Dust emission from Planck

Tuhin Ghosh
(Institut d'Astrophysique Spatiale, Orsay, France)

ON THE BEHALF OF PLANCK COLLABORATION

CITA Seminar

Monday 12 January 2015

What we have learnt about the dust emission (intensity and polarization) from the

Planck data

Outline of the talk

1. Spatial distribution of the dust emission and its polarization properties
2. Spectral properties of the dust emission as measured by Planck
3. Statistical properties of the dust emission in terms of power spectrum

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.

PLANCK

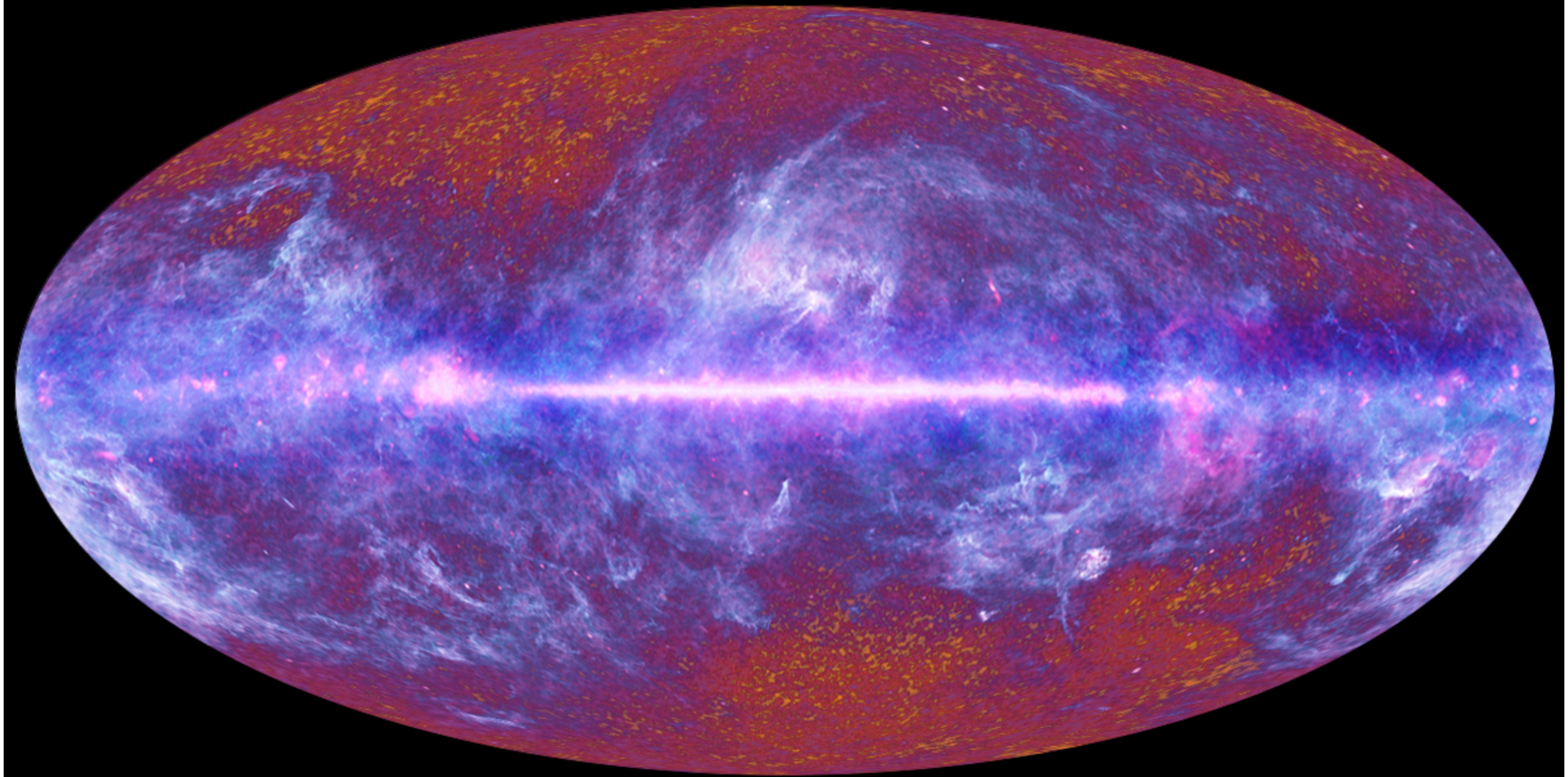
- 3^{rd} generation cosmology satellite (after COBE and WMAP). 10 times more sensitive.
- Angular resolution: 5’ – 30’
- Wavelength coverage: 30 – 857 GHz
- Focal plane instruments : HFI – LFI
- Lifetime : initially envisioned to be 1 yr. Had been 2.5 years (5 independent surveys of entire sky).

- Launched on 14^{th} May 2009, from French Guiana Space Center, Kourou
- With Herschel which was also at Sun-Earth L-2 point
- Planck polarization data will be released by the end of this month

14^{th} May 2009

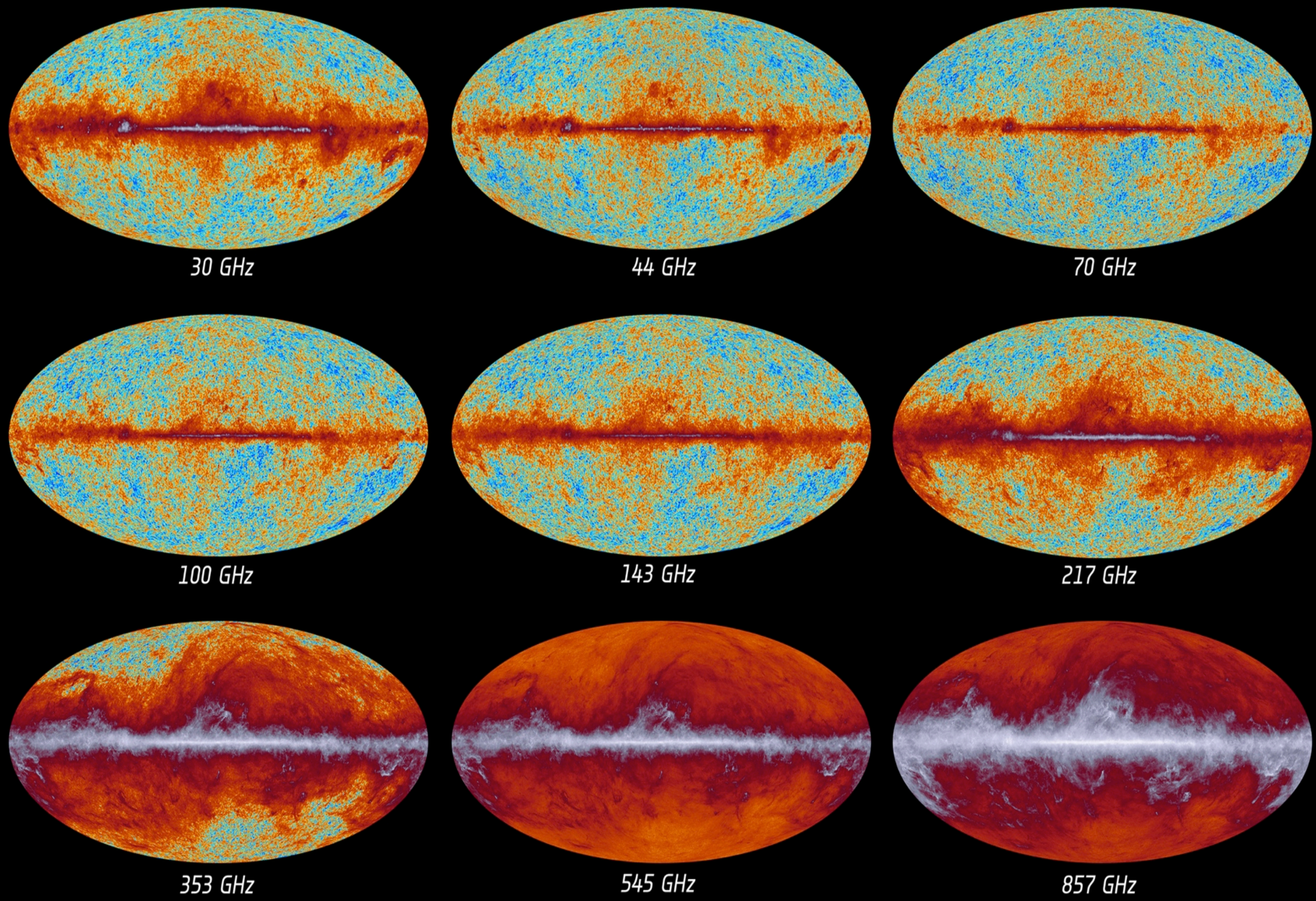
Multi-frequency sky observations

30 GHz 40 GHz 70 GHz 100 GHz 143 GHz 217 GHz 353 GHz 545 GHz 857 GHz

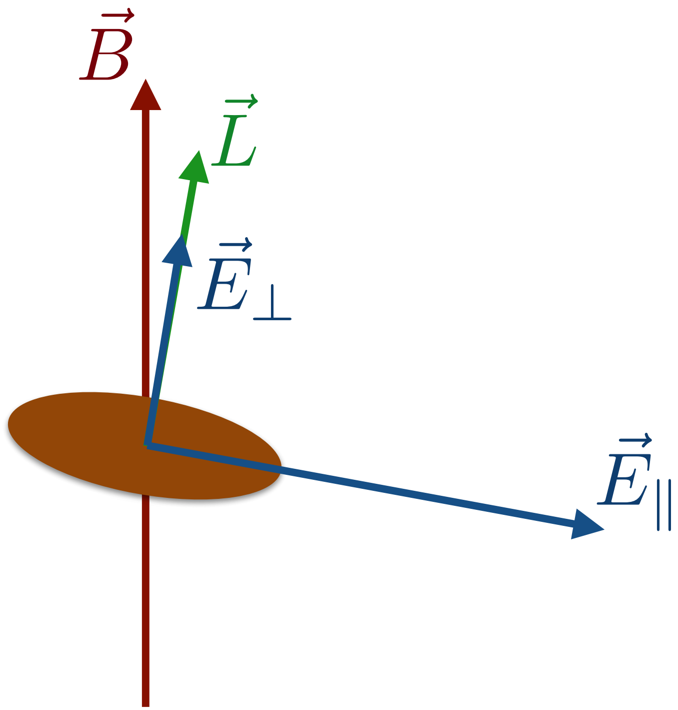


[Planck Collaboration 2011]

The sky as seen by Planck



Dust emission in intensity and polarization



Aspherical dust grains :
Emissivities larger along long axis

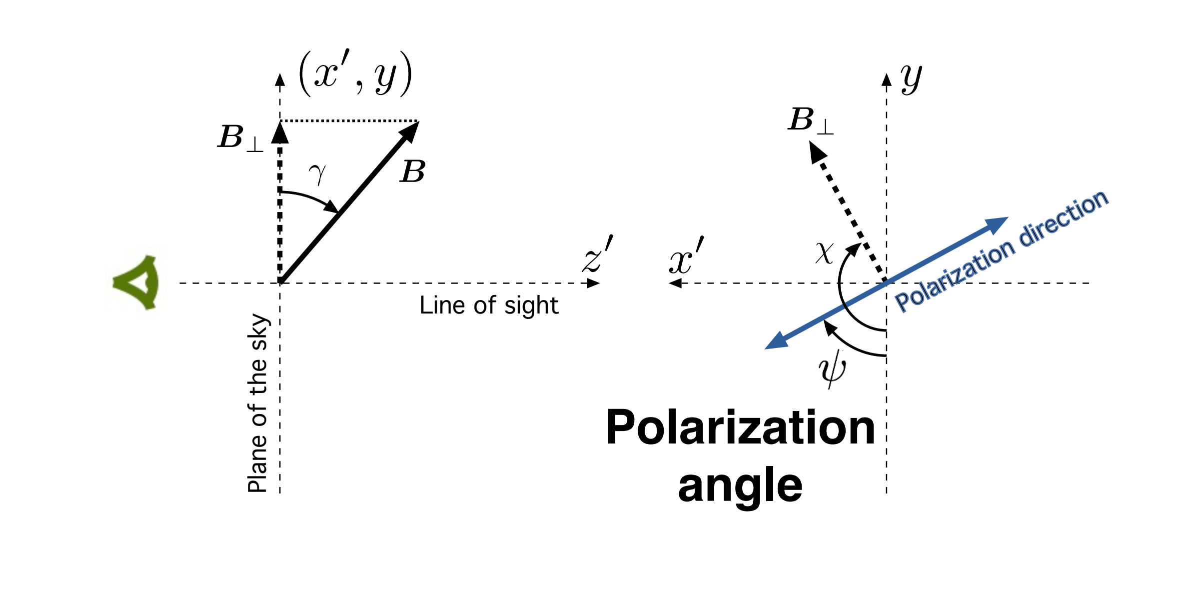
Rotating dust grains :
Angular momentum *L* aligns with *B*

Polarized thermal dust emission gives information on :

- Dust optical properties and composition
- Magnetic field topology

Stein 1966, Andersson 2012, Draine & Fraisse 2009, Hoang & Lazarian 2008, Martin 1975, 2007

What we are measuring



$$Q = \int p_{\max} R\, cos(2\psi)\, cos^2\gamma\, dI$$
$$U = -\int p_{\max} R\, sin(2\psi)\, cos^2\gamma\, dI$$

Polarization fraction

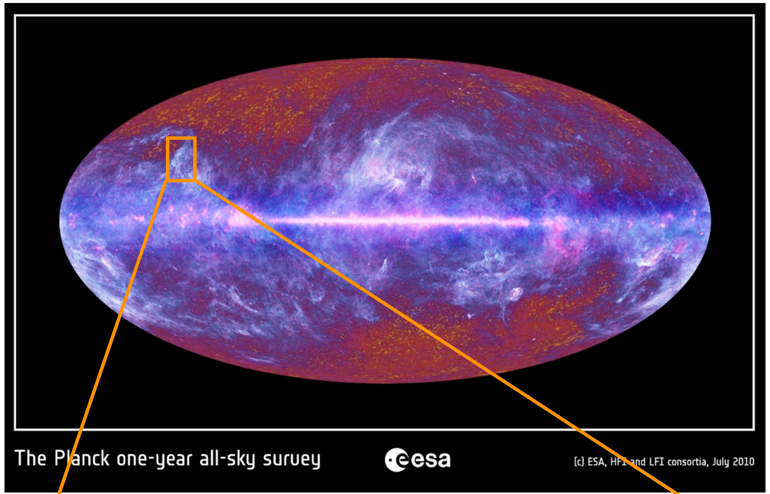
$$p = p_{\max} R\, F\, cos^2\gamma$$
$$R \text{ and } F \leq 1$$

$$P = (Q^2 + U^2)^{0.5}$$
$$p = P/I$$
$$\psi = 0.5 \arctan(-U, Q)$$

R: Rayleigh reduction factor (efficiency of grain alignment)

F: Depolarization factor (change of B orientation within the beam)

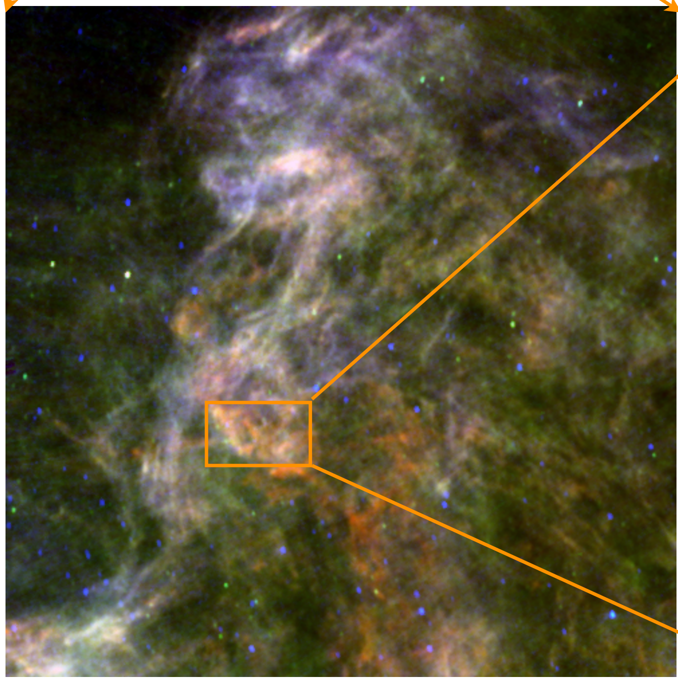
The far-infrared sky

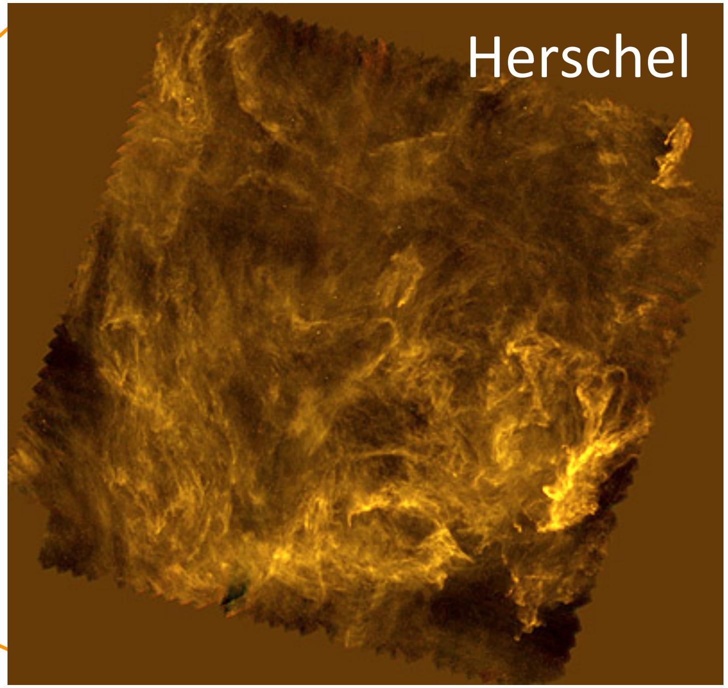


- Scale invariant structure over all observed scales.

- High dynamic range in brightness. More than 3 orders of magnitude from the Galactic plane to the faintest sky area.

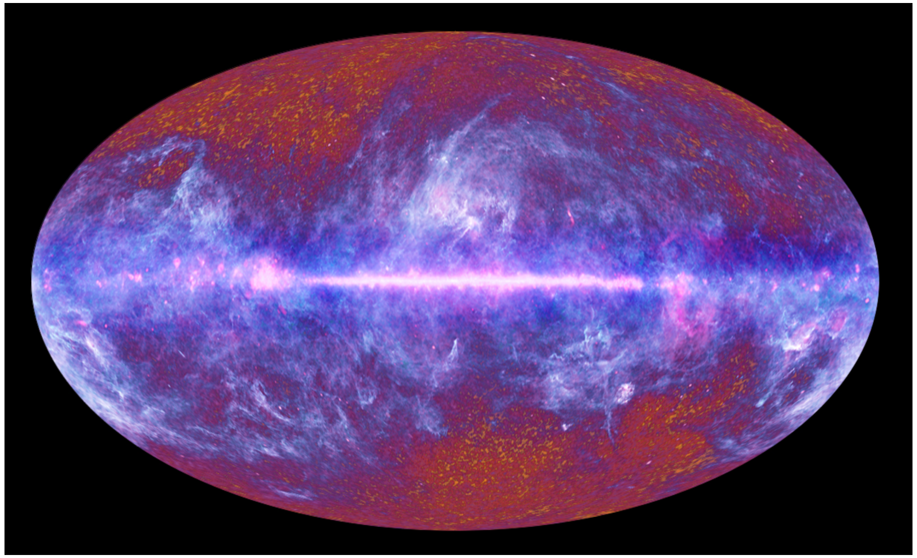
- SED variations are a source of information on dust composition and excitation.



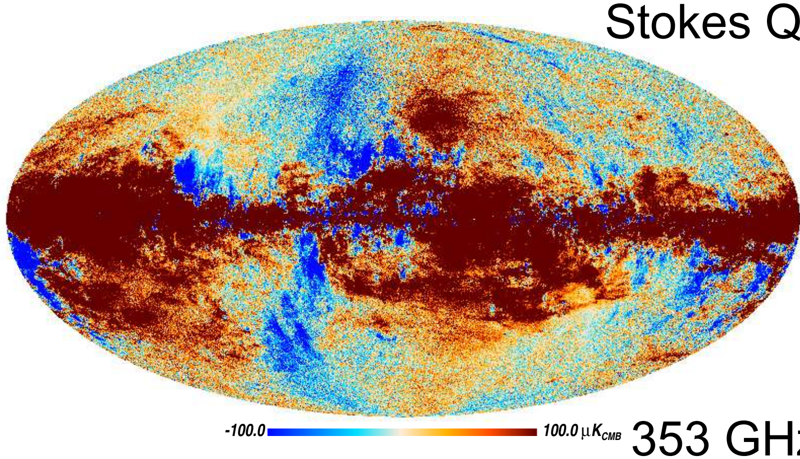


Spatial distribution of dust emission

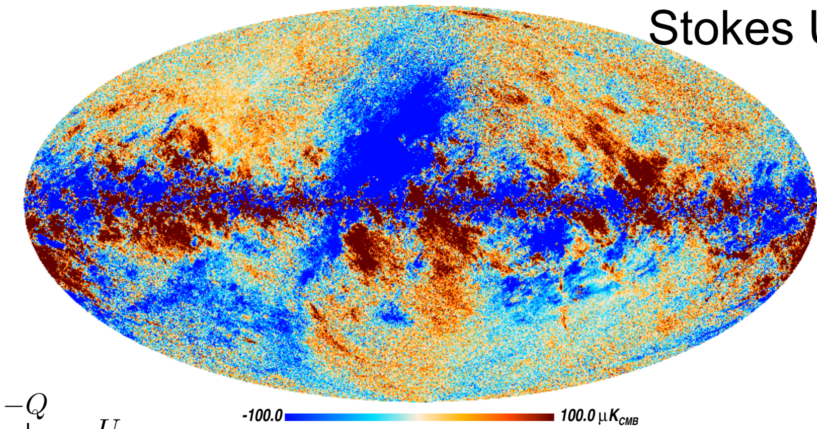
30 GHz 40 GHz 70 GHz 100 GHz 143 GHz 217 GHz 353 GHz 545 GHz 857 GHz



