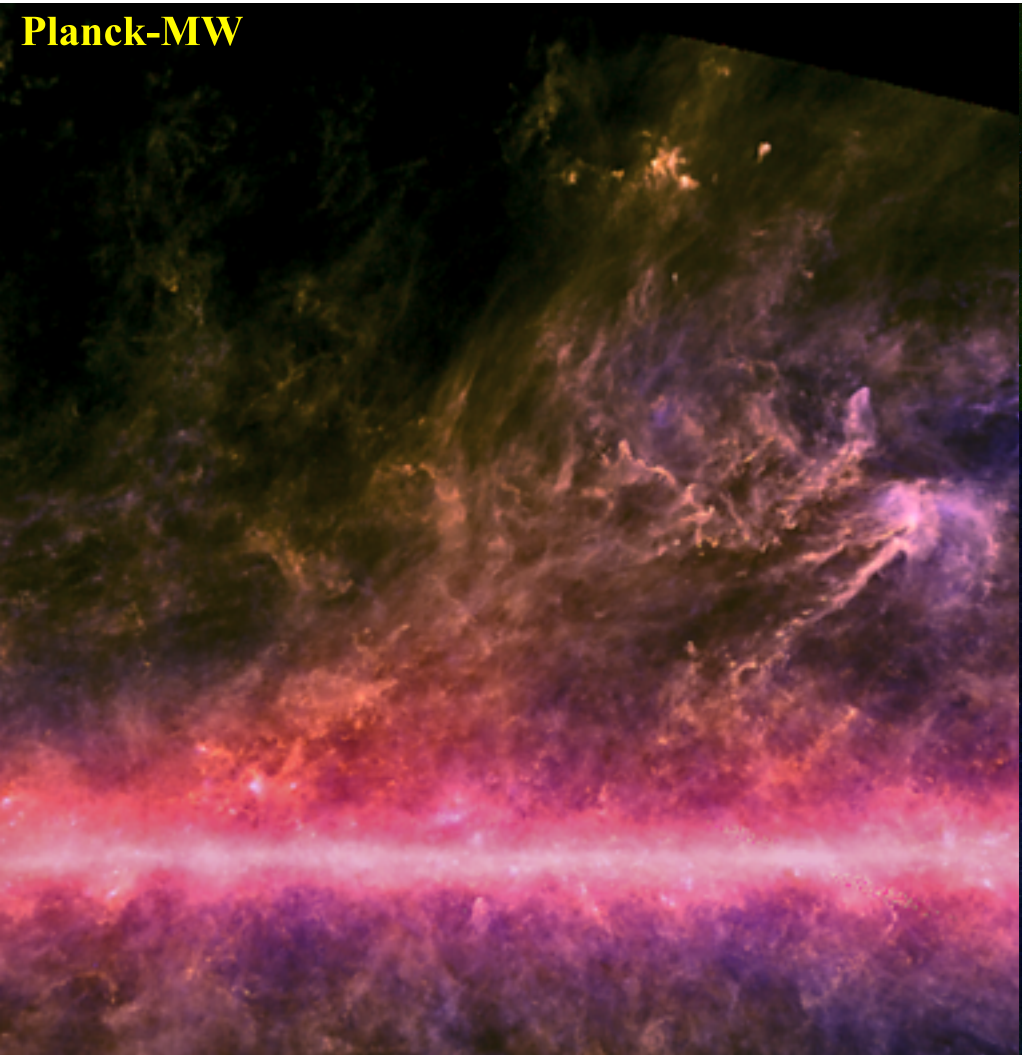
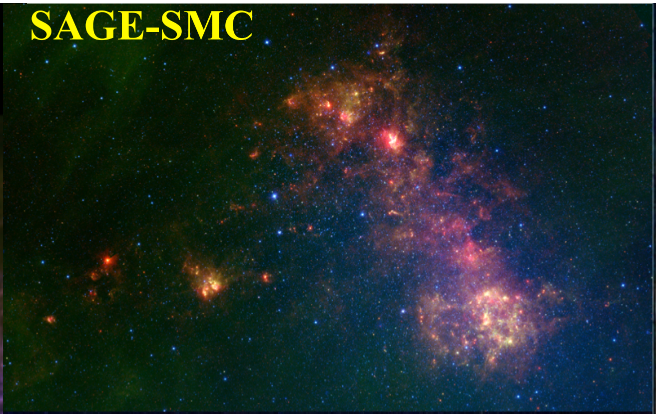
Dust observations in the Milky-Way and Magellanic Clouds

J.-Ph. Bernard, IRAP, Toulouse, France

On behalf of a few large collaborations: Spitzer SAGE, Herschel Heritage, Herschel Higal, Planck

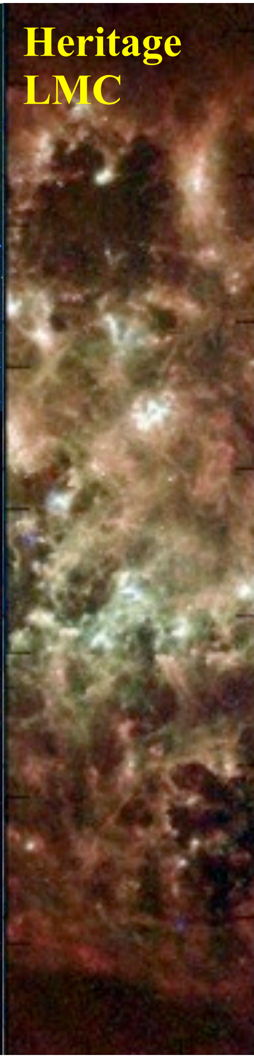


Planck-MW



SAGE-SMC

SAGE-LMC



Heritage LMC

Layout

- Dust in the Herschel-Planck domain (FIR/Submm)

- Home: Our own Galaxy (Mostly with Planck)

- Dust in the solar neighborhood (and Dark-Gas)
- Dust in the Galactic halo
- Dust in Galactic molecular clouds
- Dust in the Galactic Plane

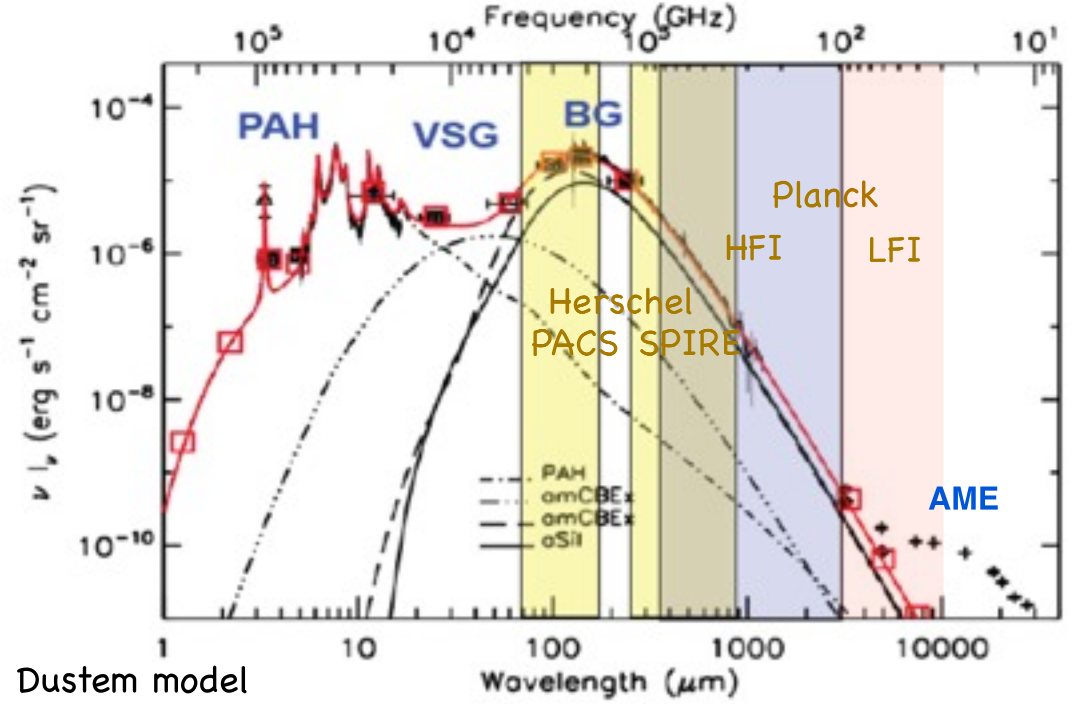
- The Magellanic Clouds (LMC/SMC):

- The Spitzer view
- The Planck view
- The Herschel view -> see talks at this meeting (F. Galliano, J. Roman-Duval, K. Gordon)

Dust Physics

Composition:

- PAH = Polycyclic Aromatic Hydrocarbons (may also produce AME)
- VSG = Very Small Grains
- BG = "Big" grains Silicates + Graphite (≈ 0.1 μm)



Dustem model

BG :

FIR observations of distant galaxies

"Universal" tracer of the ISM structure

$$\boxed{I_\nu = \tau_\nu B_\nu(T_D) = \pi a^2 Q_{abs}(\lambda) X_{dust} N_H \, B_\nu(T_D)}$$

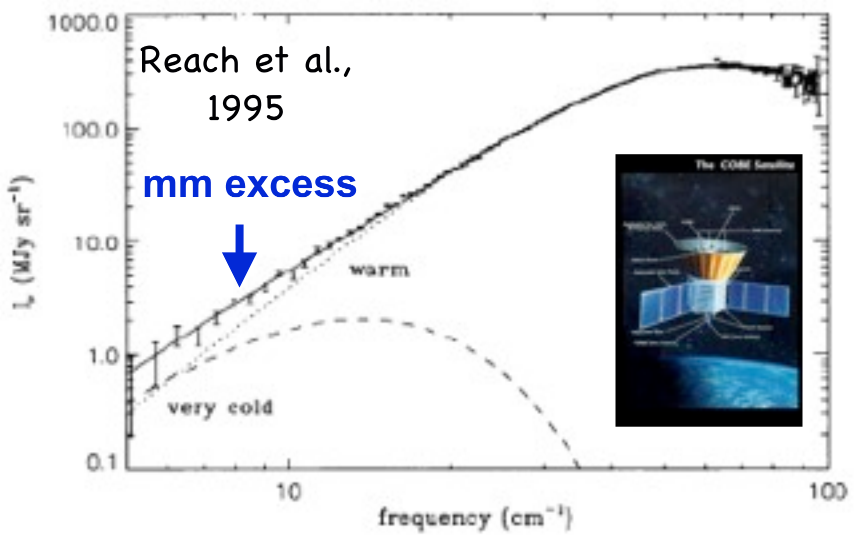
BG at thermal equilibrium -> dust temperature T_D measures radiation field intensity (G_0)

It is usual to assume $Q_{abs}(\lambda) \propto \lambda^{-\beta}$ with $\beta=2$ (Quadratic Law)

- FIR-mm optical depth are small (can account for the mass of a whole galaxy)
- In the Rayleigh-Jeans regime, $I_\nu \propto T_D$, so mass determinations not very sensitive to temperature determination in Submm-mm ...

The flat MW SED

COBE/FIRAS : MW SED much flatter than predicted by the quadratic law ($1.5<\beta<1.7$)



Reach et al., 1995

mm excess

mm excess :

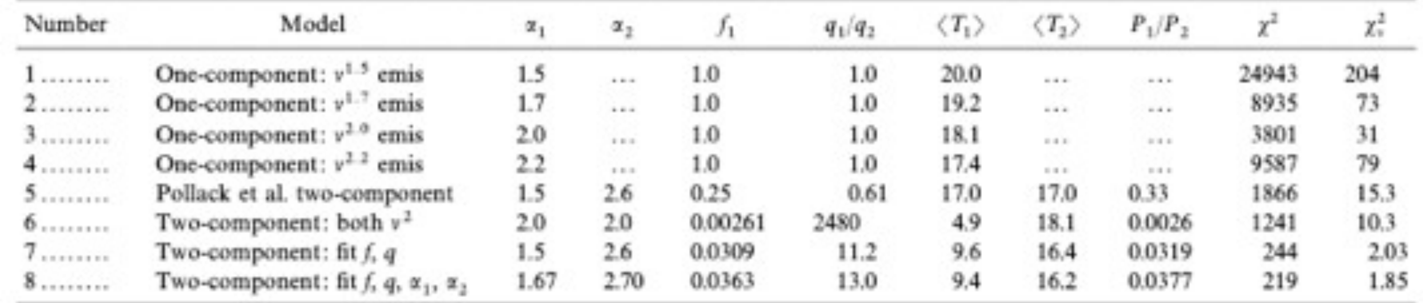
Warm dust at ~17.5 K

Very cold dust (5-7K) ?

mm excess is strongly correlated to FIR emission at high |b|
This lead Reach et al. to reject "very cold" dust.

Finkbeiner et al. 1999 (FSD)

2 components= Graphite + Silicate

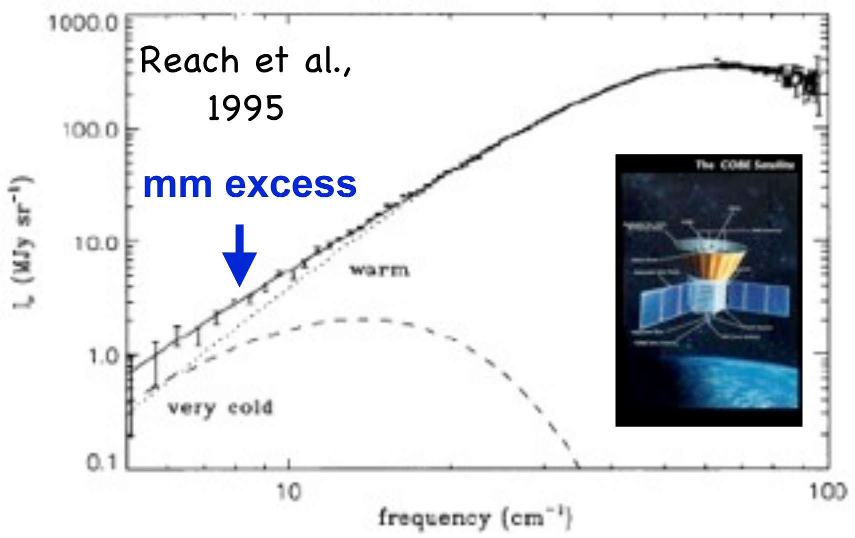


Number	Model	α_1	α_2	f_1	q_1/q_2	$\langle T_1 \rangle$	$\langle T_2 \rangle$	P_1/P_2	χ^2	χ^2_ν
1........	One-component: $\nu^{1.5}$ emis	1.5	...	1.0	1.0	20.0	...	...	24943	204
2........	One-component: $\nu^{1.7}$ emis	1.7	...	1.0	1.0	19.2	...	...	8935	73
3........	One-component: $\nu^{2.0}$ emis	2.0	...	1.0	1.0	18.1	...	...	3801	31
4........	One-component: $\nu^{2.2}$ emis	2.2	...	1.0	1.0	17.4	...	...	9587	79
5........	Pollack et al. two-component	1.5	2.6	0.25	0.61	17.0	17.0	0.33	1866	15.3
6........	Two-component: both ν^2	2.0	2.0	0.00261	2480	4.9	18.1	0.0026	1241	10.3
7........	Two-component: fit f, q	1.5	2.6	0.0309	11.2	9.6	16.4	0.0319	244	2.03
8........	Two-component: fit f, q, α_1, α_2	1.67	2.70	0.0363	13.0	9.4	16.2	0.0377	219	1.85

2 Temperature models can fit sky brightness distribution beautifully, but do not provide a physical explanation for the very cold dust at 9K

The flat MW SED

COBE/FIRAS : MW SED much flatter than predicted by the quadratic law ($1.5<\beta<1.7$)



mm excess :

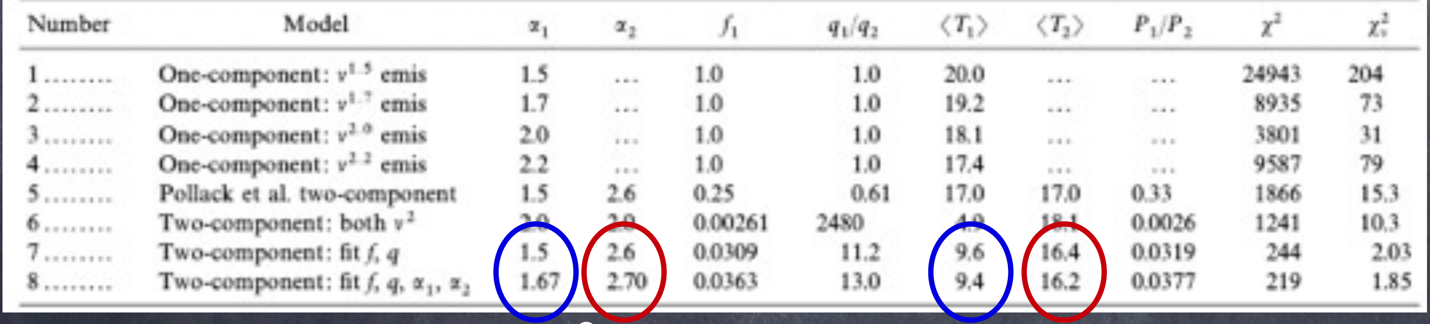
Warm dust at ~17.5 K

Very cold dust (5-7K) ?

mm excess is strongly correlated to FIR emission at high |b|
This lead Reach et al. to <u>reject</u> "very cold" dust.

Finkbeiner et al. 1999 (FSD)

2 components= Graphite + Silicate

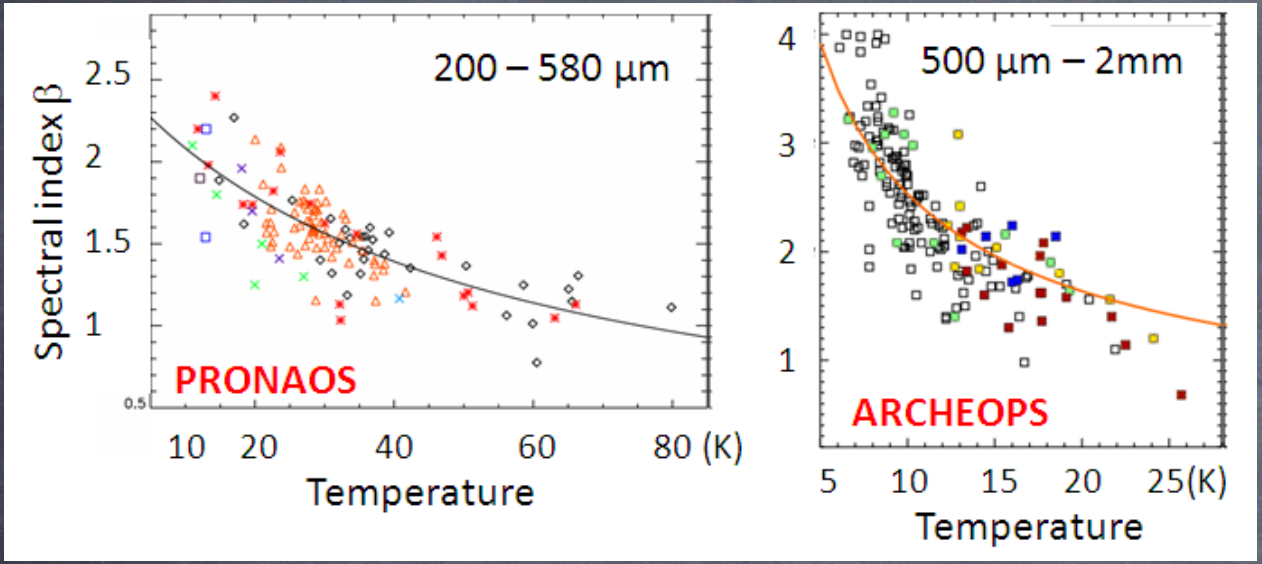


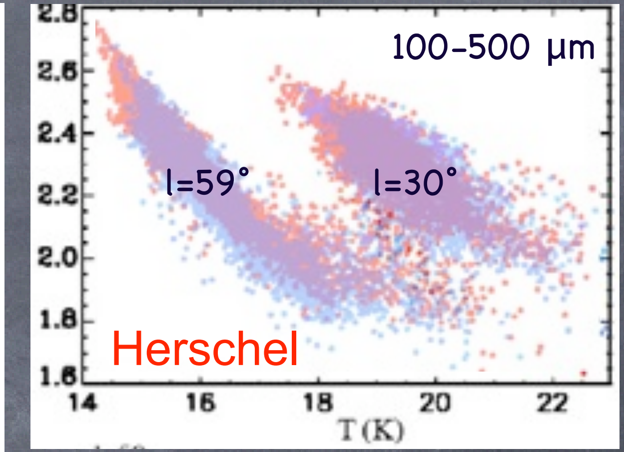
Number	Model	α_1	α_2	f_1	q_1/q_2	$\langle T_1 \rangle$	$\langle T_2 \rangle$	P_1/P_2	χ^2	χ^2_ν
1........	One-component: $\nu^{1.5}$ emis	1.5	...	1.0	1.0	20.0	...	...	24943	204
2........	One-component: $\nu^{1.7}$ emis	1.7	...	1.0	1.0	19.2	...	...	8935	73
3........	One-component: $\nu^{2.0}$ emis	2.0	...	1.0	1.0	18.1	...	...	3801	31
4........	One-component: $\nu^{2.2}$ emis	2.2	...	1.0	1.0	17.4	...	...	9587	79
5........	Pollack et al. two-component	1.5	2.6	0.25	0.61	17.0	17.0	0.33	1866	15.3
6........	Two-component: both ν^2	2.0	2.0	0.00261	2480	4.0	18.1	0.0026	1241	10.3
7........	Two-component: fit f, q	1.5	2.6	0.0309	11.2	9.6	16.4	0.0319	244	2.03
8........	Two-component: fit f, q, α_1, α_2	1.67	2.70	0.0363	13.0	9.4	16.2	0.0377	219	1.85

2 Temperature models can fit sky brightness distribution beautifully, but do not provide a physical explanation for the very cold dust at 9K

T-β correlation

Variations of spectral index appear inversely correlated with dust temperature.





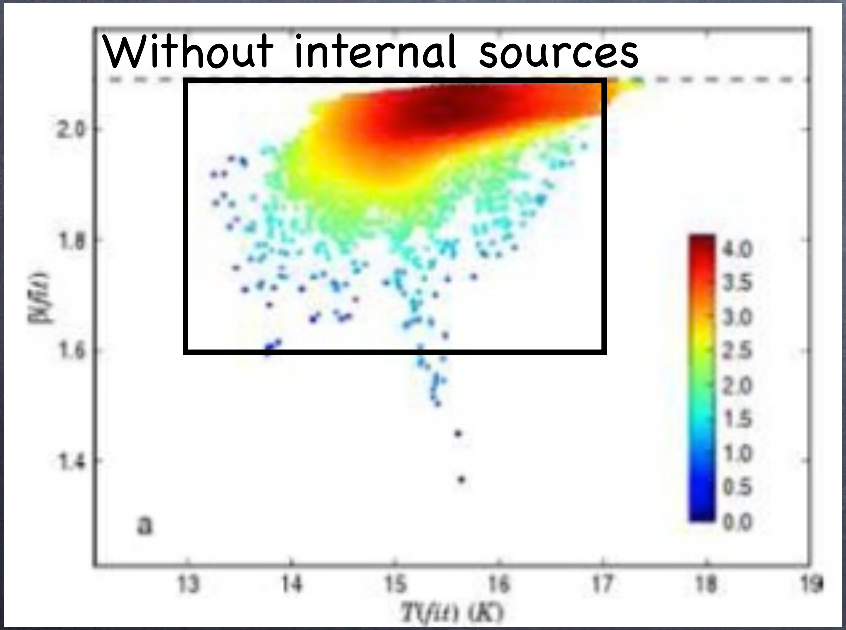
However T and β are degenerate in SED fits and naturally inversely correlated. Demonstration that the effect is real requires taking errors into account.

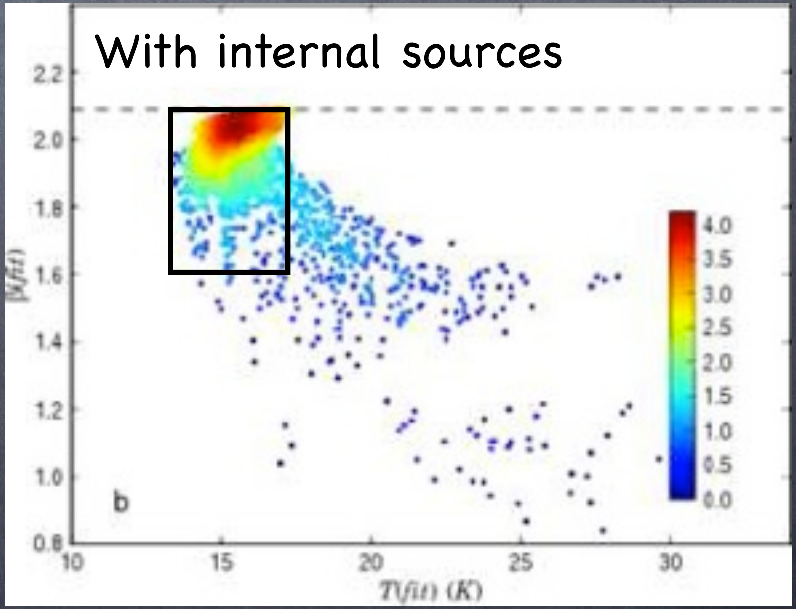
The following studies concluded that the effect is not due to this degeneracy : Dupac et al. 2003, Désert et al. 2008, Paradis et al. 2010

T-mixing ?

Malinen et al. 2010 : 3D MHD simulation + full radiative transfer + realistic distribution of heating sources (stars) + Herschel noise.

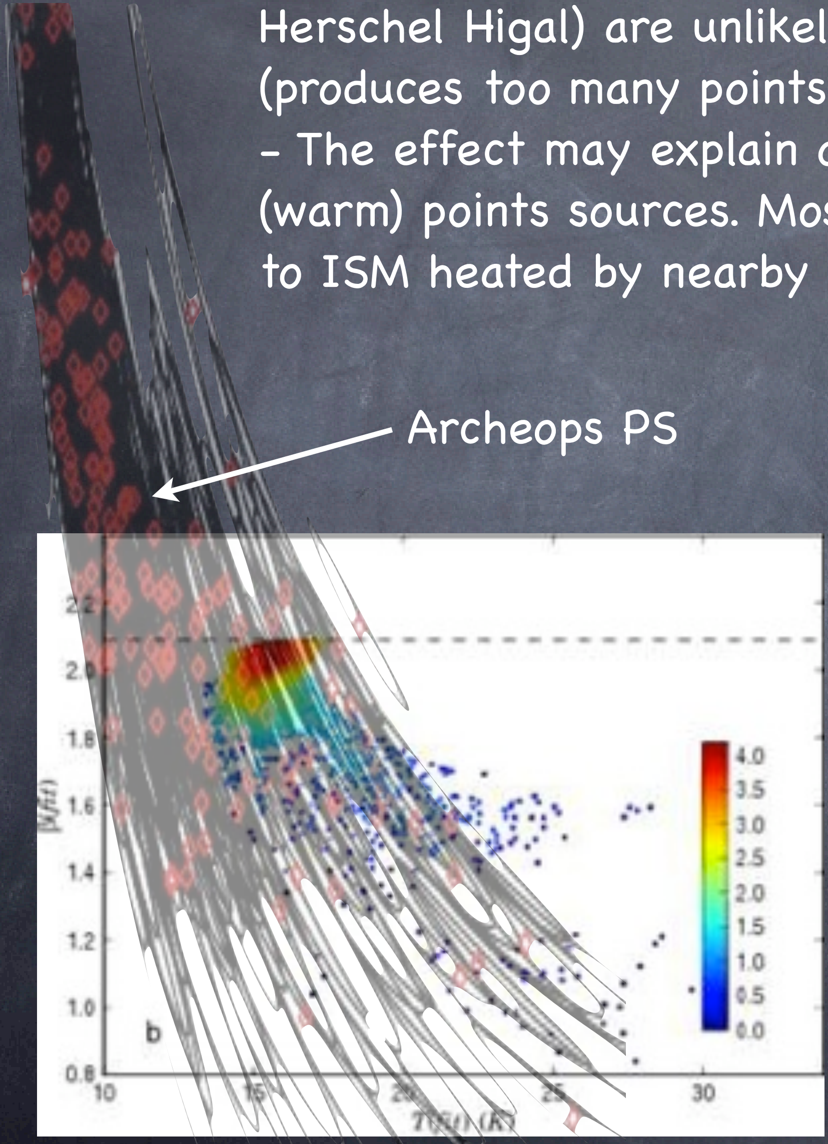
- cases with no internal sources: no fake T-beta inverse correlation (in fact produces the opposite)
- cases with internal sources: fake T-beta inverse correlation for a minority of pixels, close to embedded sources.

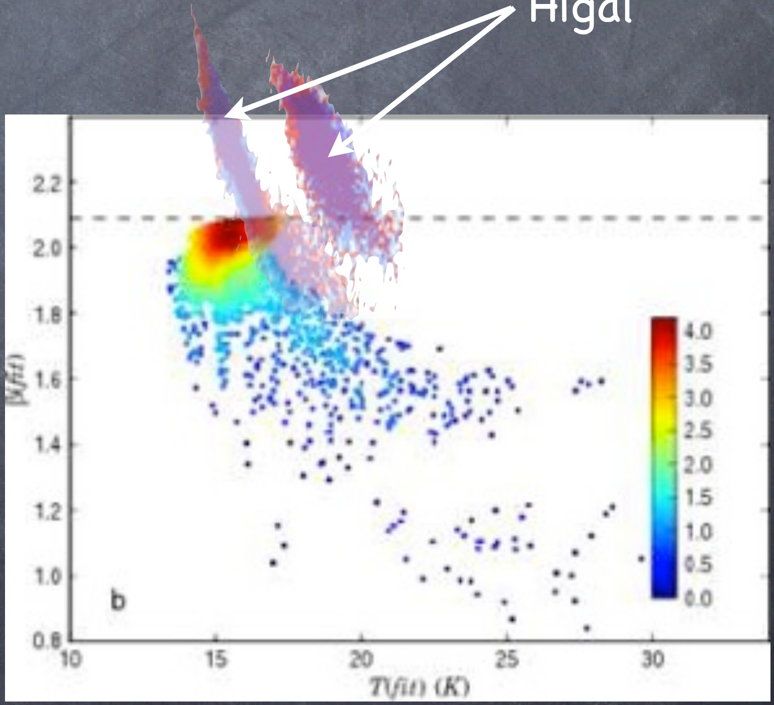

Without internal sources


With internal sources

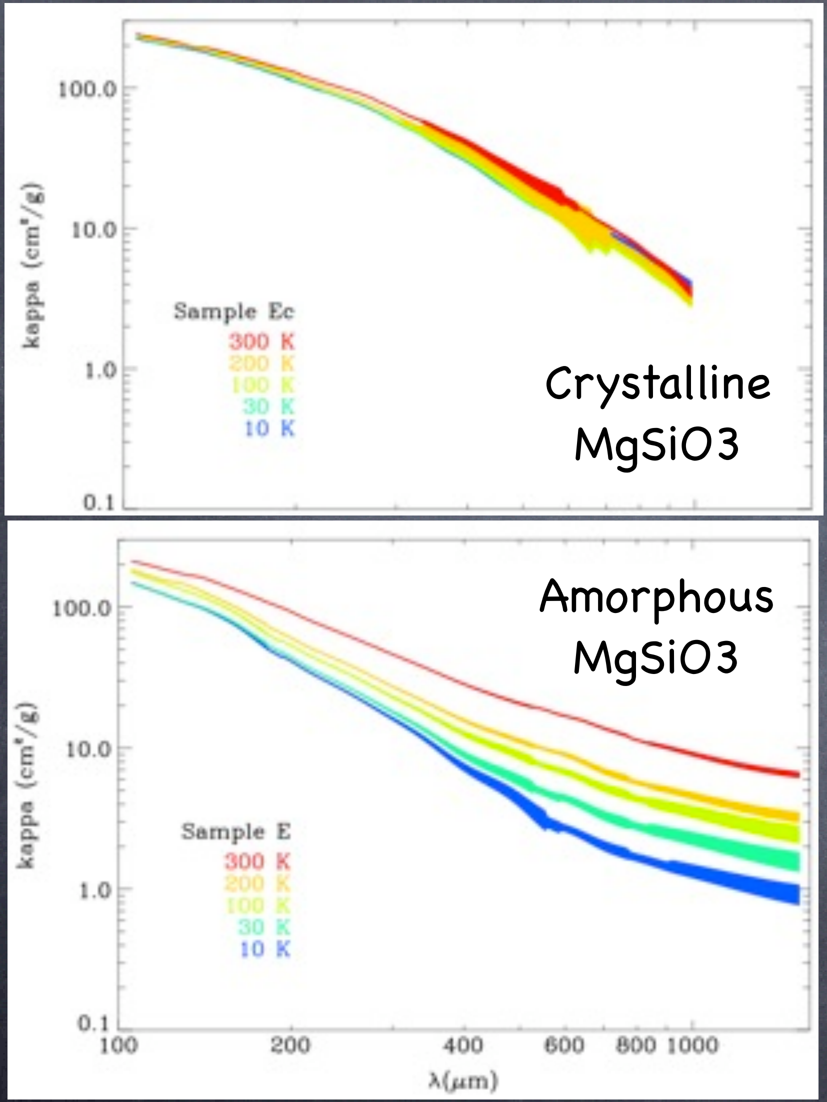
T-mixing ?

