COSMOS

Cosmic Orbital and Suborbital Microwave ObservationS

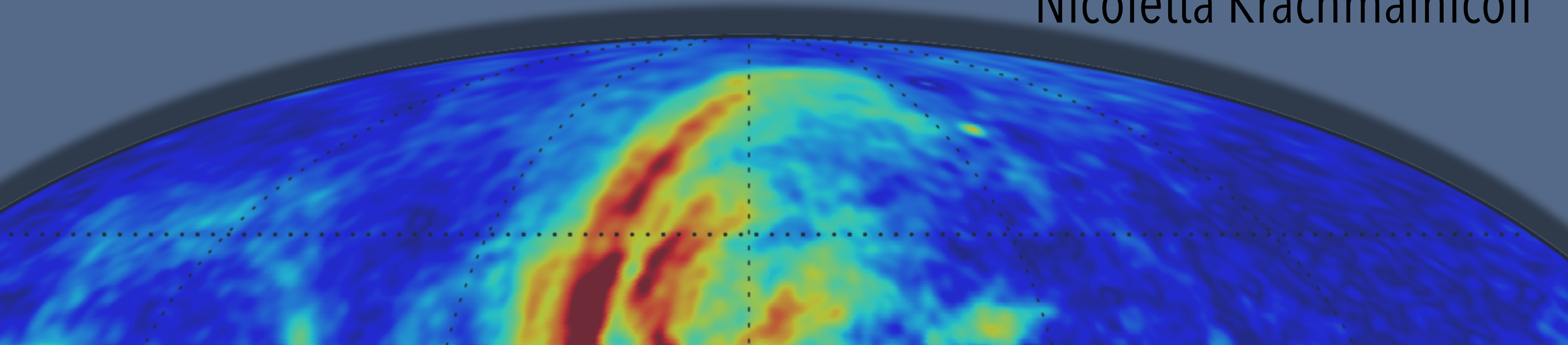
Foreground at low frequency:

a brief overview

4th ASI/COSMOS Workshop: Ground-based CMB experiments

Milano, March 2019

Nicoletta Krachmalnicoff



Outline

- Planck results on foregrounds
- Status of current experiments
- Overview of S-PASS results
- Open problems for forthcoming experiments

Foreground contamination to B-modes

"awereness timeline"

Foreground contamination to B-modes

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There exist **high Galactic regions clean enough** to detect B-modes without performing any FG cleaning

Foreground contamination to B-modes

"awereness timeline"

BICEP/Keck/Planck analysis

There exist **high Galactic regions clean enough** to detect B-modes without performing any FG cleaning

2014

Thermal Dust emission is a strong contaminant everywhere and it must be taken in to account before claiming any detection of B-modes

Foreground contamination to B-modes

"awereness timeline"

BICEP/Keck/Planck analysis

Planck 2015 release

2014

There exist **high Galactic regions clean enough** to detect B-modes without performing any FG cleaning

2015-2016

Thermal Dust emission is a strong contaminant everywhere and it must be taken in to account before claiming any detection of B-modes

Synchrotron emission is also dominant over B-modes and needs to be characterize

Foreground contamination to B-modes

"awereness timeline"

BICEP/Keck/Planck analysis

Planck 2015 release

Planck 2018 release
S-PASS results
Preliminary C-BASS results

2014

There exist **high Galactic regions clean enough** to detect B-modes without performing any FG cleaning

2015-2016

Thermal Dust emission is a strong contaminant everywhere and it must be taken in to account before claiming any detection of B-modes

2018-2019

Synchrotron emission is also dominant over B-modes and needs to be characterize

Foregrounds are complex and high sensitivity monitor channels are necessary

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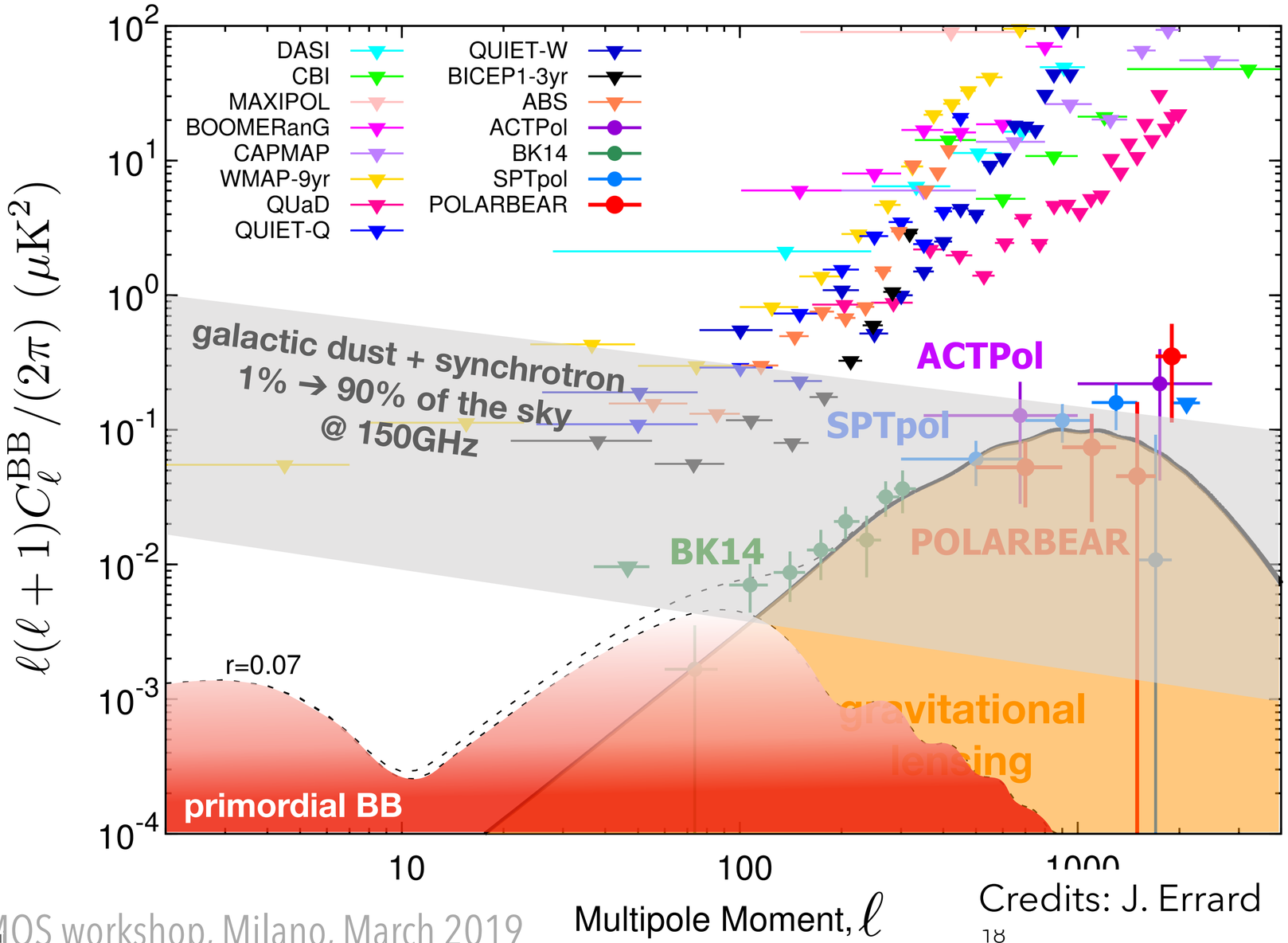
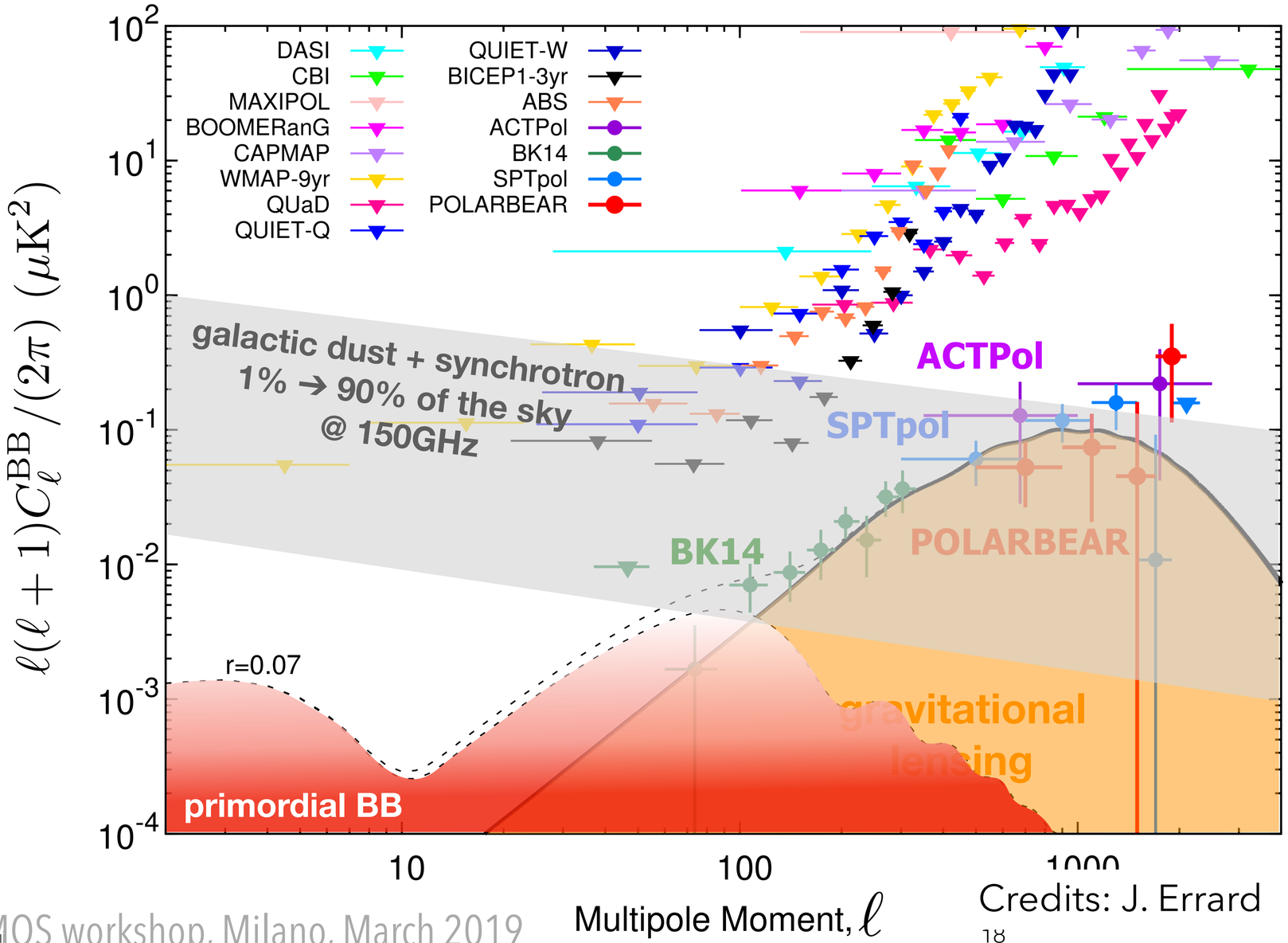
Foreground contamination to B-modes



