# The microwave sky as seen by Planck

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***on behalf of the Planck Collaboration***

# Bayesian component separation

- 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

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

Bandpass

Monopole/dipole

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

Calibration

Spectral index

Signal amplitude

- The posterior distribution reads

Likelihood

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

Prior

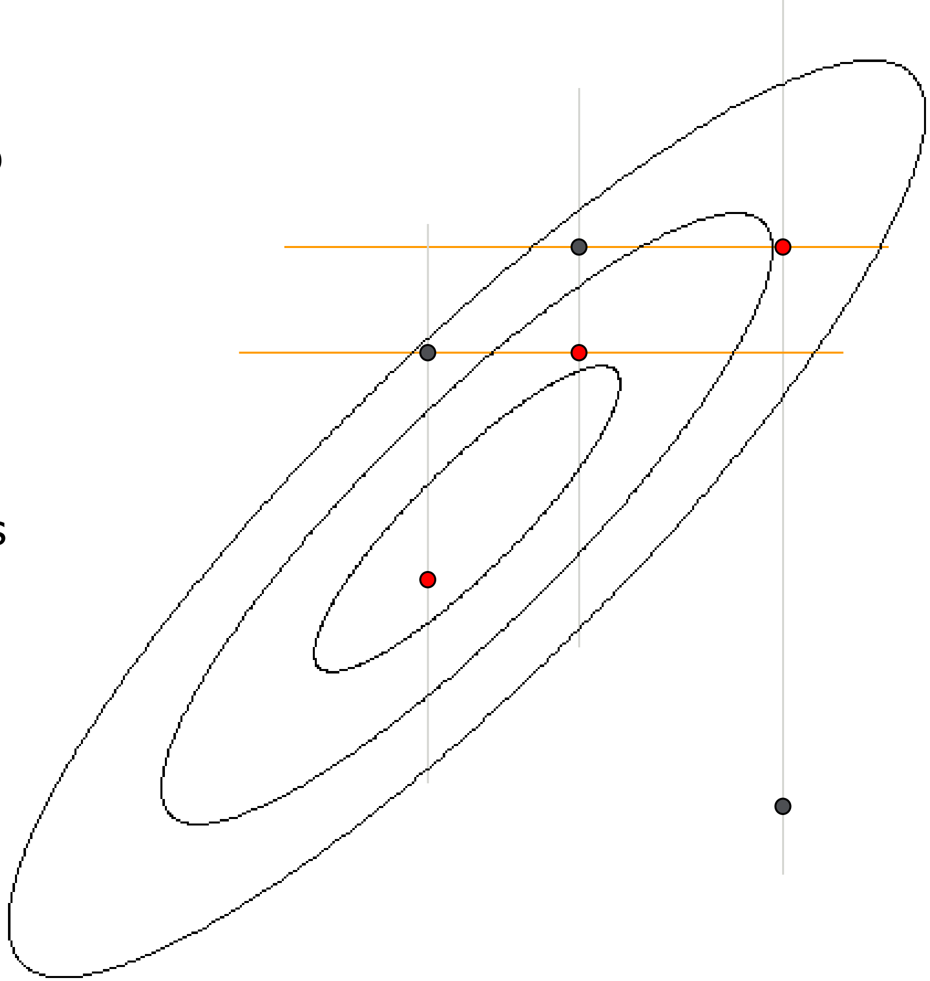
- The noise is very nearly Gaussian distributed, and the likelihood is given by

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

# 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:

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



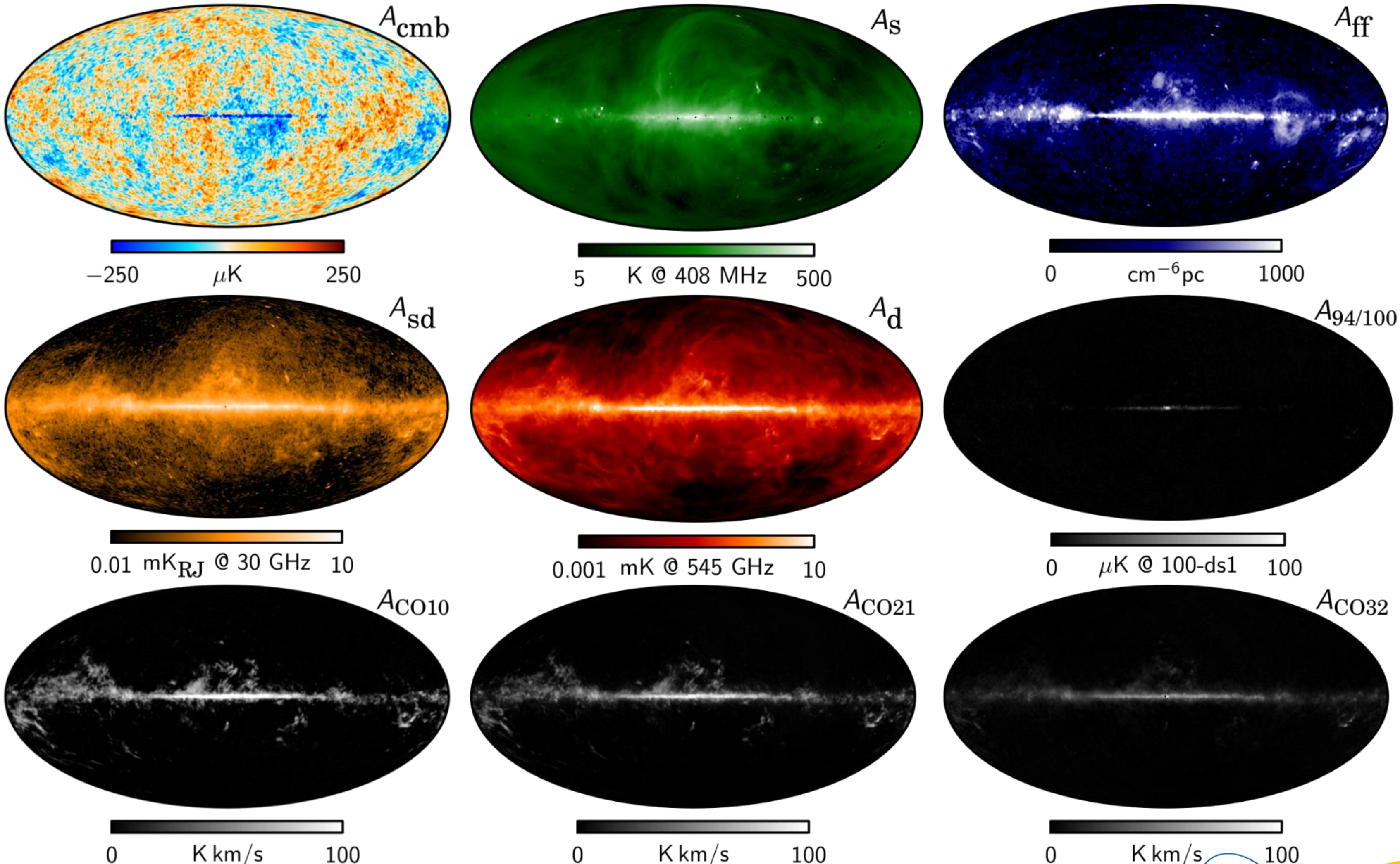
## 2013

- Temperature only
- Seven Planck channels between 30 and 353 GHz
- Co-added frequency channels
- Single low-frequency foreground
- Spatially constant dust temperature
- Single CO emission map with fixed frequency scalings
- Assumed nominal calibration and bandpass parameters

## 2015

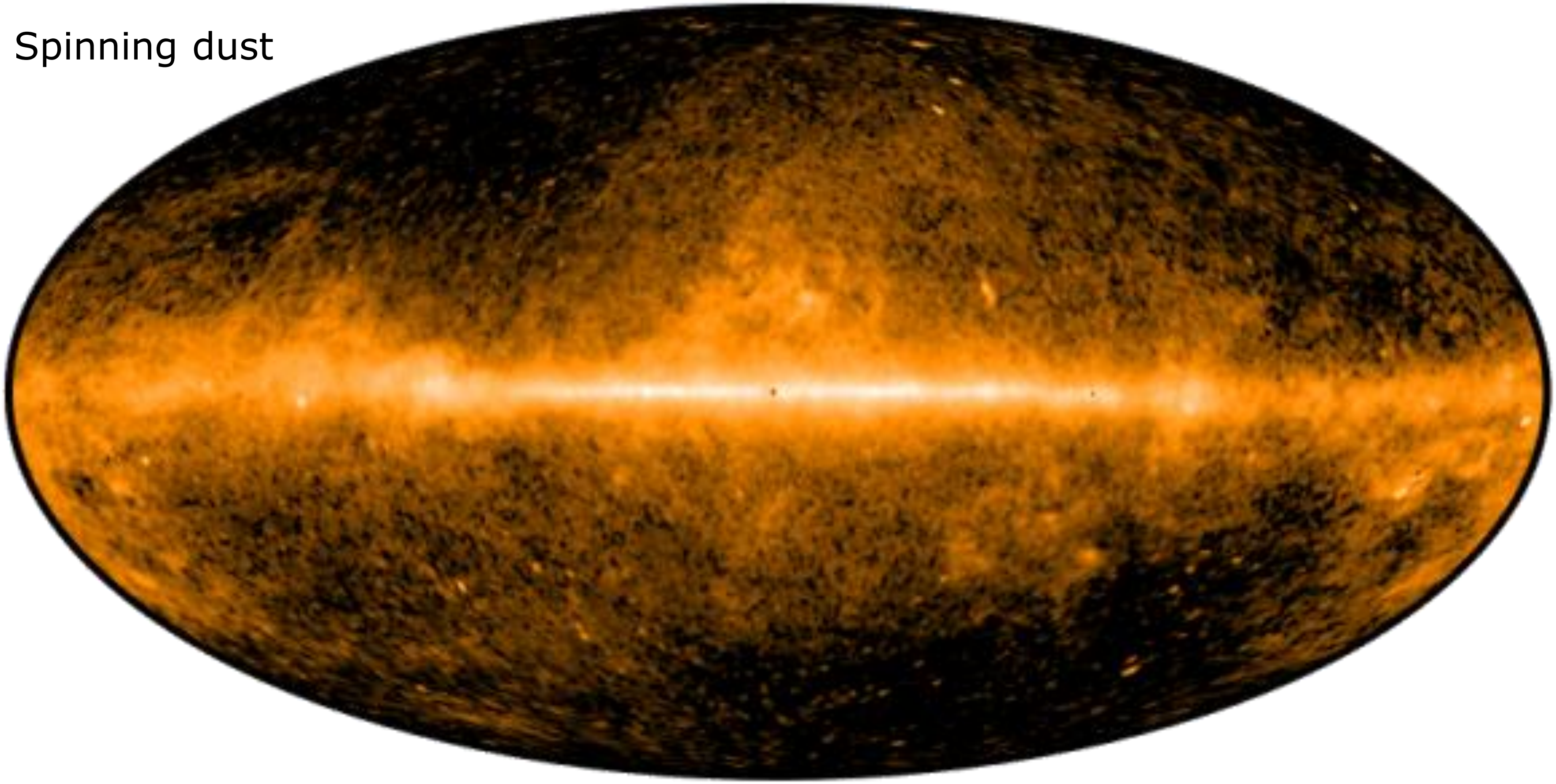
- Temperature and polarization
- Nine Planck channels between 30 and 857 GHz
  - Ancilliary data: WMAP, 408MHz
- Fine-grained detector maps
  - Better handle on line emission mechanisms and bandpass
- Separate syncrotron, free-free and spinning dust components
- Spatially varying dust temperature
- Individual CO $J=1\rightarrow0$, $2\rightarrow1$ and $3\rightarrow2$ maps; new 94/100 GHz line map
- Jointly fit calibration and bandpass parameters in signal model

