Dust emission at millimetre wavelengths in the Galactic plane

Planck Collaboration

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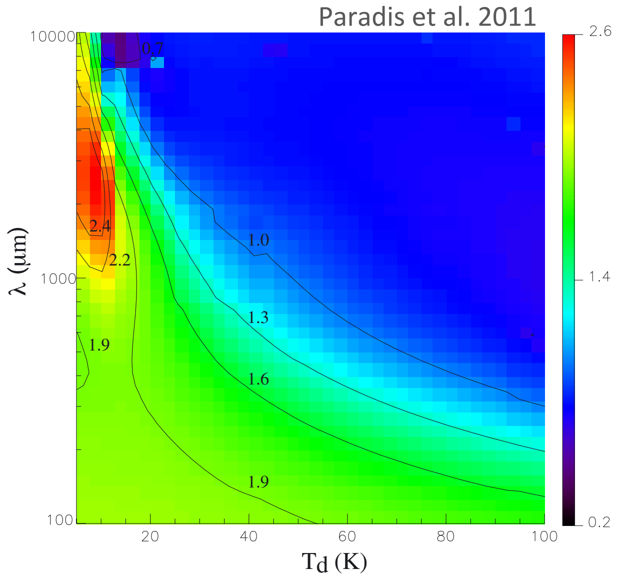
Introduction - Motivation

→ *Planck* HFI opens new windows in our understanding of Galactic emission, providing an all-sky view of the millimetre part of the thermal dust spectrum

→ Theoretical studies indicate that simple extrapolation of dust spectrum from FIR to mm wavelengths - like that preformed in silicate-carbon dust models (Draine & Li 2007, Compiègne et al. 2011) – may not work:

TLS model of Meny et al. (2007) predicts variation of emissivity spectral index β with frequency and temperature


Paradis et al. 2011

→ Observations also show that β seems to vary with frequency and also with environment, with a flattening of the spectrum relative to the best single modified black-body fit (Reach et al. 1995, Finkbeiner et al. 1999, Galliano et al. 2005, Paladini et al. 2007, Planck coll. 2011 A17&A19)

→ Another description is given by Draine & Hensley (2012): SED flattening attributed to magnetic dipole emission from a distinct new grain population

→ Characterising the dust emission at mm wavelengths is also important for Galactic component separation, in particular to constrain the high frequency end of the AME spectrum

Aims of the present work

→ Study the emissivity spectral index β of the interstellar dust emission in the HFI frequency range, in the Galactic plane - complements similar *Planck* studies of the high-latitude cirrus and nearby molecular clouds (*in prep.*)

$$I_\nu = \tau_0 \left(\frac{\nu}{\nu_0} \right)^\beta B(T_D, \nu)$$

→ Test predictions from dust models (e.g. Draine & Li 2007, Compiègne et al. 2011, Meny et al. 2007, Draine & Hensley 2012) and interpret them in the context of grain evolution, from atomic to molecular dominated regions

→ Separate dust emission from the other emission components present at these frequencies, namely CMB and free-free