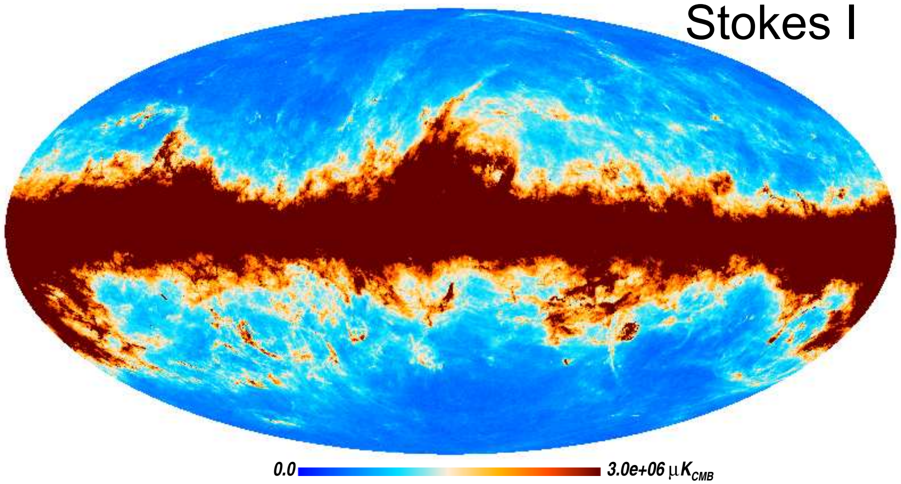
353 GHz
Stokes Q

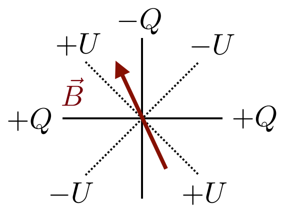


353 GHz
Stokes U



545 GHz
Stokes I

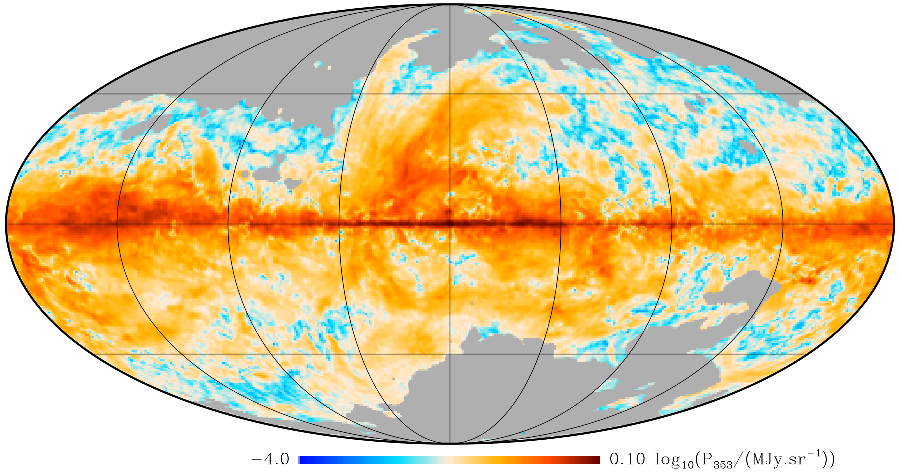




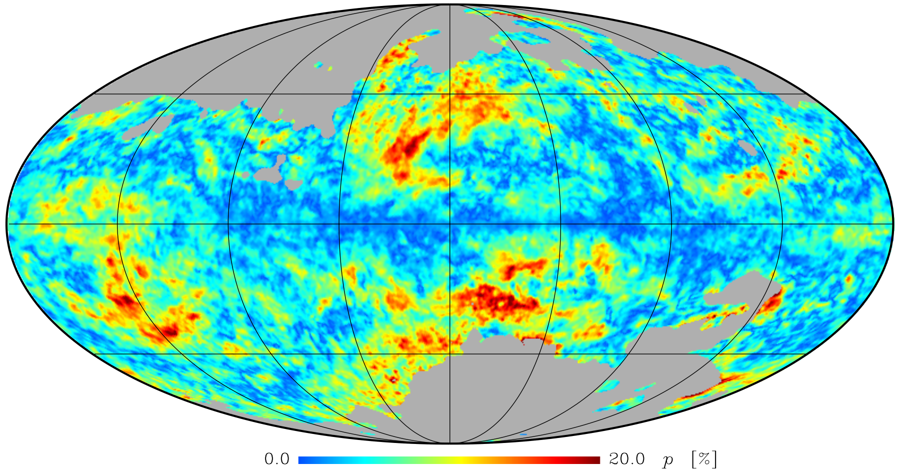
PIP XIX 2014, ArXiv: 1405.0872

Polarized intensity and polarization fraction

$$P = \sqrt{Q^2 + U^2}$$



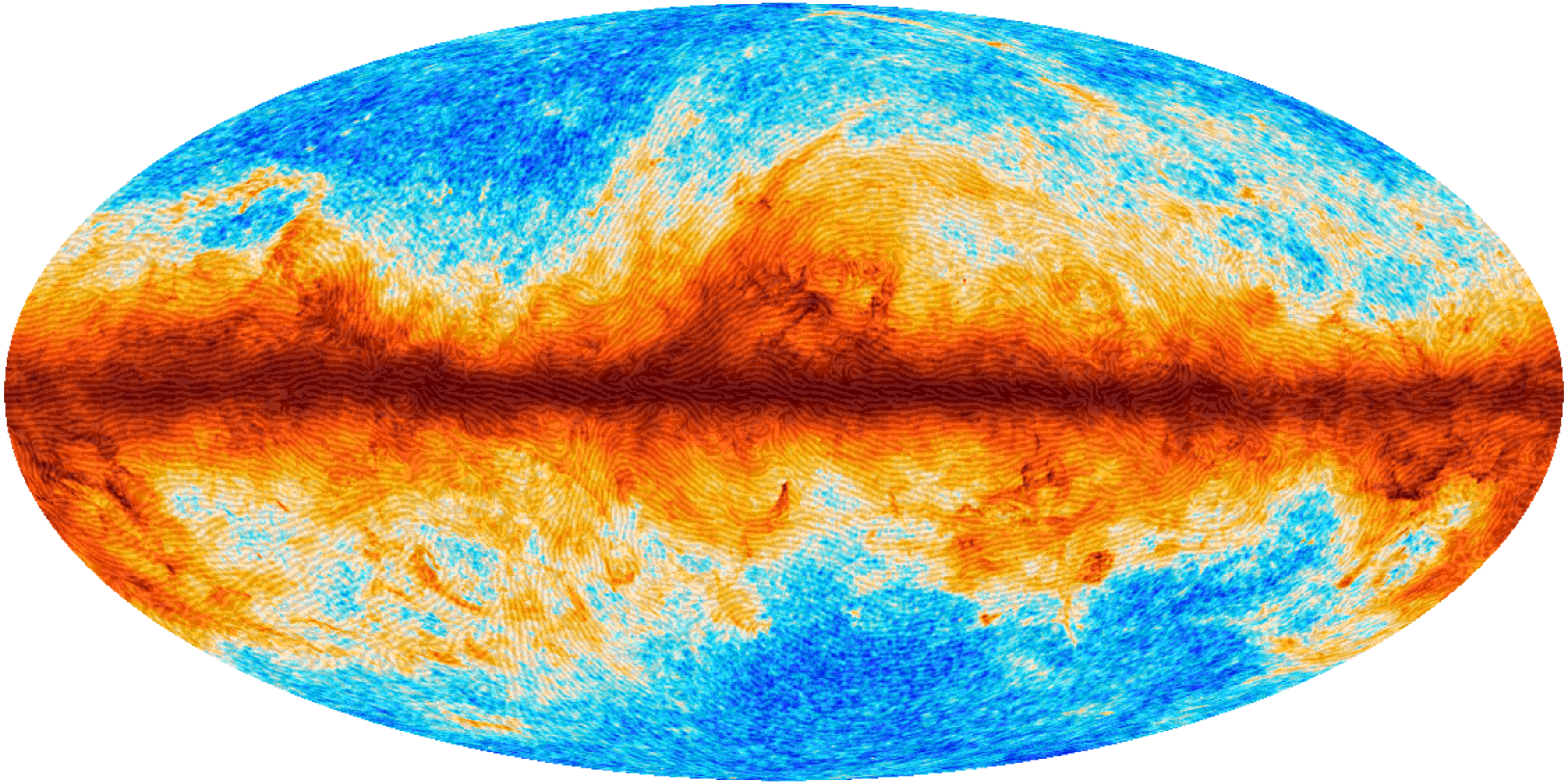
$$p = P/I$$



- Low polarization fractions in the Galactic Plane
- Some highly polarized regions (Fan/Auriga, Aquila Rift,…)
- Thin filamentary regions of low polarization

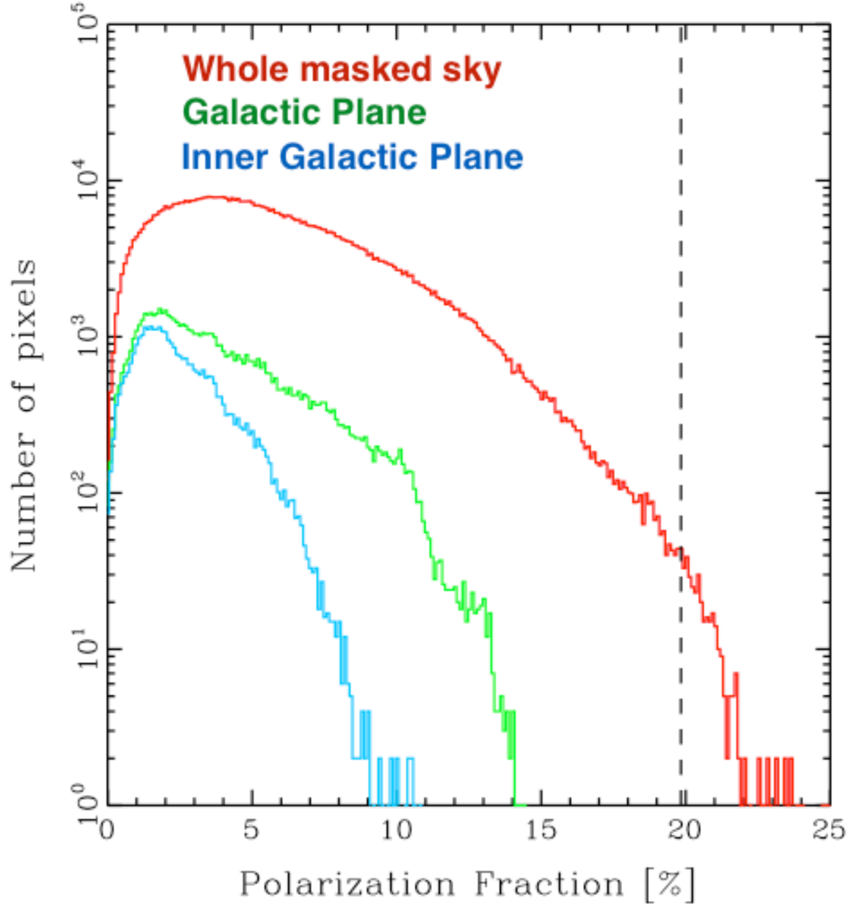
Planck intermediate results. XIX.

Magnetic field fingerprints

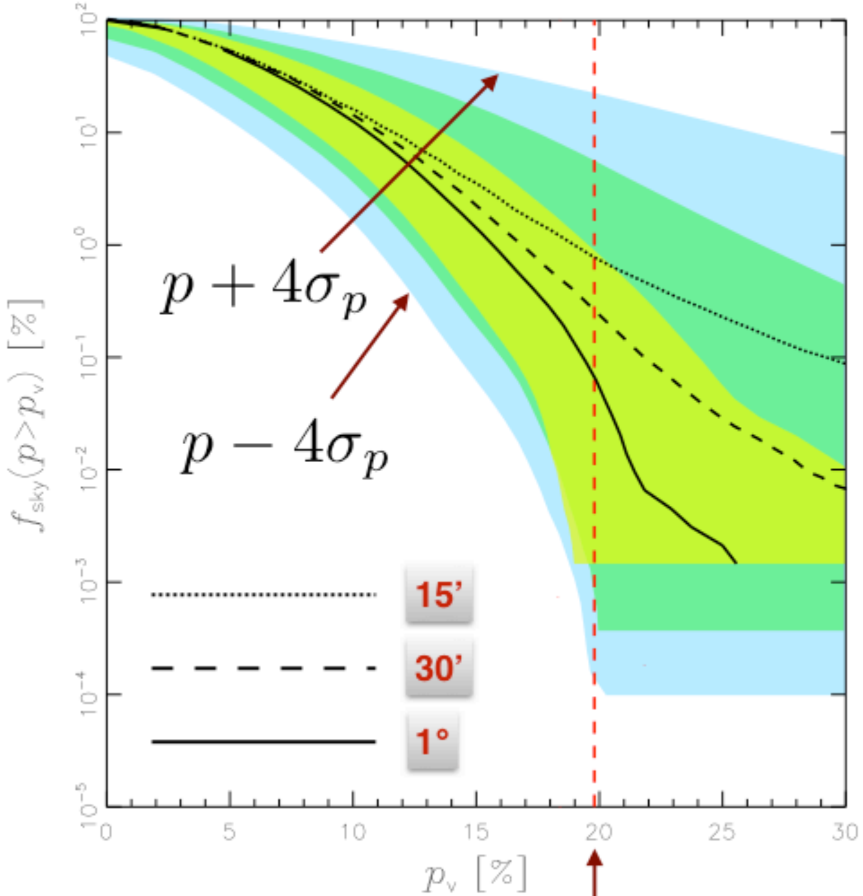


Planck Collaboration 2014

Maximum polarization fraction



1° resolution

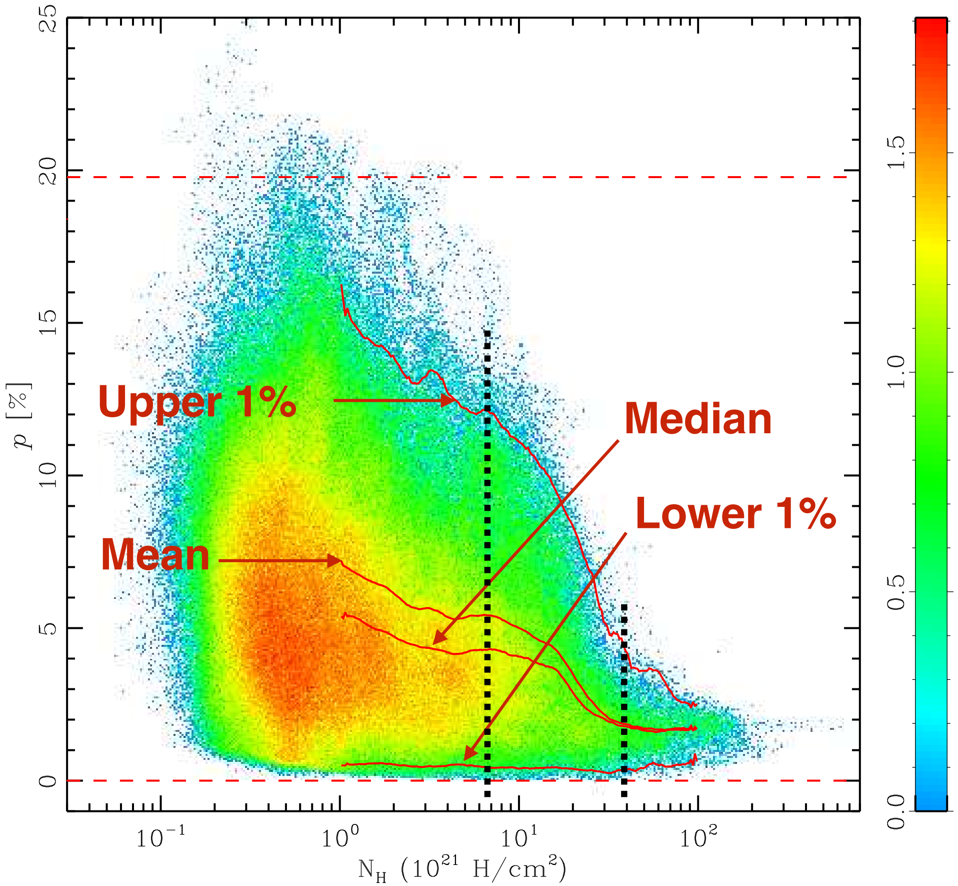


$p_{max} = 19.8\%$

Intrinsic polarization fraction of dust at least 20%

Planck intermediate results. XIX.

Polarization fraction versus column density



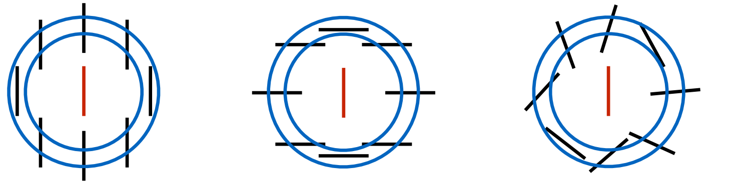
- Polarization fraction is upto 20%
- Large dispersion of *p* at all N_H, tracing changes in B-field orientation and depolarization within the beam.
- Sharp decrease of *p* > 10^{22} H cm^{-2}. Consistent with earlier results from ground-based observations. It has been interpreted by a loss of grain alignment in the shielded interiors of clouds.

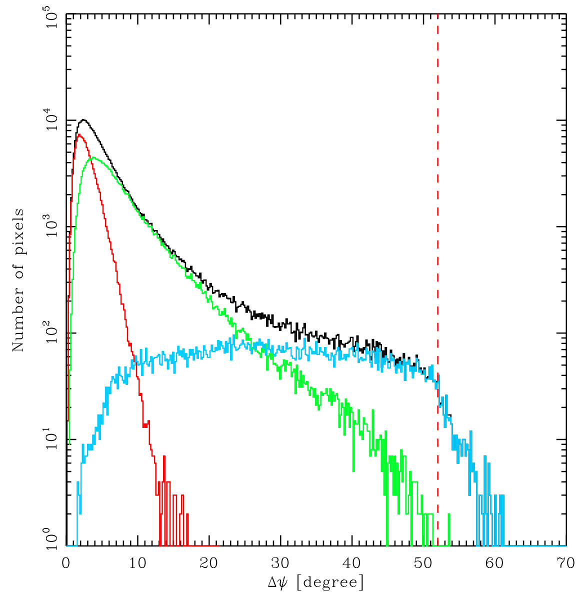
Planck intermediate results. XIX.

Polarization angle dispersion function

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi(\mathbf{r}) - \psi(\mathbf{r}+\mathbf{l}_i)\right]^2$$

$\Delta\psi = 0$ $\Delta\psi = \pi/2$ $\Delta\psi = \pi/\sqrt{12}$



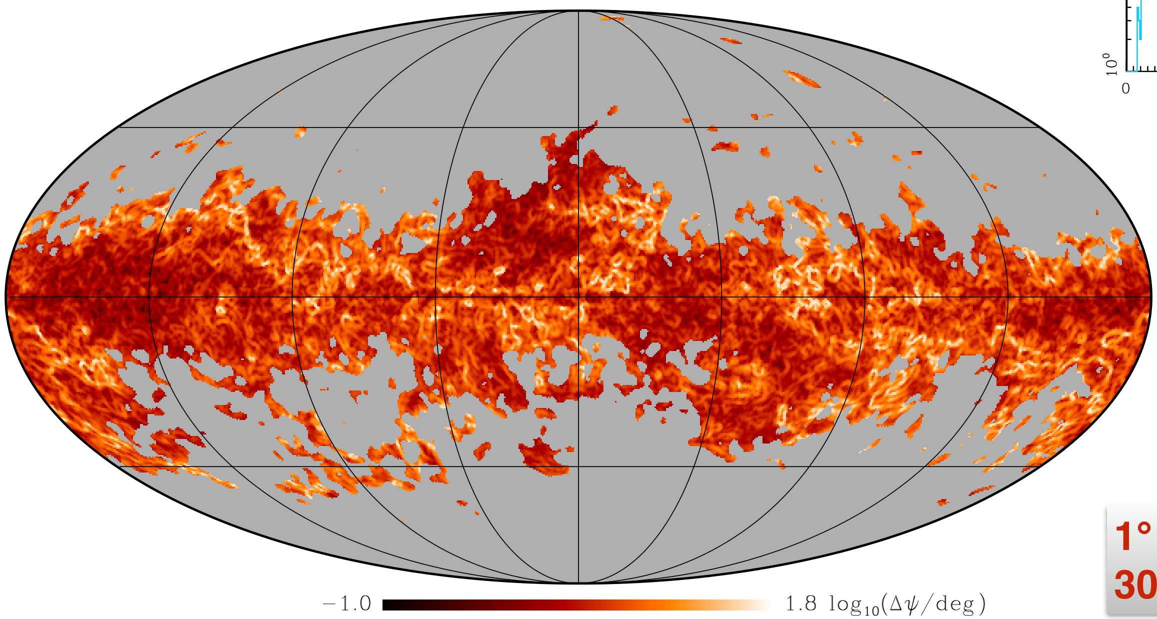


Whole masked sky

$p > 5\%$

$5\% > p > 1\%$

$p < 1\%$



1° resolution
30' lag

Planck intermediate results. XIX.

The polarization angle dispersion highlights filamentary structure of the magnetic field

Outline of the talk

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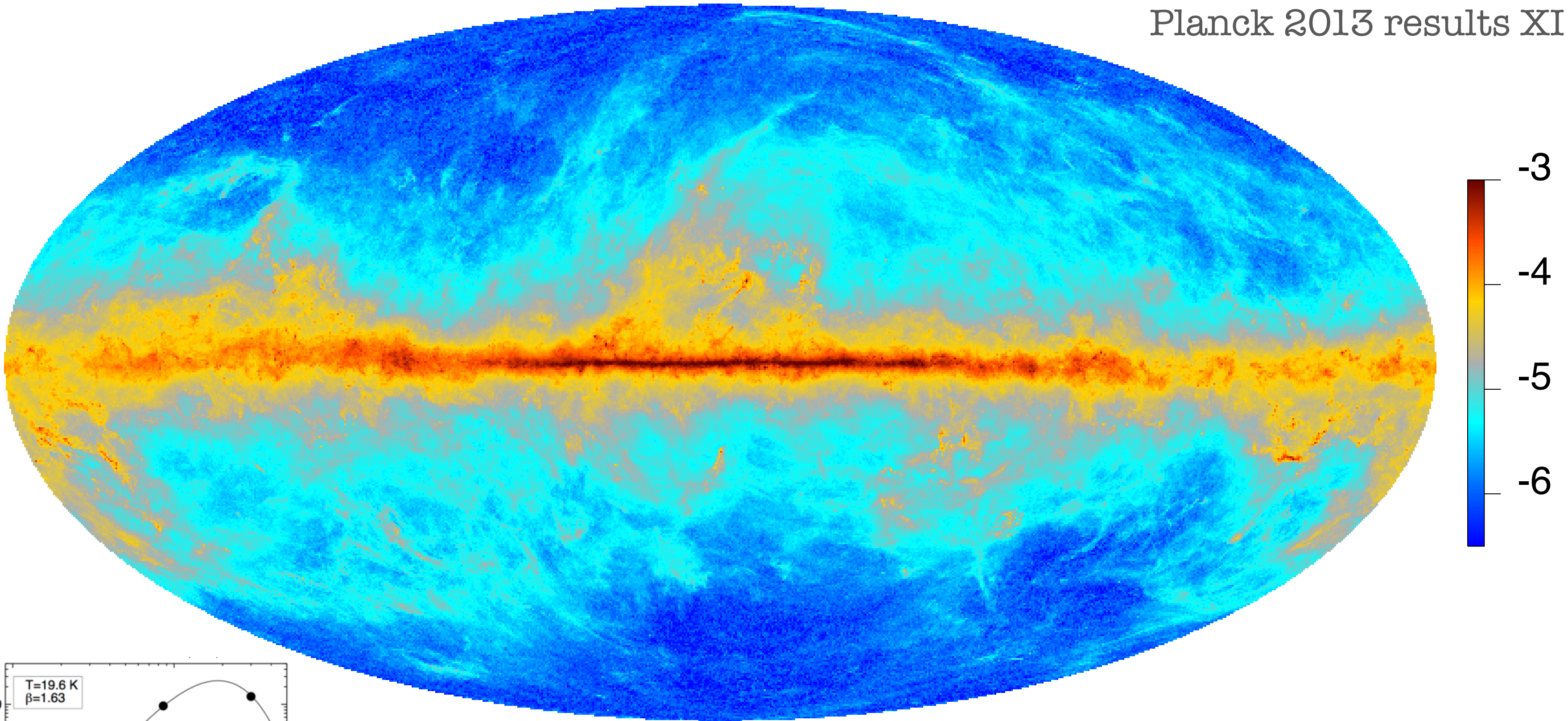
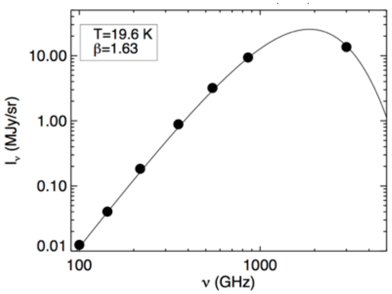
Dust optical depth

Tracer of N_H (dust-to-gas ratio, absorption cross-section)

$$\tau_{353}/N_{HI} = 8.0 \pm 0.7 \times 10^{-27} cm^2$$

Planck 2013 results XI



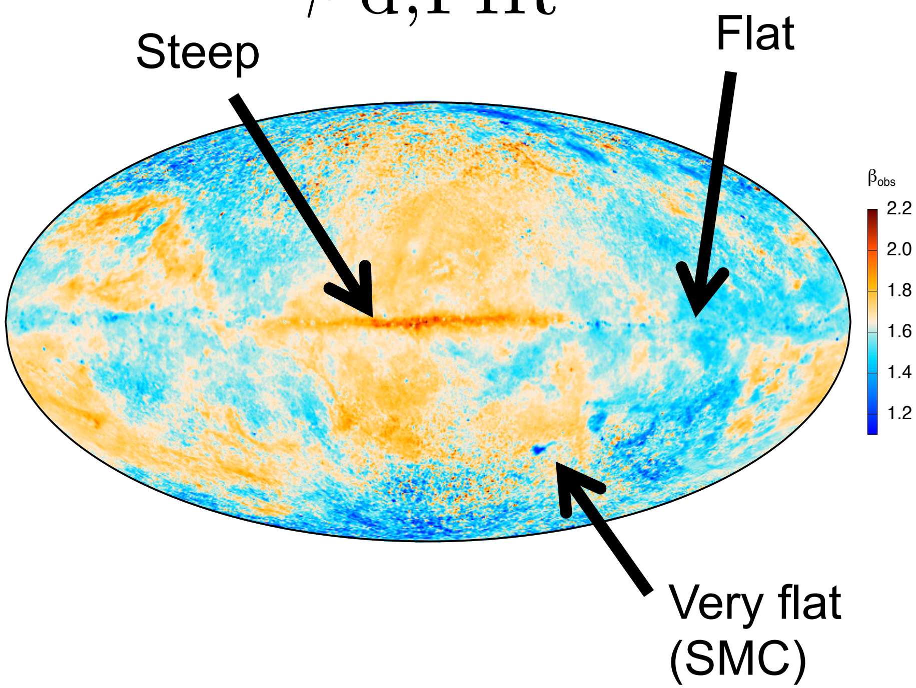


$$I_\nu = \tau_{353}\ B_\nu(T_\mathrm{d})\ \left(\frac{\nu}{353}\right)^{\beta_\mathrm{d}}$$

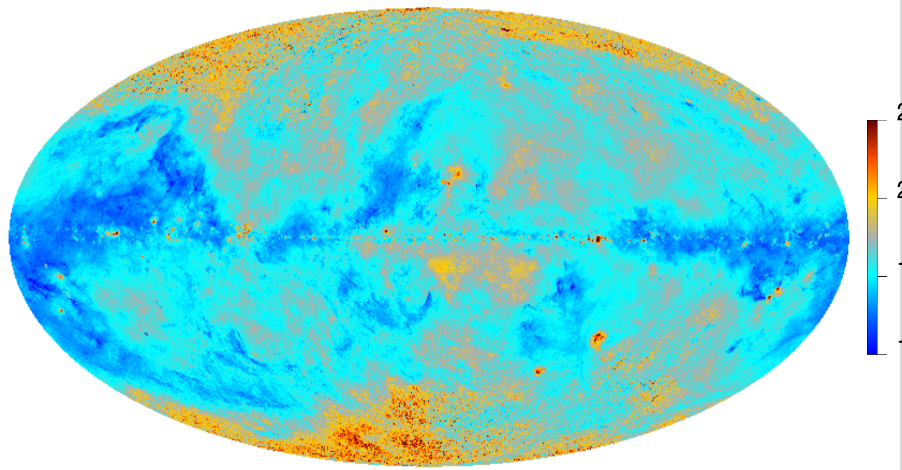
Fitting modified blackbody spectrum (MBB) to the observed data between 353 and 3000 GHz.