# Temperature sky model



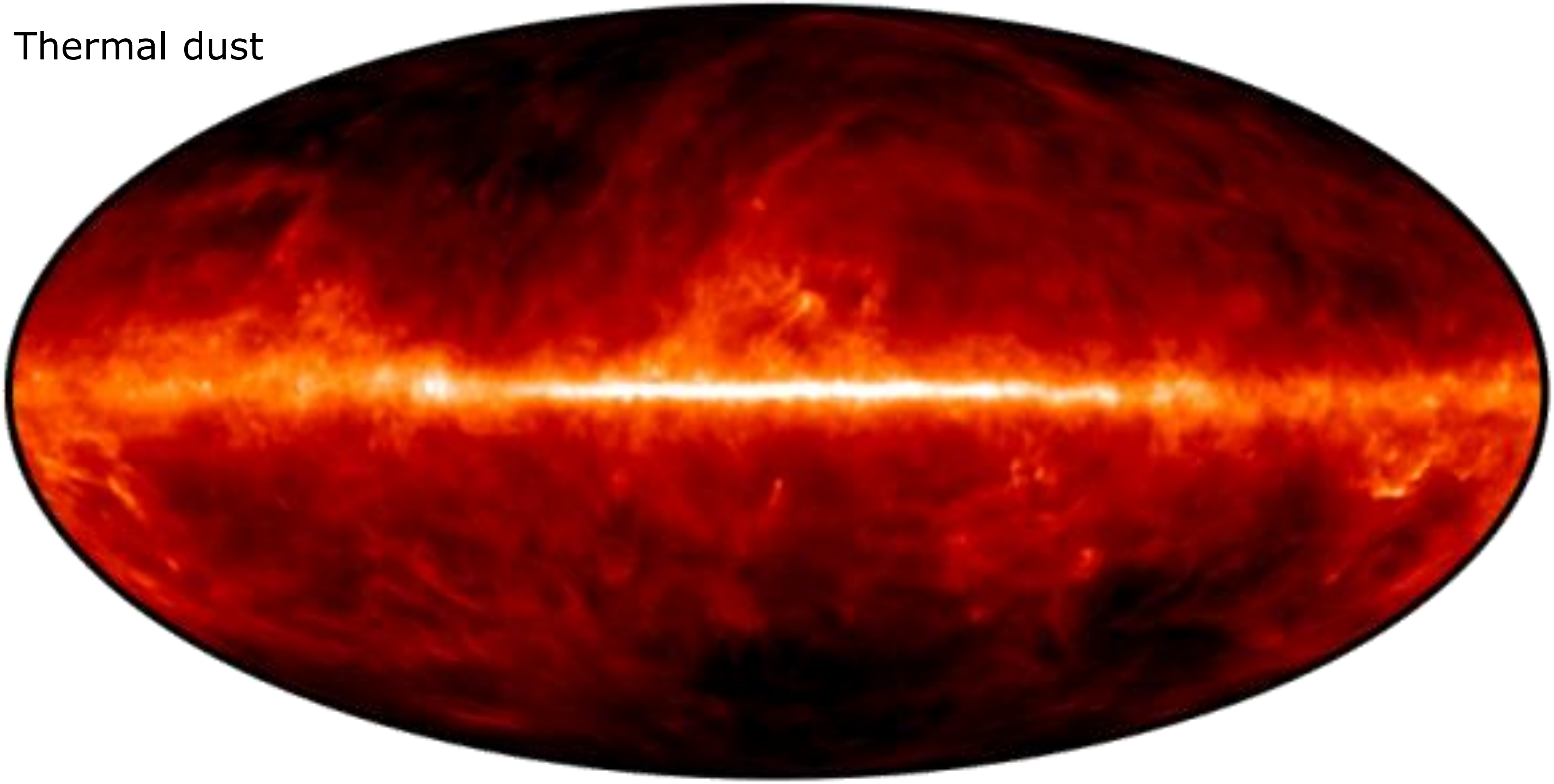
# Thermal vs spinning dust

Spinning dust

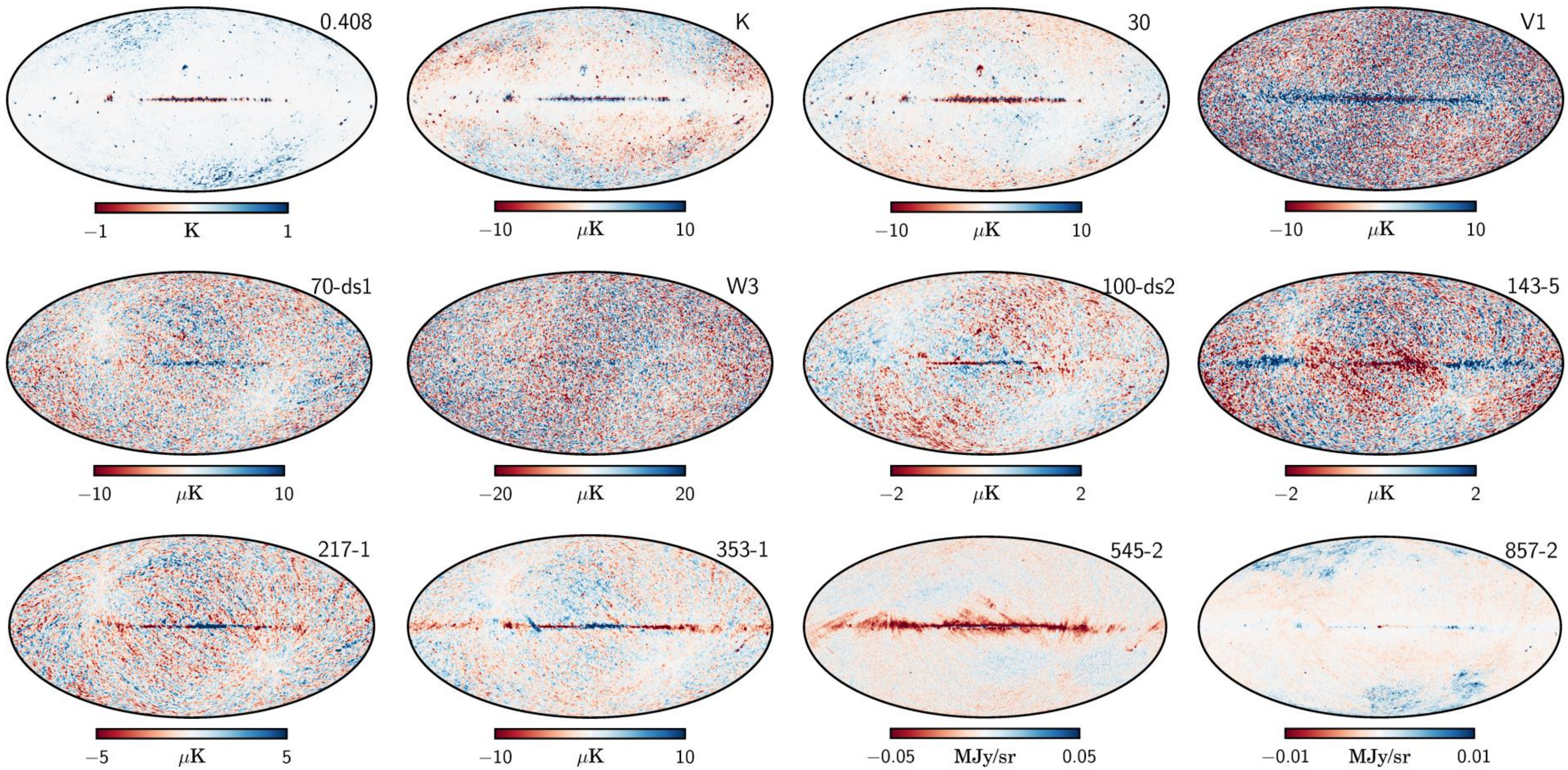


# Thermal vs spinning dust

Thermal dust

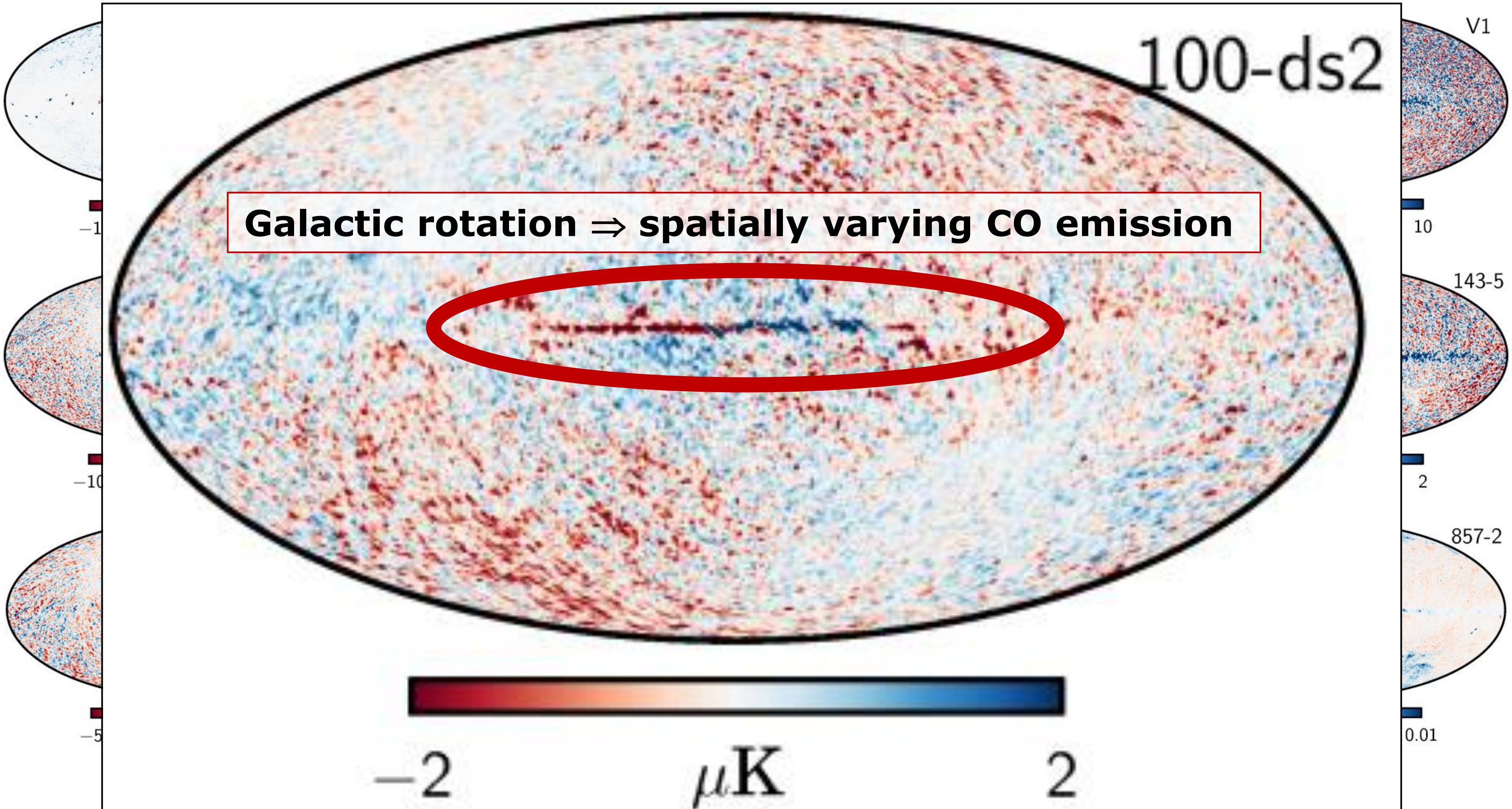


# Goodness of fit



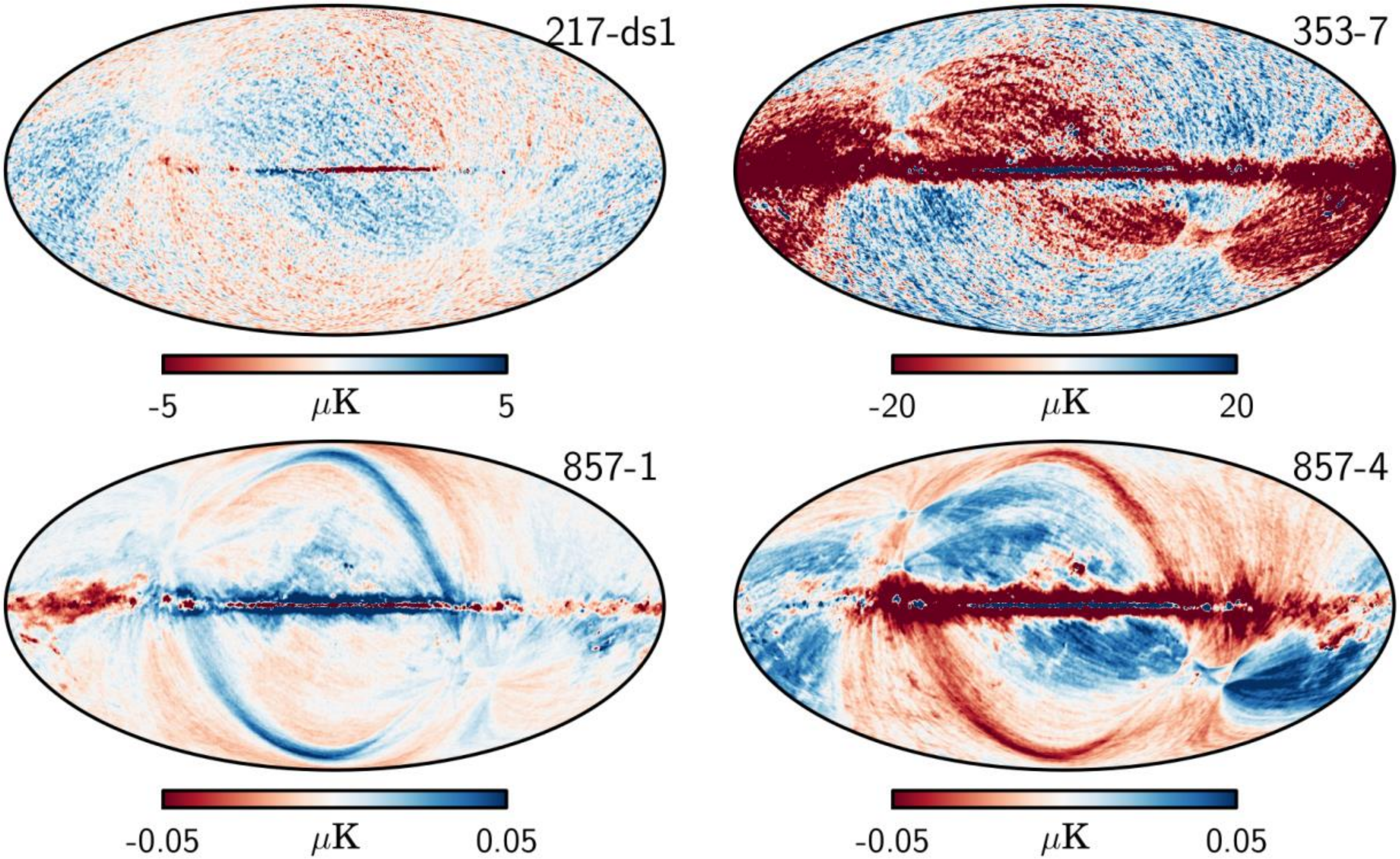

Residual maps, $\mathbf{d}_\nu - \mathbf{s}_\nu$