- pixel-to-pixel based inverse correlation observed (e.g. Pronaos, Herschel Higal) are unlikely to be explained by T-mixing alone (produces too many points at input β).
- The effect may explain observations for some of the Archeops (warm) points sources. Most Archeops PS are too cold to correspond to ISM heated by nearby stars.


Archeops PS


Higal

Laboratory Data



Coupeaud et al. 2011, in prep

Most dust (98%) in ISM is amorphous (Kemper 2004)

Laboratory measurements of dust analog materials show (*Coupeaud et al 2011, in prep*):

- Internal structure of the grain material (amorphous vs crystalline) affects both the emissivity shape and intensity
- Emissivity flattens at long wavelenghs
- Emissivity flattens at high temperature

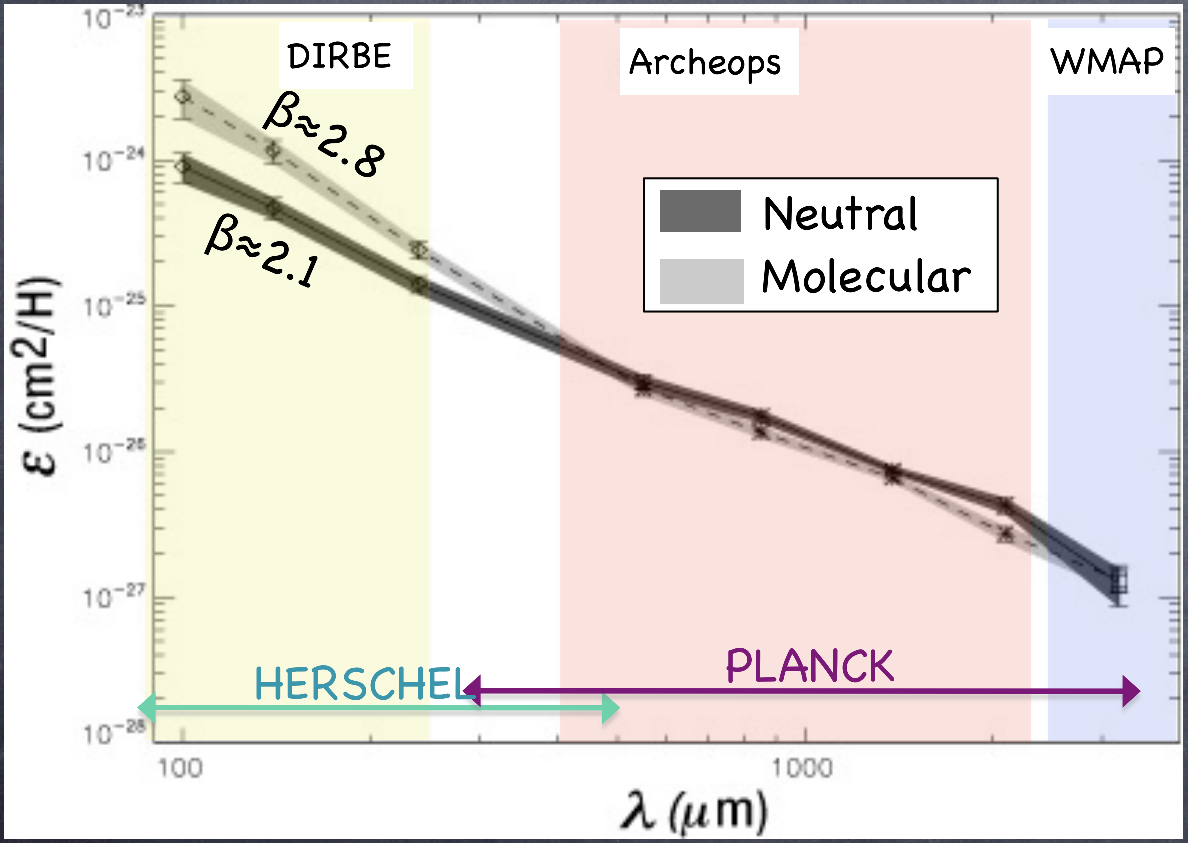
A physical explanation may be provided by models including grain structure disorder (TLS model) :

Meny et al. 2007

Paradis et al. 2011, in prep.

FIR-Submm dust emissivity

Early results from DIRBE, Archeops and WMAP towards cold molecular clouds (See talk by paradis)



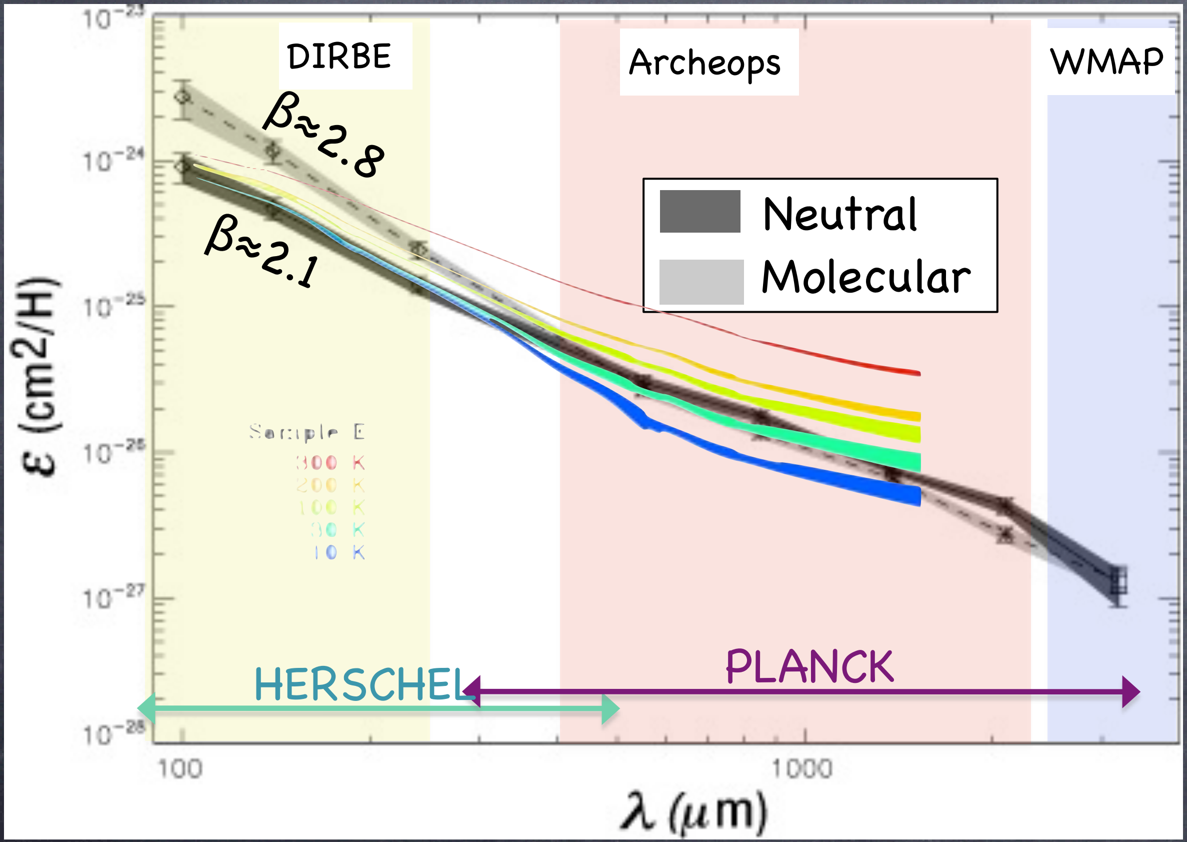
Show signs for emissivity variations :

- Flattening of dust SED above 500 microns
- Increased emissivity in cold molecular clouds

Paradis et al. 2009

FIR-Submm dust emissivity

Early results from DIRBE, Archeops and WMAP towards cold molecular clouds (See talk by paradis)



Show signs for emissivity variations :

- Flattening of dust SED above 500 microns
- Increased emissivity in cold molecular clouds

Paradis et al. 2009

Laboratory data from
Coupeaud et al. 2011, in prep

The TLS model of amorphous grains

Strongly inspired from solid-state physics : *Meny et al. 2007*

A double description of disorder in amorphous solids :

★ A Disordered Charge Distribution (DCD)

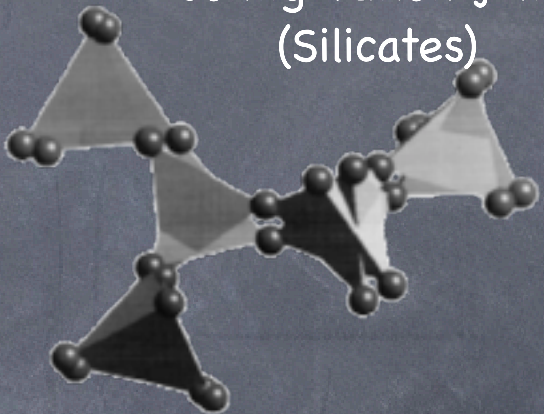
⇒ Emission independent of temperature (FIR)

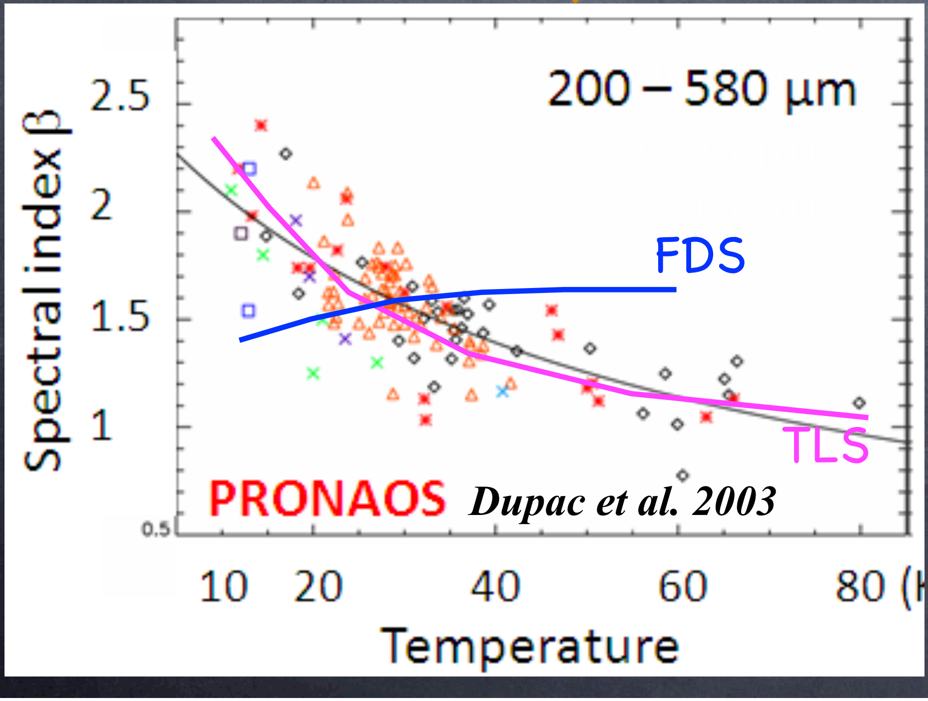
★ A microscopic distribution of asymetrical double potential wells (Two Level Systems: TLS) with small ΔE:

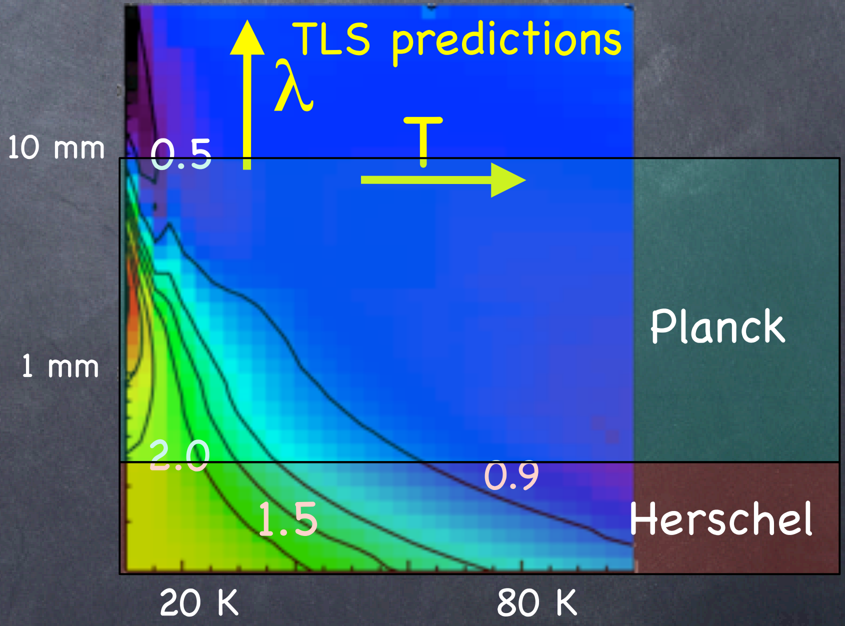
⇒ Emission dependent on temperature (submm)

(See talk by paradis)

Configuration jump (Silicates)

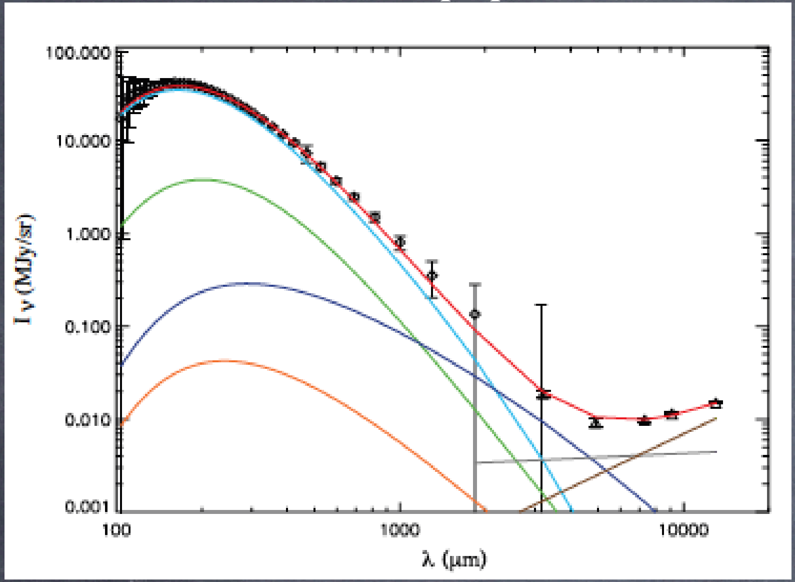


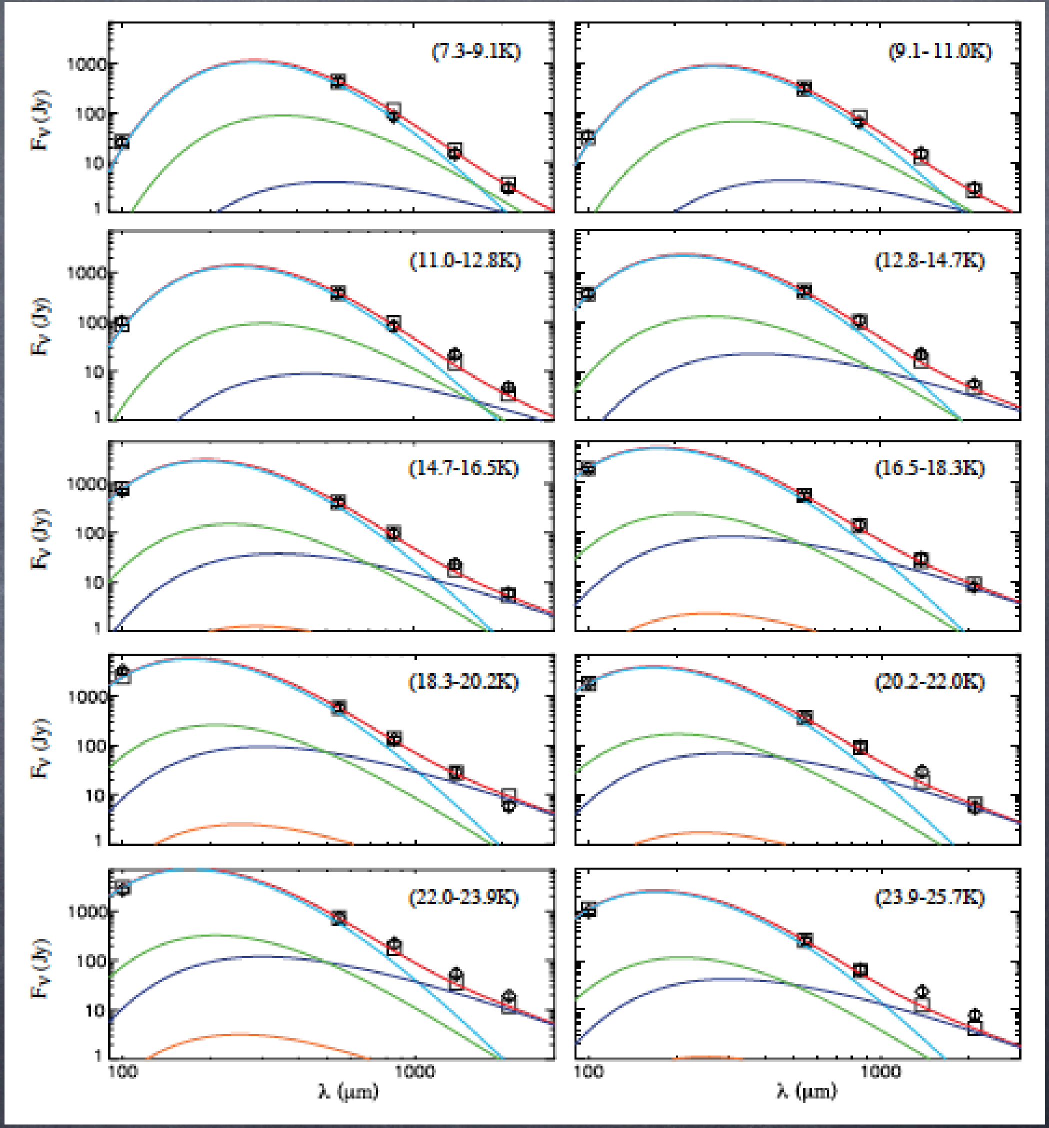




The TLS model of amorphous grains

Paradis et al. 2011, in prep.



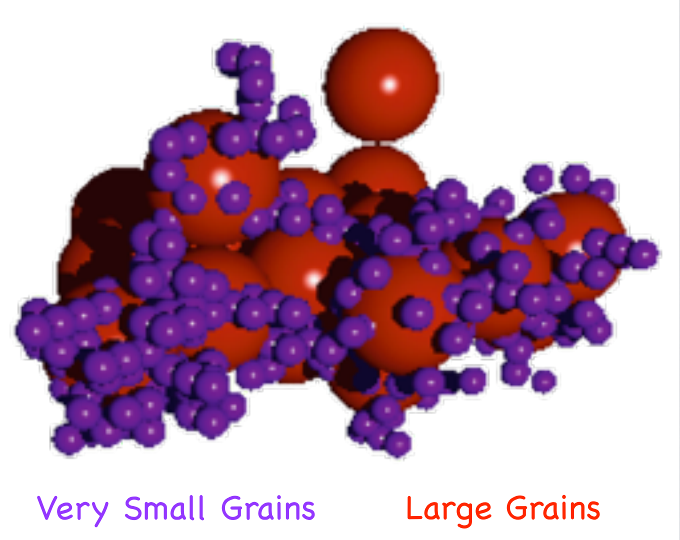


Deriving «standard» parameters of the TLS model (5 parameters) to explain both FIRAS MW and Archeops SED flattening with increasing T_d.

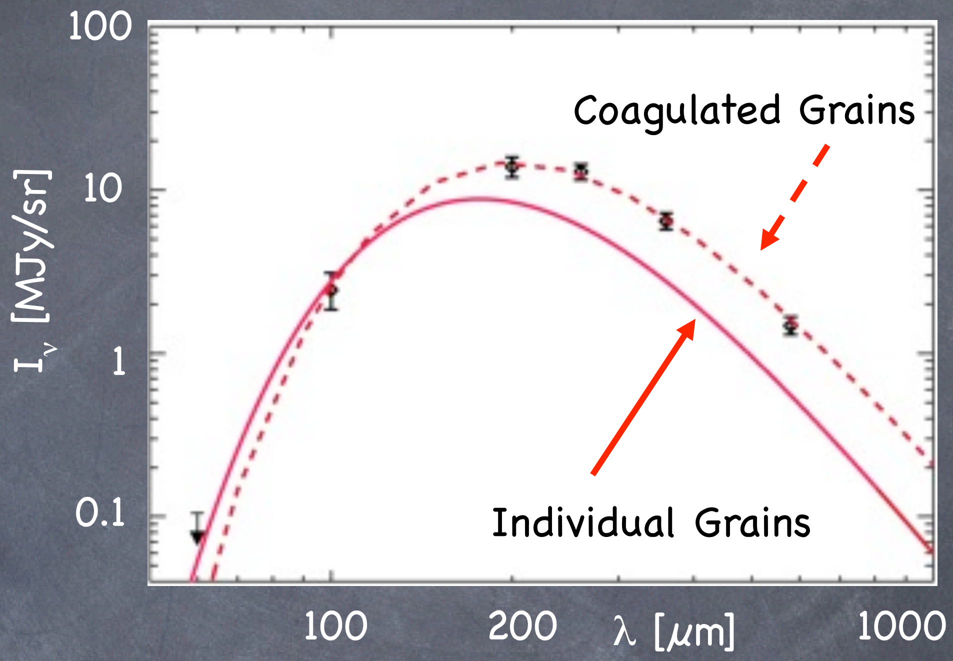
Non-negligible impact on masses derived from submm data

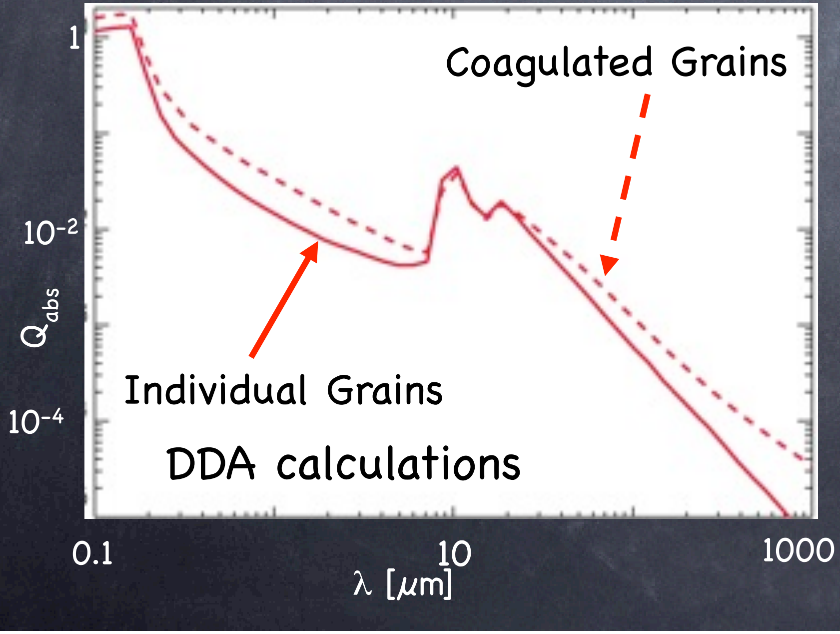
(See talk by paradis)

grain-grain Coagulation



PhD Thesis B. Stepnik

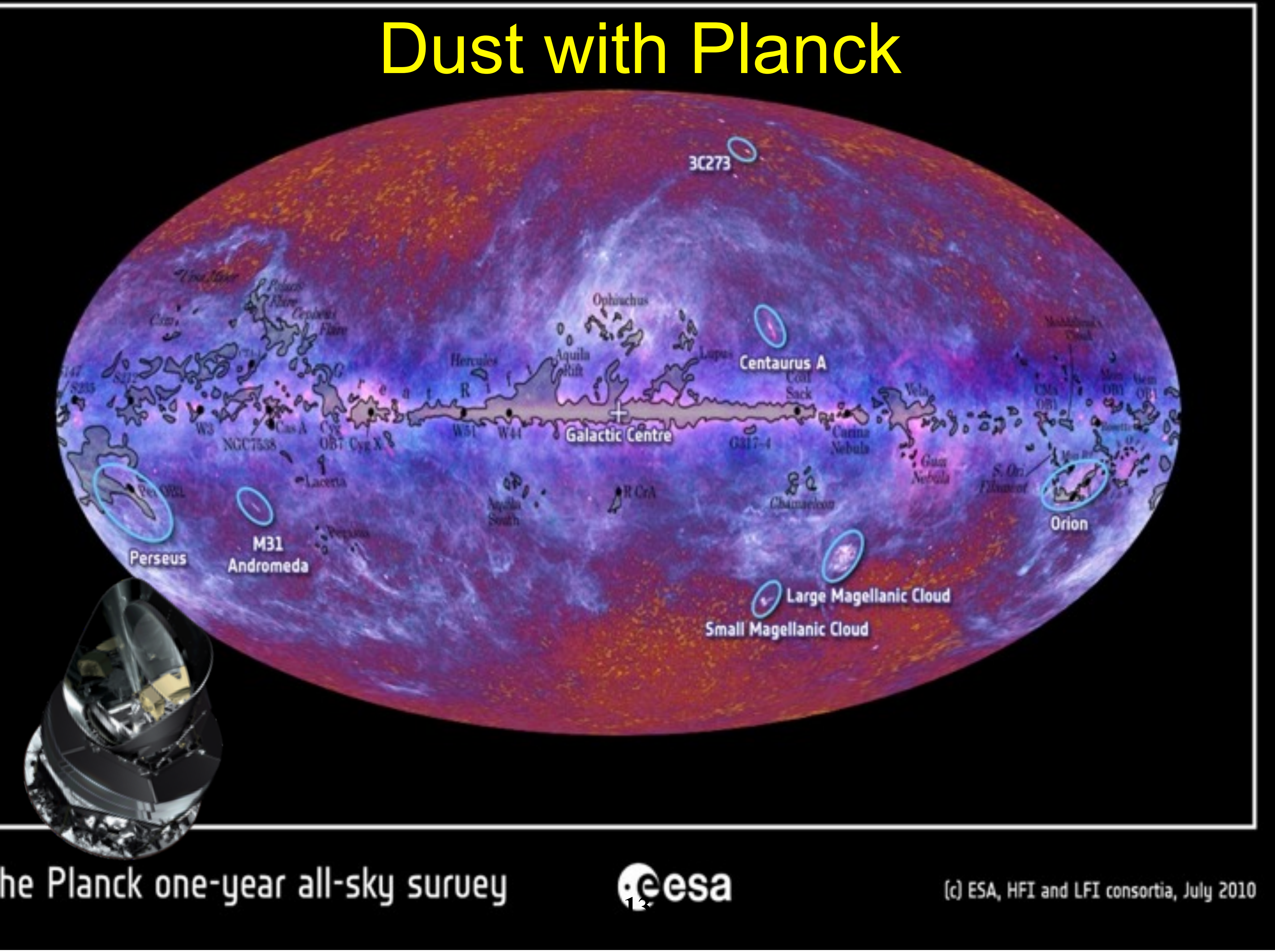




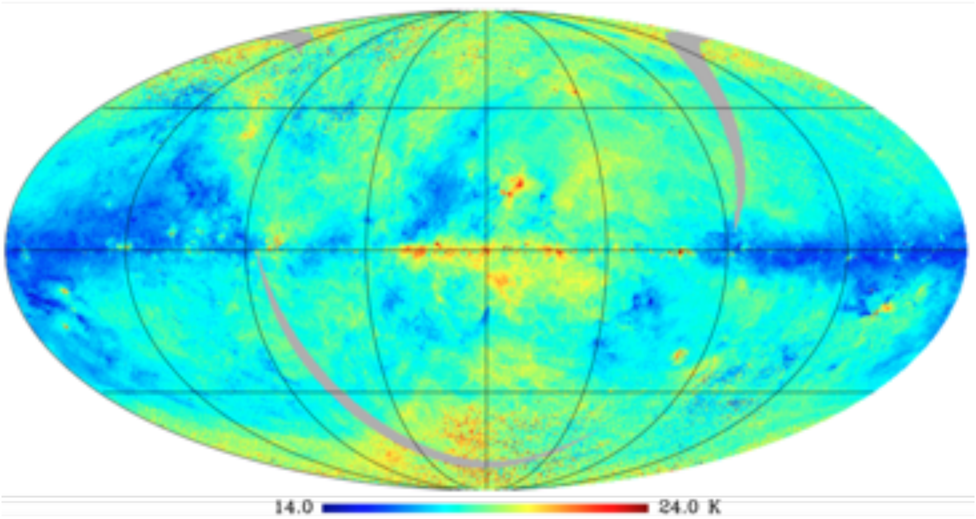
Bernard et al. 1999, A&A 347, 640
Stepnik et al. 2003, A&A 398, 551

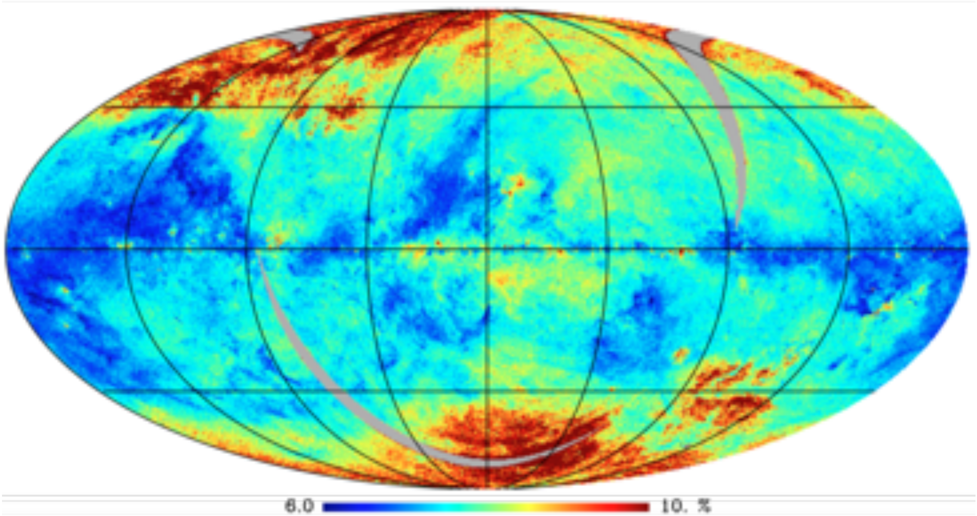
- Evidences in the Pronaos data (Polaris, Taureau)
- Coagulation of large and very small grains
- Fractal dimension ~2, N_{grains}>20
- 80-100% of small grains included in aggregates
- Fractal grains are more emissive (antena)
- Fractal grains are colder