Dust SED and temperature

$\beta_{\mathrm{d,FIR}}$



T_{d}



The steepness of dust SED varies across the sky.

Median 1.63
Standard deviation 0.09

Median 19.6 K
Standard deviation 1.3 K

$\beta_{\mathrm{d,FIR}}$ = dust spectral index between 353 and 3000 GHz

Planck 2013 results XI

Dust model (Draine and Li 2007)

The DL07 model can be parameterized via 6 parameters:

- q_{PAH} the fraction of the total grain mass contributed by polycyclic aromatic hydrocarbons (PAHs) containing less than 10^3 carbon atoms.
- U_{min} the heating starlight intensity of the diffuse ISM radiation field, relative to the intensity of the diffuse starlight in the solar neighborhood.
- α the power-law exponent of the power-law distribution of heating starlight intensities between U_{min} and U_{max}.
- U_{max} the maximum heating starlight intensity of the power-law distribution of heating starlight intensities.
- f_{PDR} the fraction of the total dust luminosity that is radiated by dust in regions where $U>10^3$
- M_d the dust mass.

- The dust model is characterized by the adjustable parameters $\{M_d, q_{PAH}, f_{PDR}, U_{min}, U_{max}, \alpha\}$.

- We can reduce the dimensionality of the problem by fixing some of the parameters. In a resolved studied of the 60 KINGFISH galaxies, we show that fixing $U_{max}=10^7$ do not deteriorate the quality of the fit. We fix $U_{max}=10^7$

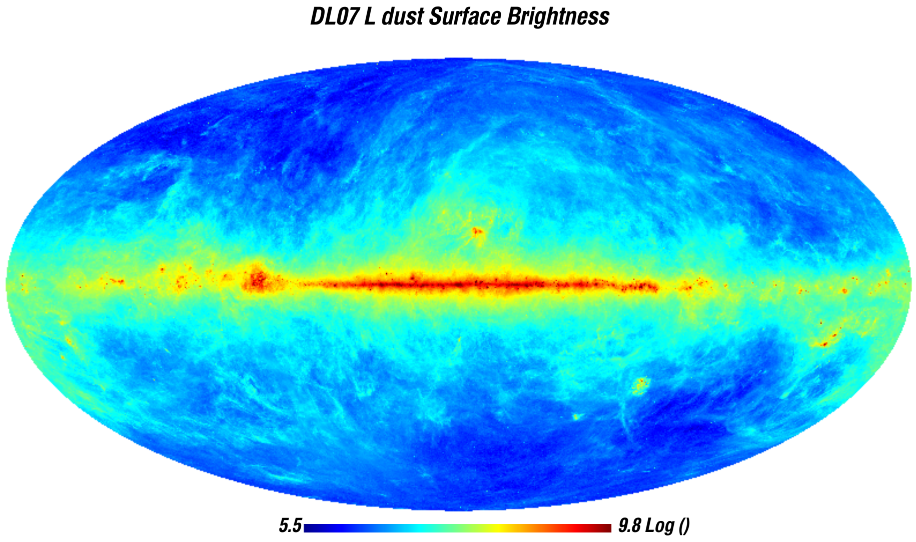
- Simple models for the geometry of dust distribution predict values of $\alpha=1.5,\ldots,2.5$. We fix $\alpha=2.0$.

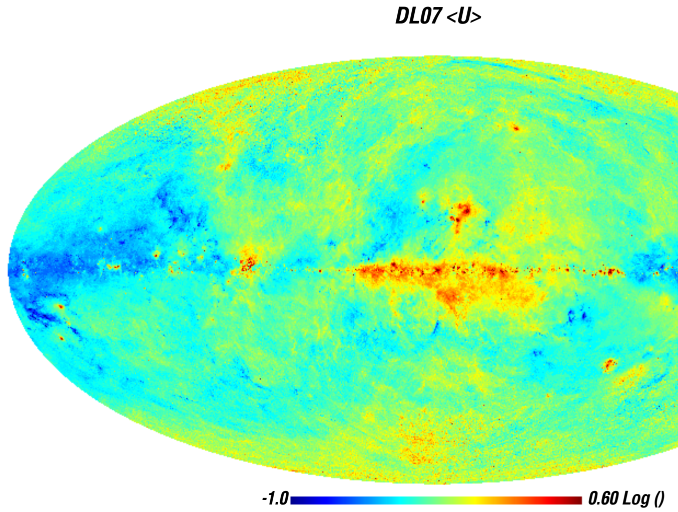
- q_{PAH} do not have any effect on the long wavelength IR emission… therefore, we assume $q_{PAH}=0.03$

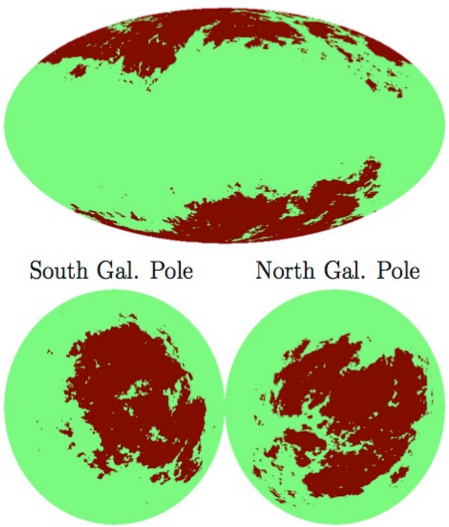
- We therefore have 3 free parameters: $\{M_d, f_{PDR}, U_{min}\}$.

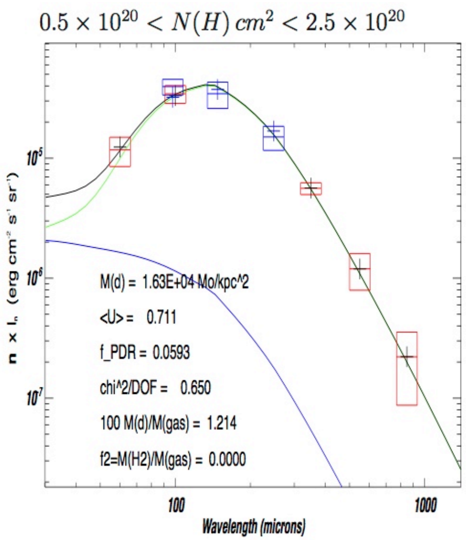
Planck intermediate results XXIX (2014)

Dust model parameters









The crosses are the model predicted fluxes, the horizontal lines are the measured flux, and squares around them the 1-sigma uncertainties.

The blue data correspond to the DIRBE measures, NOT used in the fit.

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The foreground Galactic emissions

Intensity

Polarization

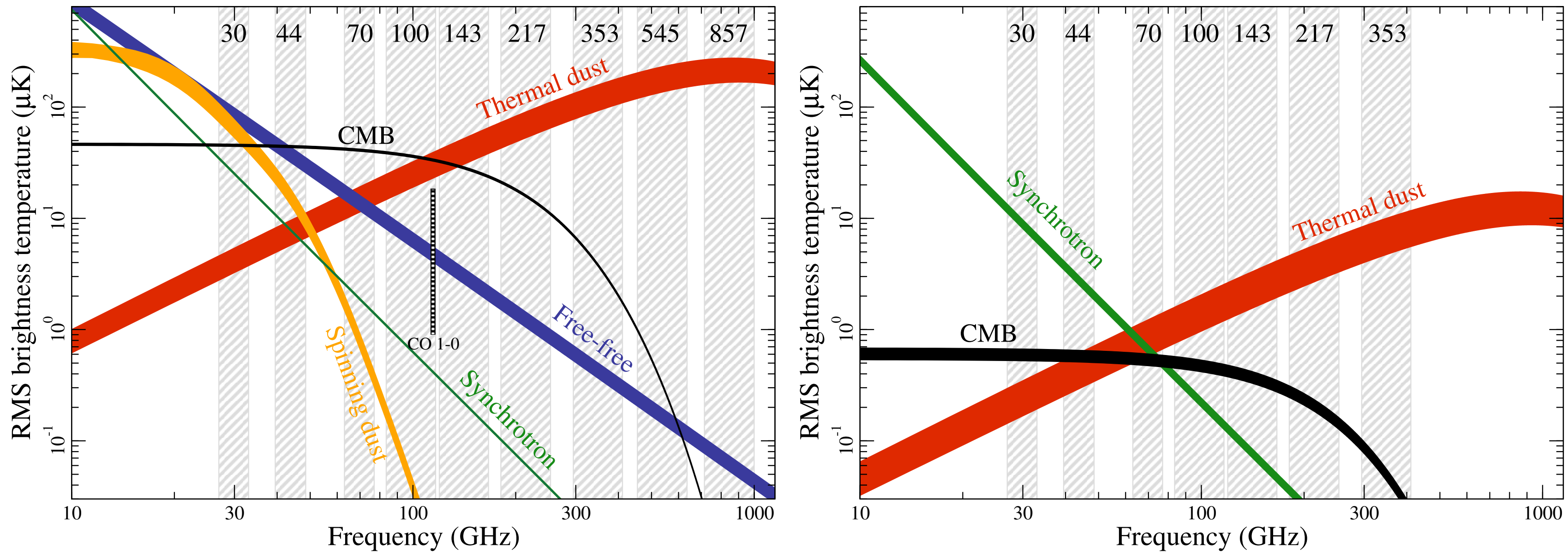


Fig. 20: Brightness temperature rms as a function of frequency and astrophysical component, for both temperature (*left*) and polarization (*right*). For temperature, each component is smoothed to an angular resolution of 1° FWHM, and the lower and upper edges of each line are defined by masks covering 81 and 93% of the sky, respectively. For polarization, the corresponding smoothing scale is 40′, and the sky fractions are 73 and 93%.

Handling polarization data is simple as compared to intensity

Amplitude of the CMB polarization is less compared to its foregrounds

Dust SED at high latitude sky

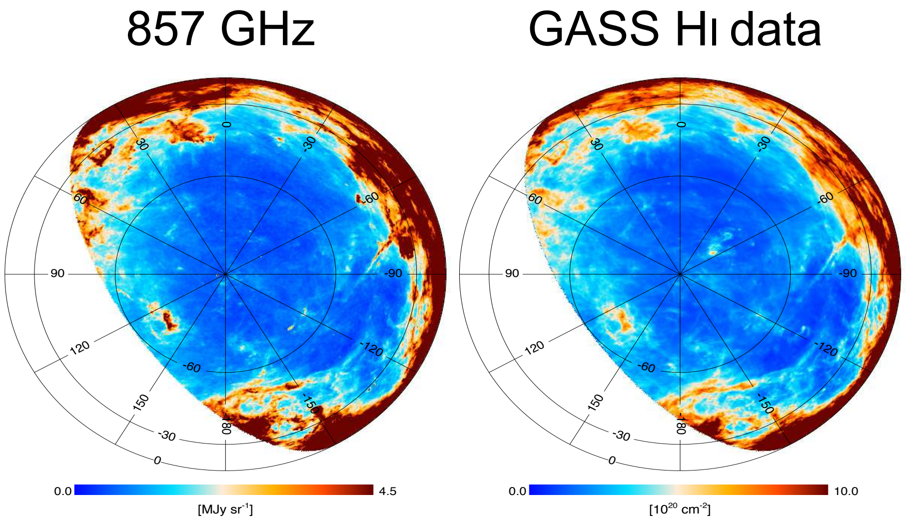
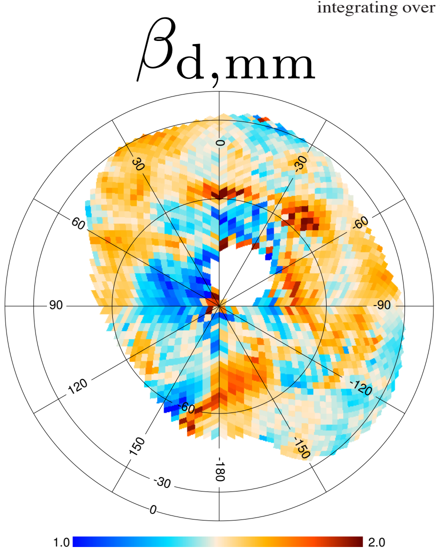
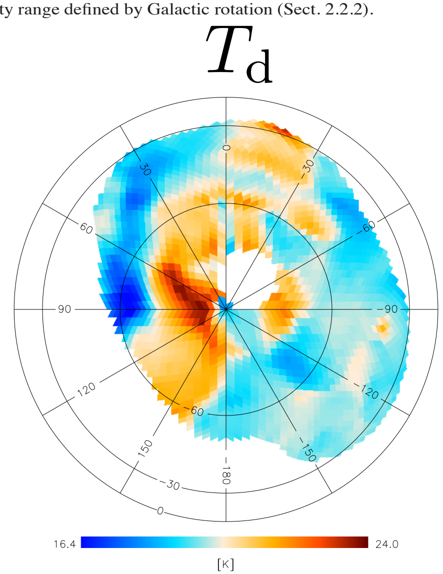
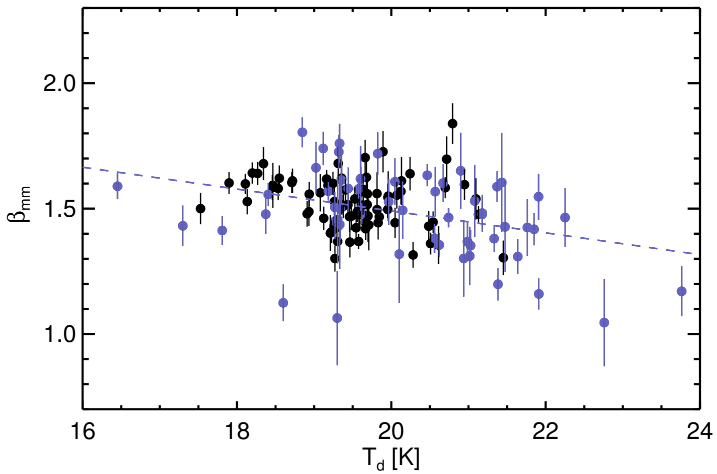


Fig. 1. *Left*: *Planck* map at 857 GHz over the area where we have H I data from the GASS survey. The center of the orthographic projection is the southern Galactic pole. Galactic longitudes and latitudes are marked by lines and circles, respectively. The *Planck* image has been smoothed to the 16′ resolution of the GASS N_{HI} map. *Right*: GASS N_{HI} map of Galactic disk emission, obtained by integrating over the velocity range defined by Galactic rotation (Sect. 2.2.2).



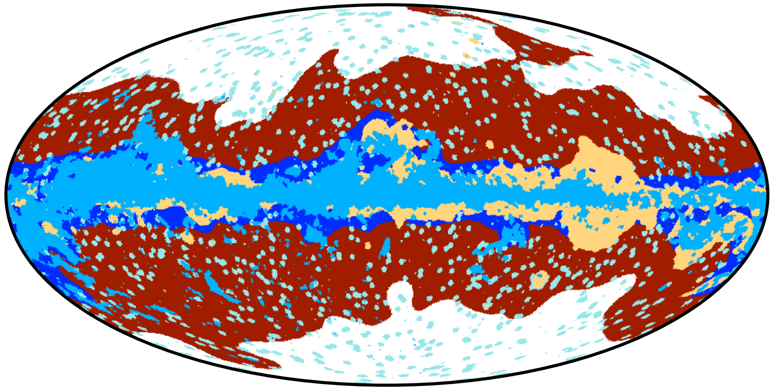




$\beta_{d,mm}$ = dust spectral index between 100 and 353 GHz

Planck intermediate results XVII (2014)

Dust SED at intermediate latitude sky



Only red region is analysed in our study

Cross-correlation analysis with three templates

a. 408 MHz survey -> synchrotron emission
b. Halpha map -> free-free emission
c. 353 GHz map -> dust emission

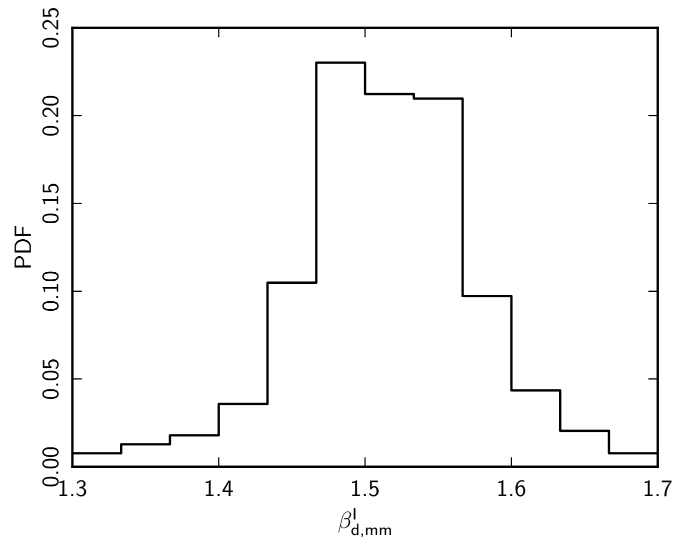
$$\langle \beta^{\rm I}_{\rm d,mm} \rangle = 1.51 \pm 0.06,\ T_{\rm d} = 19.6\ {\rm K}$$

The cross-correlation coefficients at and above 100 GHz can be decomposed as

$$[\alpha^{\rm I}_{\nu}]^{\rm 3T}_{353} = \alpha^{\rm I}(c^{3}_{353}) + \alpha^{\rm I}_{\nu}(d_{353})$$

We work with the colour ratio between two frequencies ν_1 and ν_2 (ν_0 is used as a reference to get rid of the CMB contribution)

$$R^{\rm I}_{\nu_0}(\nu_2,\nu_1) = \frac{[\alpha^{\rm I}_{\nu_2}]^{\rm 3T}_{353} - [\alpha^{\rm I}_{\nu_0}]^{\rm 3T}_{353}}{[\alpha^{\rm I}_{\nu_1}]^{\rm 3T}_{353} - [\alpha^{\rm I}_{\nu_0}]^{\rm 3T}_{353}} = \frac{\alpha^{\rm I}_{\nu_2}(d_{353}) - \alpha^{\rm I}_{\nu_0}(d_{353})}{\alpha^{\rm I}_{\nu_1}(d_{353}) - \alpha^{\rm I}_{\nu_0}(d_{353})}, = g(\beta_{\rm d}, T_{\rm d})$$

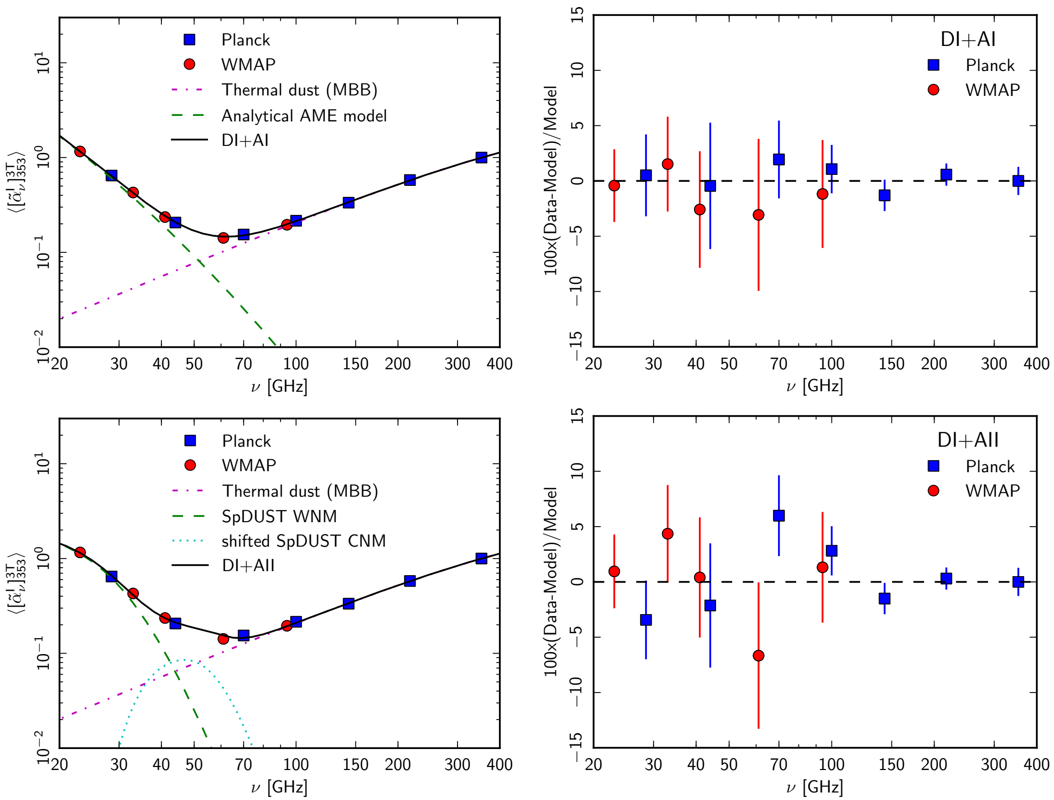


Histogram of $\beta^{\rm I}_{\rm d,mm}$

Planck intermediate results XXII (2014)