# Goodness of fit

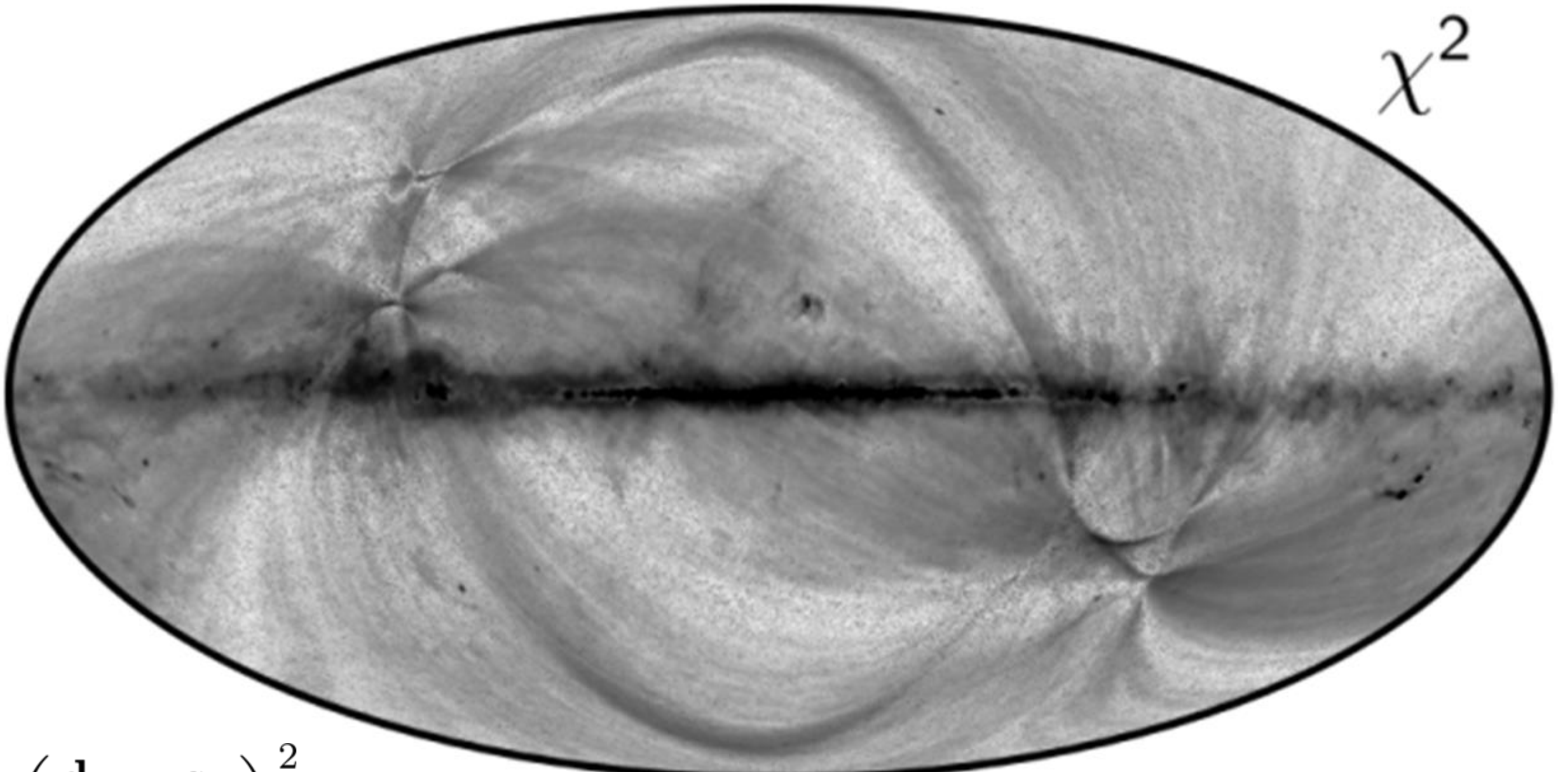



Residual maps, $\mathbf{d}_\nu$ - $\mathbf{s}_\nu$

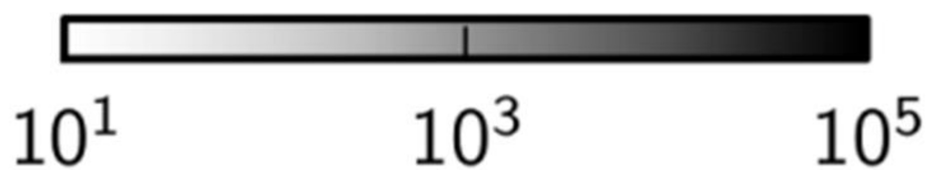
# Data selection and bad channels



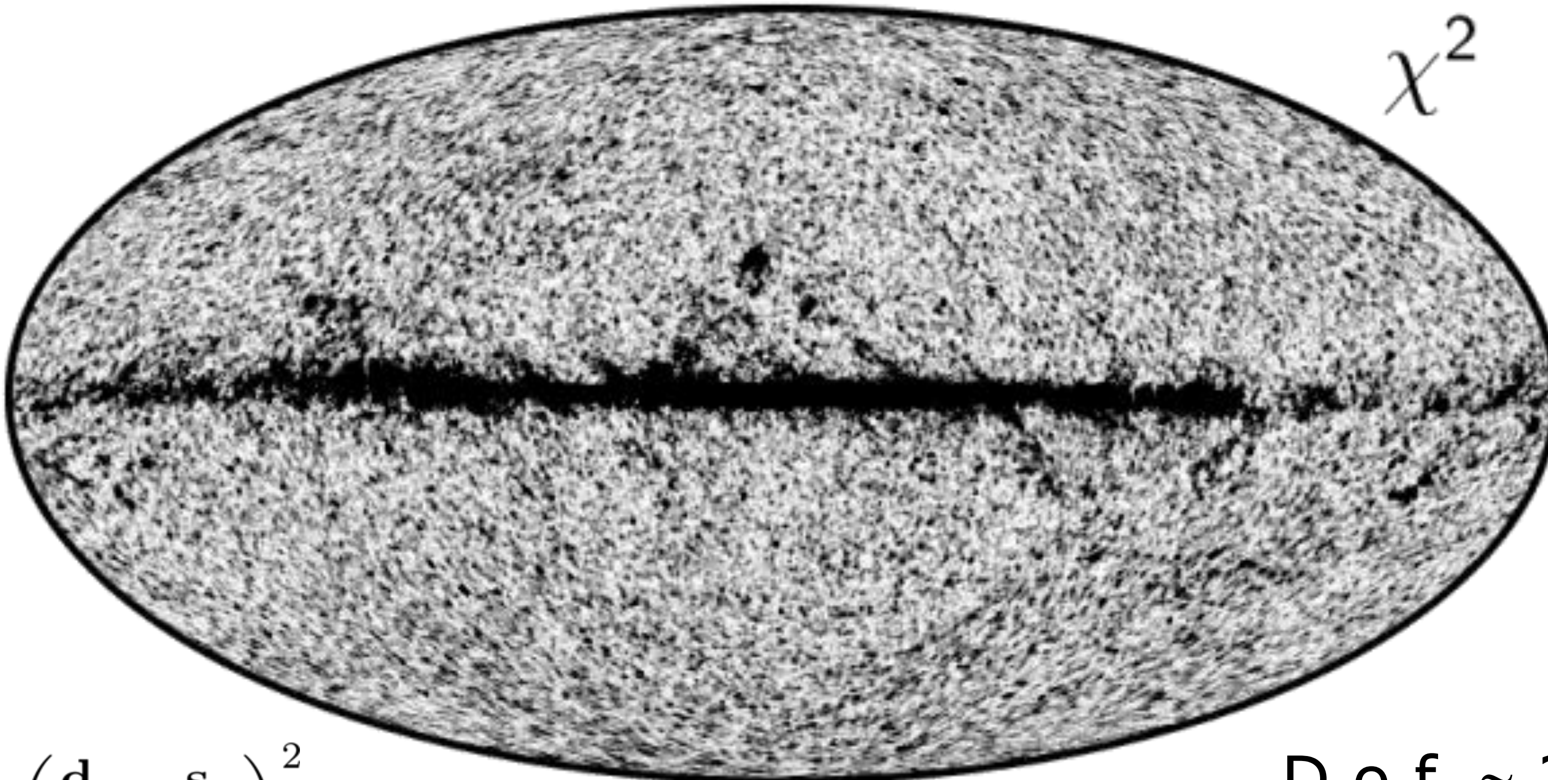
# Goodness of fit




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