Credits: J. Errard

Foreground contamination to B-modes

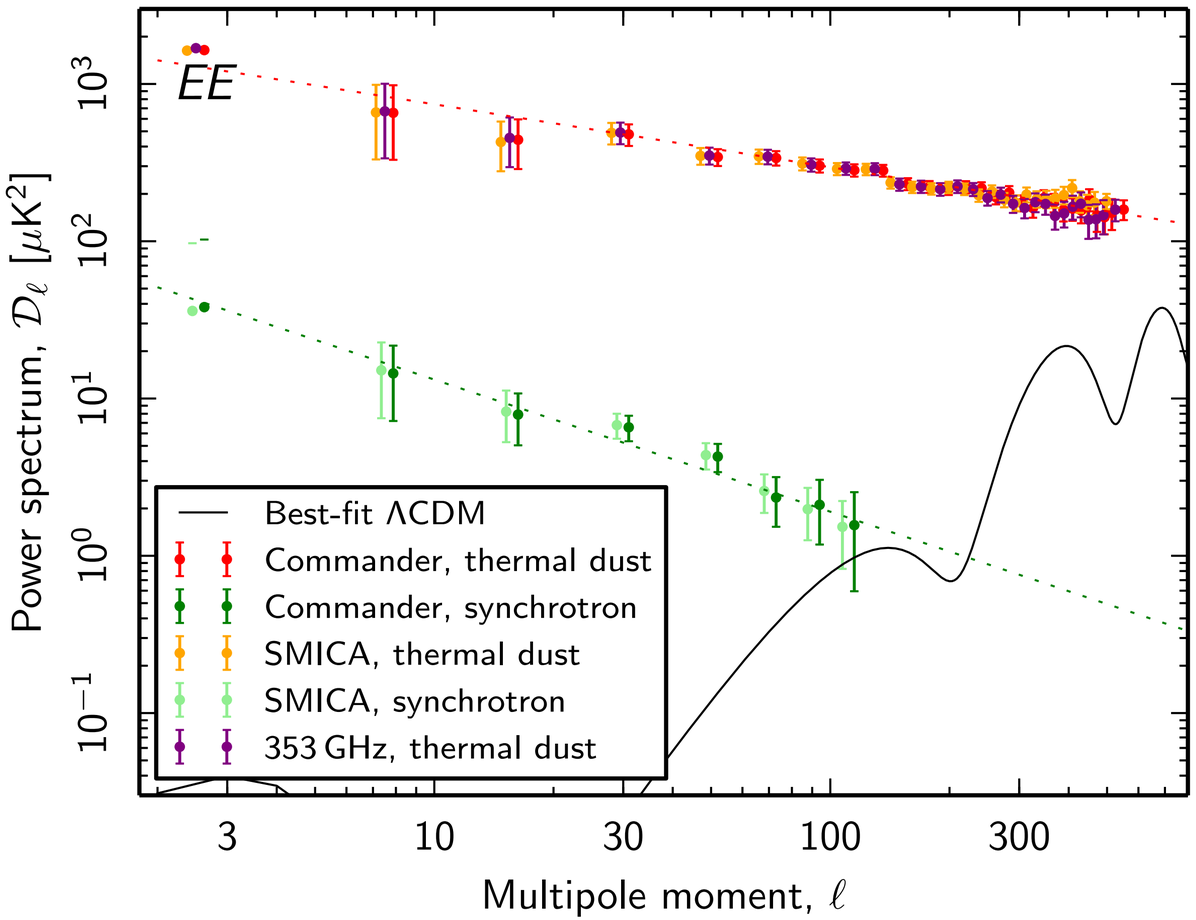


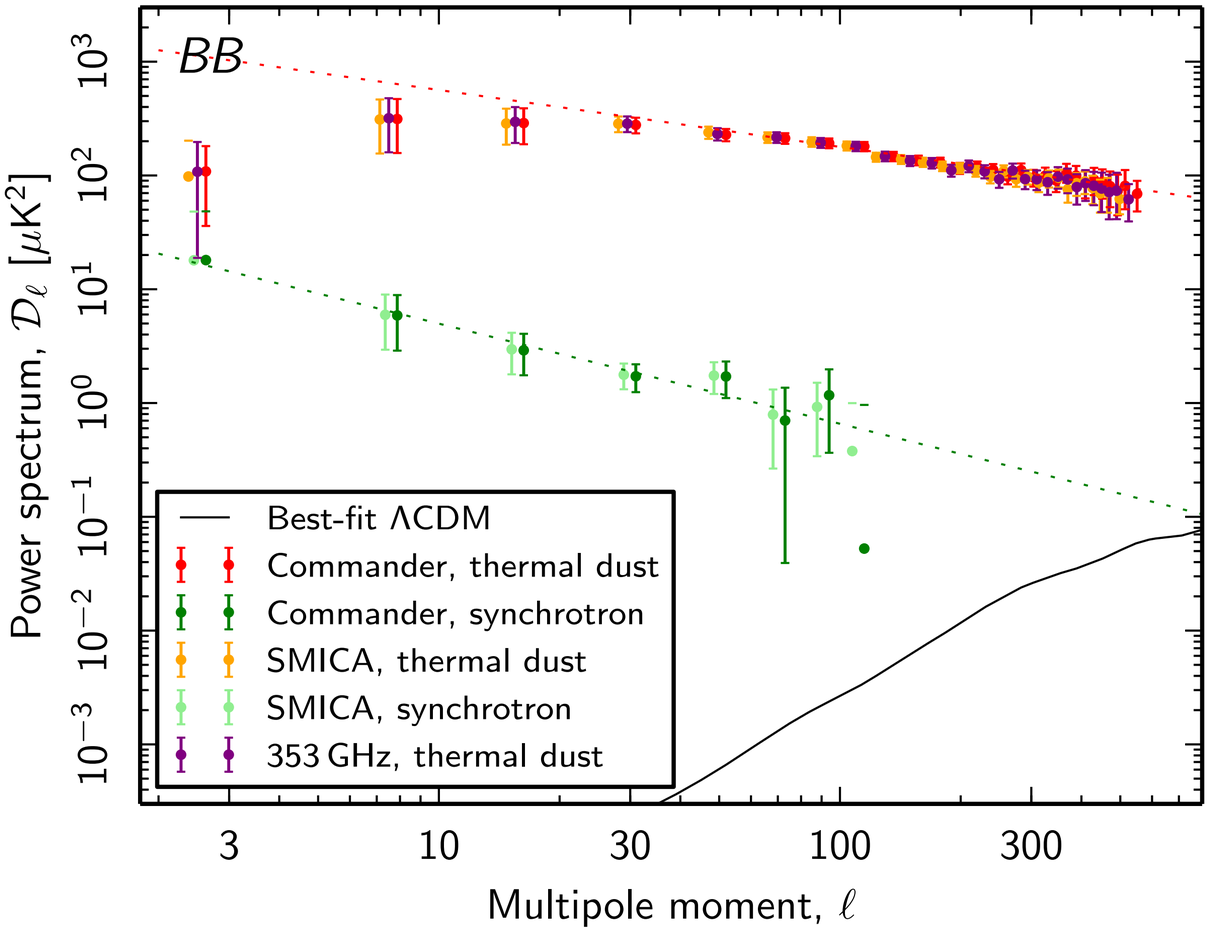
		Sensitivity (μK^2)	$\sigma(r)$
2015	Stage 2 1000 detectors		
2016		$\gtrsim 10^{-5}$	0.035
2017	Stage 3 10,000 detectors		
2018			
2019			
2020		10^{-6}	0.006
2021	Stage 4 CMB-S4 ~500,000 detectors		
2022			
2023			
Target		**10^{-8}**	**0.0005**