Data analysis

In the thin Galactic disk (|b| < 1°) at 100 GHz

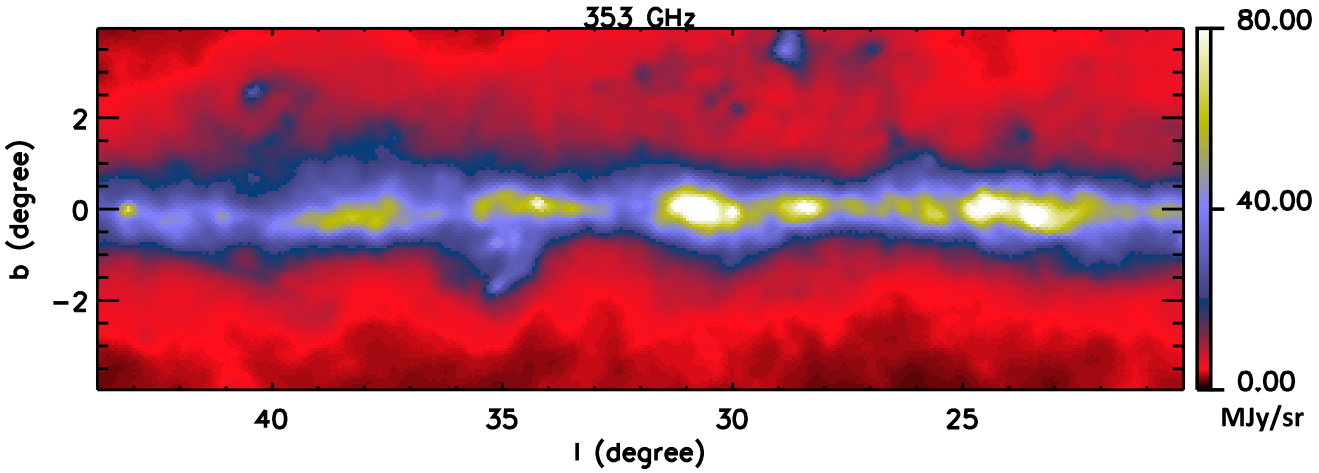
CMB (r.m.s. fluctuations ~ 90 μK_{CMB} at scales of 15') is ~ 5 % total emission

Free-free from ionised layer is 20-40 % of the total emission - subtracted using free-free map derived from Radio Recombination Line data (Alves et al. 2010, 2012)

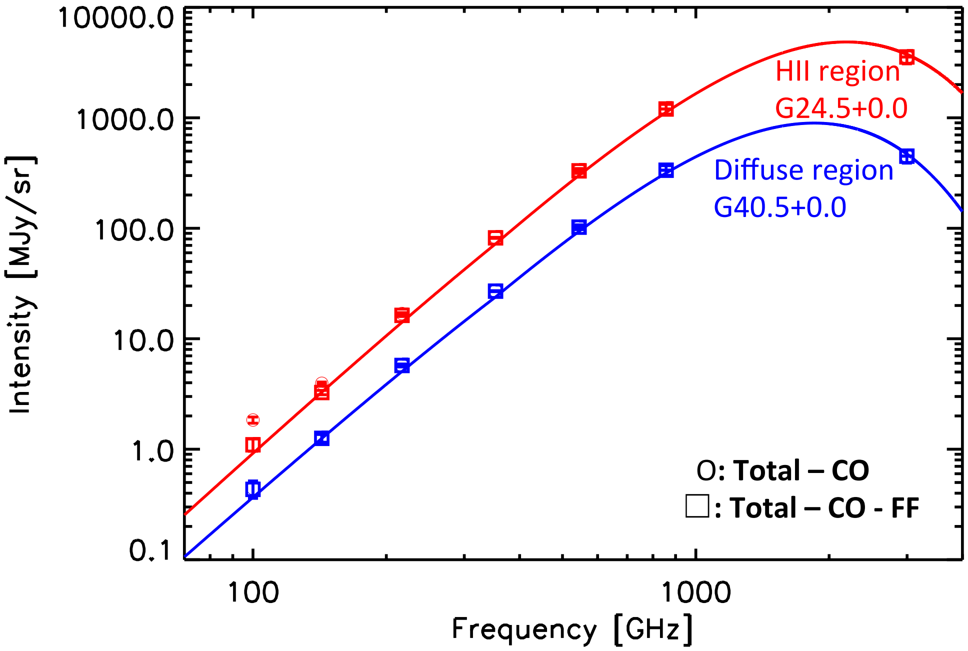
→Galactic plane region l=20° - 44°, |b| ≤ 4°

→ Common resolution of 15'