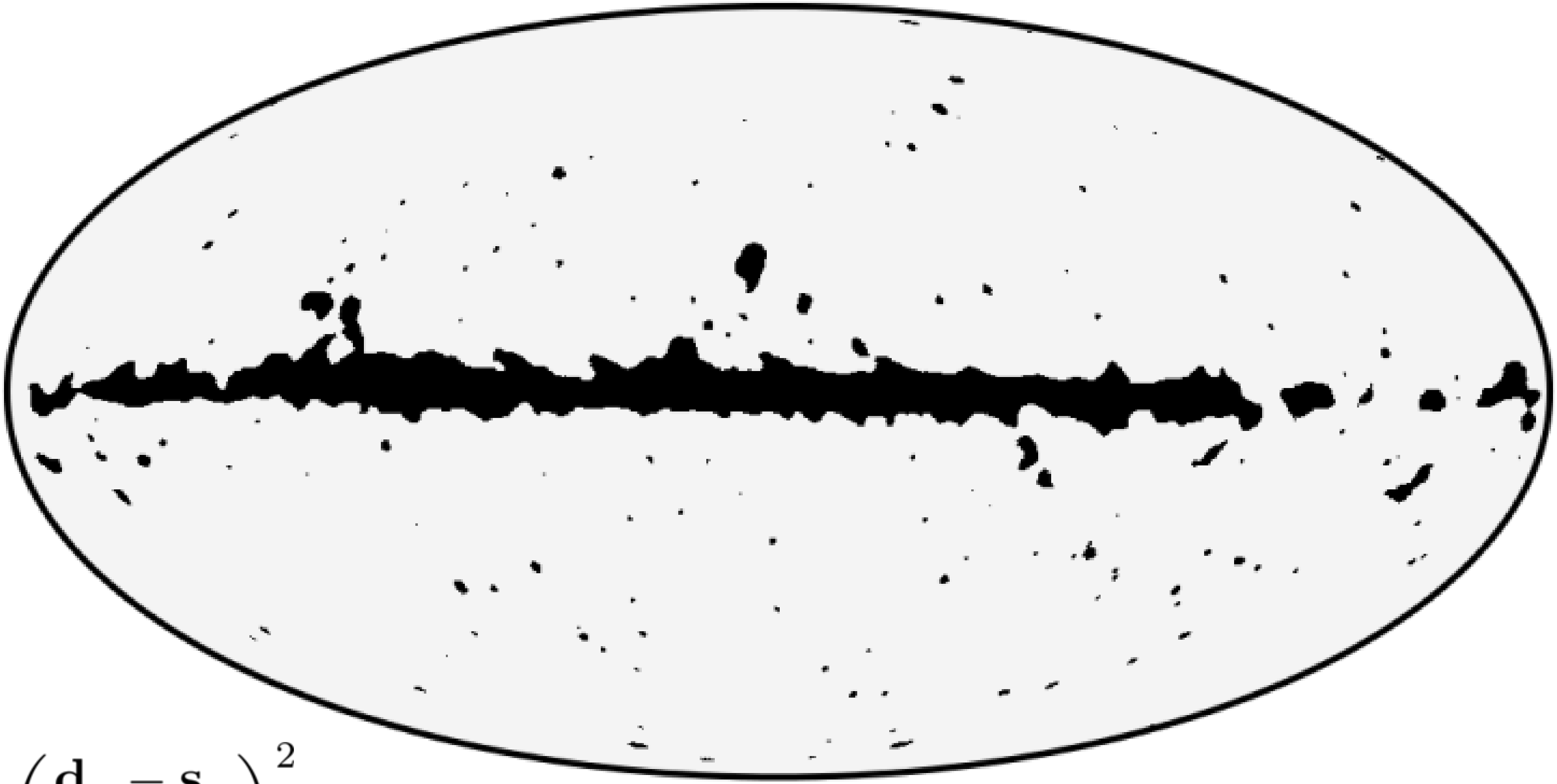
# Goodness of fit




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

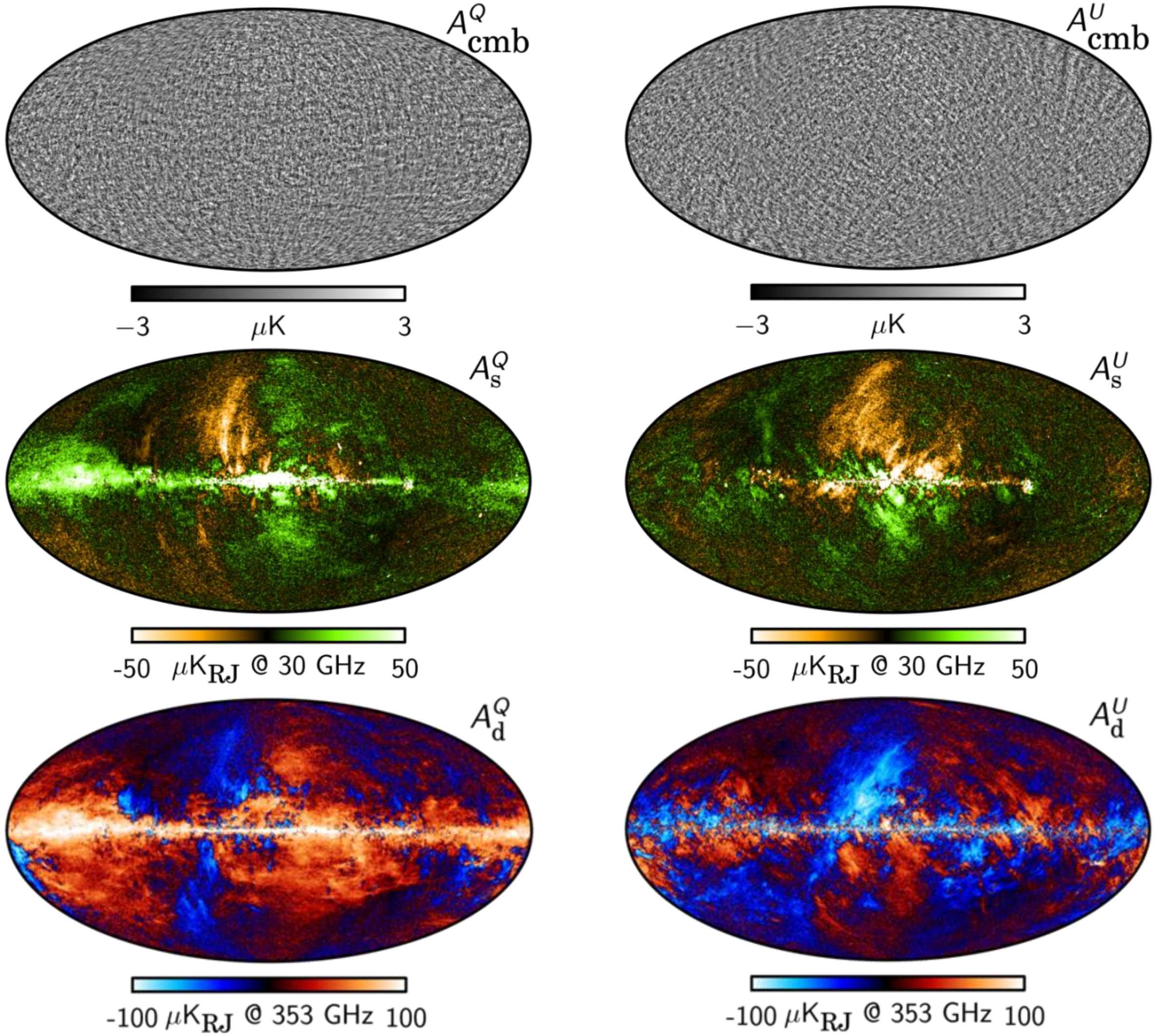

D.o.f. ≈ 20

# Goodness of fit

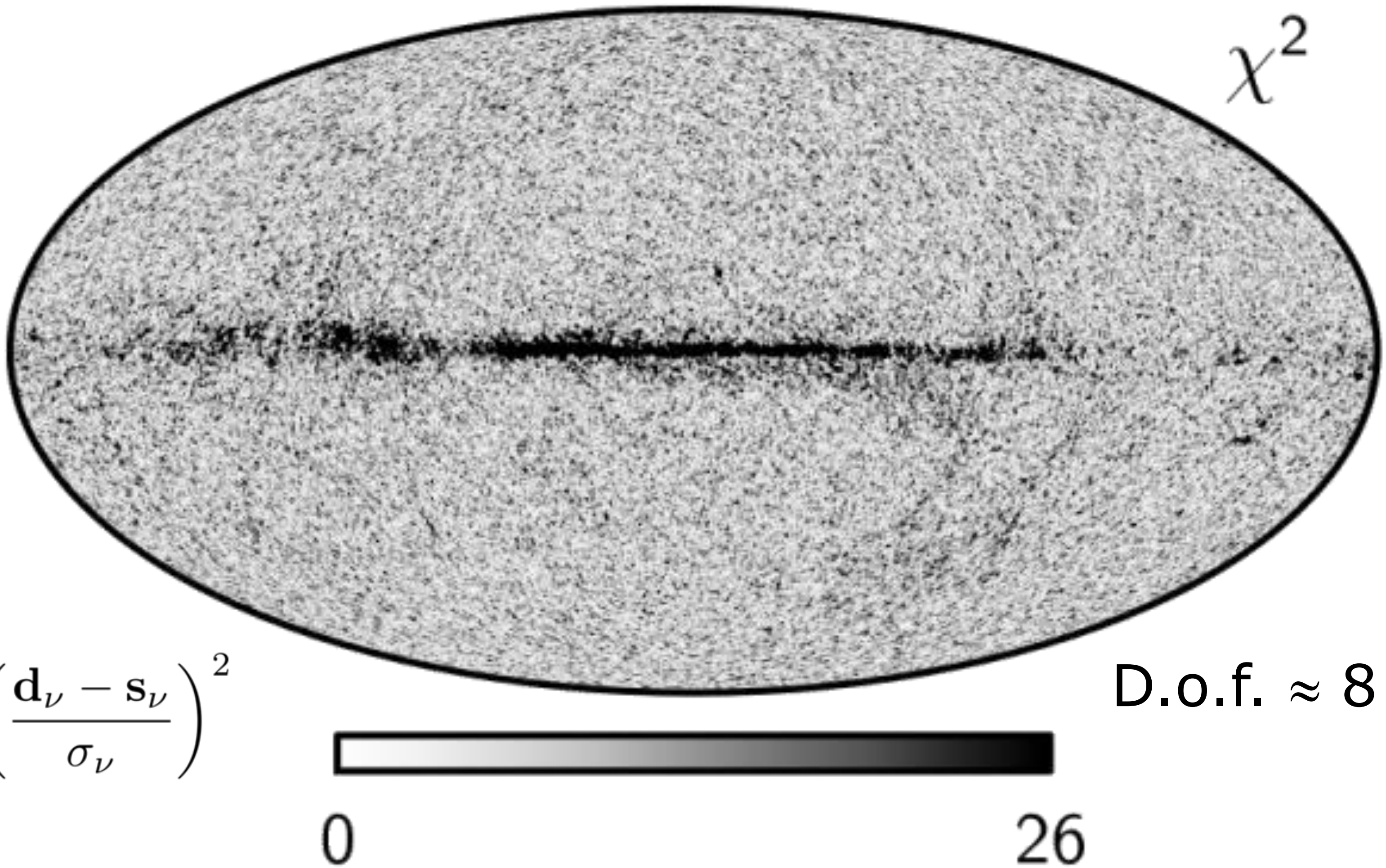


$$\chi^2 = \sum_{\nu} \left( \frac{\mathbf{d}_\nu - \mathbf{s}_\nu}{\sigma_\nu} \right)^2$$