S4 Science Book

Credits: J. Errard

Planck results

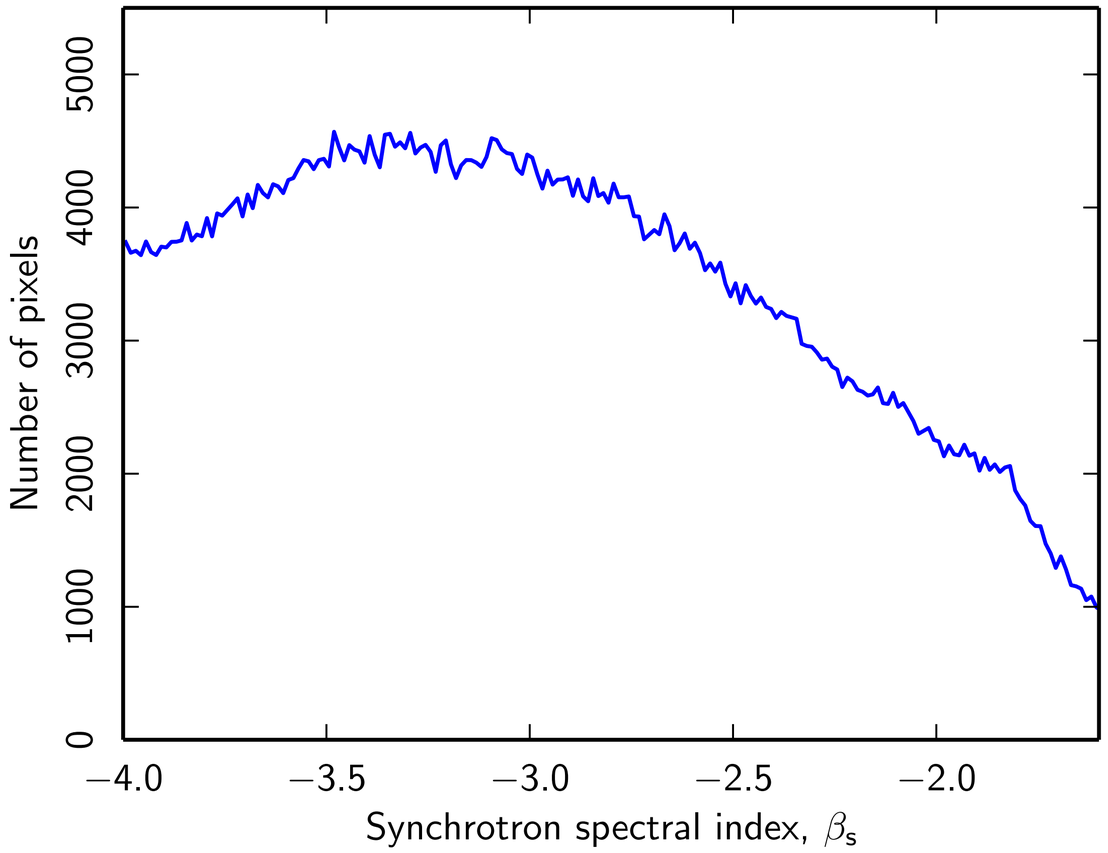


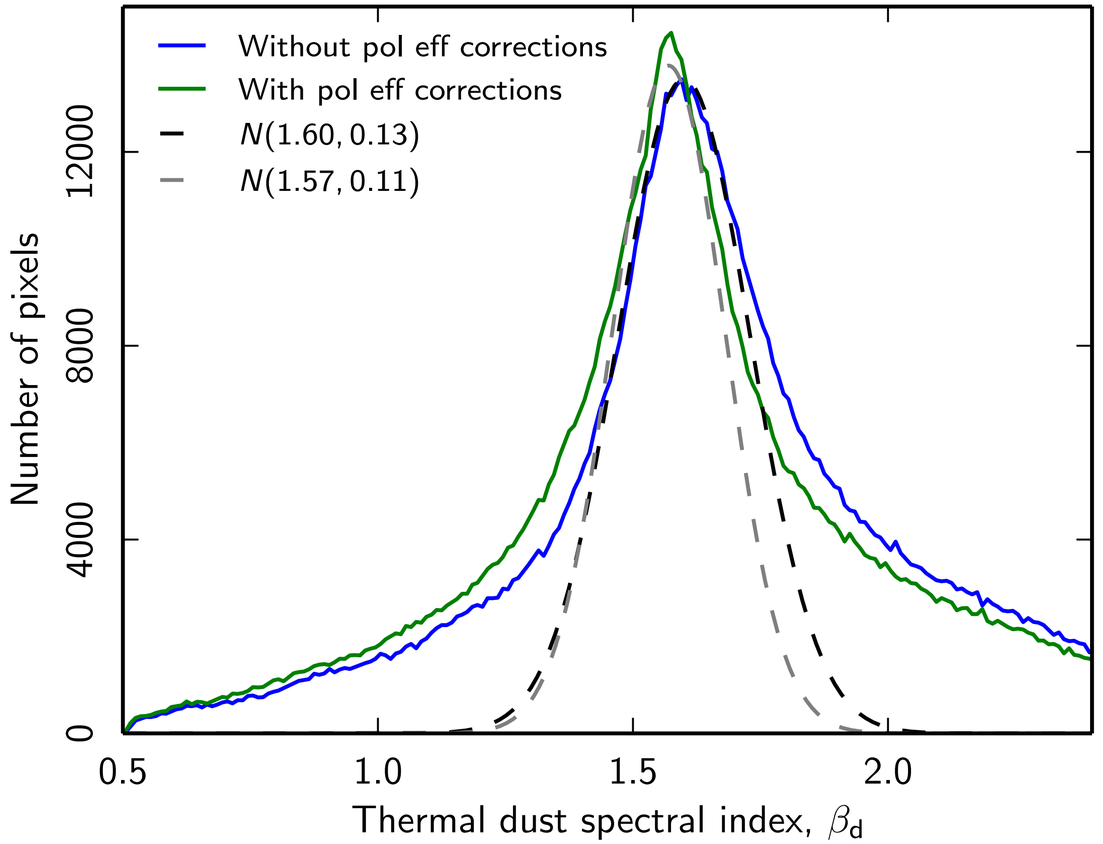


Planck IV, 2018

Planck results

Spectral indices variation in the sky, FWHM=5° for synch, 3° for dust

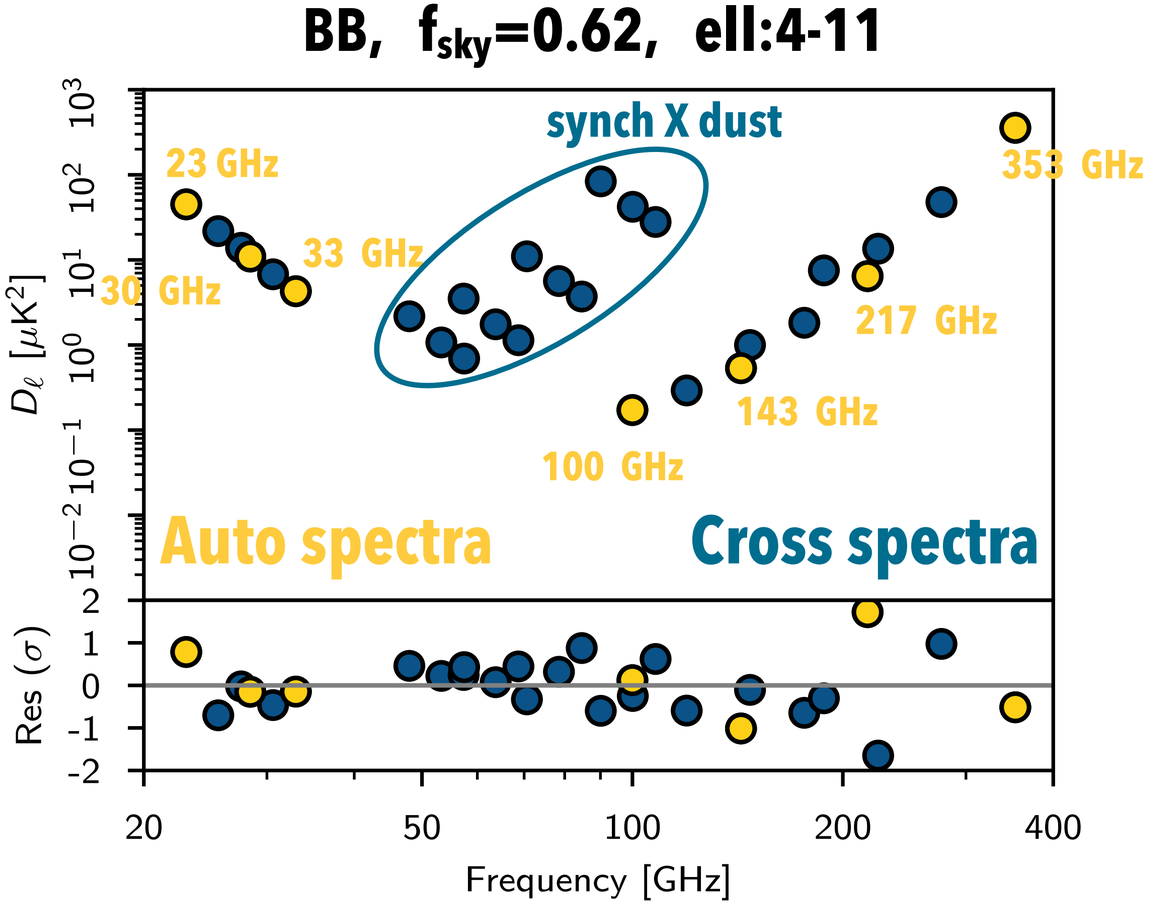




Planck IV, 2018

Planck results

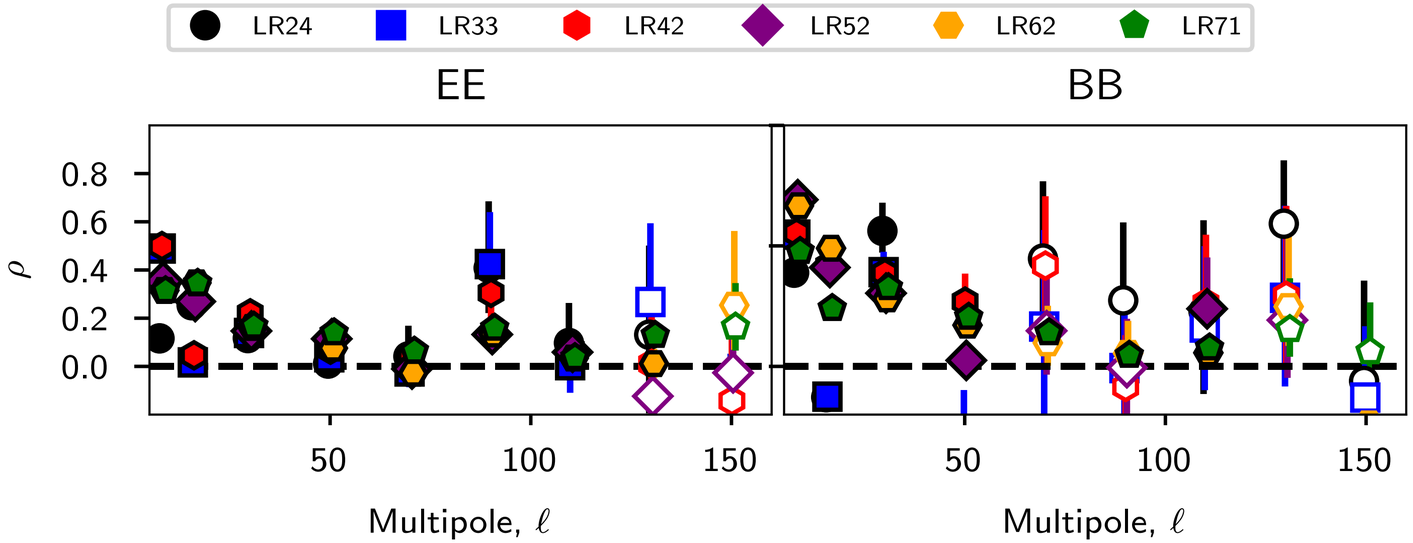
Planck XI, 2018



Fit for synch and dust spectral indices and their correlation in 5 masks, 9 multipole bins for both E and B-modes

$$\beta_d = 1.53 \pm 0.02$$

$$\beta_s = -3.13 \pm 0.13$$



Effective frequency: $\nu_{eff} = \sqrt{\nu_1 \nu_2}$

Foreground observations

- The majority of current and planned CMB experiments are focusing mostly on the high frequency obervations:

  - **BICEP/Keck**: 95, 150, 220 GHz + 30 GHz being installed
  - **POLARBEAR/Simons Array**: 95, 150, 220, 270 GHz
  - **ACTpol/advACT**: 95, 145, 220 GHz + 28, 41 GHz being designed
  - **LSPE**: 43, 140, 220, 240 GHz
  - **QUBIC**: 90, 150 GHz
  - **CLASS:** 38, 93, 148, 217 GHz
  - **Simons Observatory**: 27, 39, 93, 145, 225, 280 GHz

LiteBIRD specification

Frequency [GHz]	Beam Size [arcmin]	Pol. Sensitivity [μK · arcmin]	
40	69.2	36.1	10.17
50	56.9	19.6	5.21
60	49.0	20.2	3.05
68	40.8	11.3	2.12
78	36.1	10.3	1.44
89	32.3	8.4	1
100	27.7	7.0	1.24
119	23.7	5.8	1.75
140	20.7	4.7	2.50
166	24.2	7.0	3.77
195	21.7	5.8	5.88
235	19.6	8.0	10.70
280	13.2	9.1	20.88
337	11.2	11.4	48.82
402	9.7	19.6	129.51

Synchrotron scaling as a power law assuming a spectral index -3.1

Equal contribution of synch and dust at ~90 GHz

Thermal dust scaling as a modified BB with emissivity 1.54

LiteBIRD specification

Frequency [GHz]	Beam Size [arcmin]	Pol. Sensitivity [μK · arcmin]	
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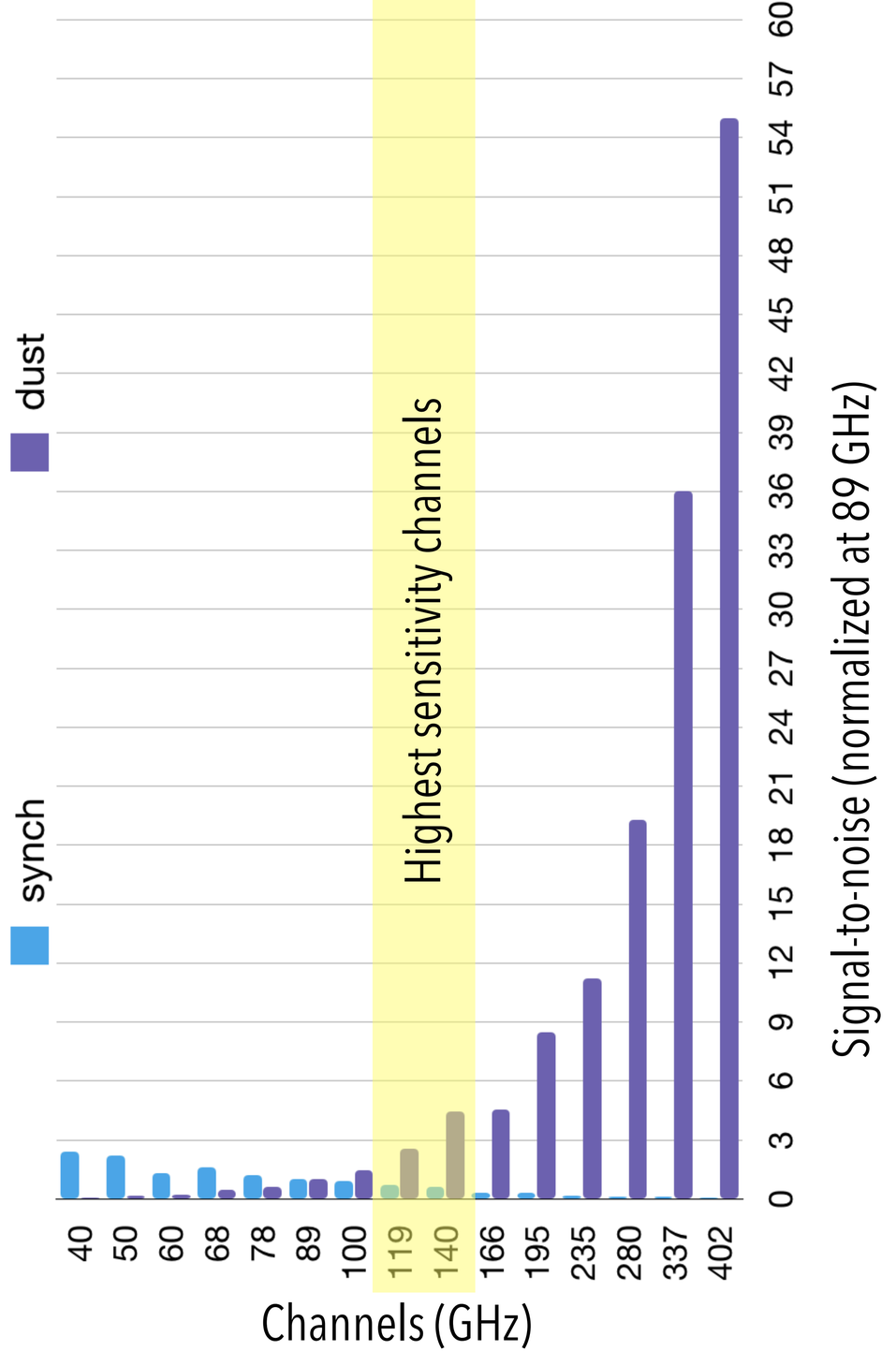