Outside the thin Galactic disk, CMB is 10 x brighter than the free-free emission



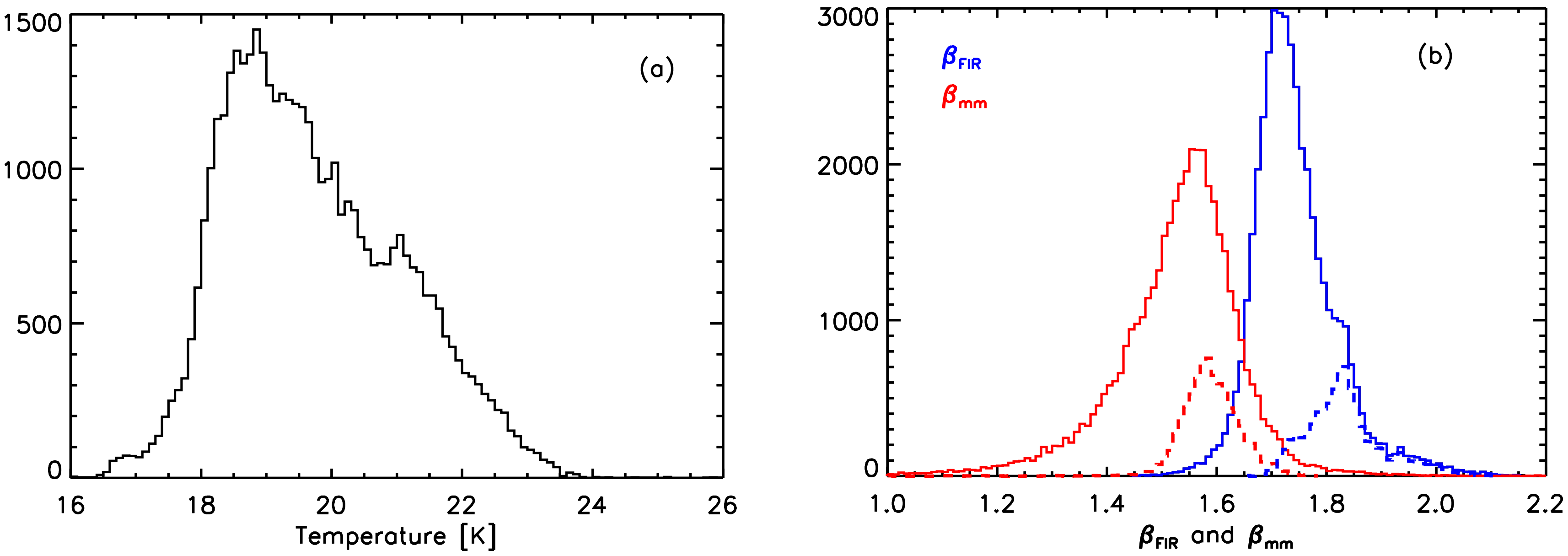
Data analysis



- Pixel-by-pixel spectral fit to IRAS 100 µm along with the *Planck* HFI bands
- Fit for τ_{353}, T_D, β_{FIR} and β_{mm} with ν_0=353 GHz
- Subtract CO contribution at 100, 217 and 353 GHz using the *Planck* MILCA CO products (Planck results 2013 XIII)

HII region	**Diffuse region**
β_{FIR} = 1.8 ± 0.1	β_{FIR} = 1.8 ± 0.1
β_{mm} = 1.7 ± 0.1	β_{mm} = 1.6 ± 0.1
T_D = 22 ± 1 K	T_D = 18 ± 1 K
τ_{353} = 13 x 10^{-4}	τ_{353} = 5 x 10^{-4}

Results from spectral fits



Thin Galactic disk, |b| < 1°

$\tau_{353} \geq 4 \times 10^{-4}$ (<u>Dashed line</u>)

β_{FIR} = 1.83 ± 0.07

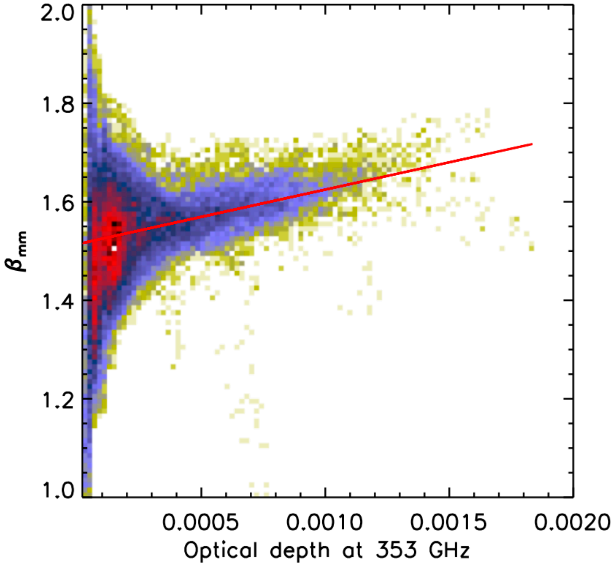
β_{mm} = 1.59 ± 0.06

Whole 24° x 8° region (<u>Full line</u>)

