PLANCK 2014

THE MICROWAVE SKY IN TEMPERATURE AND POLARIZATION

Planck component separation and foregrounds

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on behalf of the Planck Collaboration

Bayesian component separation

planck

- We adopt a parametric Bayesian approach for diffuse component separation
- We assume that the data may be written as the sum of signal and noise,

$$\mathbf{d}_\nu = \mathbf{s}_\nu + \mathbf{n}_\nu$$

where the signal may be written on the following form

$$\mathbf{s}_\nu(\theta) = s_\nu(\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu)$$

$$= g_\nu \sum_{i=1}^{N_{\mathrm{comp}}} \mathbf{F}^i_\nu(\beta_i, \Delta_\nu)\mathbf{a}_i + \mathbf{T}_\nu \mathbf{m}_\nu$$

Calibration
Spectral index
Bandpass
Signal amplitude
Monopole/dipole

- The posterior distribution reads

$$P(\theta|\mathbf{d}) = \frac{P(\mathbf{d}|\theta)P(\theta)}{P(\mathbf{d})} \propto \mathcal{L}(\theta)P(\theta)$$

Likelihood
Prior

- The noise is very nearly Gaussian distributed, and the likelihood is given by

$$\mathcal{L}(\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu) \propto e^{-\frac{1}{2}\sum_\nu [\mathbf{d}_\nu - \mathbf{s}_\nu(\theta)]^t \mathbf{N}^{-1}[\mathbf{d}_\nu - \mathbf{s}_\nu(\theta)]}$$

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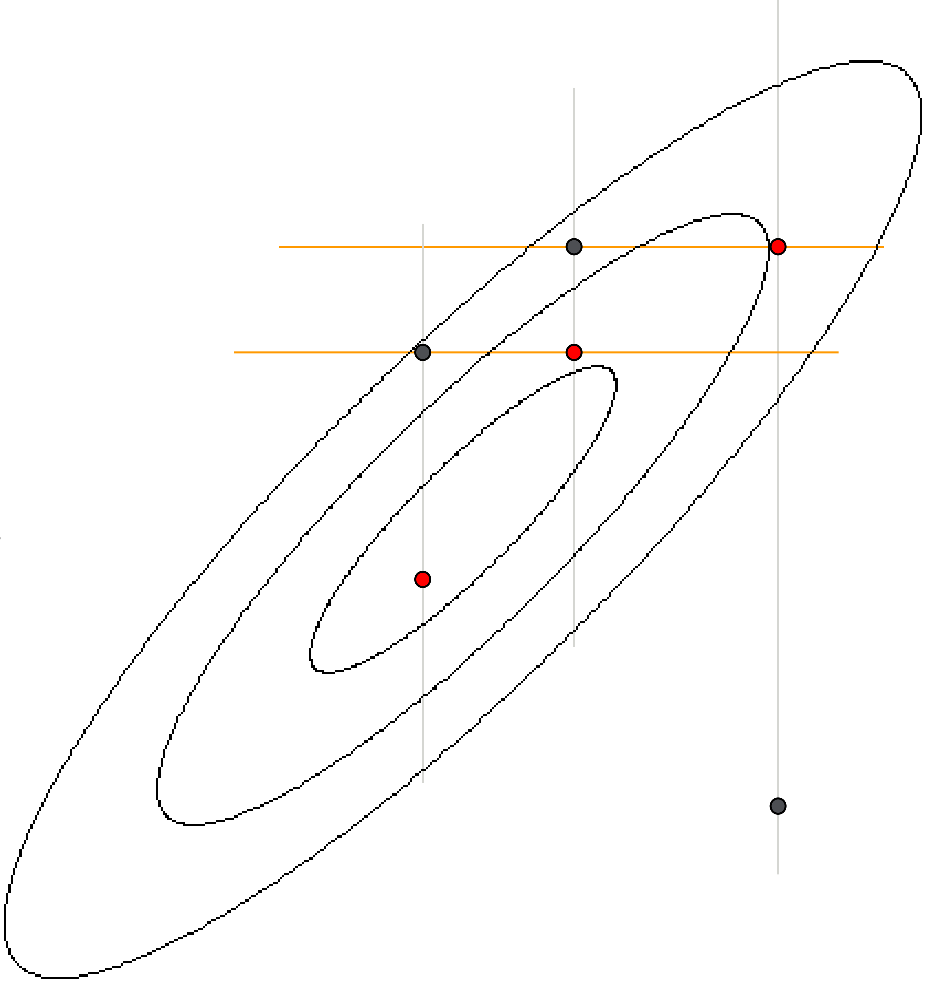
Bayesian component separation

- The posterior contains millions of correlated and non-Gaussian parameters. How is it possible to map out this distribution?
- Answer: Gibbs sampling
  - Rather than sampling from or maximizing the full joint distribution, iterate over conditionals
- We apply this to our problem in terms of the following Gibbs chain:

$$
\begin{aligned}
\mathbf{a}_i &\leftarrow P(\mathbf{a}_i|\beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
\beta_i &\leftarrow P(\beta_i|\mathbf{a}_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
g_\nu &\leftarrow P(g\nu|\mathbf{a}_i, \beta_i, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
\mathbf{m}_\nu &\leftarrow P(m_\nu|\mathbf{a}_i, \beta_i, g_\nu, \Delta_\nu, C_\ell) \\
\Delta\nu &\leftarrow P(\Delta_\nu|\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, C_\ell) \\
C_\ell &\leftarrow P(C_\ell|\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu)
\end{aligned}
$$



2013	2014
• Temperature only	• Temperature and polarization
• Seven Planck channels between 30 and 353 GHz	• Nine Planck channels between 30 and 857 GHz • Ancilliary data: WMAP, 408MHz
• Co-added frequency channels	• Fine-grained detector maps • Better handle on line emission mechanisms and bandpass
• Single low-frequency foreground	• Separate syncrotron, free-free and spinning dust components
• Spatially constant dust temperature	• Spatially varying dust temperature
• Single CO emission map with fixed frequency scalings	• Individual CO J=1→0, 2→1 and 3→2 maps; new 94/100 GHz line map
• Assumed nominal calibration and bandpass parameters	• Jointly fit calibration and bandpass parameters in signal model

Temperature sky model

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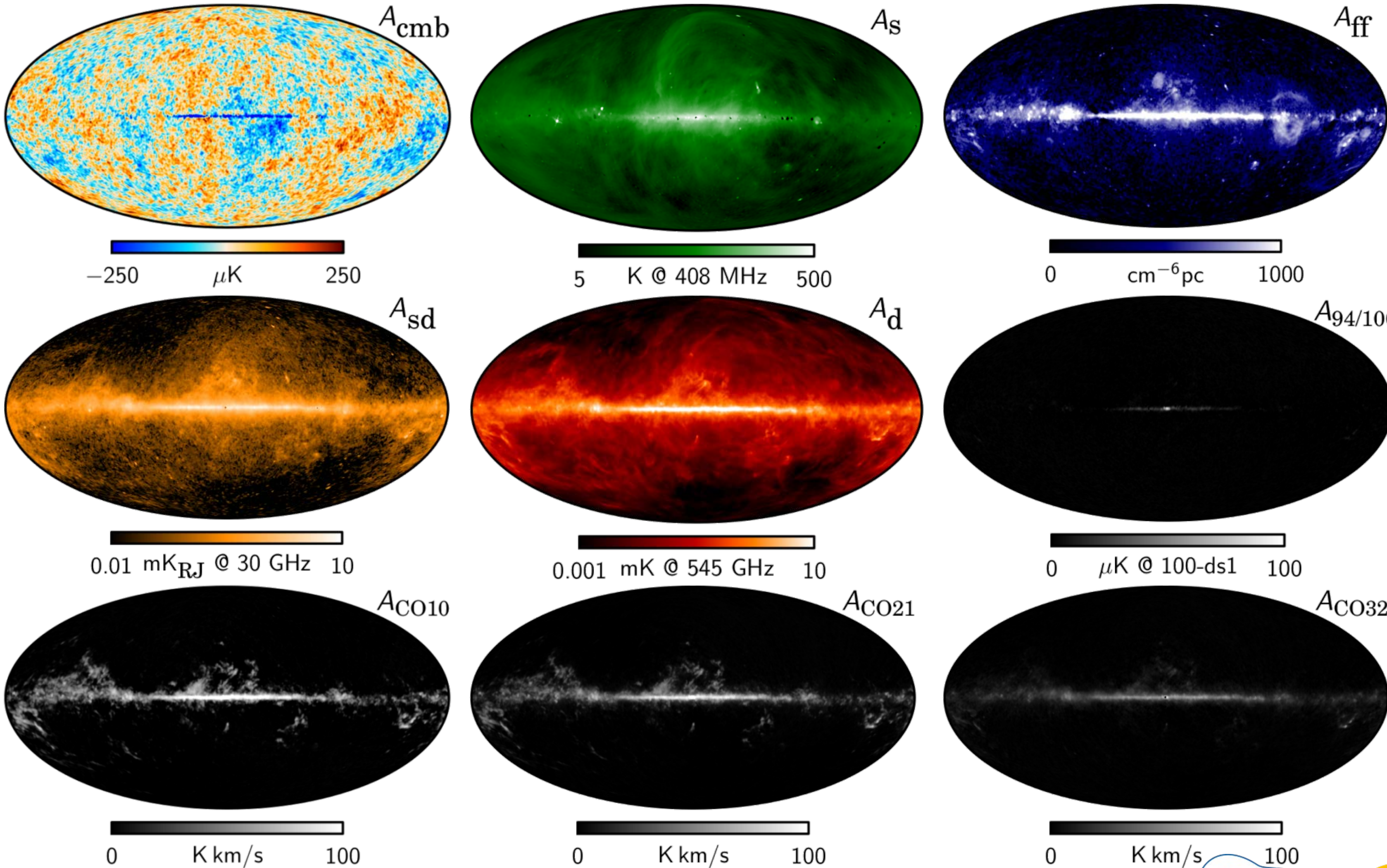