Intensity dust SED

Spectral modeling | **Residuals**



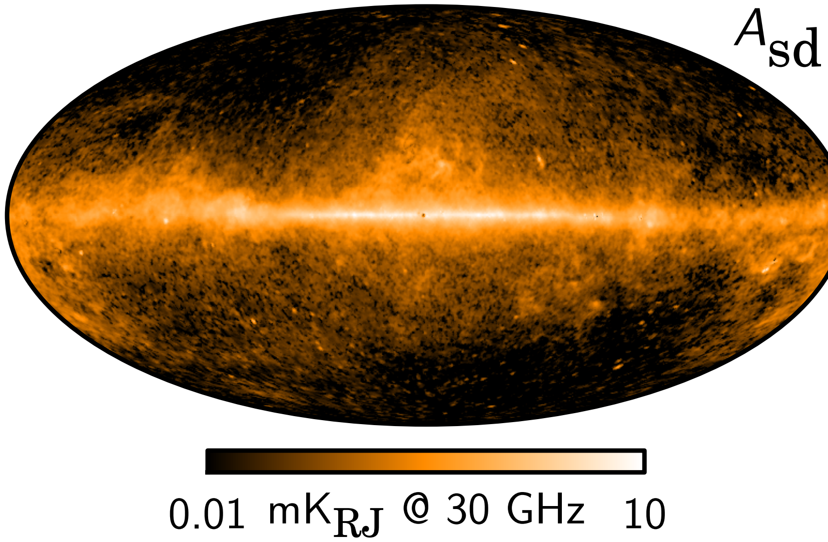
Bonaldi (2007) model of AME
+
MBB spectrum of thermal dust emission

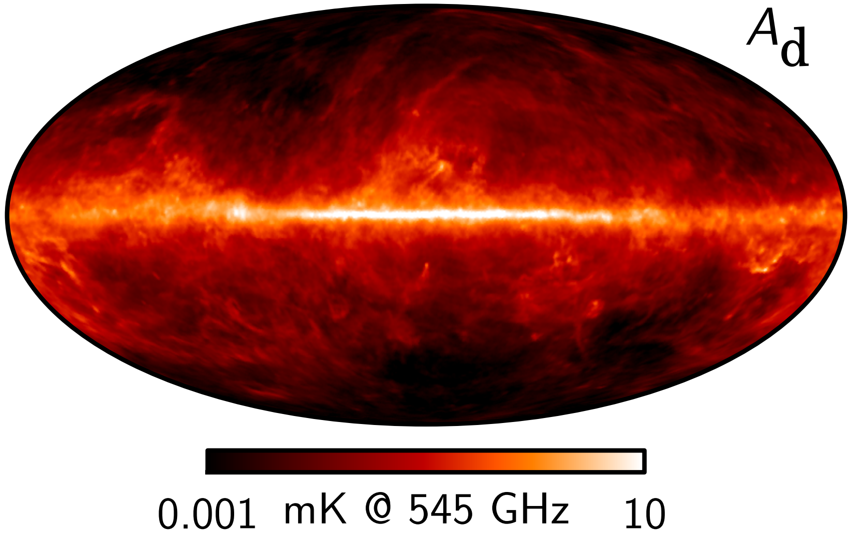
Two component spinning dust model
+
MBB spectrum of thermal dust emission

Parameters	DI+AI	Parameters	DI+AII
$\beta^{I}_{d,mm}$ . . .	1.52 ± 0.01	A^{I}_{WNM} . . .	1.12 ± 0.04
A^{I}_{a}	1.14 ± 0.04	$\Delta\nu_{WNM}$ [GHz]	-1.7 ± 0.8
ν_{p} [GHz]	9.5 ± 6.9	A^{I}_{CNM}	0.07 ± 0.01
m_{60}	1.81 ± 0.38	$\Delta\nu_{CNM}$ [GHz]	22.2 ± 1.6
χ^2/N_{dof} . .	2.4/8	χ^2/N_{dof} . .	8.7/8

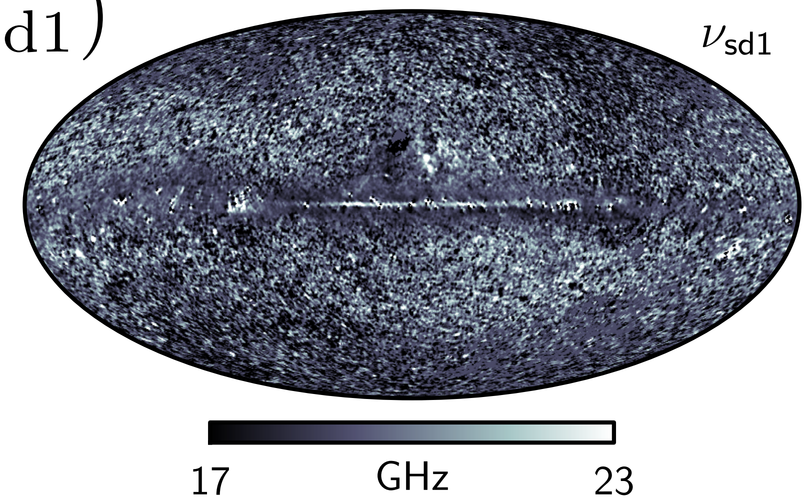
Planck intermediate results XXII (2014)

More on spinning dust model





$$\mathrm{Model} = A_{\mathrm{sd1}}\ D_{\mathrm{sd1}}(\nu + \nu_{\mathrm{sd1}}) + A_{\mathrm{sd2}}\ D_{\mathrm{sd2}}(\nu)$$

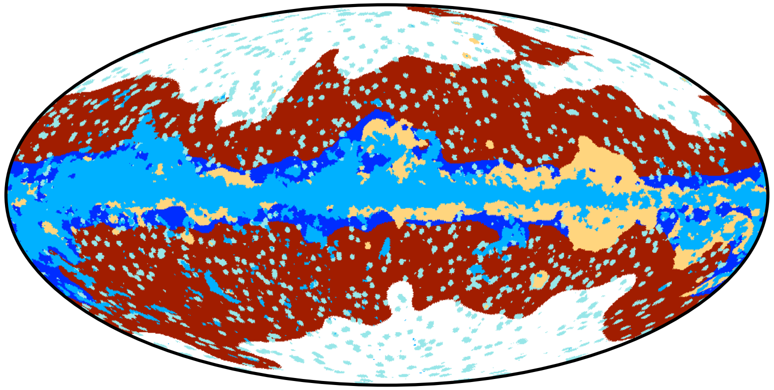


D_{sd} corresponds to the SPDUST2 spinning dust model.

preliminary

Planck 2015 results (in preparation)

Polarized Dust SED at intermediate latitude sky

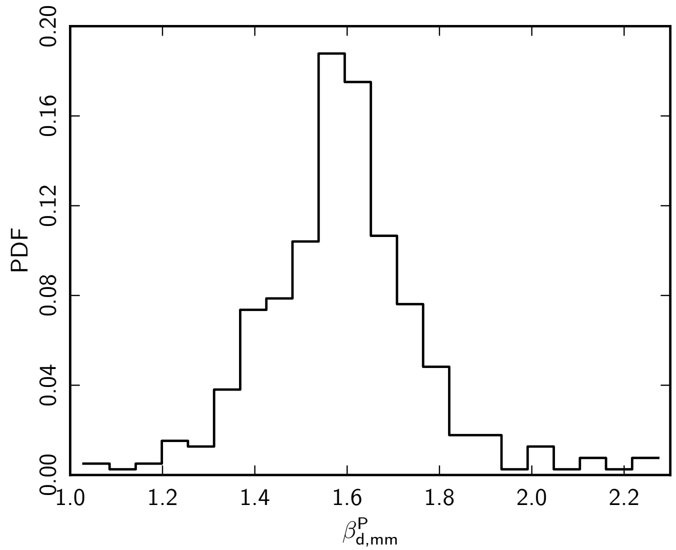


Only red region is analysed
in our study

$$\langle \beta^{\mathrm{P}}_{\mathrm{d,mm}} \rangle = 1.59 \pm 0.17,\ T_{\mathrm{d}} = 19.6\ \mathrm{K}$$

Polarized SED is slightly steeper than the intensity SED for a fixed T_d.

Cross-correlation analysis with 353 GHz polarized dust template



Histogram of $\beta^{\mathrm{P}}_{\mathrm{d,mm}}$

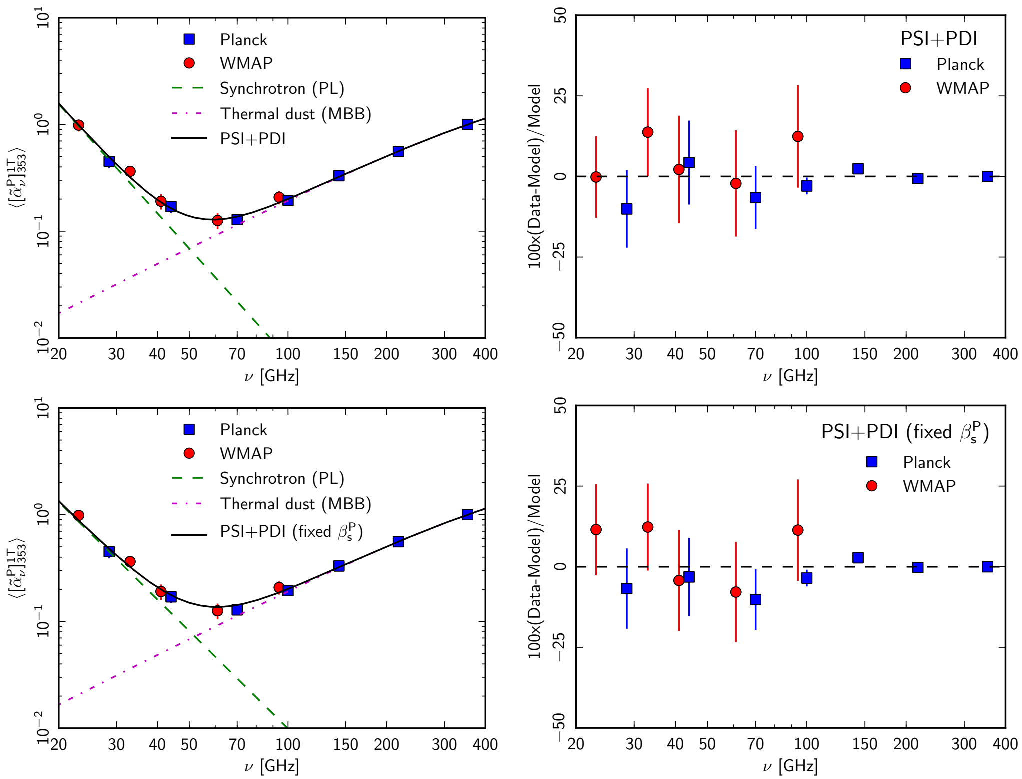
Planck intermediate results XXII (2014)

Polarization dust SED

Spectral modeling | **Residuals**

Free synchrotron spectral index

Fixed synchrotron spectral index ($\beta_s = -3.04$)



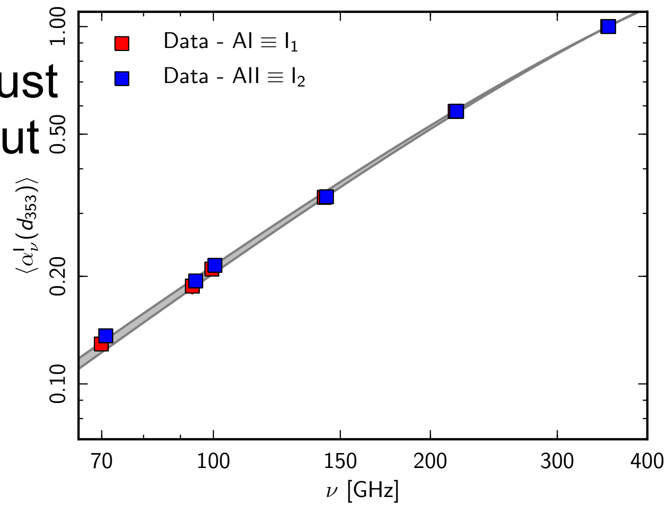
Power-law model of 353 GHz correlated synchrotron emission
+
MBB spectrum of polarized thermal dust emission

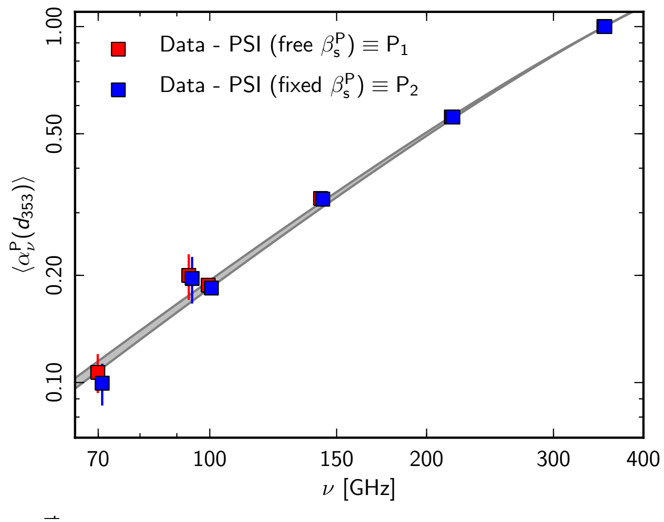
Parameters [a]	Unconstrained β_s^P	Fixed β_s^P
A_s^P	0.97 ± 0.10	0.86 ± 0.06
β_s^P	-3.40 ± 0.28	-3.04
$\beta_{d,mm}^P$	1.57 ± 0.01	1.58 ± 0.01
χ^2/N_{dof} . . .	6.6/9	8.6/10

Planck intermediate results XXII (2014)

Variation of polarization fraction with frequency

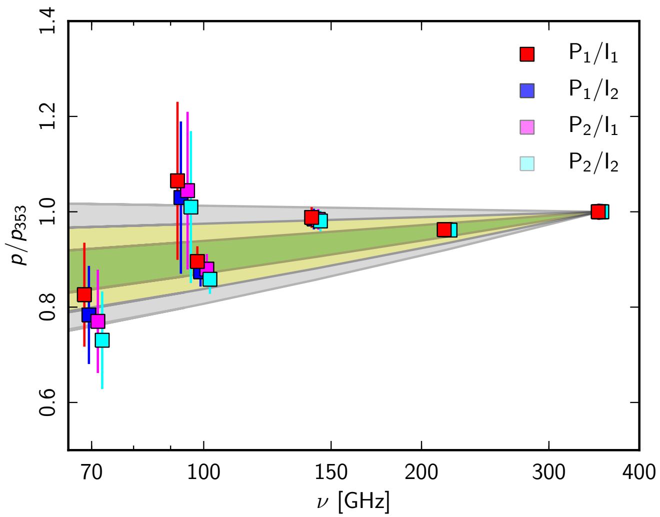
Intensity dust SED without AME





Polarized dust SED without 353 GHz correlated synchrotron emission

polarization fraction is normalized to 353 GHz

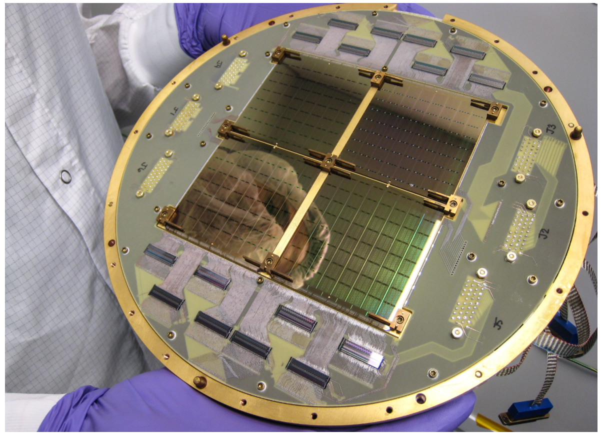


Planck intermediate results XXII (2014)

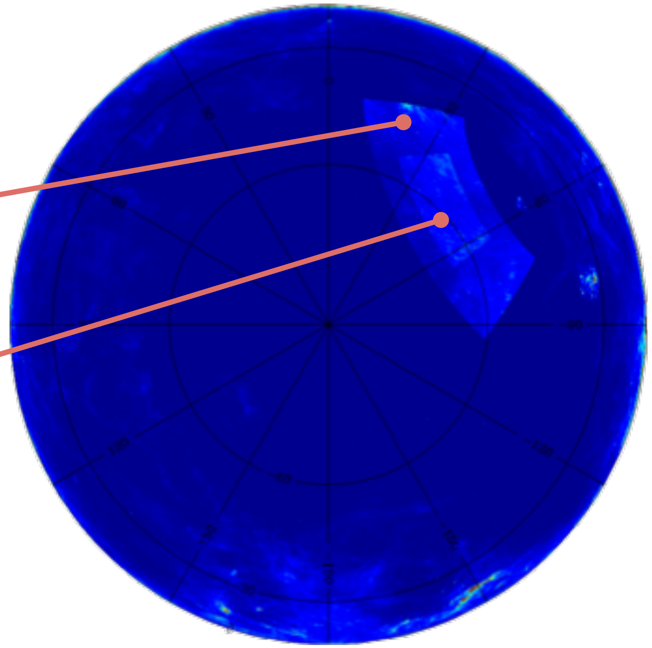
Outline of the talk

1. Spatial distribution of the dust emission and its polarization properties
2. Spectral properties of the dust emission as measured by Planck
3. Statistical properties of the dust emission in terms of power spectrum

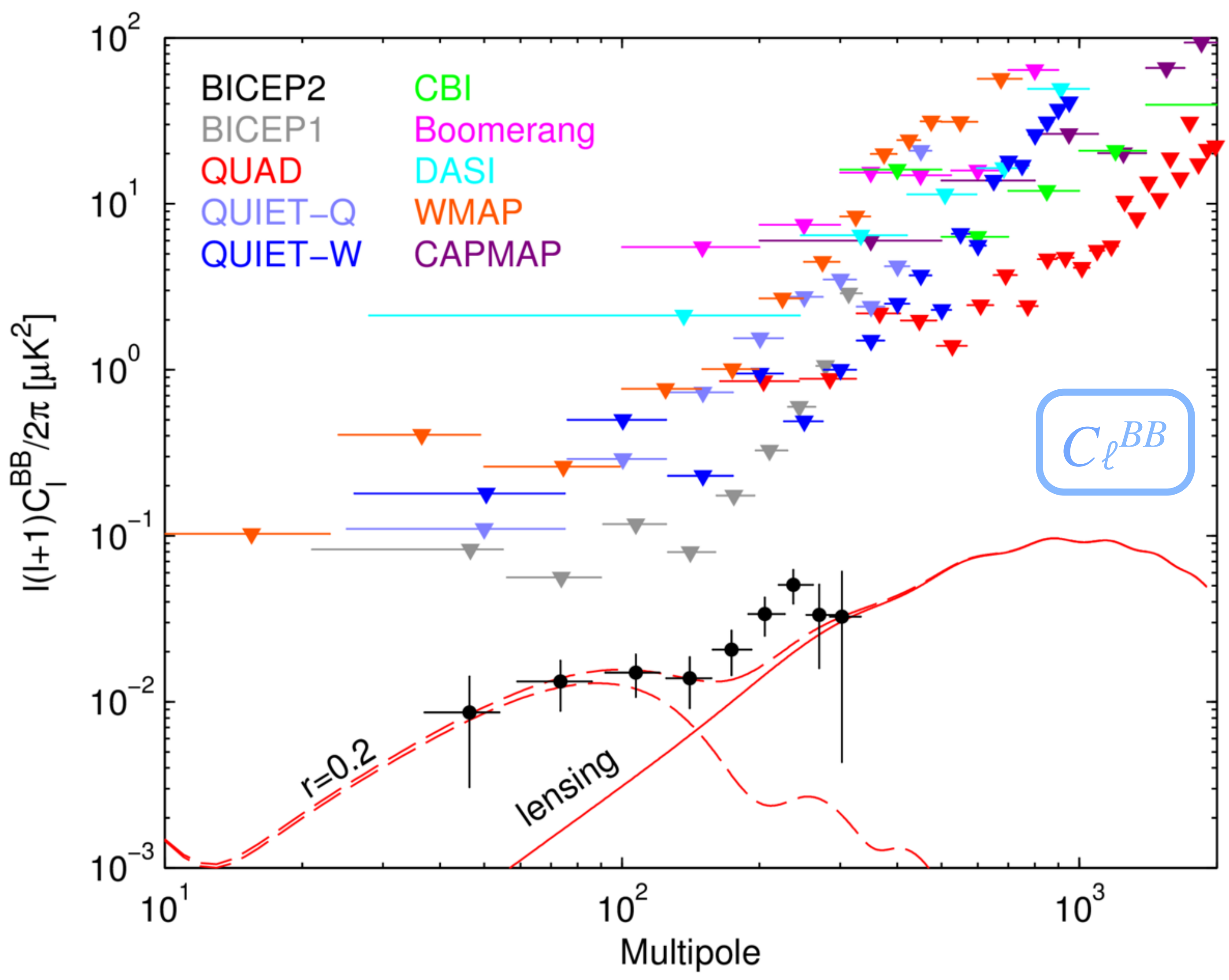
The BICEP2 telescope



Observes ~5% of the sky in the South Pole
(~1% of the sky is utilised for the analysis)
512 TES detector at 150 GHz
Resolution is 30’
Integrated sensitivity is 87 nK·degree

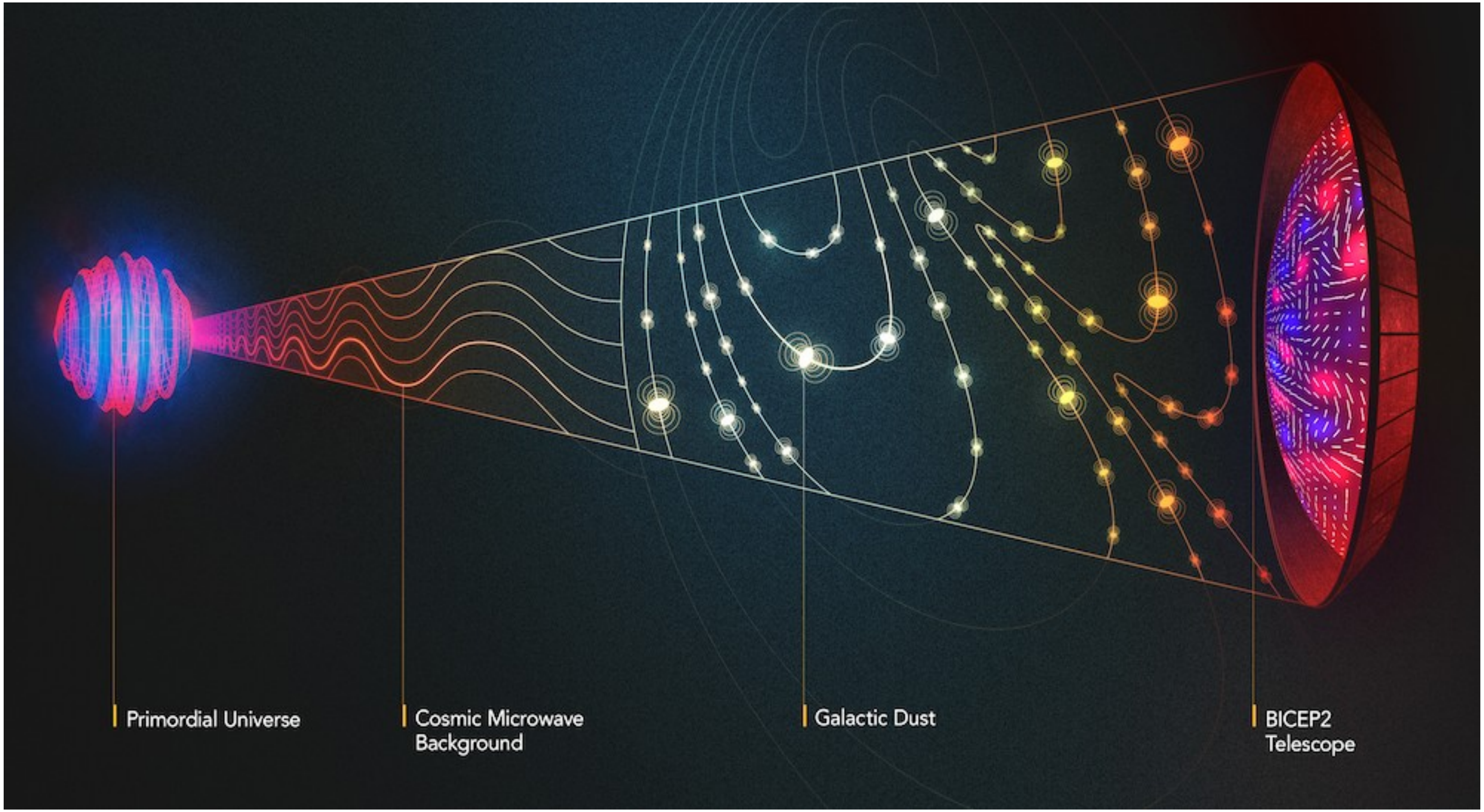


The BICEP2 results



[BICEP2 Collaboration 2014]

What fraction of the measured B-modes comes from polarized dust emission ?



artist's image

Sensitivity Comparison

Observability of B-modes

✤ Signals are extremely small!!

