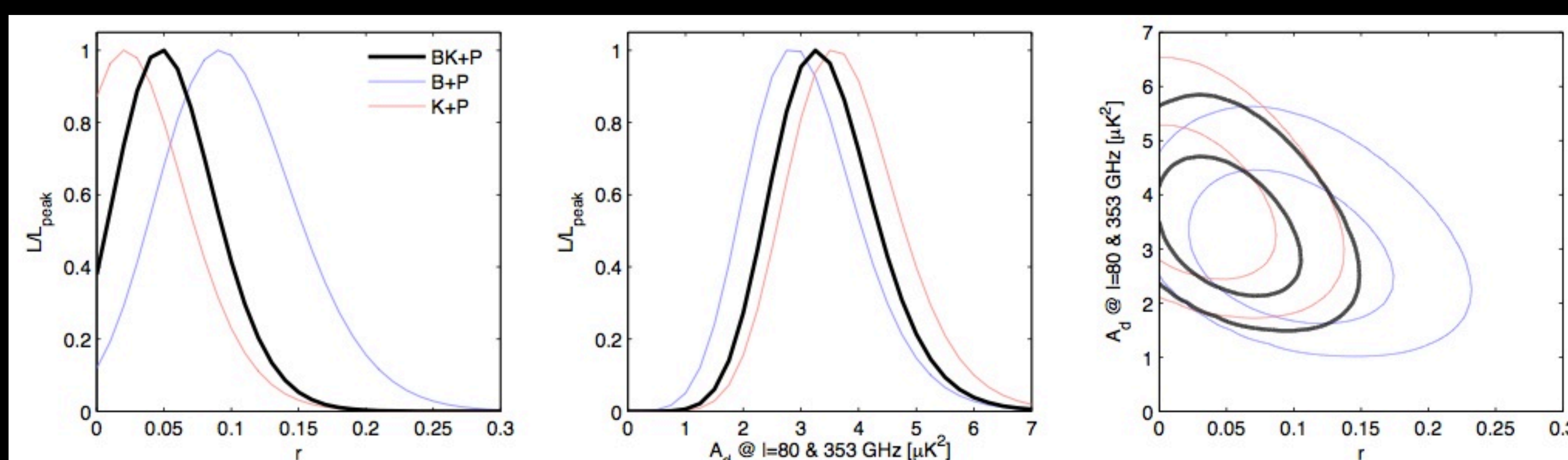
LCDM
+
Gravitational waves
r
+
Dust emission modelled by Planck

β_D = 1.59 +- 0.11

B2 + P

K + P

BK + P



r constraint consistent with zero

Dust is detected with 5.1 σ significance

As expected dust and *r* are partially degenerate - reducing dust means more of the 150x150 signal needs to be *r*