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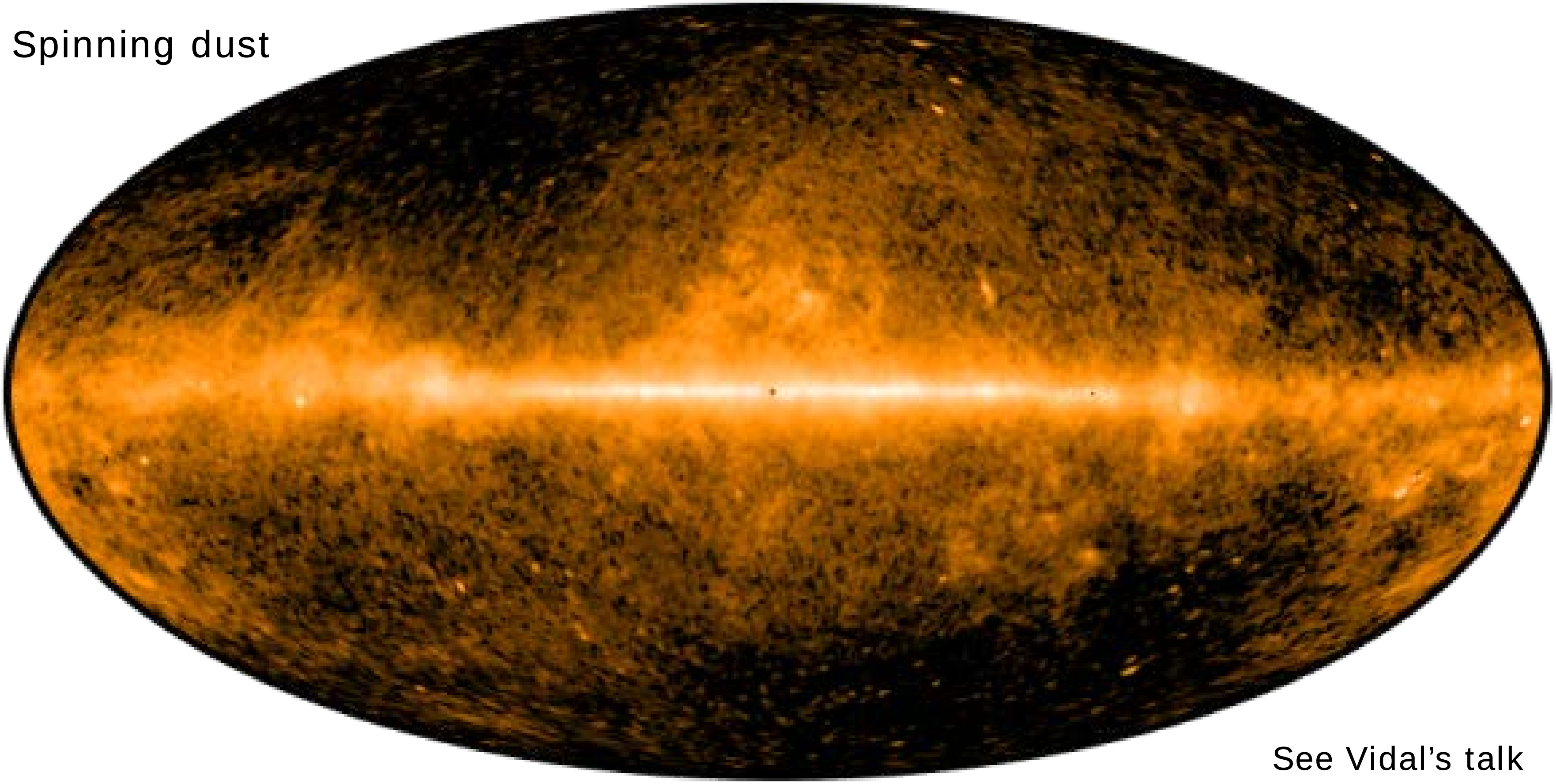
Thermal vs spinning dust

Spinning dust



See Vidal's talk

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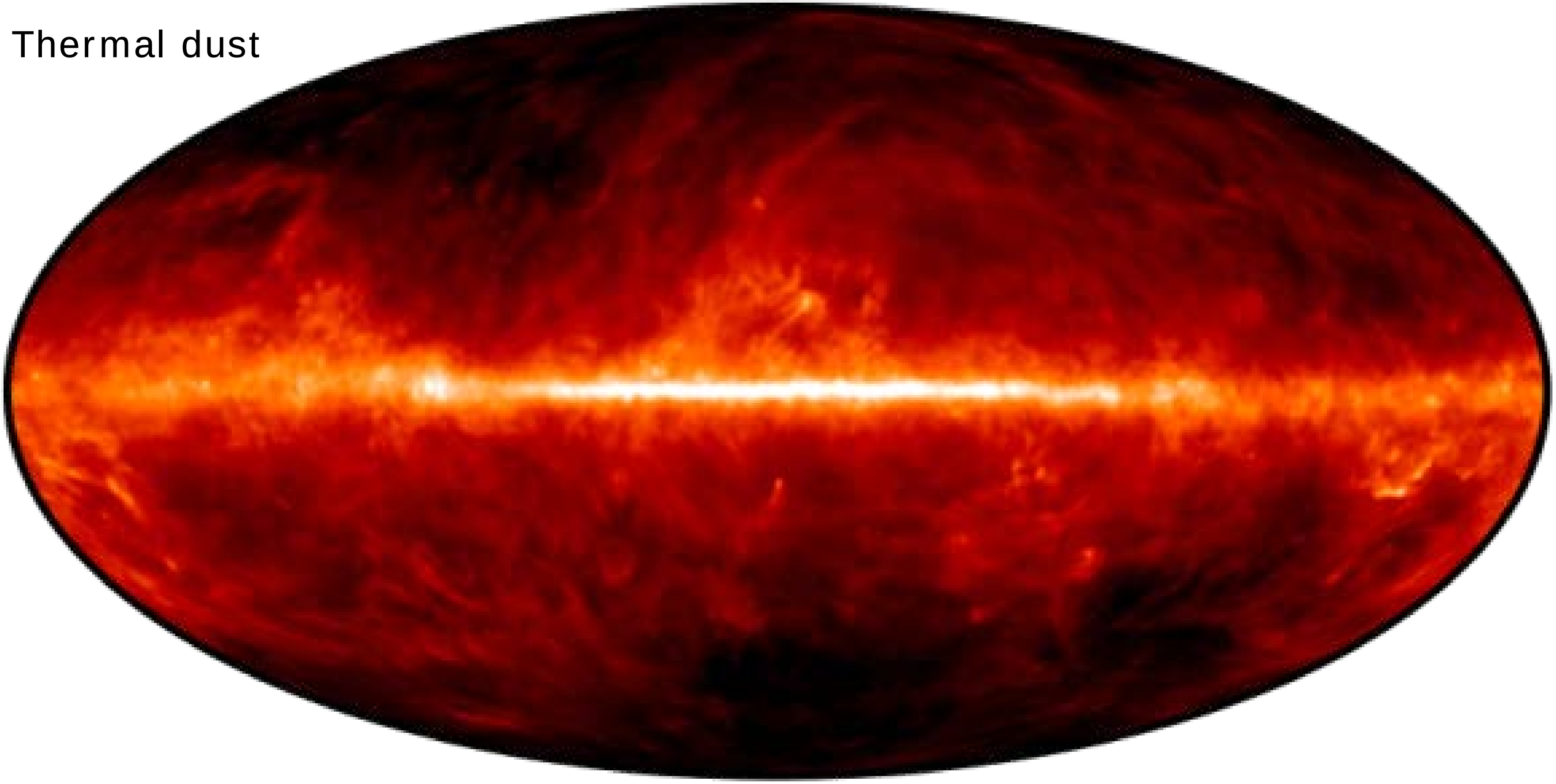
Thermal vs spinning dust