# Polarization sky model



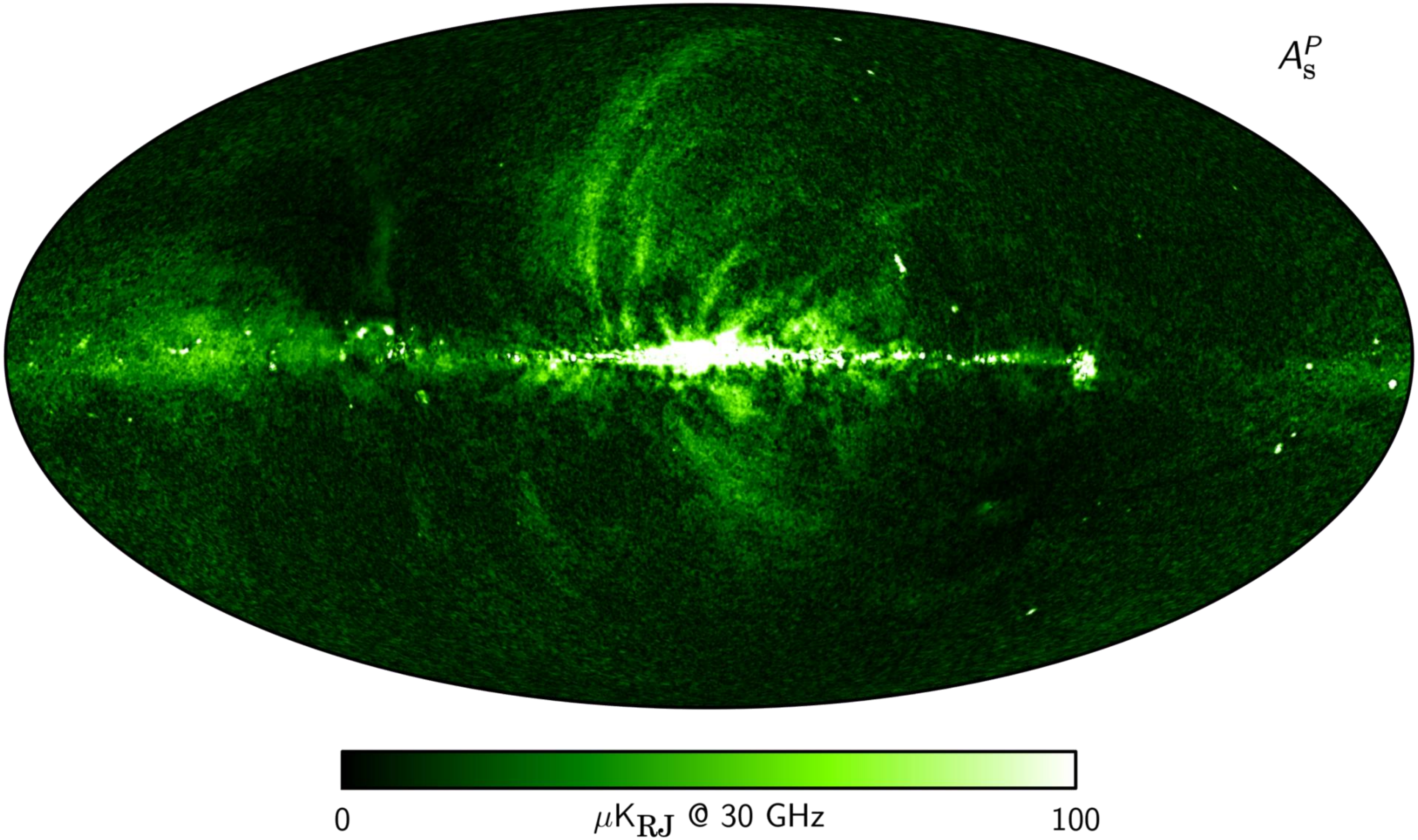
# Goodness of fit



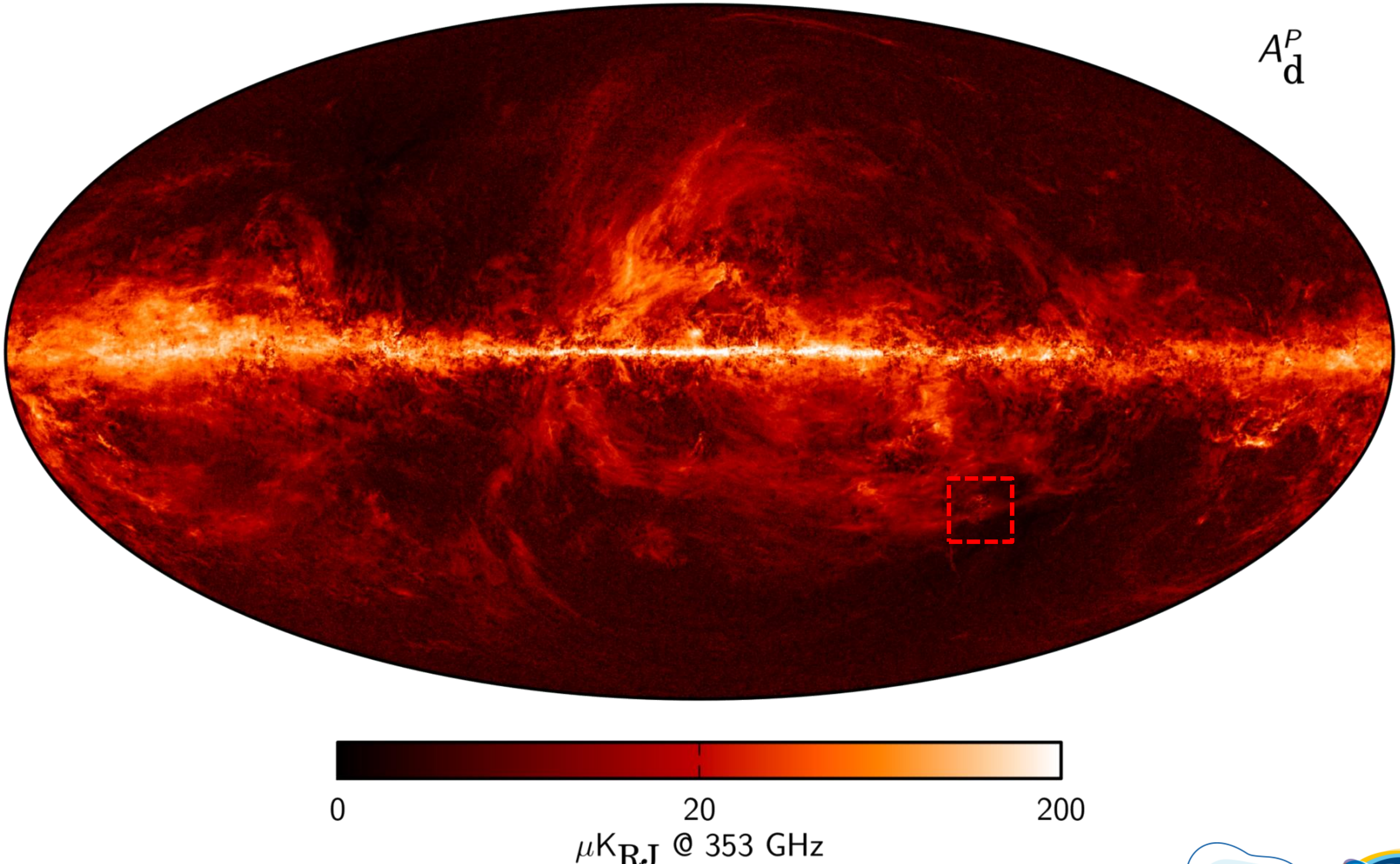

$$\chi^2 = \sum_\nu \left( \frac{\mathbf{d}_\nu - \mathbf{s}_\nu}{\sigma_\nu} \right)^2$$