Low frequency observations

- To reach high sensitivity in synchrotron observations very low frequency (<30 GHz) observations are needed:

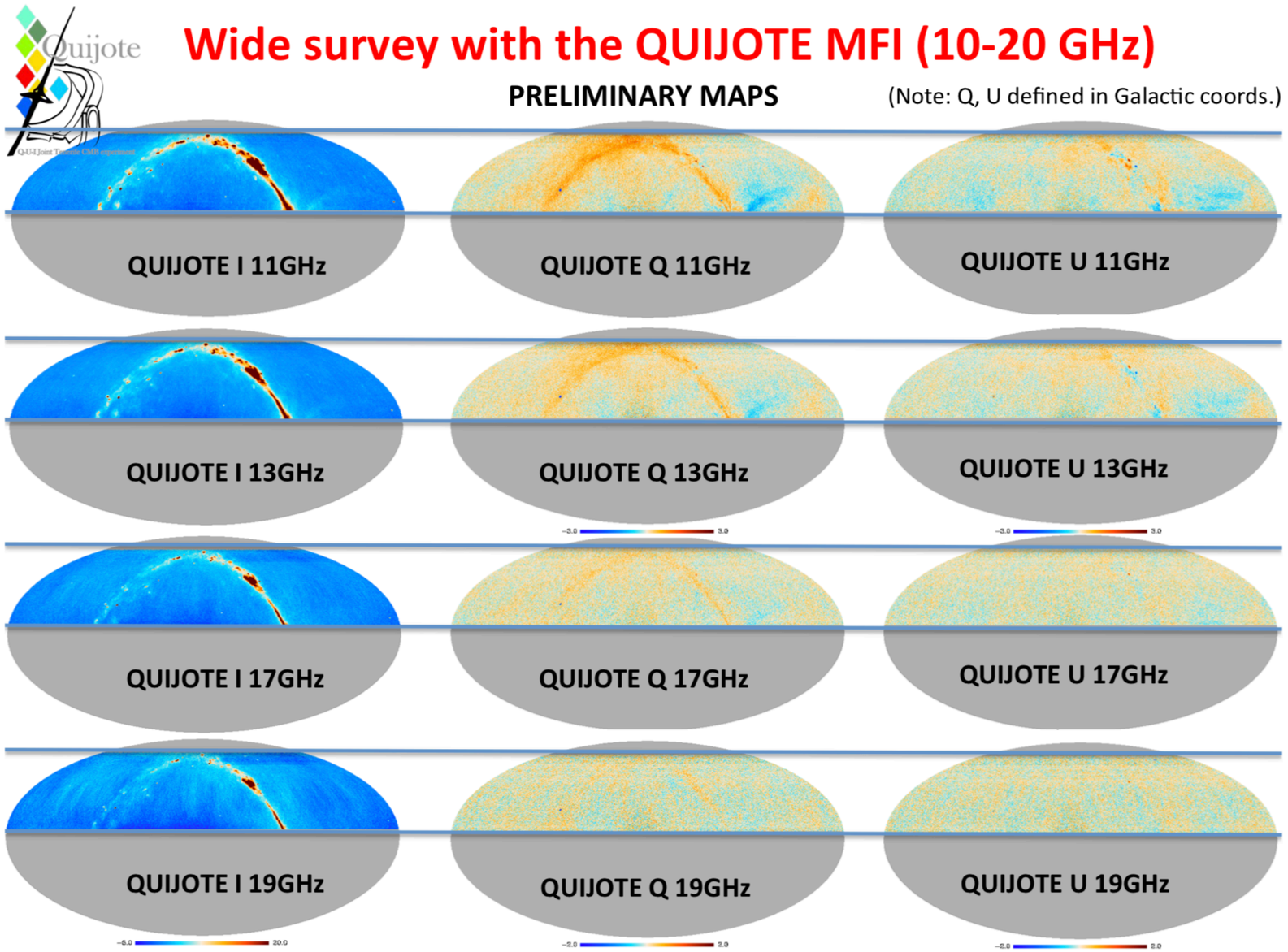
  - **QUIJOTE**: 11, 13, 17, 19, 30, 40 GHz North
  - **C-BASS**: 5 GHz North & South
  - **S-PASS**: 2.3 GHz South

The QUIJOTE experiment

From José Alberto Rubiño-Martin slides (Tenerife, Oct. 2018)

QUIJOTE overview

From José Alberto Rubiño-Martin slides (Tenerife, Oct. 2018)



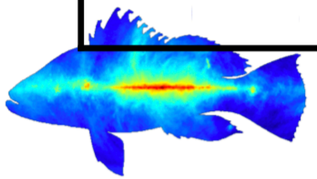
First release of papers and data in 2019, will include:

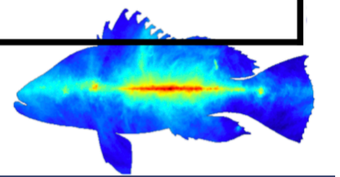
- Synchrotron spectral index, curvature, correlation with dust
- Component separation of polarized synch, combined with Planck+WMAP
- Constrainints on AME in more than 40 regions
- Radiosources
- Characterization of the North Polar Spur and FAN region

C-BASS overview

From Angela Taylor slides (Tenerife, Oct. 2018)

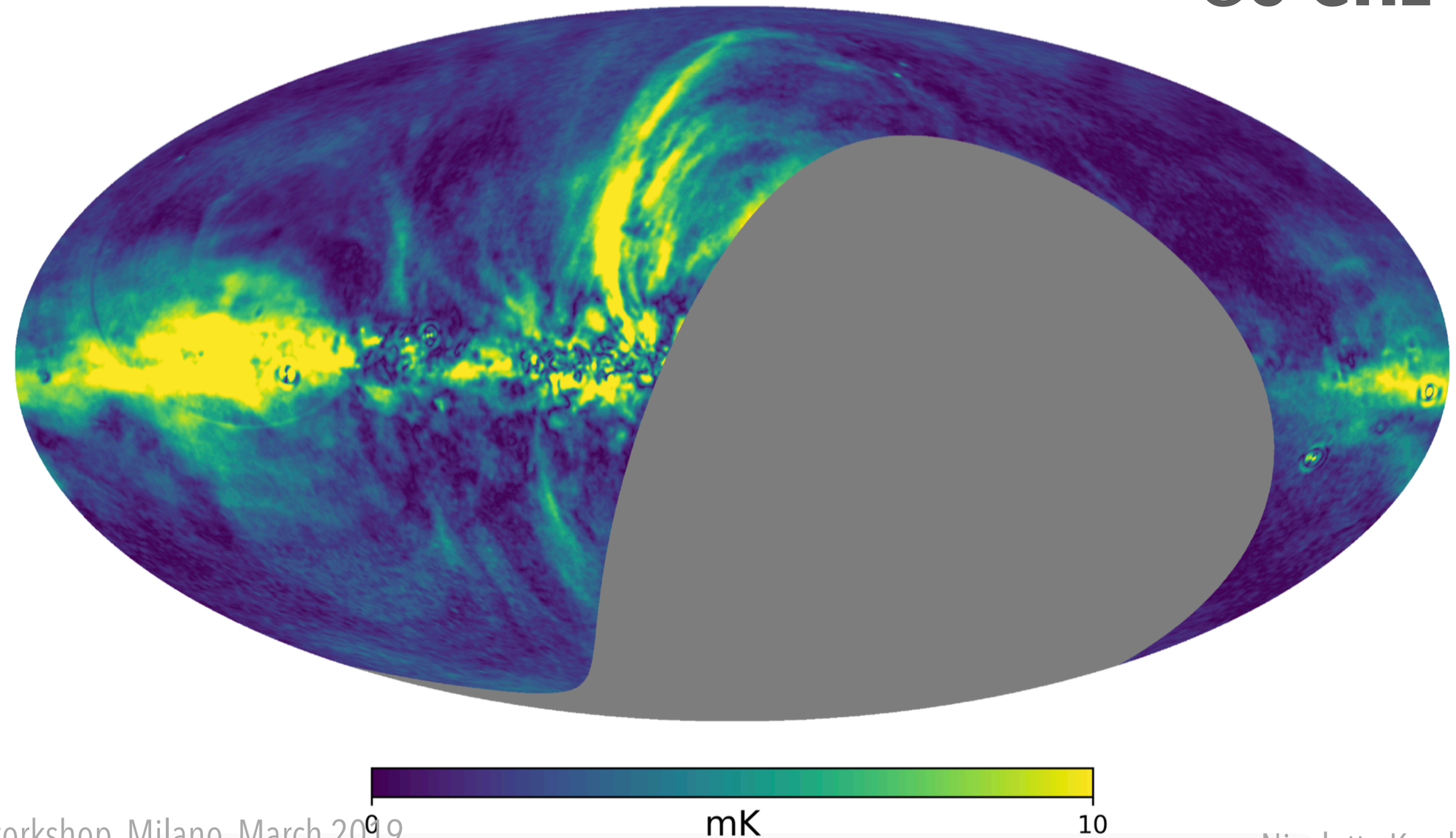
Sky-coverage	All-sky
Angular resolution	0.75 deg (45 arcmin)
Sensitivity	< 0.1mK r.m.s in 1 deg beam (confusion limited in I) 6000 μK-arcmin @ 5GHz == 0.75 μK-arcmin @ 100 GHz, β = -3
Stokes coverage	I, Q, U, (V)
Frequency 	1 (0.5) GHz bandwidth, centered at 5 GHz
Northern site 	OVRO, California Latitude, 37.2 deg
Southern site	MeerKAT/SKA site, Karoo, South Africa Latitude -30.7 deg