β_{FIR} = 1.73 ± 0.08

β_{mm} = 1.54 ± 0.12

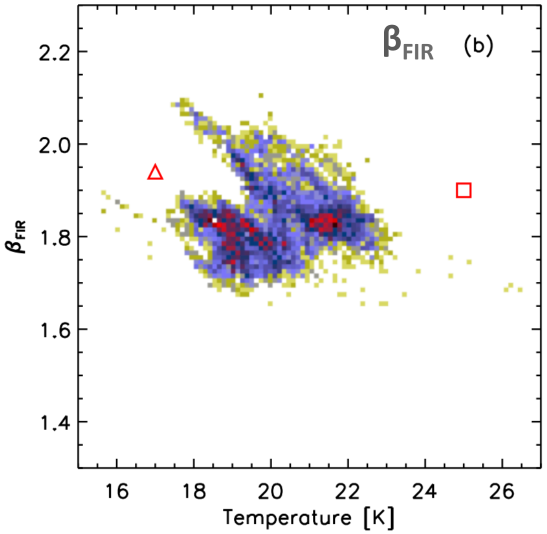
β_{mm} dependence on τ_{353} and on T_D



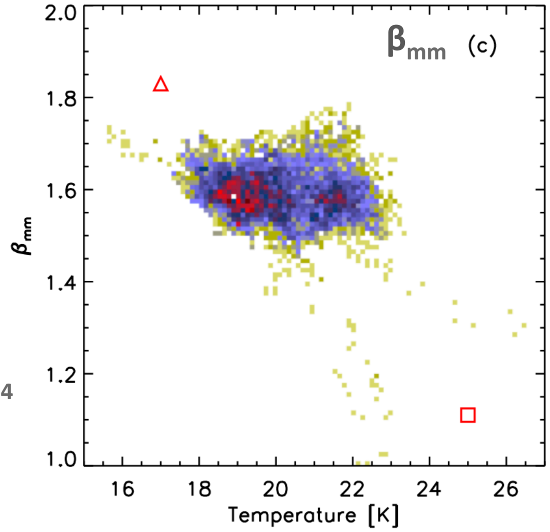
Linear correlation between β_{mm} and τ_{353} ($\tau_{353} \geq 4 \times 10^{-4}$)
Scatter at low τ_{353} values due to CMB

Simulations show that this is a robust result, but **what does it mean?** Since no model predicts it

On the other hand, the expected dependence of β with T_D is not observed – which is a prediction of the TLS model of Meny et al. (2007)



$\tau_{353} \geq 4\text{x}10^{-4}$
or |b|<1°



$\beta_{mm} - \tau_{353}$ correlation: Physical interpretation

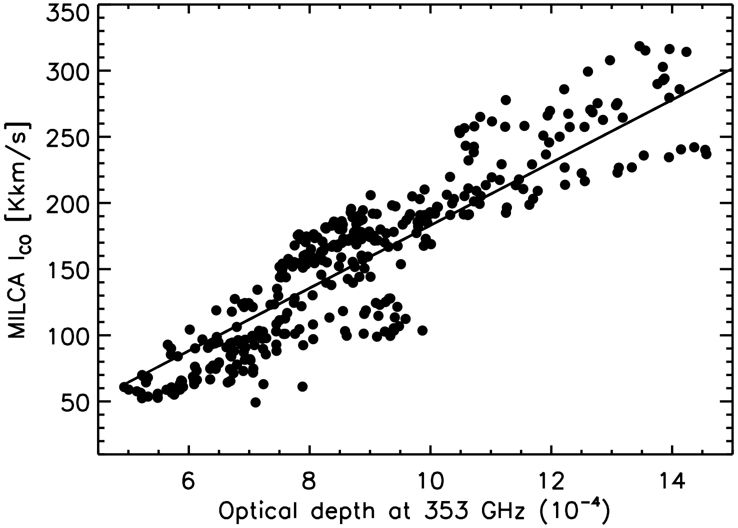
Evolution of β_{mm} with the fraction of molecular gas along the l.o.s.:

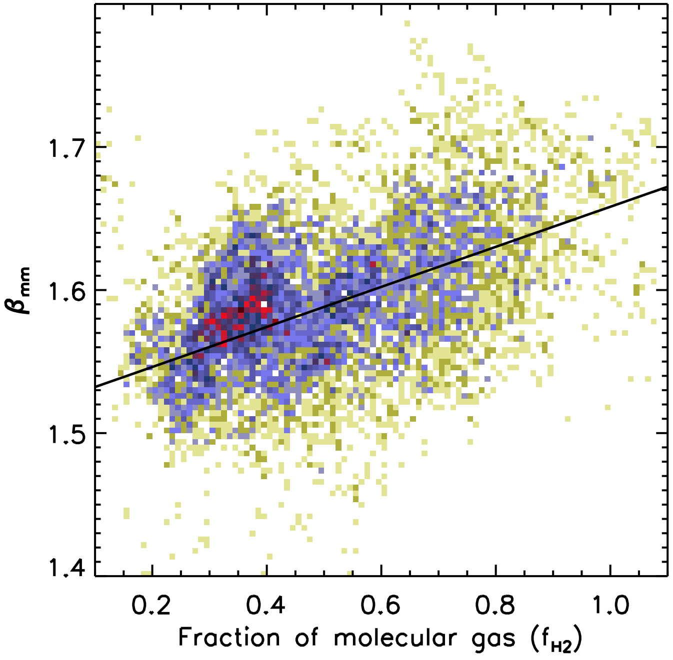
$f_{H2}=2N_{H2}/N_H^{tot}$
with $N_{H2} = X_{CO}\, I_{CO}$ and X_{CO} typical value of
2.0×10^{20} cm^{-2}(K.km/s)$^{-1}$ (Bolatto et al. 2013)

Assume that the opacity per unit gas column density of the molecular gas is **twice** that of the atomic,
$N_{HI}/\tau_{353} = 8 \times 10^{-27}$ cm^2 H^{-1} (Planck coll. 2013, *in prep.*)
→ Dust evolution due to grain coagulation (Stepnik et al. 2003, Planck coll. 2011 A24, Martin et al. 2012)

Fit to the l=20° - 44° at b=0°
$X_{CO} = 1.6 \times 10^{20}$ cm^{-2}(K.km/s)$^{-1}$

β_{mm} is correlated with f_{H2}
Atomic medium: $\beta_{mm} \approx 1.52$
Molecular medium: $\beta_{mm} \approx 1.65$





Does this fit with the existing silicate-carbon models?

Comparison with dust models

Silicate-Carbon models:

Two grain populations, silicates and carbon grains

Draine & Li (2007)

Silicates α $\nu^{1.6}$ and graphites α $\nu^{2.0}$

G_0	T_D [K]	β_{FIR}	β_{mm}
1	21.8	1.65	1.43
2	24.1	1.70	1.43
4	26.7	1.73	1.43

Compiègne et al. (2011)