r < 0.12 at 95%

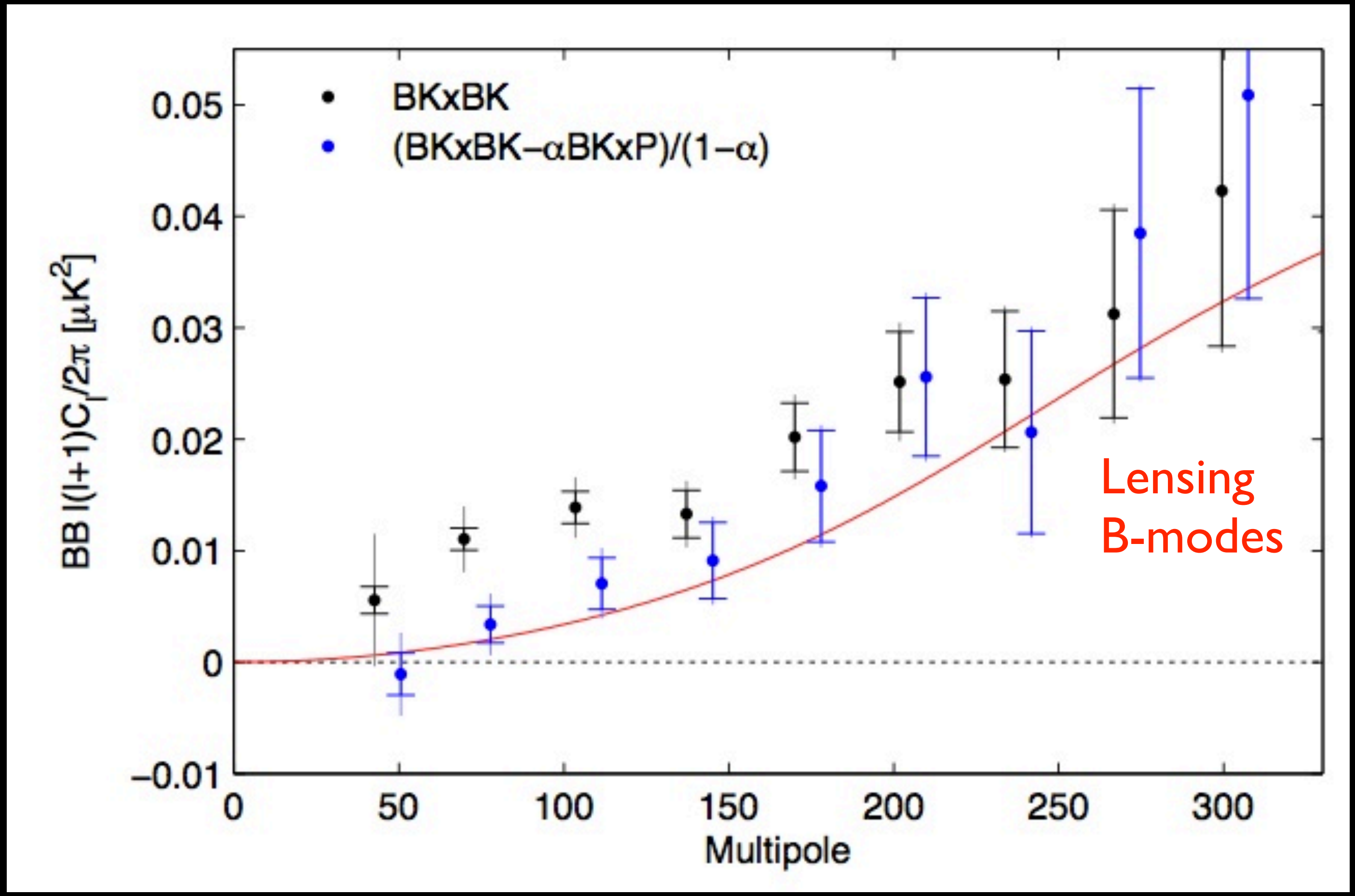
The BICEP2 / Keck / *Planck* analysis

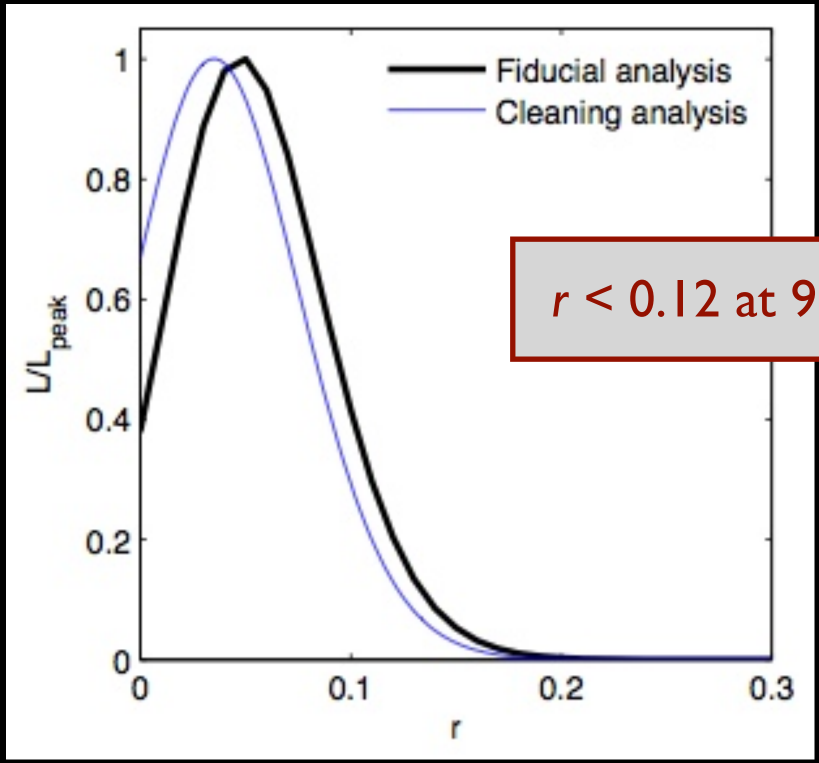
Spectral subtraction analysis

Planck 353GHz used as a dust template

Extrapolated to 150GHz using alpha = 0.04

β_D = 1.59 +- 0.11



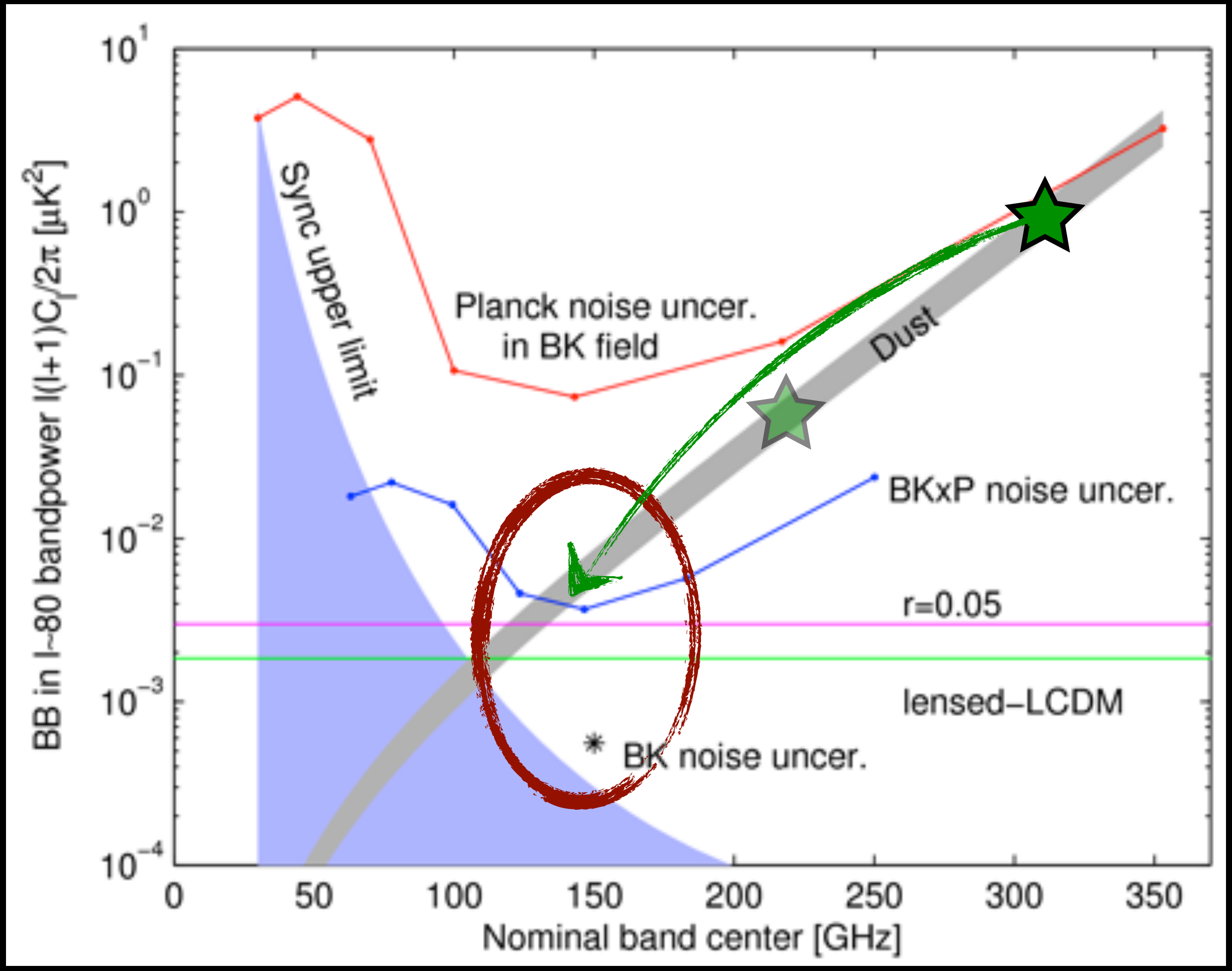


r < 0.12 at 95%

Mapping the Galactic Foregrounds

Is *Planck* 353GHz Dust template satisfactory ?

The primordial quest of B-modes is now limited by the quality of the dust foreground subtraction



Two Challenges

Build a more accurate dust foreground template

Perform an accurate extrapolatation to CMB channels

Control overall amplitude of dust in CMB channels

Control variation of dust B-Modes patterns

Physics of Dust ?