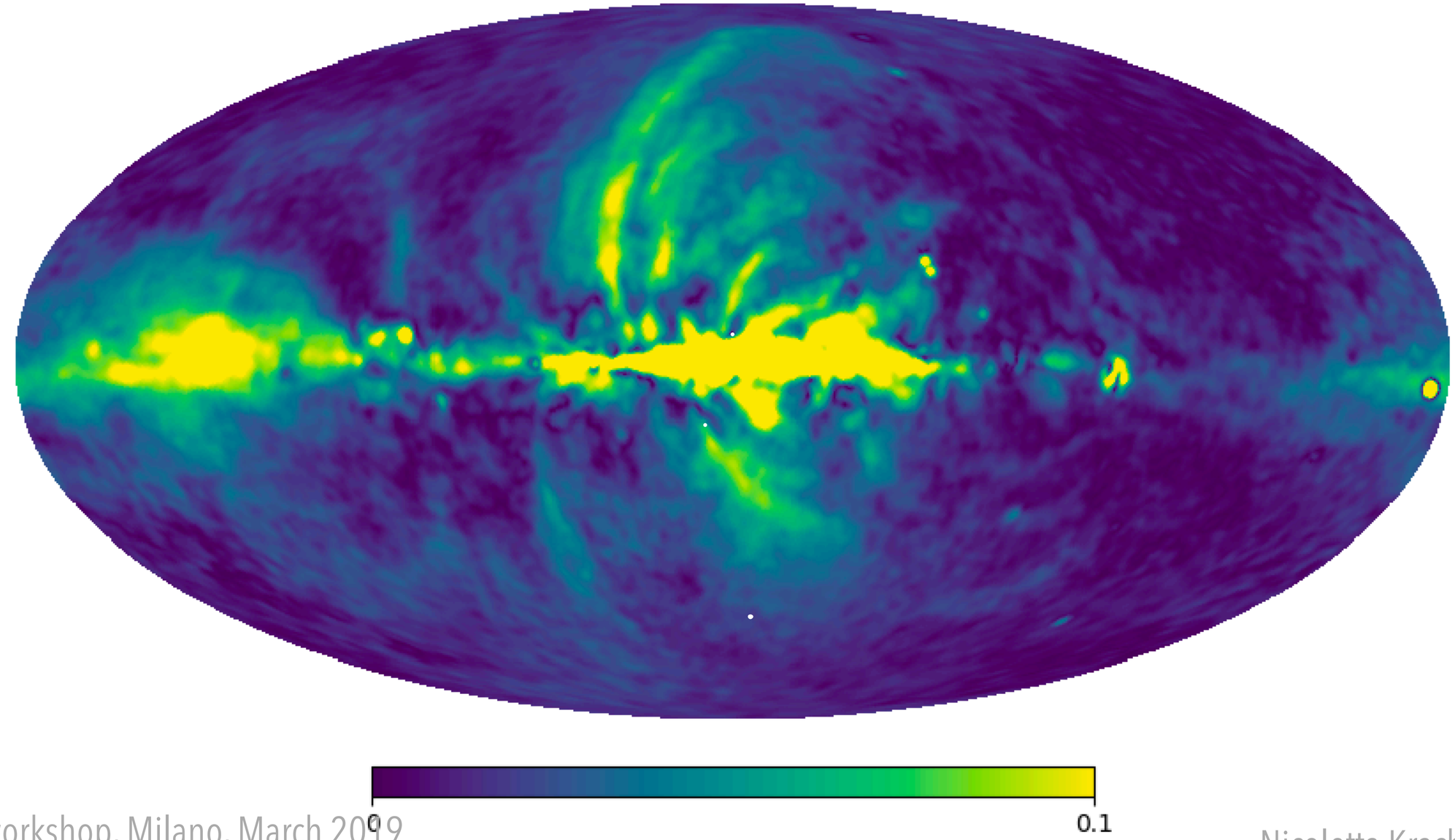


From Angela Taylor
slides (Tenerife, Oct. 2018)

C-BASS polarized intensity map **@5 GHz**



WMAP-K polarized intensity map **@23 GHz**



The **S-PASS survey**

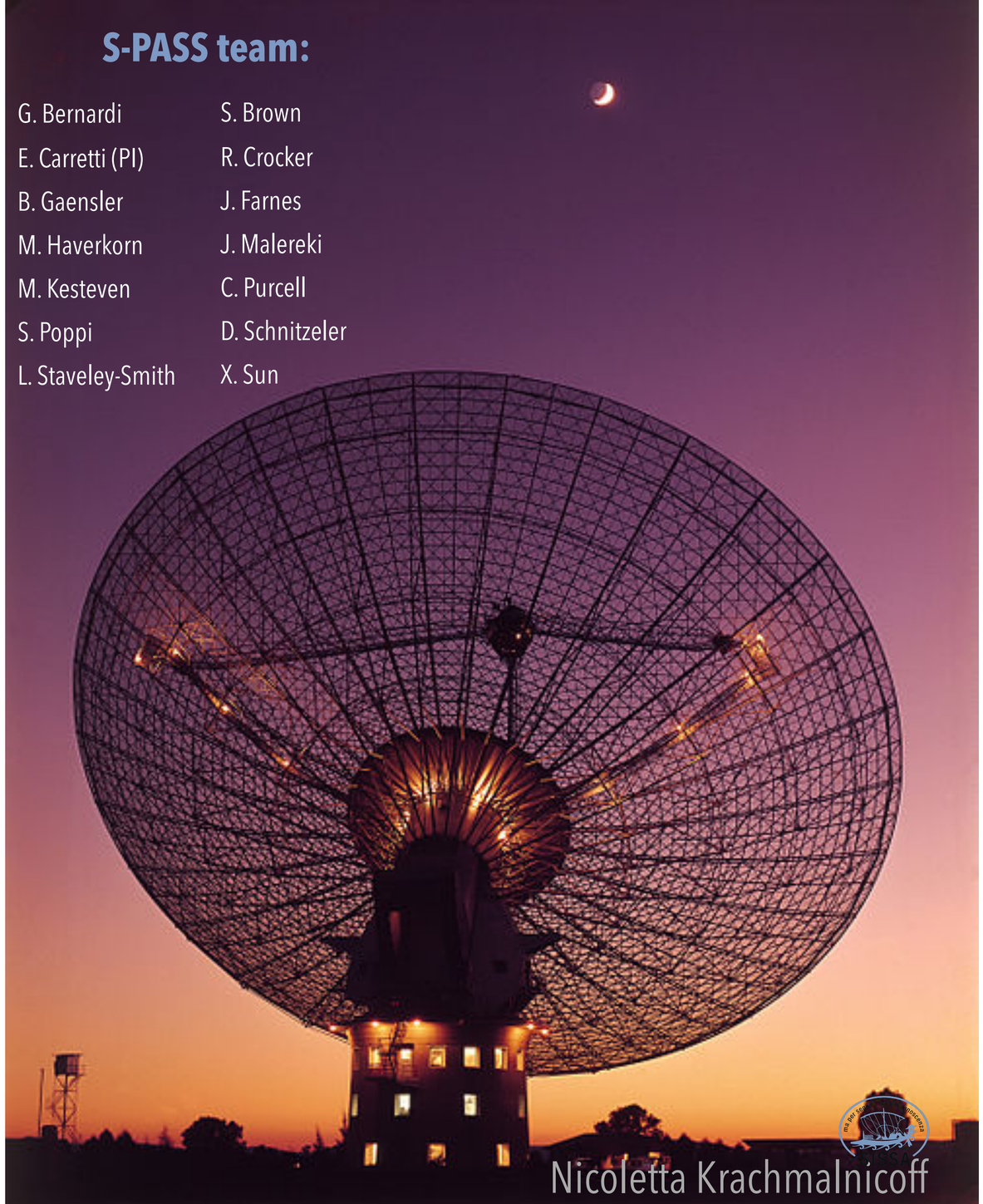
PARKES radio telescope: 64 m
Frequency: **2.3 GHz** (224 MHz BW)
Sky coverage ~ 50% (South hemisphere)
Angular resolution **~ 9 arcmin**

S-PASS science:

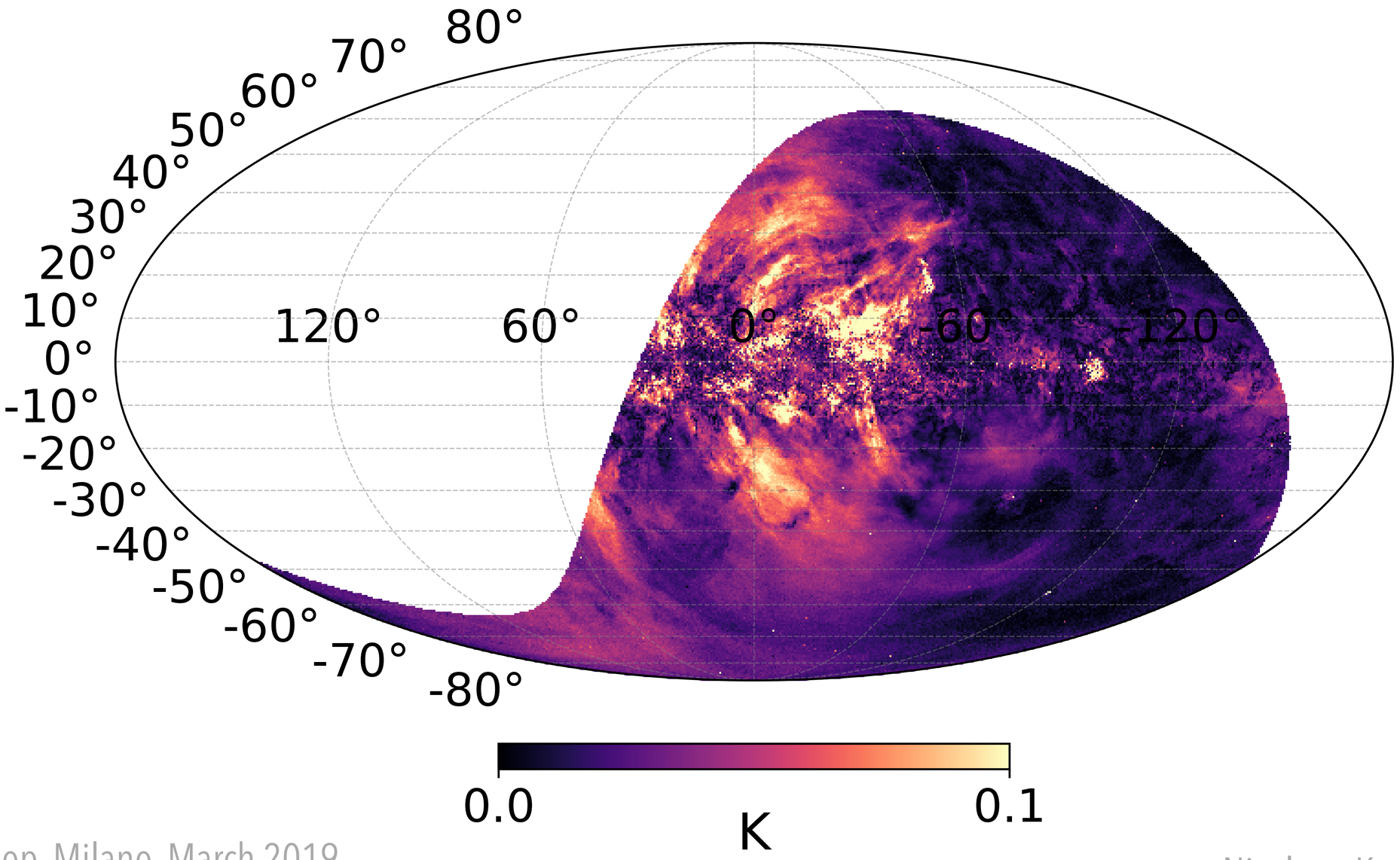
- Galactic Magnetic field
- Fermi Bubbles and Galactic structure
- ISM turbulence
- Gum Nebula
- ICM of galaxy clusters
- Extragalactic source properties
- CMB foregrounds
- ...

S-PASS team:

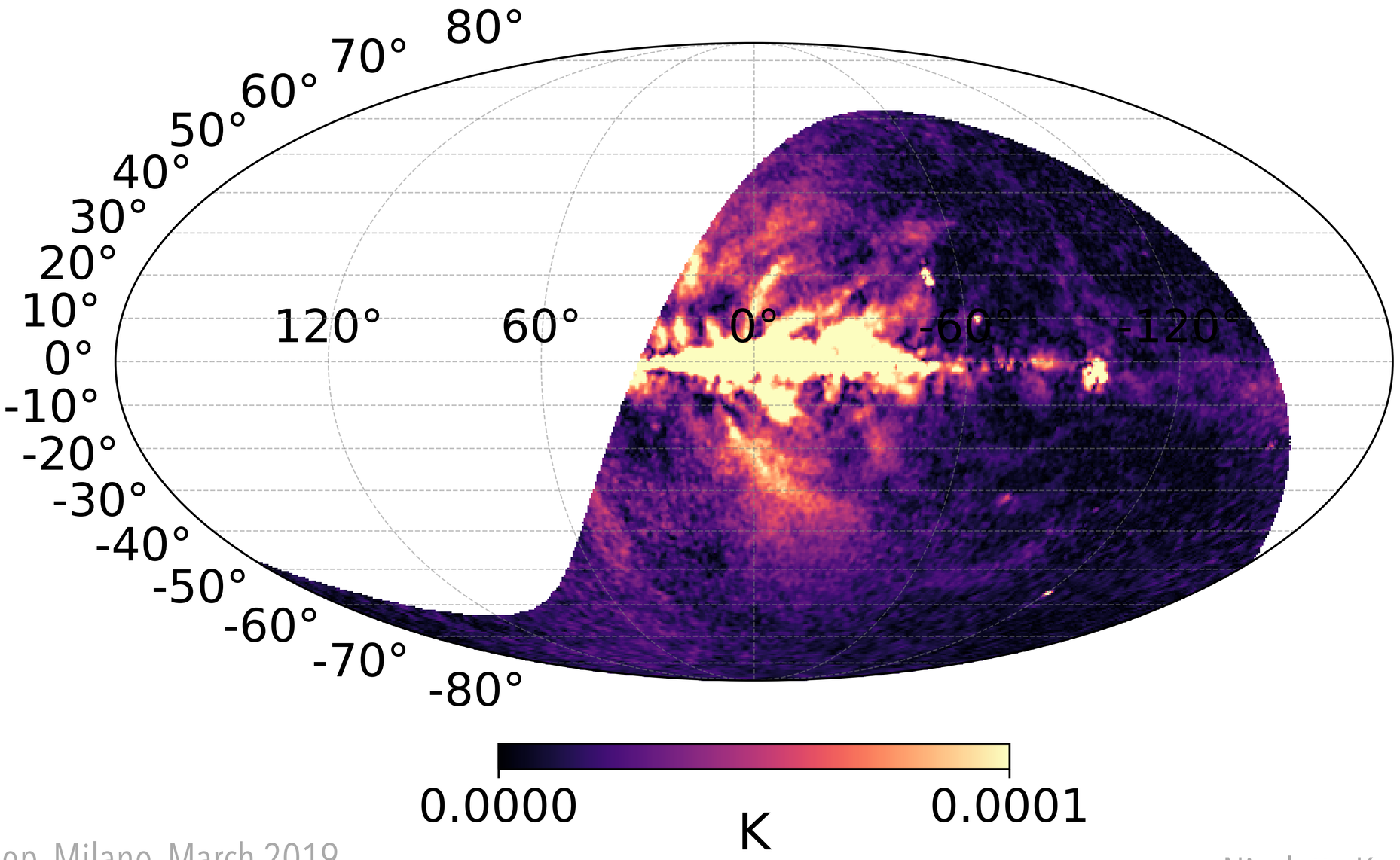
G. Bernardi
E. Carretti (PI)
B. Gaensler
M. Haverkorn
M. Kesteven
S. Poppi
L. Staveley-Smith
S. Brown
R. Crocker
J. Farnes
J. Malereki
C. Purcell
D. Schnitzeler
X. Sun



S-PASS polarized intensity map **@2.3 GHz**



WMAP-K polarized intensity map **@23 GHz**



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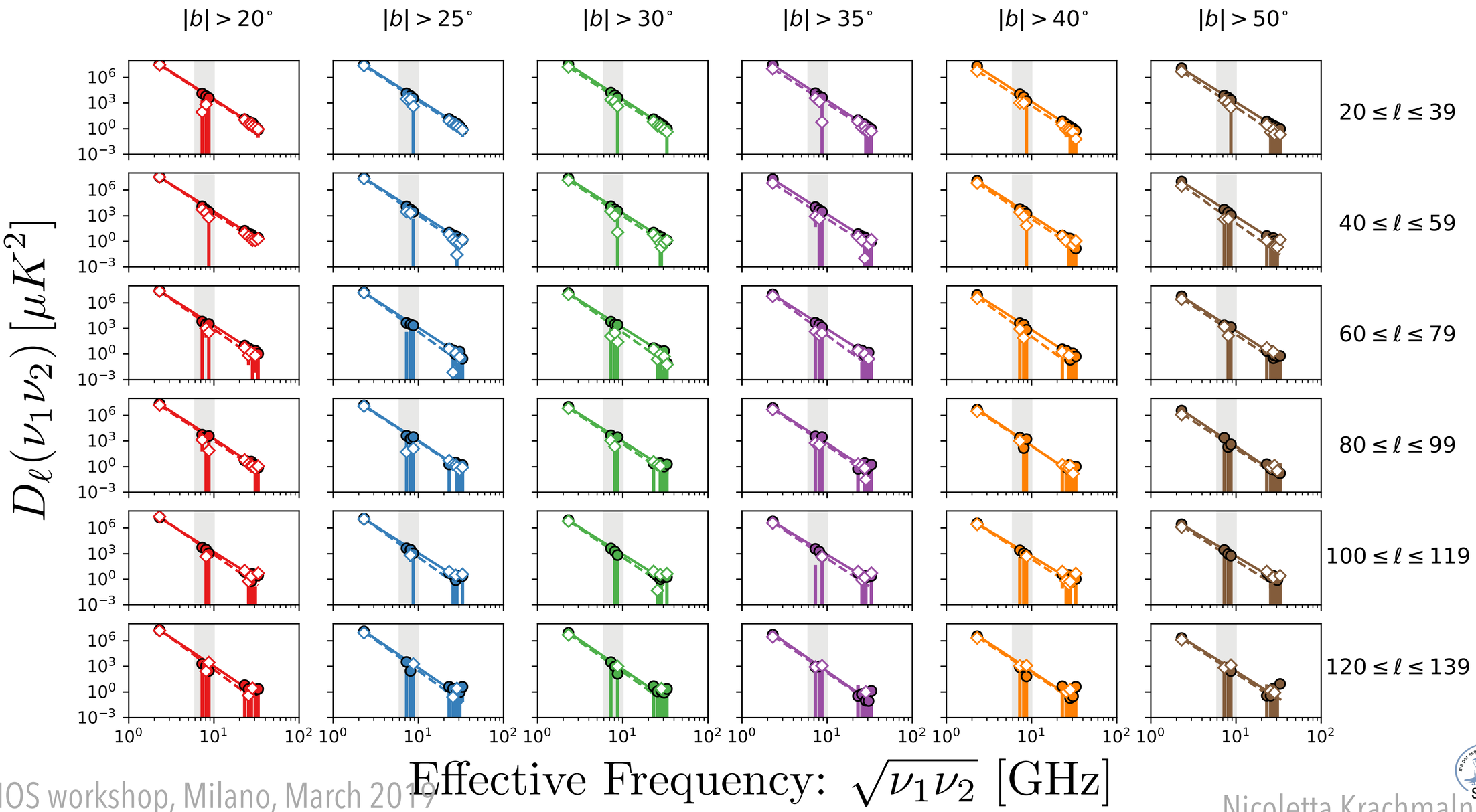
Synchrotron **SED**

S-PASS / WMAP-K / LFI-30 / WMAP-Ka

2.3 GHz 23 GHz 28.4 GHz 33 GHz



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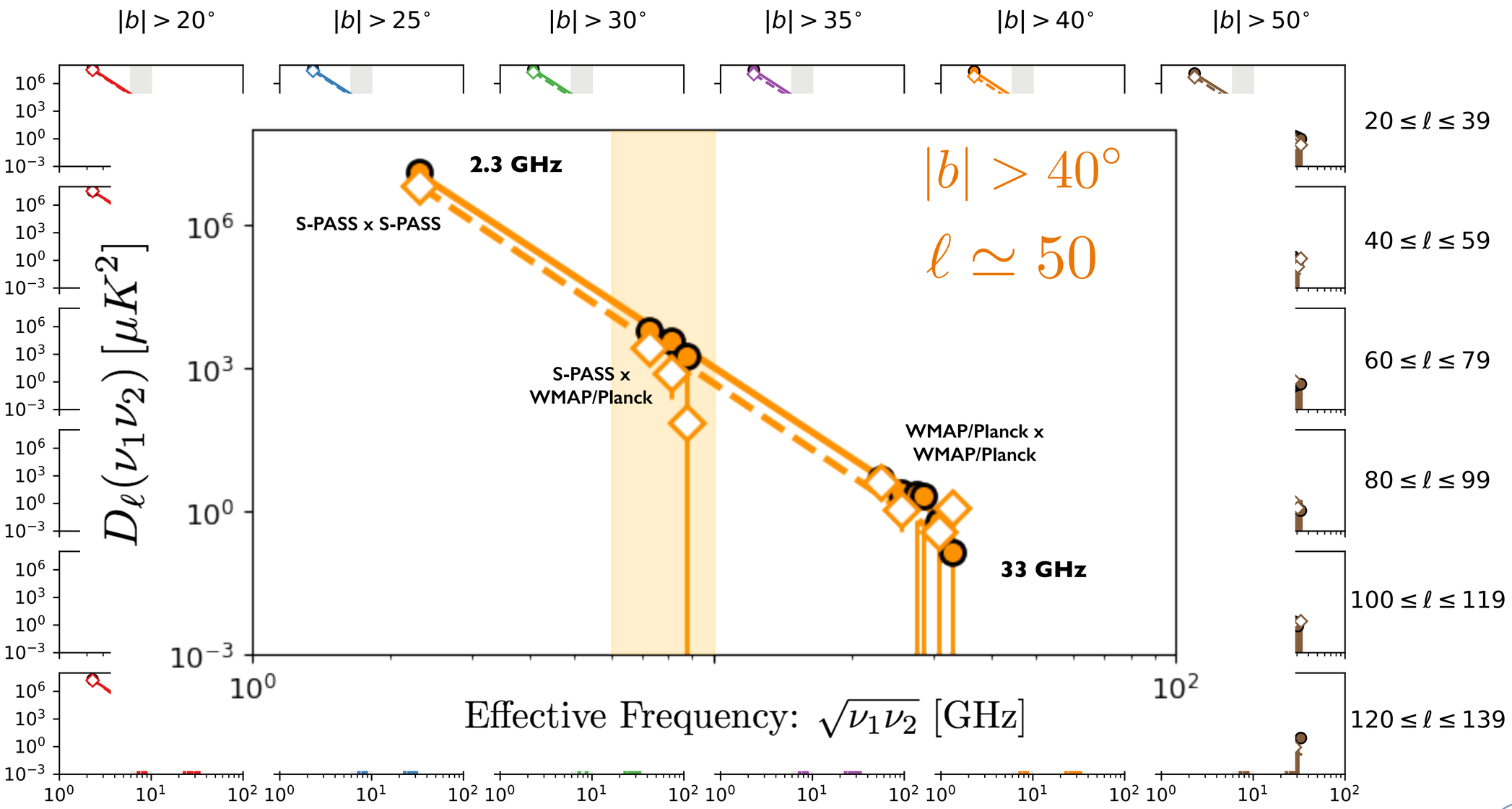

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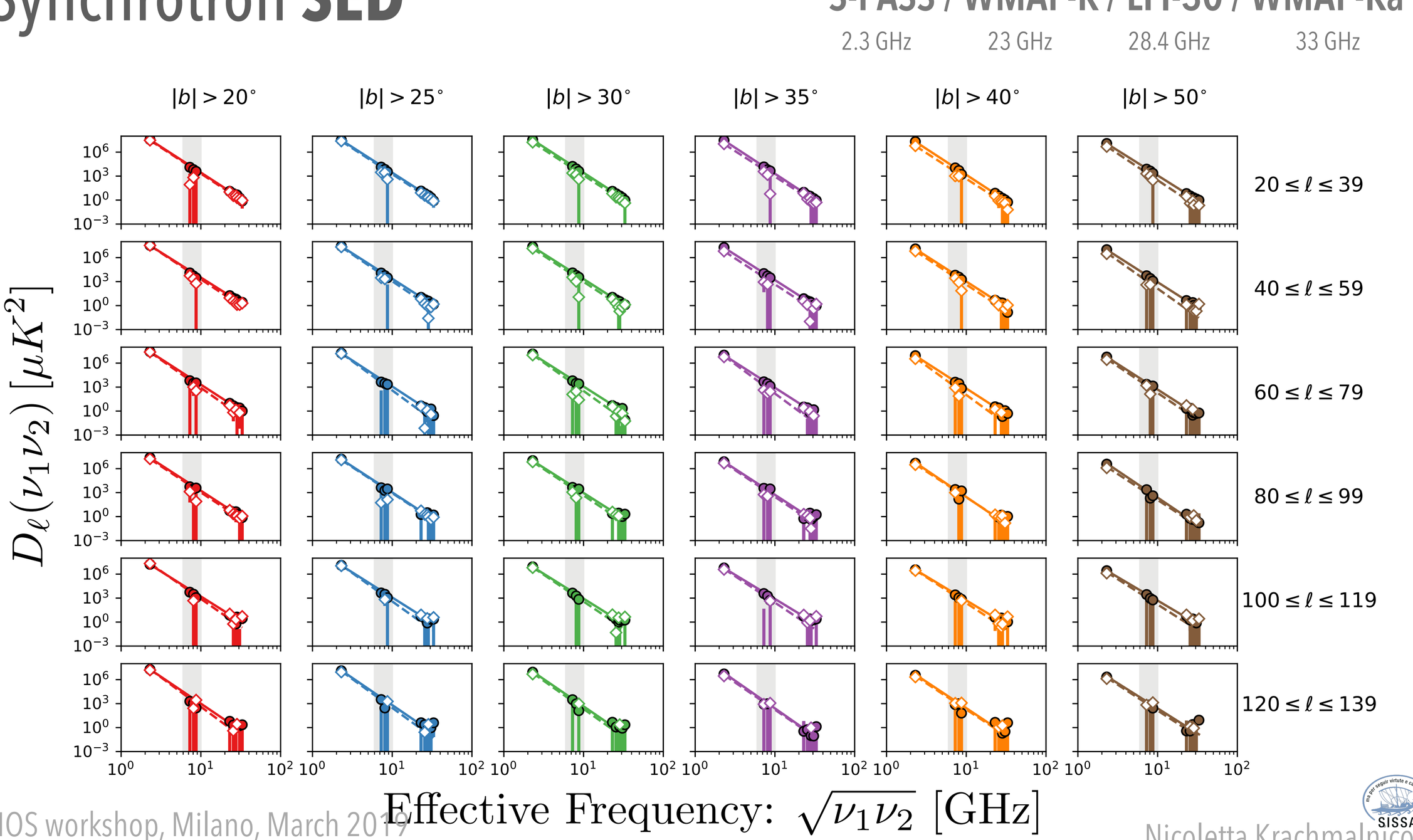
Synchrotron **SED**