Silicates α $\nu^{1.6}$ and amorphous carbon α $\nu^{1.6}$

G_0	T_D [K]	β_{FIR}	β_{mm}
1	20.1	1.58	1.48
2	22.4	1.62	1.47
4	25.0	1.64	1.46

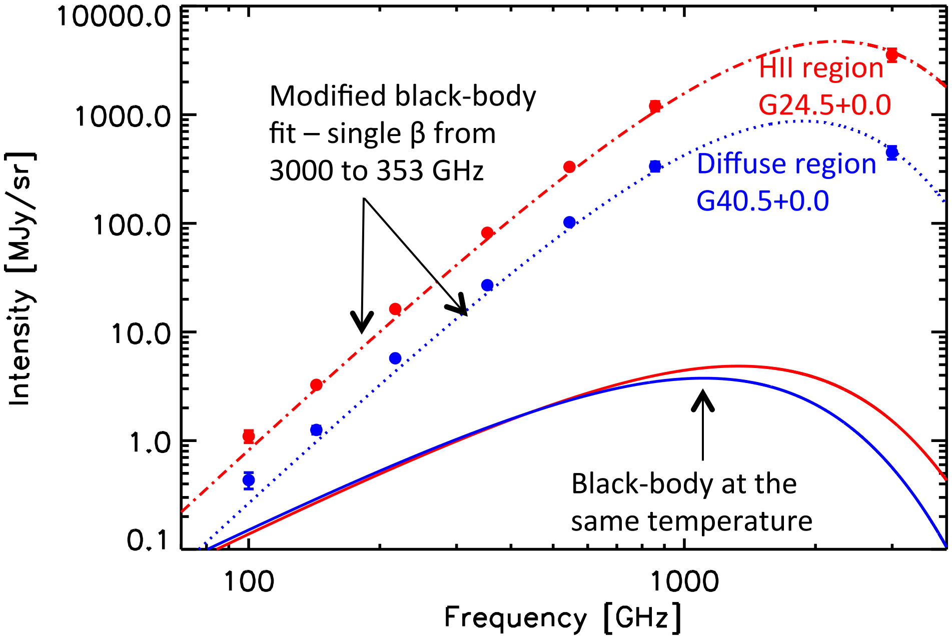
Both models predict a lower β_{mm} compared to β_{FIR}

However, none of them is able to reproduce the values measured

Comparison with dust models

Magnetic nanoparticles of Draine & Hensley (2012)

Iron missing in the gas phase is locked up in solid grains either as inclusions in larger grains, $T_D \approx 18$ K, or as free-flyers, $T_D \approx 40$ K.
Their emission, at the relevant frequency range, can be approximated by a black-body.

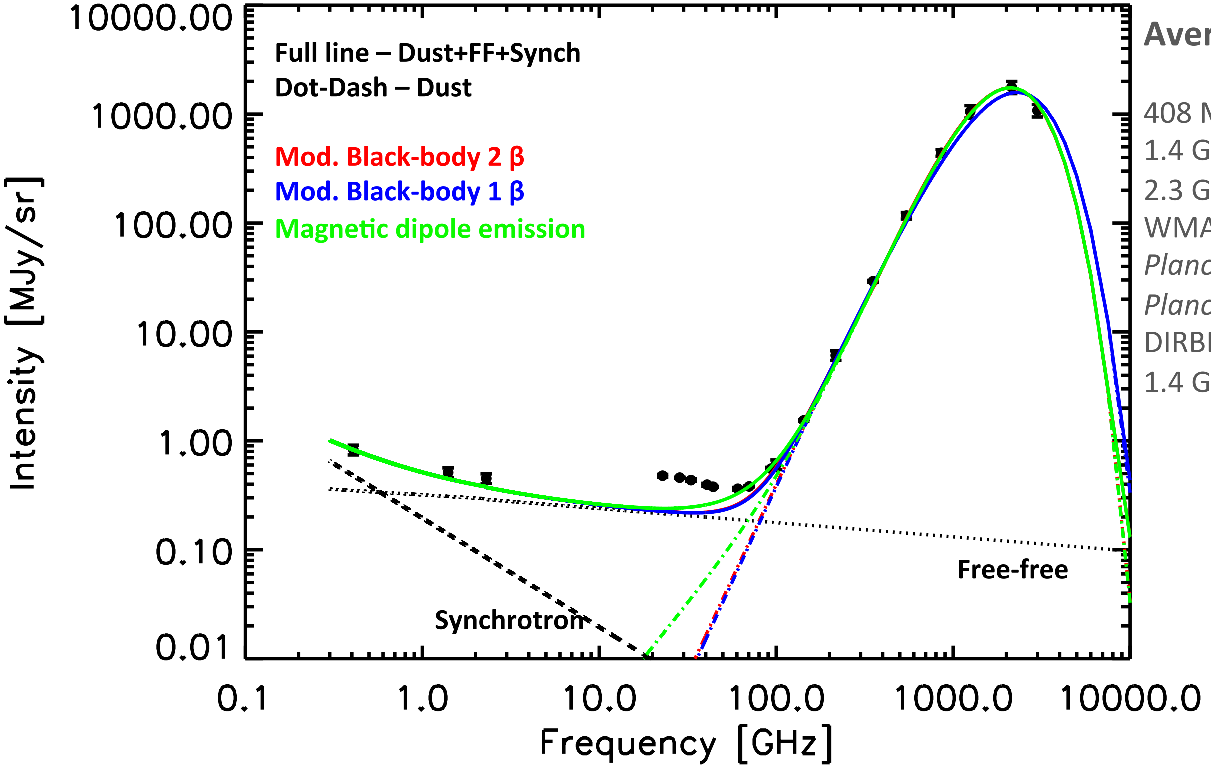


Ratio: emission by the iron nanoparticles/ emission by modified black-body at 100 GHz