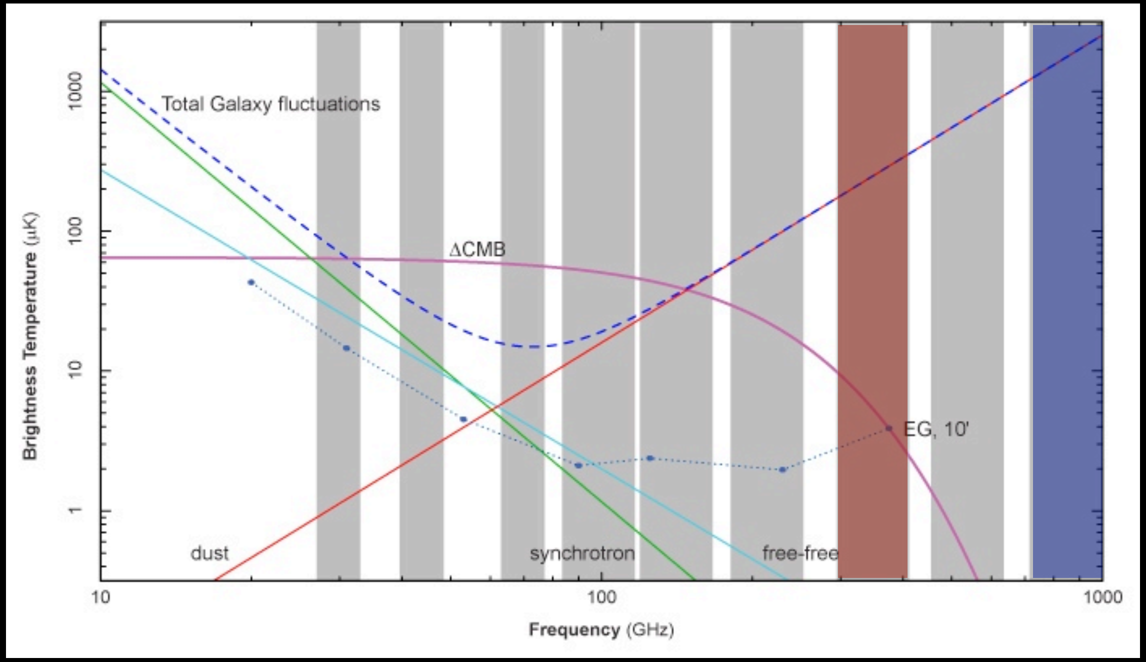
Structure of the Galactic ISM at high latitude ?

Properties of Galatic Magnetic Field ?