Thermal dust



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Instrumental parameters

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Survey	Frequency [GHz]	Detector label	Monopole [μK]	X dipole [μK]	Y dipole [μK]	Z dipole [μK]	Calibration [%]	Bandpass shift [GHz]
Planck LFI	30		-17 ± 1	0[a]	0[a]	0[a]	0.5 ± 0.1	0.3 ± 0.1
	44		11 ± 1	0.5 ± 0.2	-0.3 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.1 ± 0.1
	70	ds1	16 ± 1	0.5 ± 0.1	-1.1 ± 0.1	1.1 ± 0.1	0.6 ± 0.1	-0.4 ± 1.0
		ds2	16 ± 1	0.5 ± 0.1	-1.0 ± 0.1	1.1 ± 0.1	0.7 ± 0.1	1.1 ± 1.0
		ds3	16 ± 1	-0.1 ± 0.1	-0.9 ± 0.1	0.8 ± 0.1	0.7 ± 0.1	0.5 ± 1.0
HFI	100	ds1	9[a]	0[a]	0[a]	0[a]	0.11 ± 0.02	-0.5 ± 0.7
		ds2	8 ± 1	0.0 ± 0.1	-0.1 ± 0.1	0.3 ± 0.2	0.08 ± 0.02	-0.4 ± 0.6
	143	ds1	21[a]	0[a]	0[a]	0[a]	0[a]	0.7 ± 0.2
		ds2	21 ± 1	0.0 ± 0.1	0.0 ± 0.1	-0.1 ± 0.1	-0.04 ± 0.02	-0.2 ± 0.2
		5	21 ± 1	-0.5 ± 0.1	0.0 ± 0.1	-0.1 ± 0.1	0.09 ± 0.02	-0.5 ± 0.2
		6	21 ± 1	-0.4 ± 0.1	0.0 ± 0.1	-0.1 ± 0.1	0.12 ± 0.02	0.3 ± 0.2
		7	20 ± 1	-0.2 ± 0.1	0.0 ± 0.1	-0.0 ± 0.1	0.01 ± 0.02	-0.4 ± 0.2
	217	1	68 ± 1	-0.8 ± 0.1	-2.6 ± 0.1	2.9 ± 0.1	[a]	-0.1 ± 0.1
		2	68 ± 1	-0.7 ± 0.1	-2.8 ± 0.1	3.1 ± 0.1	0.01 ± 0.03	-0.1 ± 0.1
		3	67 ± 1	-1.0 ± 0.1	-2.6 ± 0.1	3.0 ± 0.1	0.00 ± 0.03	0.1 ± 0.1
		4	68 ± 1	-0.4 ± 0.1	-2.7 ± 0.1	3.0 ± 0.1	0.04 ± 0.03	-0.1 ± 0.1
	353	ds2	447 ± 5	-3 ± 1	-6 ± 1	6 ± 1	0.3 ± 0.1	0.3 ± 0.1
		1	449 ± 6	-4 ± 1	-16 ± 1	15 ± 1	0.8 ± 0.1	-0.0 ± 0.1
	545	2	0.370[ac]	0[a]	0[a]	0[a]	−2.8[e]	2.0[e]
		4	0.36 ± 0.01[c]	0[a]	0[a]	0[a]	−3.2[e]	2.8[e]
	857	2	0.62 ± 0.01[c]	0[a]	0[a]	0[a]	1.7[e]	5.8[e]
WMAP	23	K	-8 ± 1	-4.5 ± 2.0	1.6 ± 0.5	-3.7 ± 0.4	0[a]	0[a]
	33	Ka	3[b]	-0.7 ± 0.6	-4.7 ± 0.2	3.8 ± 0.1	0.1 ± 0.1	0[a]
	41	Q1	2 ± 1	0.5 ± 0.3	-4.6 ± 0.1	3.5 ± 0.1	-0.1 ± 0.1	0[a]
		Q2	2 ± 1	[illegible]	[illegible]	[illegible]	0.2 ± 0.1	0.3 ± 0.1
	61	V1	1 ± 1	0.2 ± 0.1	-5.5 ± 0.1	4.2 ± 0.1	0.1 ± 0.1	0[a]
		V2	1 ± 1	[illegible]	[illegible]	[illegible]	0.3 ± 0.1	-0.1 ± 0.1
	94	W1	-5 ± 2	0.3 ± 0.1	-5.3 ± 0.2	4.1 ± 0.2	0.3 ± 0.1	0[a]
		W2	-5 ± 2	[illegible]	[illegible]	[illegible]	0.4 ± 0.1	-0.7 ± 0.3
		W3	-6 ± 2	0.2 ± 0.1	-6.0 ± 0.2	4.3 ± 0.3	-0.1 ± 0.1	0.3 ± 0.3
		W4	-5 ± 2	-0.0 ± 0.1	-6.1 ± 0.1	5.2 ± 0.2	0.1 ± 0.1	-0.6 ± 0.3
Haslam	0.408		8.9[bd]	3.2[bd]	0.7[bd]	−0.8[bd]	0[a]	0[a]

0.6 % cal diff*

≈ 7-8 μK dipole difference between Planck and WMAP

* Due to different beam normalization conventions

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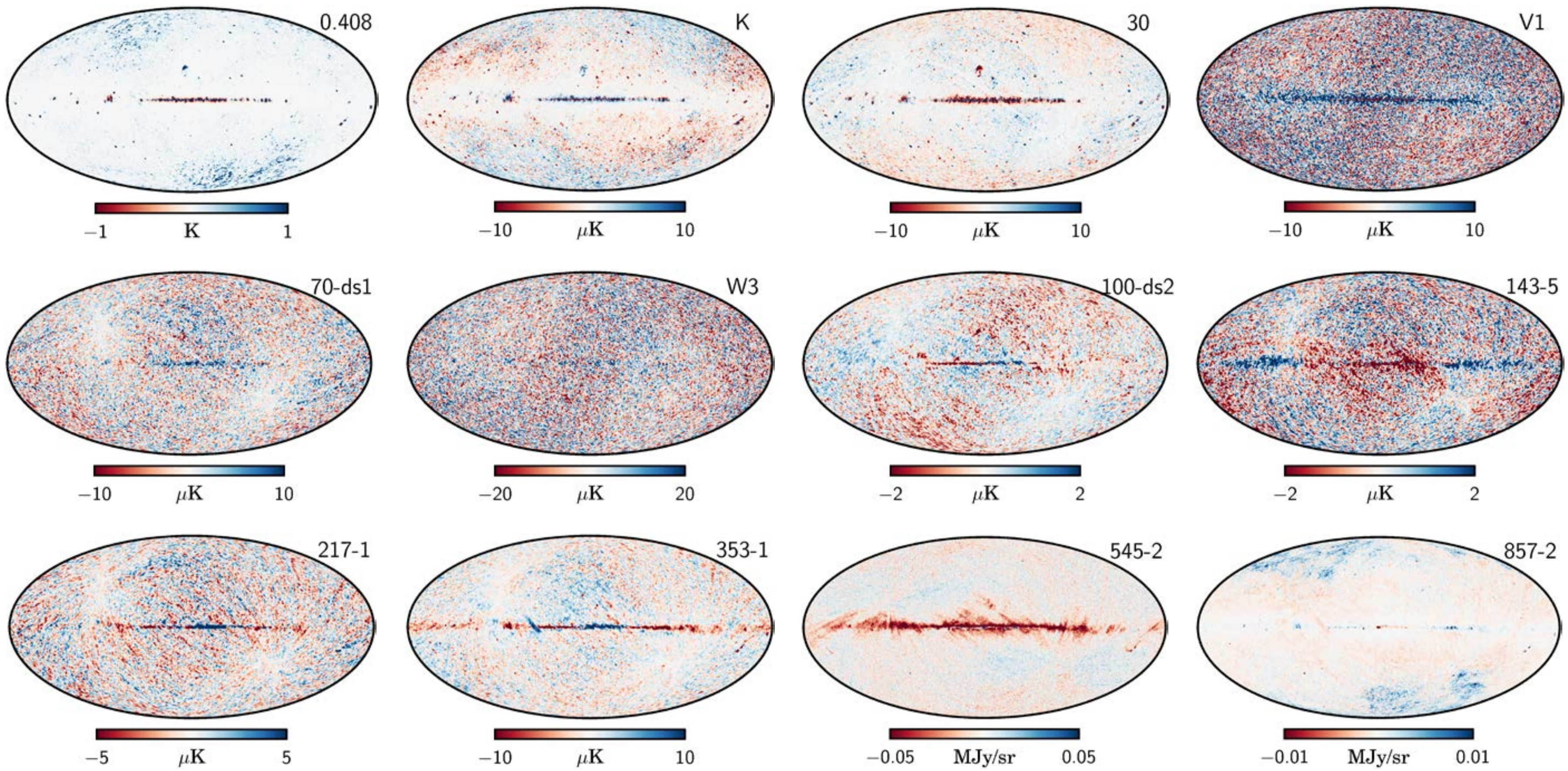
Goodness of fit