D.o.f. $\approx 8$

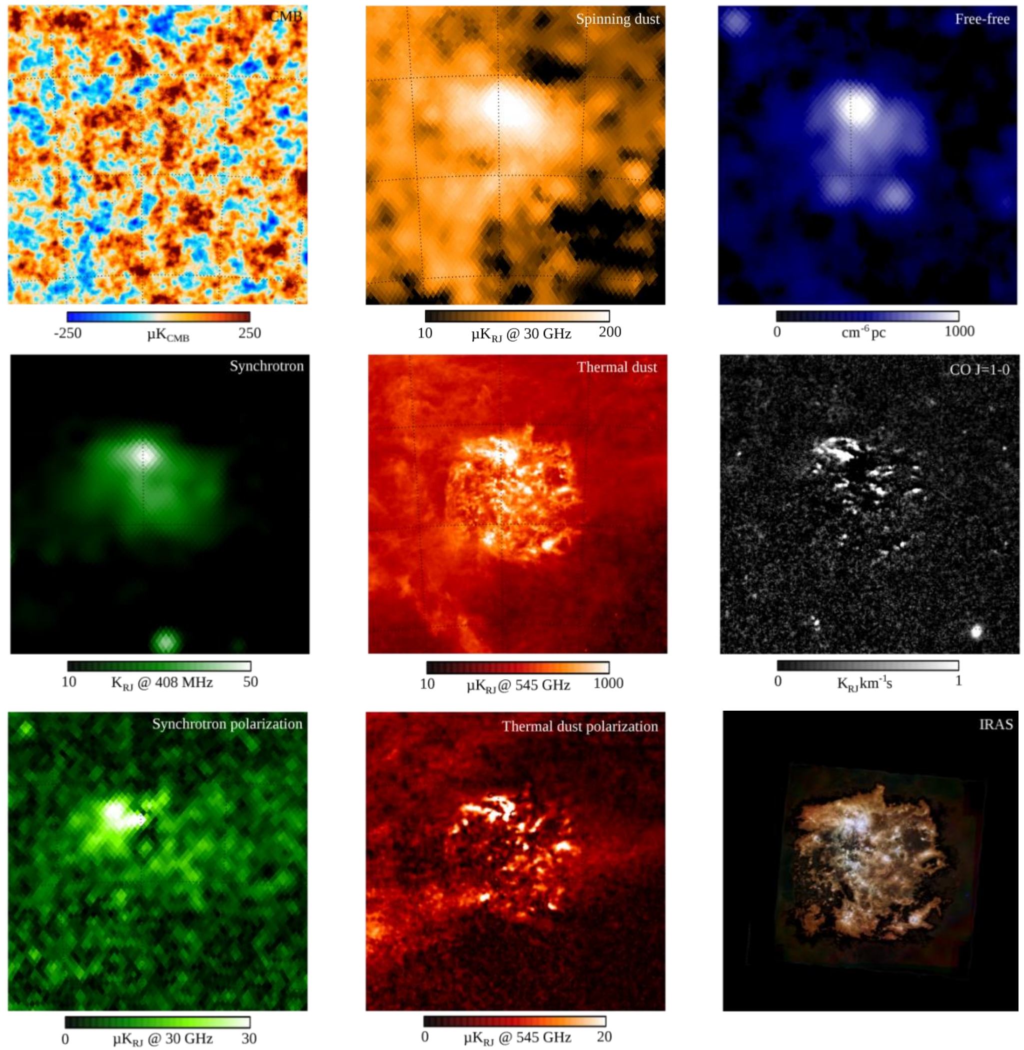
# Polarized synchrotron at 30 GHz



# Polarized thermal dust at 353 GHz



# Large Magellanic Cloud



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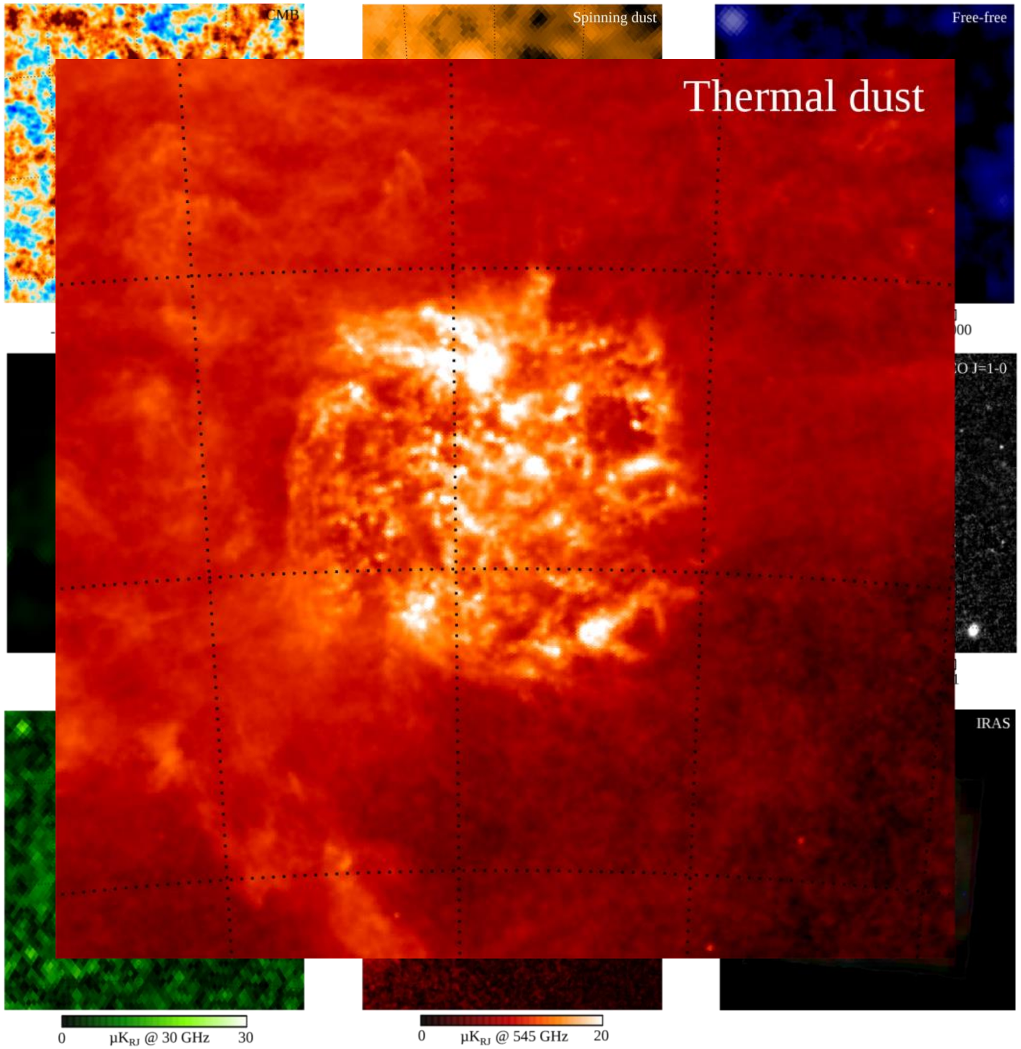
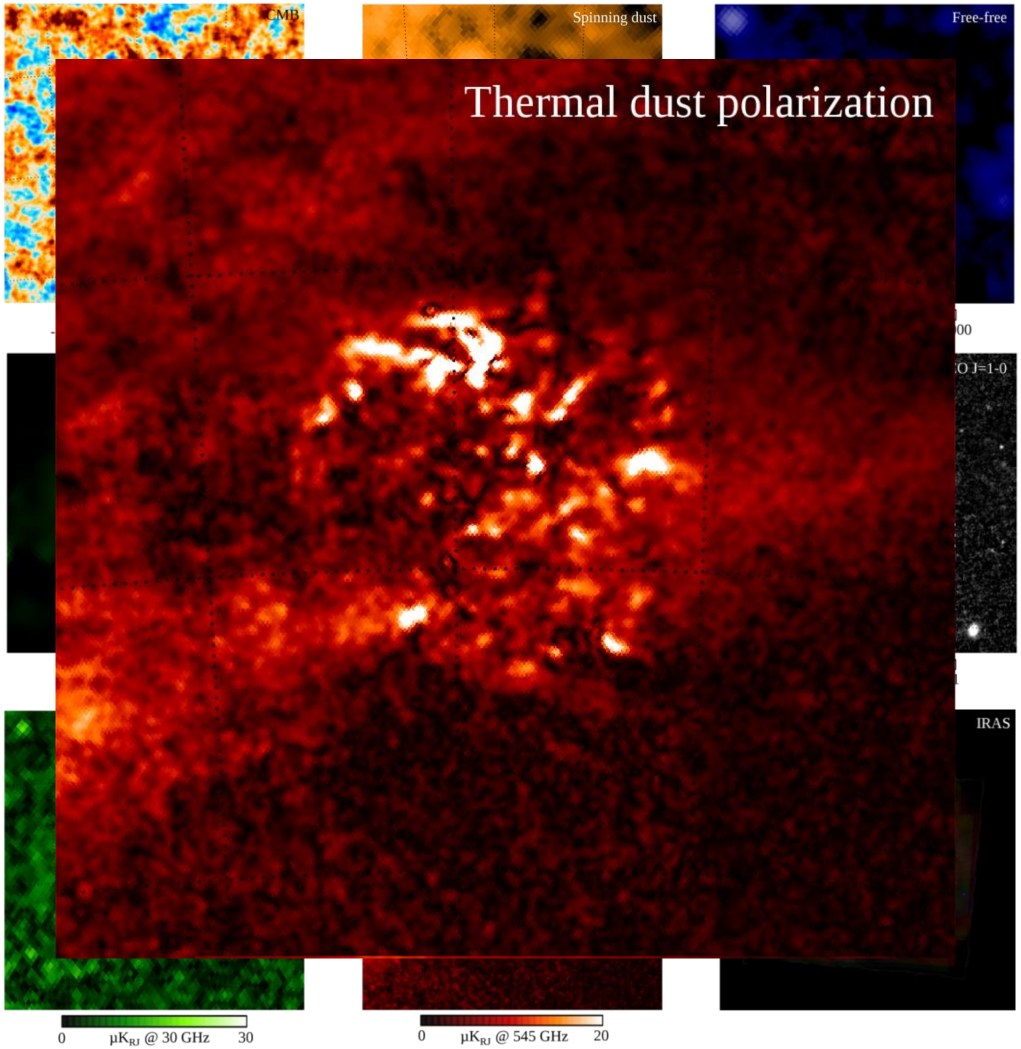
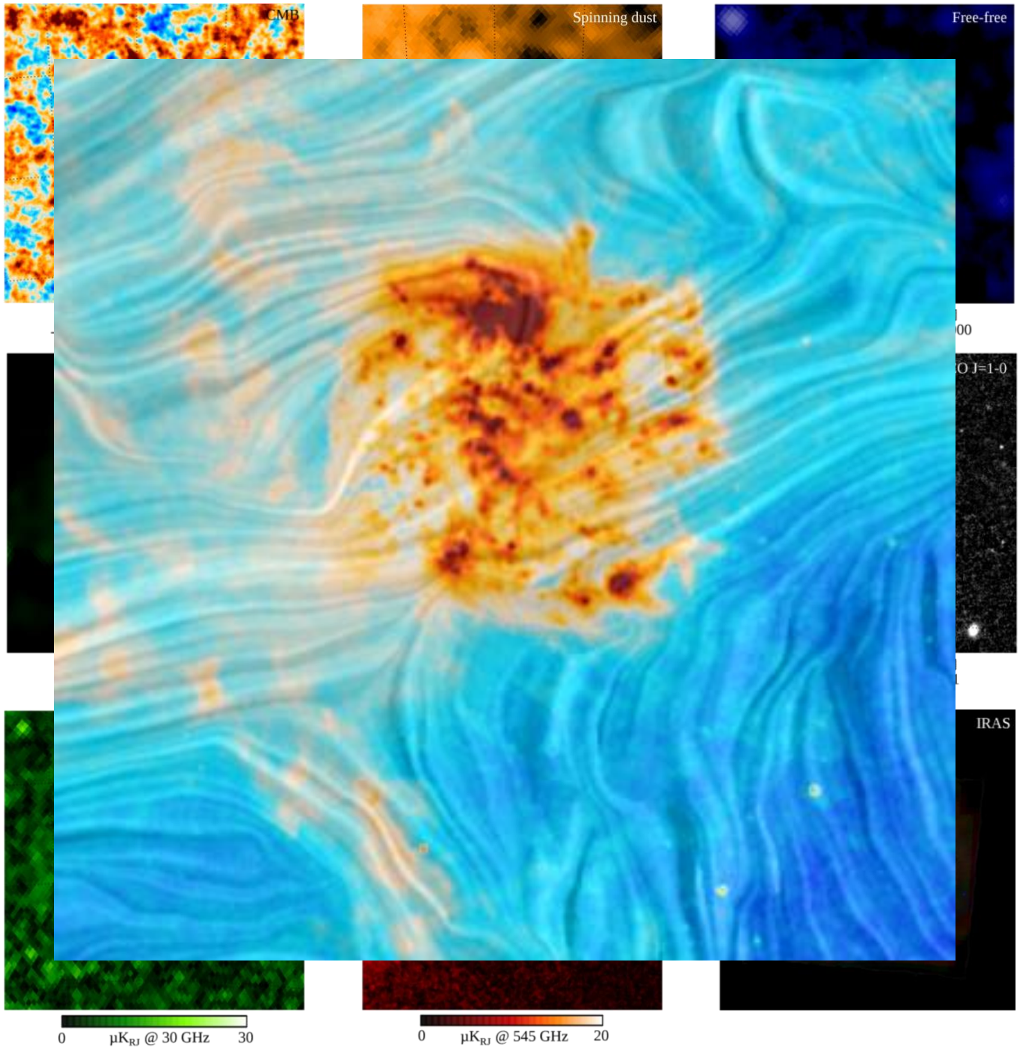