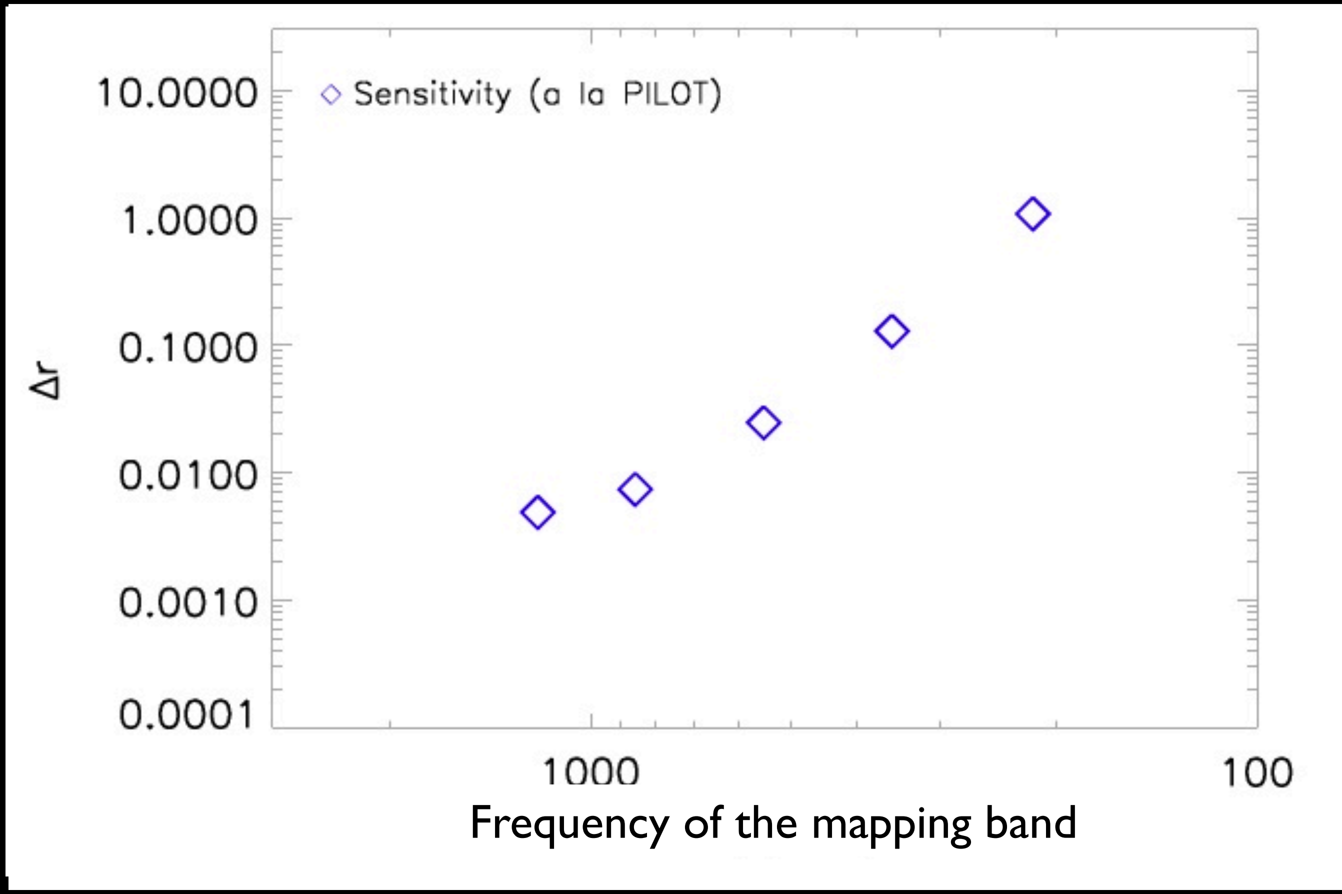
Mapping the Galactic Foregrounds

Looking for the optimal band

The higher the frequency,
The higher the S/N of the dust signal



Planck Bands
Planck Bands 353GHz
PILOT



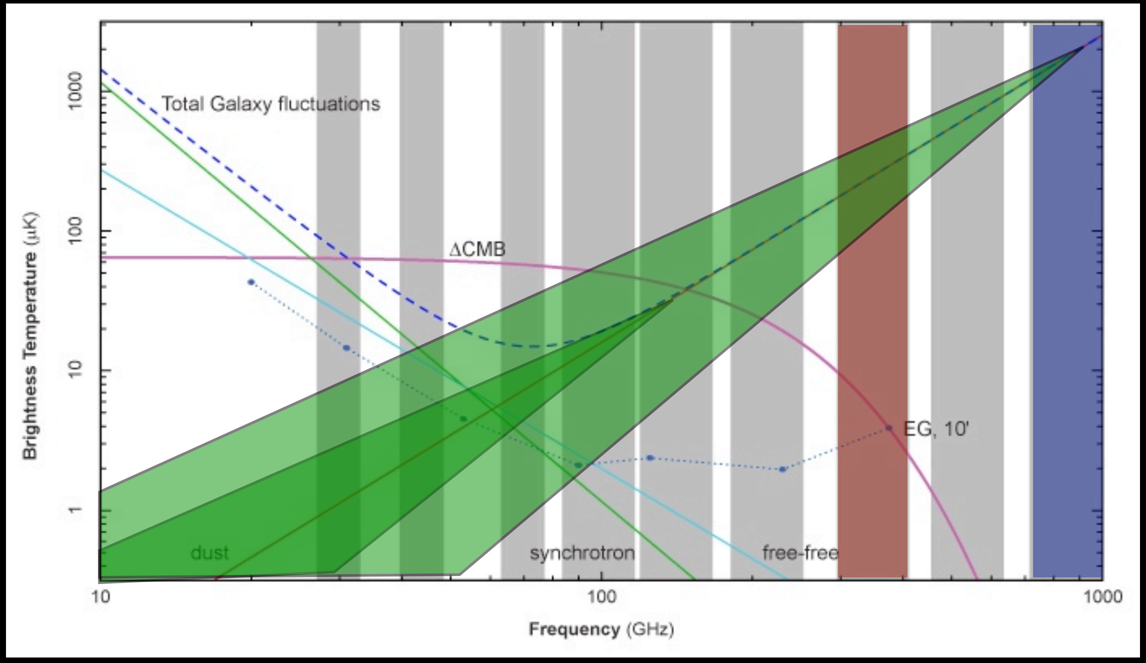
Mapping the Galactic Foregrounds

Looking for the optimal band

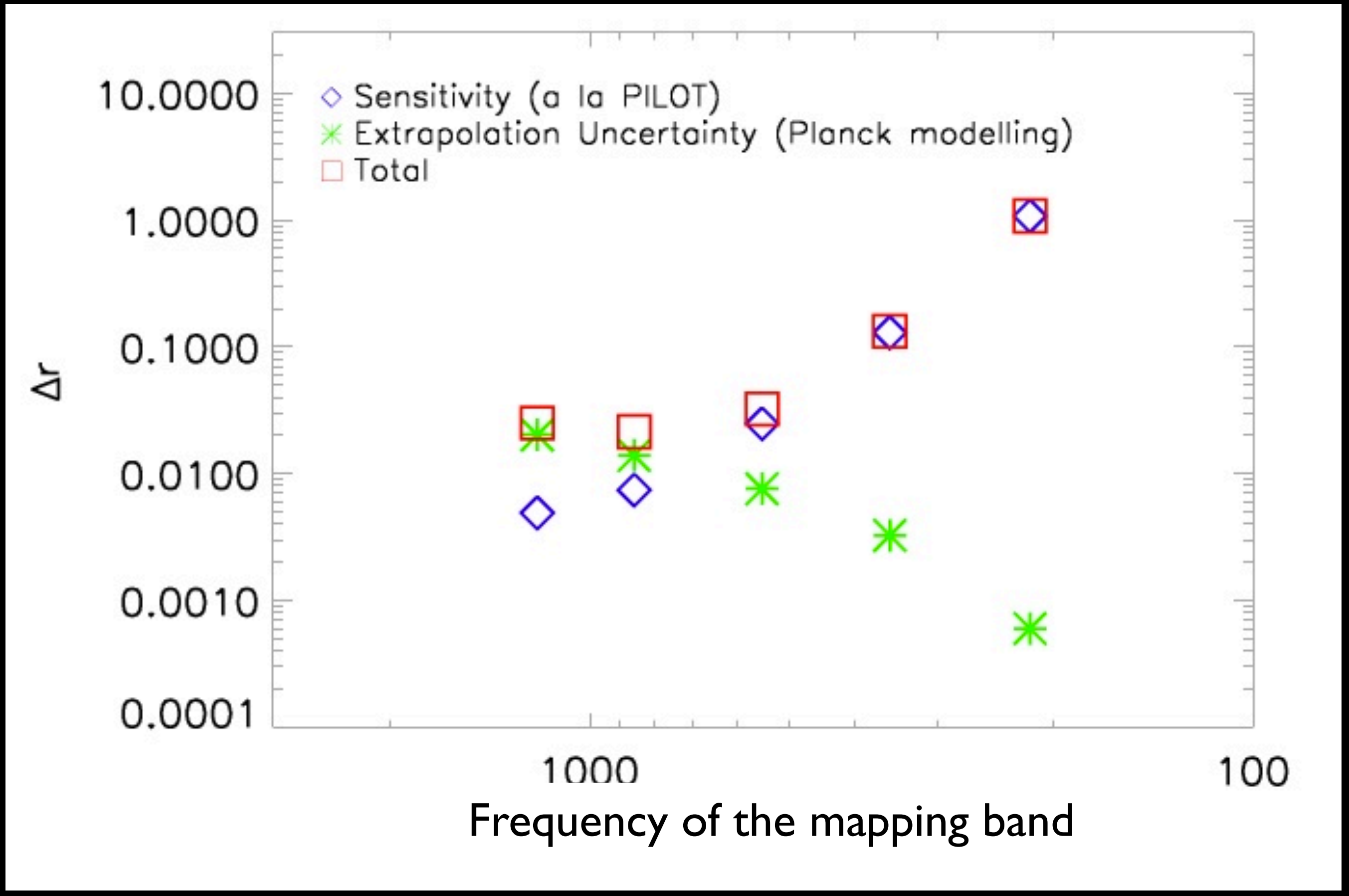
The higher the frequency,
The higher the S/N of the dust signal

Hyp: Dust emission modelled by a modified blackbody with a unique temperature and spectral index

$\beta_D = 1.59 \pm 0.11$



Planck Bands
Planck Bands 353GHz
PILOT



A compromise may be found for a given knowledge of the dust spectral index and the instrumental sensitivity