Residual maps, $\mathbf{d}_\nu$ - $\mathbf{s}_\nu$

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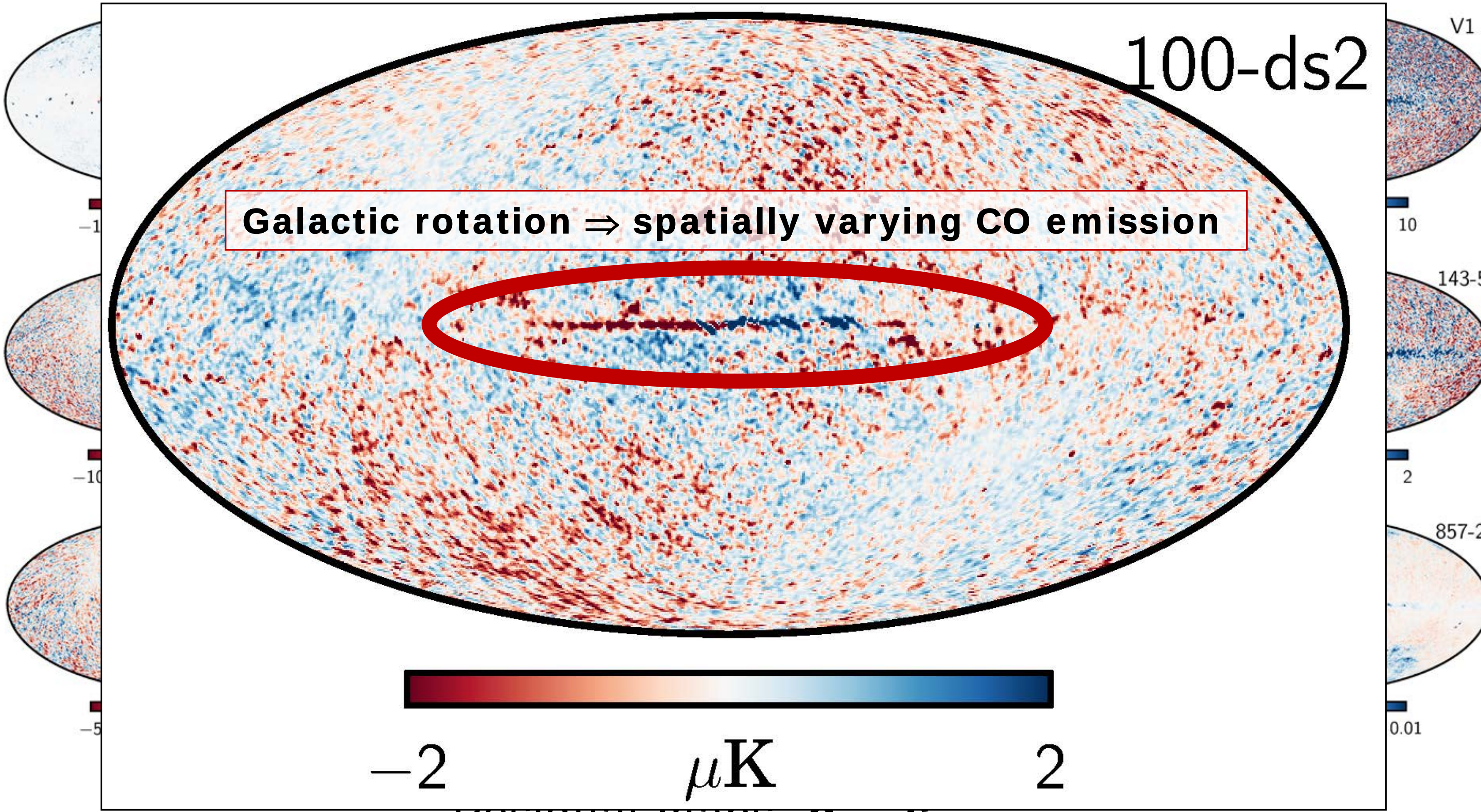
Goodness of fit



Residual maps, $\mathbf{d}_\nu$ - $\mathbf{s}_\nu$

Preliminary

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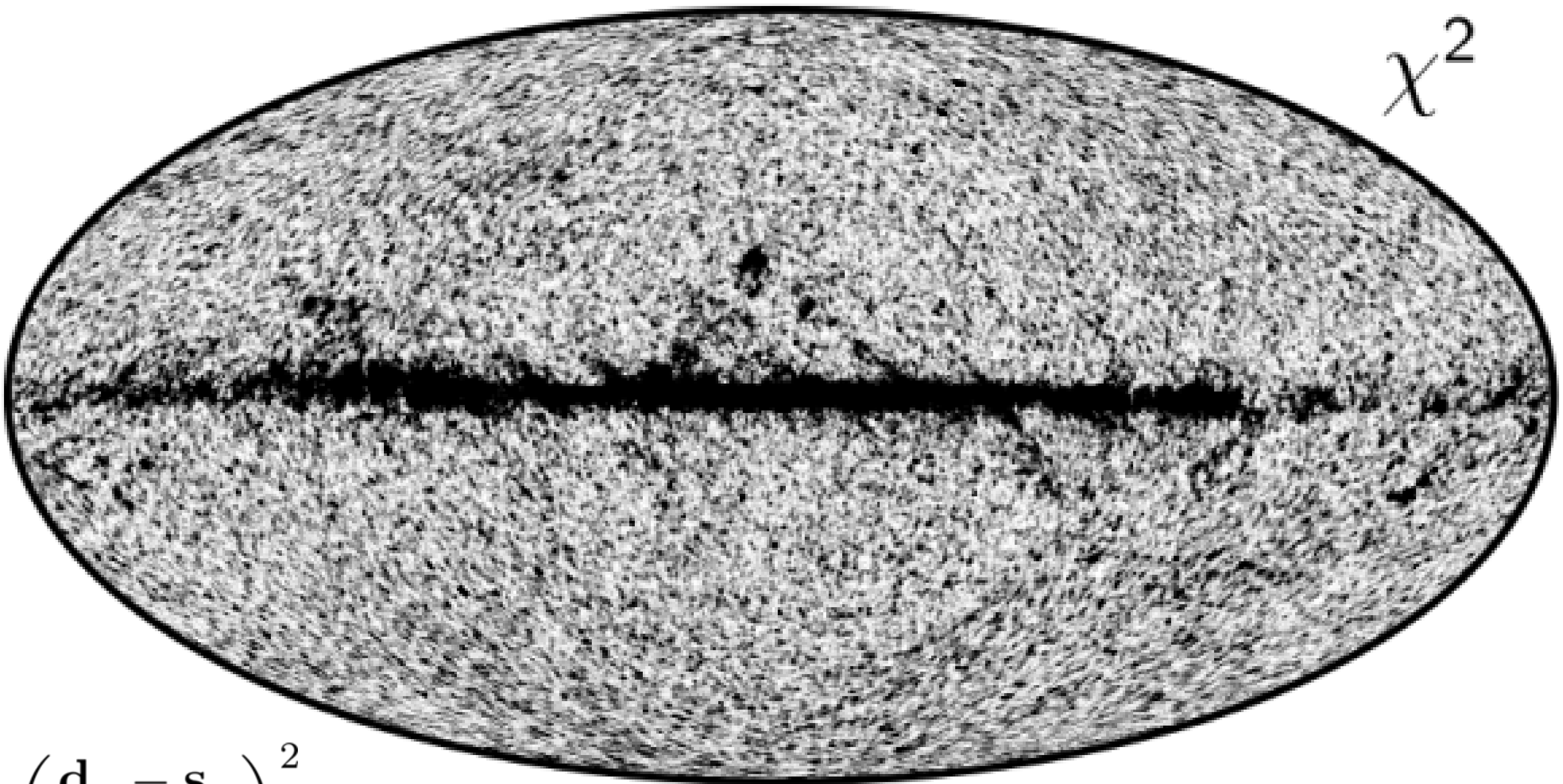

$$\chi^2 = \sum_{\nu} \left(\frac{\mathbf{d}_\nu - \mathbf{s}_\nu}{\sigma_\nu} \right)^2$$

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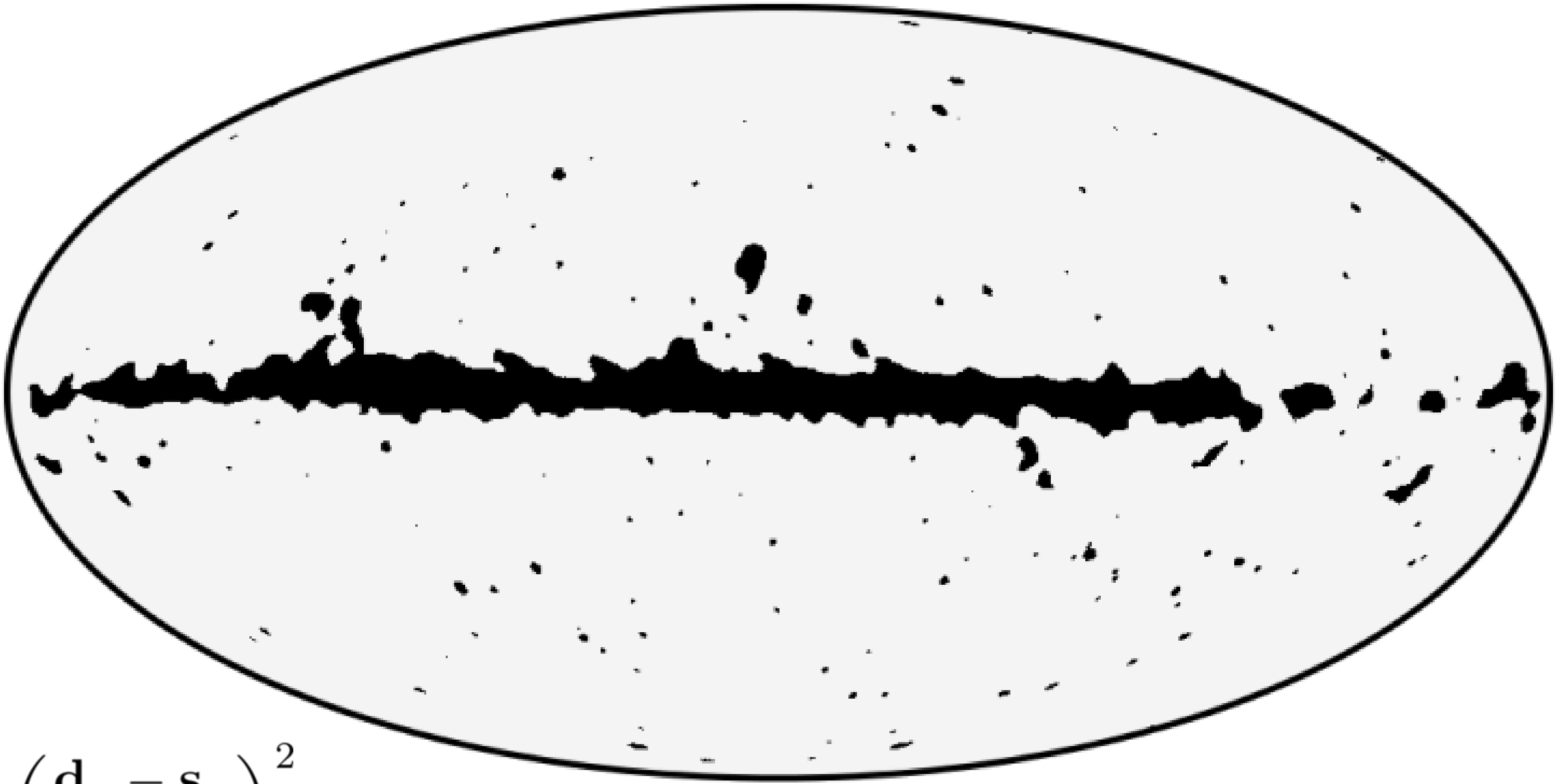
Goodness of fit