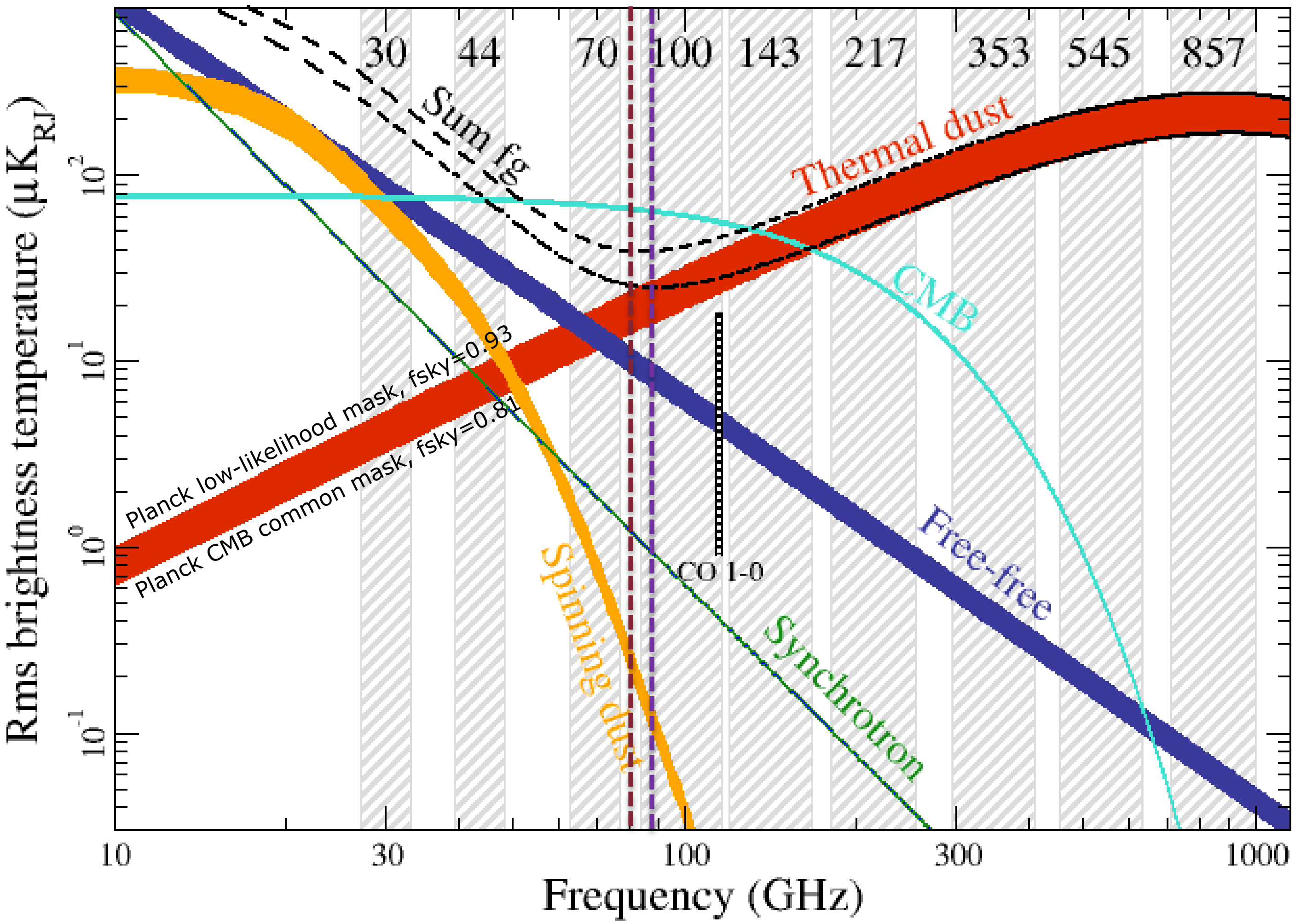
# Large Magellanic Cloud



# Large Magellanic Cloud

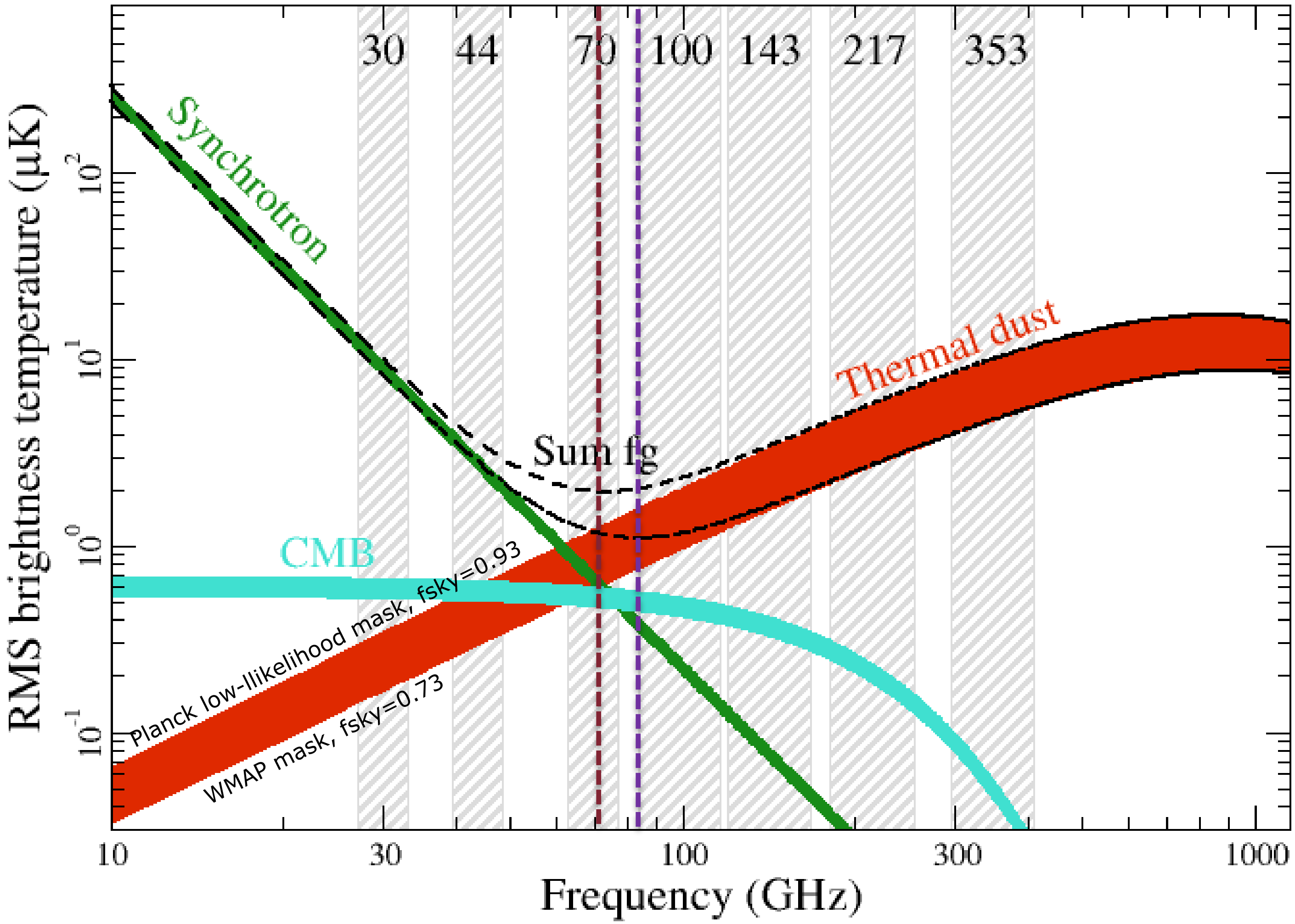


# Temperature foregrounds at a glance



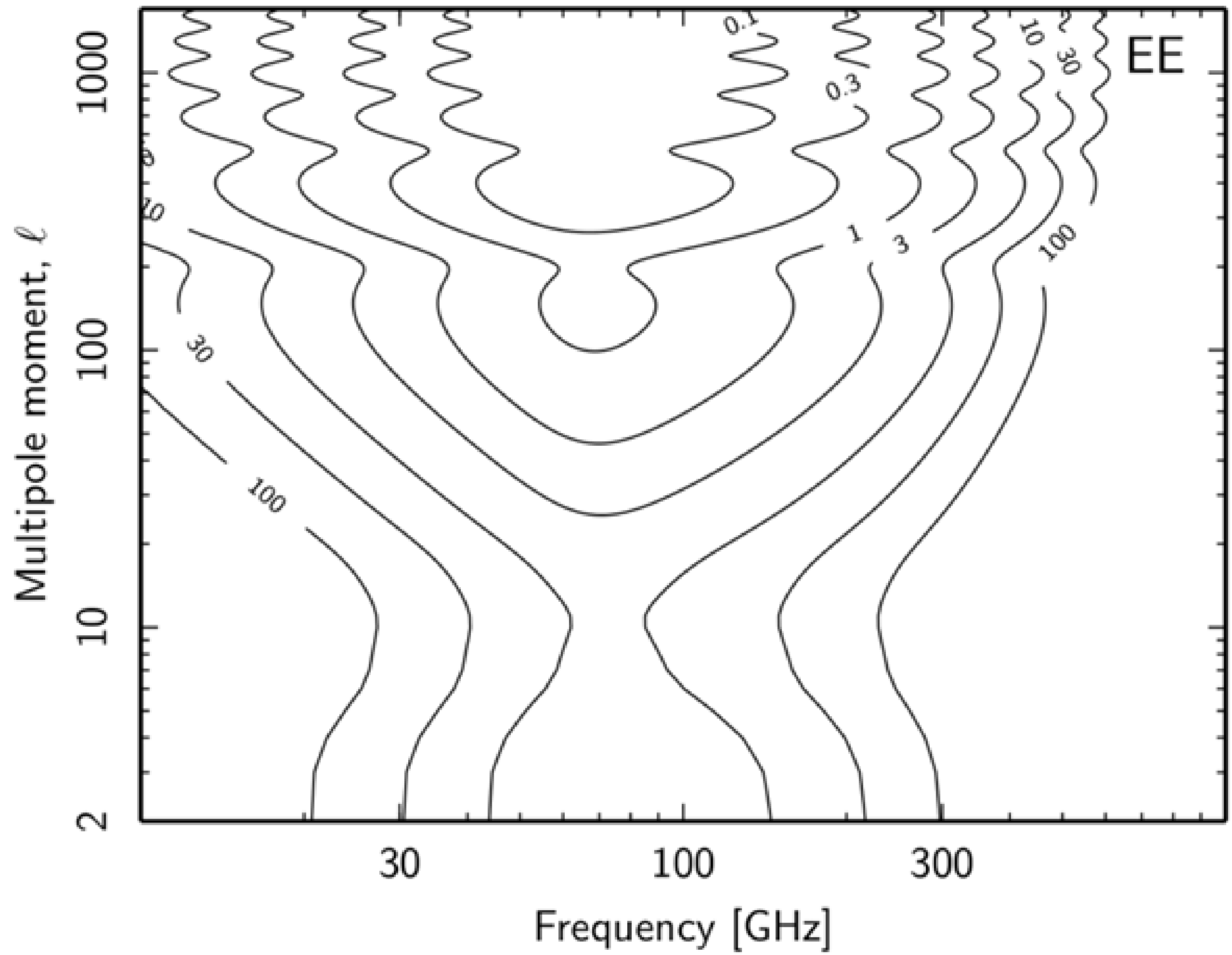

Temperature foreground minimum between **80 and 90 GHz** for sky fractions between 81 and 93% at **1 degree** resolution

# Polarization foregrounds at a glance



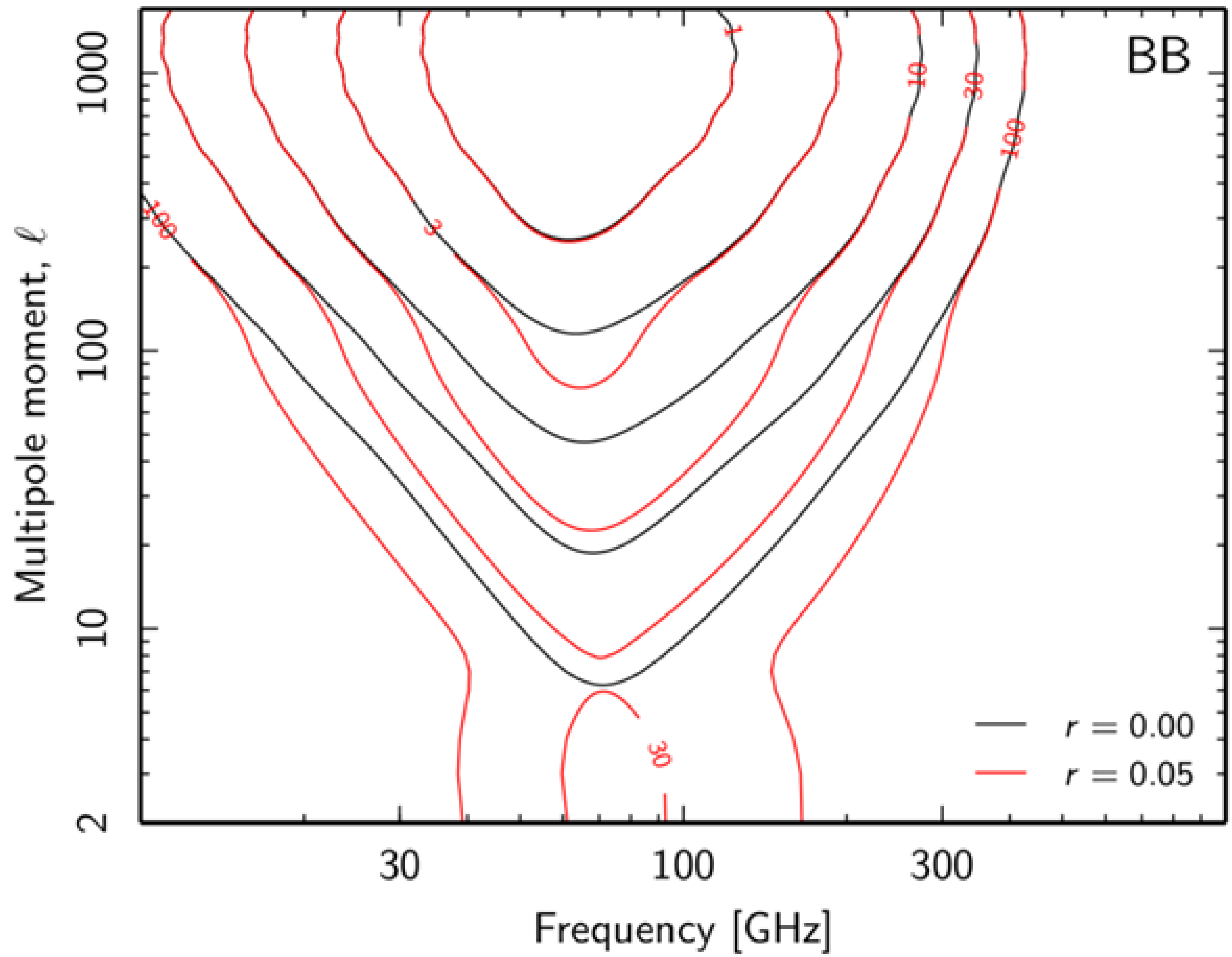

Polarization fore-ground minimum between **70 and 85 GHz** for sky fractions between 73 and 93% at **40 arcmin** reso-lution

# Foregrounds EE spectra



# Foregrounds BB spectra

planck



# 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.

# Summary

- Planck has delivered new astrophysical component maps in both temperature and polarization
  - First full-sky polarized thermal dust map

- The intensity model reproduces observations to a few $\mu$K 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 are relevant not only for CMB maps, but also for polarization foreground maps