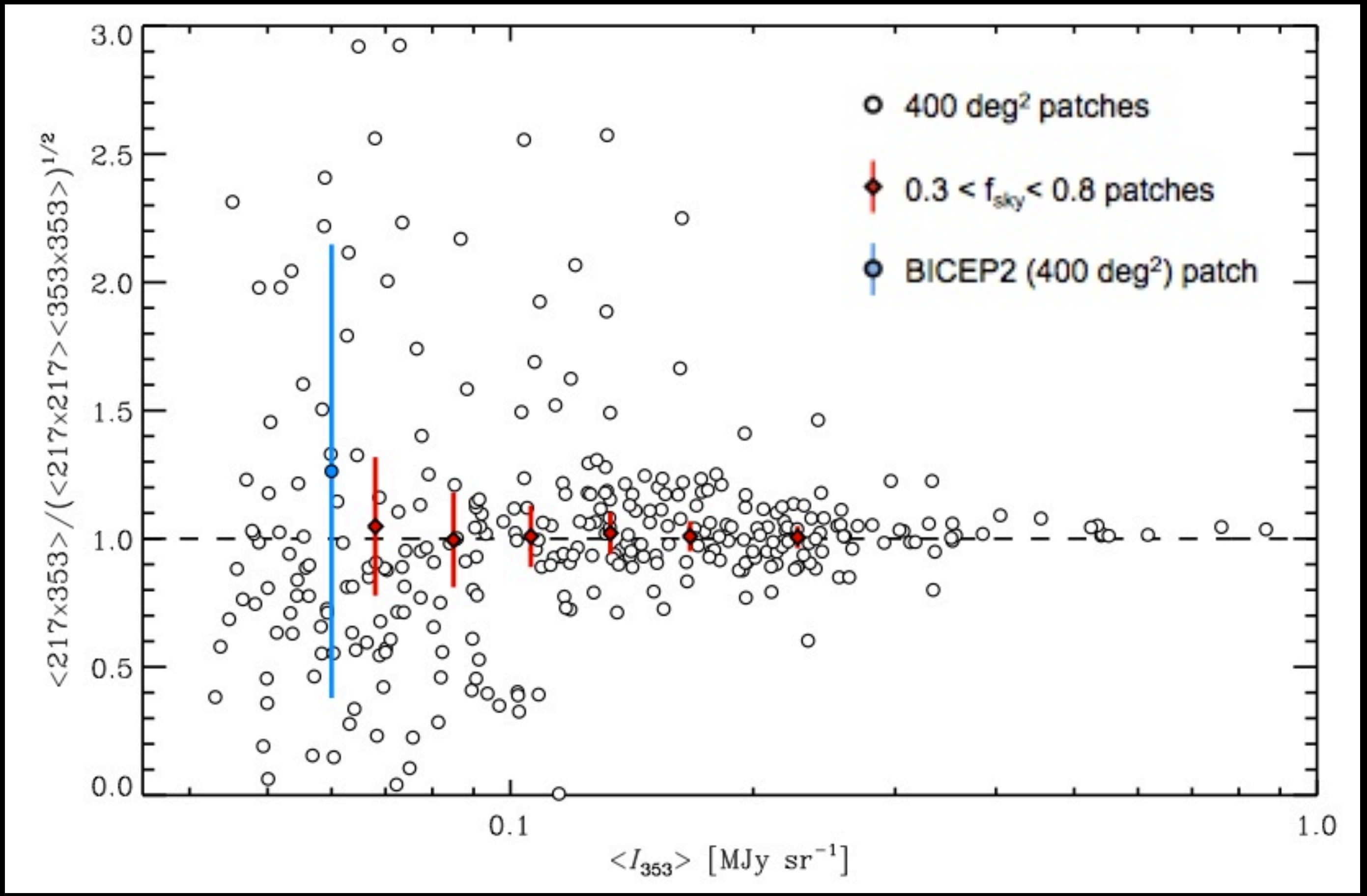
Limits on astrophysical decorrelation ?

Spatial variations of the dust spectral index

$\sigma(\beta_D) = 0.11$ (Planck Int. XXII 2014)

Frequency variations of the dust spectral index

Line of sight variations of dust temperature ?



Check consistency of

$$\frac{\langle 353 \times 217 \rangle_{BB}}{[\langle 353 \times 353 \rangle_{BB} \langle 217 \times 217 \rangle_{BB}]^{1/2}}$$

Averaging over the 400 deg^2 patches yields a mean decorrelation ratio:

d = 1.01 ± 0.07

Averaging over the six $0.3 < f_{sky} < 0.8$ patches yields:

d = 1.01 ± 0.03

Simulating (conservatively) a 10% suppression of BKxP353 leads to

bias on r of +0.018

Need to be characterized better if we want to get better constraints of r

PILOT

CNES, IRAP Toulouse(PI Bernard), IAS Orsay, CEA Saclay, Roma Univ., Chalmers Univ. of Technology, Cardiff Univ., Univ. College London

Science Objective:

- Measure linear polarization of dust emission in the Far-InfraReD
- Reveal the structure of the magnetic field
- Geometric and magnetic properties of dust grains
- **Understand Polarized foreground**

Observations: Galactic plane (|b|<20°) and diffuse Interstellar medium (cirrus).

Characteristics: λ=240 & 550 μm, resolution: 3'. Bolometer array of 2048 detectors