- r=0.2 corresponds to an RMS B-mode anisotropy < 200 nK

➡ Extremely high sensitivities are required ⇒ large number of very-sensitive detectors with large bandwidths needed

$$\Delta T_{\rm RMS} = \frac{T_{\rm sys}}{\sqrt{\Delta\nu\ t\ N_{\rm chan}}}\sqrt{\frac{\Omega_{\rm sky}}{\Omega_{\rm beam}}}$$

(Final map sensitivity)

Experiment	Final map sensitivity (μK/degree)
COBE	~190
WMAP @ 94 GHz (DR5)	4.3
Planck @ 143 GHz (DR1)	0.46
BICEP2 @ 150 GHz	0.087
Keck @ 150 GHz	0.074

Motivation of our study

- Study statistical properties of the polarized dust emission using the formalism that we commonly use for the CMB emission

- Draw general properties that can be used for cosmological analysis or separation of components

- Quantifying the amplitude of B-mode from the polarization of the Galactic dust emission, which hides the background CMB emission

- Provide constraints for modeling the dust polarization and magnetic field of our Galaxy

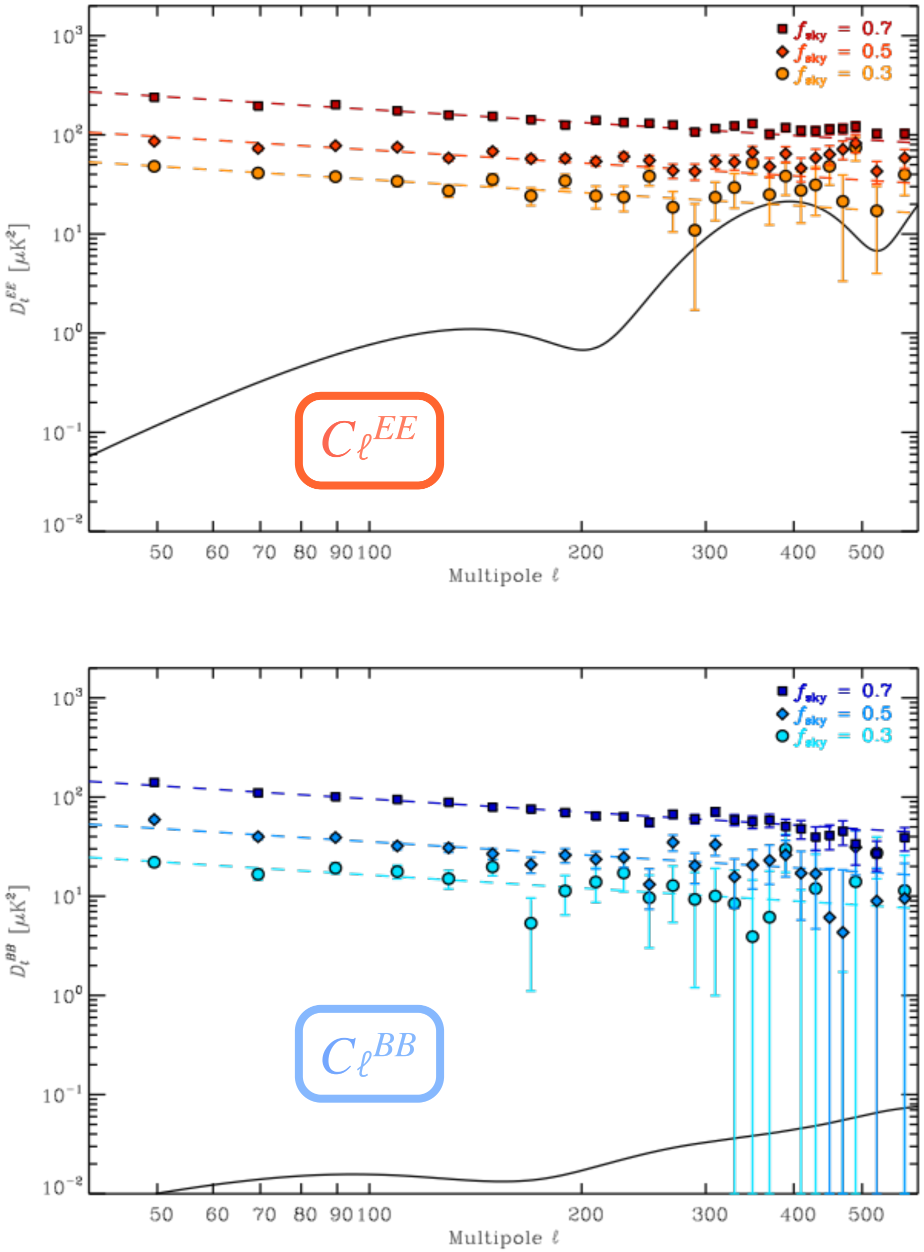
Results

First measurement of the angular power spectra of the polarized dust emission at ℓ>10

Even 30% of the sky, the polarized dust emission dominates over the CMB emission at all angular scales.

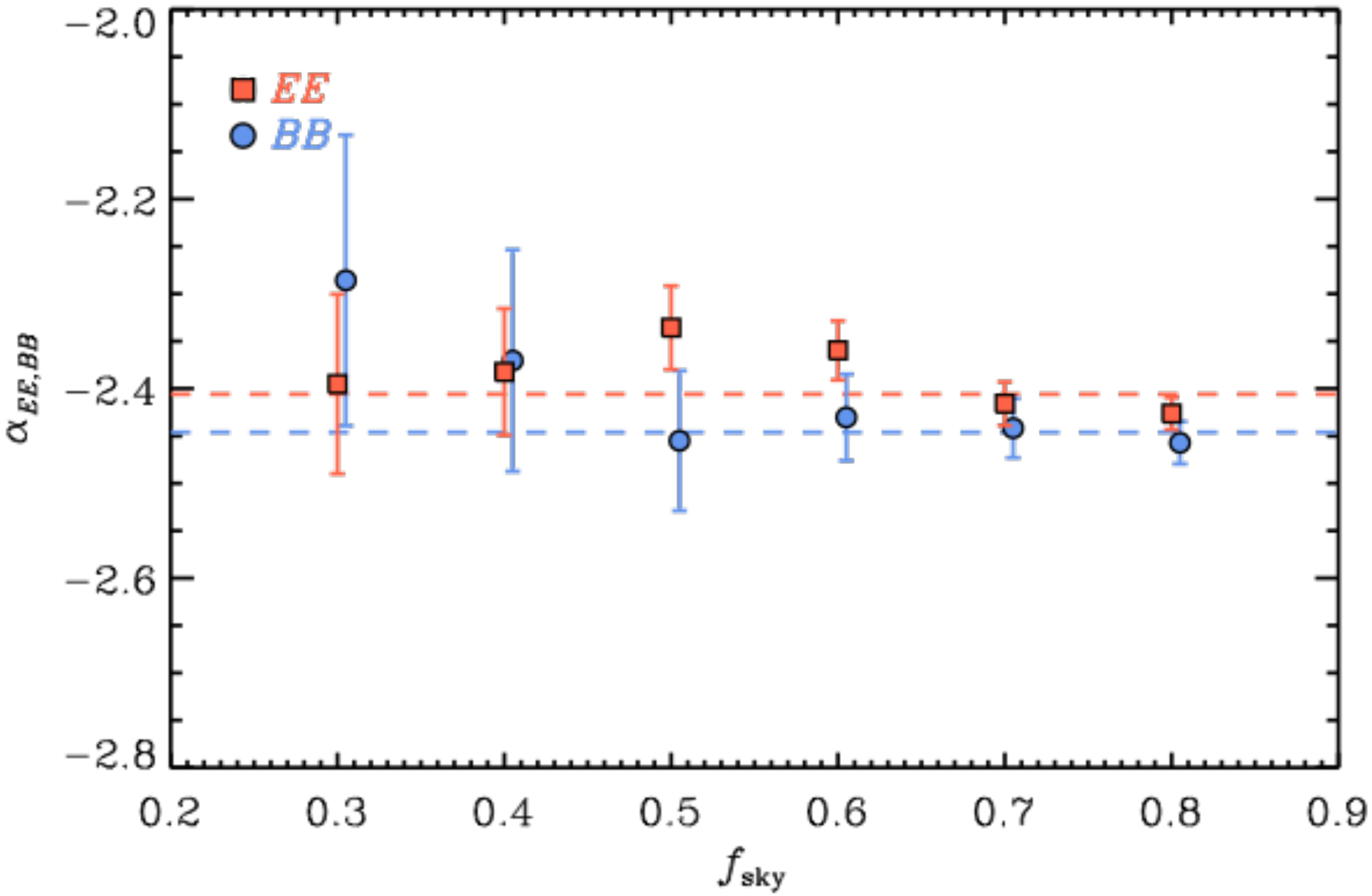
1. Shape of the spectra?
2. Variation of the amplitudes with Galactic masks?
3. Ratio *BB*/*EE*?
4. What are the amplitudes at other frequencies?

[PIP XXX, arXiv 1409.5738]



Shape of the spectra ?

Power-law model: $C_\ell^{EE,BB} \equiv A^{EE,BB} \ell^{\alpha_{EE,BB}}$



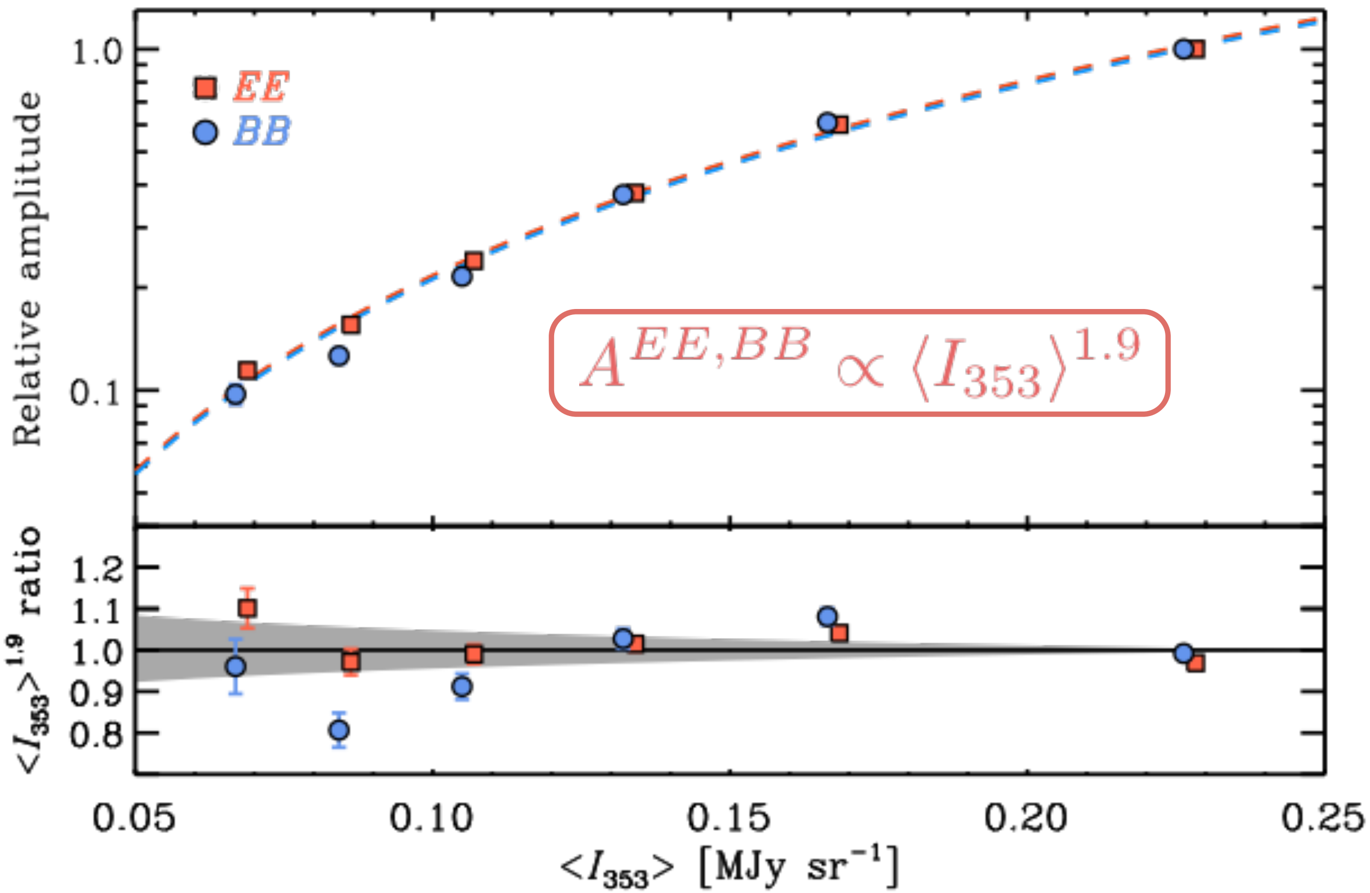
[Planck Collaboration 2014, arXiv 1409.5738]

The EE and BB spectra are consistent with power law model of slope -2.42

Amplitude as a function of Galactic mask

$$C_\ell^{EE,BB} \equiv A^{EE,BB} \ell^{-2.42}$$

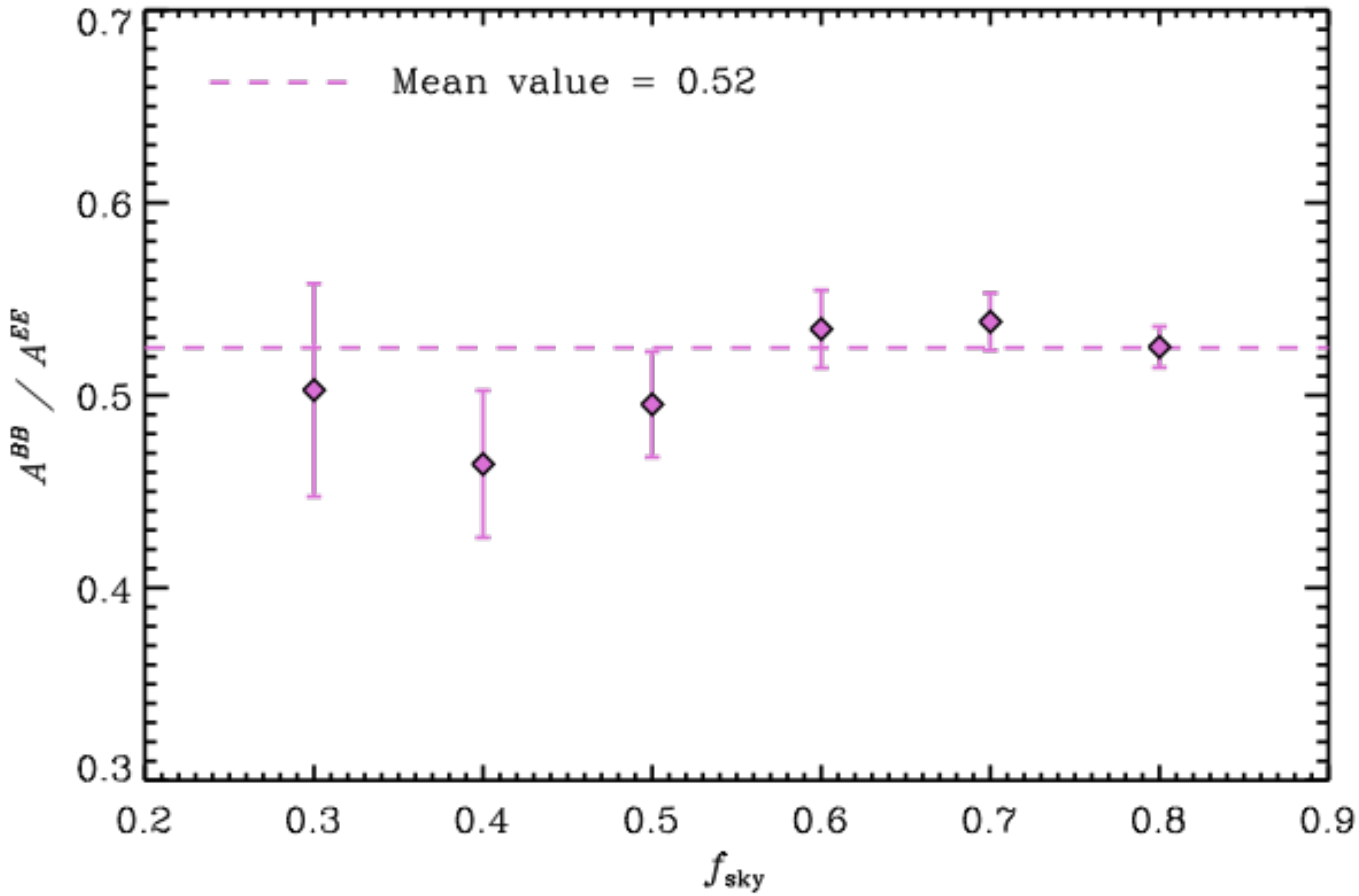
[Planck Collaboration 2014, arXiv 1409.5738]



There is an empirical relationship between the amplitude and the average intensity of the mask on which the angular power spectrum is calculated

Ratio *BB*/*EE*?

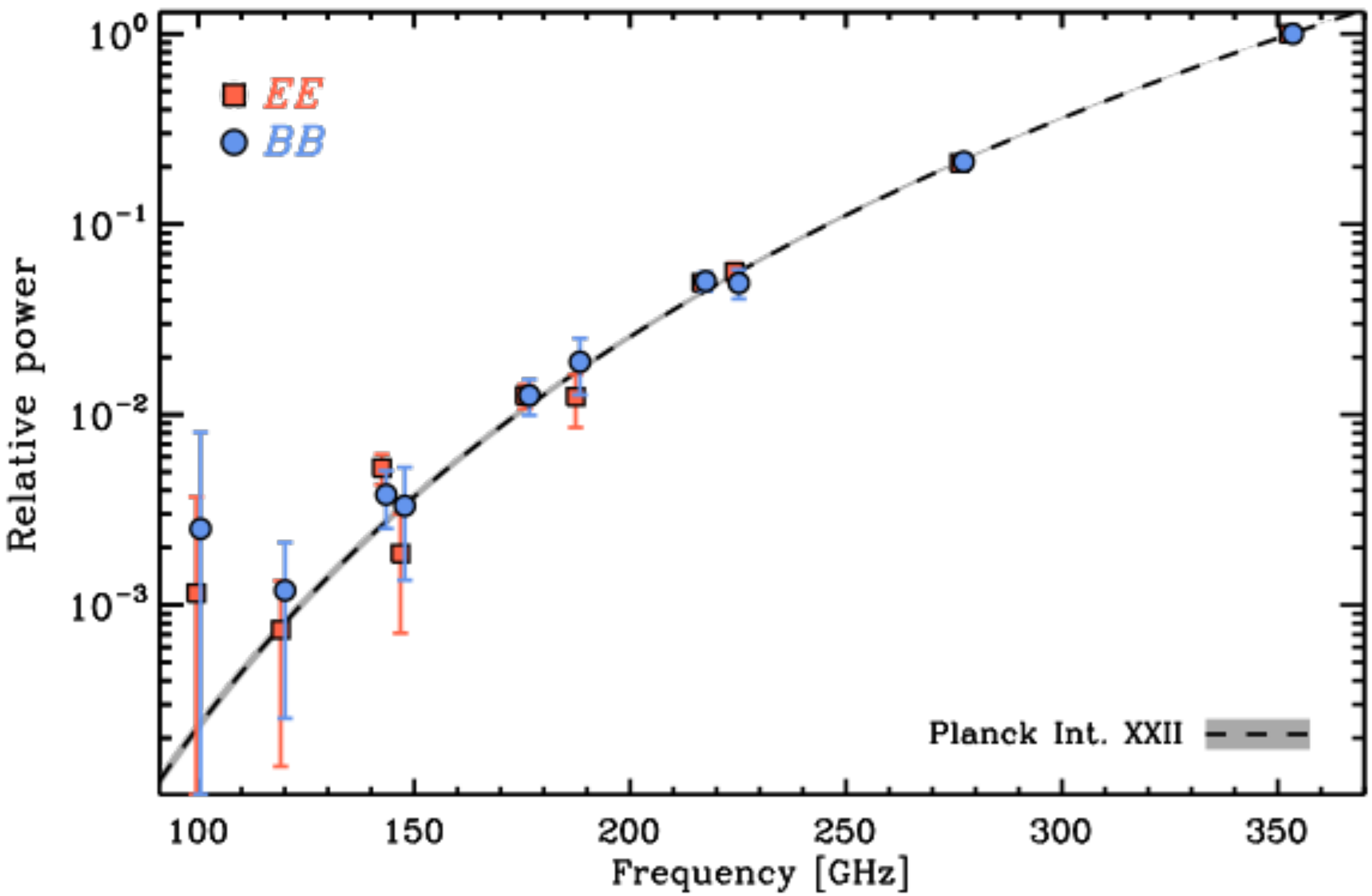
[Planck Collaboration 2014, arXiv 1409.5738]



The polarized dust emission produces about half *B* mode as compared to *E* mode.

Amplitude as a function of frequency of observation?