$$\chi^2 = \sum_{\nu} \left(\frac{\mathbf{d}_\nu - \mathbf{s}_\nu}{\sigma_\nu} \right)^2$$

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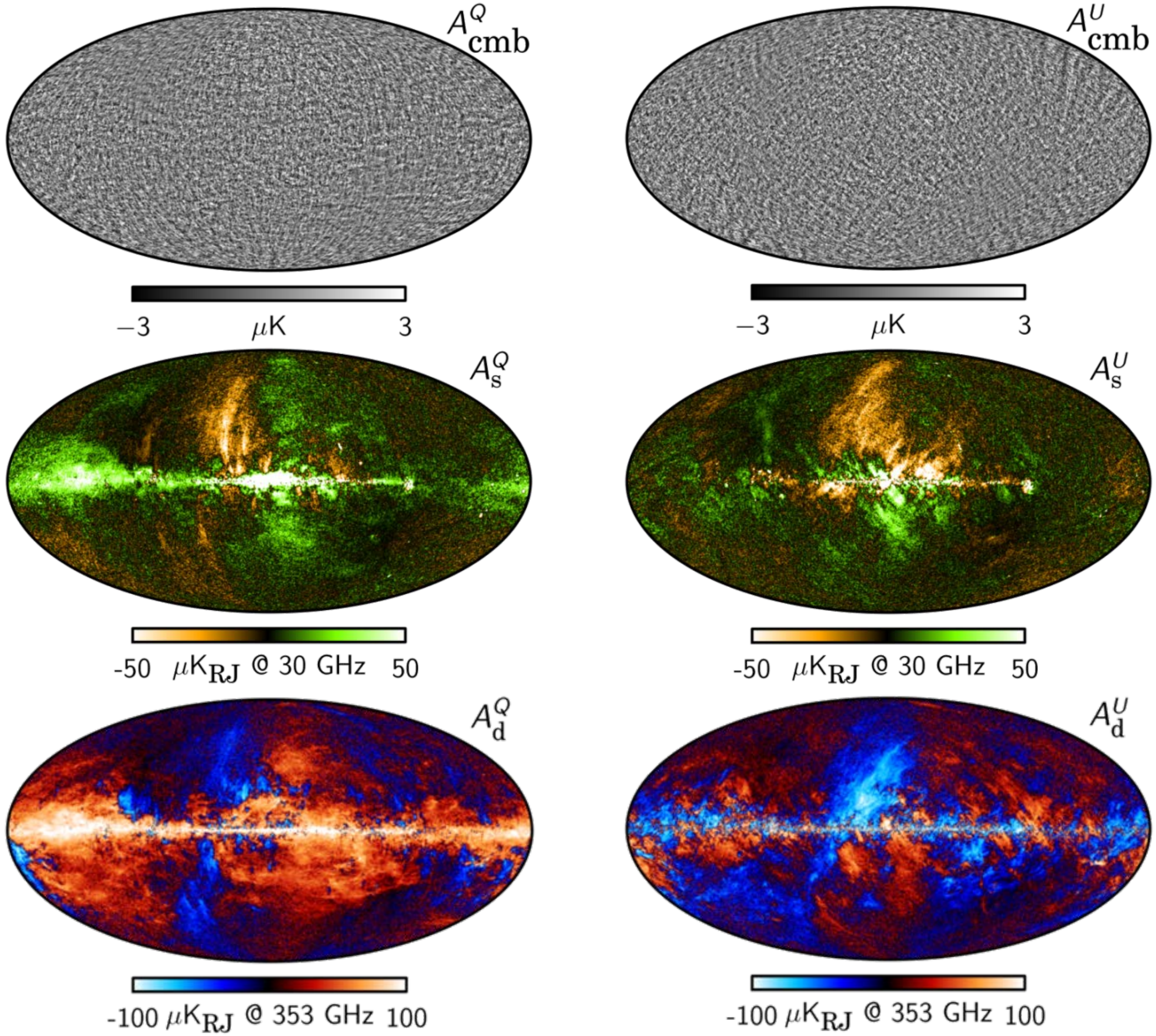
Polarization sky model



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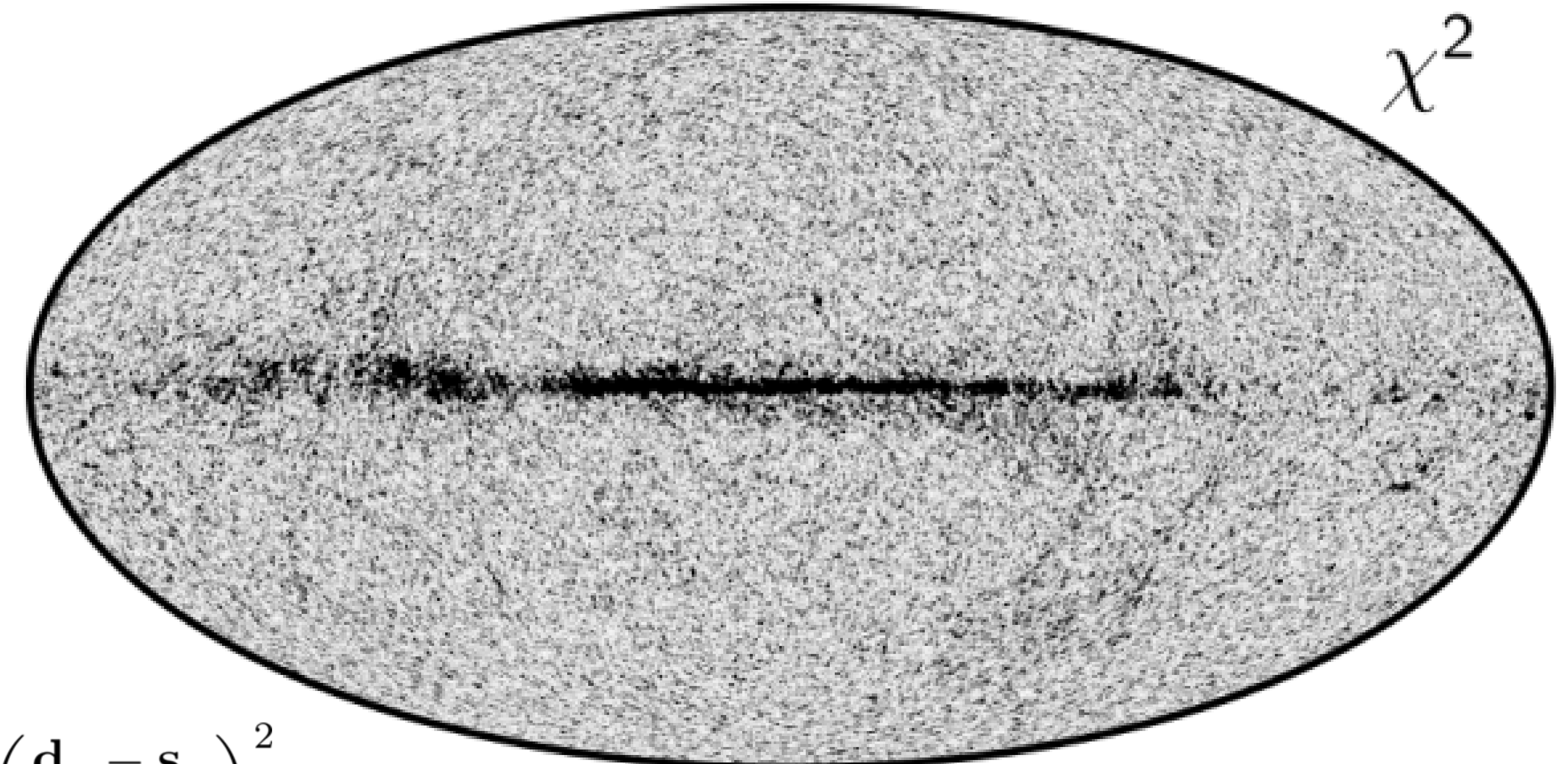
Goodness of fit



$$\chi^2 = \sum_{\nu} \left(\frac{\mathbf{d}_\nu - \mathbf{s}_\nu}{\sigma_\nu} \right)^2$$