Weight, Altitude: ~ 1 ton, 40 km

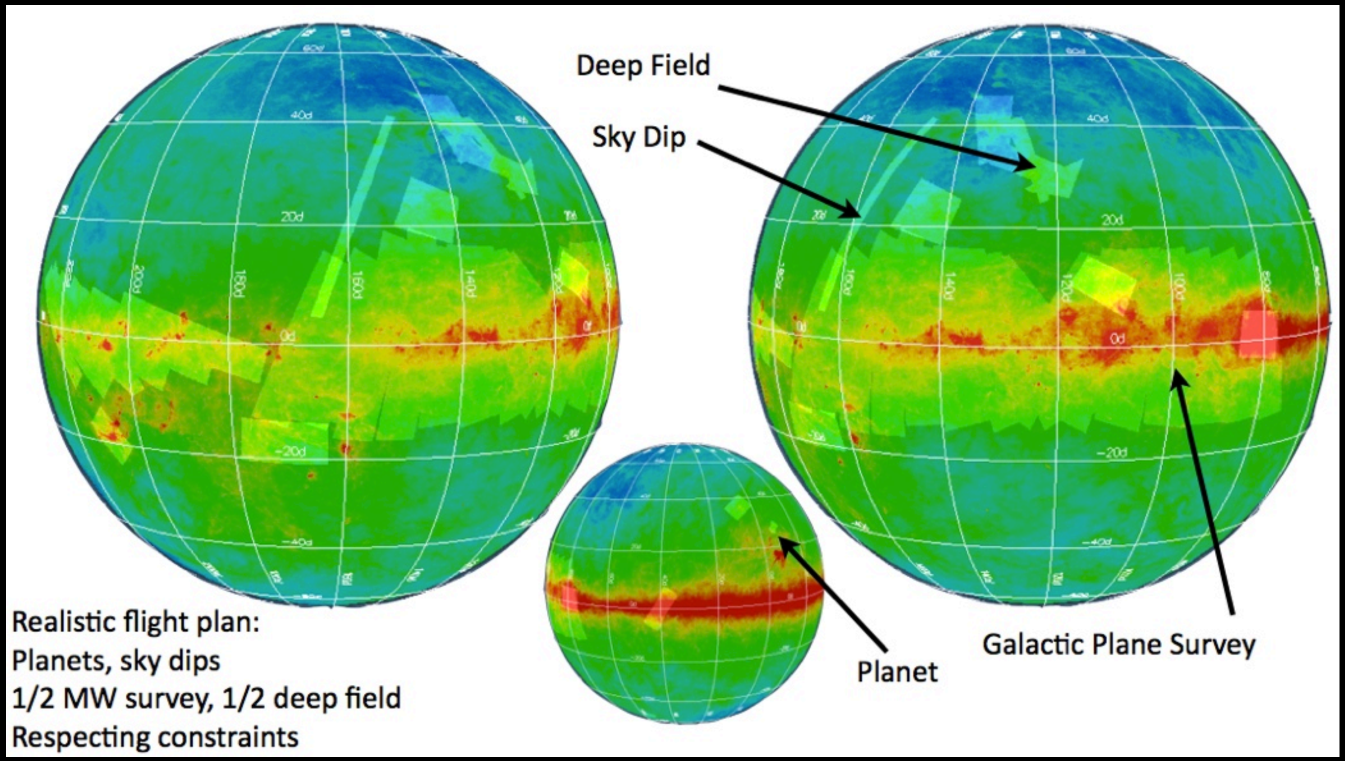
Status: Financed by CNES. Currently in assembling phase

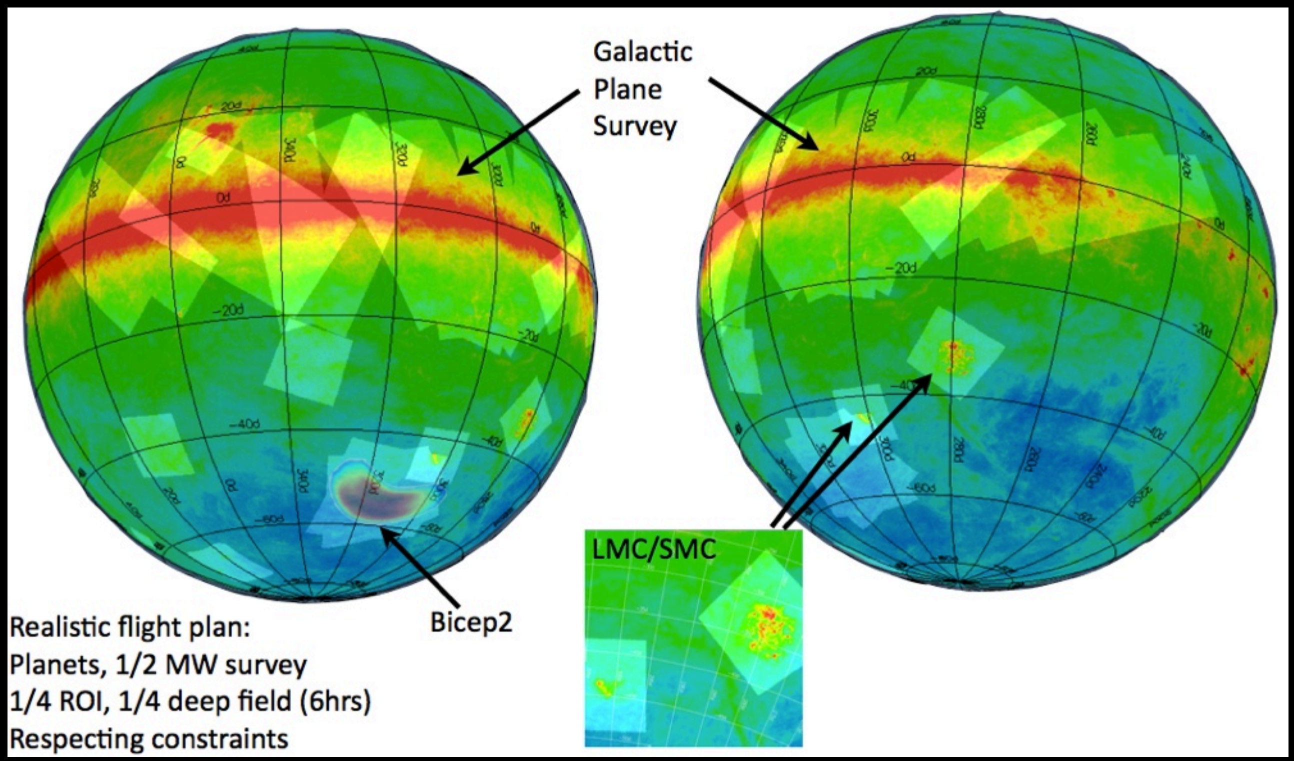
Mapping the Galactic Foregrounds

PILOT

1st Flight: Sep. 2015 from Timmins, Canada

2nd Flight: Apr. 2017 from Australia





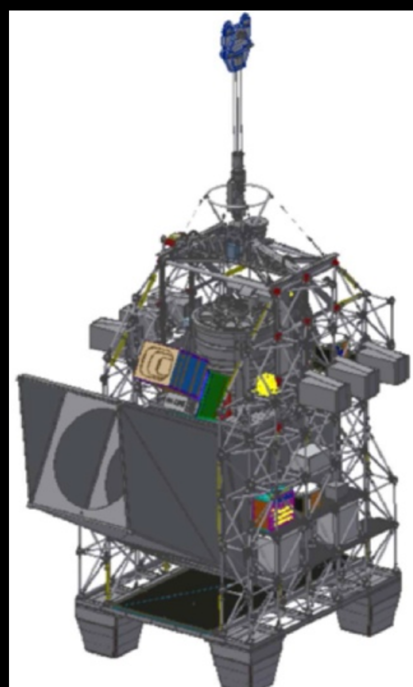
Deep fields at high latitude in the south hemisphere
at 240 um