[Planck Collaboration 2014, arXiv 1409.5738]



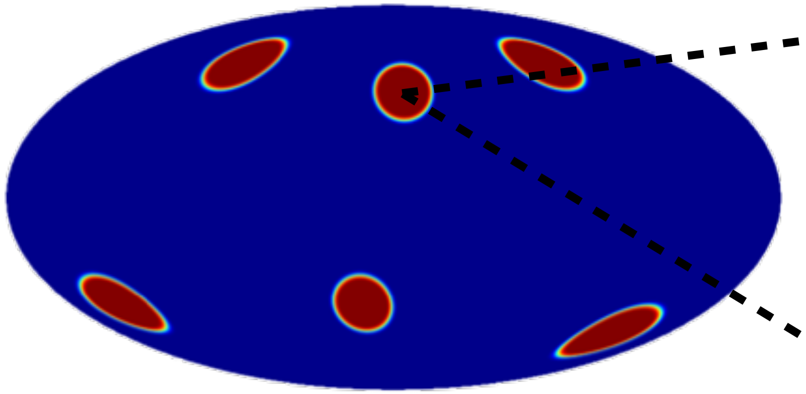
Frequency dependence of the polarized dust *BB* and *EE* power spectrum amplitudes

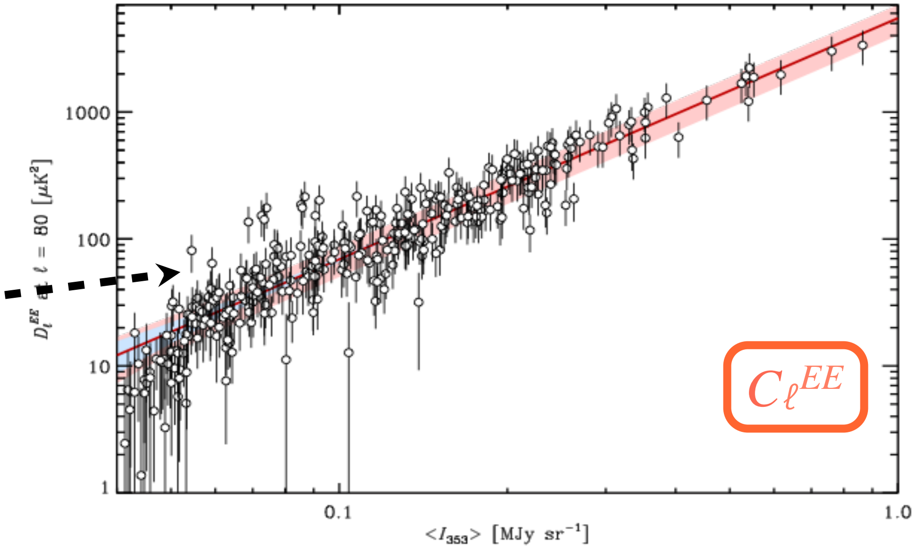
[PIP XXII 2014, arXiv 1405.0874, C.A.- T. Ghosh]

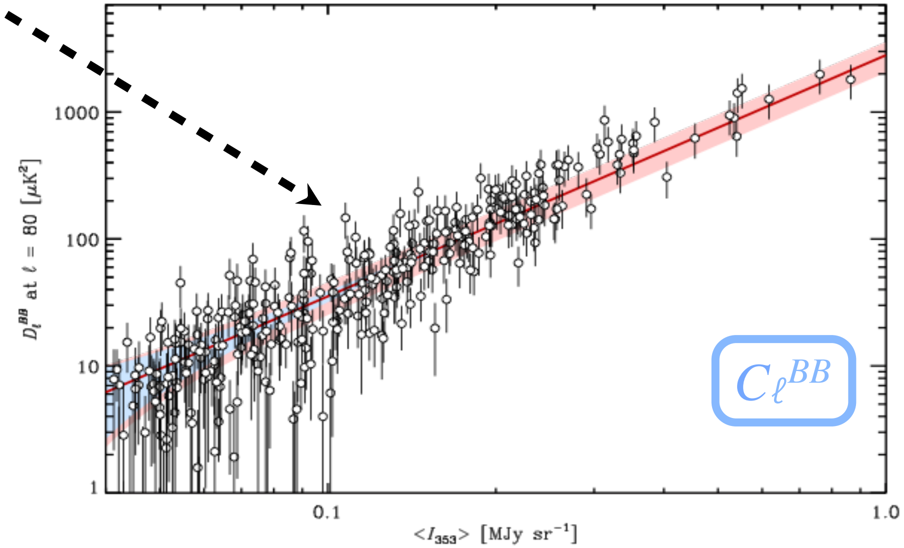
Statistics on 400 deg^2 patches

[Planck Collaboration 2014, arXiv 1409.5738]

352 patches at $|b|>35°$



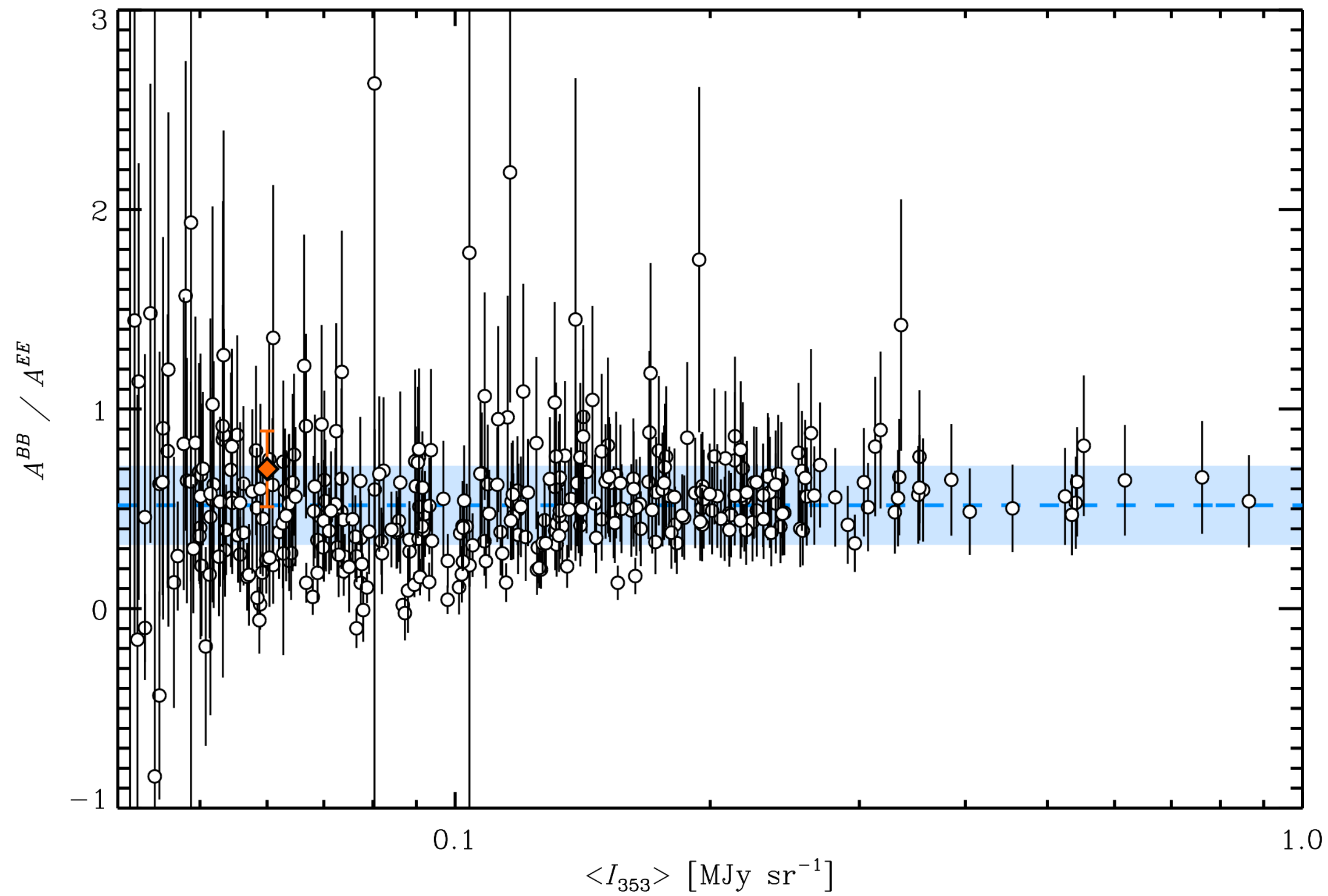




Satisfy the same empirical relation with average dust intensity as found for the bigger masks

The scatter of points is larger than that expected from a Gaussian random field.

Statistics on 400 deg^2 patches



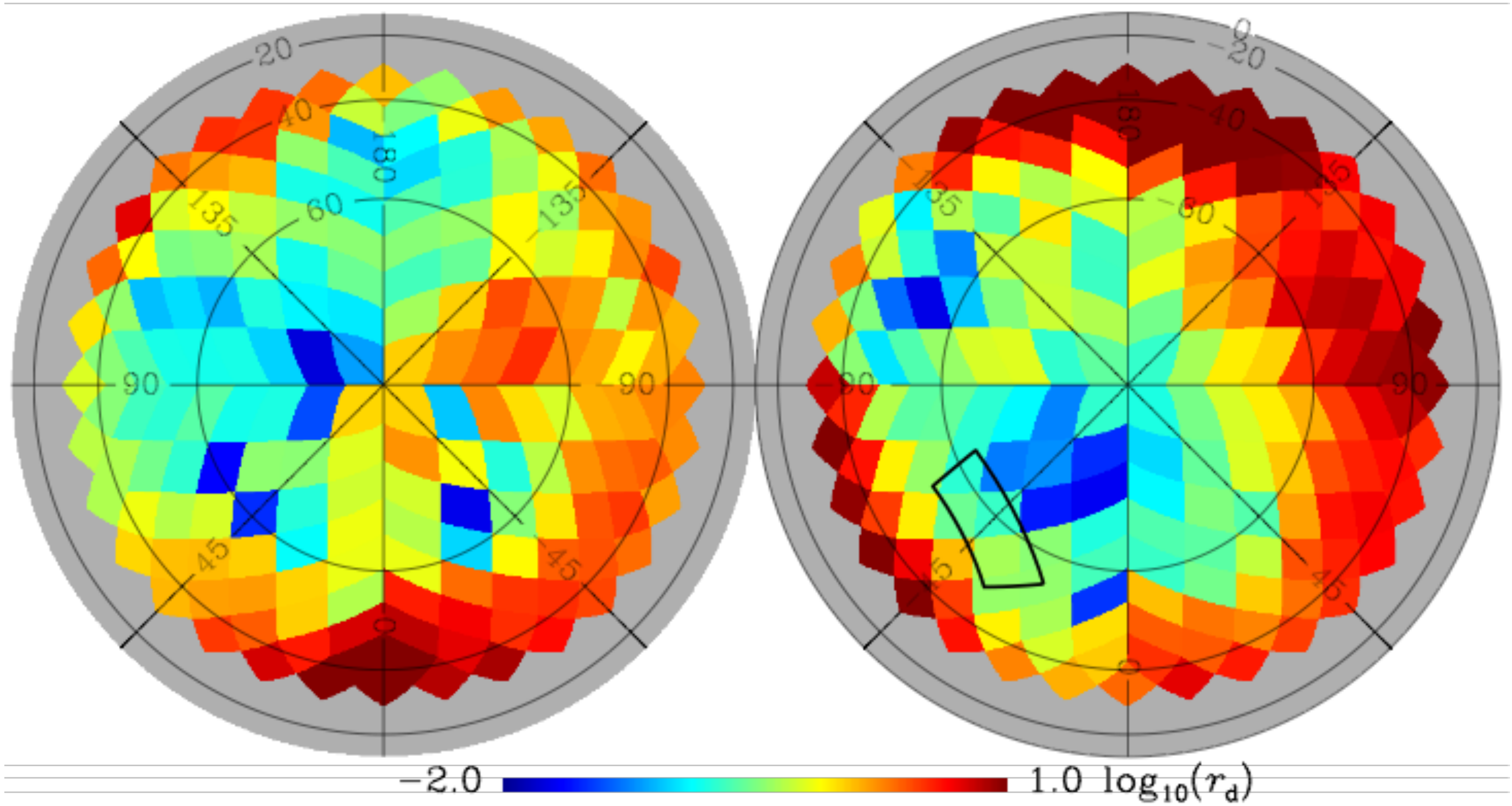
The polarized dust emission produces about half *B* mode as compared to *E* mode.

Statistics on 400 deg^2 patches

Extrapolation of *BB* amplitudes at 150 GHz

Amplitudes in the units of r_d (r_d = 0.2 means the dust emission is at same level as the CMB emission for r = 0.2 at ℓ=80)

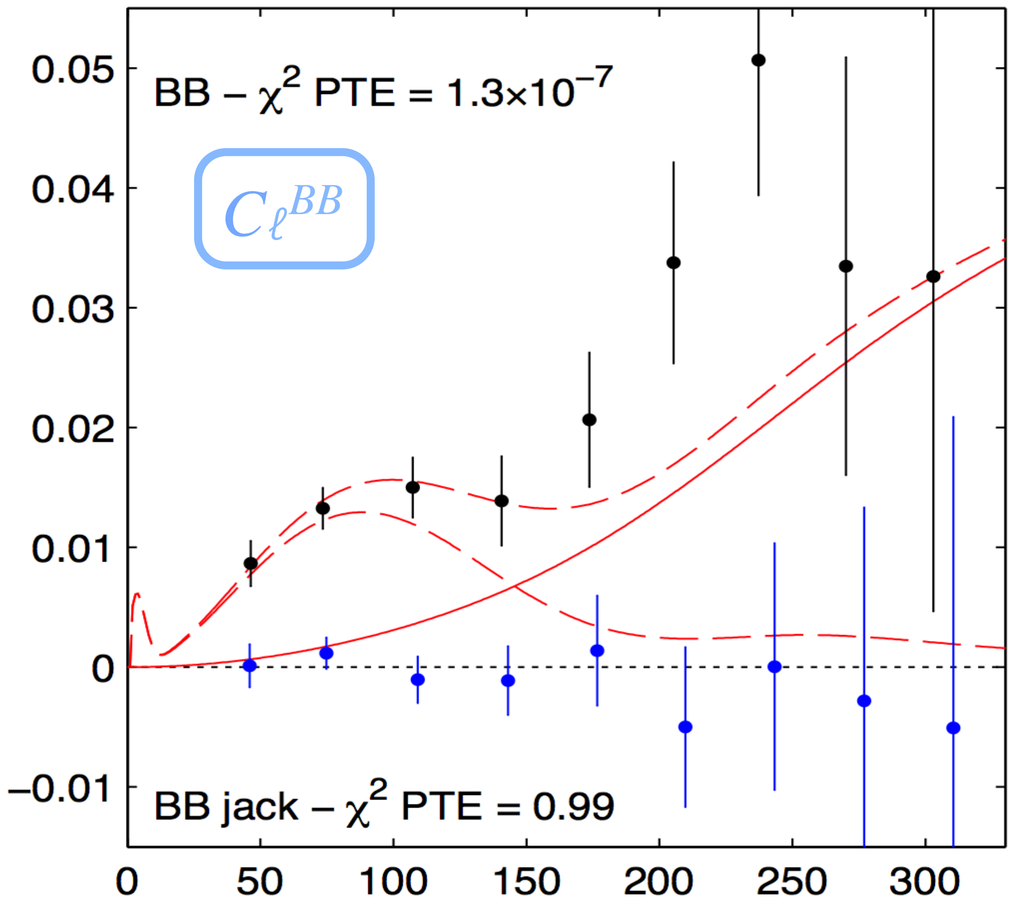
[Planck Collaboration 2014, arXiv 1409.5738]



The cleanest sky regions have r_d ~ 0.01±0.06

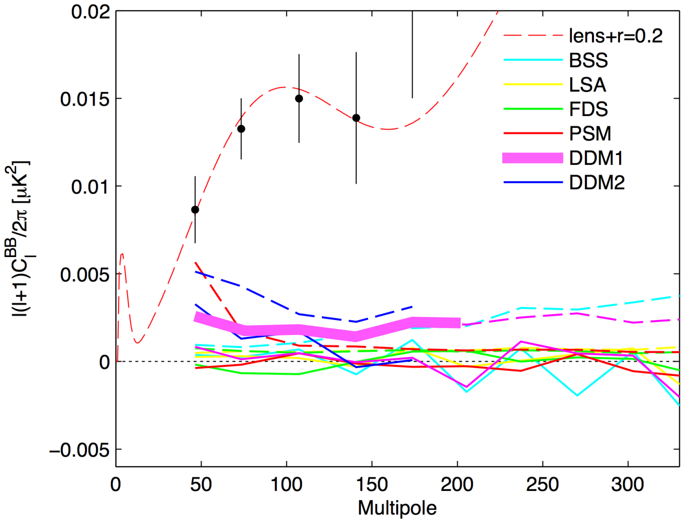
There are no regions on the sky where dust emission can be neglected

BICEP2 measurements

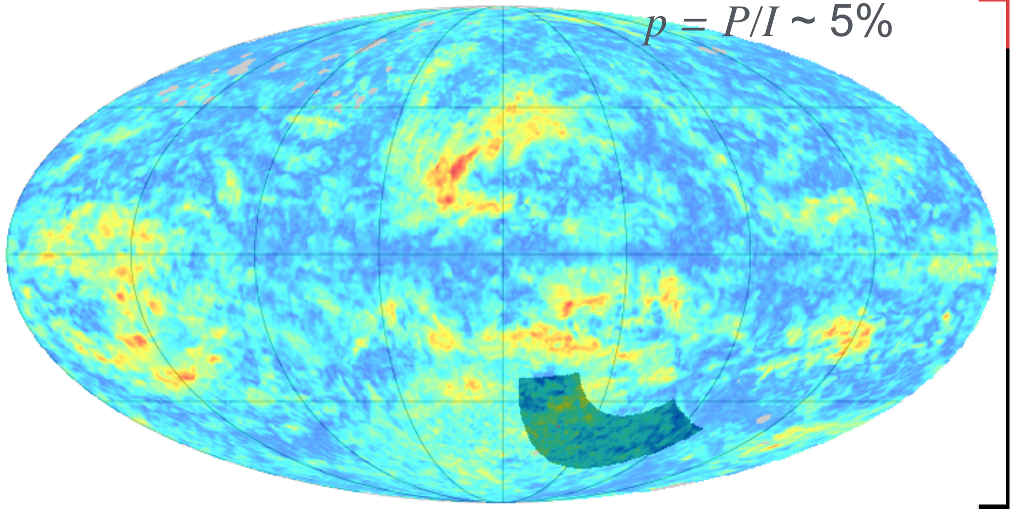


[BICEP2 Collaboration 2014]

Dust in BICEP2 field?

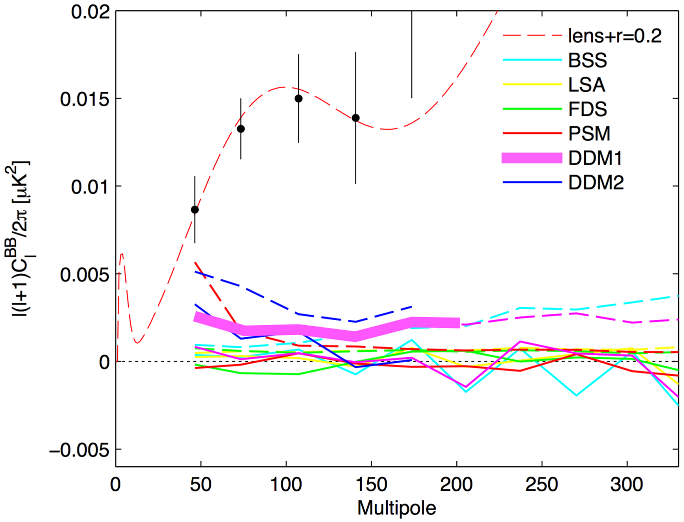


With CIB offset term,
$p = P/I \sim 5\%$

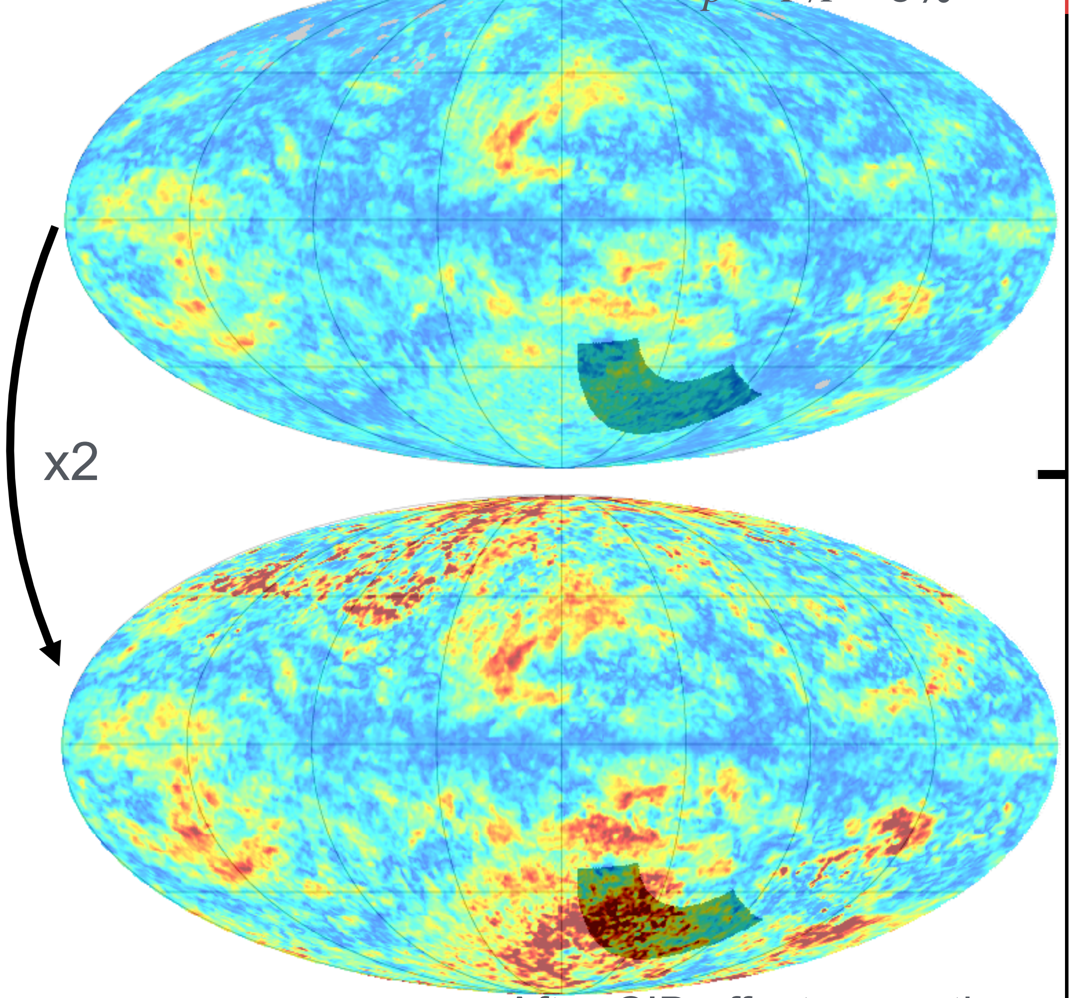


[BICEP2 Collaboration 2014] [Planck Collaboration 2013]

Dust in BICEP2 field?



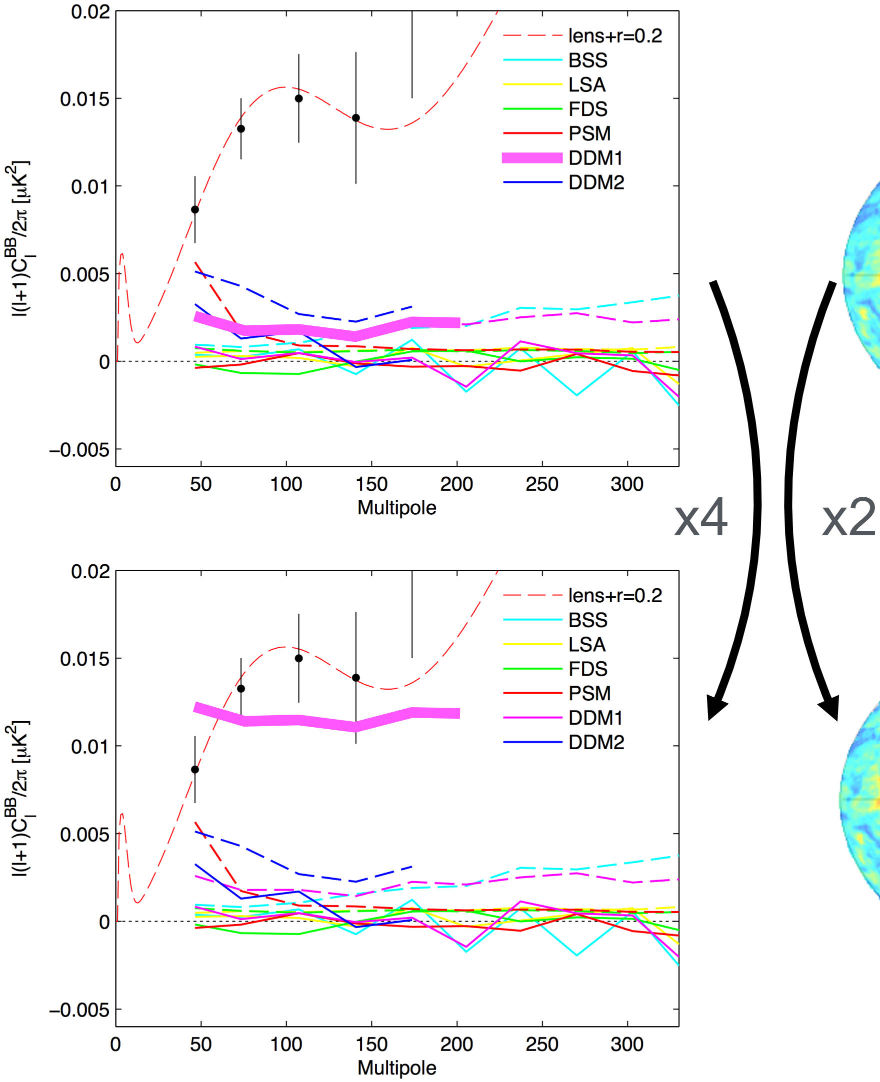
With CIB offset term, $p = P/I$ ~ 5%



After CIB offset correction, $p = P/I$ ~ 11%

[BICEP2 Collaboration 2014] [Planck Collaboration 2013]

Dust in BICEP2 field?