Dust with Planck



Dust Temperature





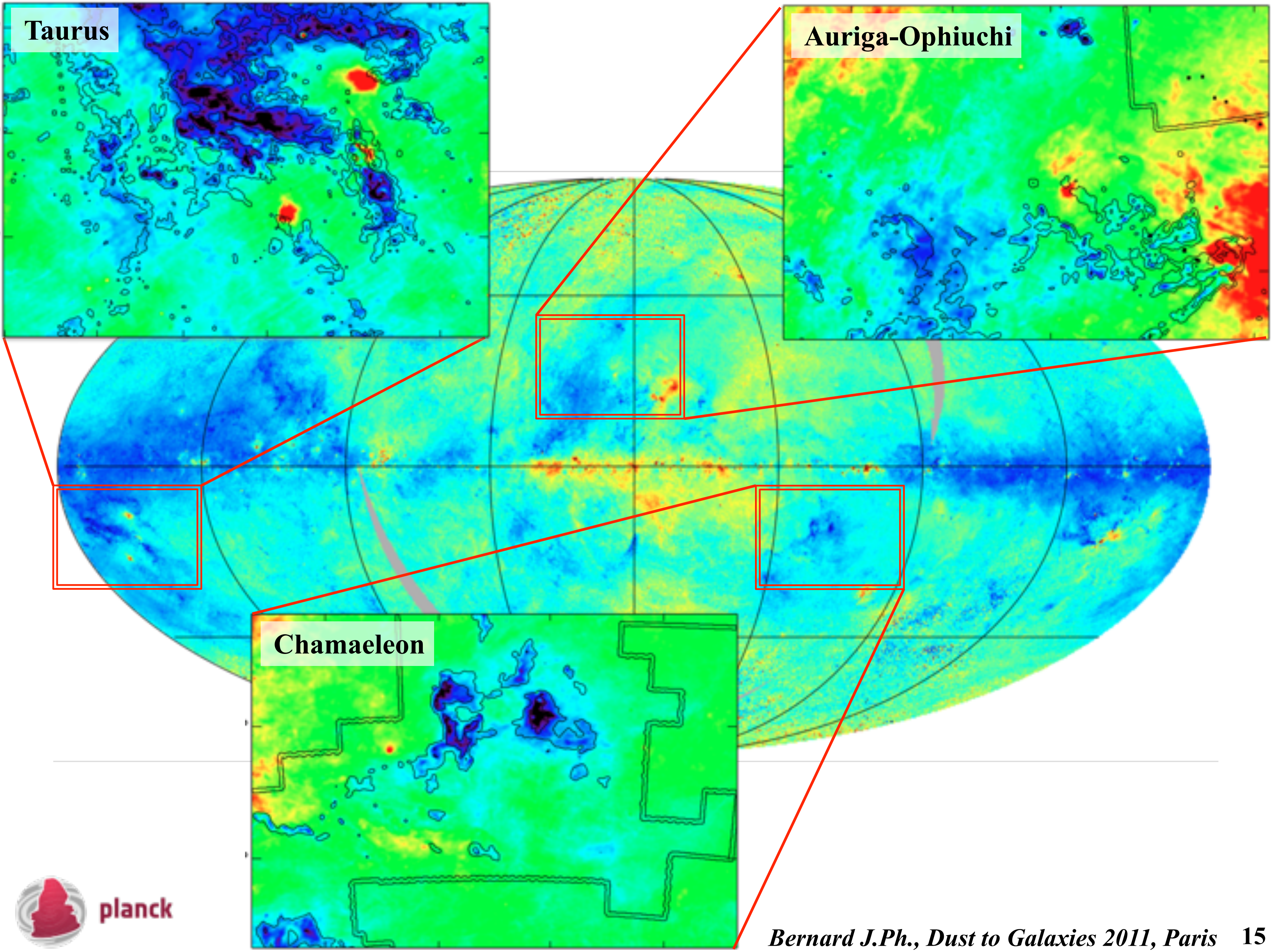
Temperature (T_D) computed from IRAS 100 μm, HFI 857 GHz, HFI 545 GHz, using $\beta=1.8$ (median value derived fromT-β fit)

$12\ K<T_D<50\ K$

- **Dust temperature clearly traces the intensity of the radiation field:**
- **External galaxy is colder than inner Galaxy (was already known from COBE data)**
- **Molecular clouds are colder than surrounding**
- **Warm regions are star forming regions, HII regions, etc ..**

Uncertainty on dust temperature from X^2 minimization using relative and absolute error. $\Delta T_D/T_D<10\%$ except at high latitudes (low brightness)

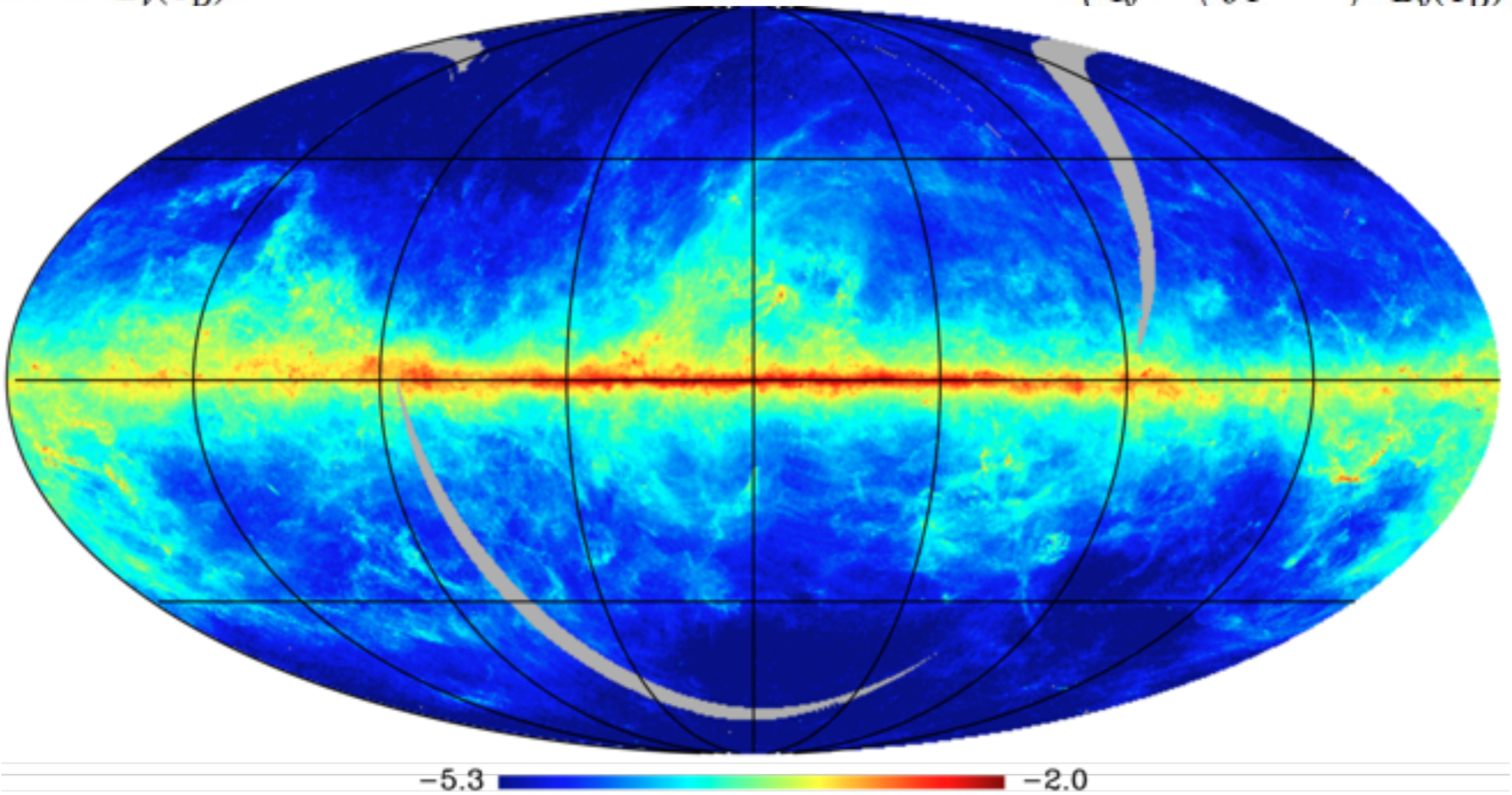
See arXiv: 1101.2029. C. author J.Ph. Bernard

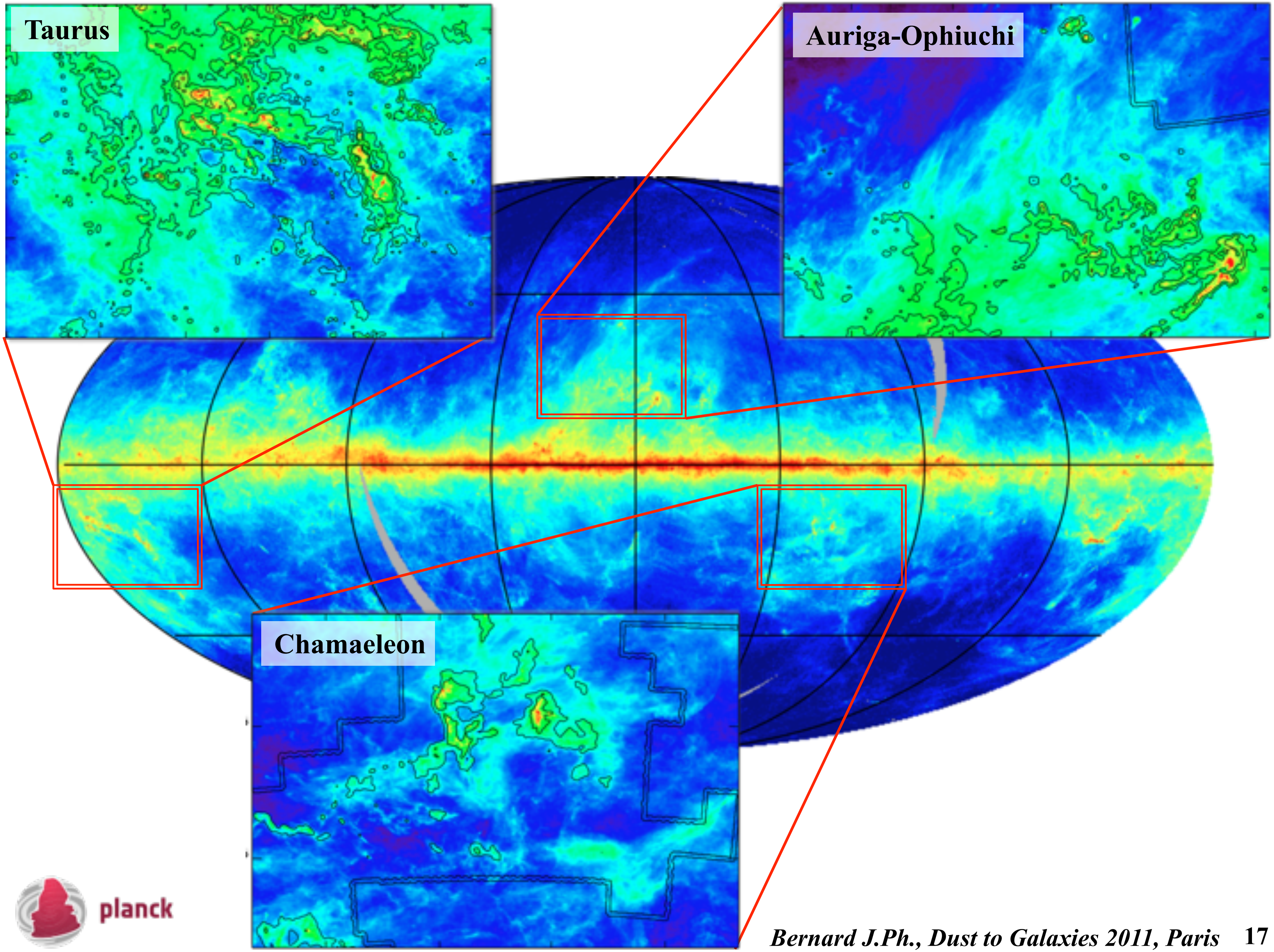

Taurus
Auriga-Ophiuchi
Chamaeleon

Dust Optical depth (MW)

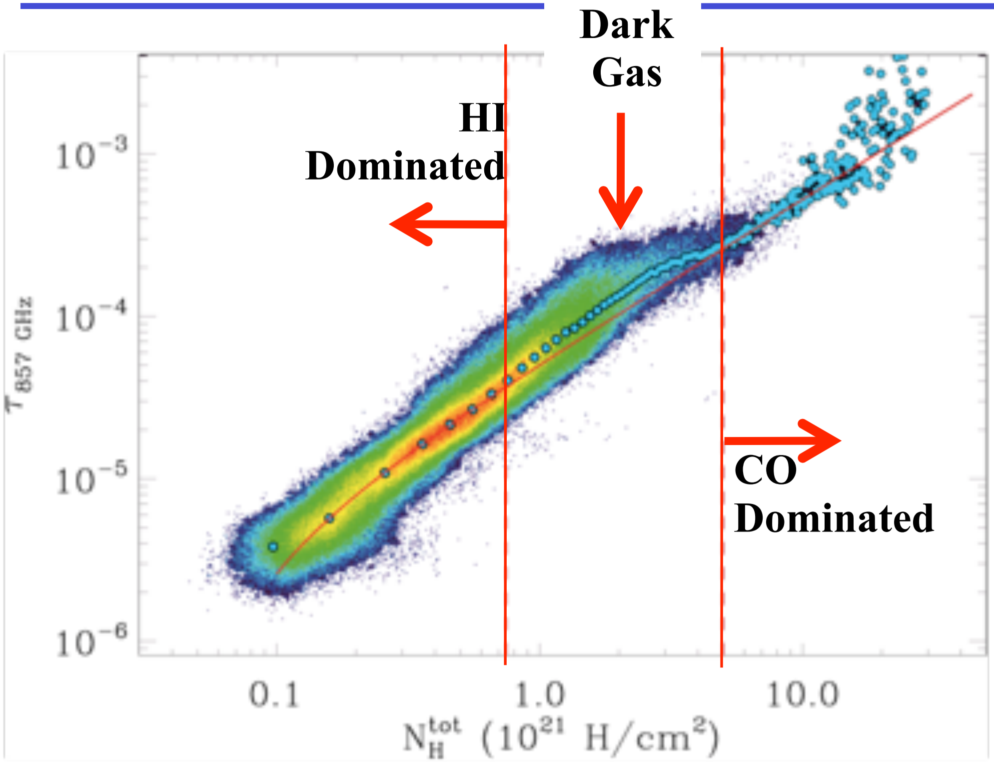
$$\tau_D(\lambda) = \frac{I_\nu(\lambda)}{B_\nu(T_D)},$$

$$\Delta\tau_D(\nu) = \tau_D \left(\frac{\sigma_{II}^2}{I_\nu^2} + \left(\frac{\delta B_\nu}{\delta T}(T_D) \right)^2 \frac{\Delta T_D^2}{B_\nu^2(T_D)} \right)^{1/2}$$




Taurus
Auriga-Ophiuchi
Chamaeleon

Evidence for Dark Gas



Dark Gas

HI Dominated

CO Dominated

See arXiv: 1101.2029. C. author J.Ph. Bernard

- LAB HI data (atomic gas)
- 3 ^{12}CO(J=1-0) surveys: *Dame et al. 2001*, Dame unpublished, Nanten (unpublished) 68% of the sky

Very similar plots obtained from IRAS 100 μm, HFI 857, 545, 353 GHz

As computed in solar neighbourhood (|b|>10°) and assuming thin HI :
Transition between HI dominated and Dark Gas found at Av=0.4+-0.03 mag
τ/N_H ~power law with β=1.8. Consistent with $\tau/N_H = 10^{-25}$ cm^2 @ 350 μm (Boulanger et al 1996).
Average Xco factor Xco=2.54+-0.13 H_2/cm^2/(Kkm/s)
Dark Gas mass fraction: 28%+-2.8% of HI gas, 118%+-1.2% of molecular gas

γ-ray observations find a similar "Dark-Gas" phase, with a similar mass fraction (*Grenier et al 2005, Abdo et al. 2010*)
Herschel GotC+ find similar Dark-Gas fractions in the MW plane (*Langer et al. 2010*)

planck

Dark Gas origin ?

Possible origins :
- **Dust abundance variations (unlikely in solar neighbourhood, DG seen in γ-ray)**
- **Dust property variations (unlikely as DG seen in γ-ray, TBC with dust extinction)**
- **HI 21 cm can be optically thick: Assuming Ts=80 K reduces the DG fraction by about half**
- **Weak CO below the threshold of the surveys: (Wco~ 0.5 Kkm/s): can contribute <20% of DG**

Planck in solar neighbourhood (|b|>10°):

Mass fraction of Dark Gas: 28% of HI (118% of CO)

Av(DG)=0.4 mag

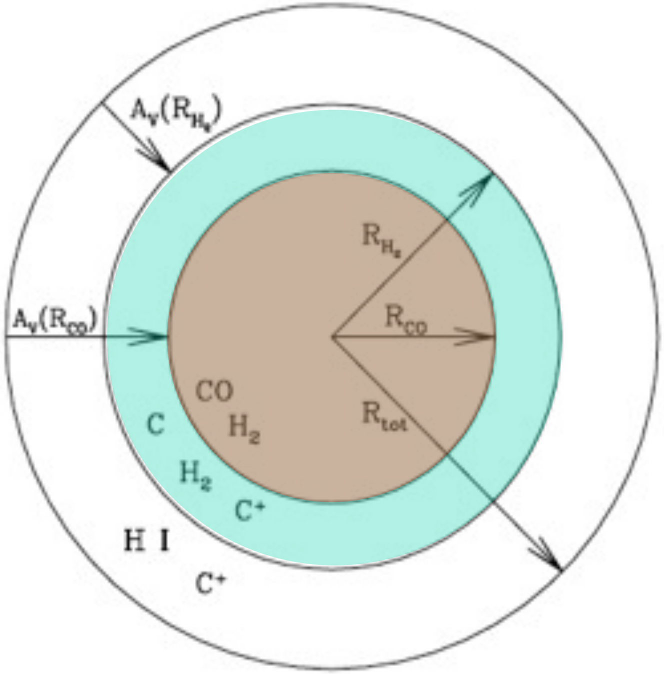
Xco=2.54 10^{20} $H_2cm^{-2}/(Kkm/s)$

Predictions by Wolfire et al. 2010:

H_I/H_2 transition at $Av(R_{H2})=0.2$ mag

H_2/CO transition at $Av(R_{CO})=1$ mag

f_{DG} ~ 30% of CO gas

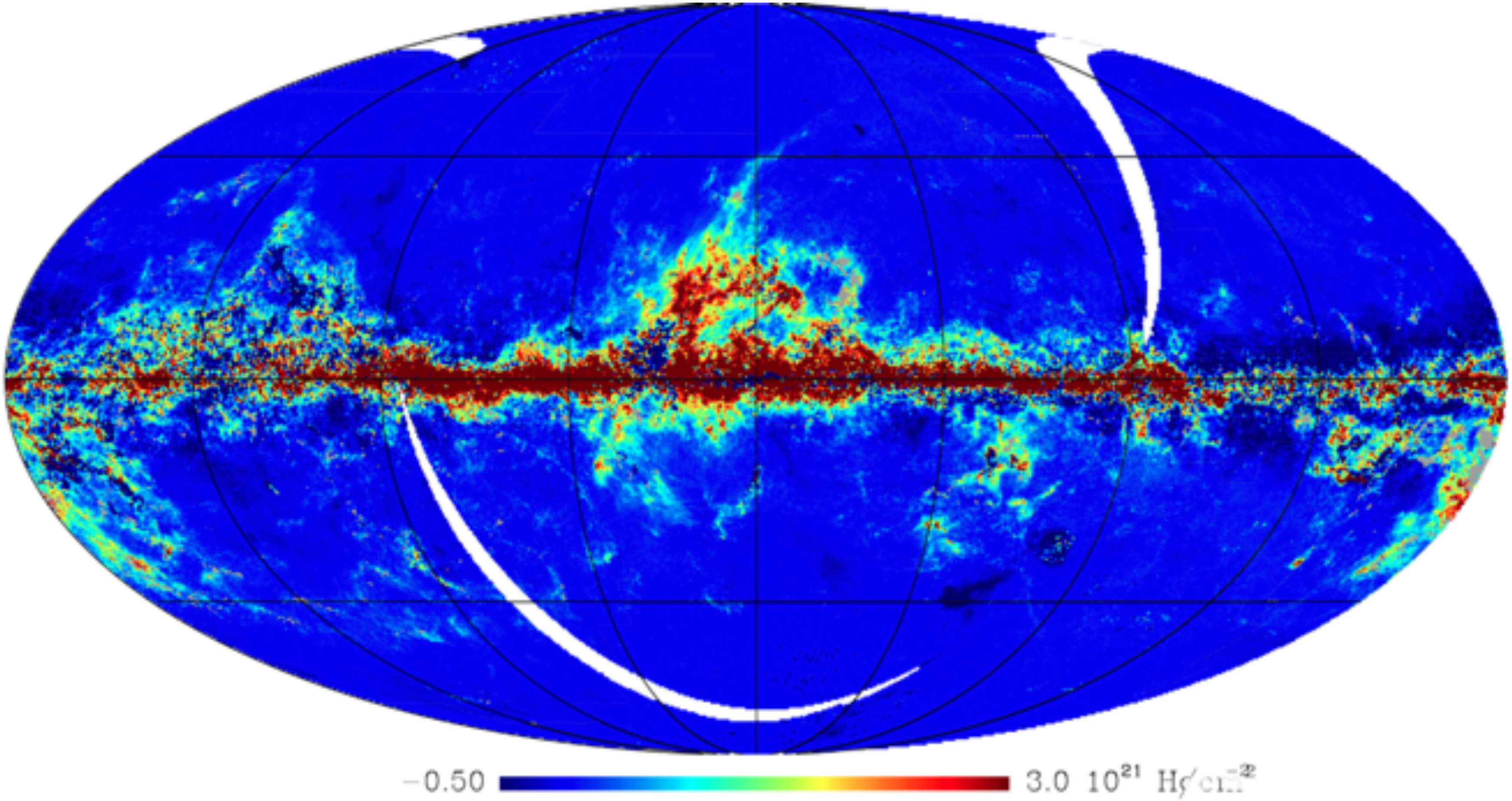


Clouds in theoretical study much more massive than in solar neigbourhood

Unclear if difference in f_{DG} due to assumed cloud mass …

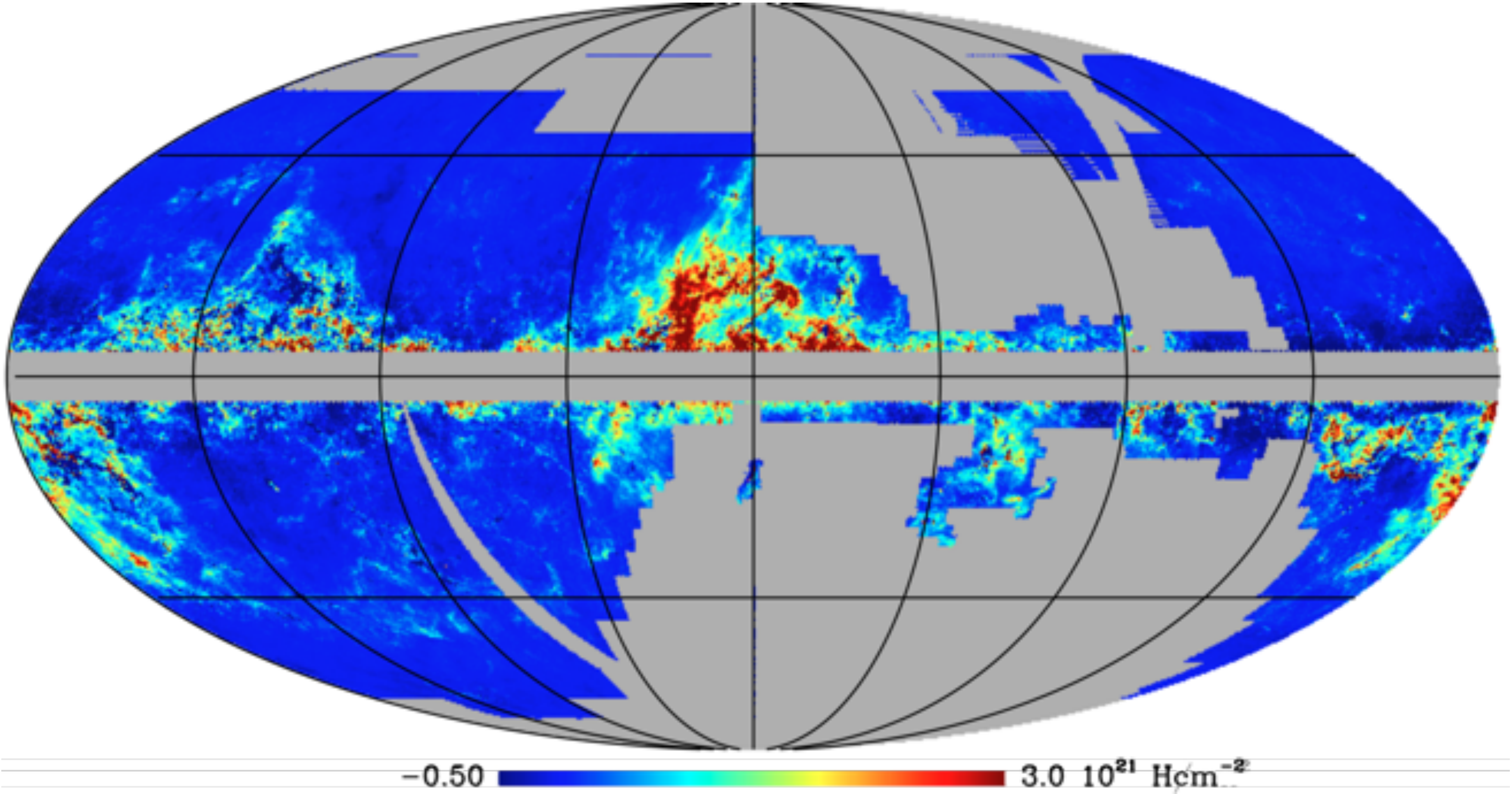
Bernard J.Ph., Dust to Galaxies 2011, Paris

Dark Gas distribution



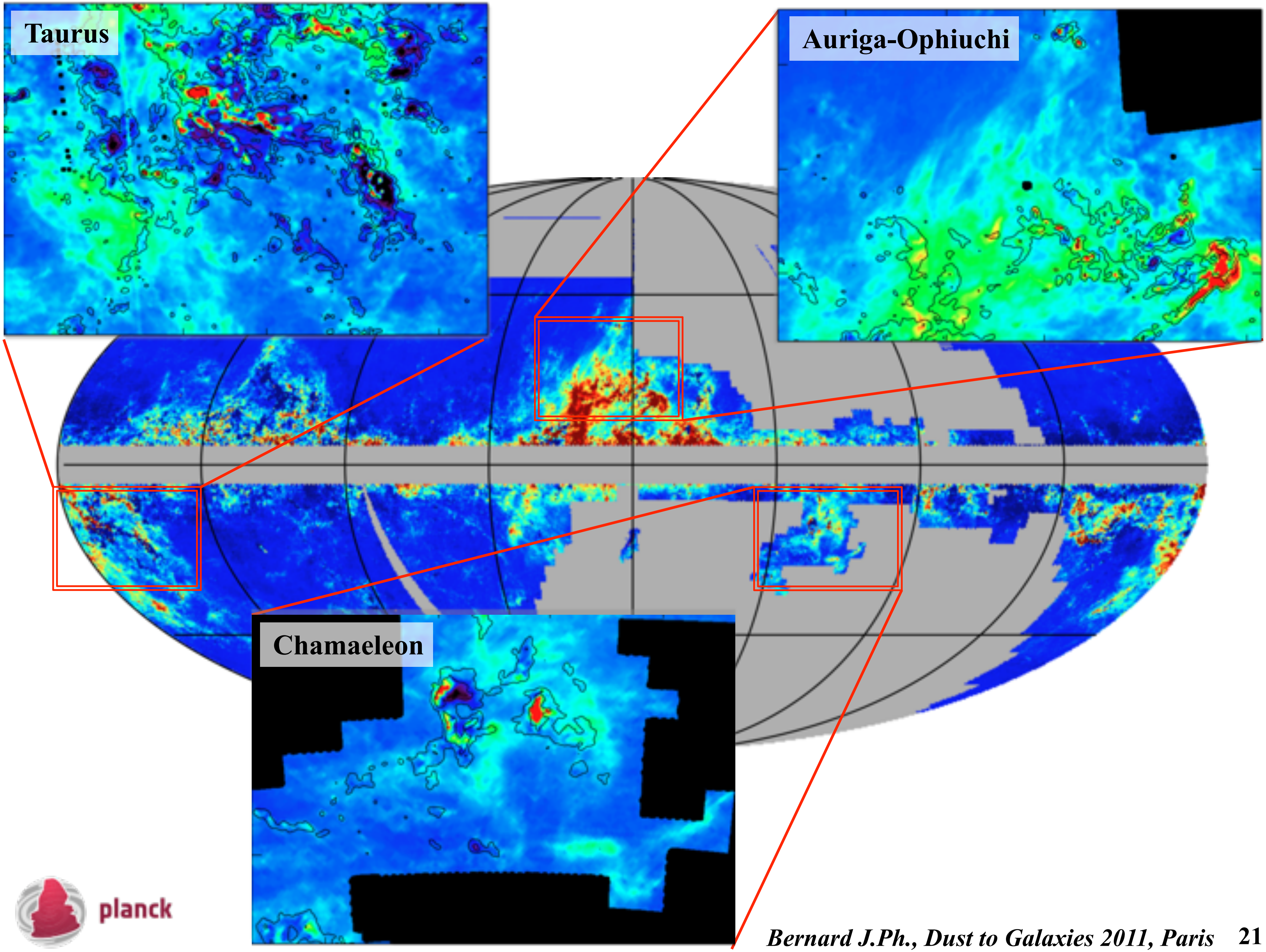
See arXiv: 1101.2029. C. author J.Ph. Bernard

Dark Gas distribution



See arXiv: 1101.2029. C. author J.Ph. Bernard

planck



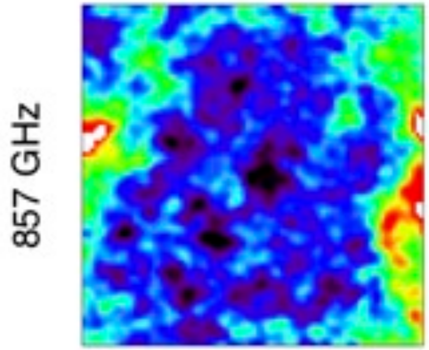
planck

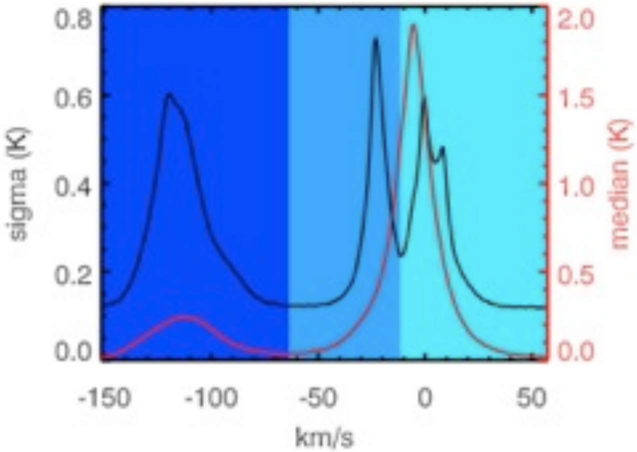
Bernard J.Ph., Dust to Galaxies 2011, Paris