Mapping the Galactic Foregrounds

“PlanB”

IRAP / IAS / LPSC

Using PILOT Platform and Mirror



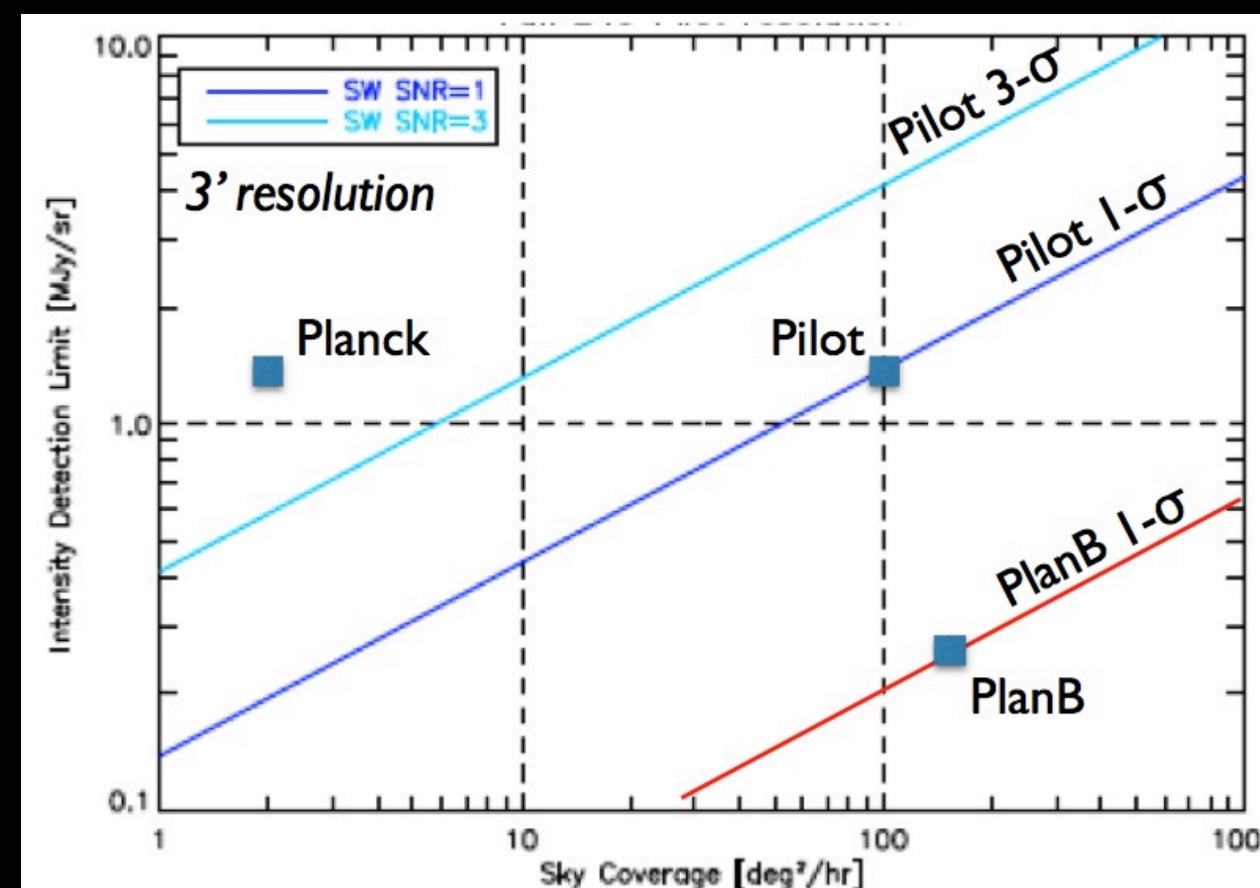
New focal plane with 5000 LEKID: (Lumped Element KID)

- Working from 150mK to 300mK
- From 80GHz to 1.2THz
- Already implemented on NIKA & NIKA2
- Built by PTA Grenoble

Sensitivity predictions:

Extrapolated at 353GHz

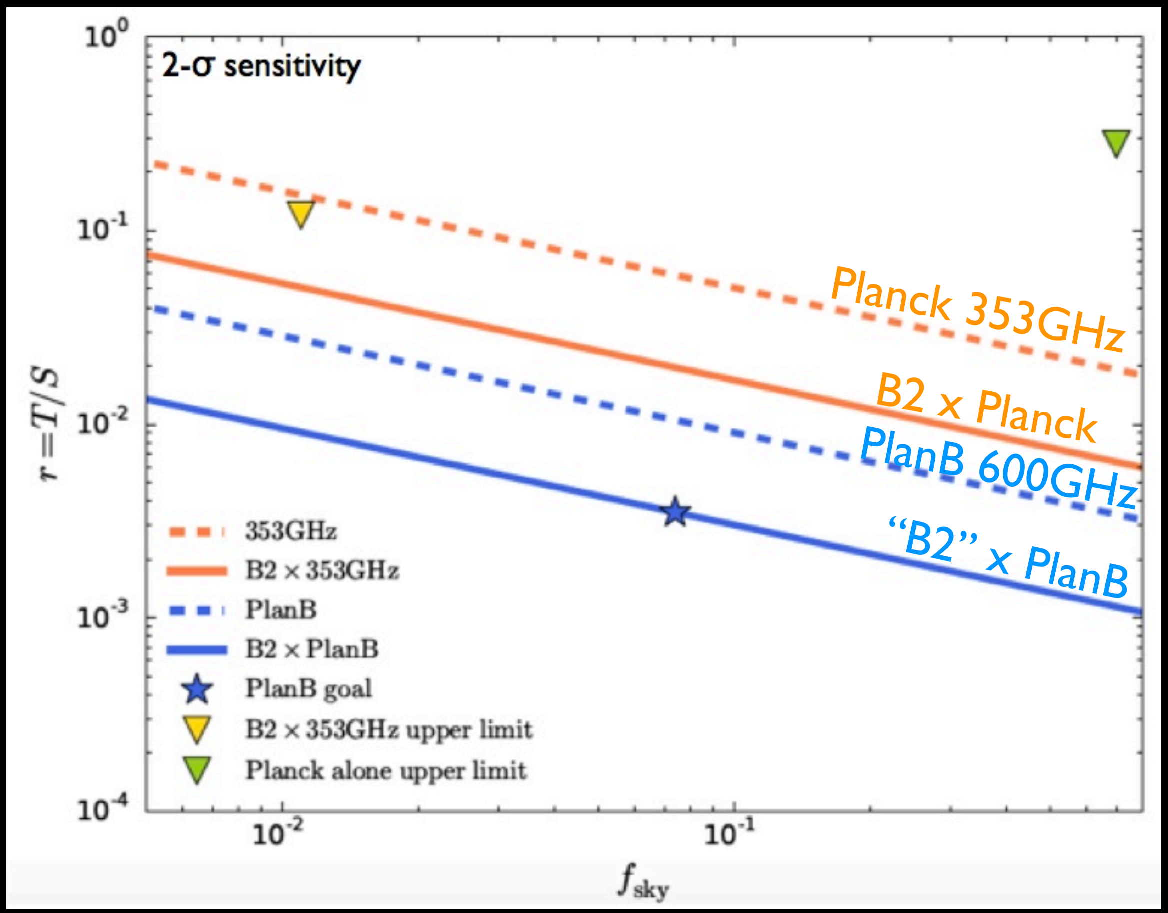
frequency [GHz]	270	350	600	1000
BG Power [pW]	2.0	2.7	4.7	8.0
BG NEP [$10^{-17}W/\sqrt{Hz}$]	2.8	3.6	6.2	10.3
S 1-σ [kJy/sr-deg]	0.37	0.61	1.8	5.0
I_ν(dust) †	0.44	1.0	4.8	15.9
S 1-σ [μK_{CMB}-deg]	2.9	2.1	1.3	1.1
S/S_{planck} ‡	2.5	3.4	5.6	6.7