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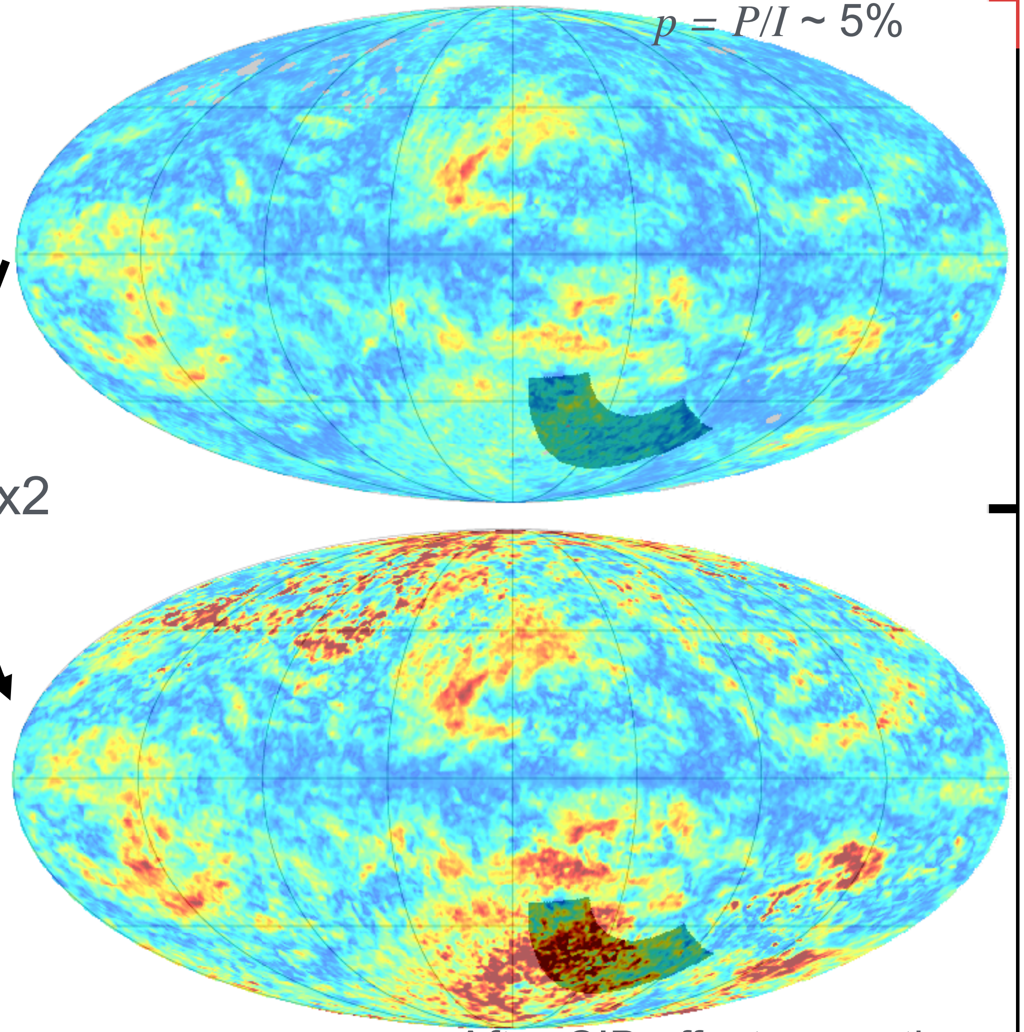

After CIB offset correction,
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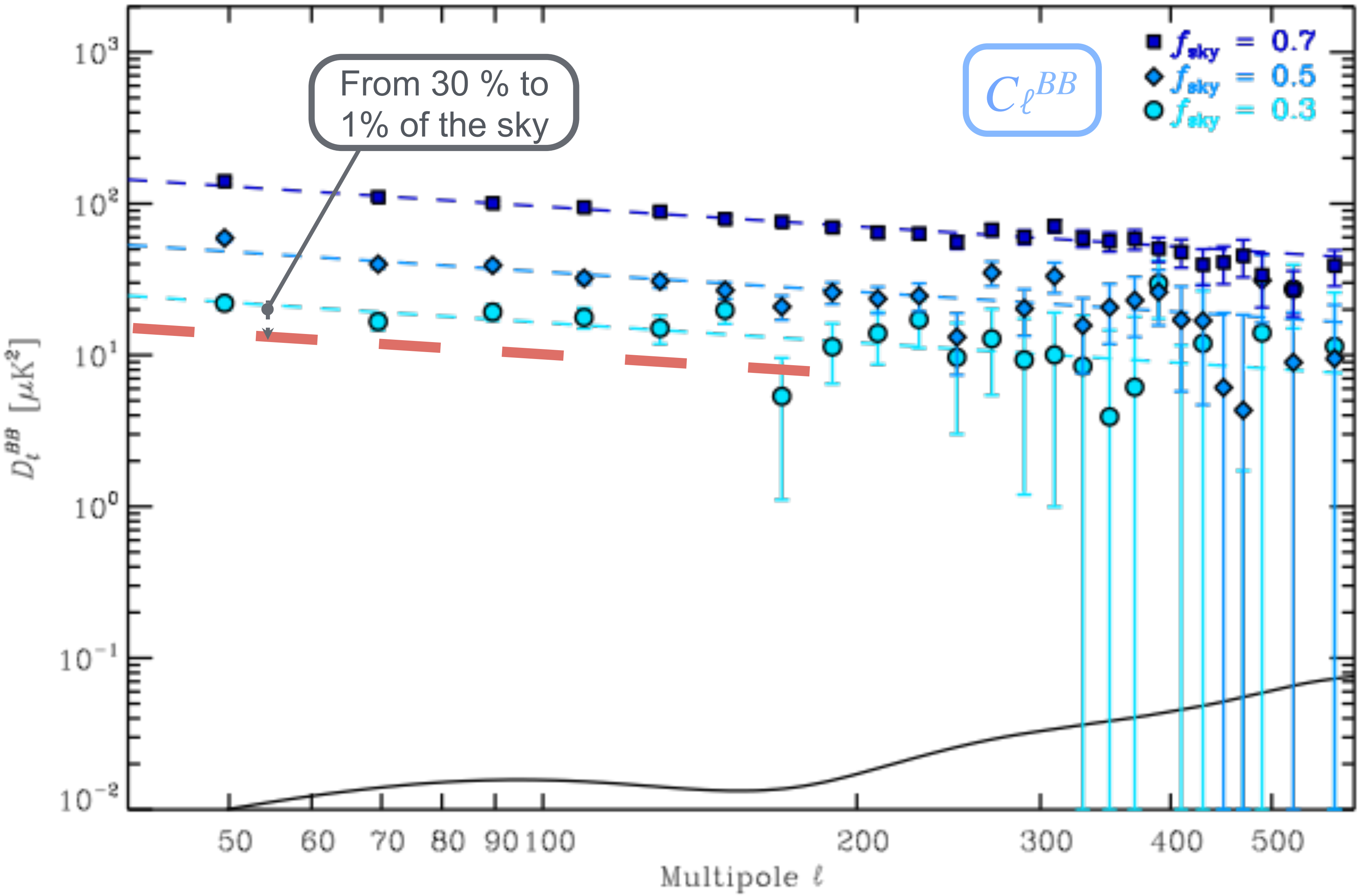
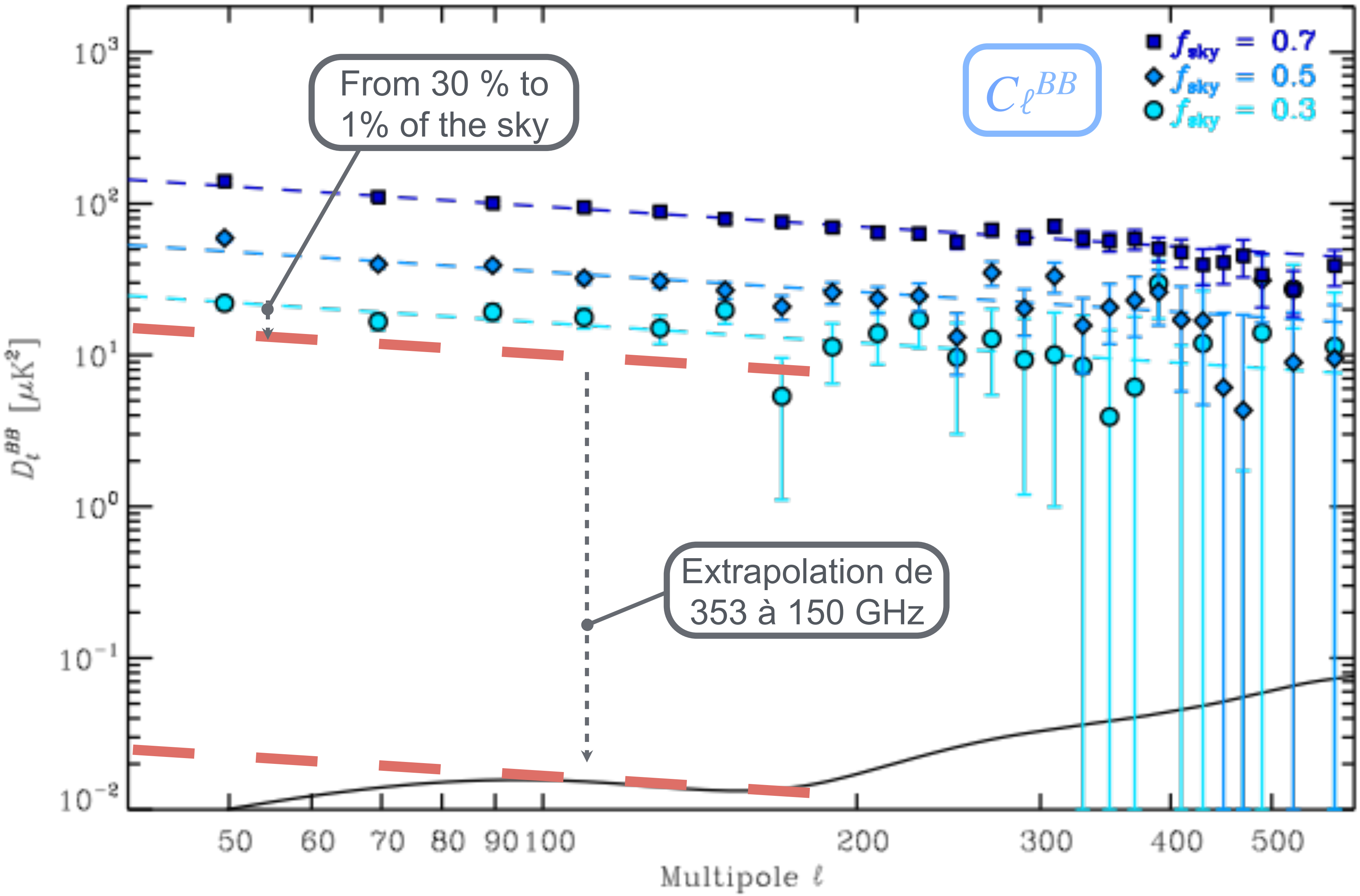
[BICEP2 Collaboration 2014] [Planck Collaboration 2013]

Dust in BICEP2 field?



[Planck Collaboration 2014, arXiv1409.5738]

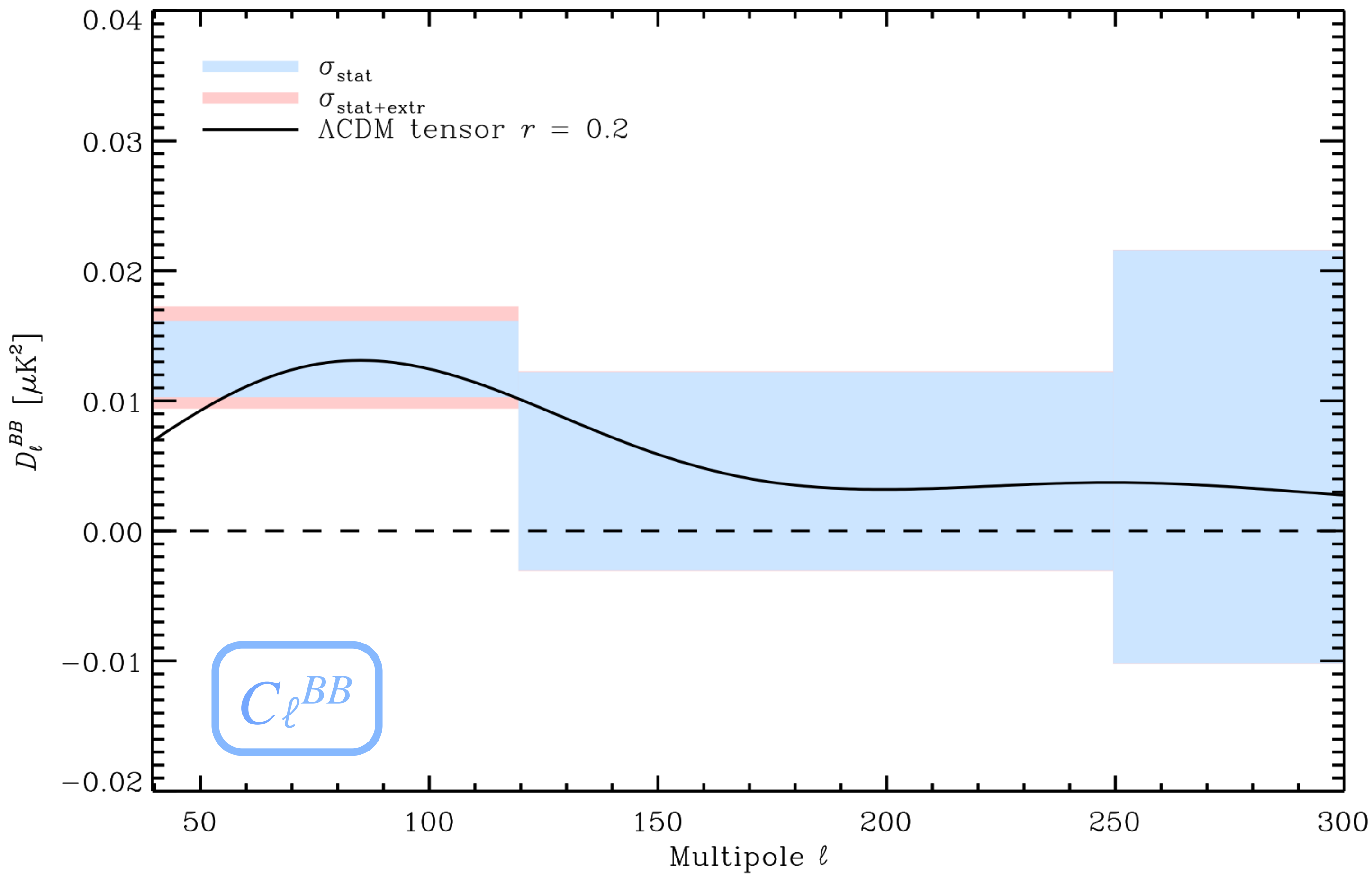
Dust in BICEP2 field?



[Planck Collaboration 2014, arXiv1409.5738]

Measurement of the dust in BICEP2 field?

Amplitude of *BB* spectrum at 353 GHz in the BICEP2 region
Extrapolation to 150 GHz



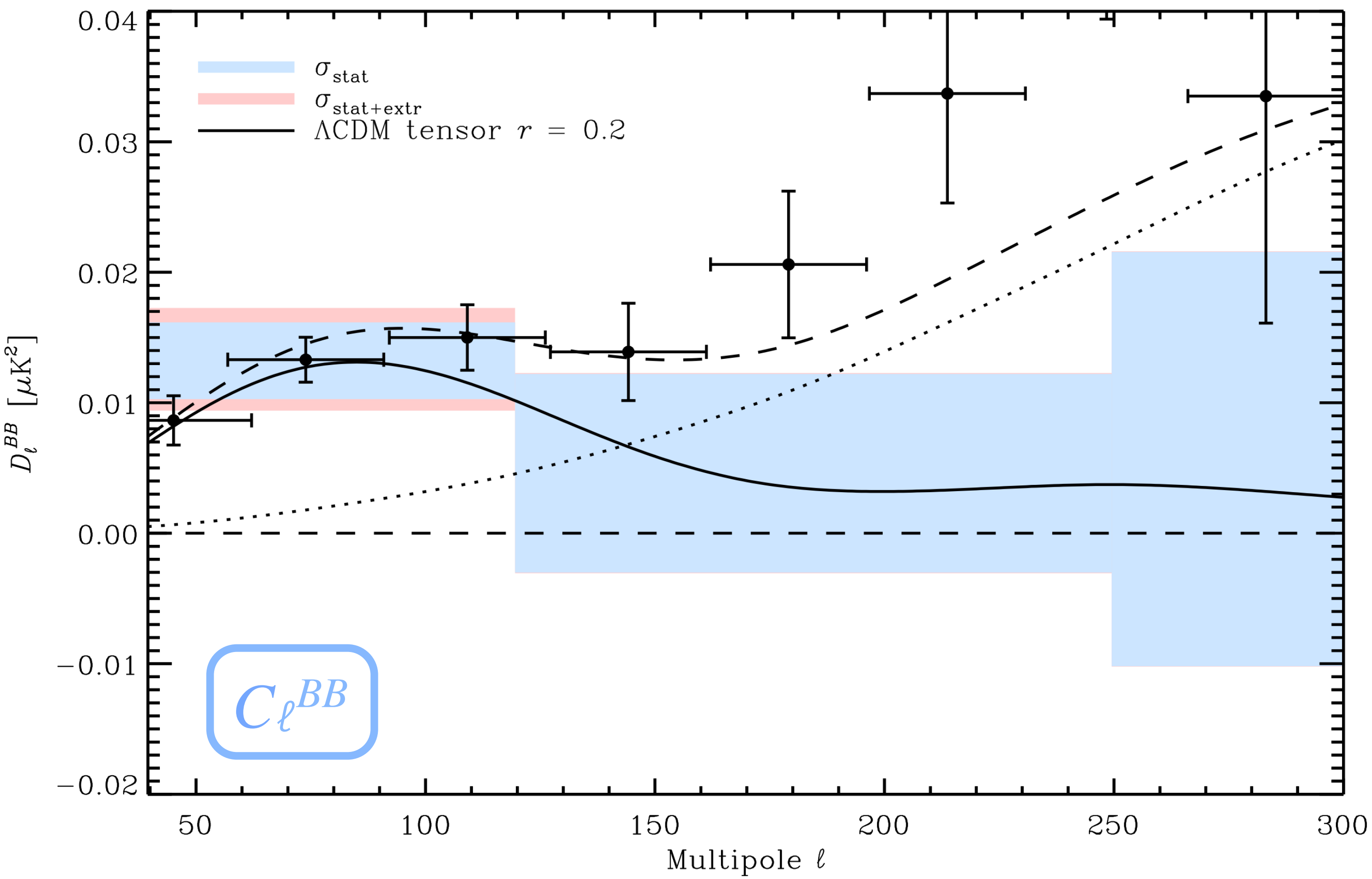
[Planck Collaboration 2014, arXiv 1409.5738]

4.5σ detection of dust at 353 GHz
Prediction 3.6σ at 150 GHz

Measurement of the dust in BICEP2 field?

[Planck Collaboration 2014, arXiv 1409.5738]

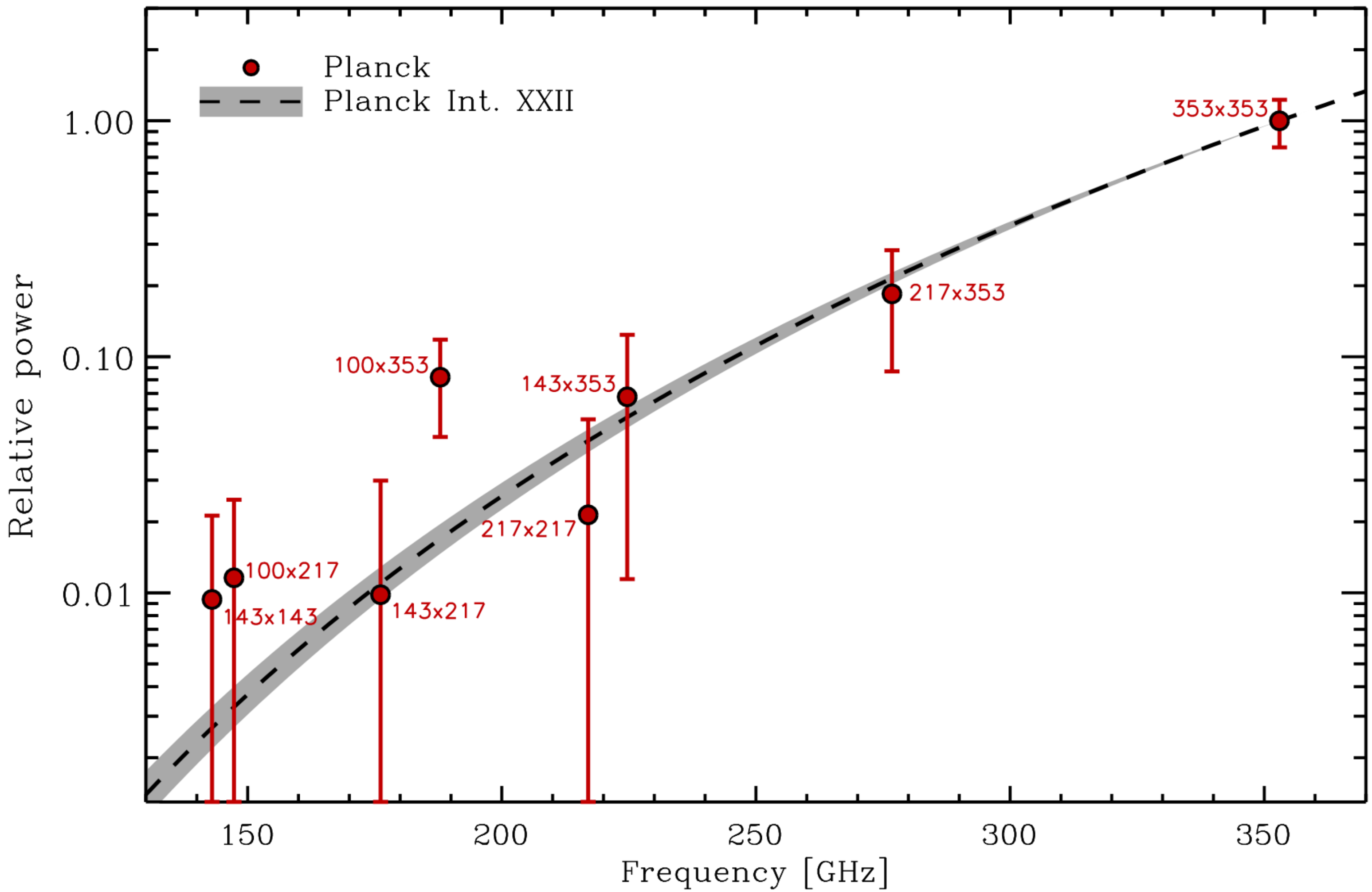
Amplitude of *BB* spectrum at 353 GHz in the BICEP2 region
Extrapolation to 150 GHz



4.5σ detection of dust at 353 GHz
Prediction 3.6σ at 150 GHz
Prediction of the level of dust similar to BB modes measured by BICEP2

Measurement of the dust in BICEP2 field?