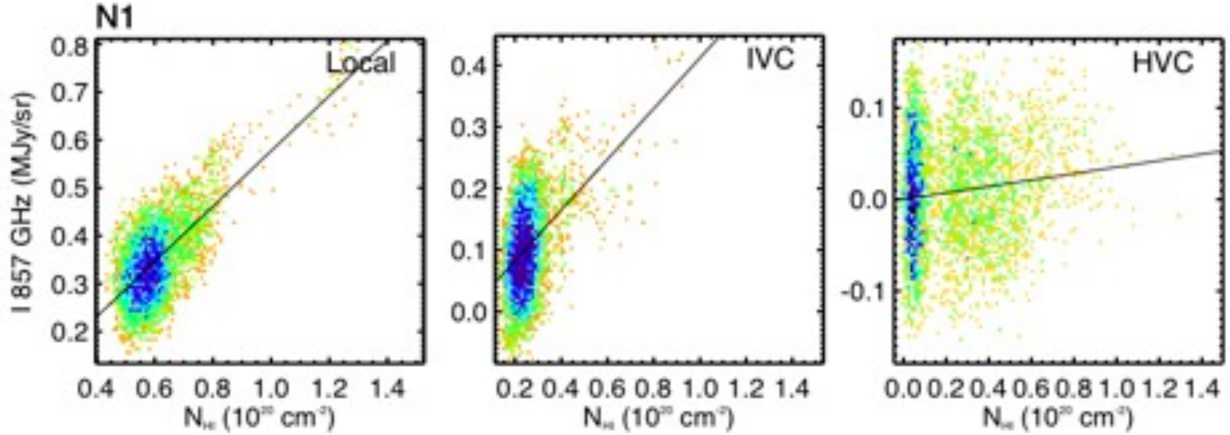
Dust-HI correlation in the Halo

See arXiv: 1101.2036. C. author M.A. Miville-Deschenes

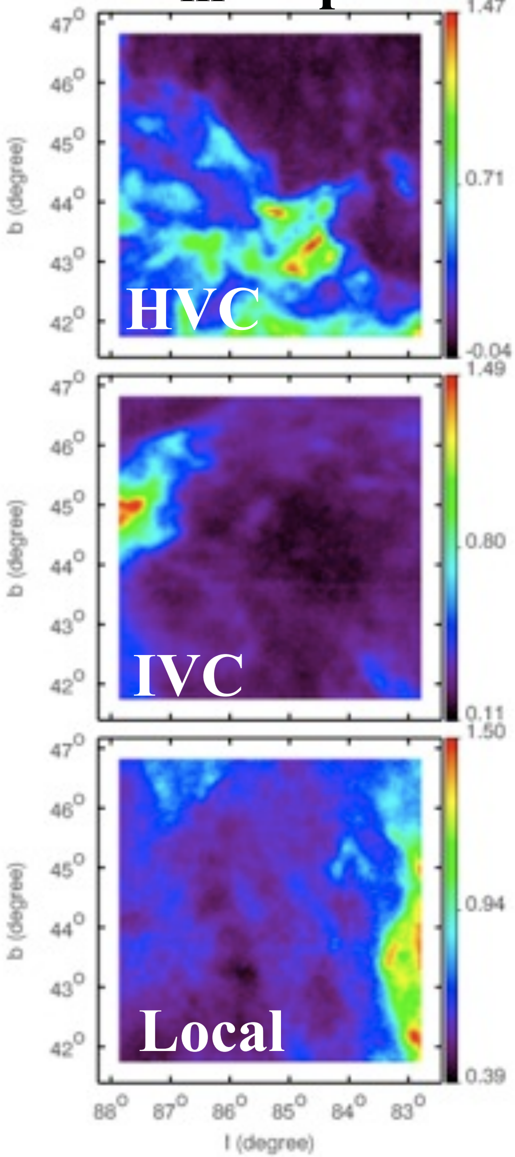
N1-Field :







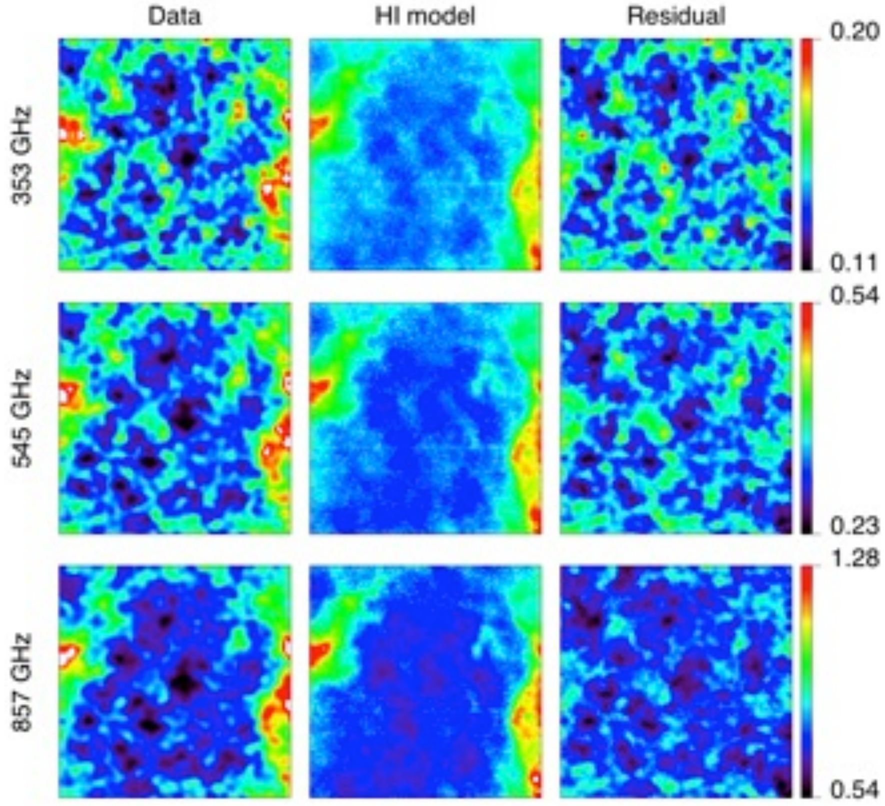
N_{HI} maps



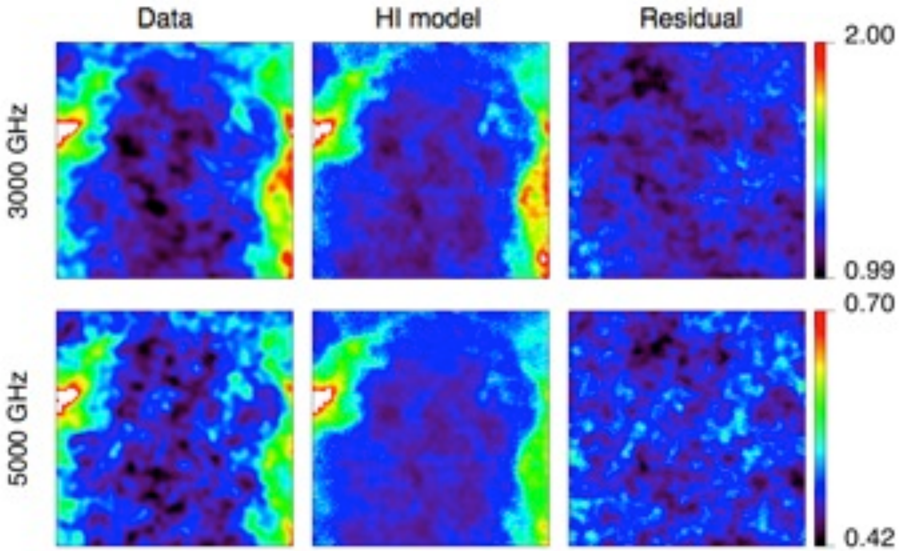
$$I_\nu(x,y) = \sum_{i=1}^{3} \epsilon_\nu^i N_{HI}^i(x,y) + R_\nu(x,y) + Z_\nu$$

Dust-HI correlation in the Halo

Planck



IRAS



$$R_\nu(x,y) \equiv I_\nu(x,y) - \sum_{i=1}^{3} \epsilon_\nu^i N_{HI}^i(x,y) - Z_\nu$$

HI - dust correlation over 825 square degrees at high latitudes, N_{HI} from 0.6×10^{20} to 10×10^{20} cm^{-2}

Dust in the diffuse local ISM: good fit with ($T=17.9$ K, $\beta=1.8$) from 3000 to 353 GHz (100 to 850 µm)

Faint fields ($N_{HI} < 2 \times 10^{20}$ cm^{-2}) : residual compatible with CIBA - no evidence for dust in the WIM

Excess emission for $N_{HI} > 3 \times 10^{20}$ cm^{-2} (0.15 mag) compatible with Dark-Gas (10% in mass)

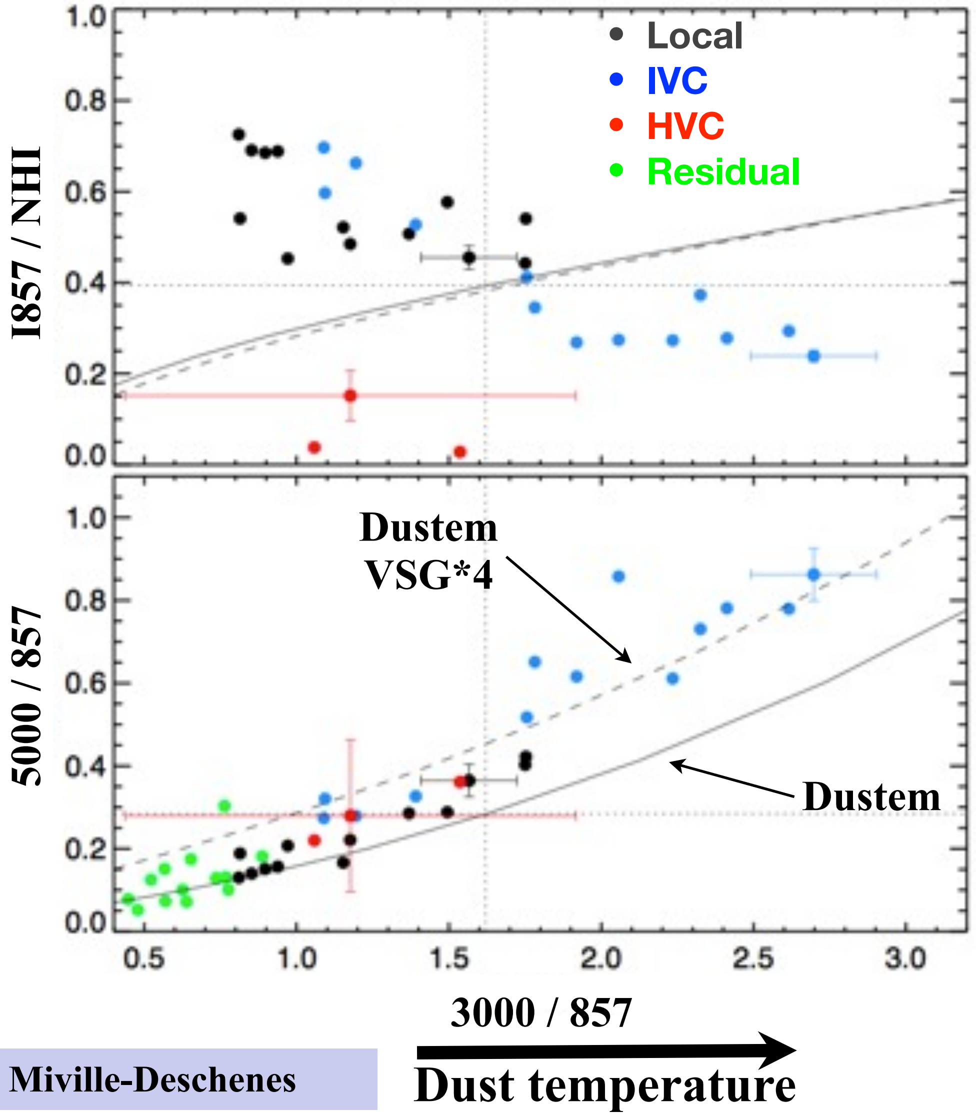
Dust-HI correlation in the Halo

Unexpected evidences for dust evolution in the diffuse ISM:

- Temperature - emission cross-section anti-correlation suggesting modification of grain structure (or size) through coagulation.

- IVC : 4 times larger VSG abundance, hotter dust (T~20K). Compatible with clouds part of the Galactic fountain (dust shattering)

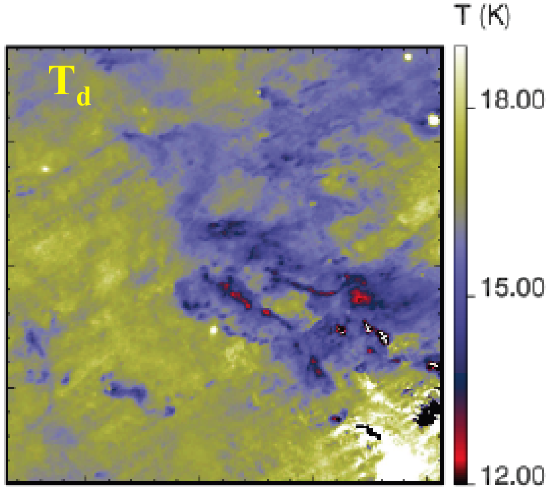
Marginal detection of HVCs (1-3.8 σ) compatible with low metallicity (~0.1 solar)

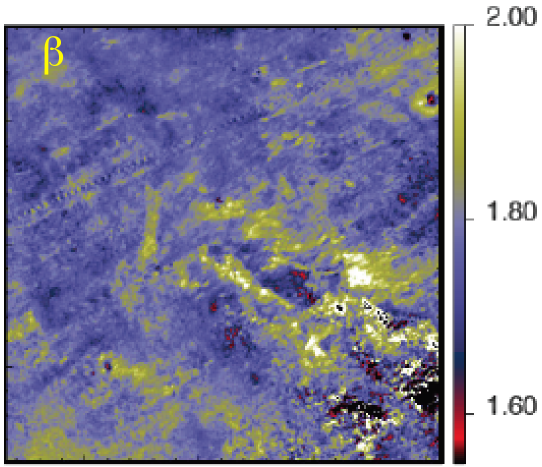


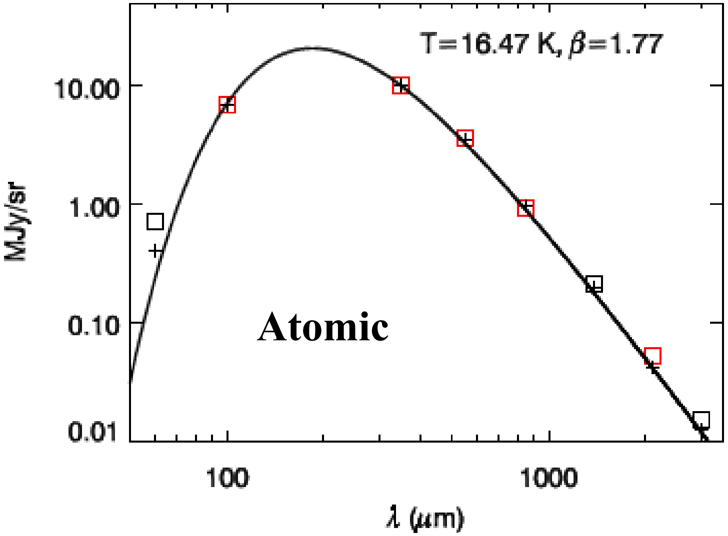
See arXiv: 1101.2036. C. author M.A. Miville-Deschenes

Dust in Molecular Clouds (Taurus)

Temperature and spectral index maps







- Narrow β distribution: 1.78 +- 0.08 (rms) +- 0.07 absolute

- Systematic residuals at 353 GHz (-7%) and 143 GHz (+13%) indicate spectrum more complex than a simple modified black-body

- Dust temperature maps from 16–17 K (diffuse regions) to 13–14 K (dense regions)

- Emissivity increase in dense regions :

τ/N_H @ 250 μm from ~ 10^{-25} cm^2 (diffuse) to ~2×10^{-25} cm^2 (dense)

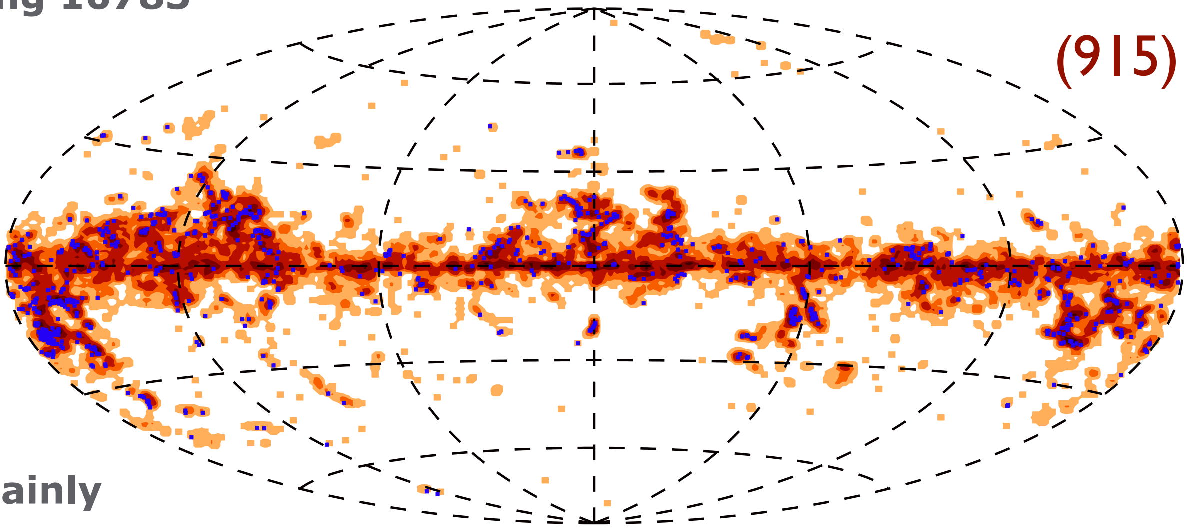
-Such variations of τ/N_H have an impact on the equilibrium temperature of the dust particles

See arXiv: 1101.2037. C. author A. Abergel

planck

Cold-Cores

- The Early Cold Core (ECC) catalogue counting 915 objects is the high reliable subset the Cold Core Catalogue of Planck Objects (C3PO) containing 10783 sources over whole sky.



All-sky map of the number of C3PO objects per square degree (10783)

■ ECC Selection (915)

- These sources are dense and cold molecular objects, potentially pre-stellar objects.

- These cold sources are mainly cold clumps, intermediate sub-structures between clouds and cores, organized in groups, filaments and aligned on large-scale loops.

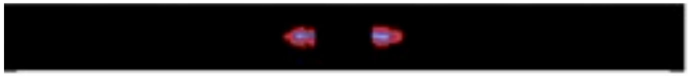
- These catalogues give an unprecedented statistical view to the properties of these potential pre-stellar clumps and offers a unique possibility for their classification in terms of their intrinsic properties and environment.

See arXiv: 1101.2035. C. author L. Montier

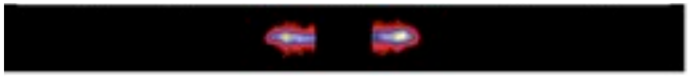
Galactic plane decomposition

See arXiv: 1101.2032. C. author D. Marshall

HI Ring 1



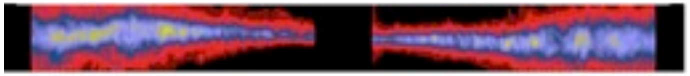
HI Ring 2

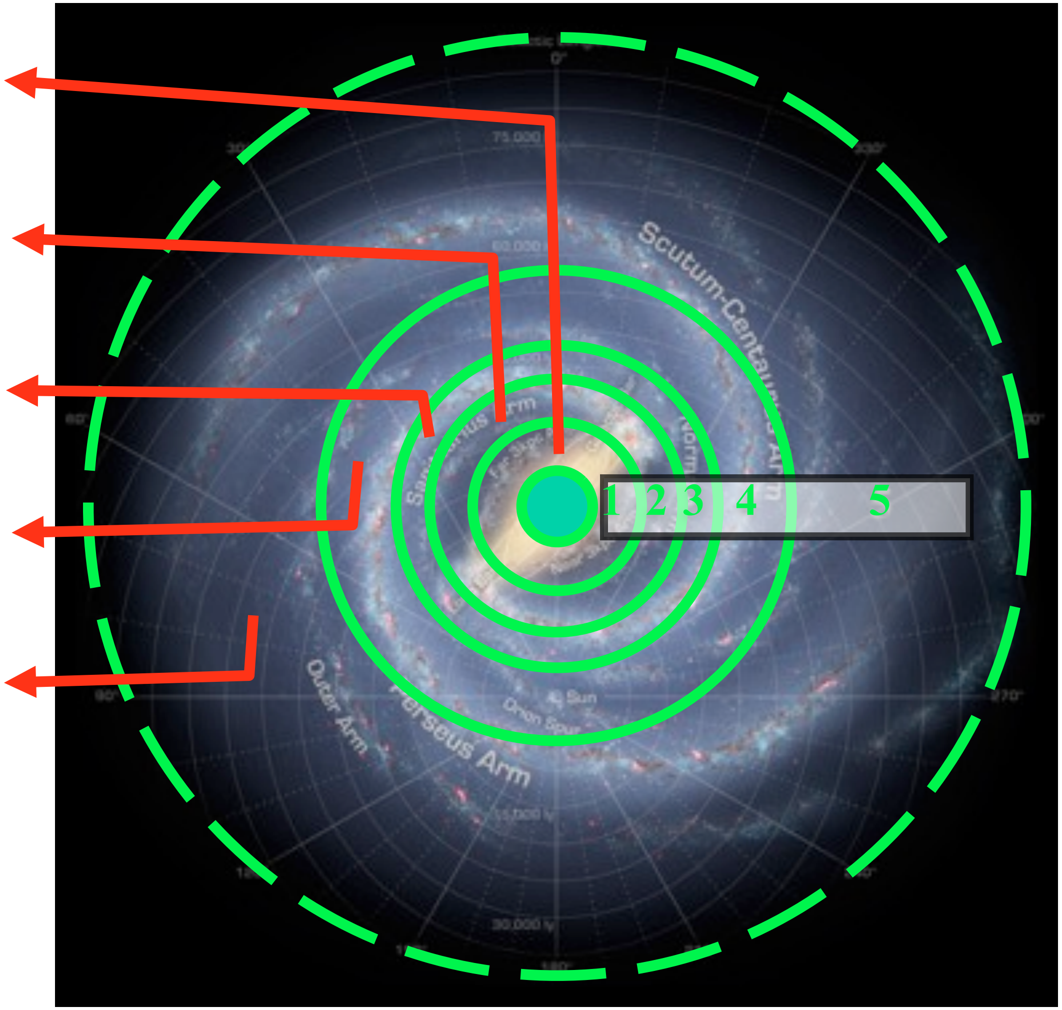


HI Ring 3

HI Ring 4

HI Ring 5





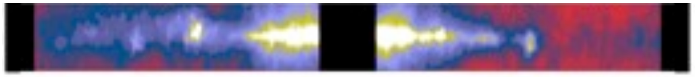
Radii chosen to minimize correlation between rings

Galactic plane decomposition

See arXiv: 1101.2032. C. author D. Marshall

HII (WMAP free-free)

Synchrotron (Haslam 408 MHz)

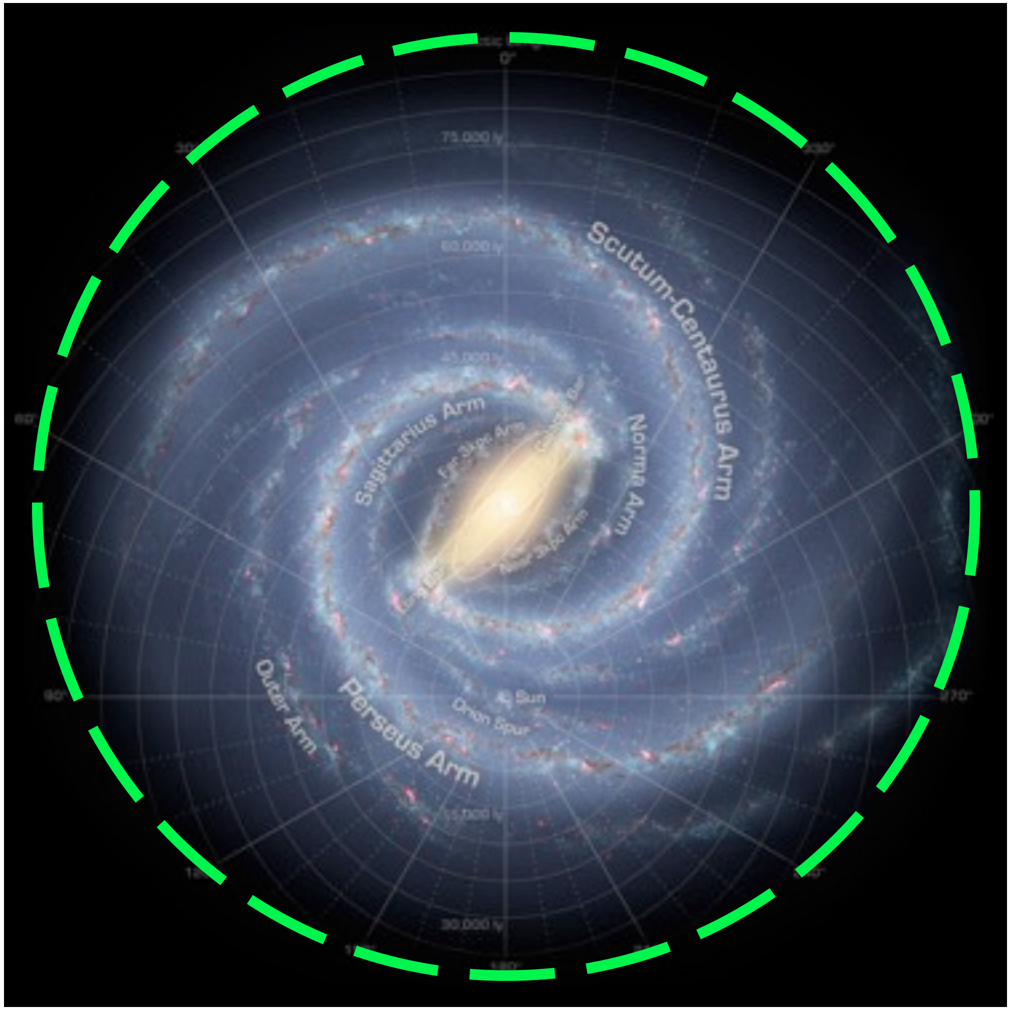


Dark gas

Result is 13 spatial templates (HI, CO, HII, Synchrotron & Dark gas

Frequency maps can be expressed as a linear combination of the spatial templates

All templates and data are smoothed to 1° FWHM



Example at 857 GHz

Data

Model

HI

H_2

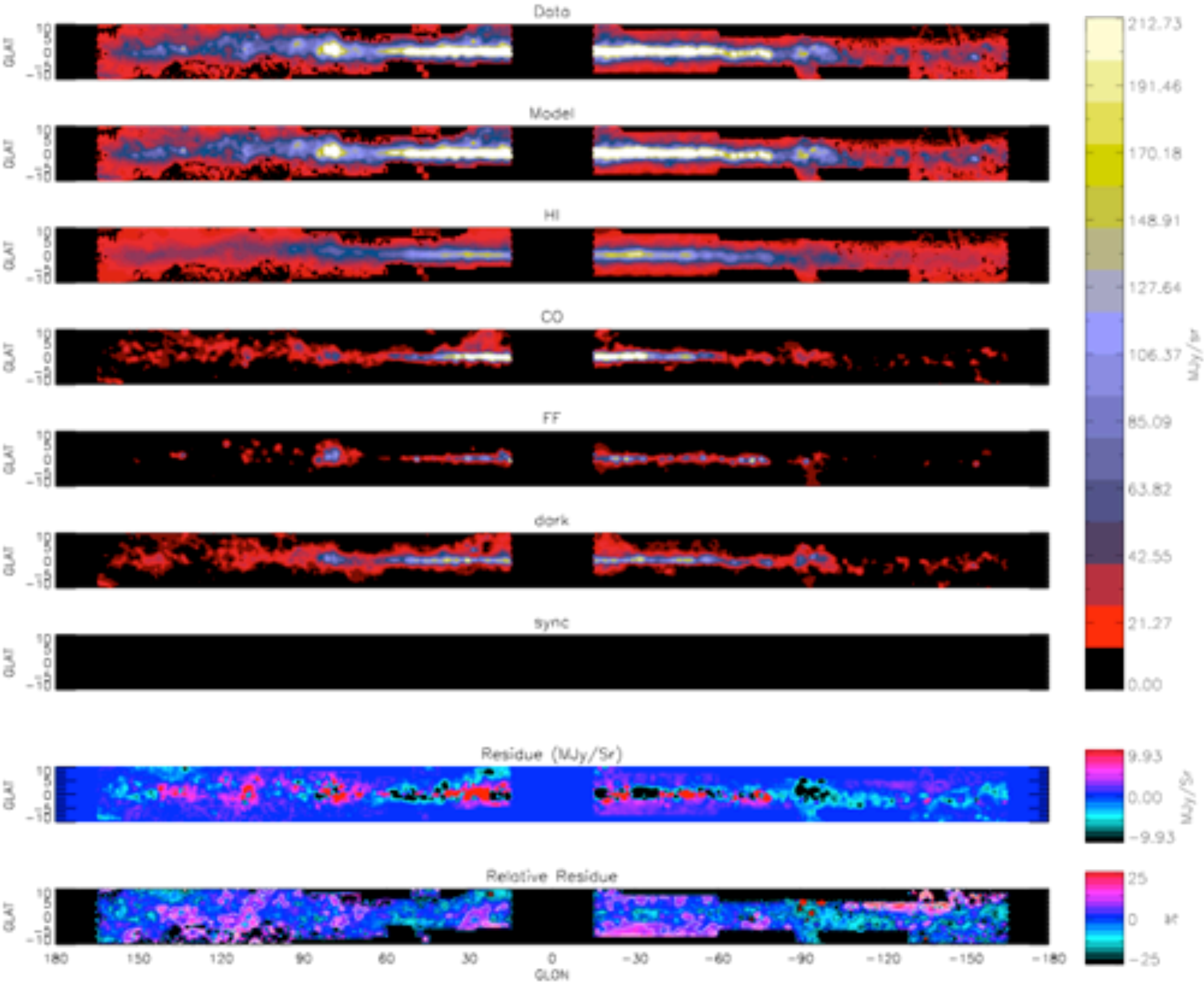
HII

Dark

Sync.

Residue

Relative Residue

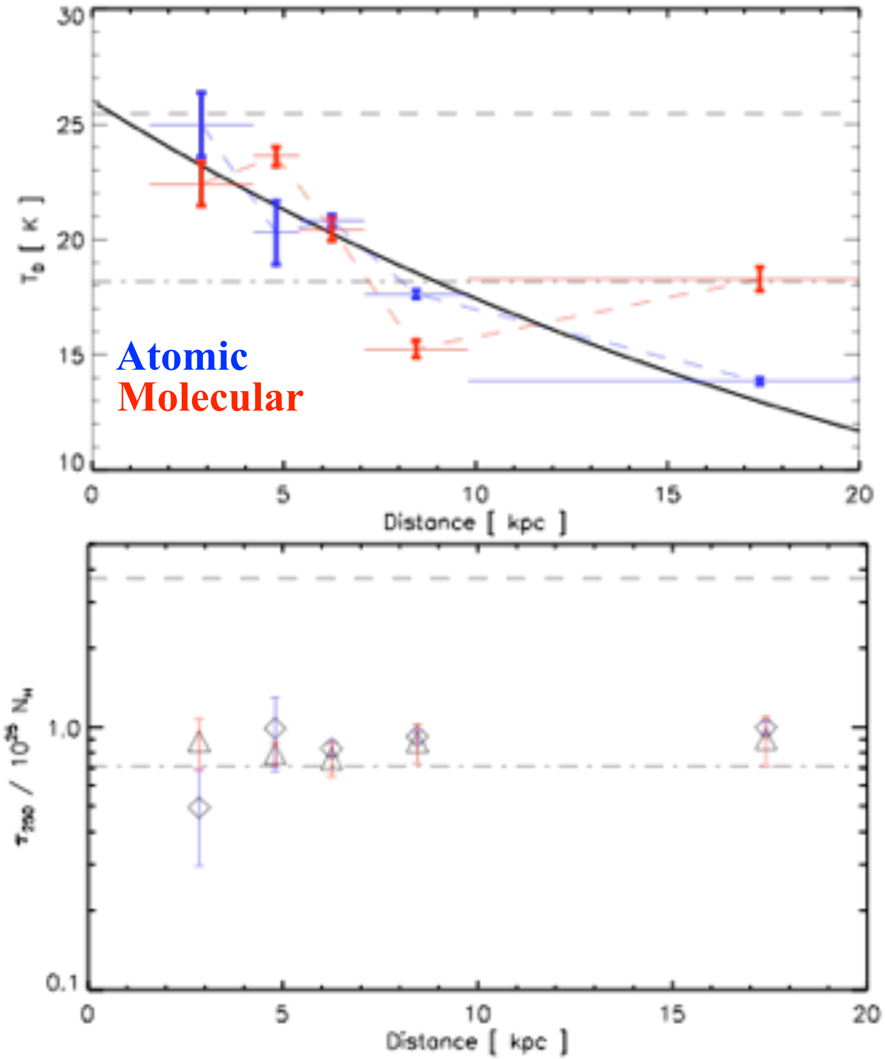


Thermal dust

Emission modeled with modified blackbody

$$I_\nu = B_\nu \nu^\beta = \frac{2h\nu^3}{c^2(e^{h\nu/kT}-1)}\nu^\beta ,$$

Dust spectral index ß = 1.8



-Temperature follows the general ISRF decrease with R
- Solar circle values (T, τ/N$_H$) in agreement with high latitude studies
- Temperature in the molecular phase maybe more sensitive to local star formation (molecular ring)

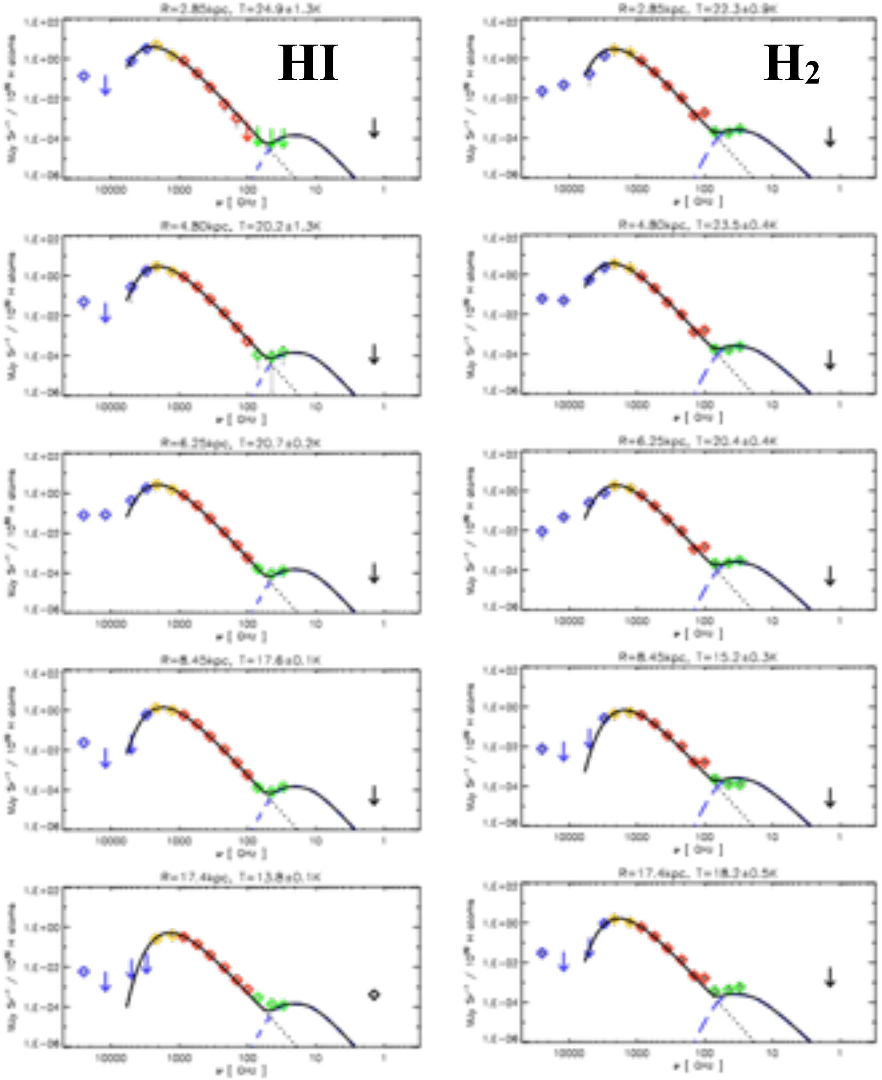
=> No significant emissivity variation with galacto-centric radius

Dust emission associated to ionized gas also detected.