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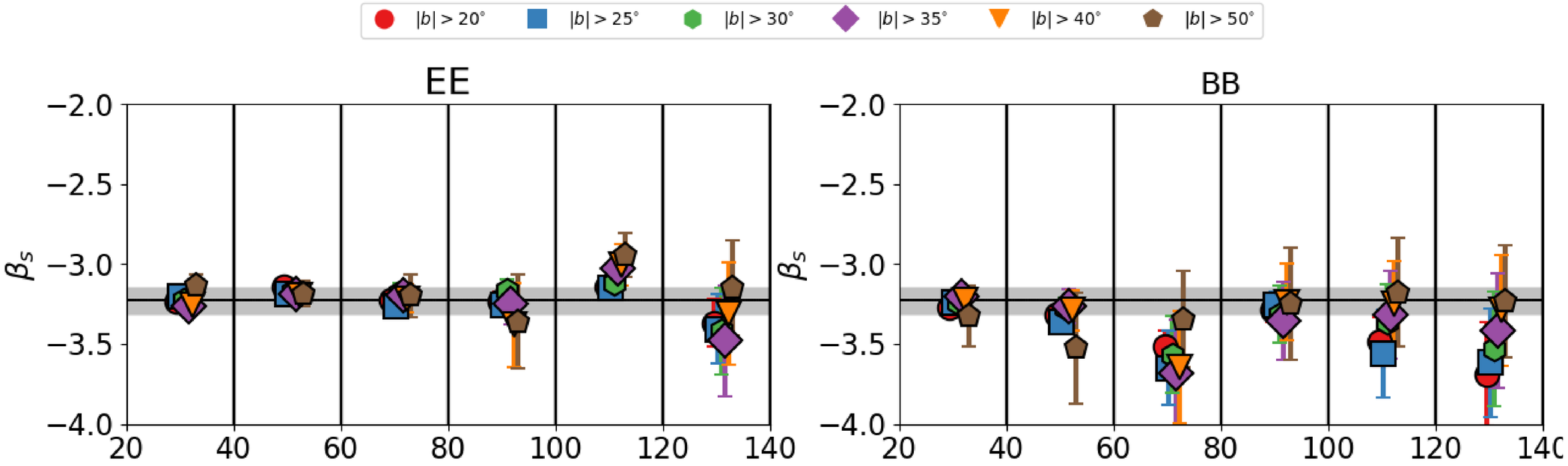
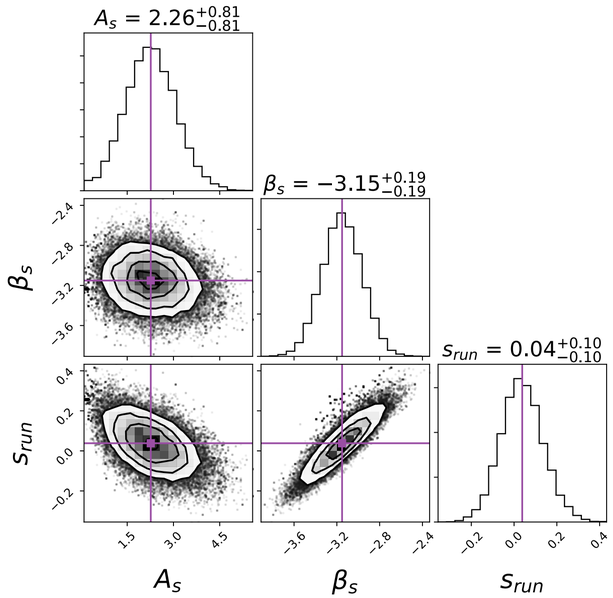


$$\beta_s = -3.22 \pm 0.08$$

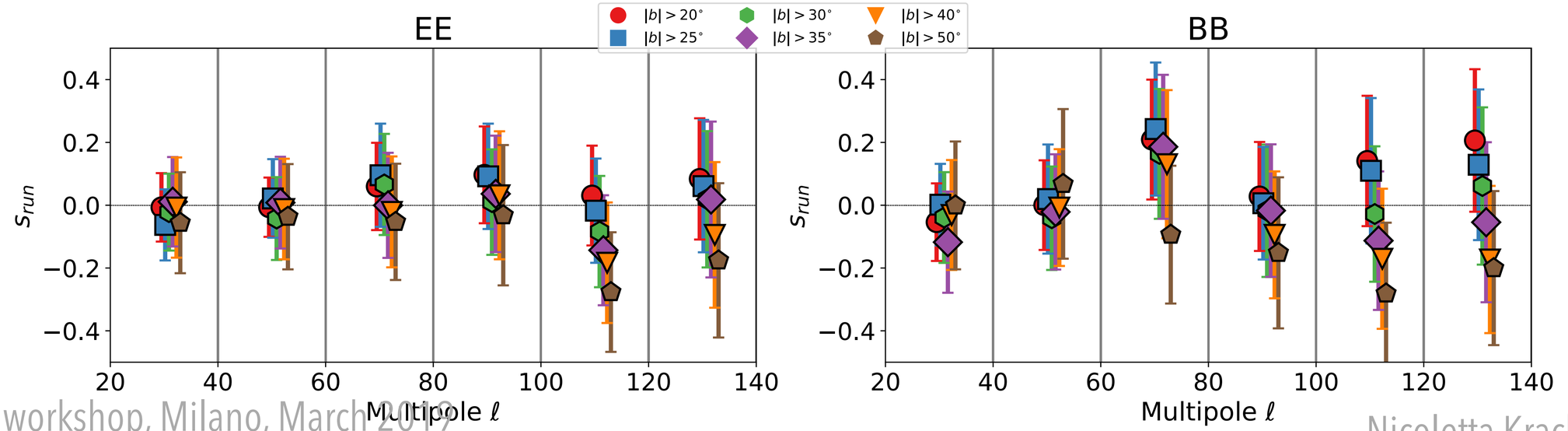
- Constant along the multipole range and for E and B-modes
- **In agreement with constraints coming from WMAP and Planck**

Constraints on **curvature**

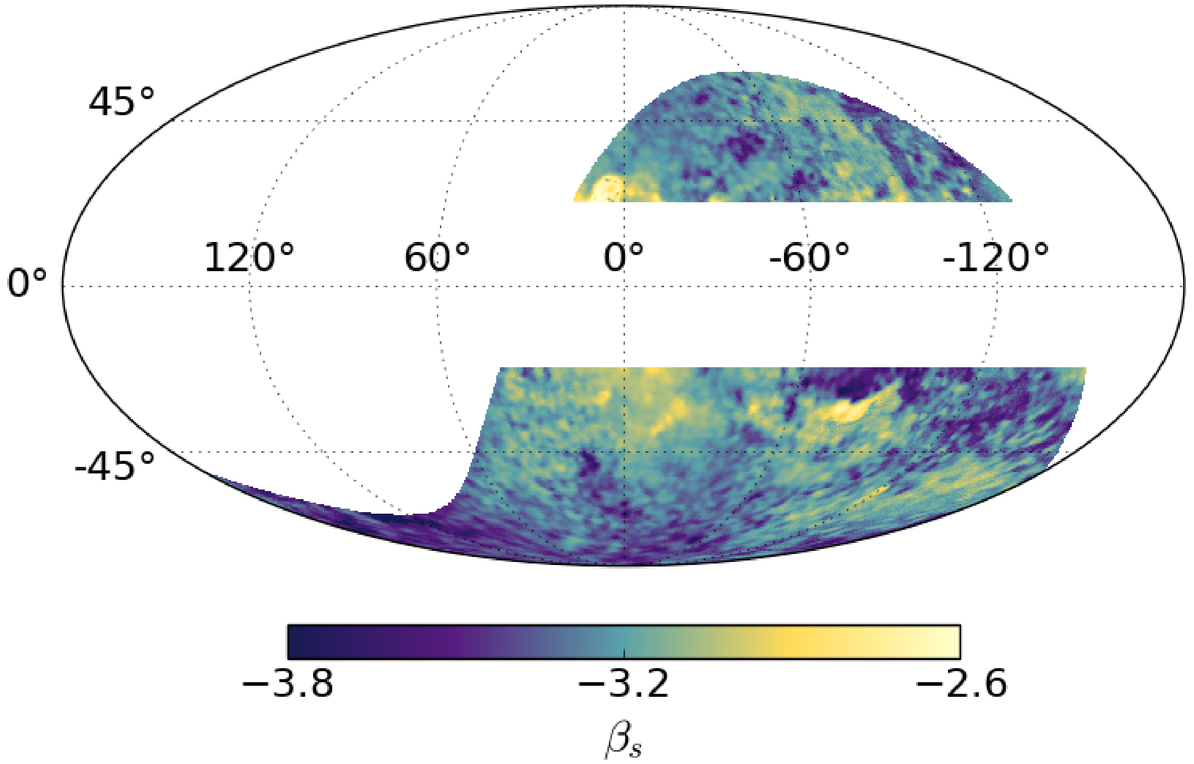
$$D_\ell(\nu_1 \times \nu_2) = A_s \left(\frac{\nu_1}{\nu_0}\right)^{\beta_s + s_{run}\log(\nu_1/\nu_0)} \left(\frac{\nu_2}{\nu_0}\right)^{\beta_s + s_{run}\log(\nu_2/\nu_0)}$$