[Planck Collaboration 2014, arXiv 1409.5738]



Our measurement is compatible with the polarized emission of dust through Planck HFI bands

[PIP XXII 2014, arXiv 1405.0874, C.A.- T. Ghosh]

Key Ingredient

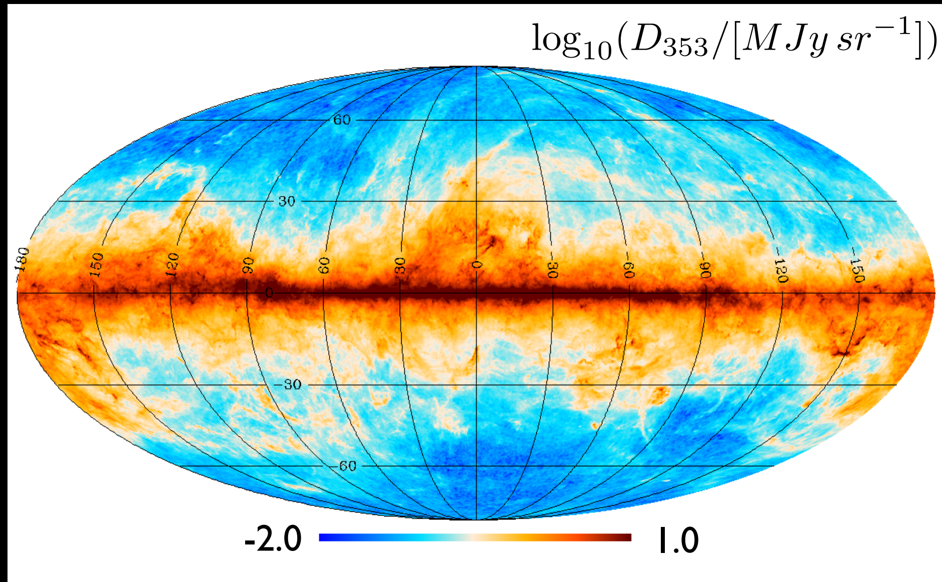
1. Spatial distribution of the dust emission and its polarization properties
2. Spectral properties of the dust emission as measured by Planck
3. Statistical properties of the dust emission in terms of power spectrum
4. Correlation between the matter and magnetic field

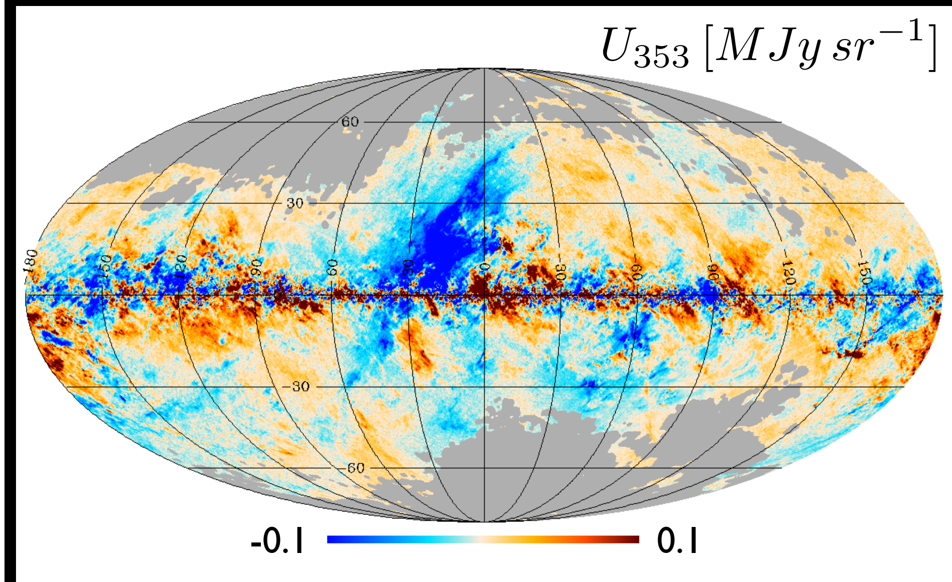
Planck polarization data at 353 GHz (2013 maps)

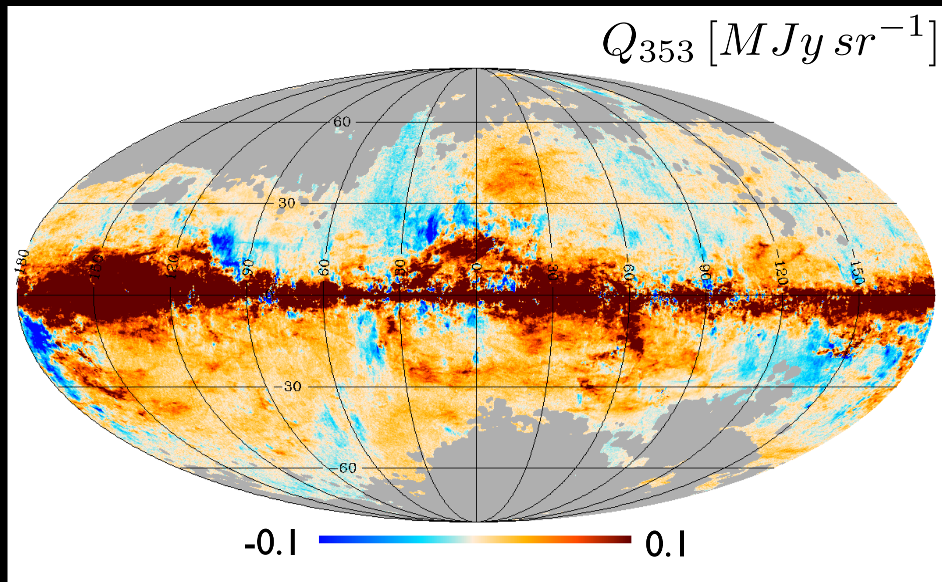
- Model map (D_{353}) for intensity with a better S/N and cleaned for CMB, CIB monopole, and point sources.
  All-sky modified black-body fit for dust emission (Planck Collaboration XI. 2014)

- Q and U maps masked where uncertainties from uncorrected data systematics are a significant error on dust polarization.
  They provide the orientation of the **B** field on the POS. Changes in the field orientation of 90 deg change their sign

- Maps at 15' resolution (5' nominal)





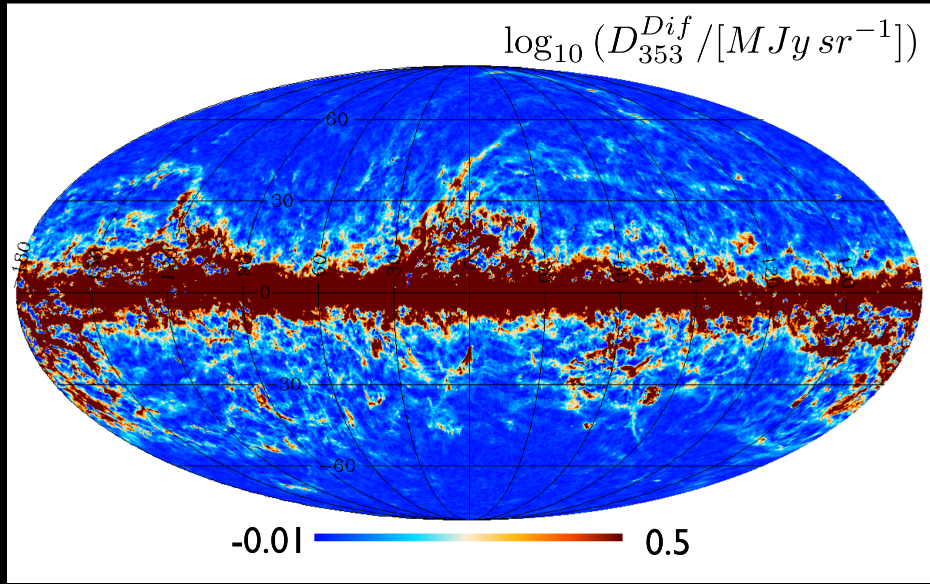


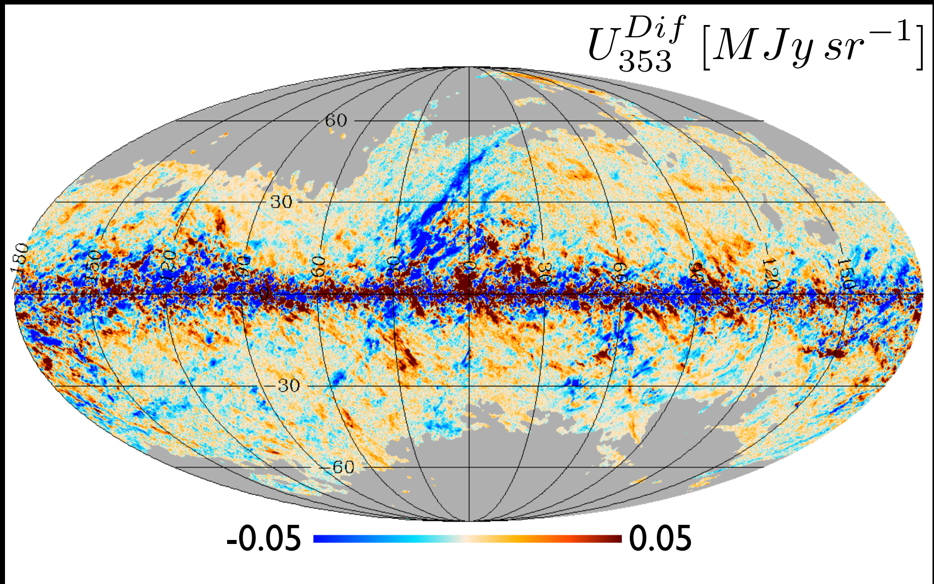
PIP XXXII (2014)

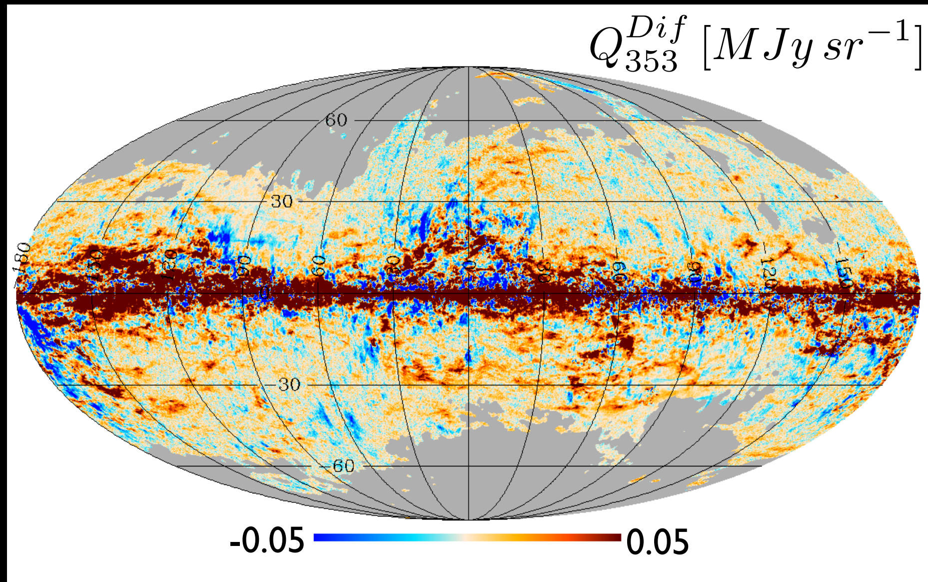
Highlighting filamentary structures (2013 maps)

- Filtered maps (Dif)

- Local background within 2.5°around each pixel defined as the mean value of the 20% lowest values in D_{353} (the choice of 2.5° and the threshold of 20% are not critical for the data analysis)

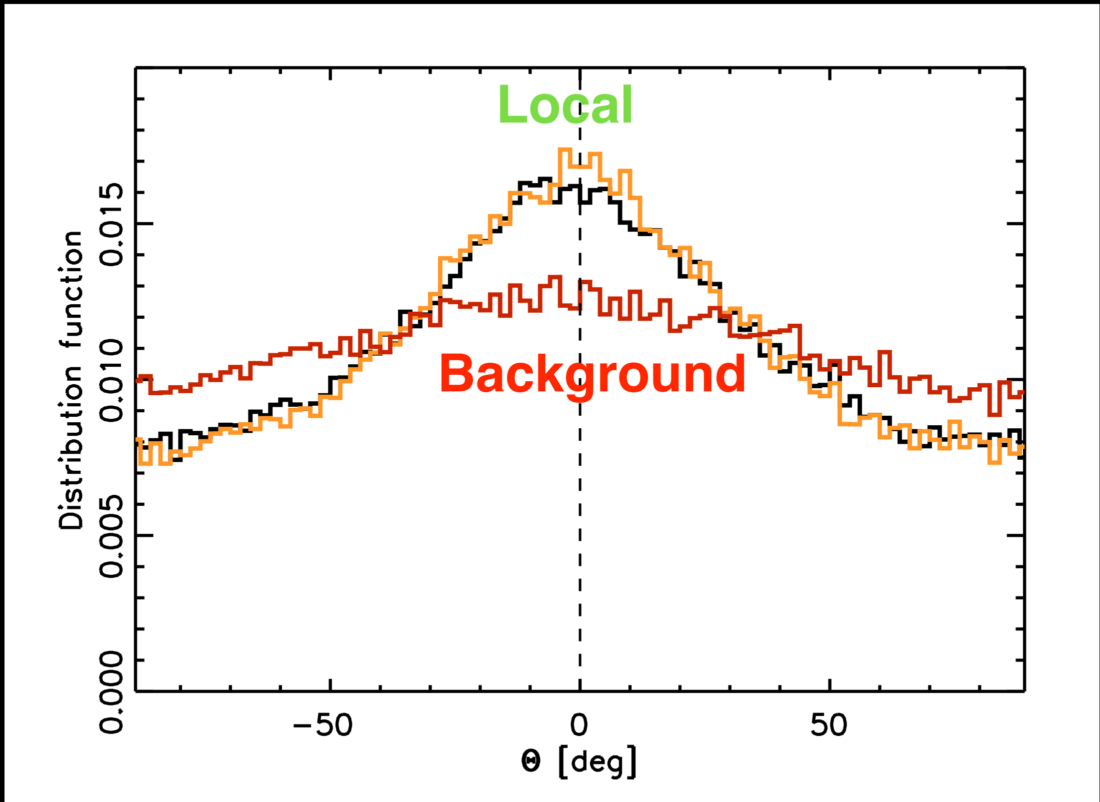


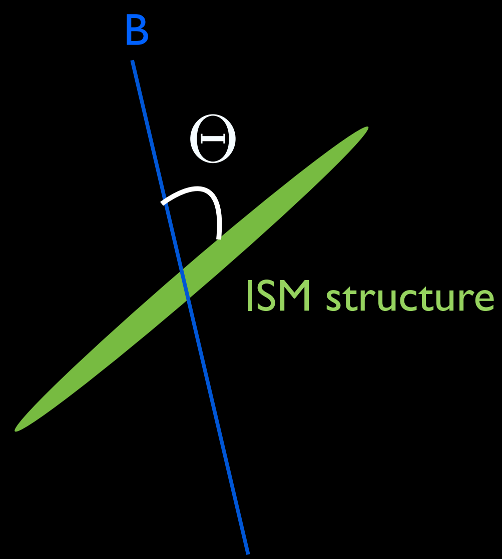




PIP XXXII (2014)

Matter vs Magnetic Field





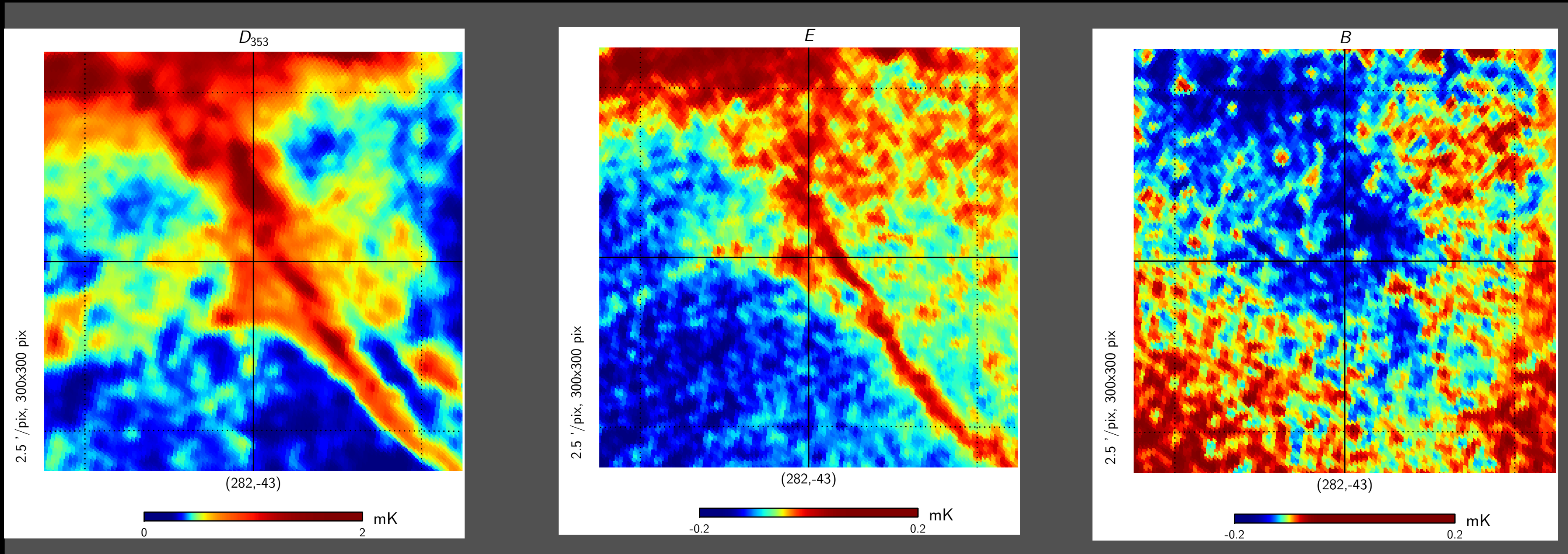
The structures tend to be aligned with the local magnetic field

Projection effects (3D to 2D) are crucial for the interpretation of the shape of the distribution!

PIP XXXII (2014)

E/B Decomposition

D_{353}	E	B



- Filaments aligned with their magnetic field have mainly E-mode polarization
- The correlation between matter and the field might explain E/B ratio of dust polarization
- We are investigating this possibility quantitatively

Preliminary

WHAT NEXT ?

BICEP2 – Planck Collaboration

physicstoday

News Picks : BICEP2 and *Planck* teams negotiating to share data

By: Physics Today

03 July 2014

PREVIOUS POST | NEWS PICKS | NEXT POST

BBC: The teams behind the ground-based BICEP2 experiment and the *Planck* satellite have announced that they are negotiating to share data. The groups have only just begun talking, but hope that the data sharing could result in the publication of a joint paper. In March, BICEP2 announced that the project appeared to have detected evidence of gravitational waves in the cosmic microwave background (CMB) radiation. One of the immediate responses was that the project didn't accurately account for interstellar dust in the area that was observed. An updated map of cosmic dust from the *Planck* satellite, which has been mapping the CMB, is expected this fall.

In News Picks:

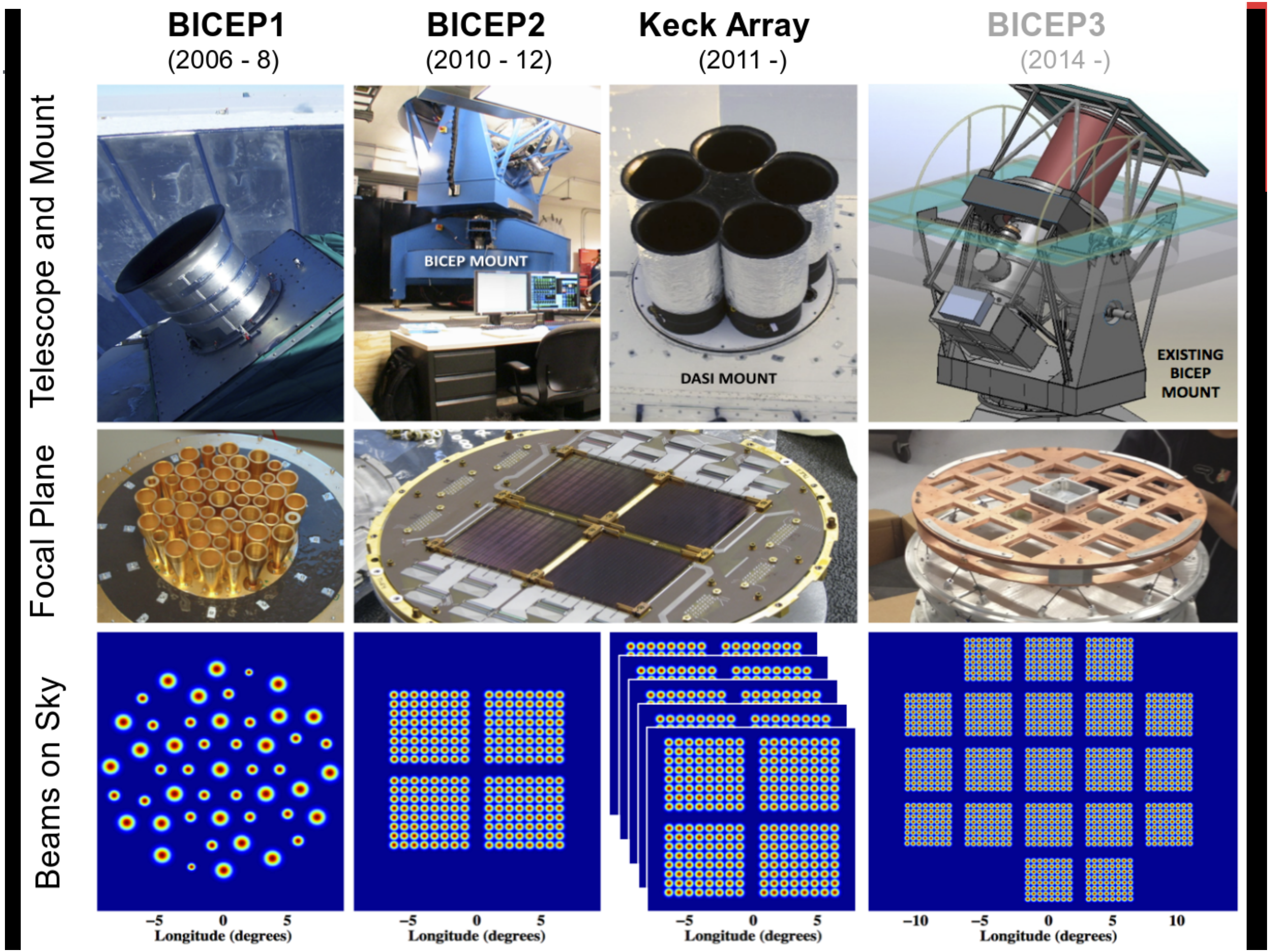
Twisted light transmits data across Vienna

China and US sign greenhouse gas reduction agreement

Send electrical charges from your phone to your brain to change your mood

Magma pockets surrounding Earth's core could explain hot-spot volcanism

Denmark aims to ban fossil-fuel burning by 2050


BICEP1
(2006 - 8)
BICEP2
(2010 - 12)
Keck Array
(2011 -)
BICEP3
(2014 -)
Telescope and Mount
Focal Plane
Beams on Sky
BICEP MOUNT
DASI MOUNT
EXISTING BICEP MOUNT
−5 0 5
Longitude (degrees)
−5 0 5
Longitude (degrees)
−5 0 5
Longitude (degrees)
−10 −5 0 5 10
Longitude (degrees)

Dust Cleaning

$$C_\ell^{353\times353} = C_\ell^{\mathrm{d}}$$ → low signal to noise ratio

$$C_\ell^{150\times150} = C_\ell^{\mathrm{CMB}} + \alpha^2\, C_\ell^{\mathrm{d}}$$ → high signal to noise ratio

$$C_\ell^{150\times353} = C_\ell^{\mathrm{CMB}} + \alpha\, C_\ell^{\mathrm{d}}$$ → intermediate signal to noise ratio

$$C_\ell^{\mathrm{CMB}} = \frac{C_\ell^{150\times150} - \alpha\, C_\ell^{150\times353}}{1-\alpha}$$

$$\alpha = \frac{A^{\mathrm{d}}_{150}}{A^{\mathrm{d}}_{353}} = \left(\frac{150}{353}\right)^{\beta_{\mathrm{d}}} \frac{B_{150}(T_{\mathrm{d}})}{B_{353}(T_{\mathrm{d}})}$$

Conclusions

First time Planck has measured the angular power spectrum of the polarized emission from the Galactic dust

We have shown that the spectra of the dust polarization can be described by a simple empirical model

- ★ C_ℓ follows a power-law model with slope -2.42
- ★ Amplitudes described by $<I_{353}>^{1.9}$
- ★ BB/EE ~ 0.5
- ★ Frequency dependence is described by modified blackbody[PIP XXII]
- ★ Statistically conserve its property even for 1% of the sky

There are no sky areas where the polarized dust emission can be neglected (although some areas are ``cleaner" than the BICEP2 patch)

It is necessary to take into account the polarized dust emission, before drawing any conclusions from the BICEP2 results.