See arXiv: 1101.2032. C. author D. Marshall

Anomalous microwave emission (AME)

See arXiv: 1101.2032. C. author D. Marshall



AME seen at all radii, in all phases but the ionized phase
25+/-5% (stat.) of 30 GHz signal

One possibility is spinning dust as modeled by Silsbee et al. (2010)

We use simple assumptions :
1) Solar ISRF
2) Standard PAH abundance
3) Single size distribution, centered 0.6 nm, width 0.4 nm, log normal
- Standard gas parameters :

Atomic (CNM) $n_H = 30\ cm^{-3}$
Atomic (WNM) $n_H = 0.4\ cm^{-3}$
Molecular $n_H = 350\ cm^{-3}$
Ionised $n_H = 10\ cm^{-3}$

See arXiv: 1101.2032. C. author D. Marshall

Anomalous microwave emission (AME)

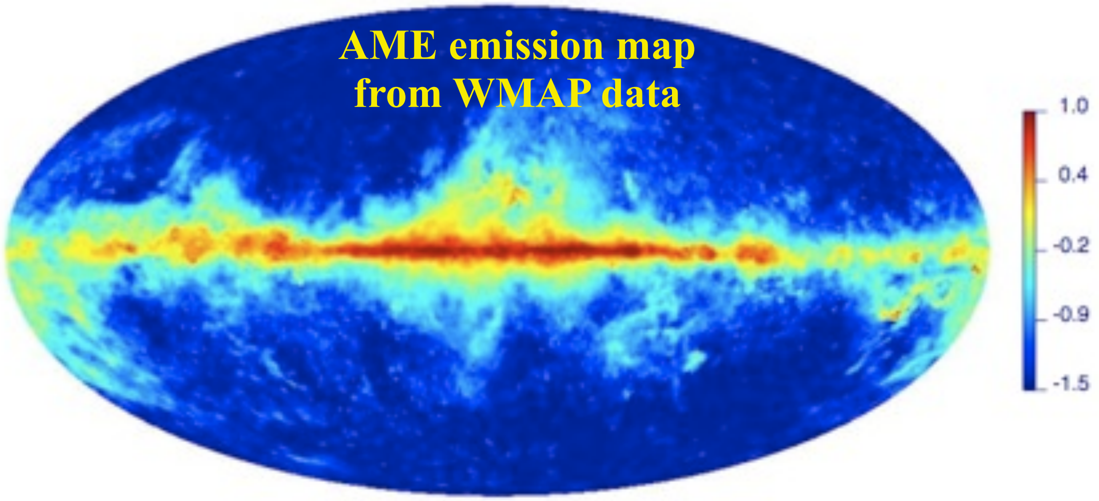
Previous studies (Miville-Deschênes et al. 2008) used the asumption that AME is not polarized to isolate AME in the WMAP data.

The excess was previously wrongly attributed to Synchrotron spectral index variations

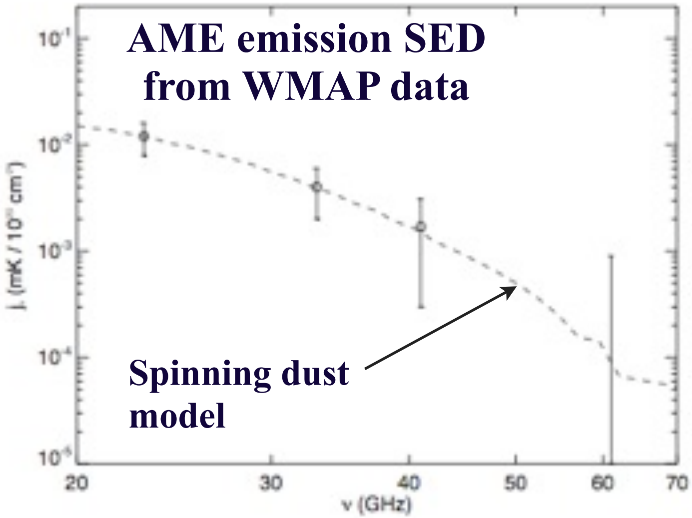
- AME is widespread and globally correlated to dust emission

- AME better correlates with 12 µm than 100 µm emission (Ysard et al. 2010)

- AME spectrum is consistent with spinning dust from very small particles (PAH)



AME emission map from WMAP data



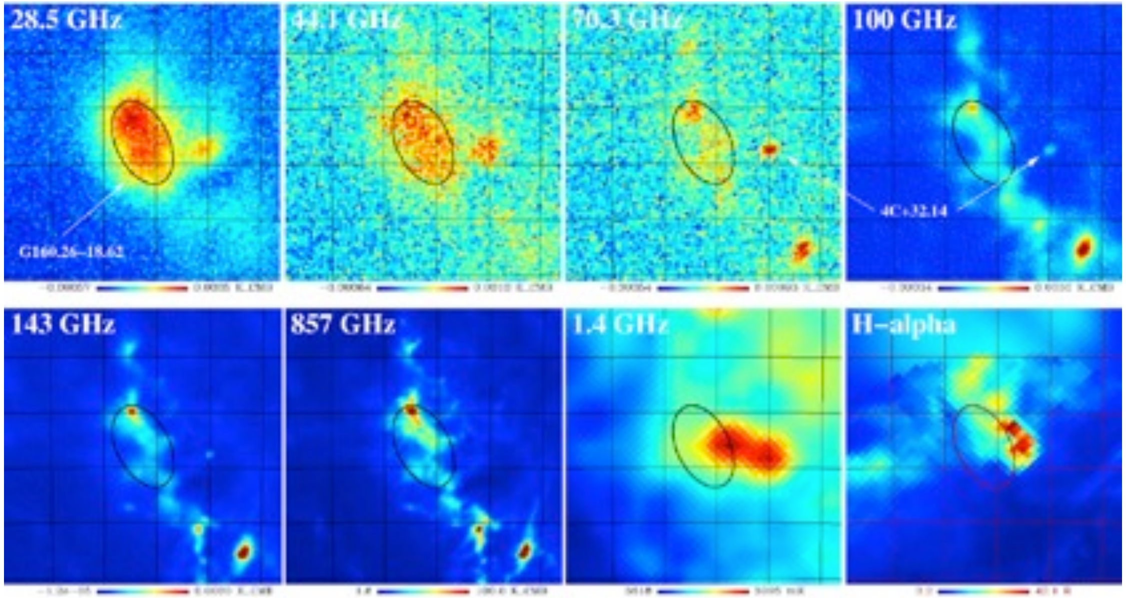
AME emission SED from WMAP data

Spinning dust model

Miville-Deschênes et al. (2008)

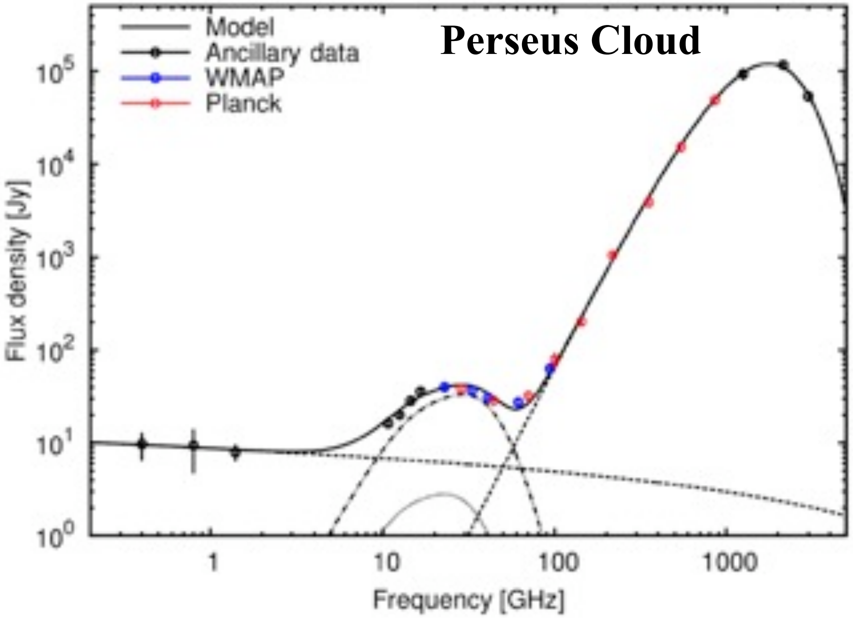
Anomalous Microwave Emission (AME)

Perseus Cloud



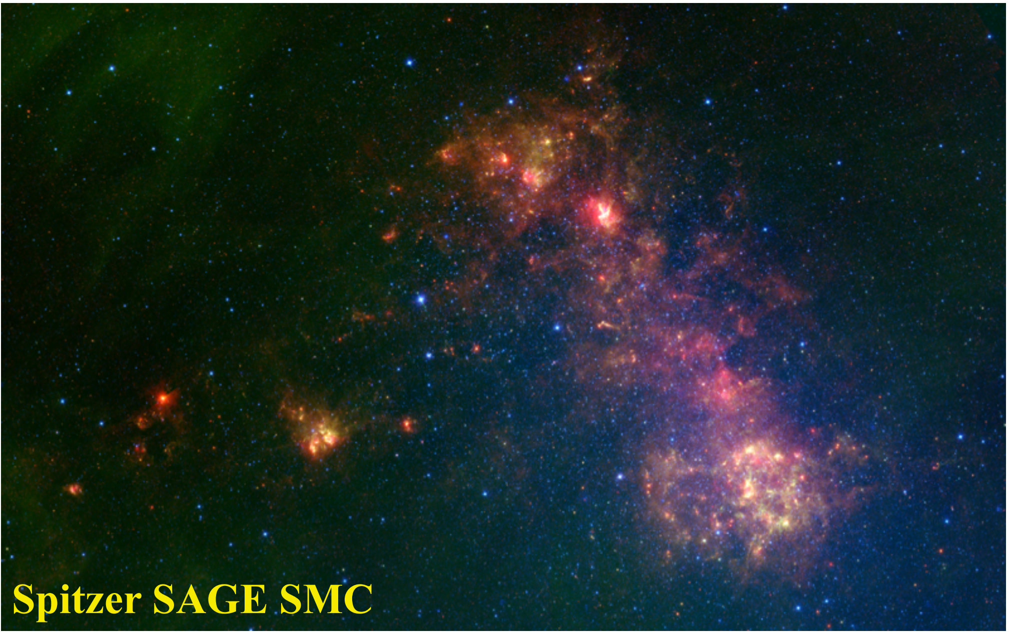
AME emission in the Perseus Cloud

- Integrated spectrum fitted by single grey-body (thermal dust), optically thin free-free
- Residual spectrum has clearly peaked spectrum compatible with spinning dust
- highly significant (17-σ)



- New AME regions identified
- 50 candidates inspected for early papers, a few selected for further modeling

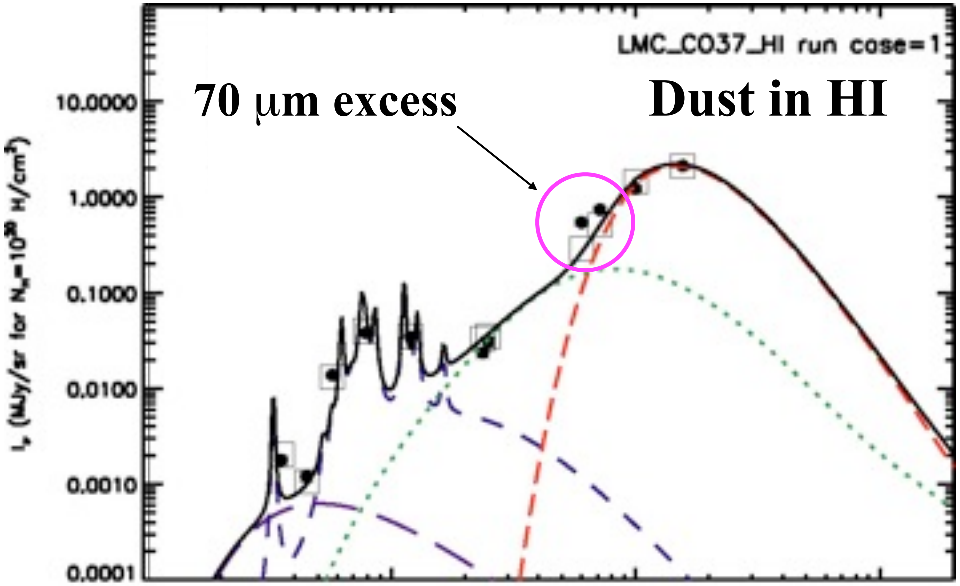
See arXiv: 1101.2031. C. author C. Dickinson

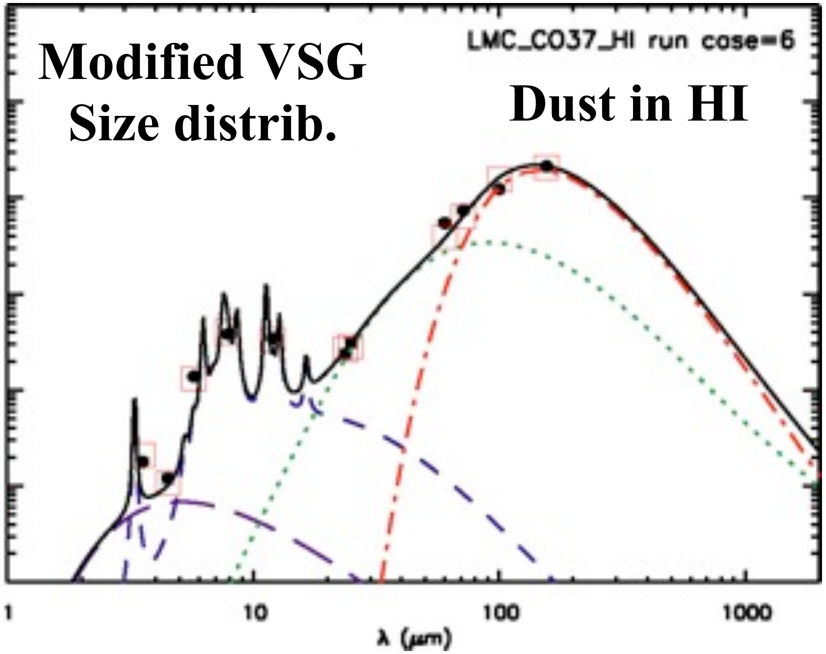


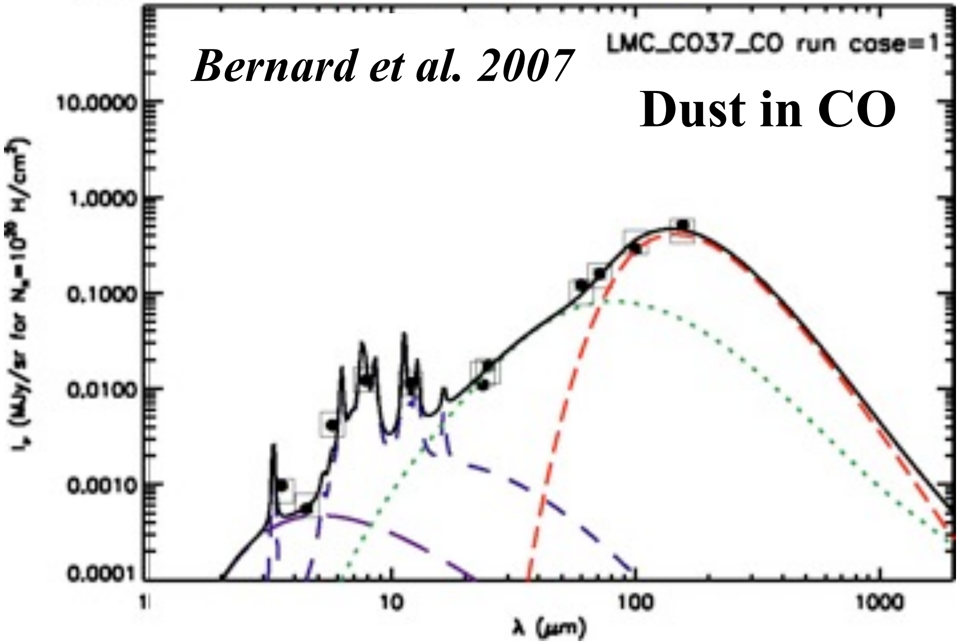
The magellanic Clouds

- Some of the most **nearby** galaxies: LMC ~50kpc, SMC ~60kpc
- High resolution observations
- **Low metallicity** galaxies (LMC~1/2 and SMC ~1/6 solar)
- Perfect laboratories for dust studies in a very different environment than our Galaxy with access to relatively small scales

Origin of 70 μm excess



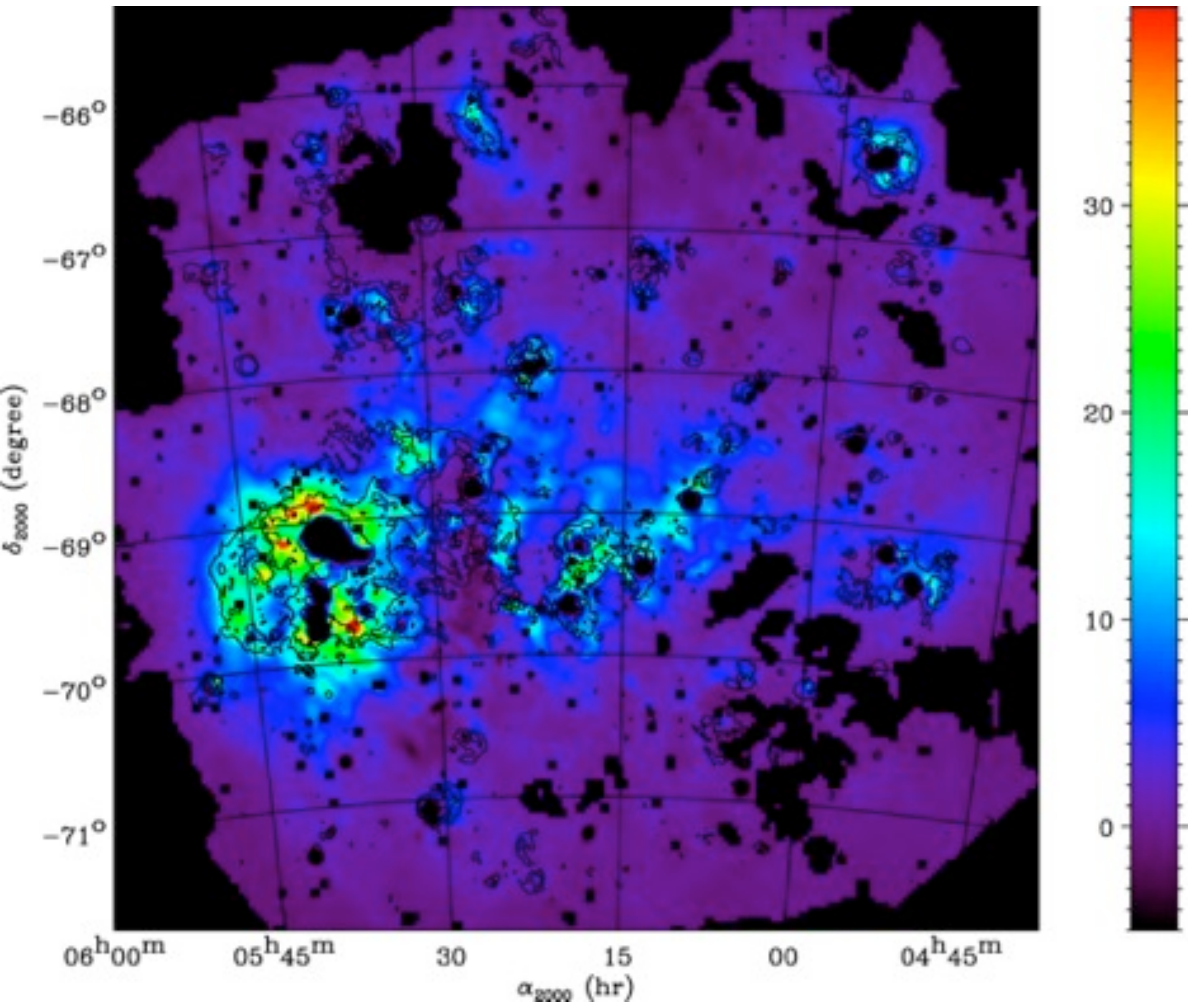



Bernard et al. 2007

- **70 μm excess found mainly in HI**
- **Can be explained by modifying the grain size distribution.**
- **Requires an increase abundance of the large VSGs (or of the small BGs).**
- **corresponds to ~13 % of the total dust mass**
- **Grain erosion processes in the diffuse medium ?**

- **Dust in ionized gas also identified (Paradis et al. 2011)** (See talk by paradis)

Distribution of 70 μm excess



ε_{70} map
H_α regions contours

$$\boxed{e_{70} = I_{70} - \frac{I_{70}^{VSG}}{I_{24}^{VSG}} * I_{24} - \frac{I_{70}^{BG}}{I_{100}^{BG}} * I_{100}}$$

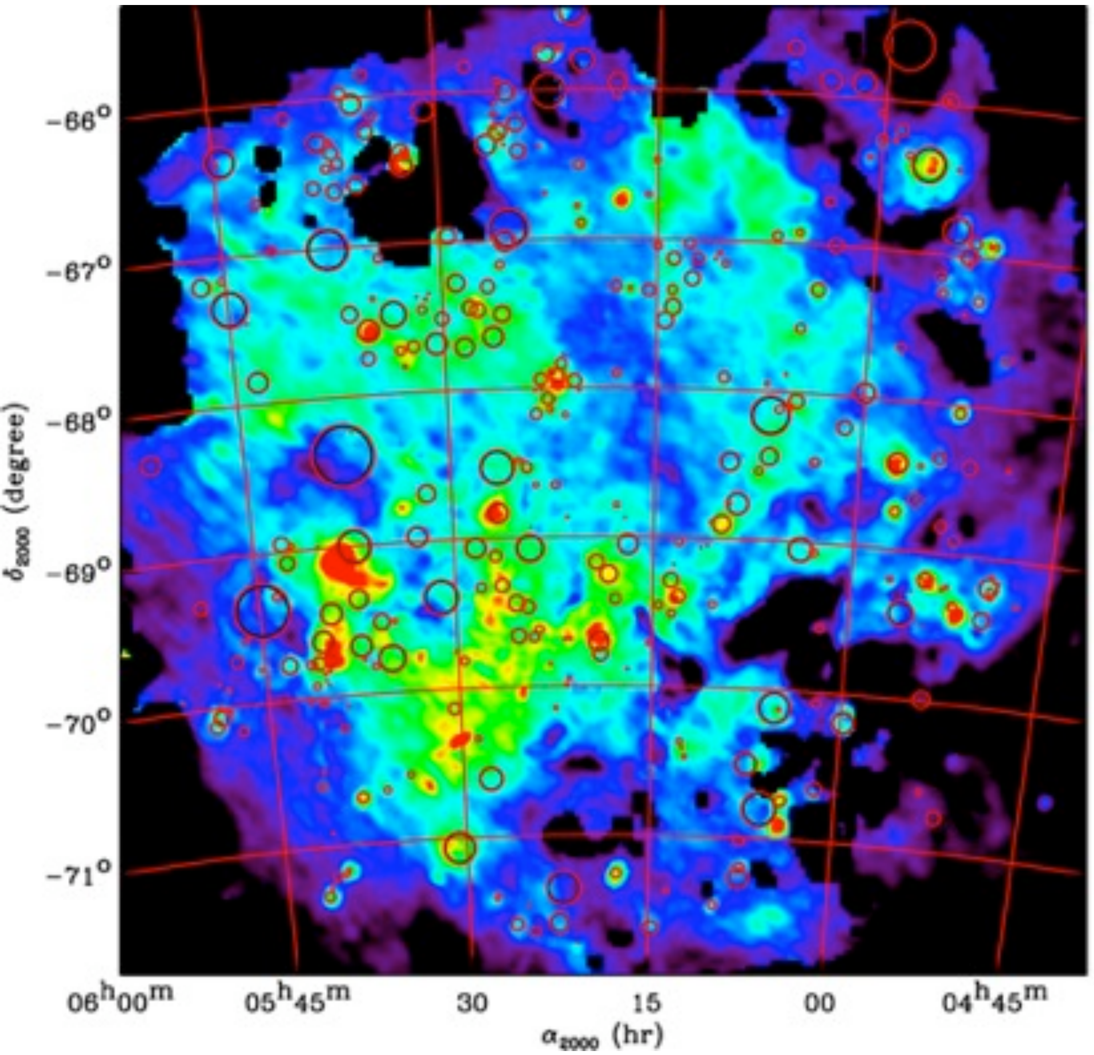
$$\left.\begin{array}{l} \frac{I_{70}^{VSG}}{I_{24}^{VSG}}(X_{ISRF}) \\ \frac{I_{70}^{BG}}{I_{100}^{BG}}(X_{ISRF}) \\ X_{ISRF}(T_{dust}) \end{array}\right\}$$

using DUSTEM

- **70 μm excess correlates partially with ionized gas**
- **Grain erosion processes in the diffuse medium ?**
- **ISRF mixing along LOS ?**

Bernard et al. 2008

Dust Temp. map



Bernard et al. 2008

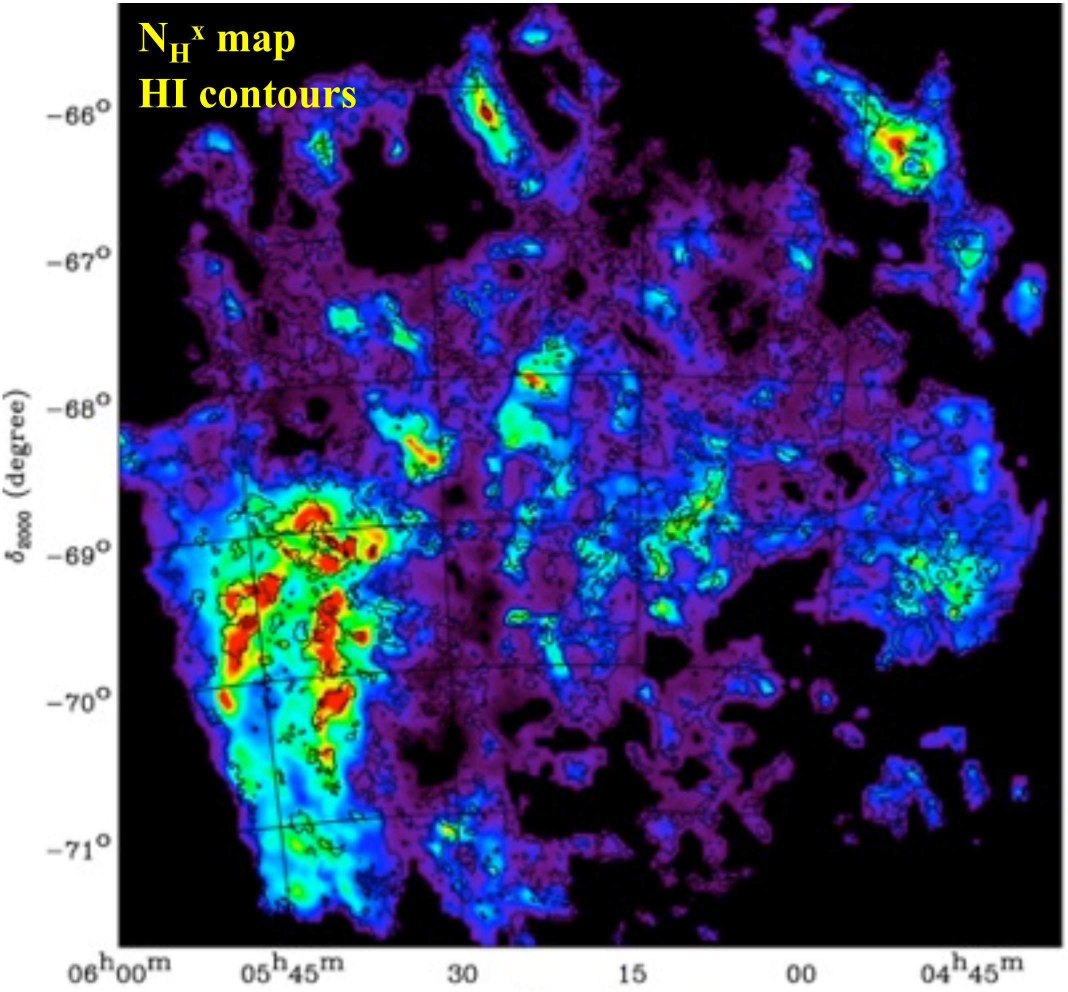
T map derived from I_{160}/I_{100} using $\beta=2$
HII regions contours

First time the T_d derived at galactic scale at 4' resolution.

$12.1<T_d<34.7$ K
$0.11 < X_{isrf} < 61$
(uses $X_{isrf}=(T_d/17.5)^6$)

- **T_d smaller than past evaluations based on IRAS**
- **In most regions: $T_d<22$K ($X_{isrf}<4$)**
- **No clear T_d decrease toward molecular clouds**
- **Warm regions associated to star formation regions**
- **Existence of warm regions with no star formation**

Dark gas ?