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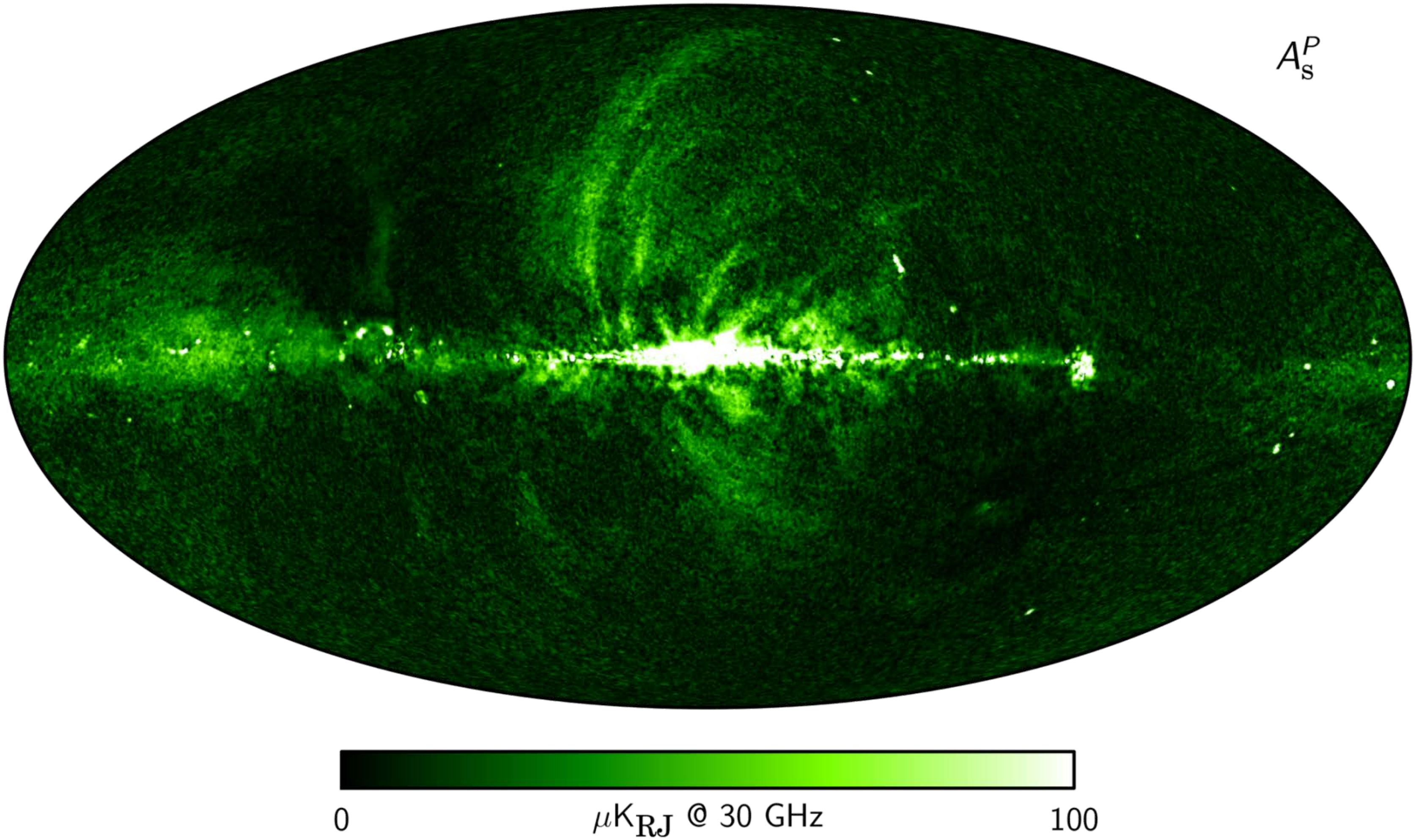
Polarized synchrotron at 30 GHz



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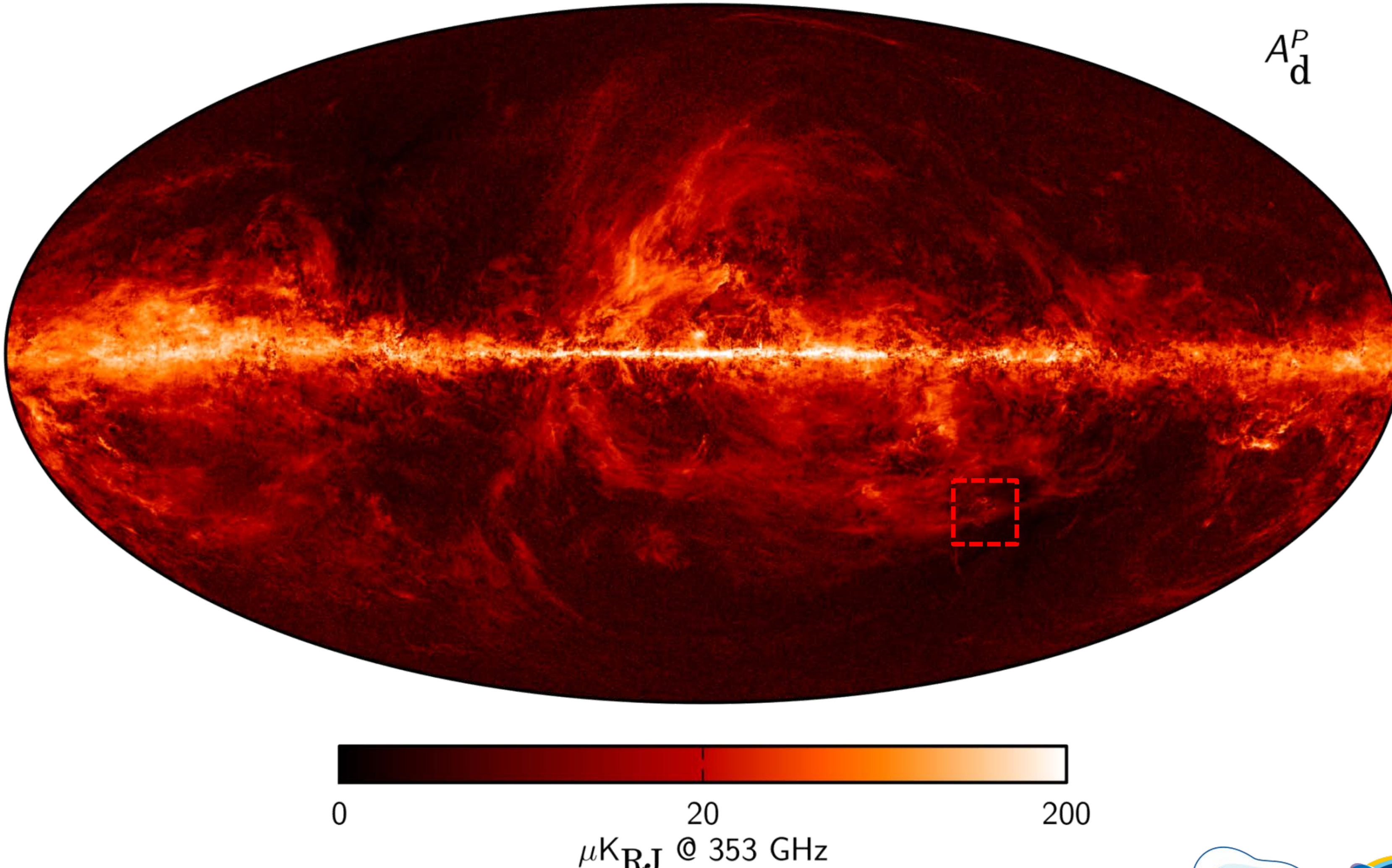
Polarized thermal dust at 353 GHz