Mapping the Galactic Foregrounds

"PlanB"

Sensitivity Goal

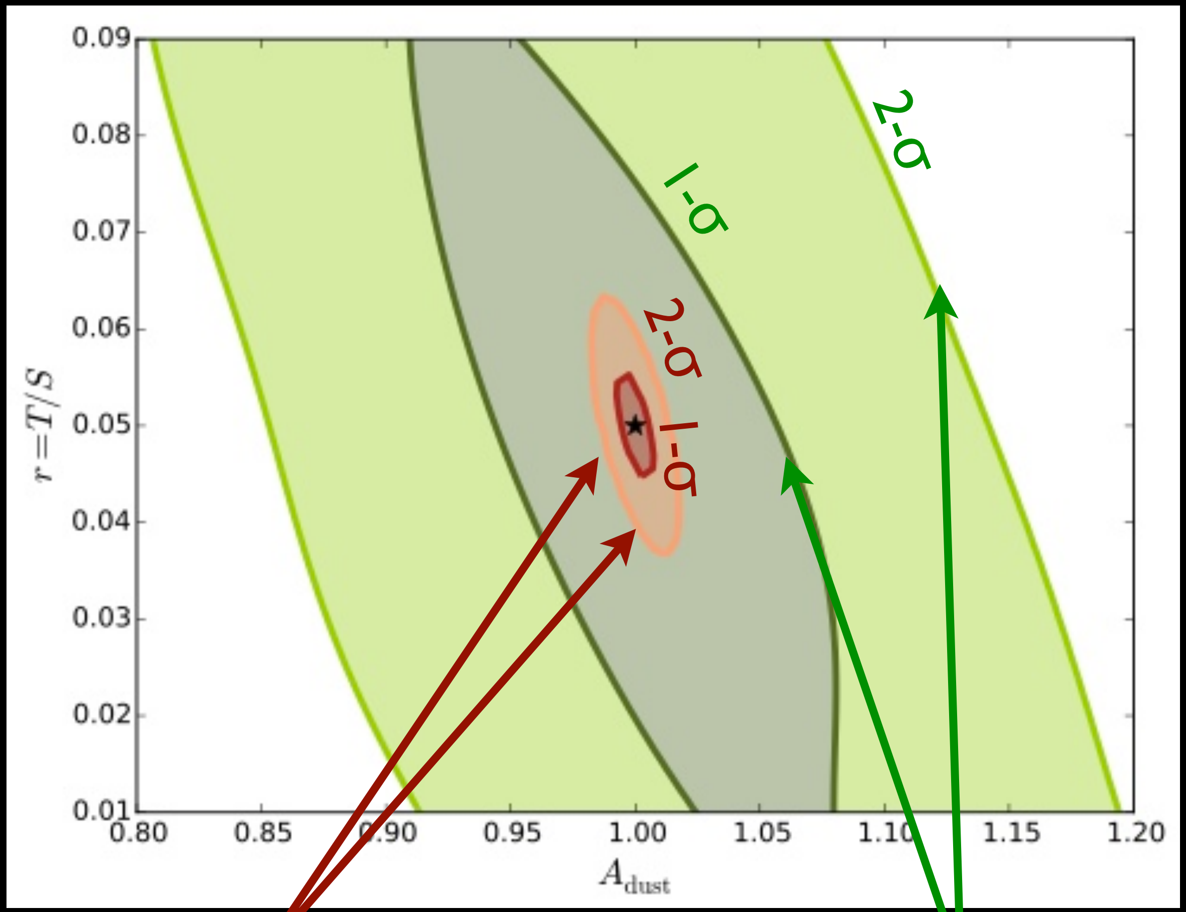


3-days flight covering 3000deg^2

Proposal submitted to CNES (Ballon French Agency)

1st flight: 2019 ?

Constraining the Dust SED

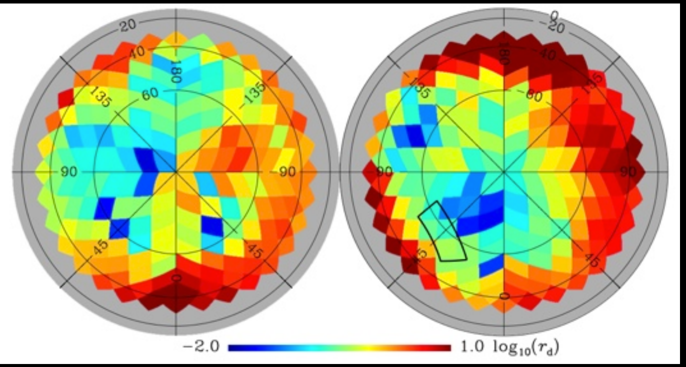


Dust polar. SED known (measured using PlanB + Planck)

Dust polar. SED varies within Plank uncertainties

Take Home Message

Main limitation on primordial B-Modes detection is Galactic dust foreground



New designs to map the Galactic dust polarization at high latitude: Balloon or Satellite
(SPIDER, EBEX, BFore, PILOT, PlanB)
(LiteBird, Core+)

Collaboration between Galactic dust mapping experiments and CMB B-Modes ground experiments