- **Correlation in low NH regions :**

$$\left(\frac{\tau_{160}}{N_H}\right) = 8.8\,10^{-26}\,cm^2$$

- **Excess map N_H^X computed as :**

$$\frac{N_H^X}{N_H^{obs}} = \left(\frac{\tau_{160}}{N_H^{obs}}\right)\left(\frac{\tau_{160}}{N_H}\right)^{-1} - 1$$

with $N_H^{obs} = X_{HI}W_{HI} + 2X_{CO}W_{CO}$

$$X_{CO} = 7\,10^{20}\ H_2/cm^2/(Kkm/s)$$

- **Excess correlates with total N_H**
- **Total mass = 2*HI mass**

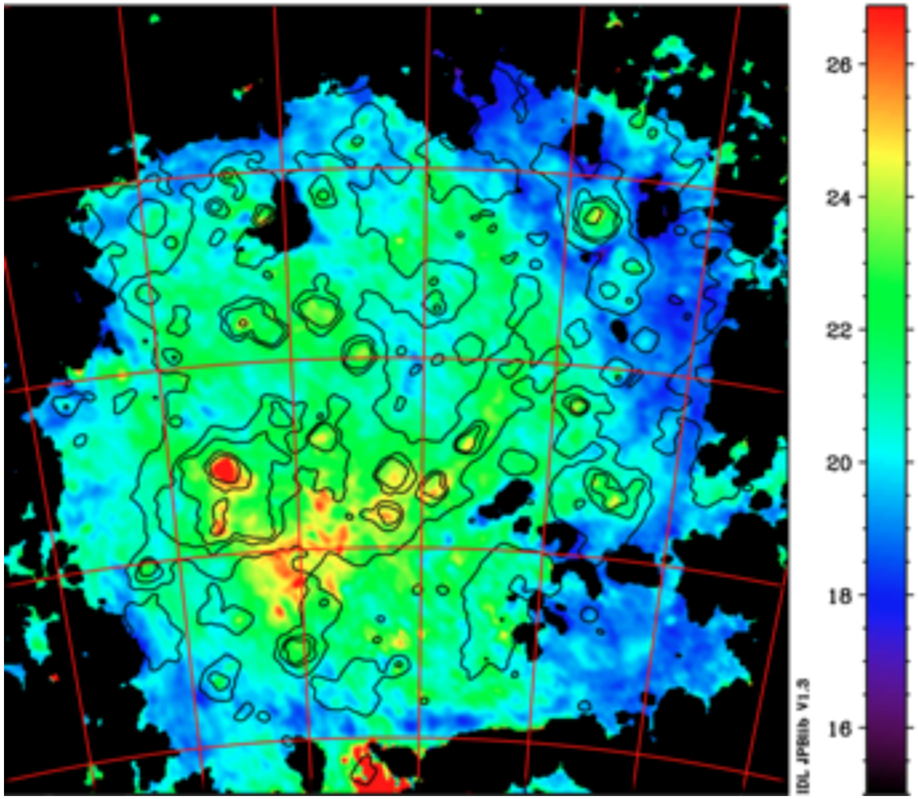
(20 times CO mass) !

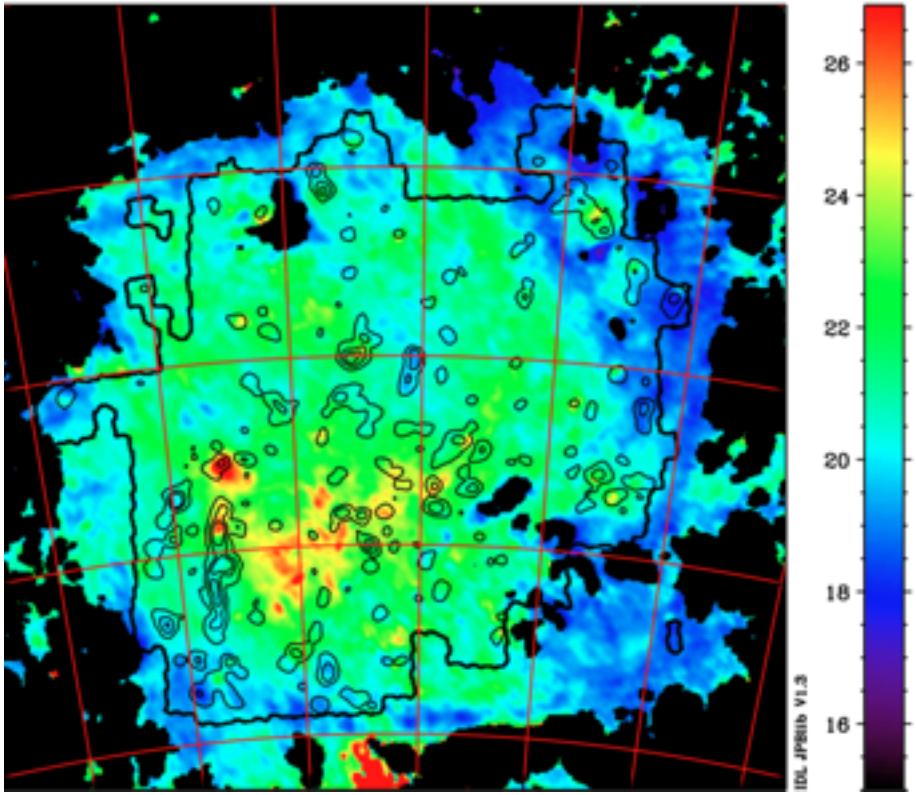
- **Could partially be due to dust abundance variations, HI optical depth effects …**

Main limitation: dust abundance variations are degenerate with Dark-Gas.

(But see talks by Galliano, Roman-Duval for the Herschel view)

Planck Dust Temperature (LMC)

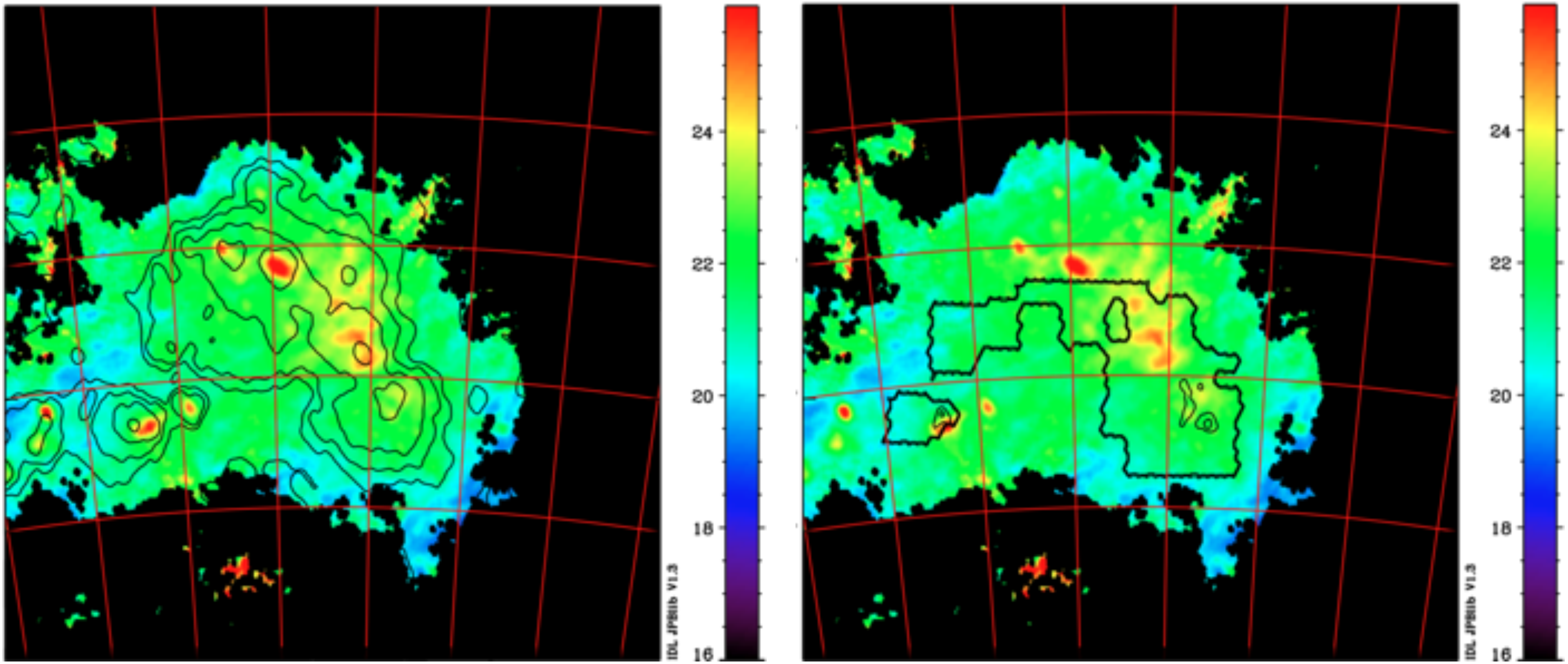




- **Temperature (T_D) computed from IRAS 100 μm, HFI 857 GHz, HFI 545 GHz, using β=1.5 (median value derived from T-β fit)**
- **Foreground subtraction using MW emissivity measured around galaxies and MW HI emission**
- **T_D correlates with Hα emission (star formation)**
- **Warm inner arm already revealed by Spitzer and Herschel measurements**
- **Cold outer arm (South and West) revealed by Planck for the first time**

See arXiv: 1101.2046. C. author J.Ph Bernard

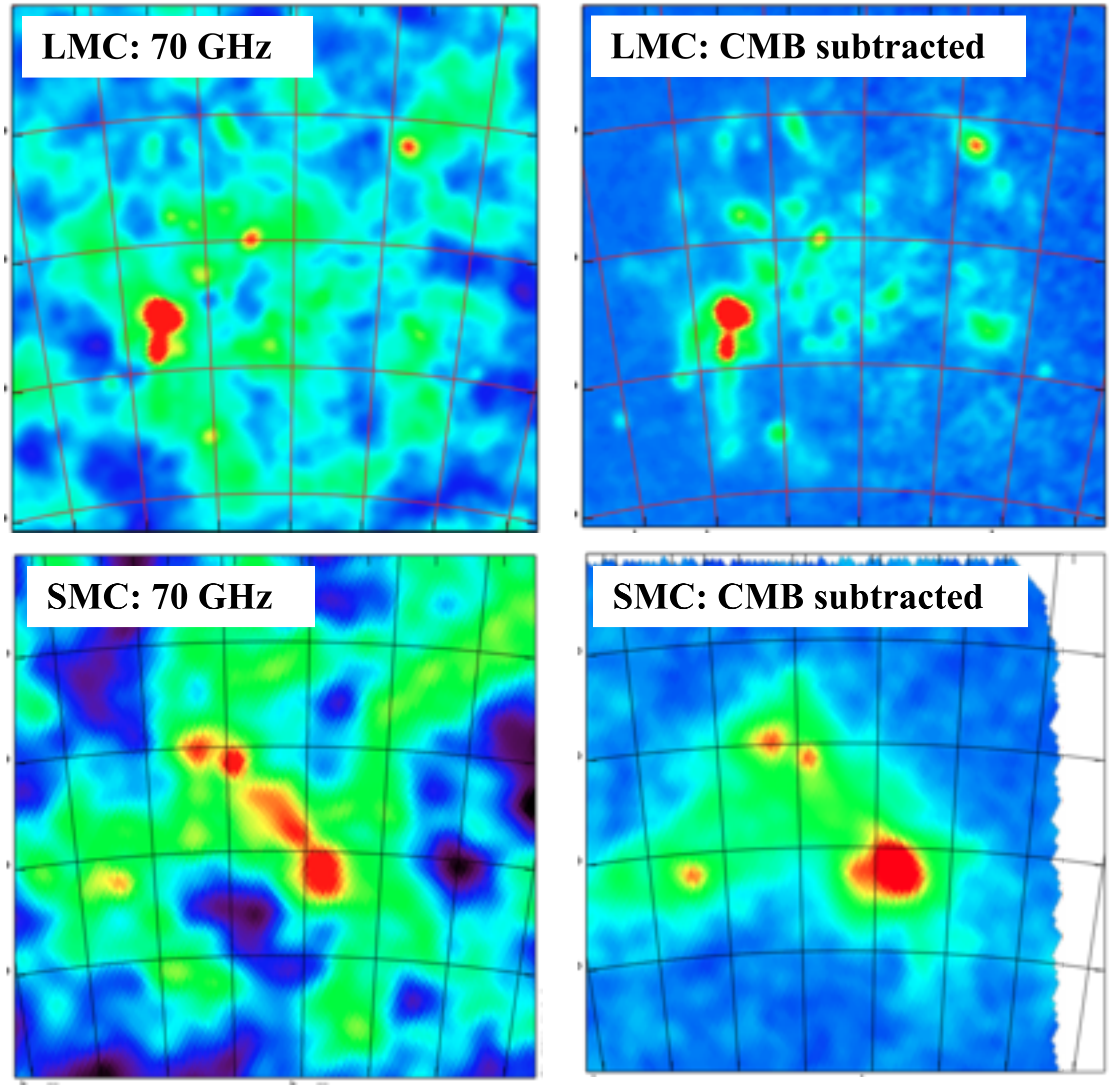
Planck Dust Temperature (SMC)



- Temperature (T_D) computed from IRAS 100 μm, HFI 857 GHz, HFI 545 GHz, using β=1.2 (median value derived from T-β fit)
- Foreground subtraction using MW emissivity measured around galaxies and MW HI emission
- T_D correlates with Hα emission (star formation)
- Globally warmer than LMC. Colder dust only towards the bridge

See arXiv: 1101.2046. C. author J.Ph Bernard

CMB Subtraction

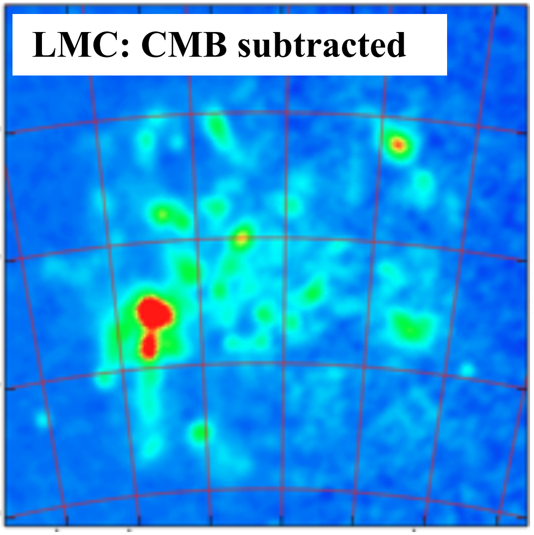


At long wavelengths (here 4.2 mm), CMB is a strong contaminant to LMC and SMC emission ... !!

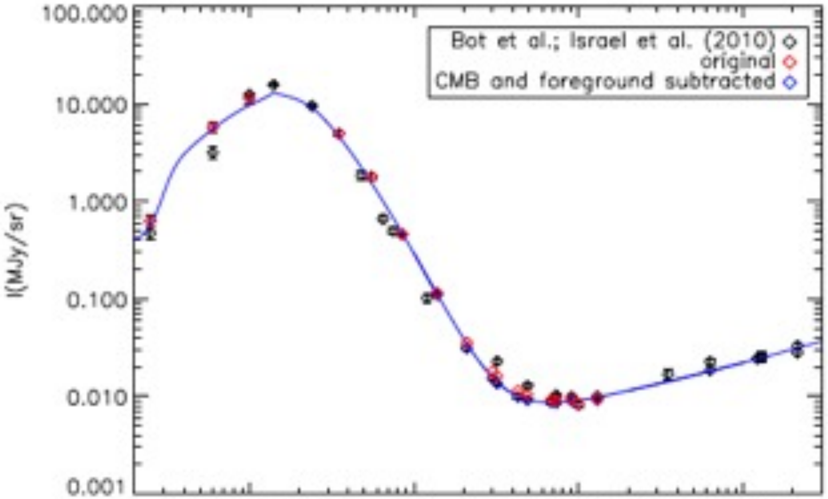
Subtraction used Internal Linear Combination (ILC)
with patch size optimized to minimize CMB residuals, based on Monte-Carlo simulations.
Uncertainties on CMB subtraction derived from Monte-Carlo simulations.

See arXiv: 1101.2046. C. author J.Ph Bernard

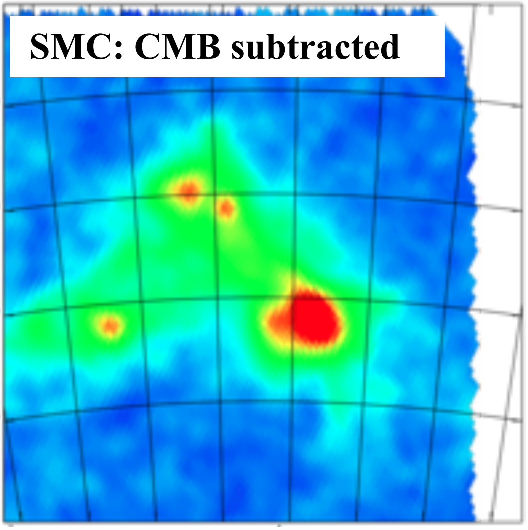
Integrated SEDs



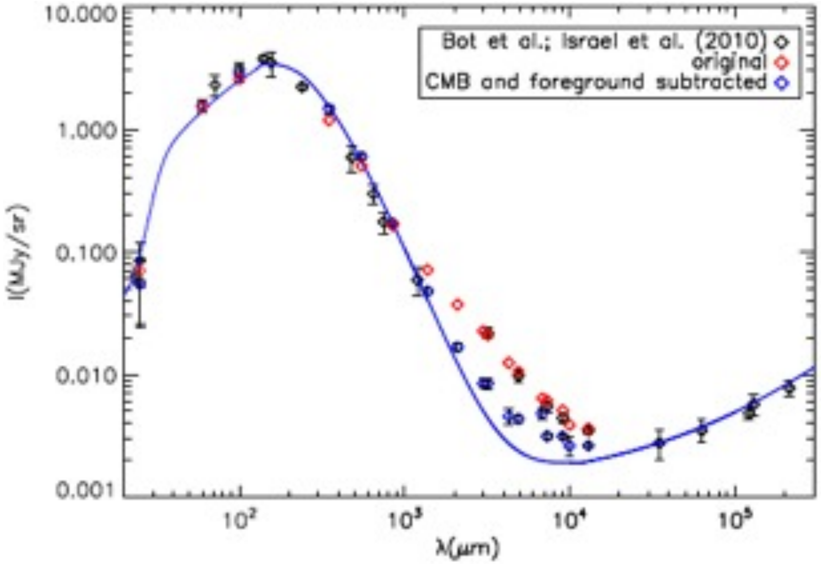
LMC: CMB subtracted



The submm excess in the LMC goes away with CMB subtraction



SMC: CMB subtracted

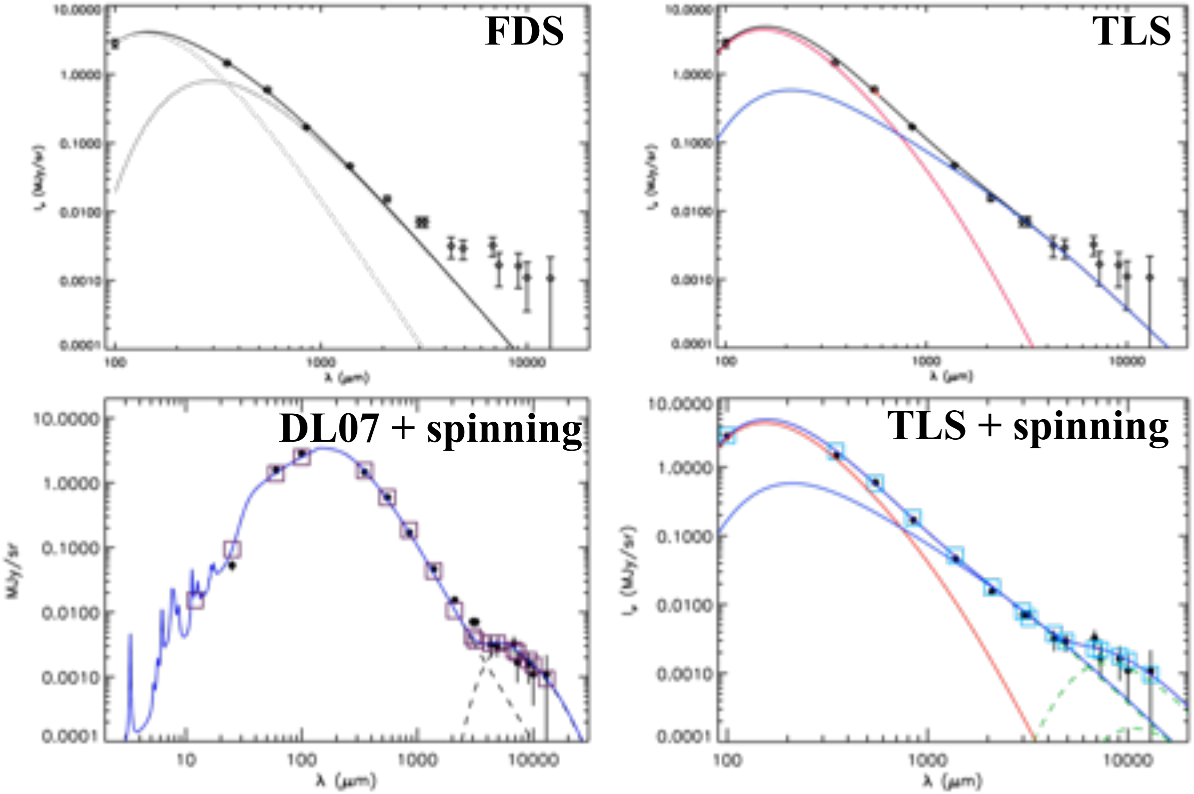


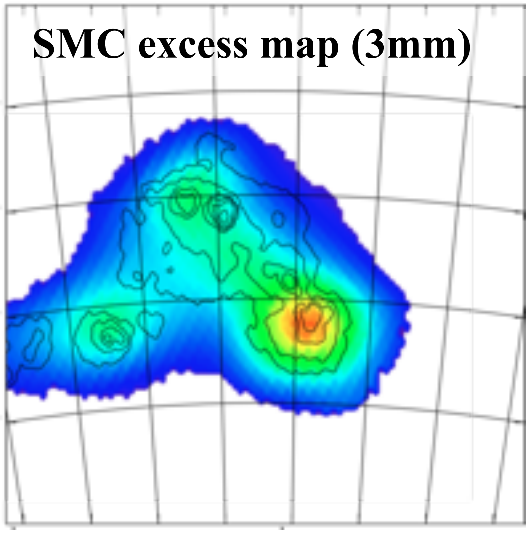
Some submm excess in the SMC remains after CMB subtraction

Model Draine & Li 2007 (see Bot et al. 2010)

See arXiv: 1101.2046. C. author J.Ph Bernard

Submm excess of the SMC





Submm excess follows the spatial distribution of thermal dust at high frequencies

- **Free-Free contribution subtracted, extrapolated from Hα emission, assuming no extinction**
- **Very Cold dust (FDS model) provides poor fit. Requires IR/optical opacity ratio 15 times larger than MW. Unlikely given spatial distribution.**
- **Best fit obtained for a combination of the Two-Level System (TLS) model and spinning dust**
- **Amorphous grains with similar parameters as MW, but more amorphous than in MW**
- **Spinning dust parameters compatible with PAH emission in the SMC**

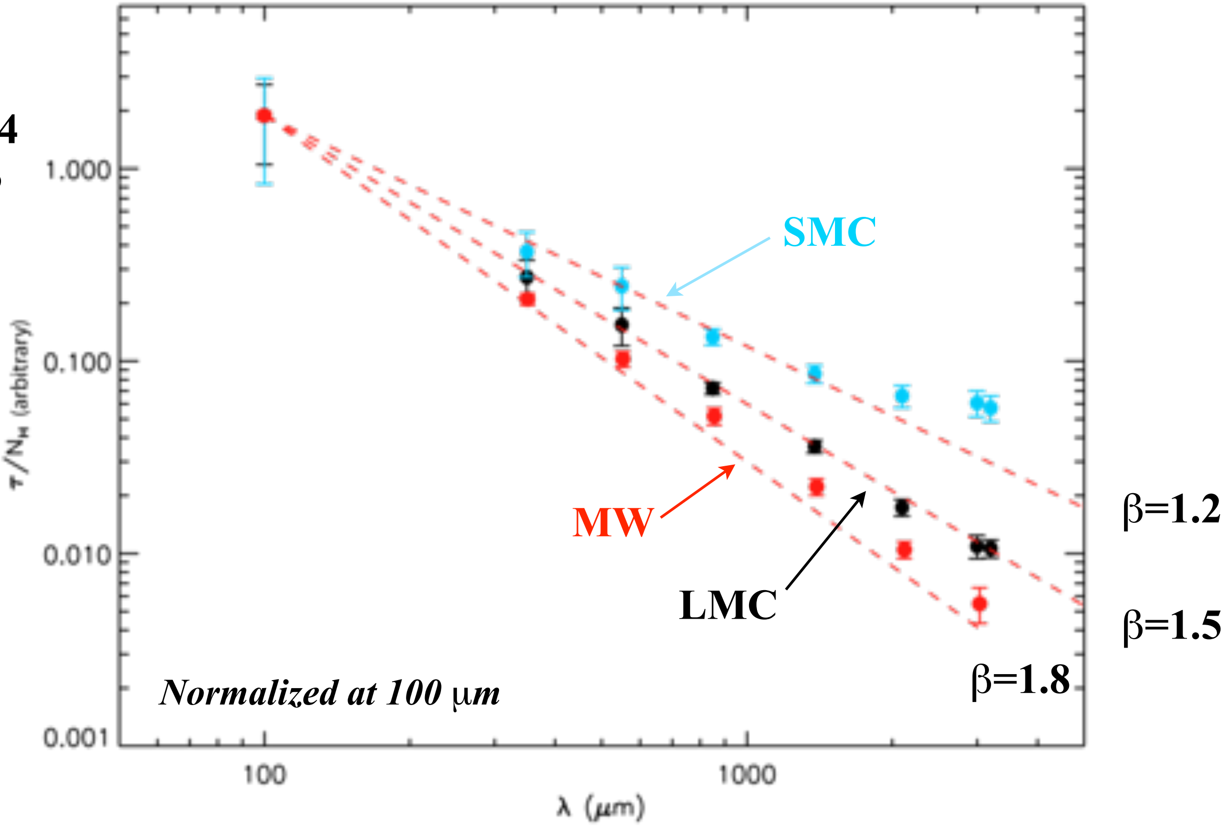
See arXiv: 1101.2046. C. author J.Ph Bernard

Submm emissivity of MW, LMC, SMC

Large variations of the sub-mm emissivity are observed between the MW, the LMC and the SMC
MW: β (FIR)=1.8
LMC: β (FIR)=1.5 (consistent with Gordon et al. 2010)
SMC: β (FIR)=1.2

Absolute value in the FIR :
MW: consistent with accepted value
LMC: consistent with Dust/Gas=1/2.4
SMC: consistent with Dust/Gas=1/13

MW emissivity flattens above λ~500 μm
SMC emissivity flattens above λ~700 μm
LMC emissivity seems «straight»



Normalized at 100 μm

Nearby Galaxies with Planck

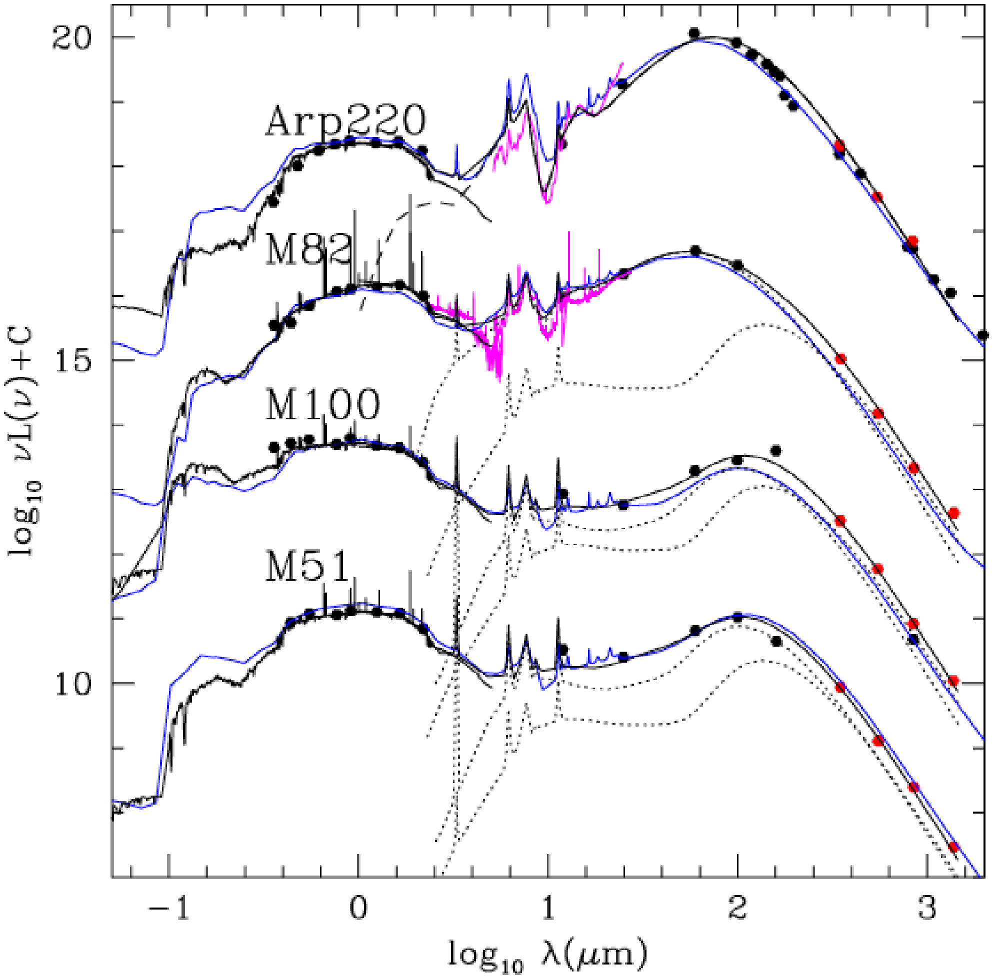
First results on the properties of nearby galaxies from the all-sky Planck Early Release Compact Source Catalogue (ERCSC)

468 for SED among a list of 1717 galaxies with reliable IRAS association and strong detections in the three highest frequency Planck bands and no evidence of cirrus contamination

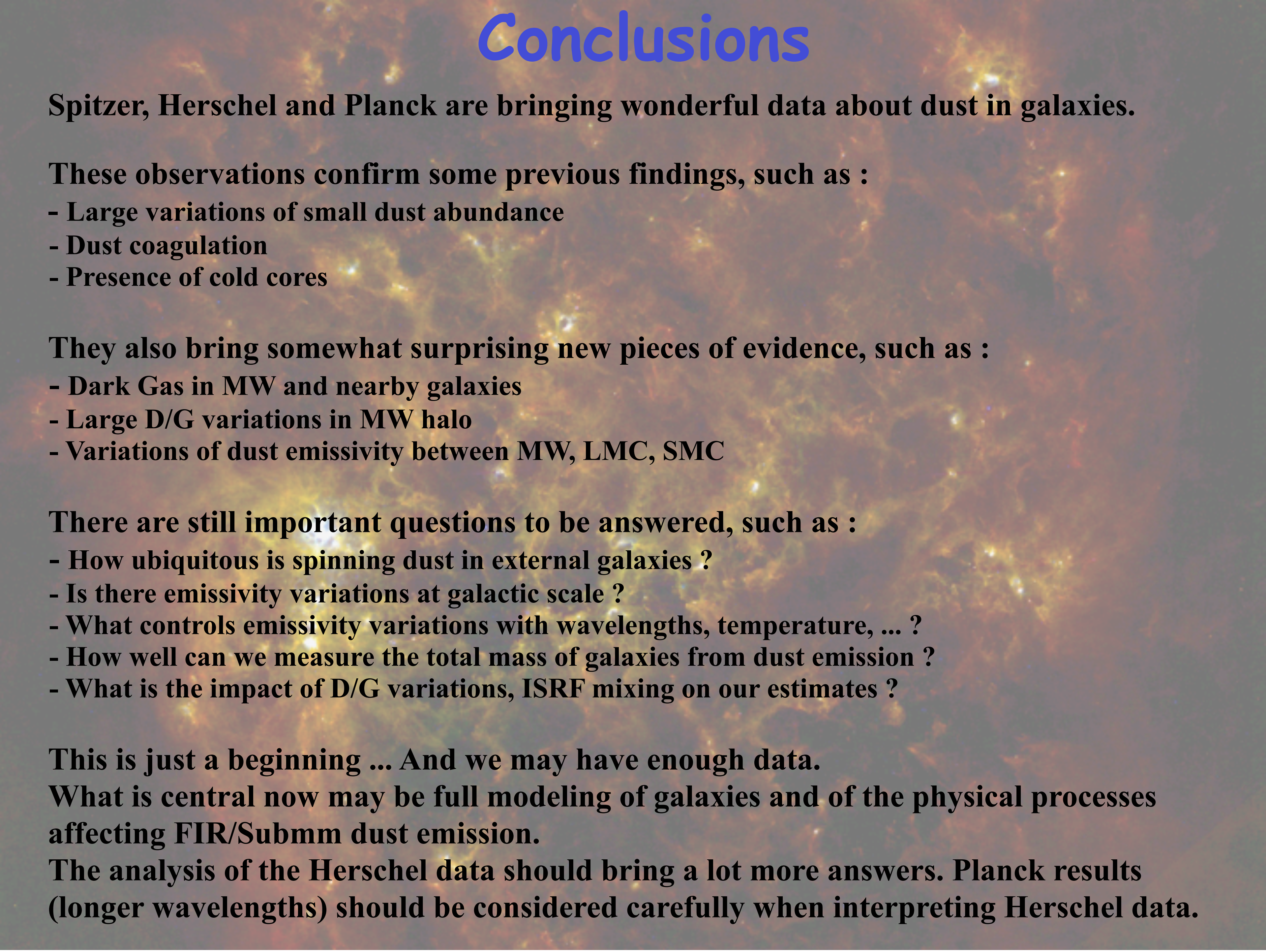
Evidence for colder dust than previously found in external galaxies, with T < 20K

Most galaxies SED requires warm and cold (as low as 10 K) dust

β varying with wavelength, may lead to different results regarding this very cold component



See arXiv: 1101.2045. C. author D. Clements



Conclusions

Spitzer, Herschel and Planck are bringing wonderful data about dust in galaxies.

These observations confirm some previous findings, such as :

- **Large variations of small dust abundance**
- **Dust coagulation**
- **Presence of cold cores**

They also bring somewhat surprising new pieces of evidence, such as :

- **Dark Gas in MW and nearby galaxies**
- **Large D/G variations in MW halo**
- **Variations of dust emissivity between MW, LMC, SMC**

There are still important questions to be answered, such as :

- **How ubiquitous is spinning dust in external galaxies ?**
- **Is there emissivity variations at galactic scale ?**
- **What controls emissivity variations with wavelengths, temperature, ... ?**
- **How well can we measure the total mass of galaxies from dust emission ?**
- **What is the impact of D/G variations, ISRF mixing on our estimates ?**

This is just a beginning ... And we may have enough data.
What is central now may be full modeling of galaxies and of the physical processes affecting FIR/Submm dust emission.
The analysis of the Herschel data should bring a lot more answers. Planck results (longer wavelengths) should be considered carefully when interpreting Herschel data.

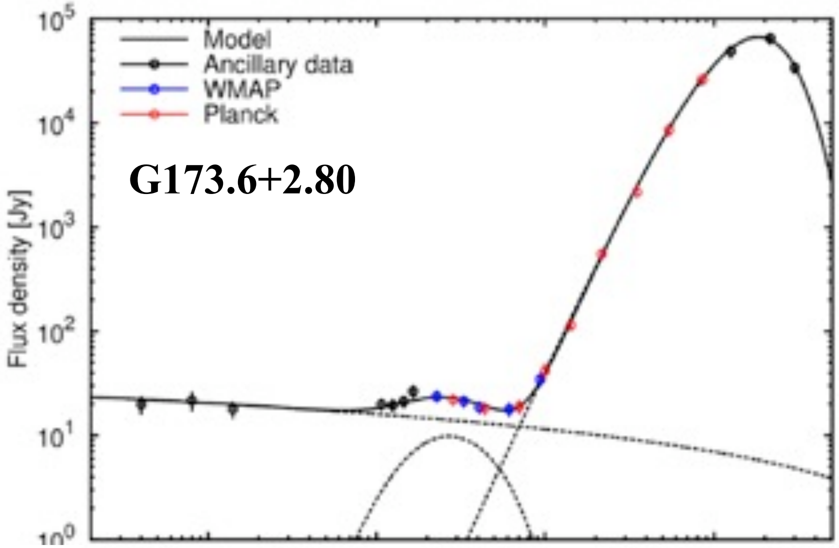
The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

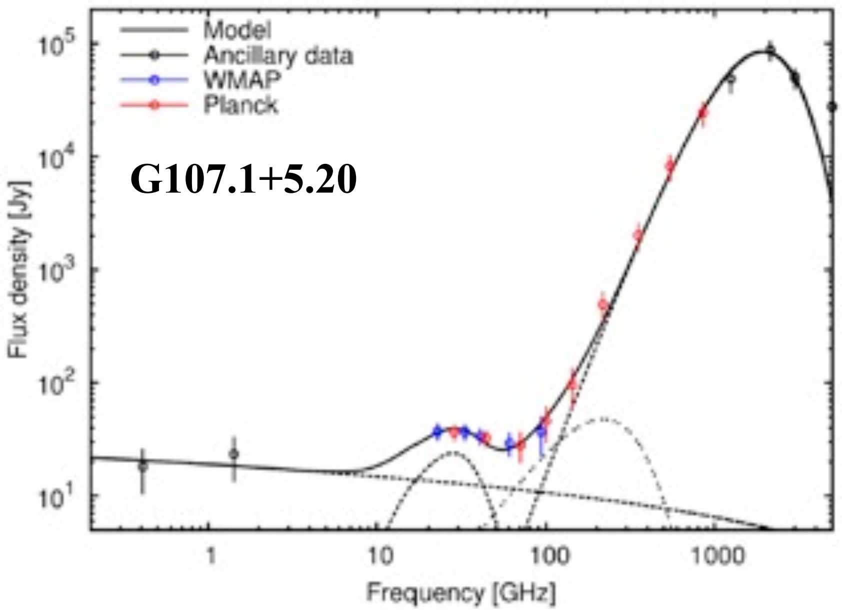
Planck is a project of the European Space Agency -- ESA -- with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a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

Planck Early Papers

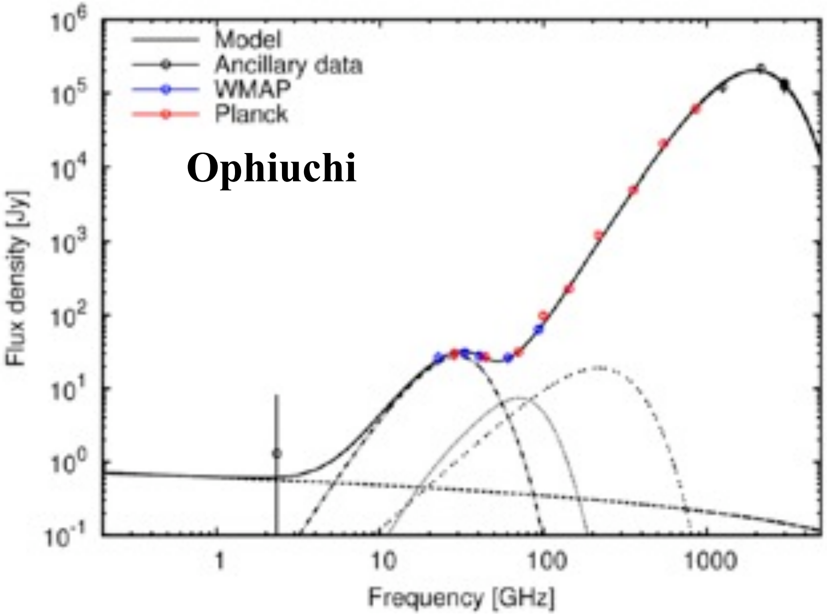
arXiv:1101.2029:
All sky temperature and dust optical depth from Planck and IRAS: Constraints on the "dark gas" in our galaxy
(contact author: J.-Ph. Bernard)
arXiv:1101.2046:
Origin of the submm excess dust emission in the Magellanic Clouds
(contact author: J.-Ph. Bernard)
arXiv:1101.2032:
Properties of the interstellar medium in the Galactic plane
(contact author: D. Marshall)
arXiv:1101.2037:
Planck Early Results: Thermal dust in Nearby Molecular Clouds
(contact author: A. Abergel)
arXiv:1101.2035:
Planck Early Results: The Galactic Cold Core Population revealed by the first all-sky survey
(contact author: L. Montier)
arXiv:1101.2034:
Planck Early Results: The submillimetre properties of a sample of Galactic cold clumps
(contact author: I. Ristorcelli)
arXiv:1101.2031:
Planck Early Results: New Light on Anomalous Microwave Emission from Spinning Dust Grains
(contact author: C. Dickinson)
arXiv:1101.2036:
Planck Early Results: Dust in the diffuse interstellar medium and the Galactic halo
(contact author: M.A. Mivilles-Deschenes)

Anomalous Microwave Emission (AME)



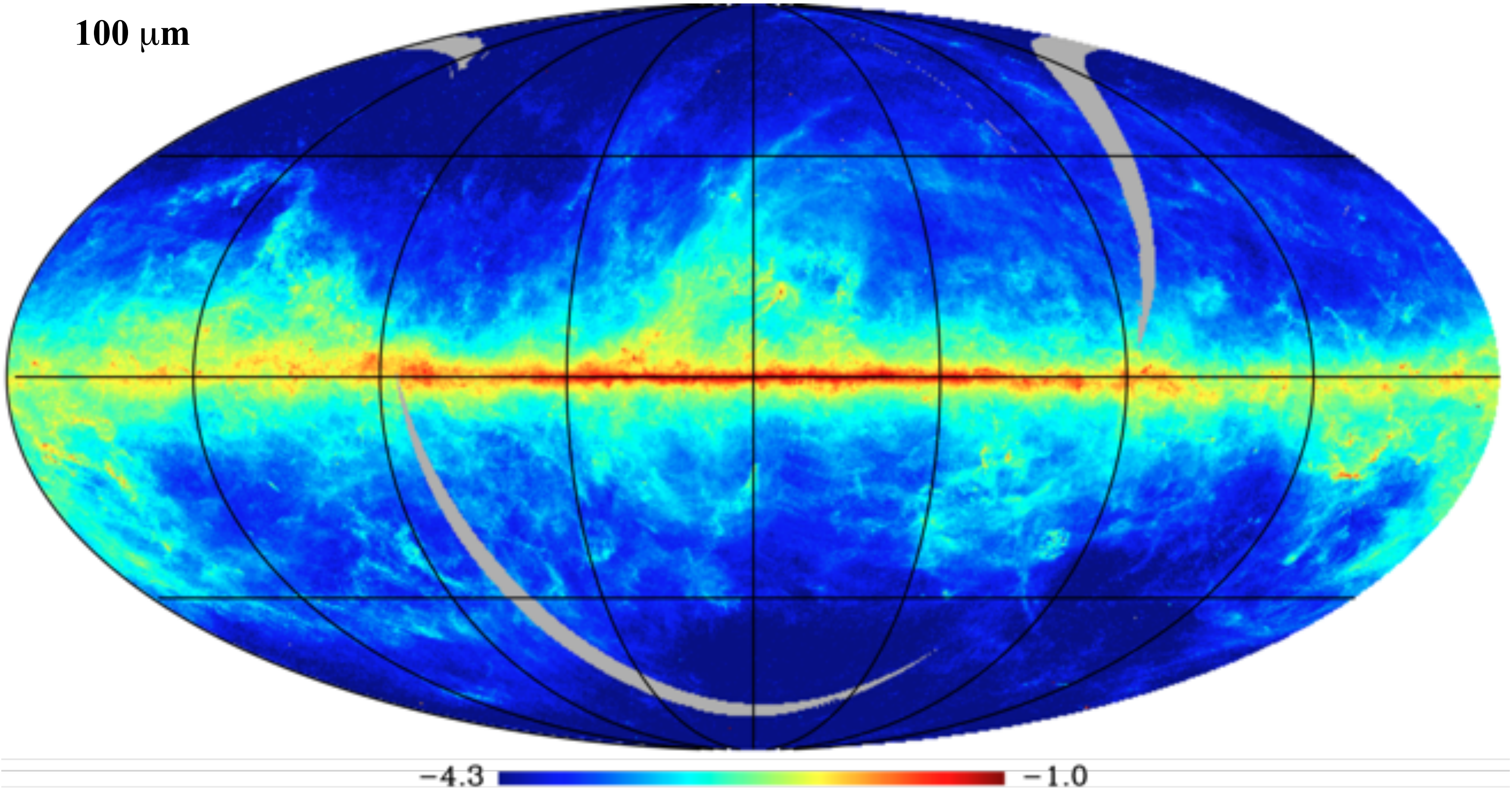


- New AME regions identified
- Simplistic approach to remove synchrotron (Haslam), free-free (H-alpha) and thermal dust
- Residual map inspected for strong AME regions
- 50 candidates inspected for early papers, a few selected for further modeling



See arXiv: 1101.2031. C. author C. Dickinson

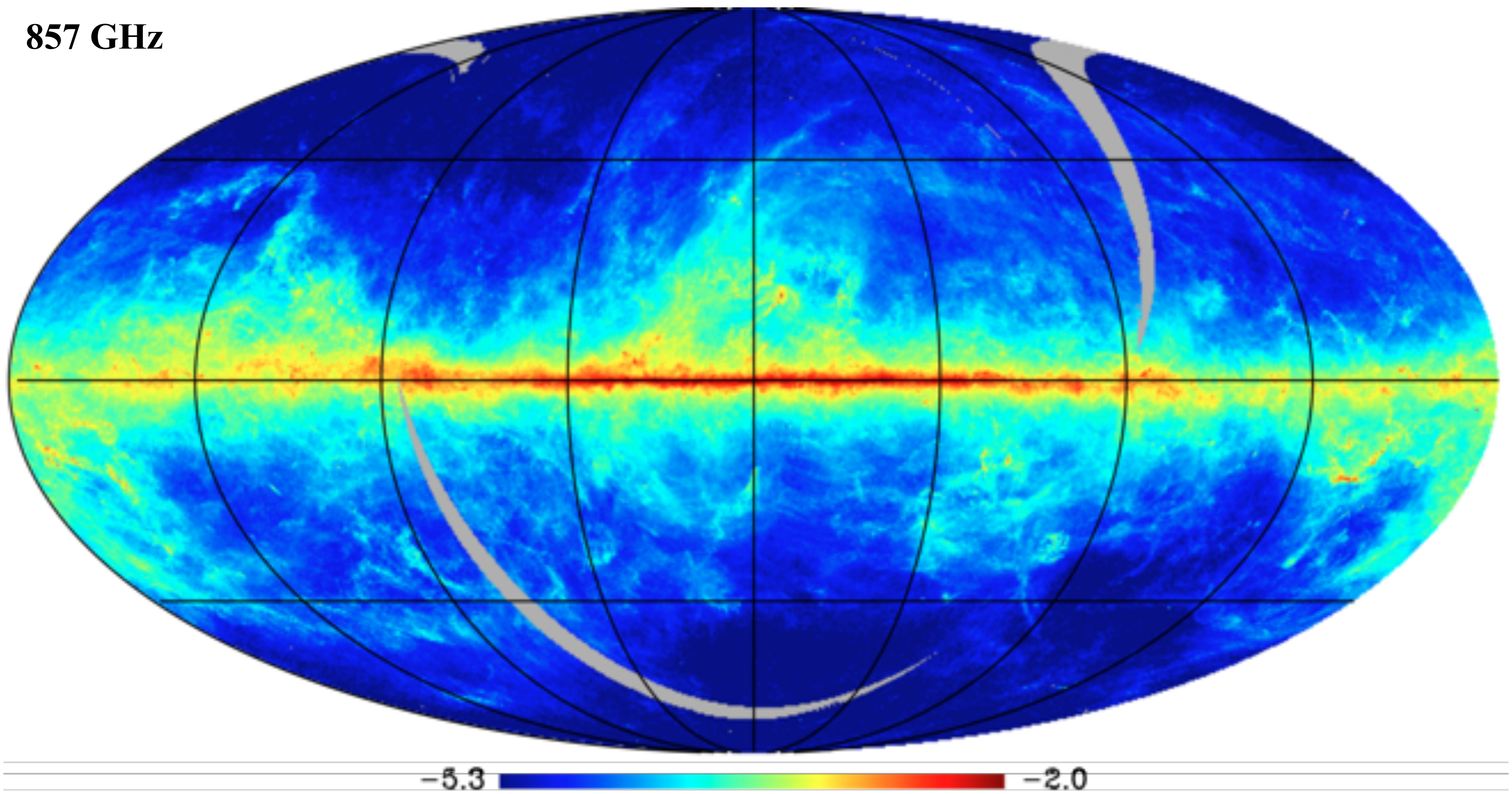
Dust Optical Depth (MW)



planck

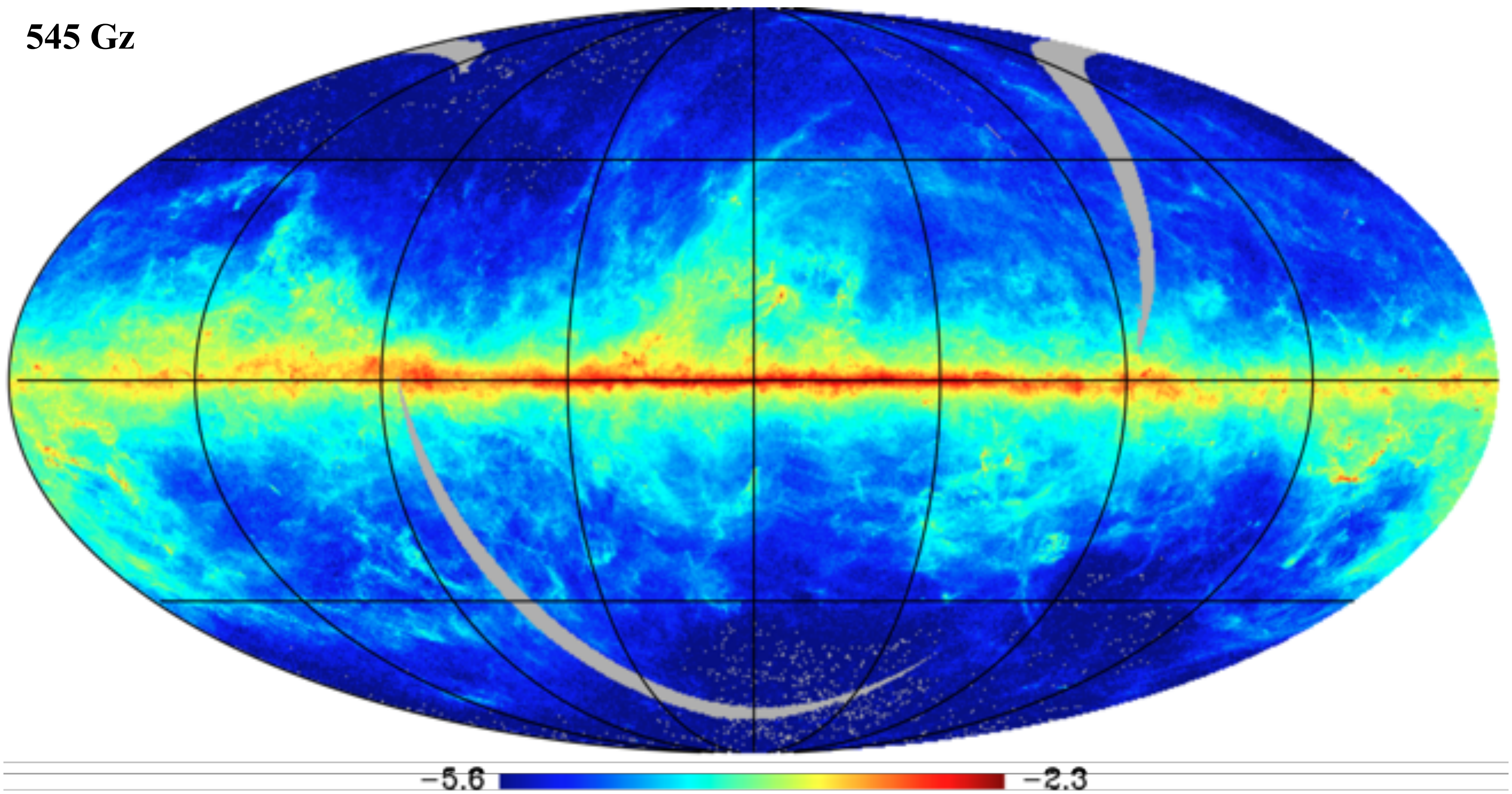
Bernard J.Ph., Dust to Galaxies 2011, Paris

Dust Optical Depth (MW)



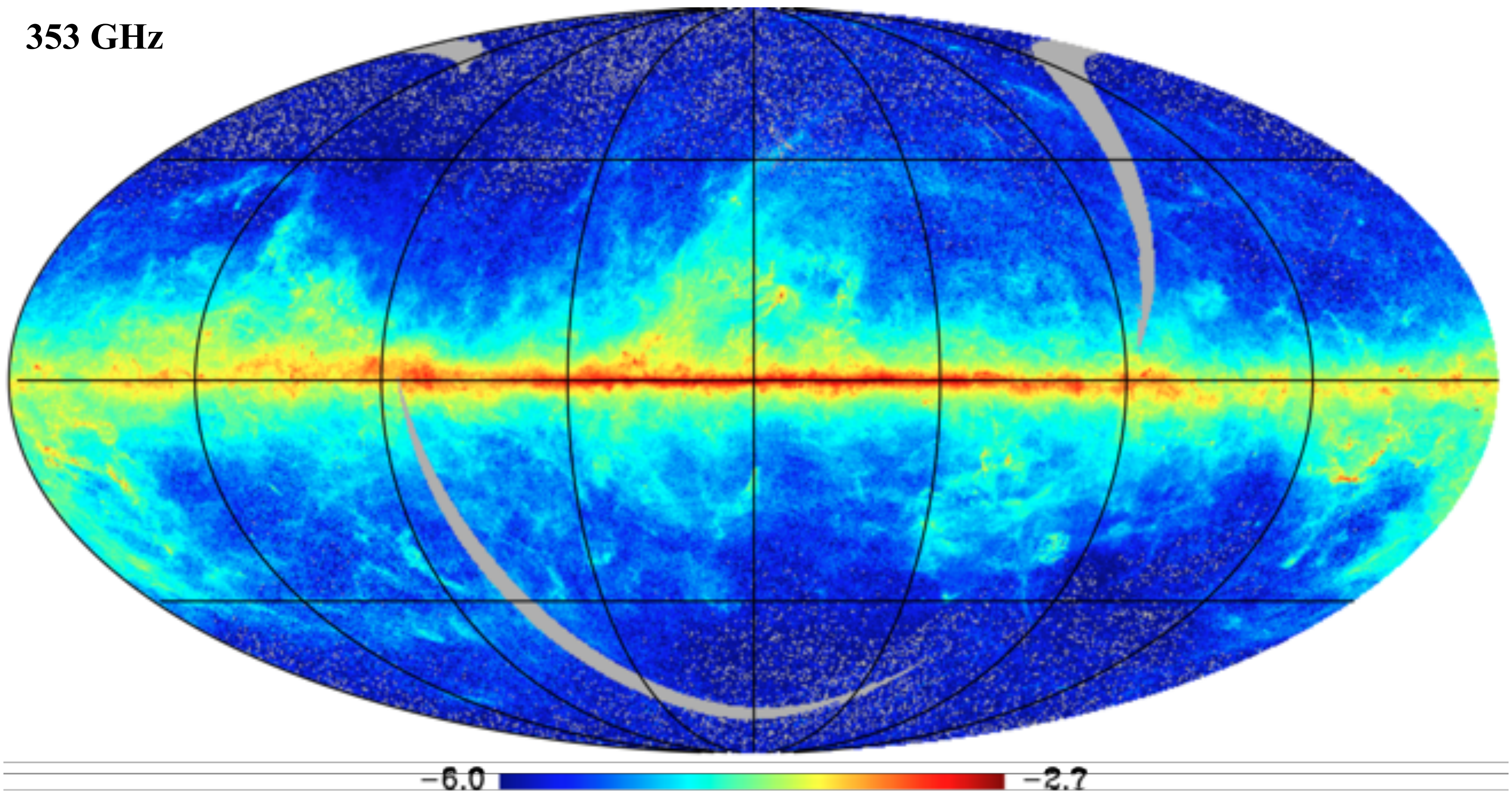
Bernard J.Ph., Dust to Galaxies 2011, Paris

Dust Optical Depth (MW)

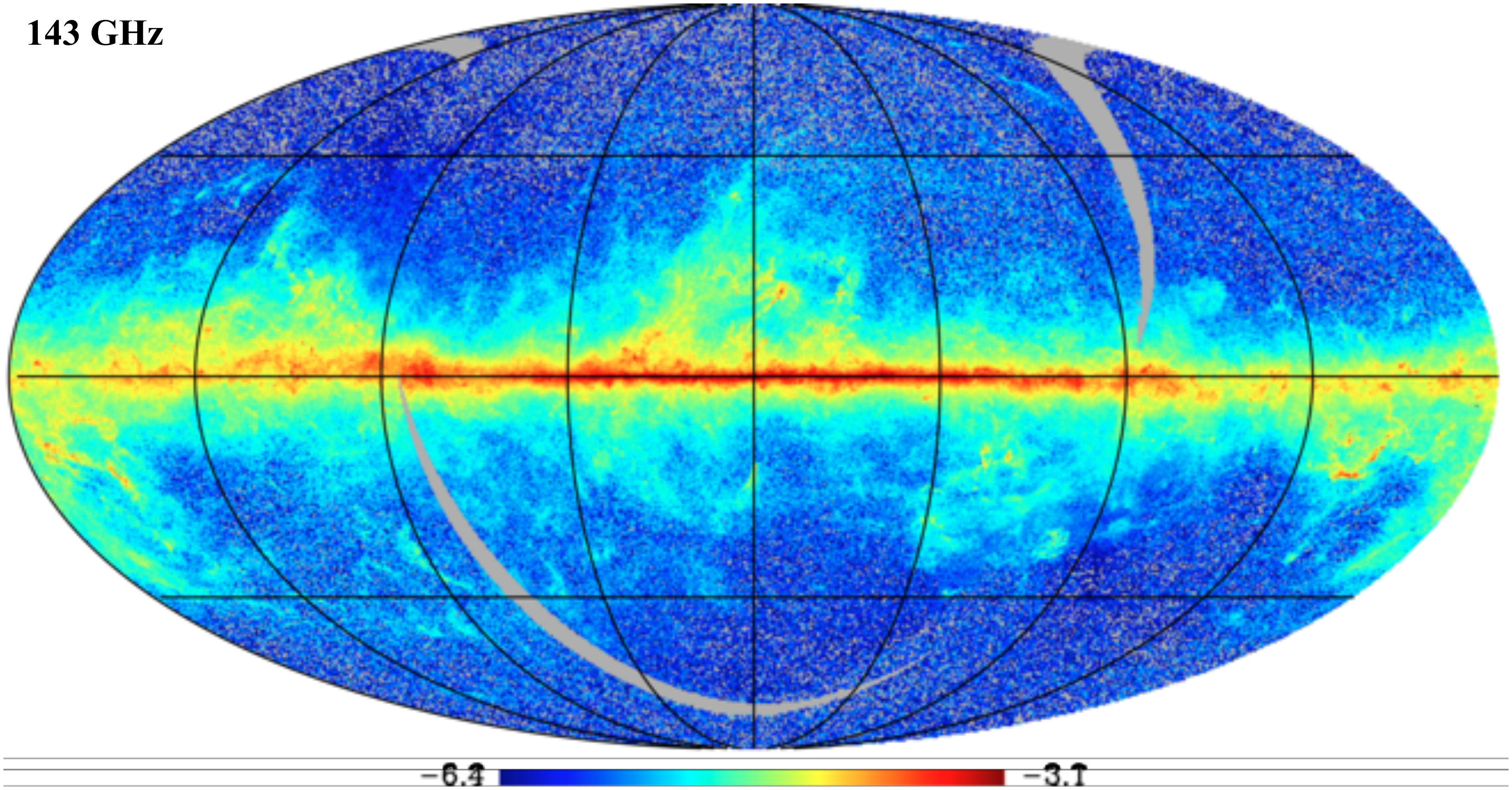


Bernard J.Ph., Dust to Galaxies 2011, Paris

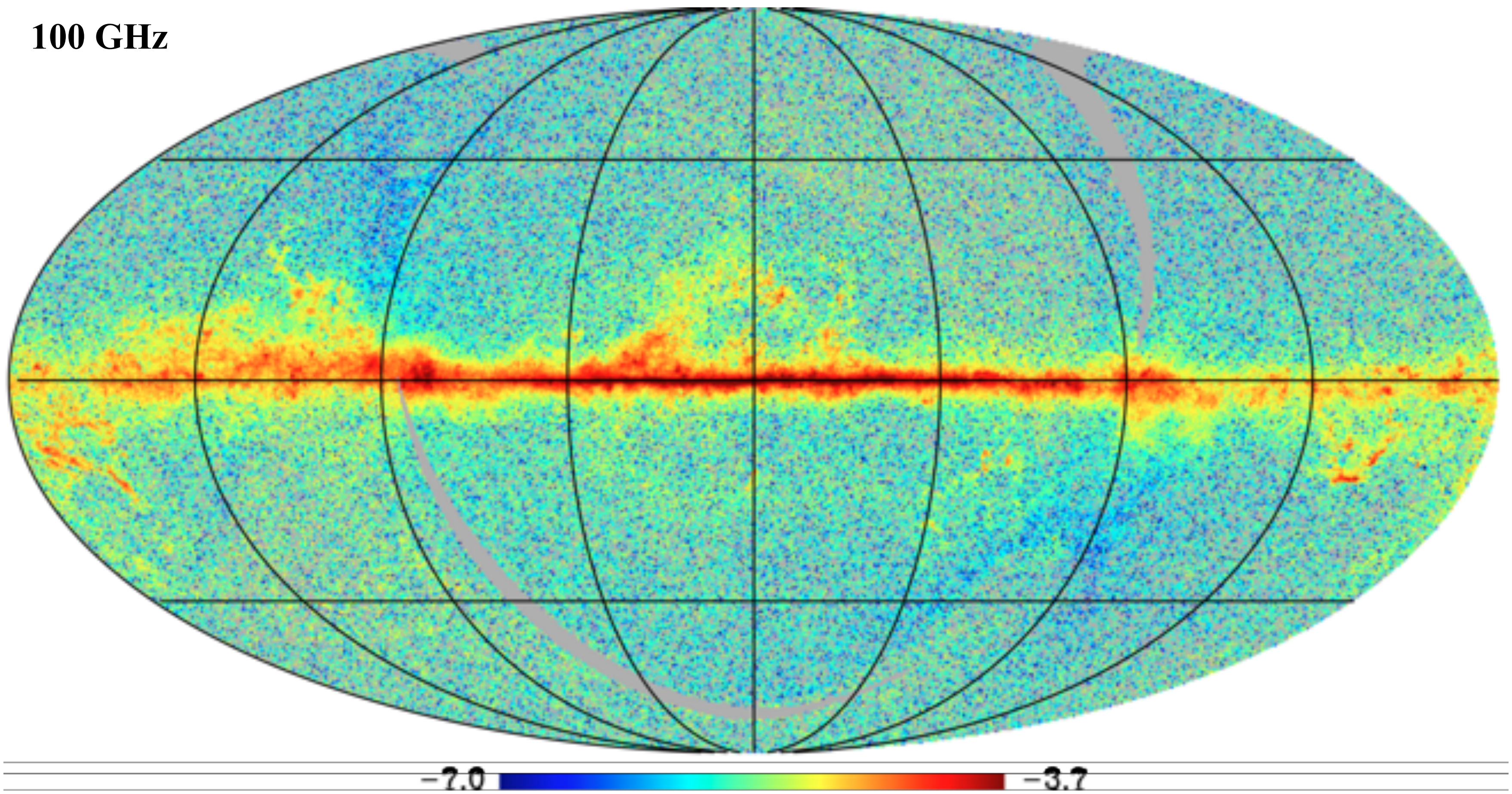
Dust Optical Depth (MW)



Dust Optical Depth (MW)

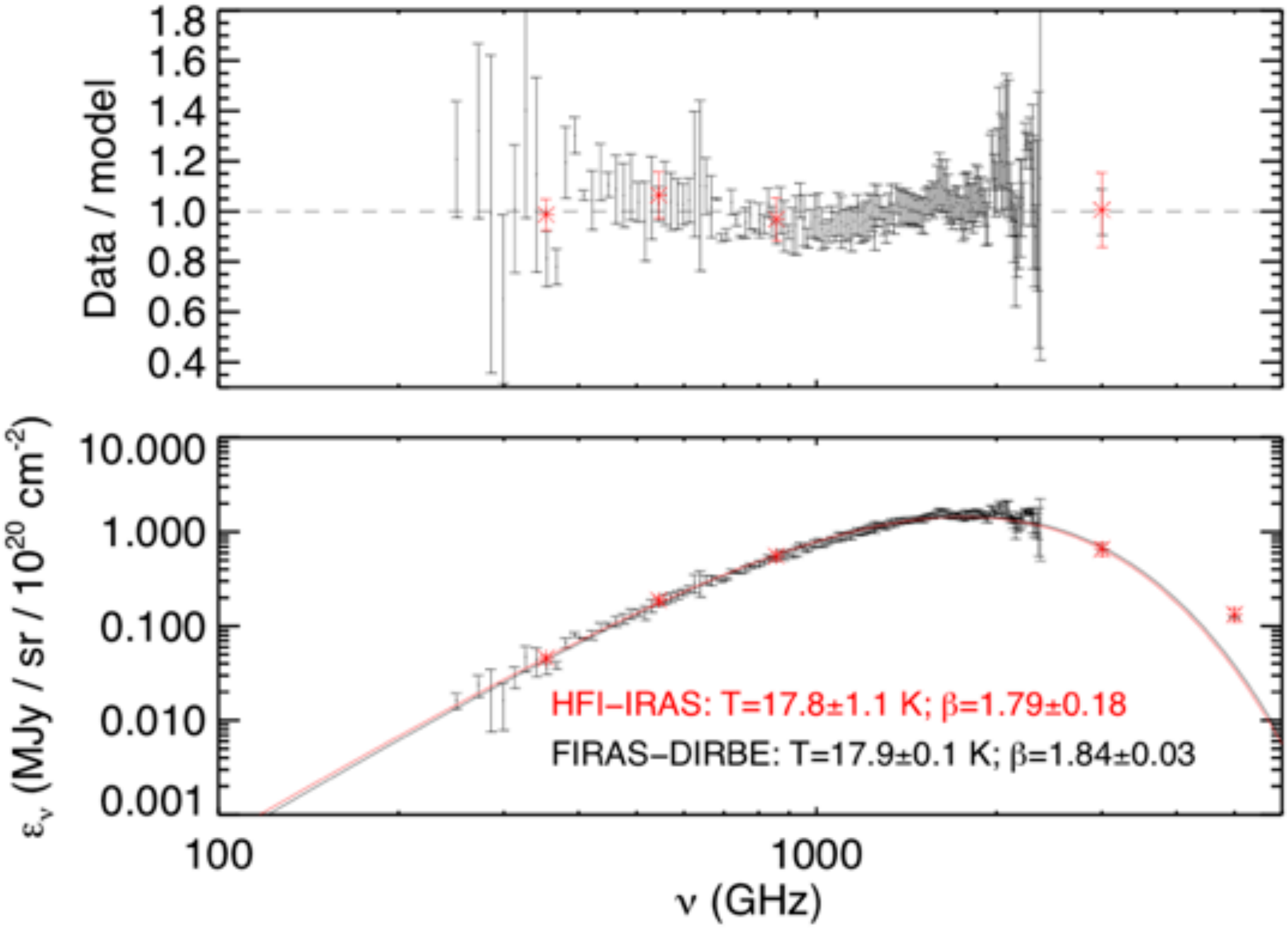


Dust Optical Depth (MW)



Bernard J.Ph., Dust to Galaxies 2011, Paris

Spectre de la poussière du milieu diffus



Ionized phase

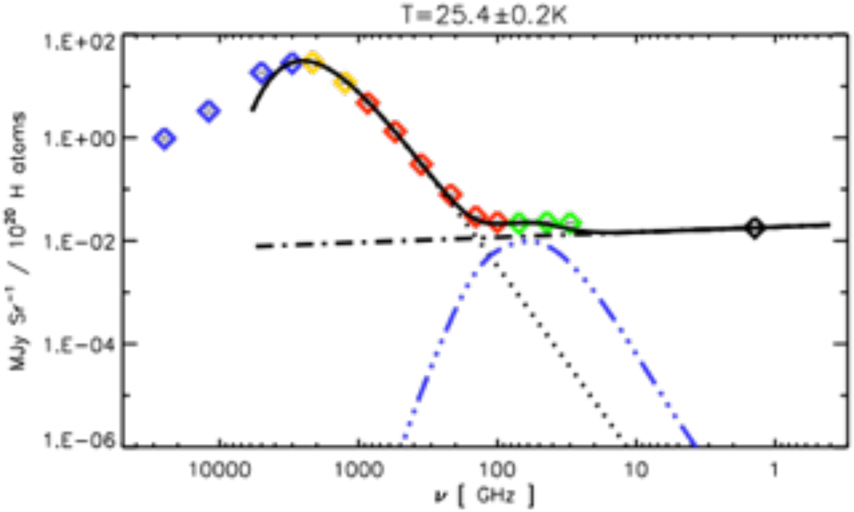
Thermal dust SED represented by warm grains

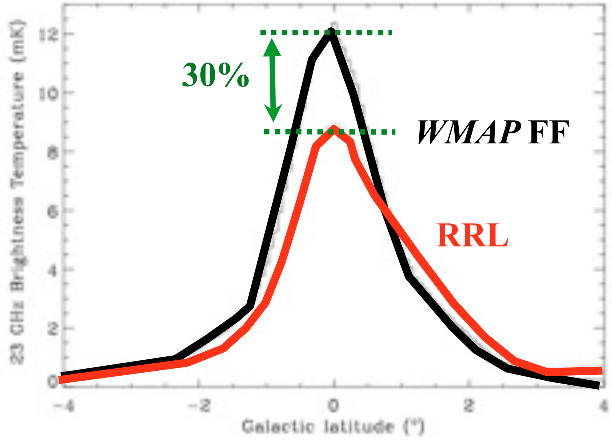
Free-free emission modeled by power law (spectral index = -0.1)

- **80% of WMAP free-free emission accounted for**
- **Consistent with very recent RRL measurements in the plane**

AME barely visible

1) **In agreement with our simple assumptions**
2) **Free-free emission dominates**
3) **Contrary to other phases**



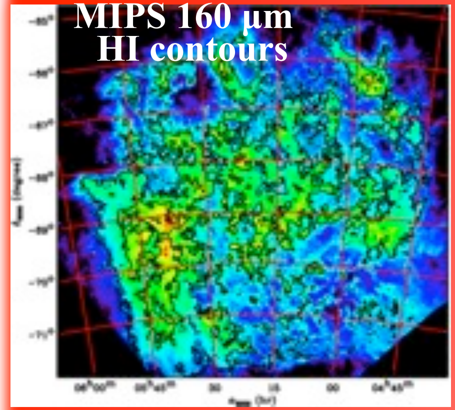


Adapted from Alves et al. (2010)

See arXiv: 1101.2032. C. author D. Marshall

Dust in various phases of LMC

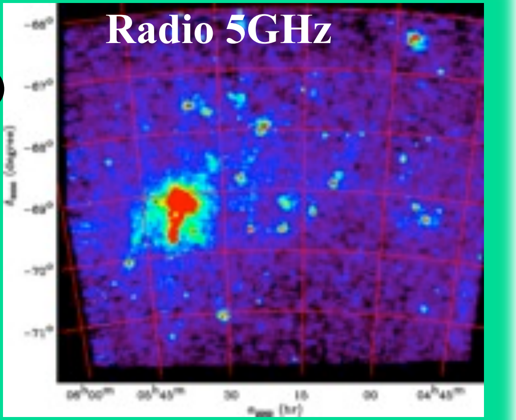
$$IR_\nu = a_\nu(\lambda) N_H^{HI} + b_\nu(\lambda) N_H^{CO} + c_\nu(\lambda) N_H^{H+} + d(\lambda)$$

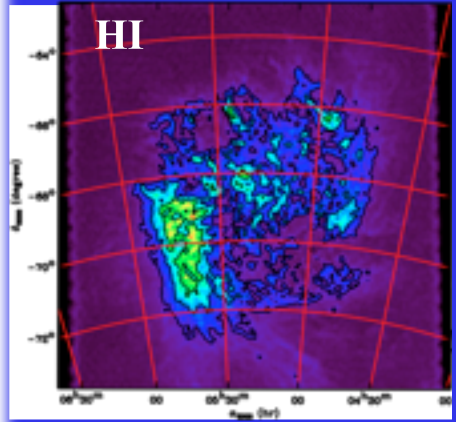


IR : Spitzer data from 3.6 to 160 µm, θ=1.6" to 42" (Meixner et al, 2006) combined with IRIS 12 and 100 µm data (Improved Reprocessing of IRAS) at 4'.

H_α: SHASSA survey (Gaustad et al., 2001) θ=0.8'.

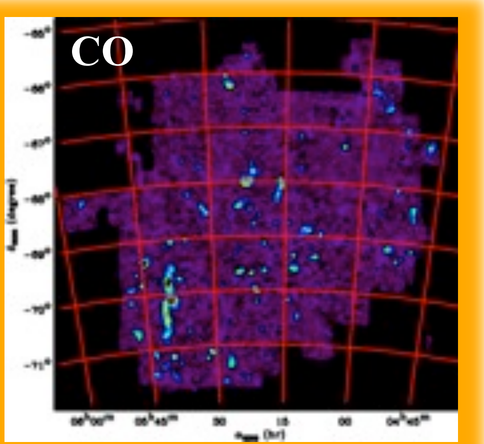
Radio @ 5 GHz : Parkes data, θ=5.6' (Filipovic et al., 1995).





- 21 cm integrated intensity map
- Combination ATCA (θ=1', Kim et al, 2003) and Parkes data (θ=14'; Staveley-Smith et al., 2003).

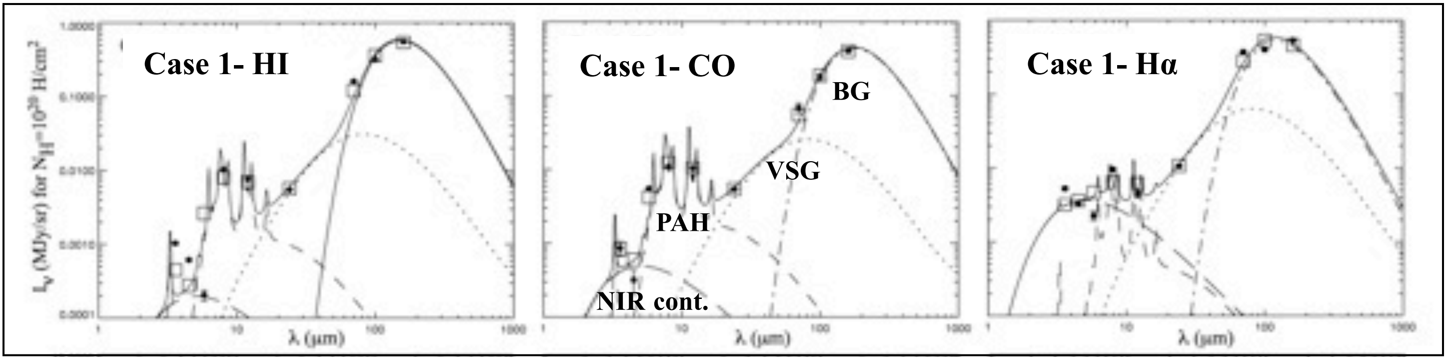
^{12}CO(J=1-0) 2nd survey (θ=2.6'), with the 4-m radio NANTEN telescope (Fukui et al., 2008).

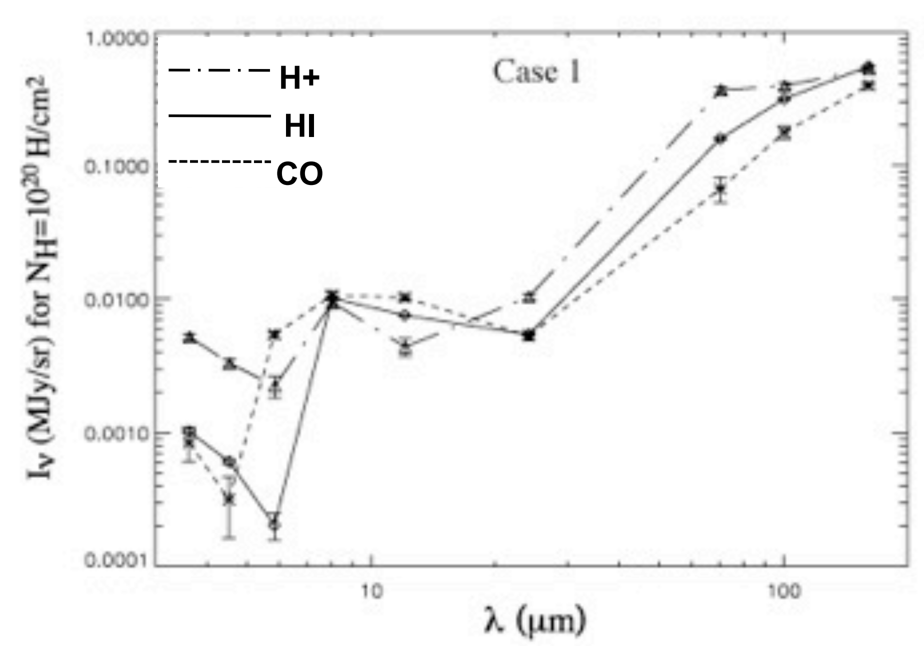


Paradis et al. 2011

Dust in the diffuse ionized gas (LMC)

Modeling with a single RF



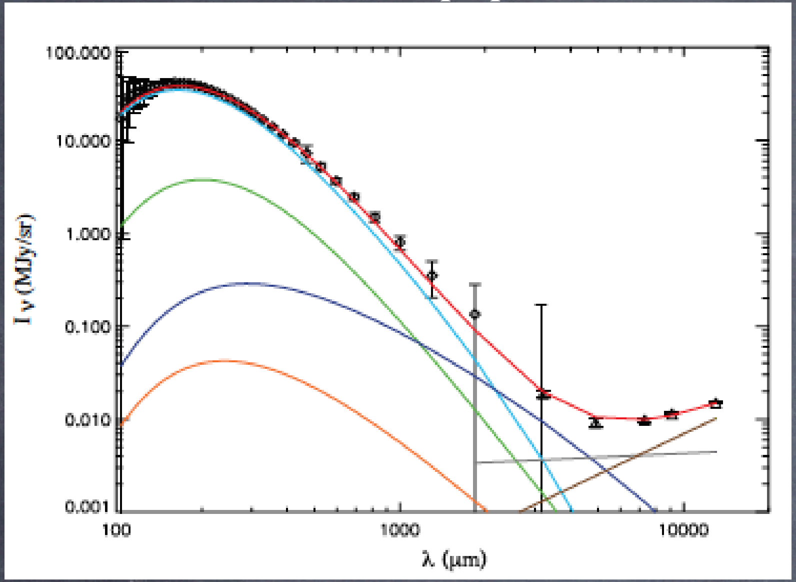


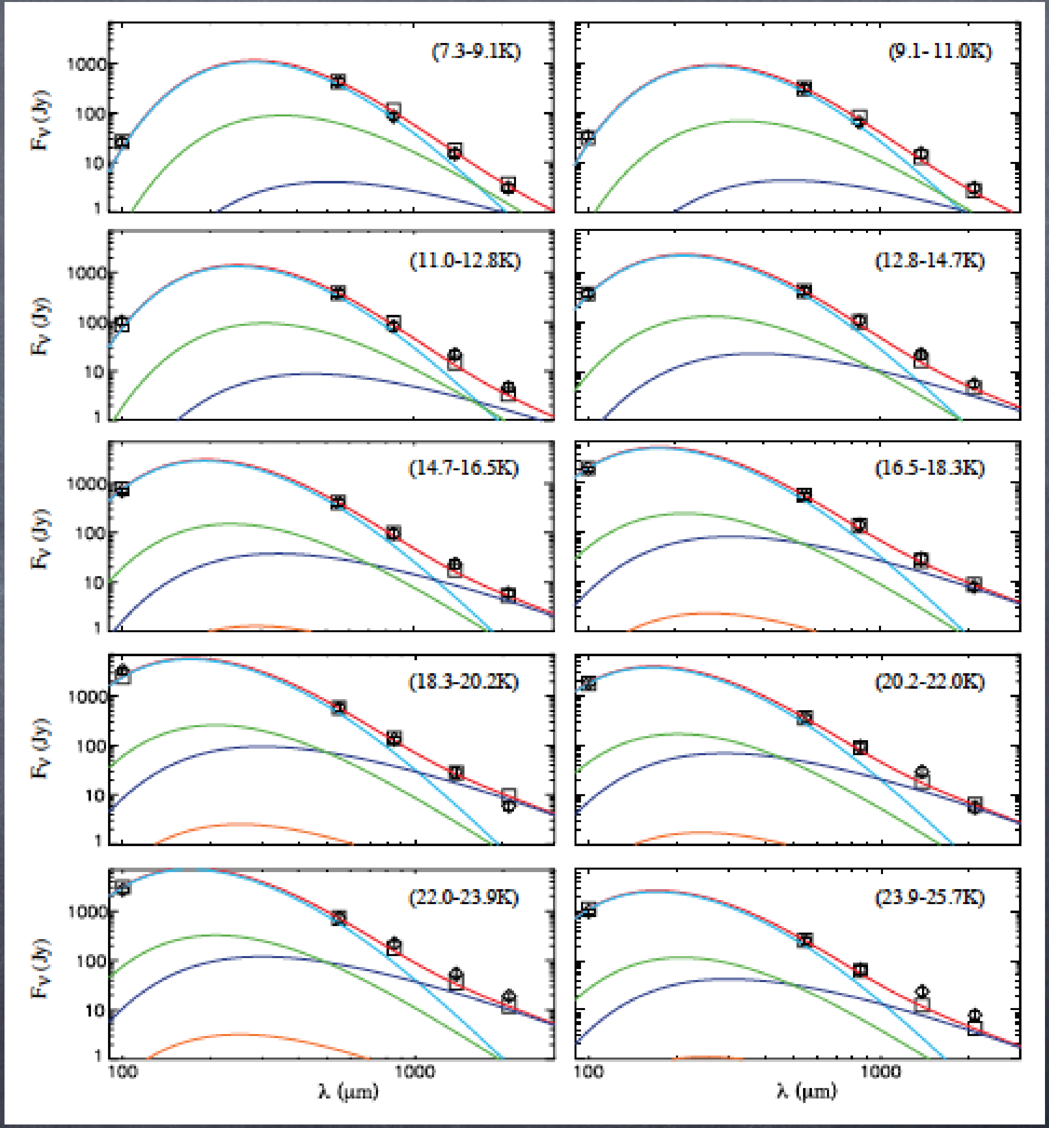
- ✓ Dust emission in H+ dominant in the FIR
- ✓ T_d^{H+}=23.9 K, T_d^{HI}=18.7 K and T_d^{CO}=16.1 K
- ✓ ε_{160}^{H+}= 2.3x10^{-26} cm^2/H
  => ε_{LMC}=1/10 $\varepsilon_\odot$= 1/40 ε_{GAL}
- ✓ $(Y_{PAH}/Y_{BG})^{H+}$ =1/3 $(Y_{PAH}/Y_{BG})^{HI}$
  =1/6 $(Y_{PAH}/Y_{BG})^{CO}$
- ✓ ↗ of the NIR continuum in the H+ phase

Paradis et al. 2011

The TLS model of amorphous grains

Paradis et al. 2011, in prep.

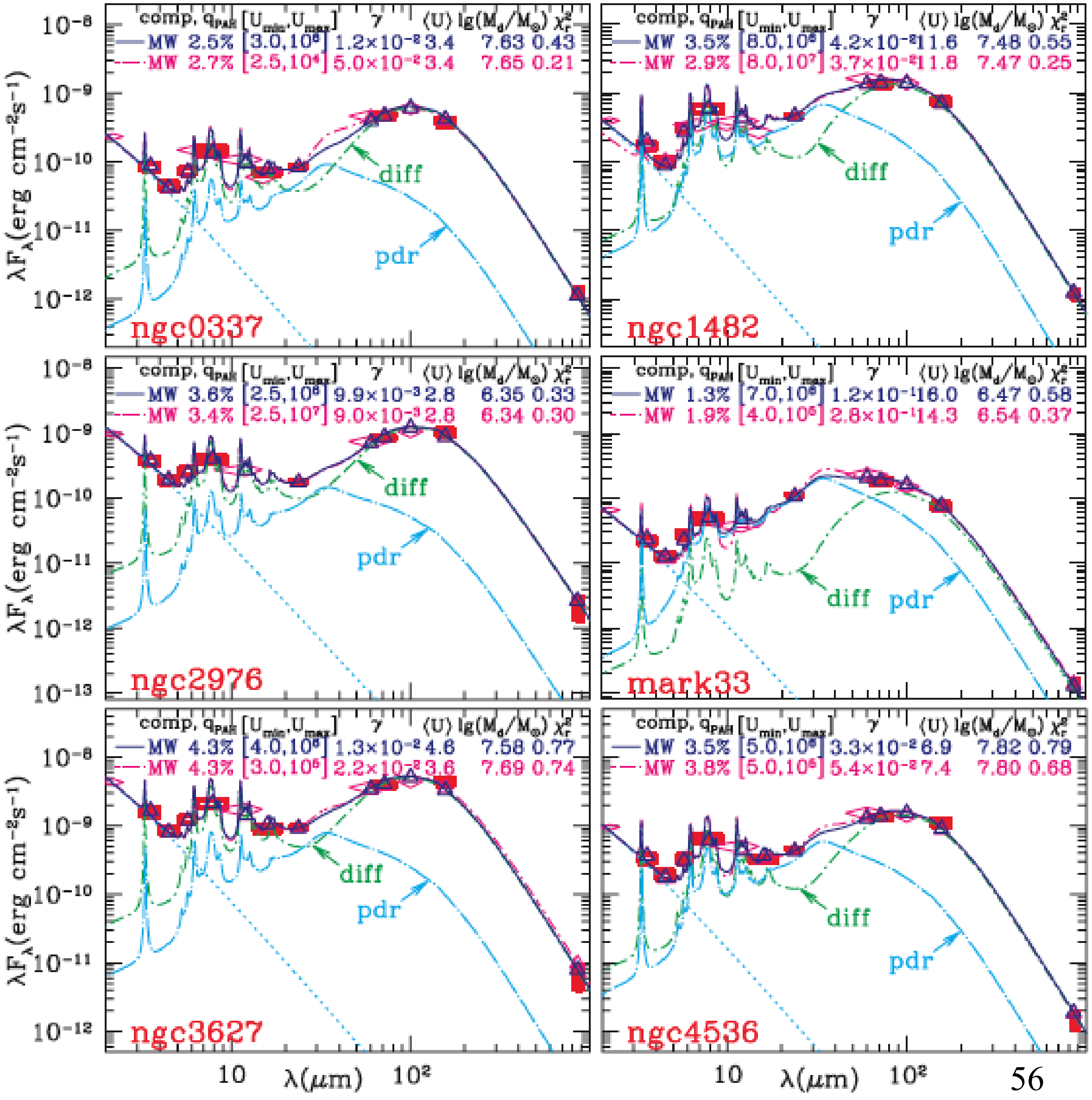




Deriving standard parameters of the TLS model (5 parameters) to explain both FIRAS MW spectrum and Archeops observed SED flattening with increasing T_d.

(See talk by paradis)

Spitzer SINGS galaxies



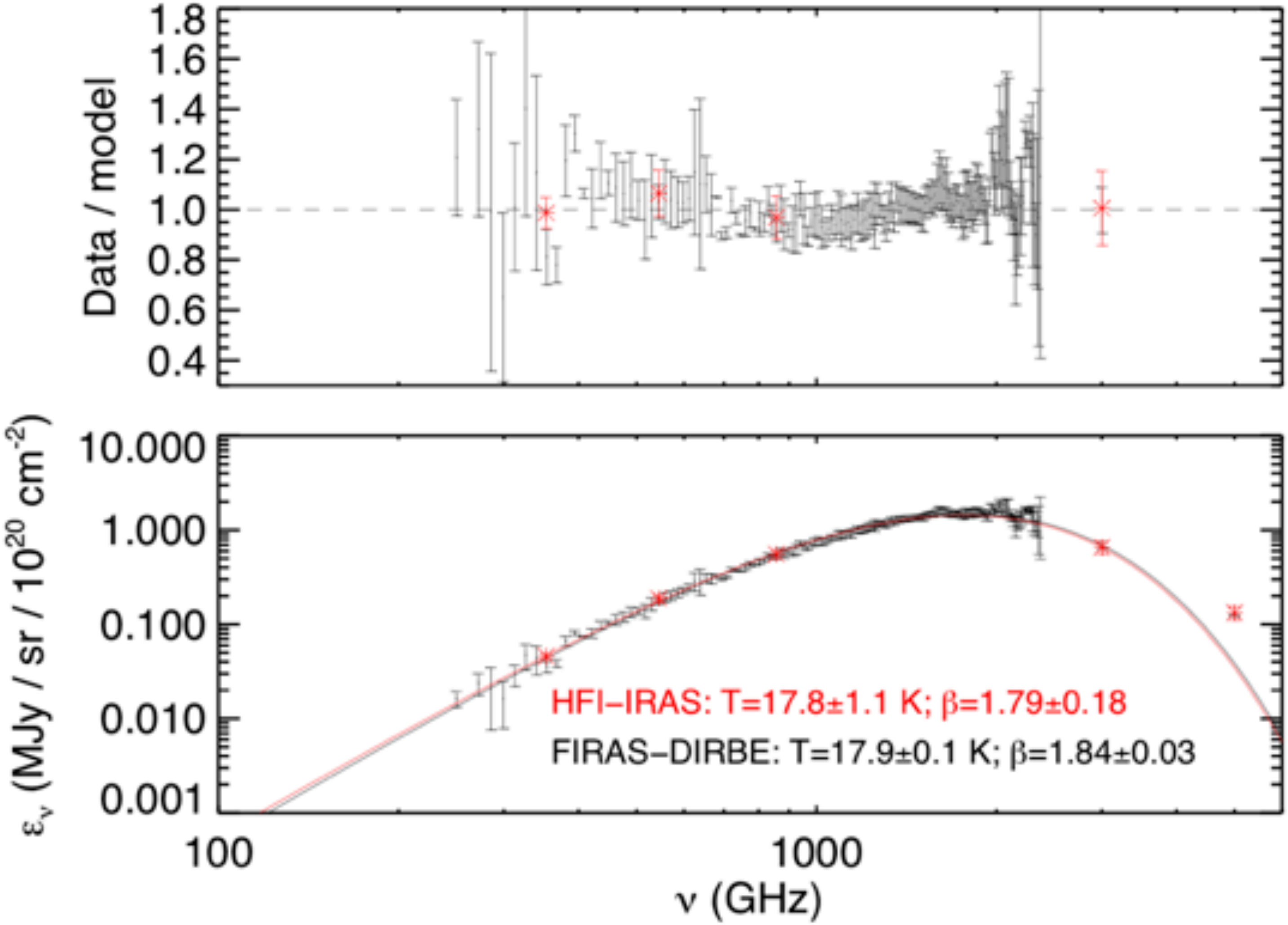
Modeled 65 galaxies of SINGS, some with submm photometry (SCUBA)

Uses a mix of radiation field intensities with diffuse (U_{min}) and PDR (U^{γ}) contribution

Find:
- spiral galaxies have dust properties Similar to MW solar neigbourhood (D/G and q_{pah})
- Do not require very cold dust (T<10 K)
- Dust-to-gas ratio is observed to be dependent on metallicity
- q_{pah} correlates with metallicity

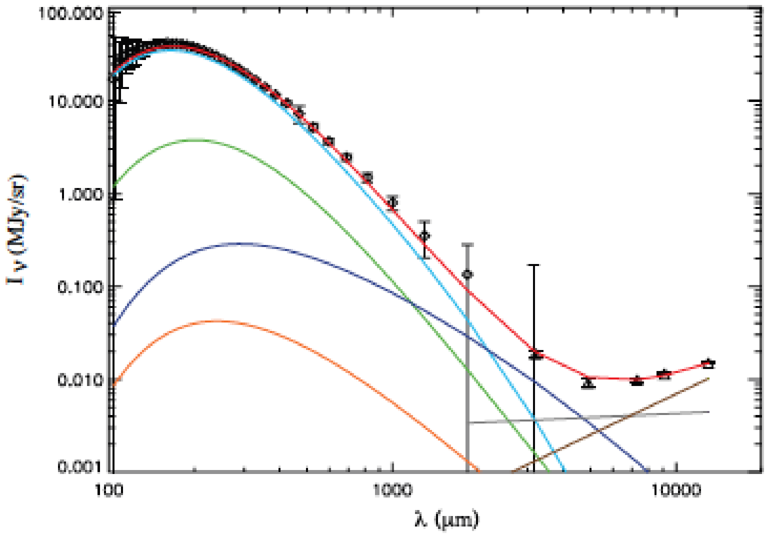
Draine et al. 2007

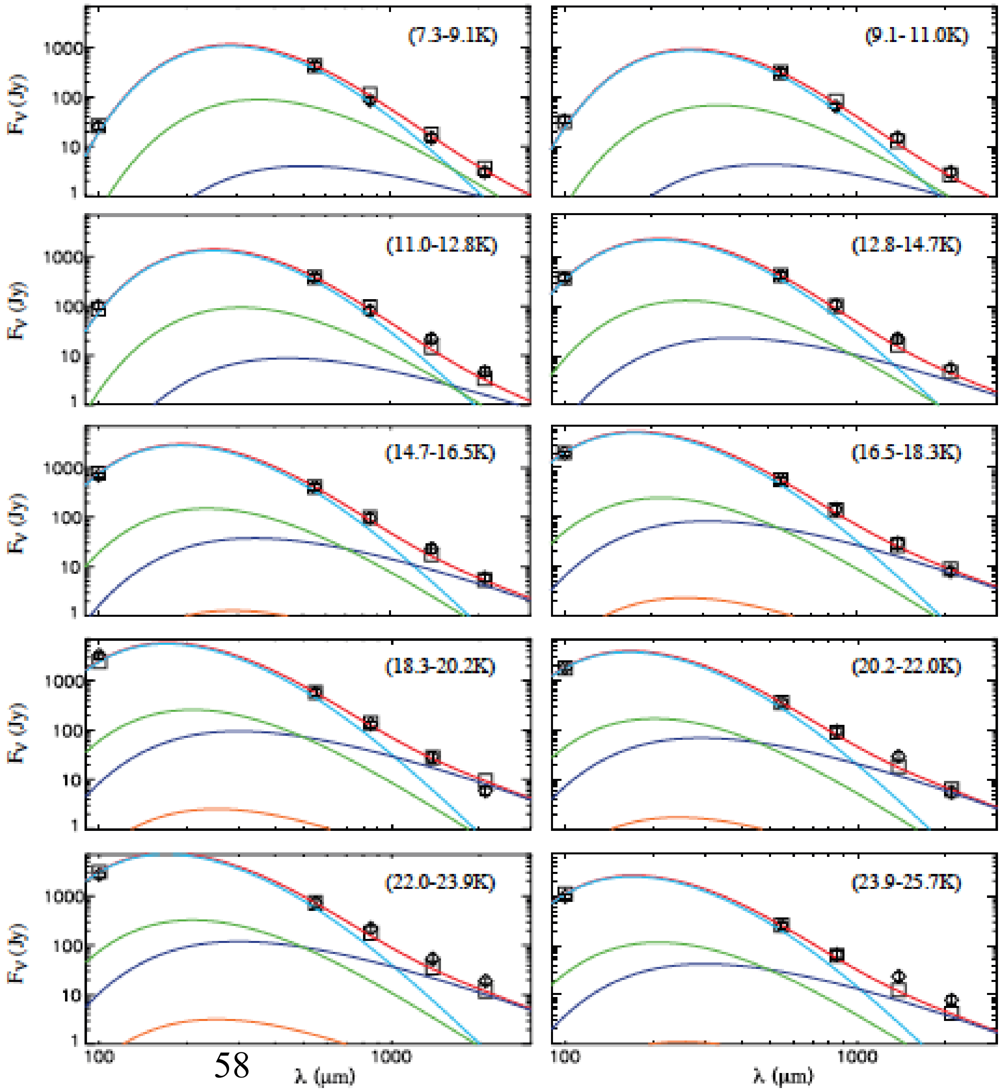
Spectre de la poussière du milieu diffus



The TLS model of amorphous grains

Paradis et al. 2011, in prep.





Deriving standard parameters of the TLS model (5 parameters) to explain both FIRAS MW spectrum and Archeops observed SED flattening with increasing T_d.