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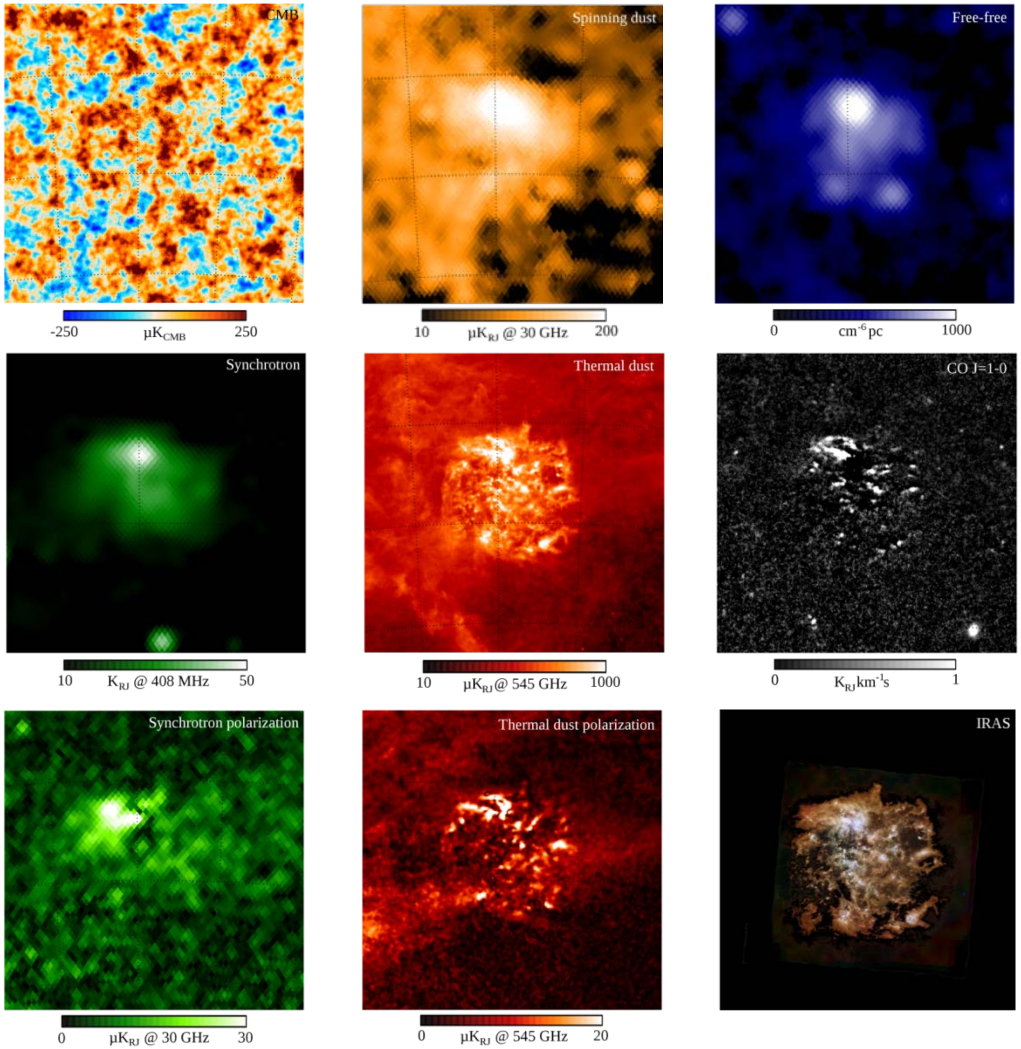
Large Magellanic Cloud



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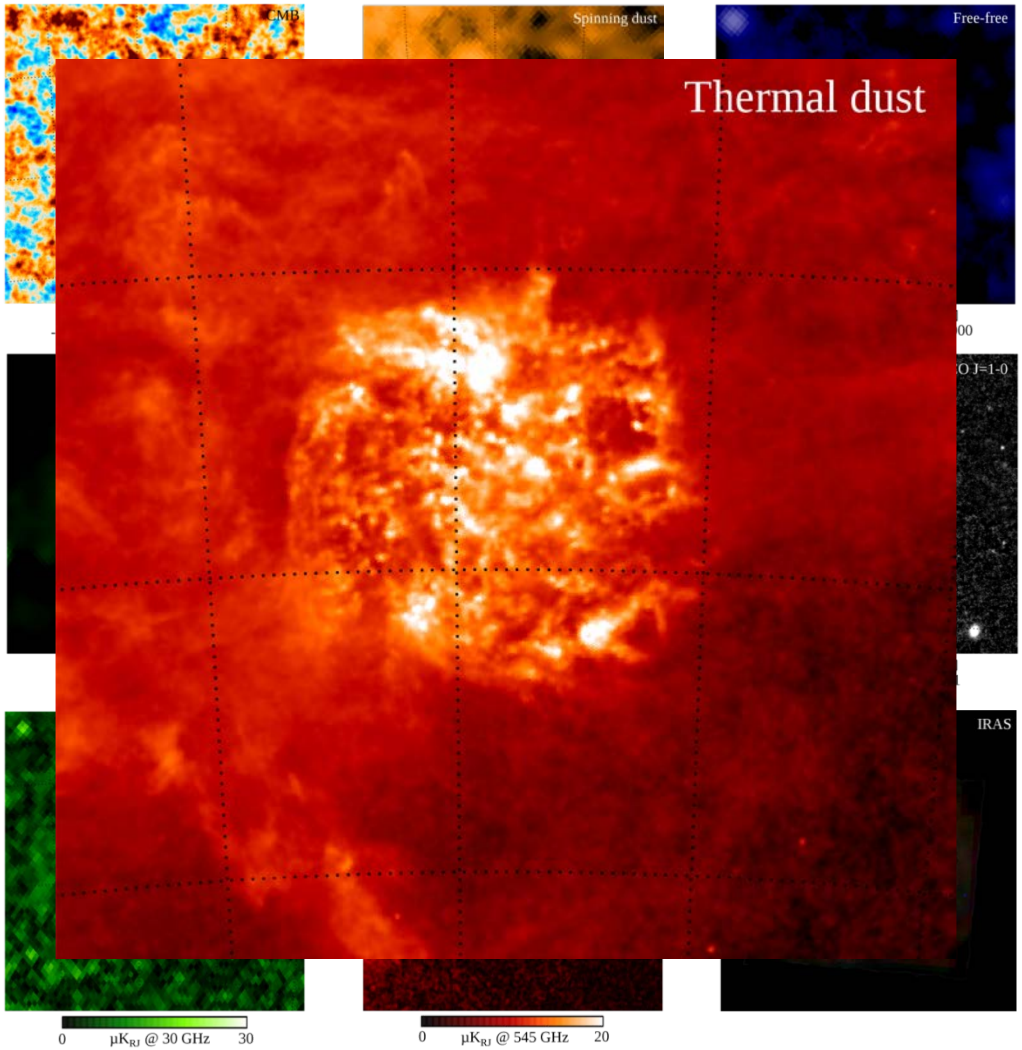

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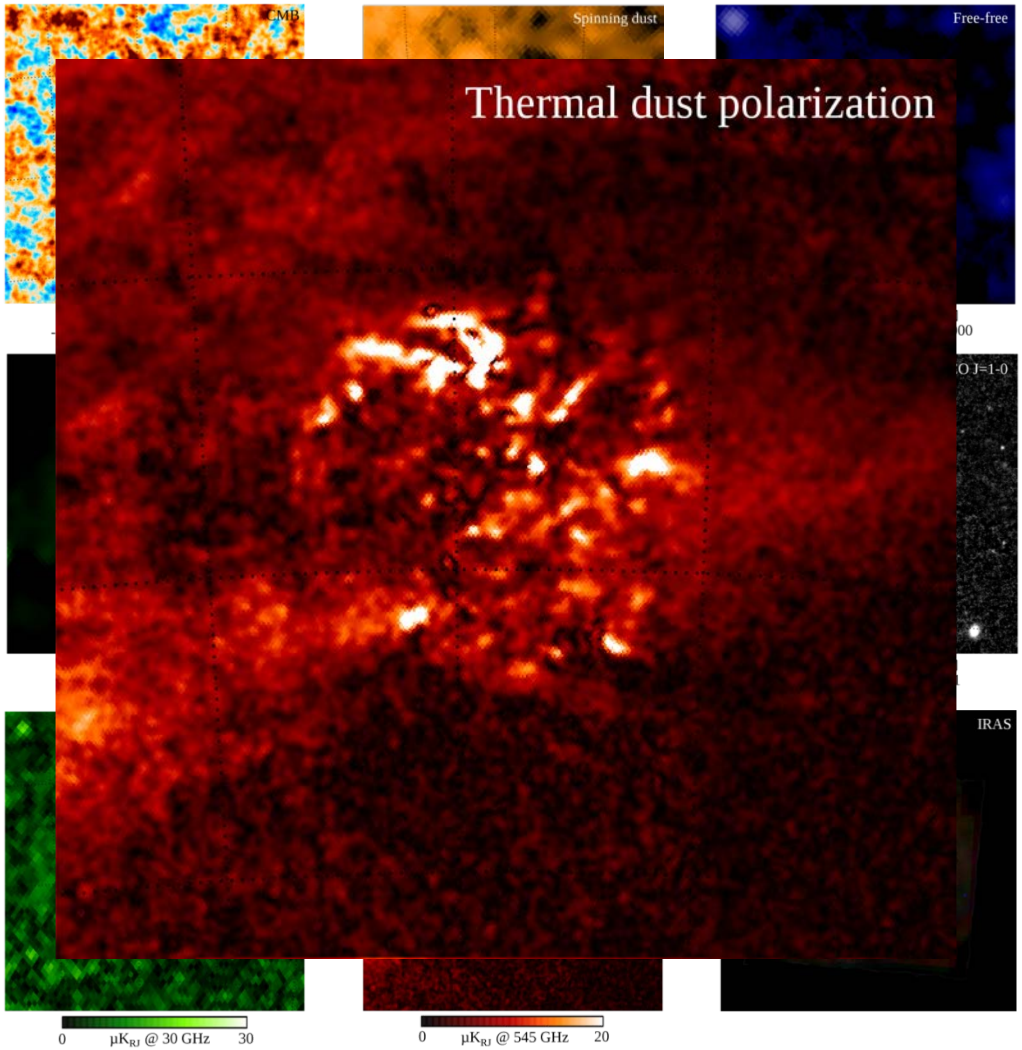