Ratio ≈ 60 % - obtained by Draine & Hensley for the diffuse Galactic emission, if 100 % of iron is in a= 0.01 μm particles of metallic Fe at T = 18 K

HII region → 17 %
Diffuse region → 57 %
Whole 24° x 8° region → 66 %

Impact on Galactic component separation



Average SED l=20° - 44°, b=0°

408 MHz (Haslam et al. 1982)
1.4 GHz (Reich et al. 1982)
2.3 GHz (Jonas et al. 1998)
WMAP 9-yr (Bennett et al. 2013)
Planck LFI
Planck HFI
DIRBE (Hauser et al. 1998)
1.4 GHz RRL Free-free map (Alves et al. 2012)

AME/Total Emission (%)

Model / Freq [GHz]	**28.5**	**70.3**
Mod. Black-body 2 β	51 ± 5	36 ± 6
Mod. Black-body 1 β	51 ± 5	36 ± 6
Mag. Dipole emission	46 ± 5	0 ± 6

Conclusions

Planck offers the opportunity to study the dust spectrum from FIR to mm wavelengths across the whole sky

→ The spectral index of the dust opacity in the Galactic plane decreases from FIR to mm wavelengths: $\beta_{FIR} = 1.83 \pm 0.07$ and $\beta_{mm} = 1.59 \pm 0.06$

→ β_{mm} does not seem to vary with temperature, as opposed to β_{FIR} – does not agree with predictions from TLS model of Meny et al. (2007)

→ β_{mm} is correlated with the dust optical depth, which we interpret as an evolution of the opacity spectral index with the fraction of molecular gas along the l.o.s. - $\beta_{mm} \approx 1.52$ in the atomic medium and $\beta_{mm} \approx 1.65$ in molecular medium

→ Both the silicate-carbon models of Draine & Li (2007) and Compiègne et al. (2011) predict a too flat SED in the mm

→ The magnetic dipole emission model by Draine & Hensley (2012) can also explain the observed β_{mm} (but it is not favoured by the polarisation results, *see poster by T. Ghosh*)

These results are key for Galactic component separation

→ Dust emission has an impact on the high-frequency spectral shape of the AME - the AME fraction at its peak is essentially unchanged

→ The estimation of the free-free emission from microwave CMB data depends critically on the dust emission