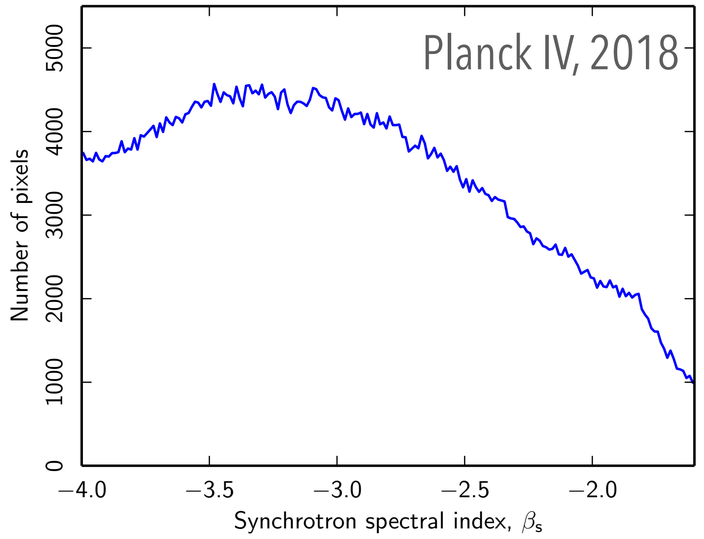


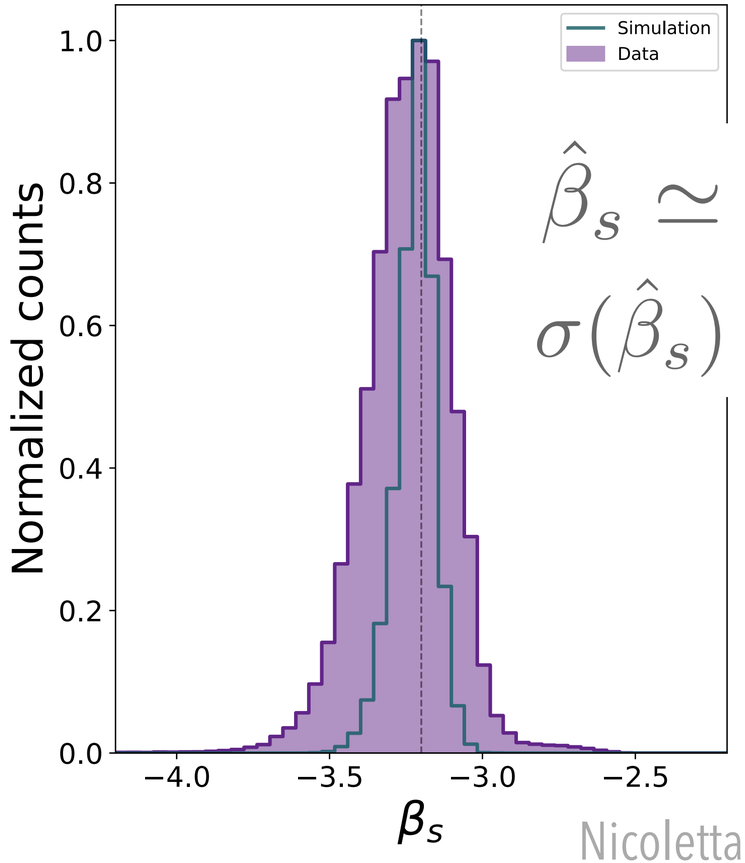
- Strong degeneracy between β_s and s_{run}
- **Gaussian prior on spectral index** from WMAP and Planck: **β_s = -3.13±0.13**
- **s_{run} compatible with zero**, with 1σ errors between 0.07 and 0.14
- More data at intermediate frequencies are needed (C-BASS in south, QUIJOTE and C-BASS in north)



Synchrotron **spectral index map**





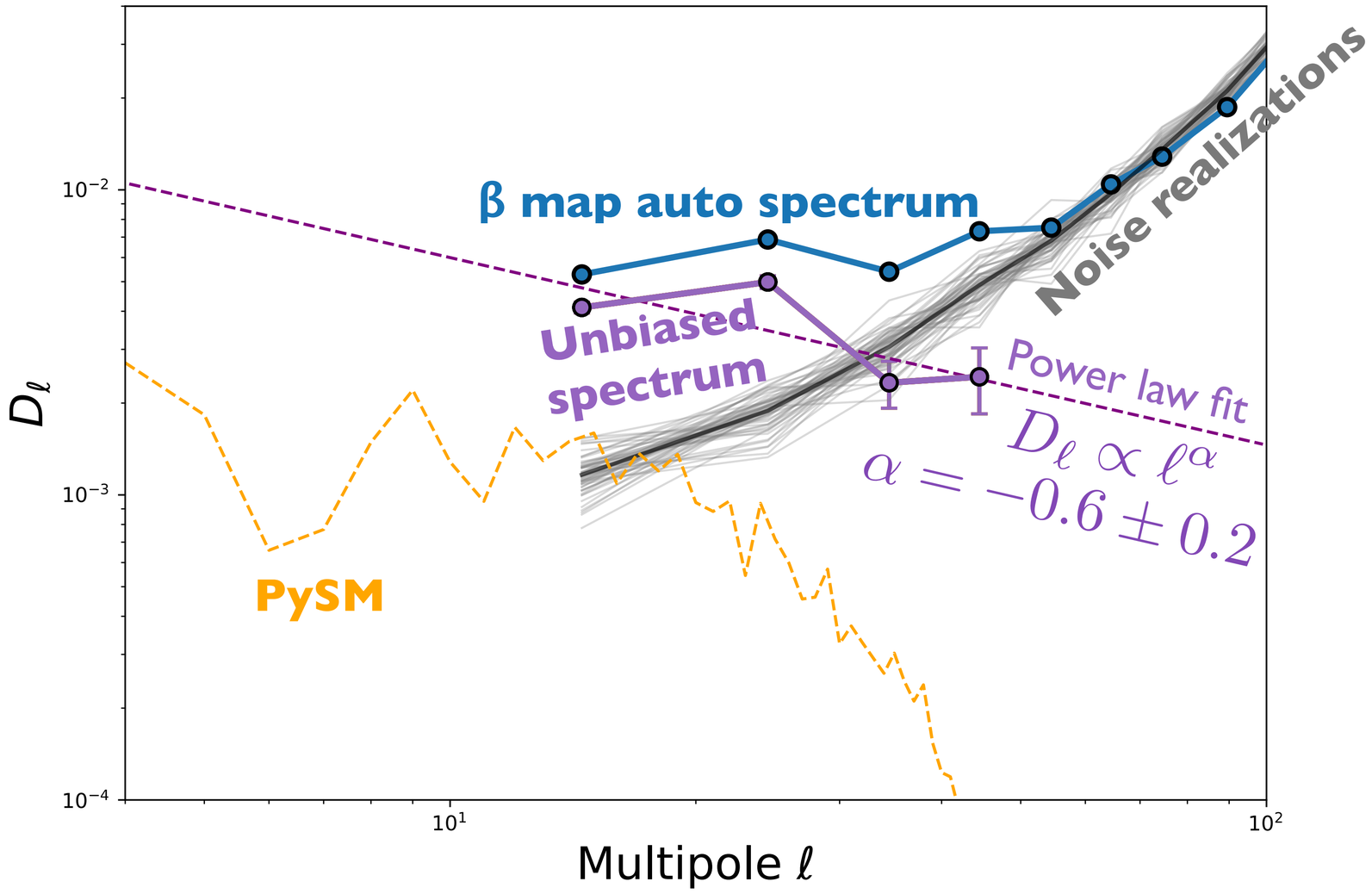


$$\hat{\beta}_s \simeq -3.20$$

$$\sigma(\hat{\beta}_s) \simeq 0.15$$

- Power law fit in range **2.3 - 33 GHz**
- Fit in each pixel in **total polarized intensity** taking into account the noise bias
- **Angular resolution of 2°**
- Sky coverage ~ 30%
- No prior

Power spectrum of spectral index map



Noise realizations:

S-PASS maps @ 2.3 GHz

↓

Extrapolate in frequency using β map at WMAP-K/Ka, LFI-30 frequencies

↓

Add noise on extrapolated maps

↓

Estimate β^*

↓

Compute spectrum of $(\beta^*-\beta)$

SISSA
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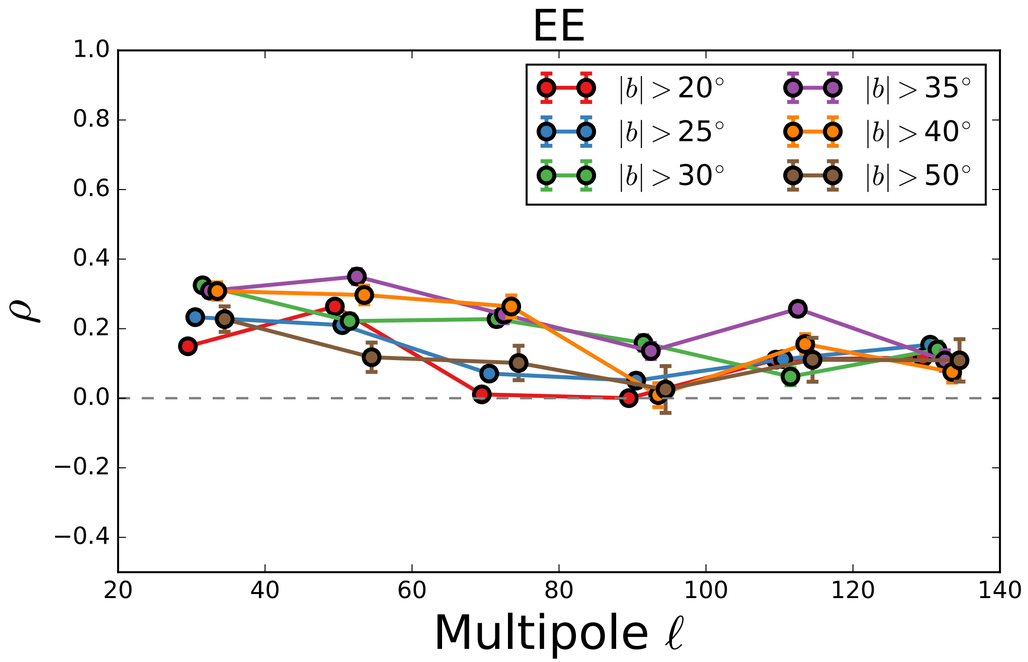
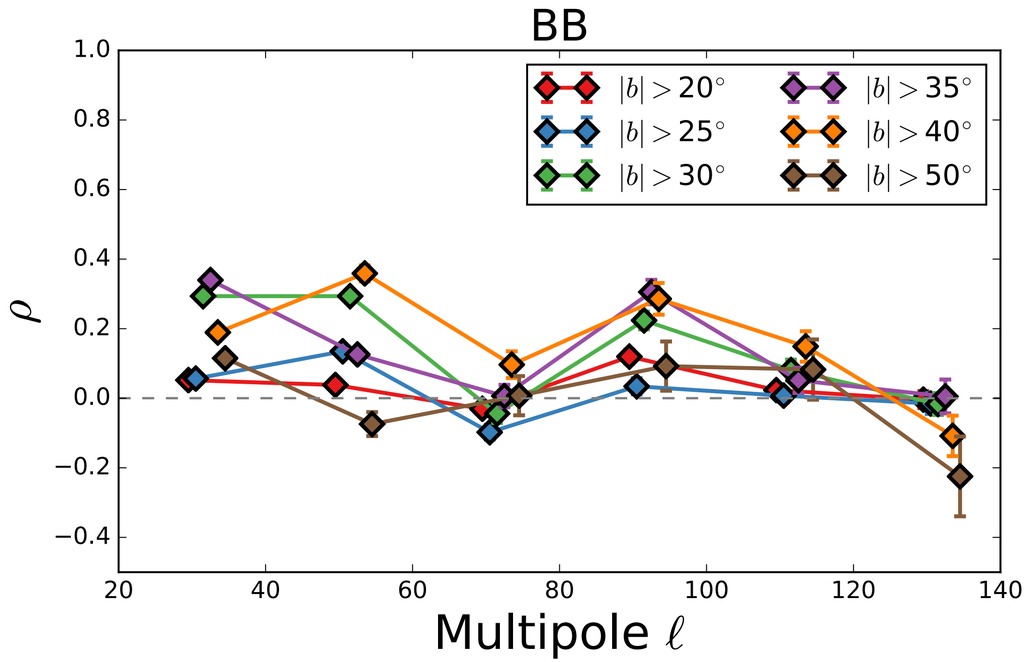
Synch x Dust

$$\rho_\ell = \frac{C_\ell(2.3 \times 353)}{\sqrt{C_\ell(2.3) C_\ell(353)}}$$

- level of **correlation between 2.3 and 353 GHz** is **compatible with what measured with WMAP and Planck** channels





Conclusions and open questions

- In the recent years great progress in the analysis and characterization of synchrotron
- Very low frequency (< 20 GHz) observations are needed
- More data are coming soon
- Open problems:
  - Synchrotron spectral index variation: decorrelation, impact on component separation
  - Cuvature?