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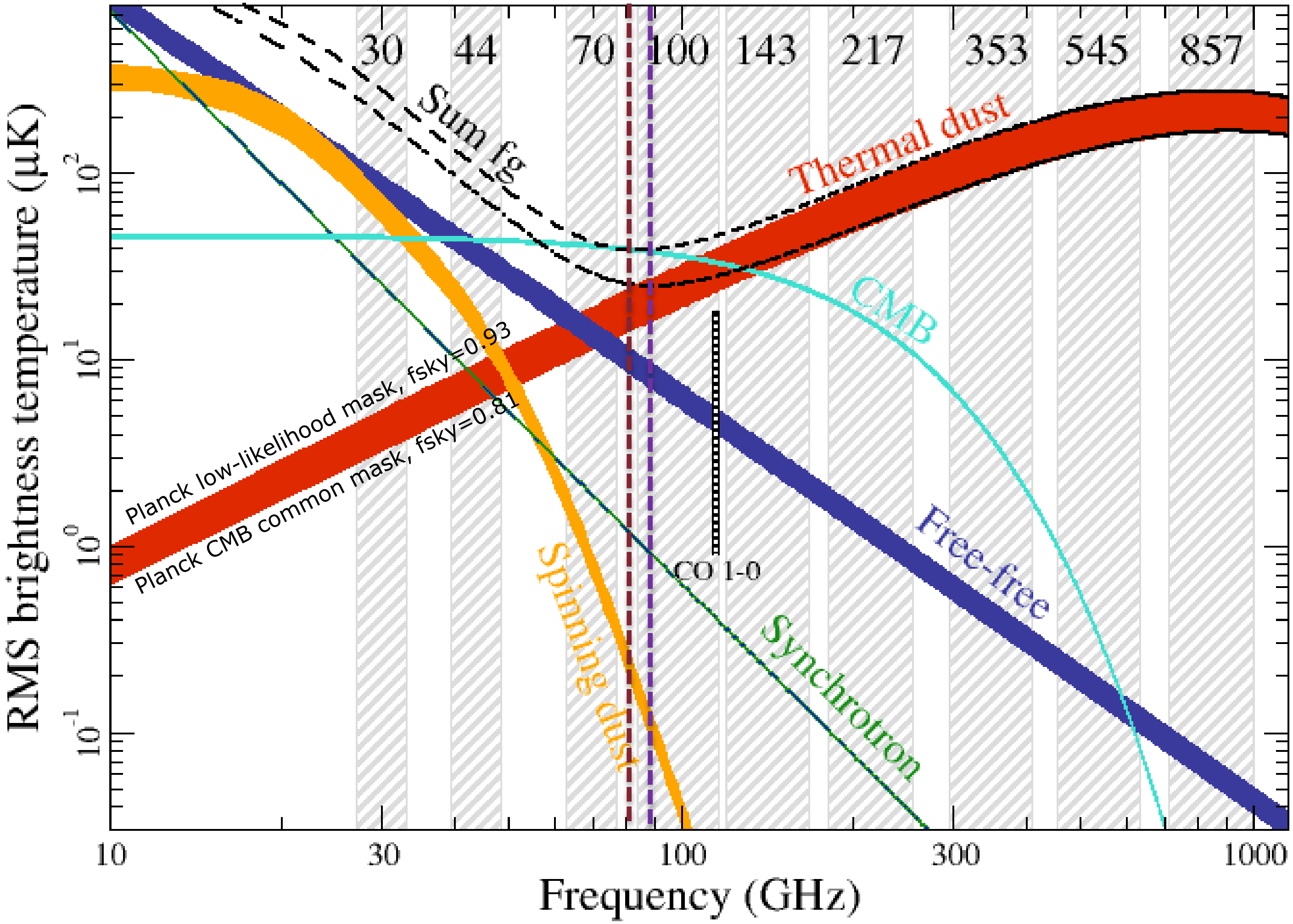
Temperature foregrounds at a glance



Temperature fore-ground minimum between **80 and 90 GHz** for sky fractions between 81 and 93% at **1 degree** resolution

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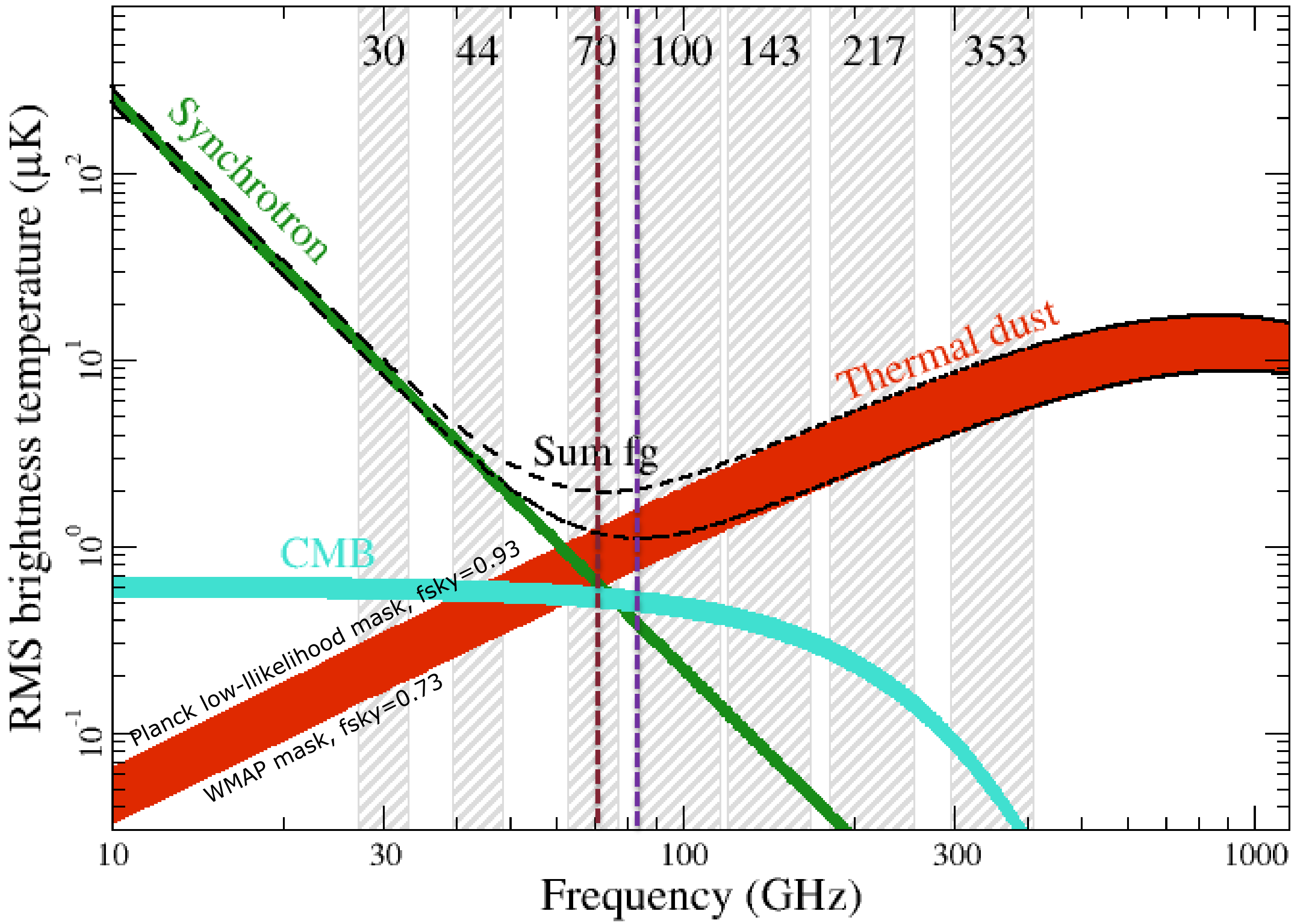
Polarization foregrounds at a glance



Polarization foreground minimum between **70 and 85 GHz** for sky fractions between 73 and 93% at **40 arcmin** resolution

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Summary

- Planck will soon deliver new astrophysical component maps in both temperature and polarization
  - First full-sky polarized thermal dust map
- The intensity model reproduces observations to a few μK over 93% of the high-latitude sky across the CMB channels, and to 1% in the remaining 7% of the sky
- Although the results look promising, important caveats to have in mind are:
  - There are still significant degeneracies between synchrotron, free-free and spinning dust, and observations from C-BASS, S-PASS, QUIJOTE etc. are needed to break these
  - The 545 and 857 GHz calibrations are uncertain by several percent, leading to corresponding uncertainties in the thermal dust model
  - Large-scale polarization systematics, as discussed yesterday, are relevant not only for CMB maps, but also for polarization foreground maps

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.


Thank you