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

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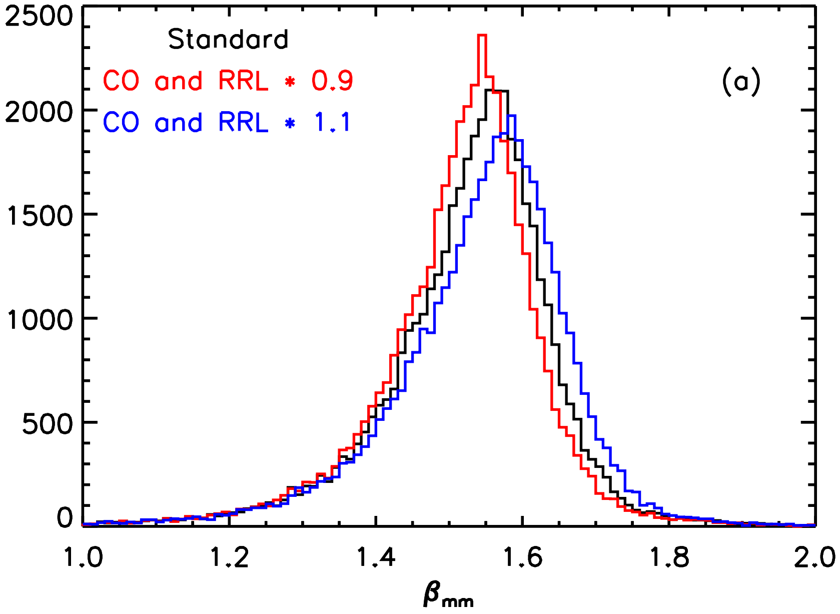
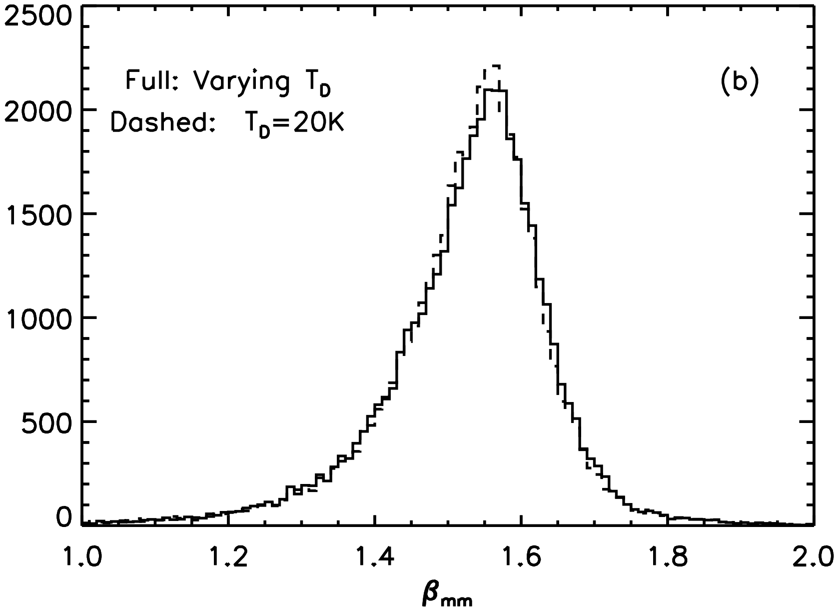
Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

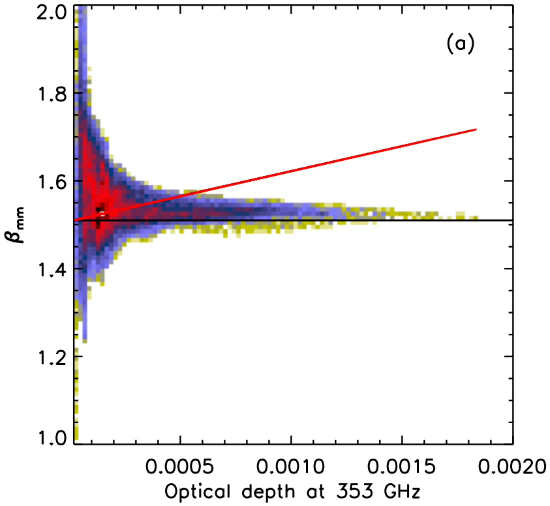
Varying the calibration of CO and RRL data by 10 %

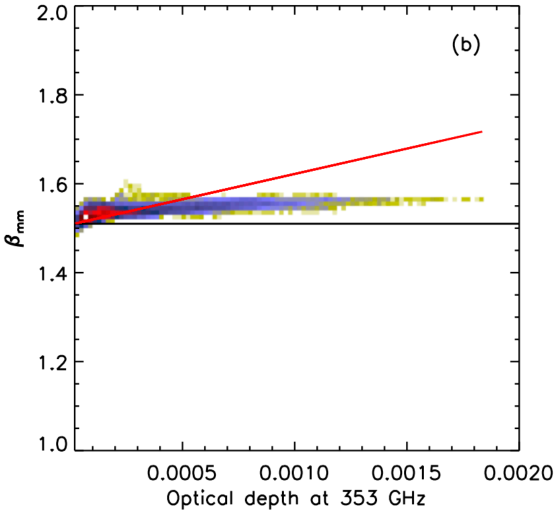


Fixing the dust temperature to 20 K across the whole region



Test with simulations:


Dust+CMB


Dust+CO+RRL

Subtracting SMICA CMB map: