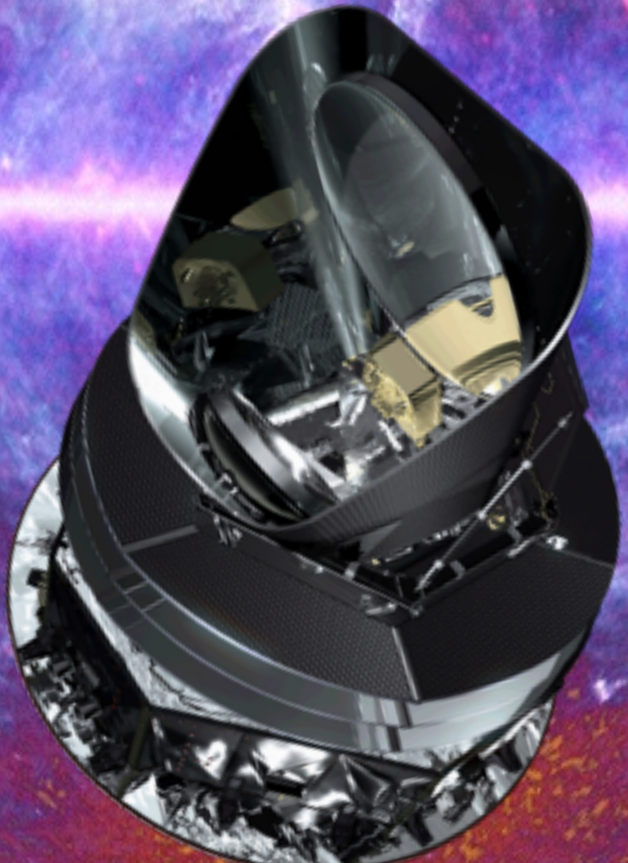
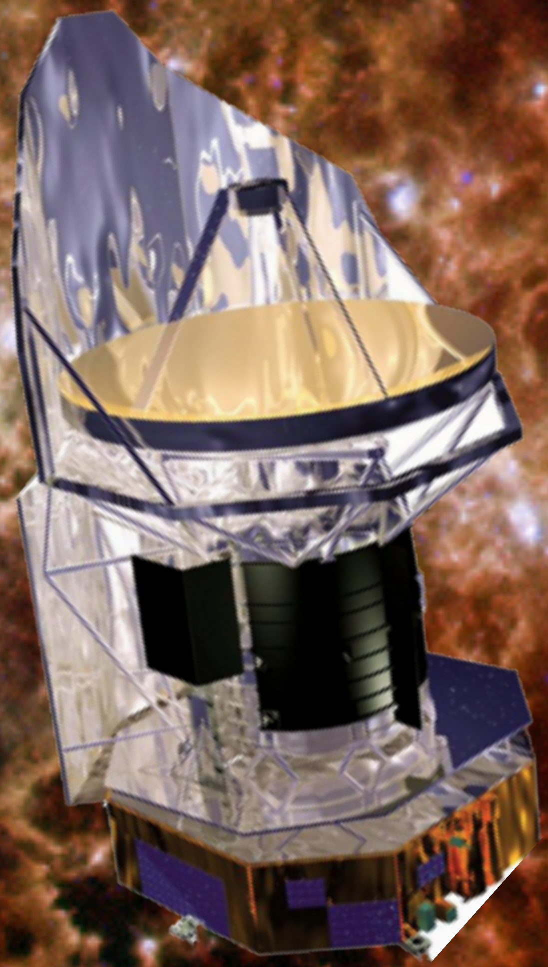
Observing dust and polarization with ALMA (?)

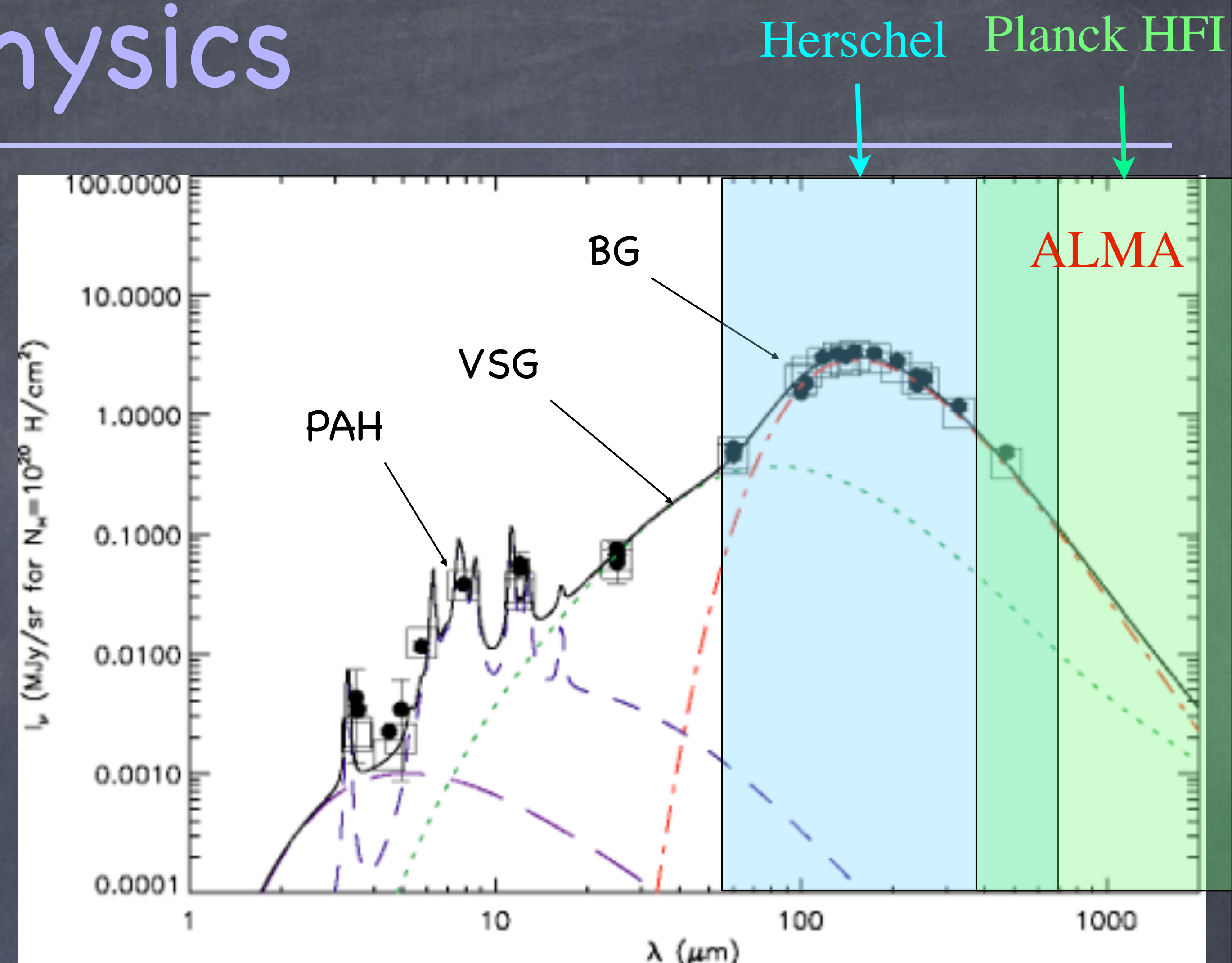
- Dust emission in the MW
- Dust emission in nearby galaxies
- Dust polarization
- Perspectives for ALMA/NOEMA





J.P. Bernard
on behalf of the Planck collaboration
and the Herschel Heritage & Higal Teams

Dust Physics



Dust:
Catalysis of molecule formation
Gas heating (photo-electric effect)
Cooling in dense regions
"Universal" tracer of the ISM structure
FIR observations of distant galaxies
Foreground Emission / CMB Cosmology

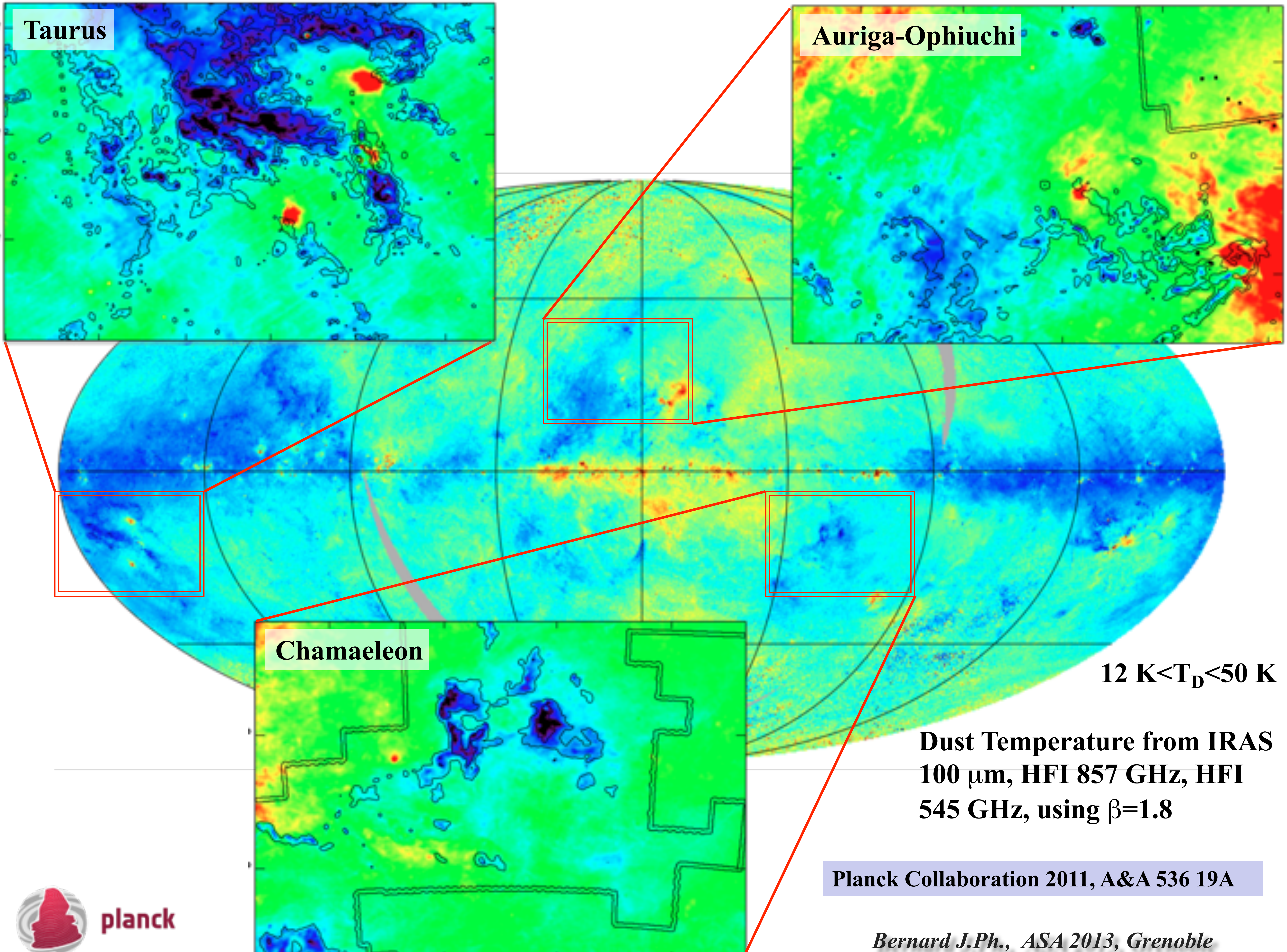
Composition:
PAH = Polycyclic Aromatic Hydrocarbons
VSG = Very Small Grains
BG = "Big" grains Silicates + Graphite (≈ 0.1 μm)

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

BG at thermal equilibrium -> dust temperature T_D measures radiation field intensity (G0)

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

- In the 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 determination not very sensitive to temperature determination in Submm-mm …
- However, recent results question the above.



$12\ K < T_D < 50\ K$

Dust Temperature from IRAS 100 μm, HFI 857 GHz, HFI 545 GHz, using β=1.8

Planck Collaboration 2011, A&A 536 19A

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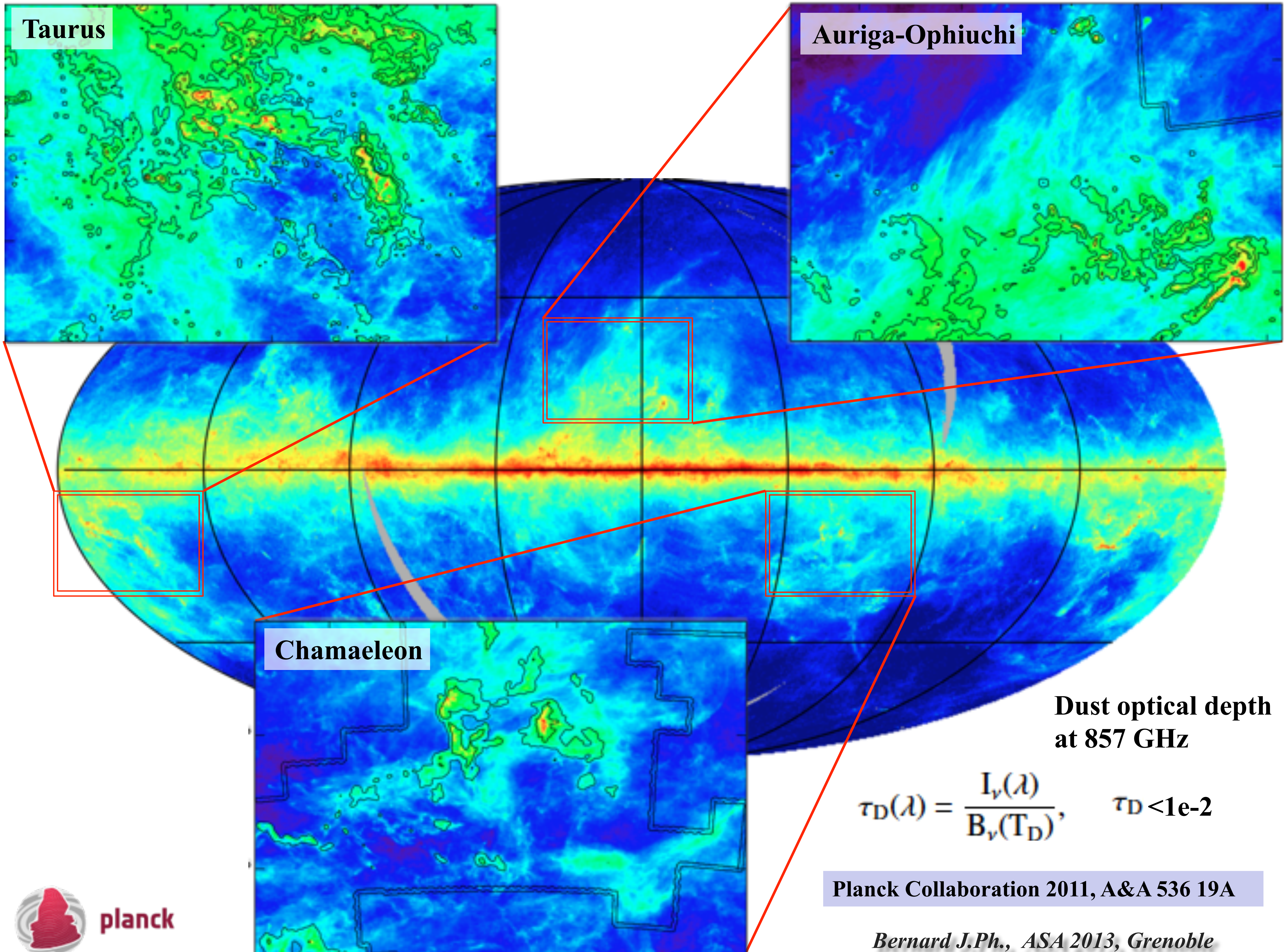
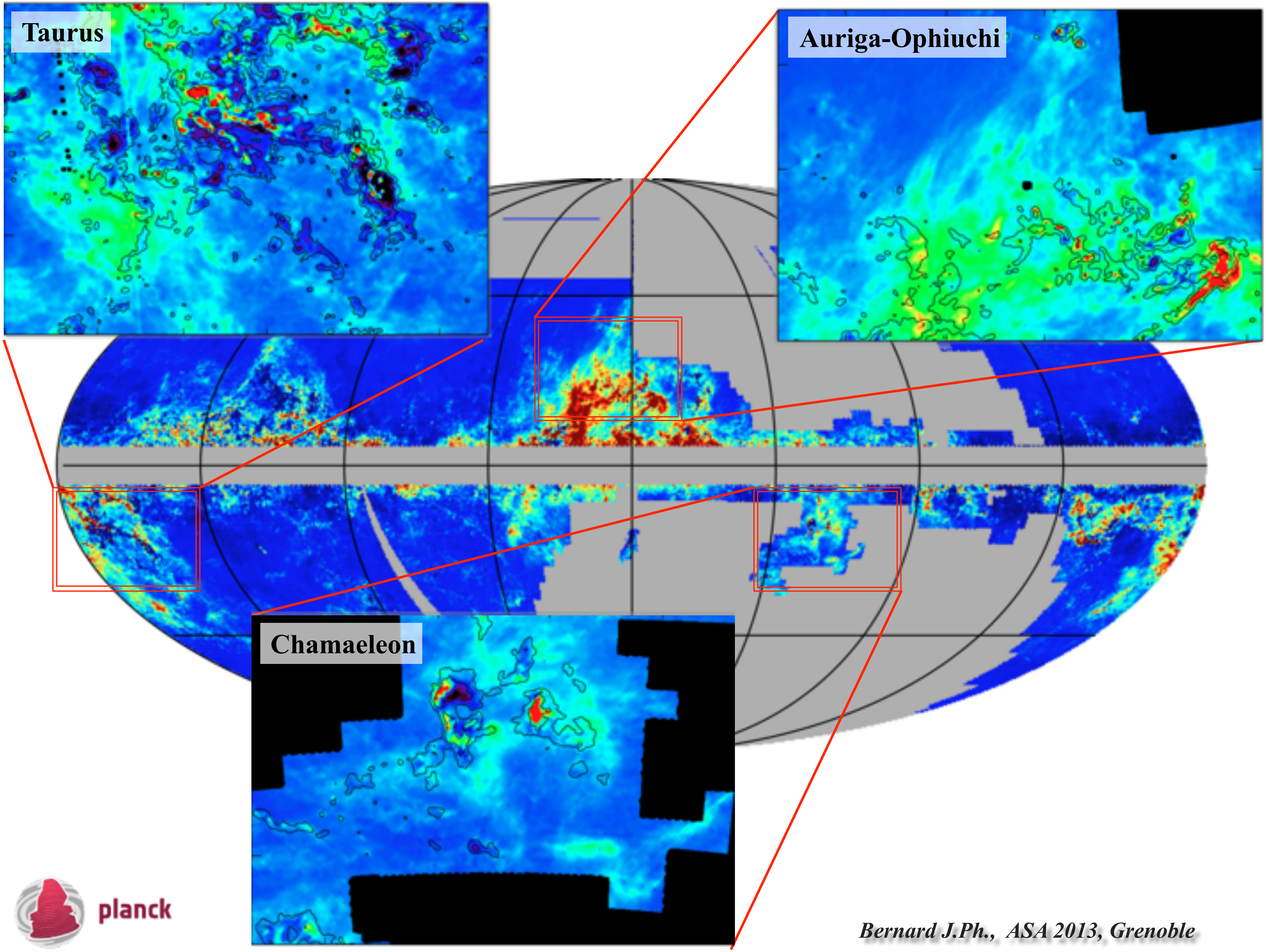
Bernard J.Ph., ASA 2013, Grenoble



Dust optical depth at 857 GHz

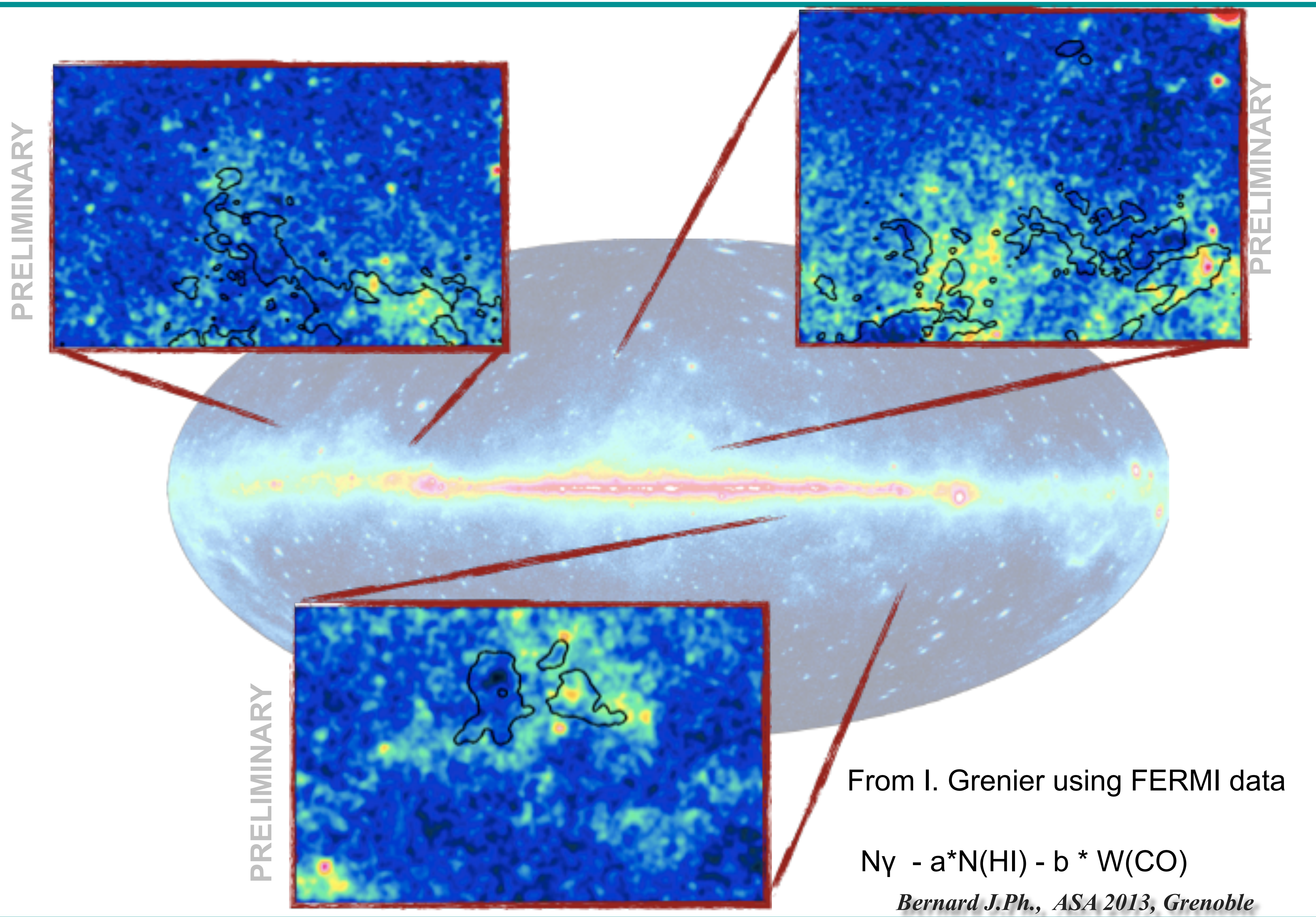
$$\tau_D(\lambda) = \frac{I_\nu(\lambda)}{B_\nu(T_D)}, \qquad \tau_D < 1e\text{-}2$$

Planck Collaboration 2011, A&A 536 19A



Bernard J.Ph., ASA 2013, Grenoble

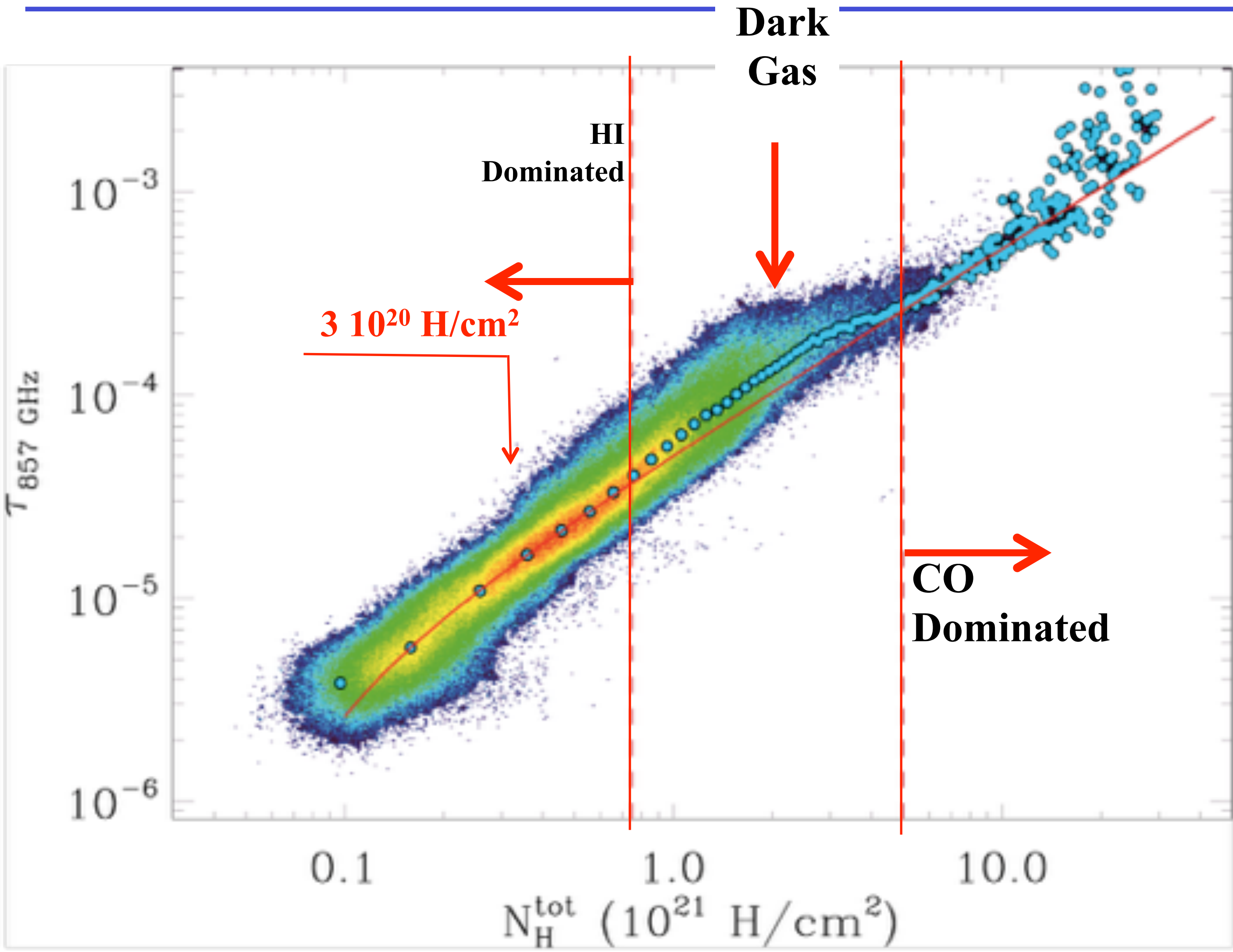
dark neutral gas map from γ rays



From I. Grenier using FERMI data

Nγ - a*N(HI) - b * W(CO)

Evidence for Dark Gas



Planck Collaboration 2011, A&A 536 19A

Possible origins :

- **Dust abundance variations (unlikely in solar neighbourhood)**
- **Dust property variations**
- **Optically thick HI 21 cm emission**
- **Weak CO below the threshold of the surveys**
- **Molecular dark gas: photodissociated CO but H_2**

Currently a very debated topic, with important implications on star formation efficiency (Kennicutt-Schmidt Law)

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. Absolute value consistent with value at 250 μm (Boulanger et al 1996)
Average Xco factor Xco=2.54+-0.13 10^{20} $H_2/cm^2/(Kkm/s)$
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*)

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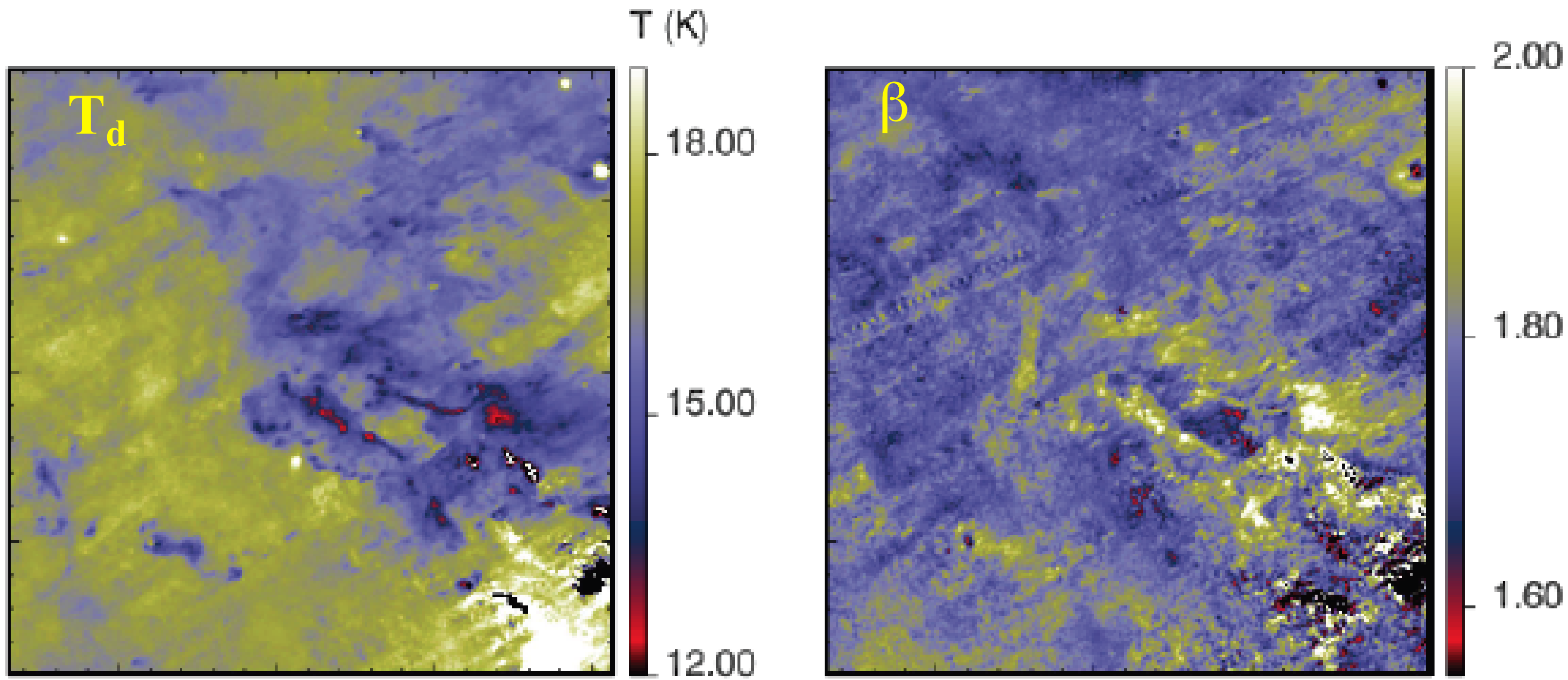
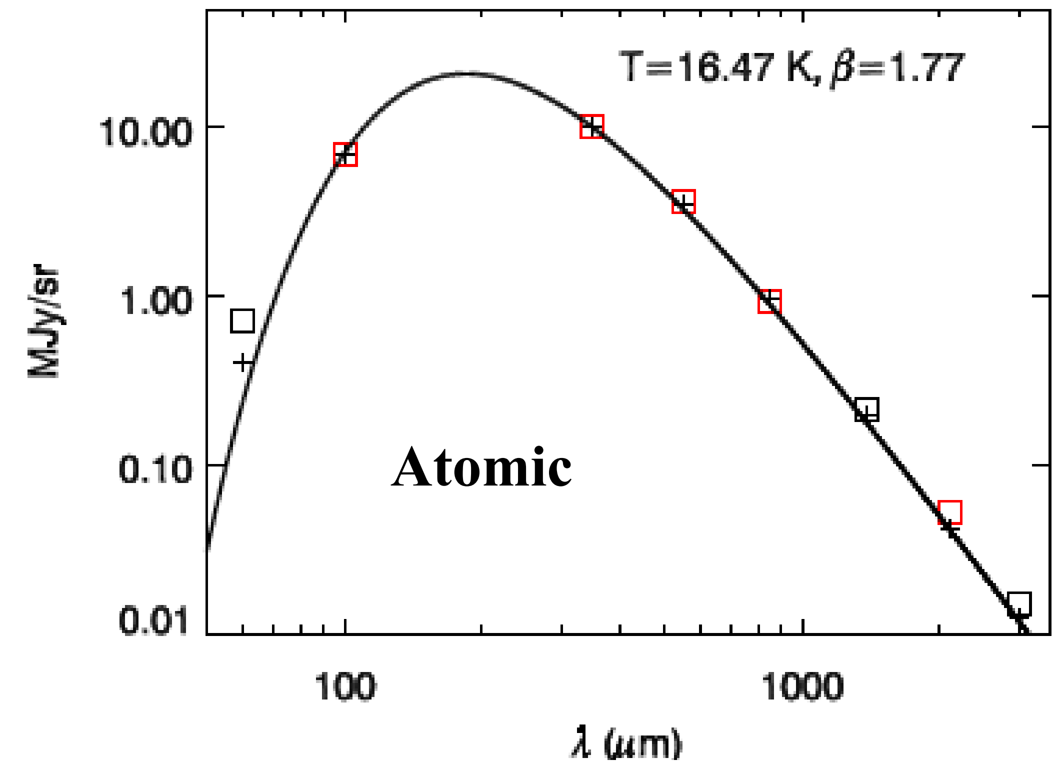
Dust in Molecular Clouds (Taurus)

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

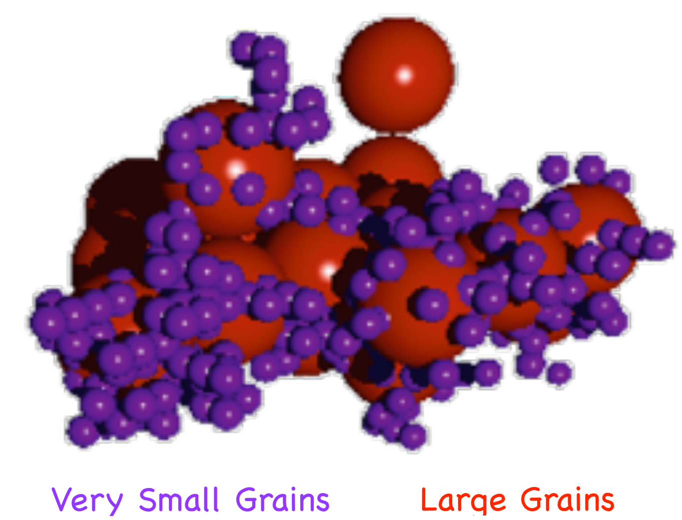
- Dust temperature maps from 16–17 K (diffuse regions) to 13–14 K (dense regions)

- Emissivity increase in dense regions :

τ/N_H @ 250 μm from ~ 10^{-25} cm² (diffuse) to ~2×10^{-25} cm² (dense)

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

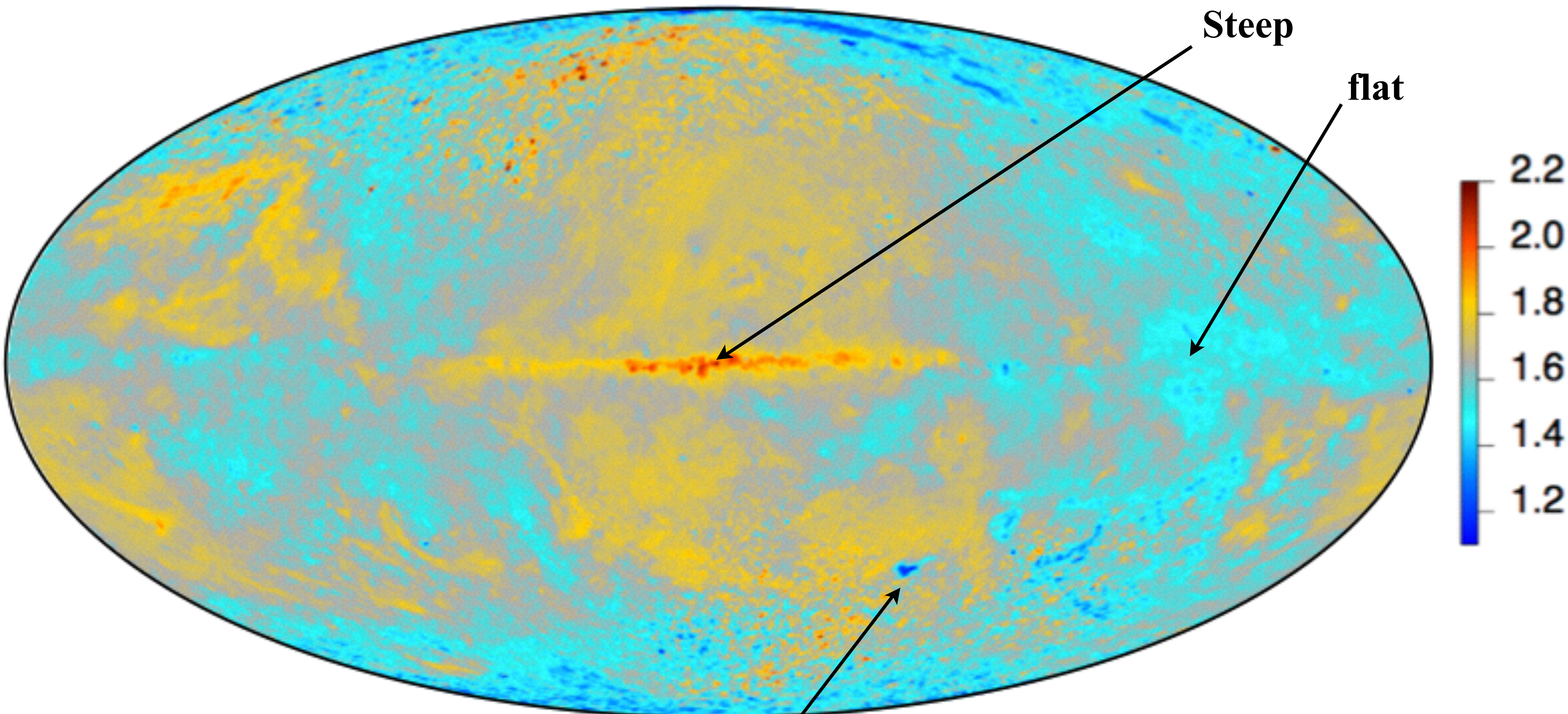
They are likely due to dust aggregation.



Planck Collaboration 2011, A&A 536 XXV
C. Author A. Abergel

Dust spectral index : 353-3000 GHz

The steepness of the dust SED varies on the sky

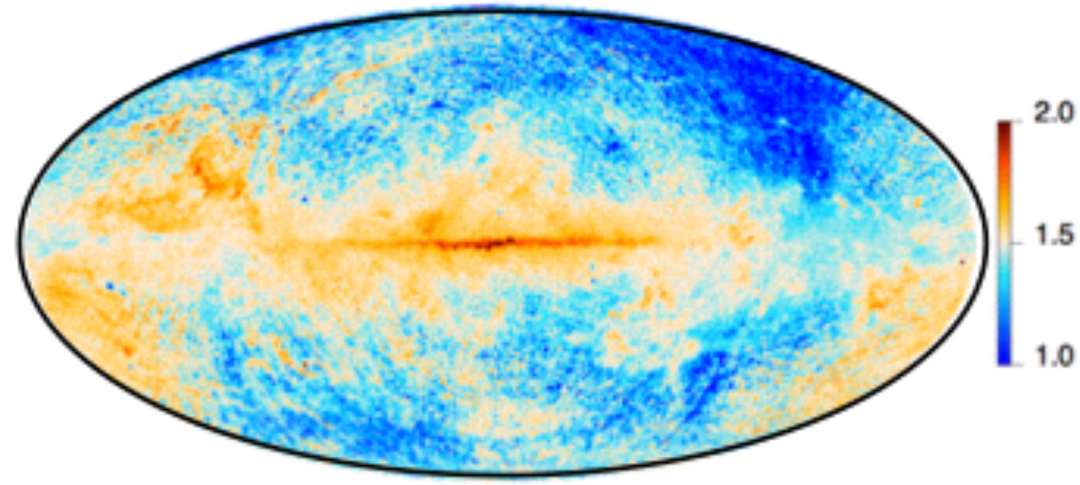


<Beta> = 1.63
sigma(Beta) = 0.09
<statistical error> = 0.05

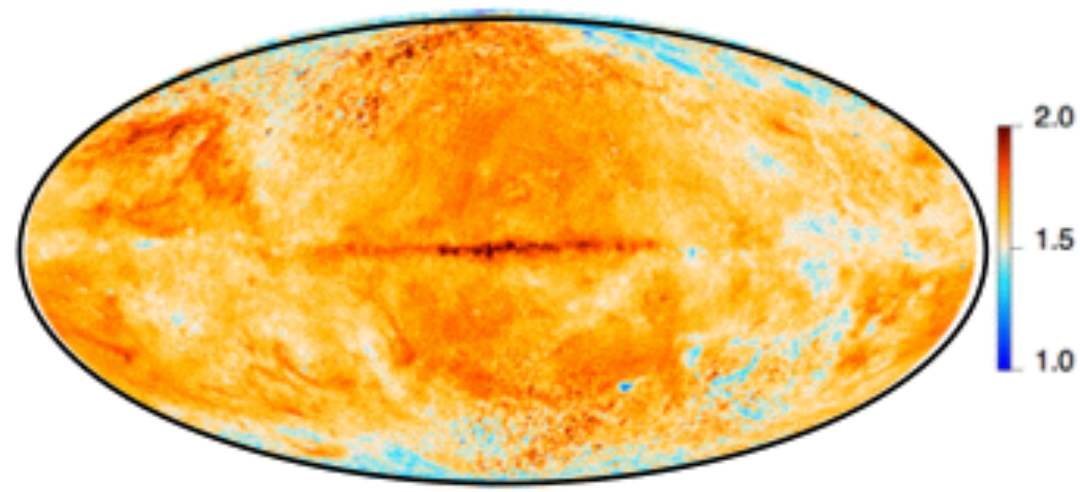
Microwave dust spectral index

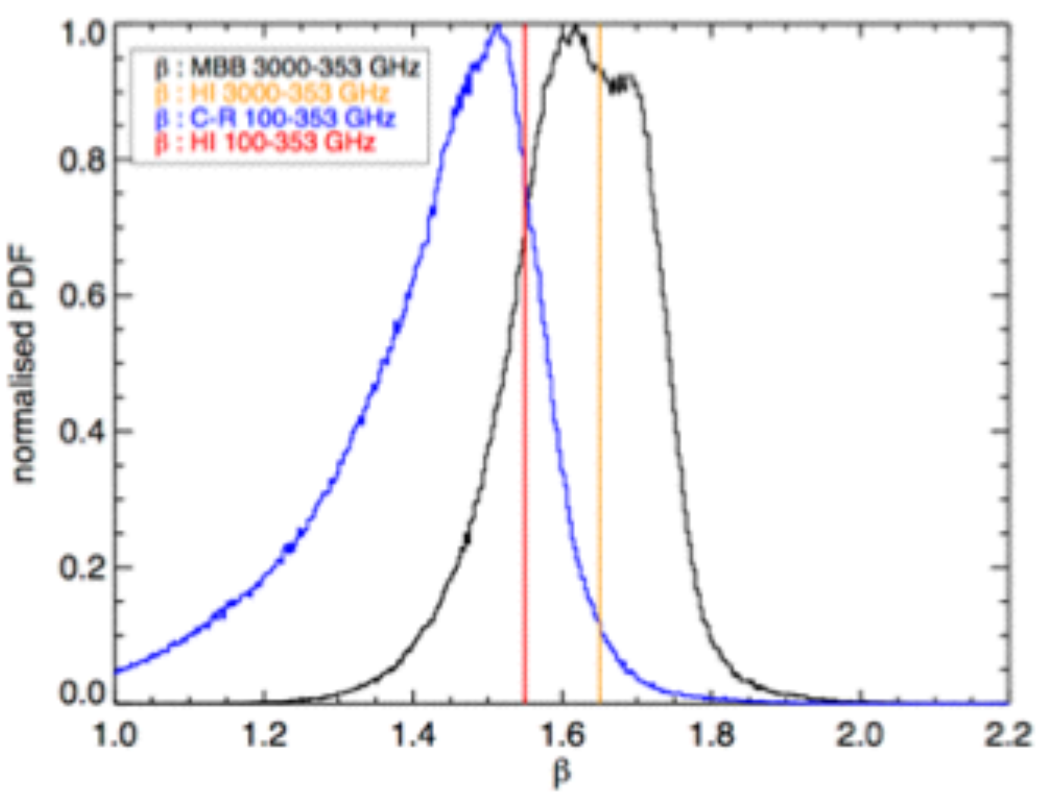
- Similarities in the spatial structure of the high and low frequency spectral indices
- Clear flattening at low frequencies observed by all analysis : cirrus (red line in PDF), molecular clouds, Galactic plane
- C-R result provides a first attempt at estimating Beta_mm over the whole sky

Commander-Ruler : 100-353 GHz



Thermal dust model : 353-3000 GHz





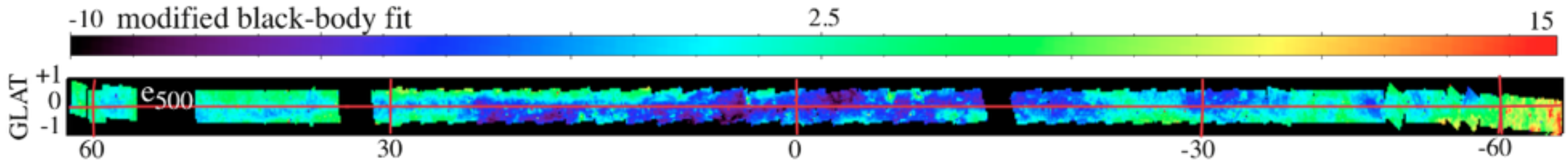
Beta_FIR = 1.65
Beta_mm = 1.55

The steepness of the dust SED changes with frequency (flatter at loner wavelengths)

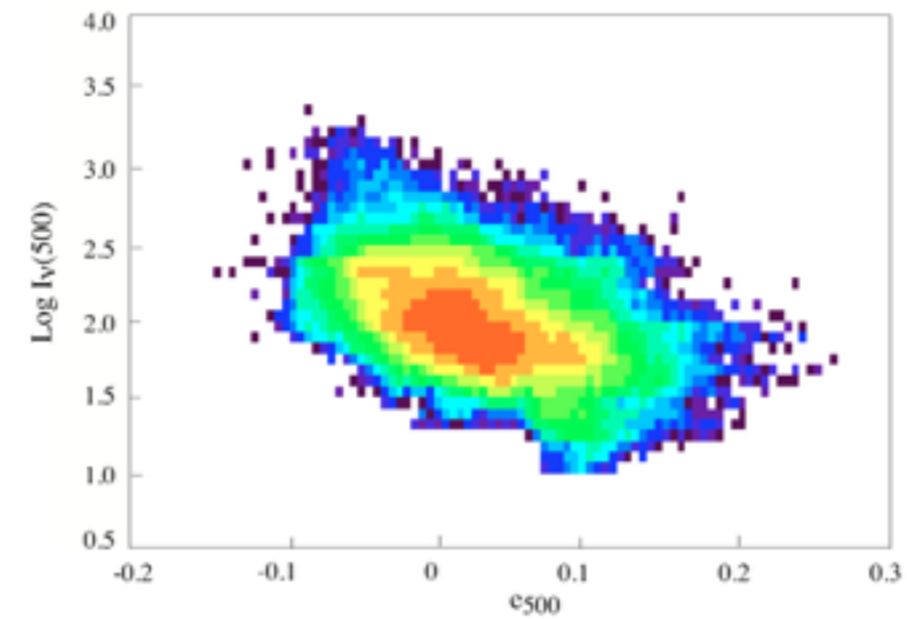
Bernard J.Ph., ASA 2013, Grenoble

Submm excess

Milky Way :

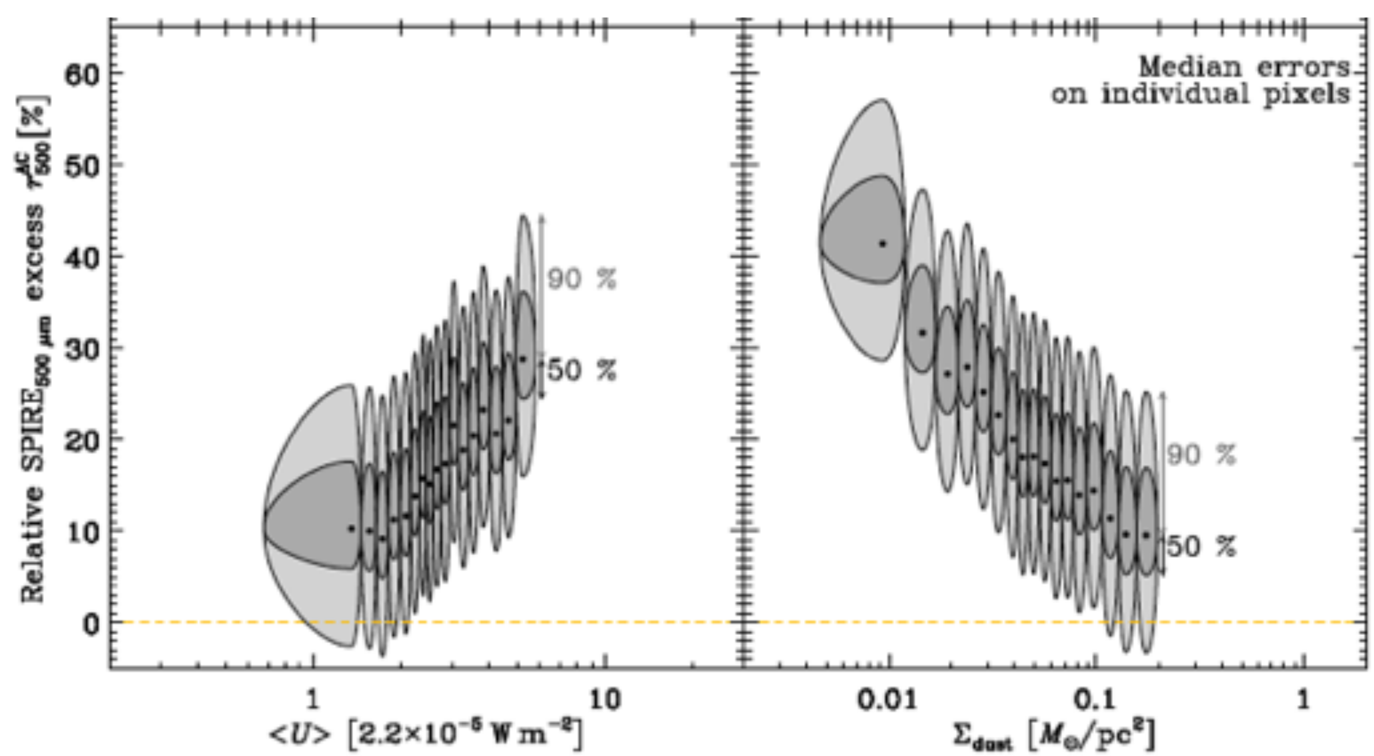


==> Paradis et al. (2012) β ≈ 1.8 (entire Galaxy)
Hi-Gal Herschel data
- β decreases (spectrum flattens) from the inner to the peripheral parts of the Galactic plane
- 500 μm excess near |l|=60° is up to 16-20%
- little excess in the inner Galaxy



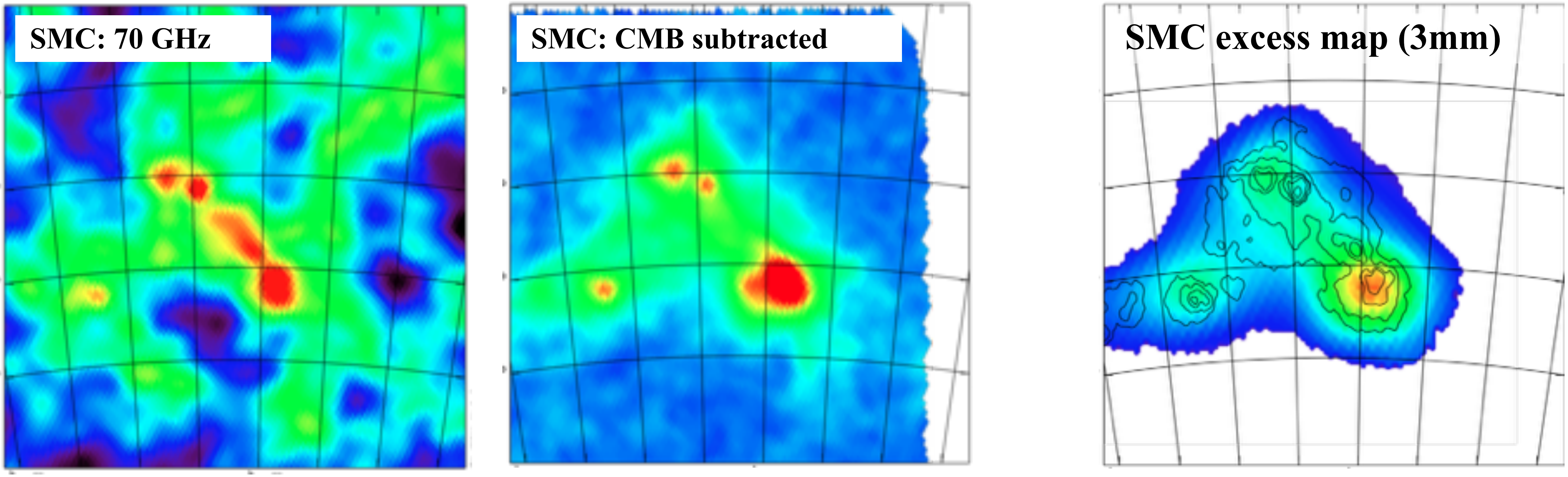
Magellanic Clouds :

==> Galliano et al. (2011), Gordon et al. (2010)
β ≈ 1.5 (LMC) 1.2 (SMC)
Heritage Herschel data
- 500 μm excess correlated with T
- 500 μm excess anti-correlated with N_H
- 500 μm excess not due to very cold dust

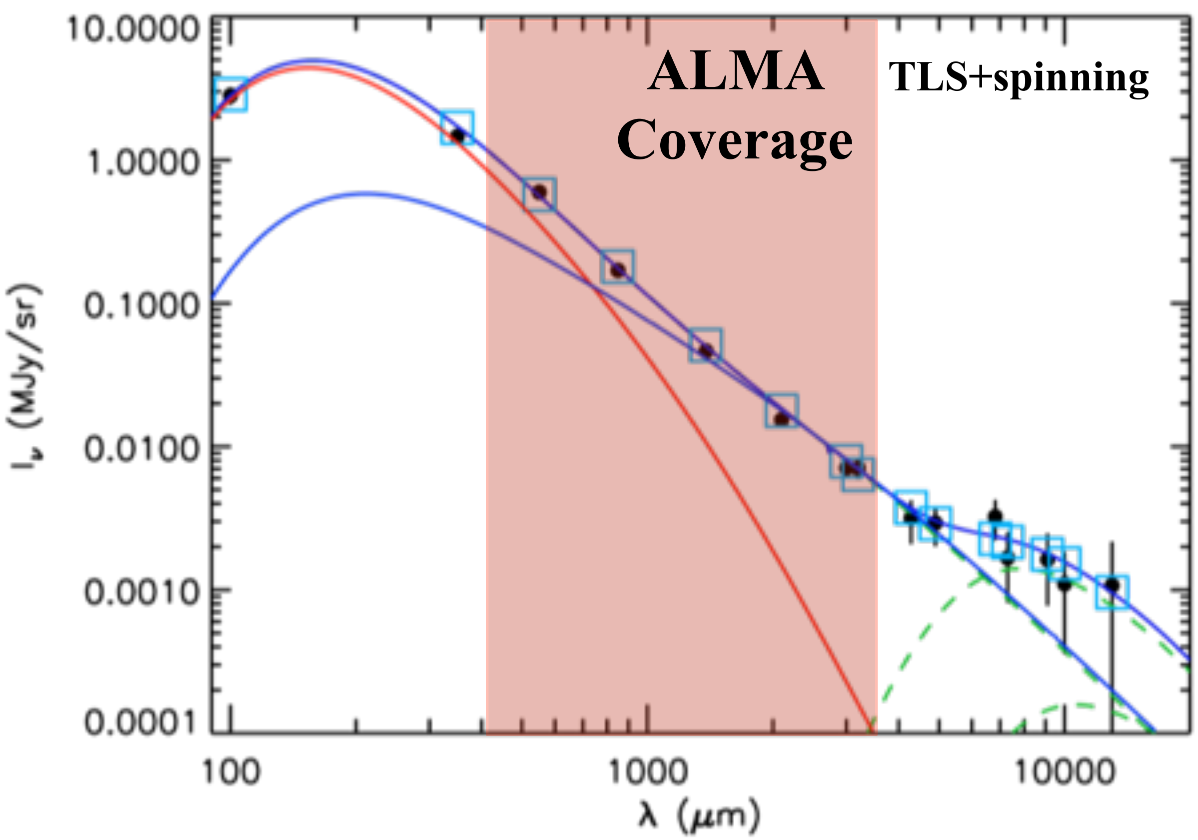


500 μm excess is correlated with dust T and anti-correlated with column density (!)

Submm excess of the SMC



- Free-Free contribution subtracted, extrapolated from Hα emission, assuming no extinction
- Submm excess follows the spatial distribution of thermal dust at high frequencies
- 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



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Planck Collaboration 2011, A&A 536, A17
(C. Author J.-Ph. Bernard)

Submm emissivity of MW, LMC, SMC

Large variations of the sub-mm emissivity are observed between the MW (actually solar neighbourhood), the LMC and the SMC

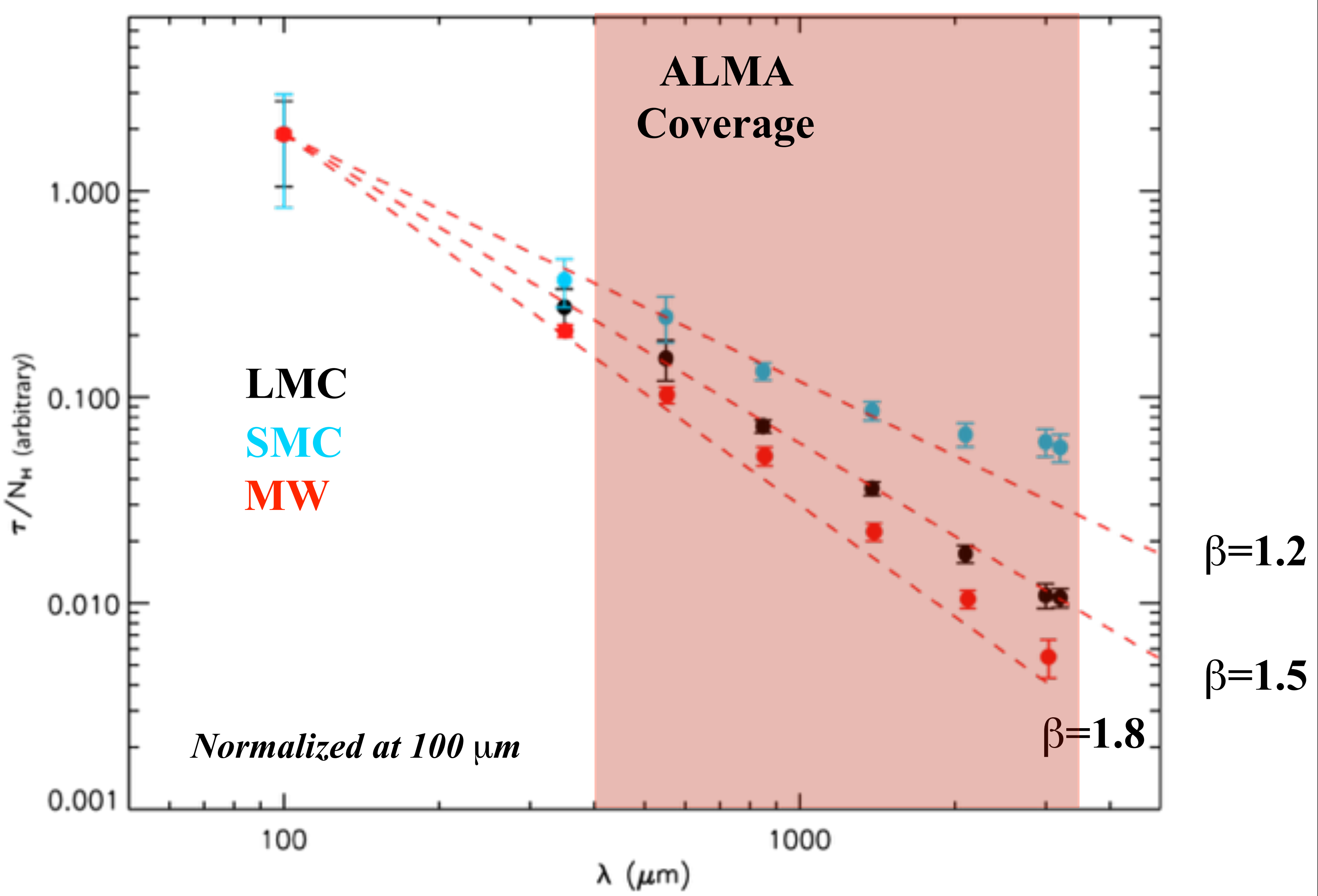
MW: β (FIR)=1.8

LMC: β (FIR)=1.5 (consistent with Gordon et al. 2010 with Herschel)

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 does not flatten



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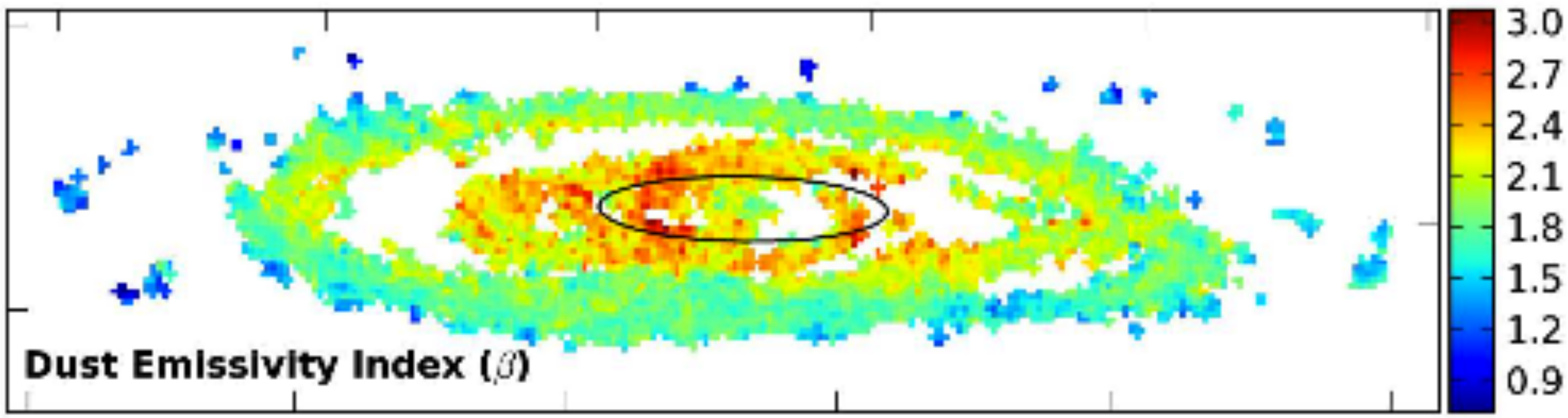
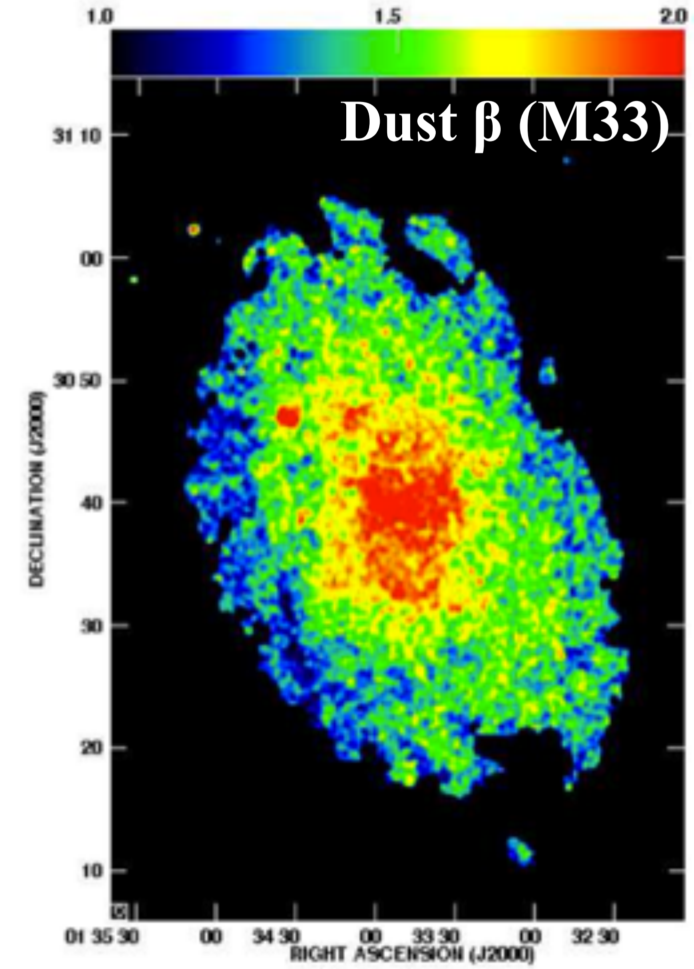
Dust emissivity and Submm excess in External Galaxies

M31, M33:
==> Smith et al. (2012)
==> Tabatabei et al. (2013)

β decreases from the center to the outer galaxy
Effect not due to T-mixing



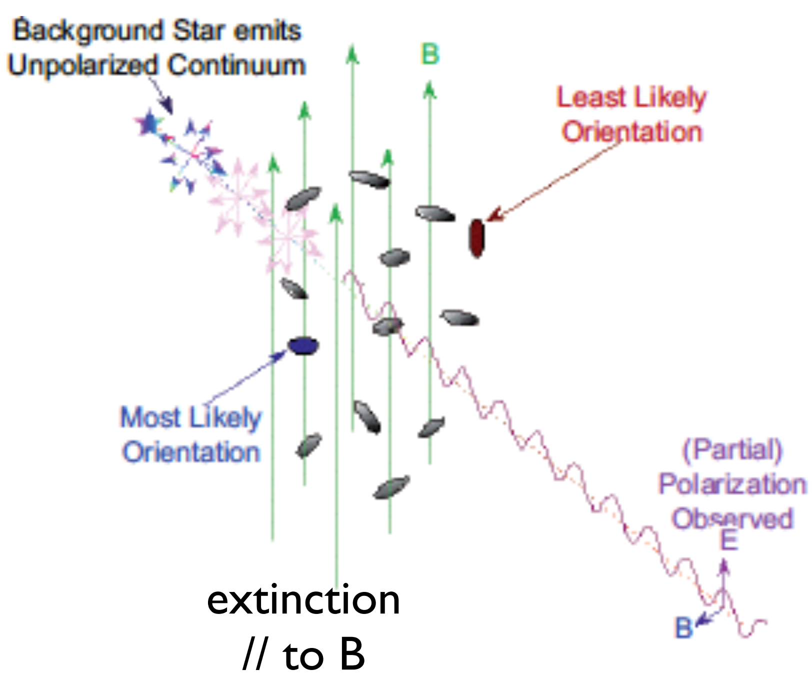
Confirmed with Planck in M31

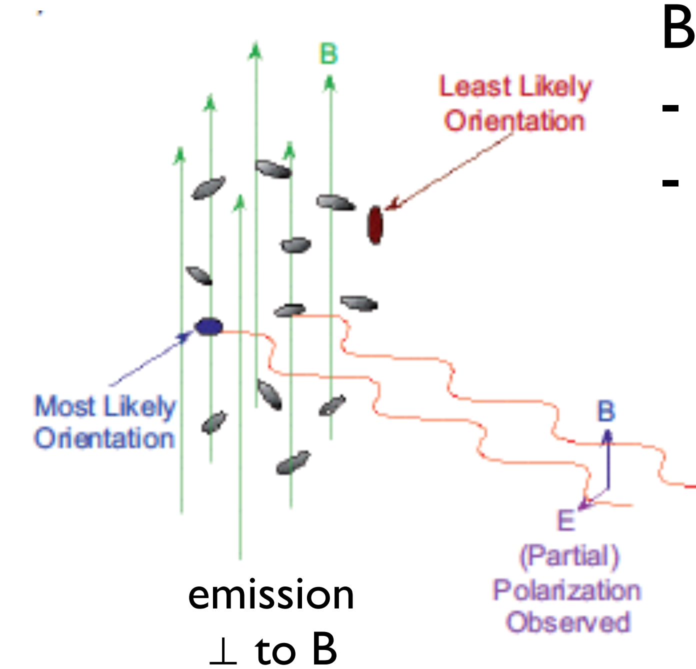


Nearby galaxies from the KINGFISH sample:
==> Dale et al. (2012): 8/9 dwarf/irregular/Magellanic galaxies with detection at 500 μm show evidence for significant 500 μm excess compared to the Draine & Li (2007) model fits.
==> Kirkpatrick et al. (2013): Claim no systematic 500 μm excess (improved photometry or a definition issue ?)

Low metallicity galaxies:
==> Galliano et al. (2003, 2005): strong sbmm excess in Dwarf low Z galaxies (very cold dust ?)
==> Madden et al. (2011) : 50% of the DGS (dwarf galaxy survey) galaxies detected at 500 μm show a submm excess of 7% to 100%.
==> Dwarf Galaxy Survey (DGS) is confirming the flater submm slope, indicative of the submm excess, in most dwarf galaxies (Rémy et al. in preparation)

Dust Polarization





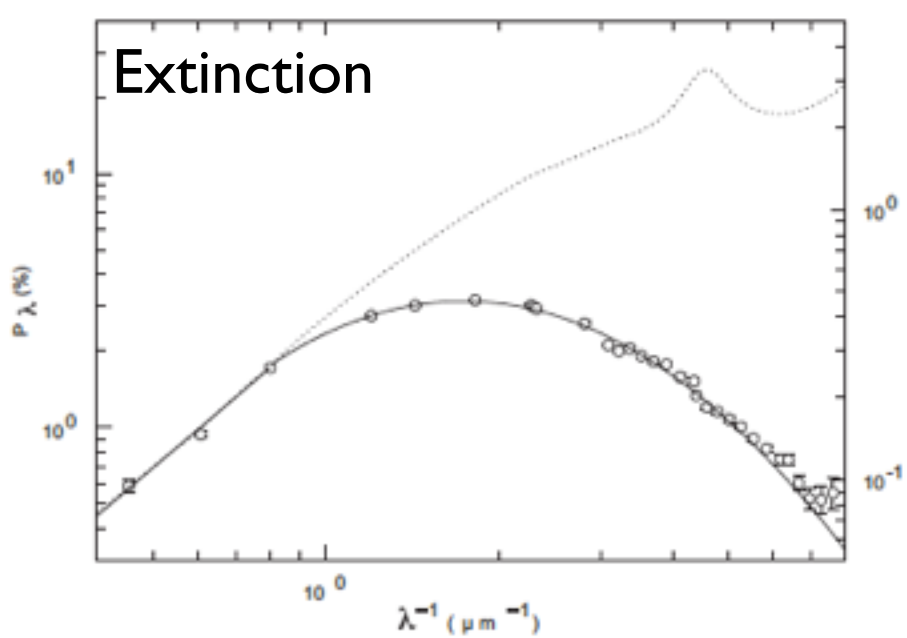
BG:
- Rotating, elongated and align partially on B
- Produce polarized emission & extinction

Possible alignment mechanisms:
- Paramagnetic relaxation alignment
- Radiative Alignment Torques

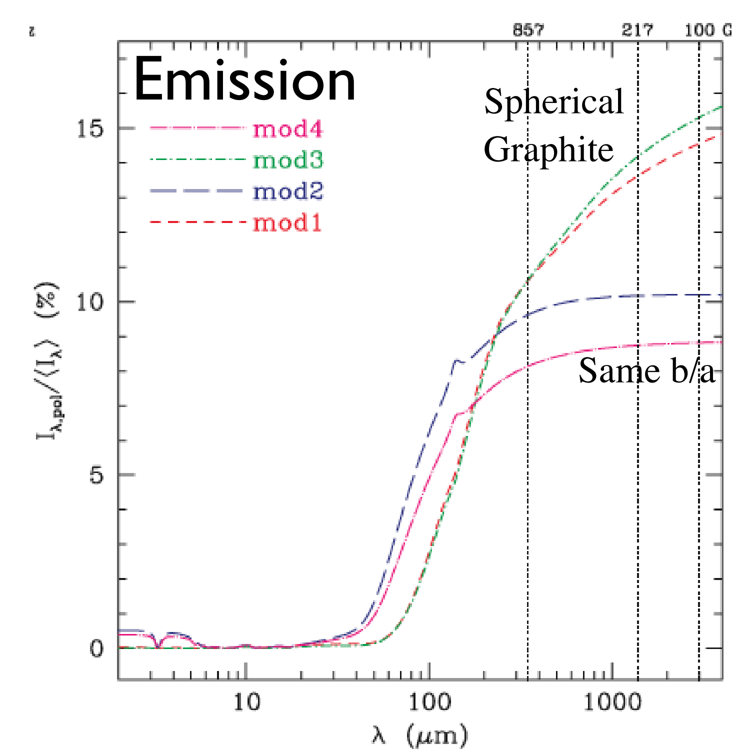
Grain disalignment by:
- Gas/grain collisions
- Plasma drag

- 2200 Å bump and FUV rise, DIBs not polarized ==> PAH & VSG unlikely to align (too small)
- 3.4 mic feature not polarized ==> Carbonaceous BG may not align or be spherical
- 10-20 mic feature polarized ==> Silicate grains aligned & elongated

Emission predicted ~10-15% polarized



Draine & Fraisse 2009



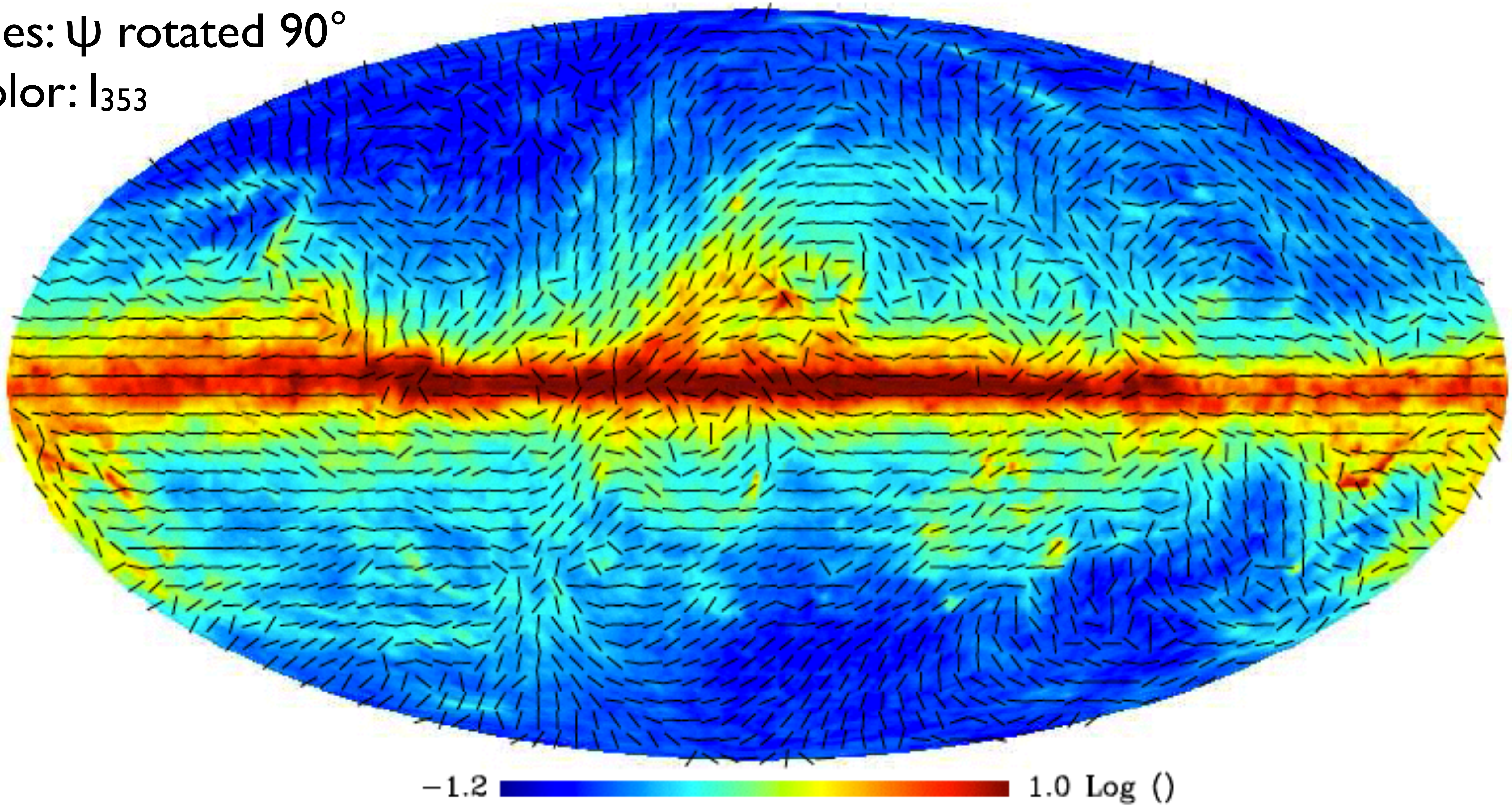
Various possible dust models lead to different predictions in polarization

B field direction at 353 GHz, 1° resolution

$\psi = 0.5 \times tg^{-1}(U, Q)$

lines: ψ rotated 90°

color: I_{353}



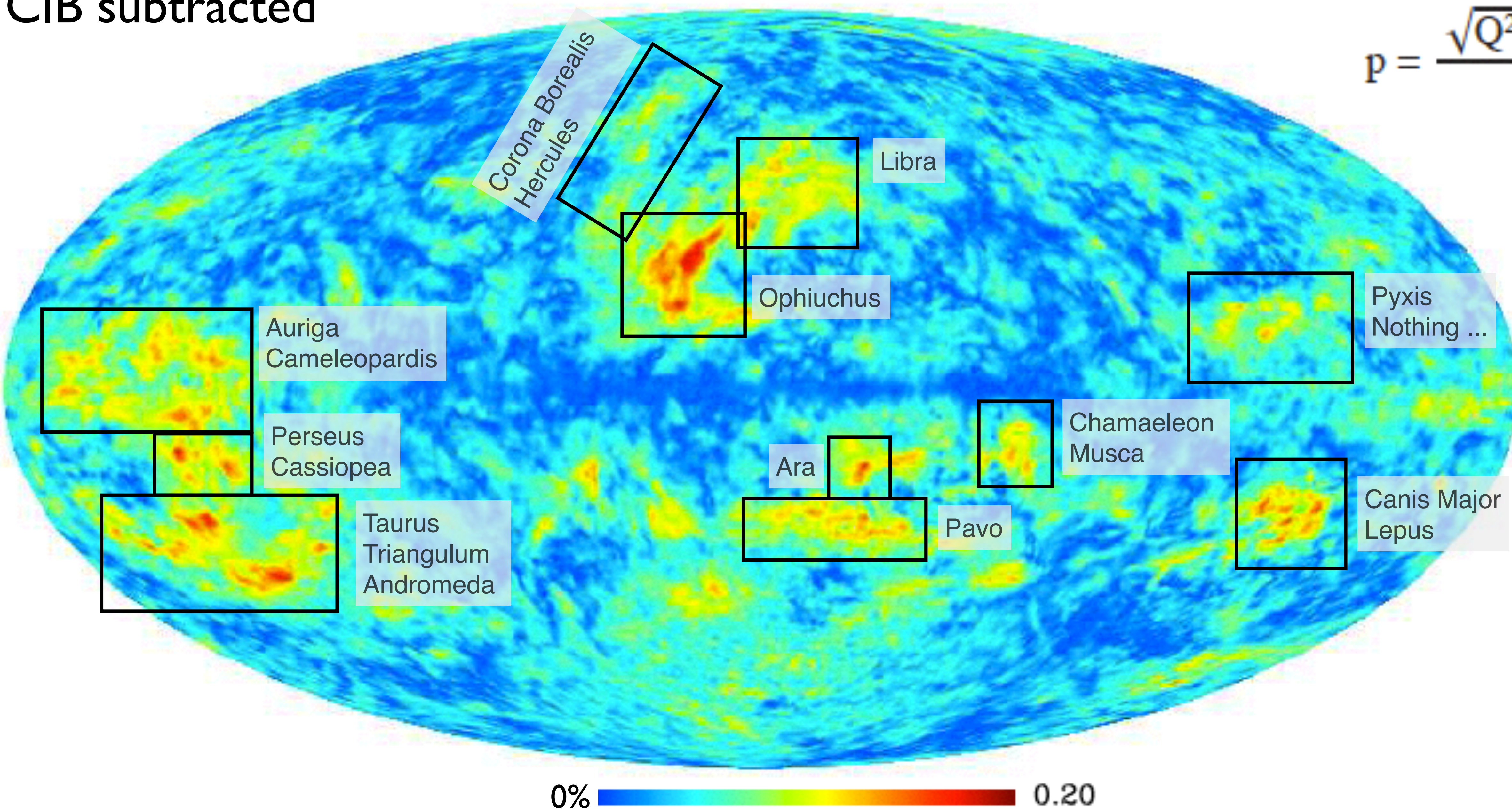
Field direction consistent with B in MW plane

Field homogeneous over large regions with strong p (e.g. Fan)

Apparent polarization fraction (p) at 353 GHz, 1° resolution

Not CIB subtracted

$$p = \frac{\sqrt{Q^2 + U^2}}{I}$$

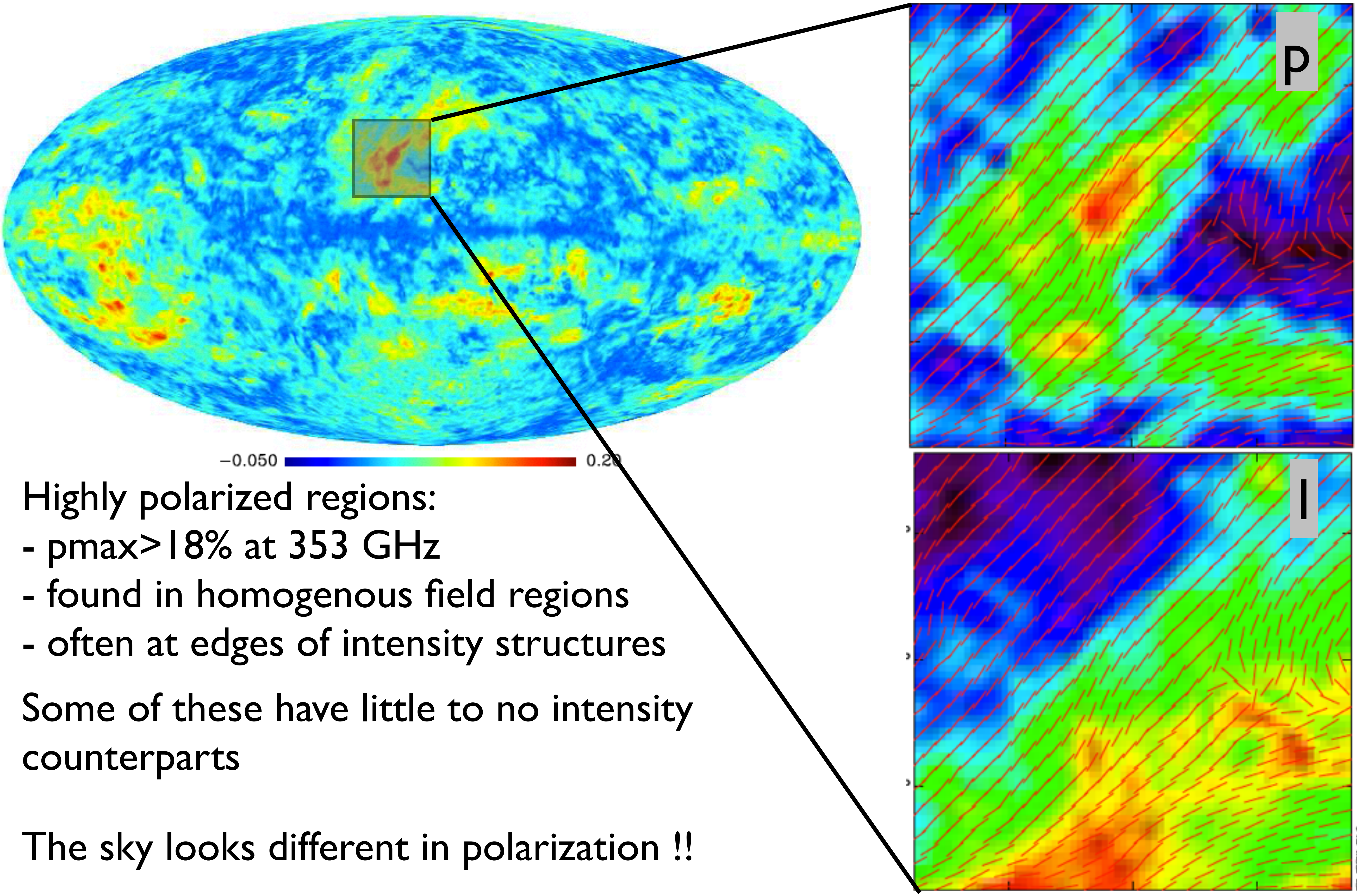


p ranges from 0 to ~20%

Low p values in inner MW plane

Large p values in outer plane and intermediate latitudes

Aquila Rift



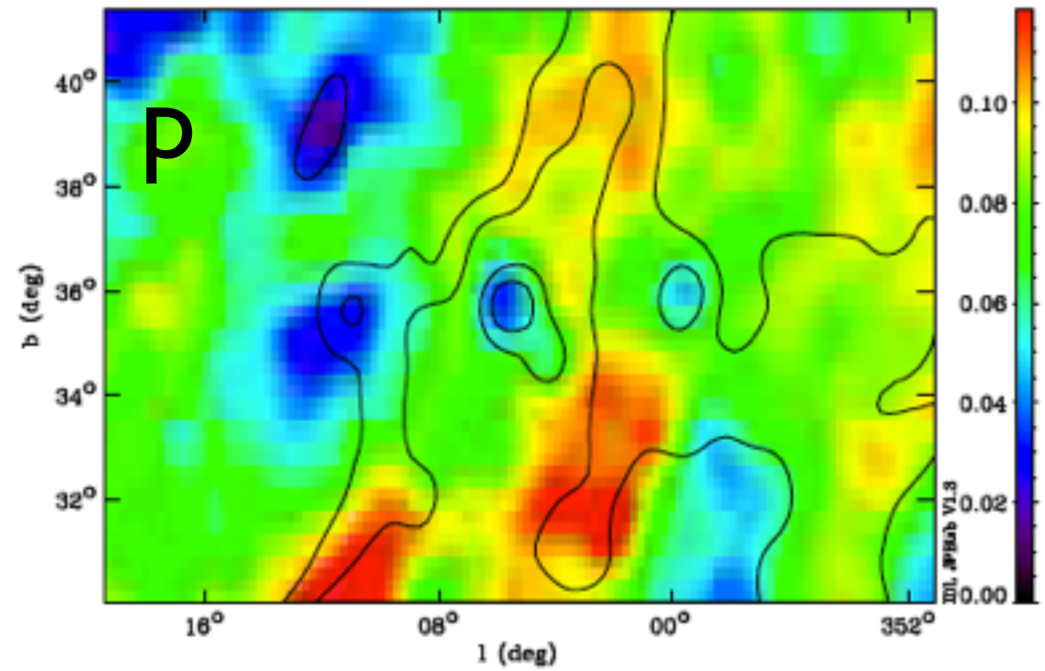
Highly polarized regions:
- pmax>18% at 353 GHz
- found in homogenous field regions
- often at edges of intensity structures

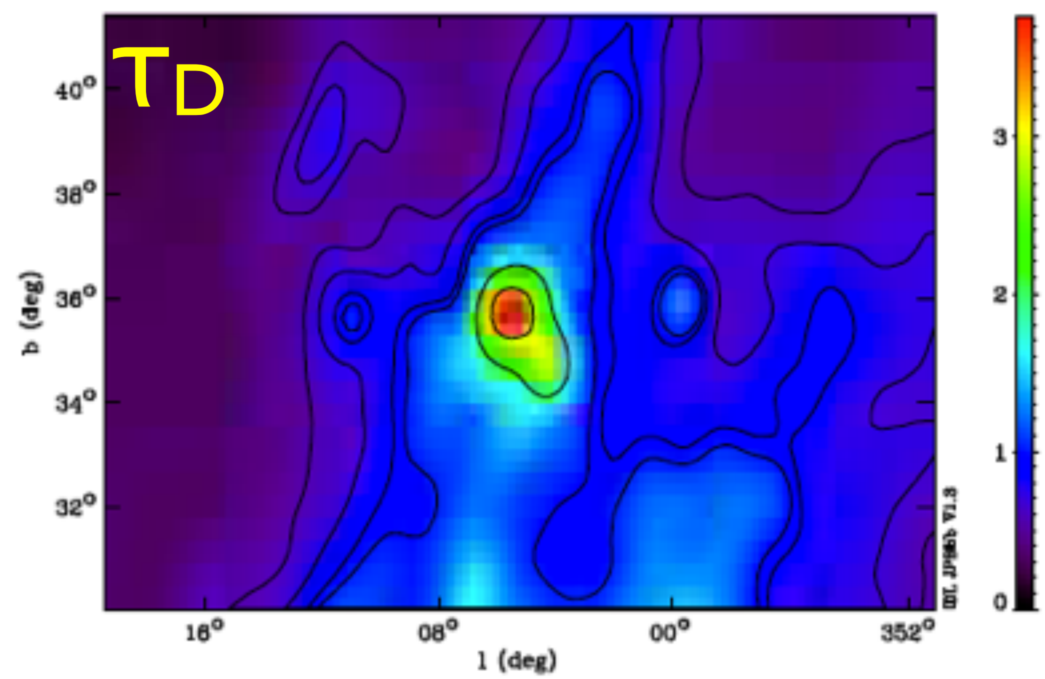
Some of these have little to no intensity counterparts

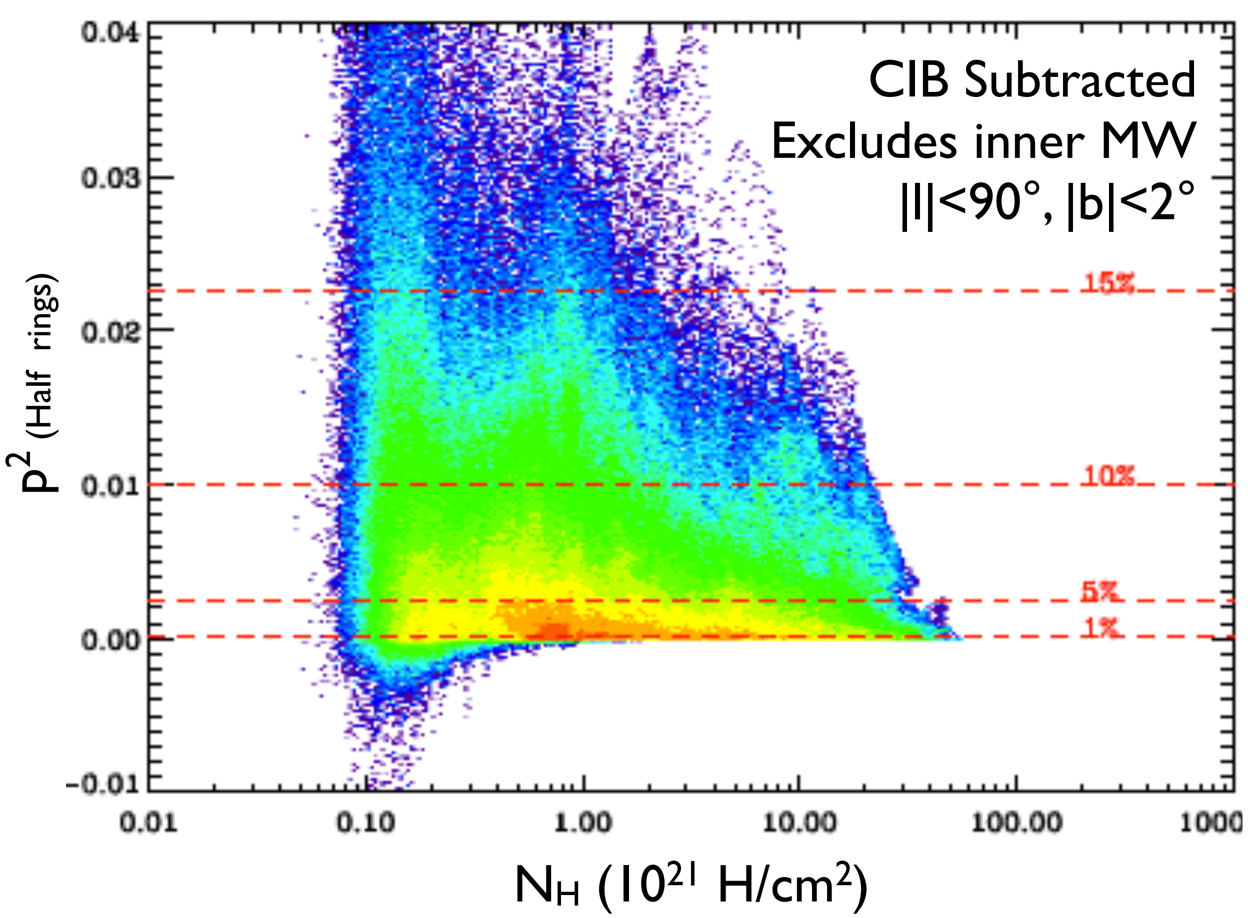
The sky looks different in polarization !!

- p shows general decrease with column density
- Consistent with ground observations
- Reasons for this likely to be either:
  - lack of dust alignment in opaque regions
  - B field tangling
- Large scatter probably due to field geometry

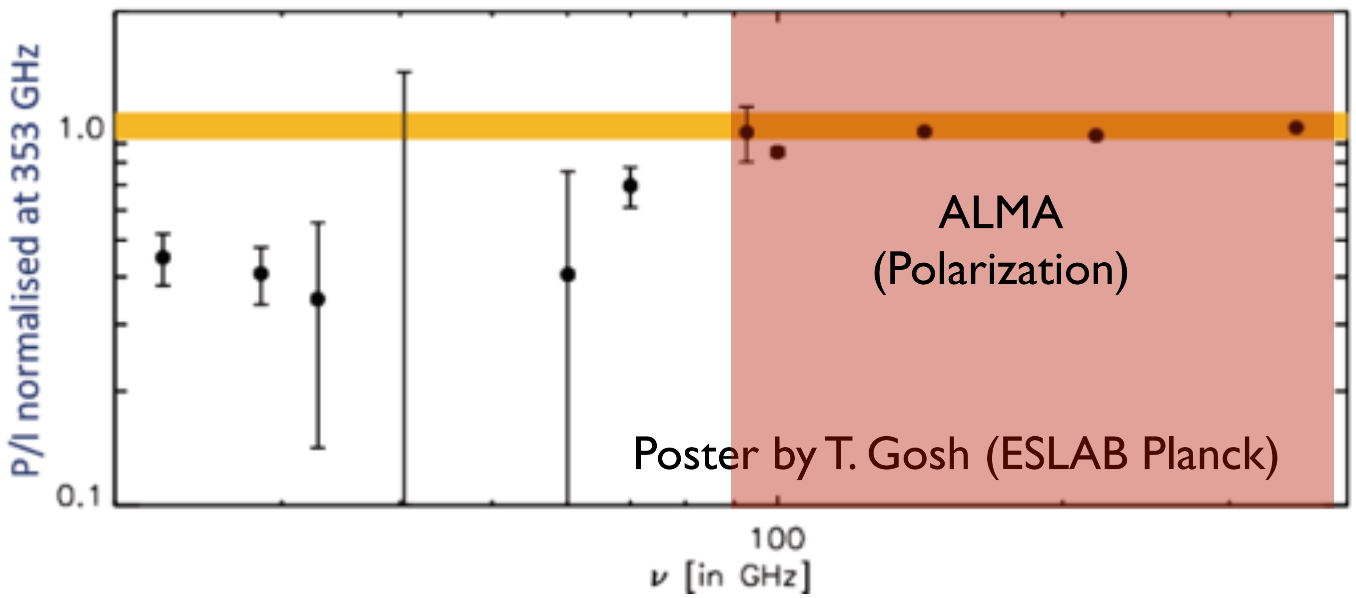
Example in L134

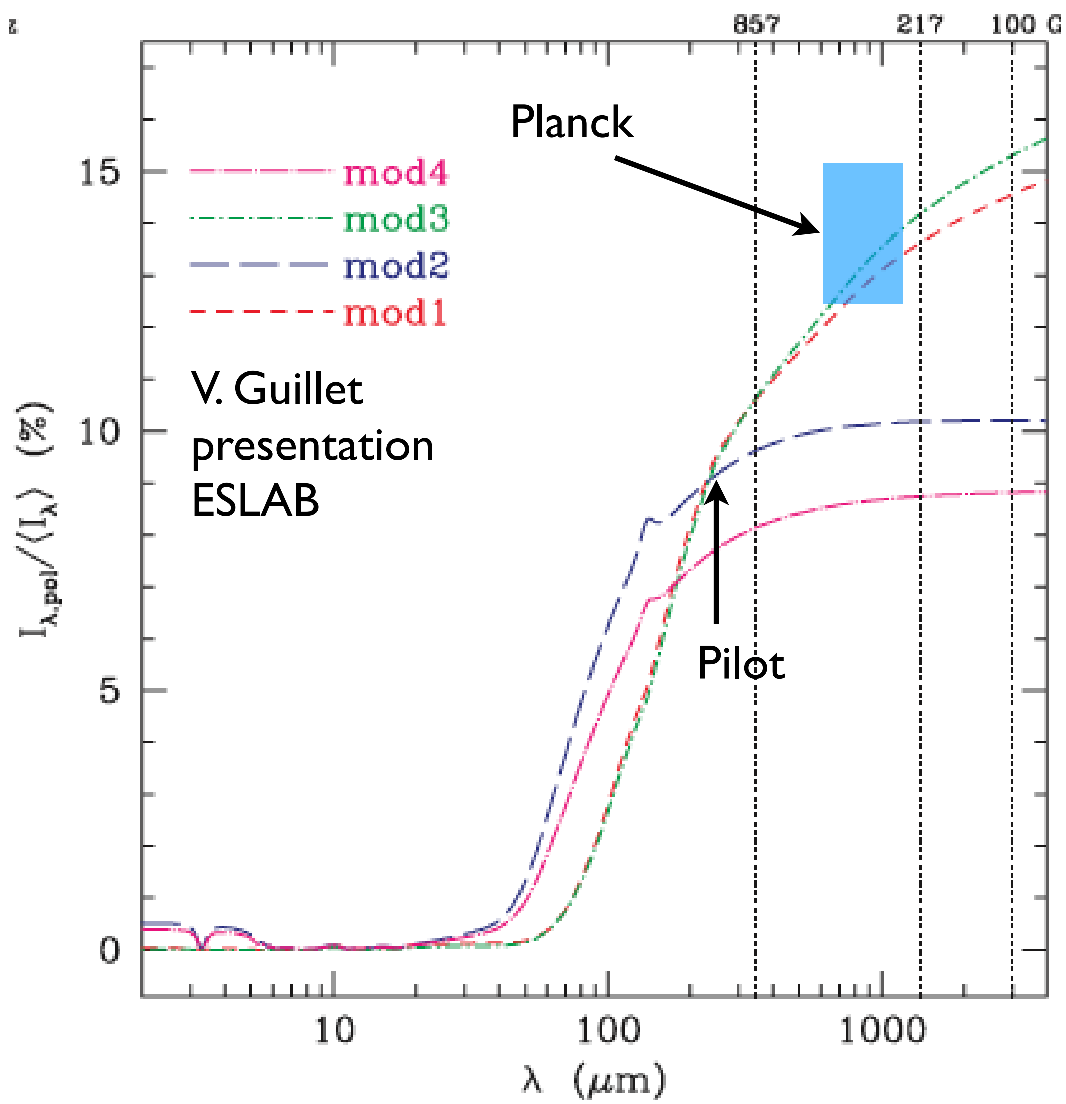






Planck Results: polarization frequency dependence ?





Dust polarization fraction seems frequency independent over Planck range (!)
(J. Aumont, T. Gosh presentation ESLAB)

Most likely indicates that a single grain component dominates emission and polarization

Large ratio of submm/visible polarization : $(p_{353GHz})/(p/\tau)_{Vis}$ =4.5
(V. Guillet presentation ESLAB)

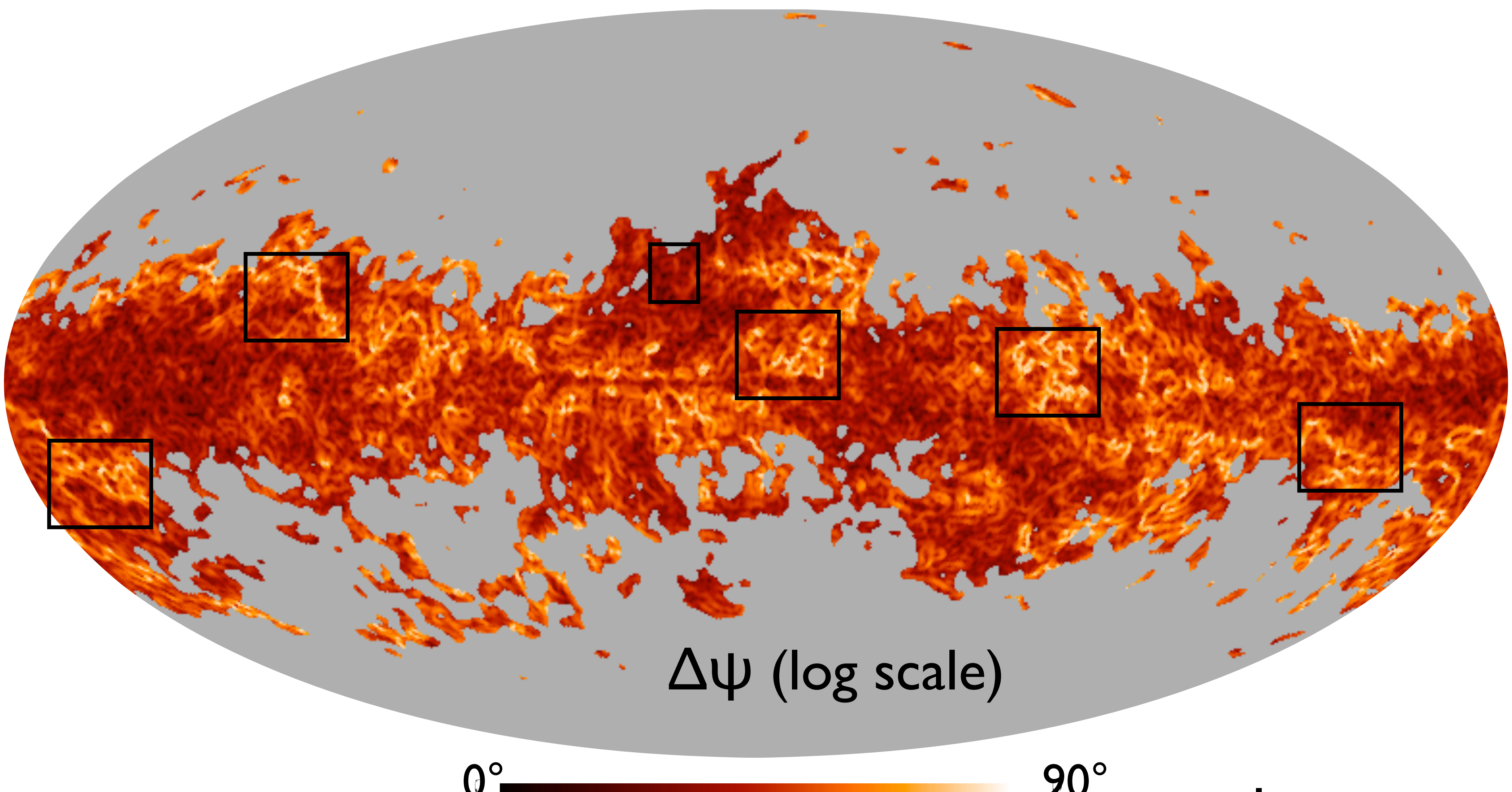
Combination difficult to explain with current dust models

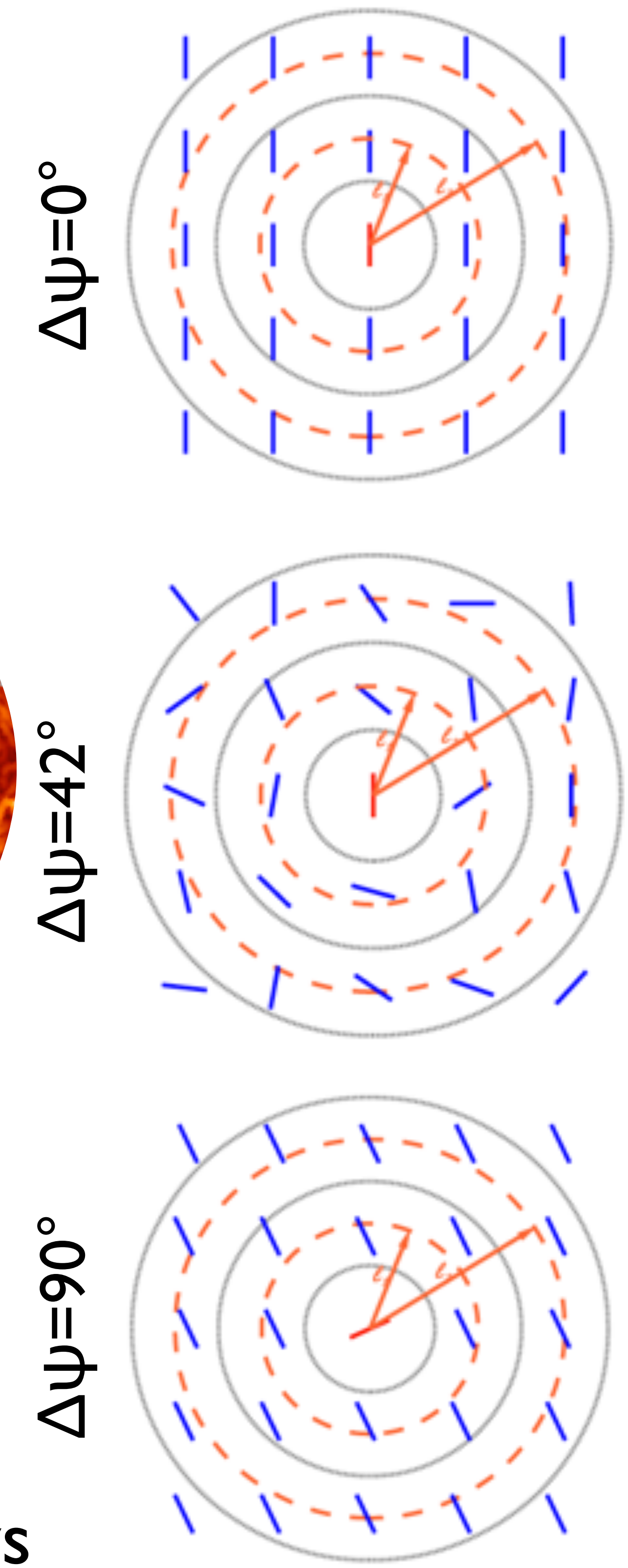
Angular Structure Function

Measure of polarization direction homogeneity at scale l :

$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi(\mathbf{r}) - \psi(\mathbf{r}+\mathbf{l}_i)\right]^2$$

(Hildebrand et al. 2009)

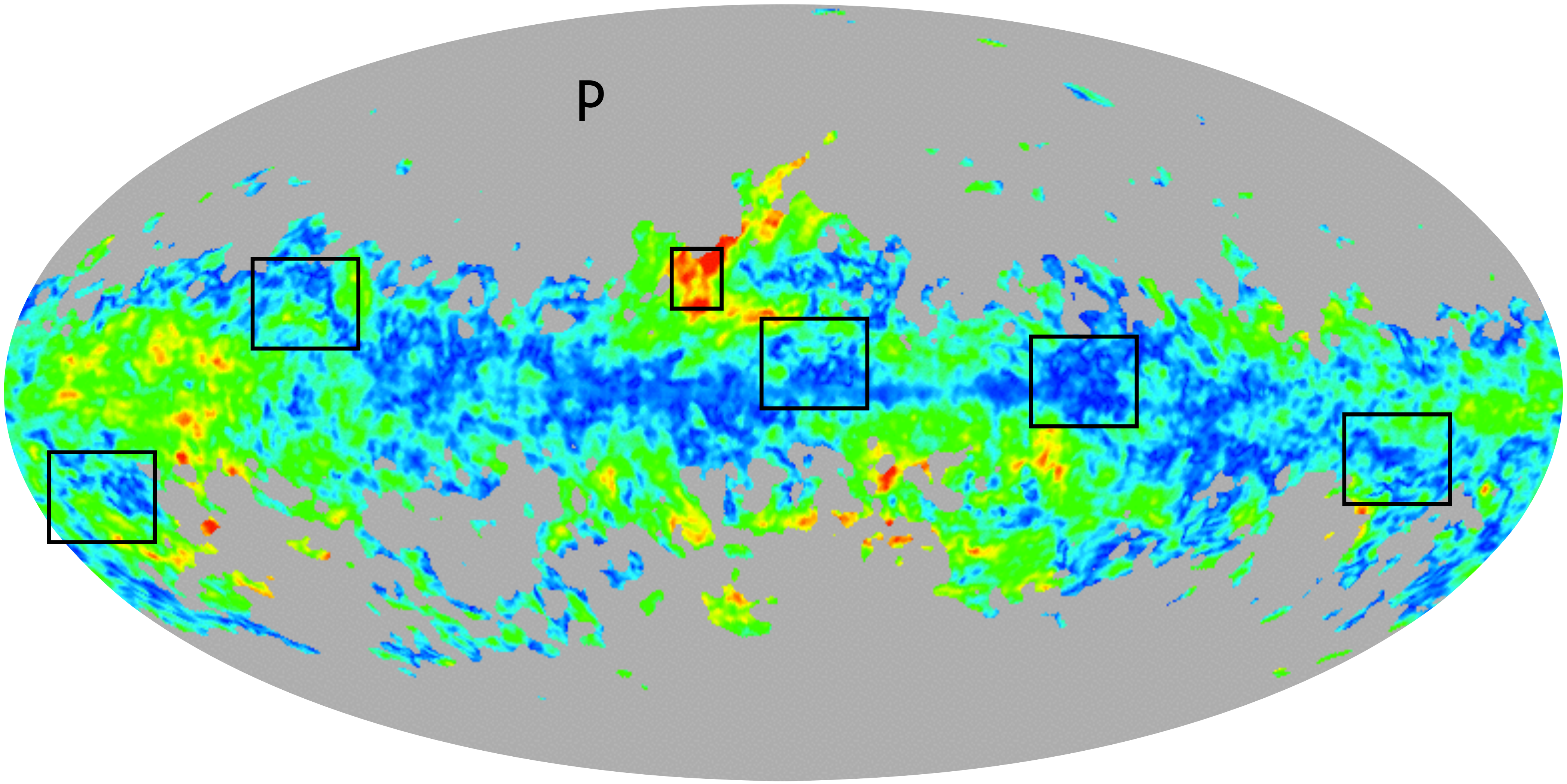


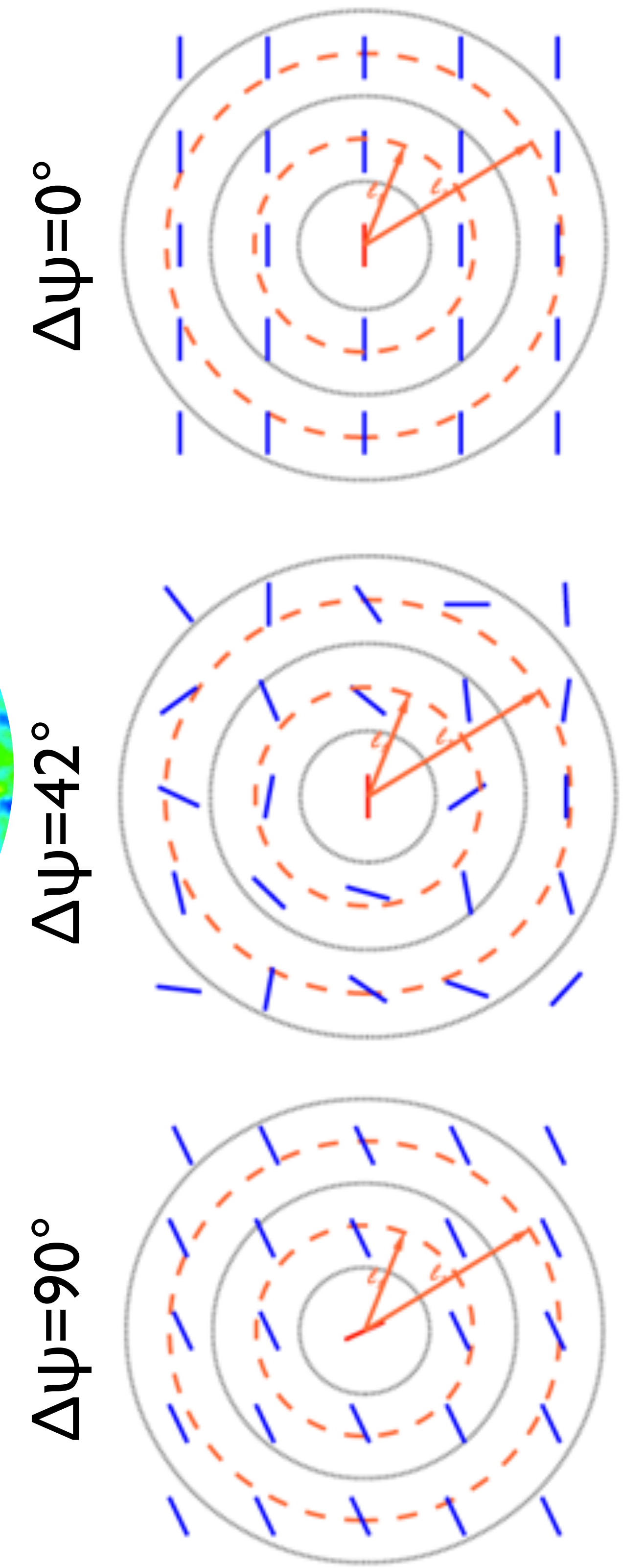


- Computed on Full survey on 1° resolution map at l=30'.
- Masked where SN(Δψ)<3 (uncertainties using MC)
- Similar maps for all 5 individual surveys and 2 half-ring surveys
- Spaghetti shaped regions of high polarization rotation

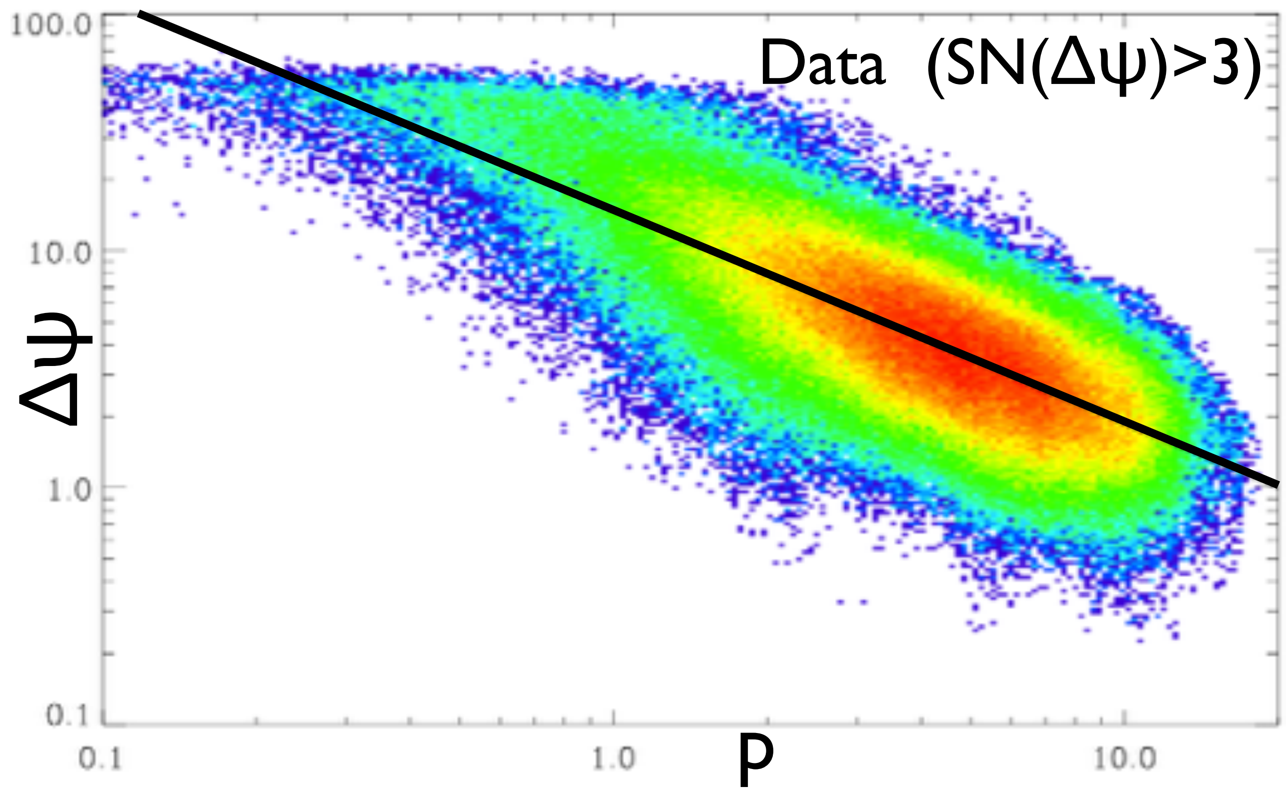
Measure of polarization direction homogeneity at scale l :

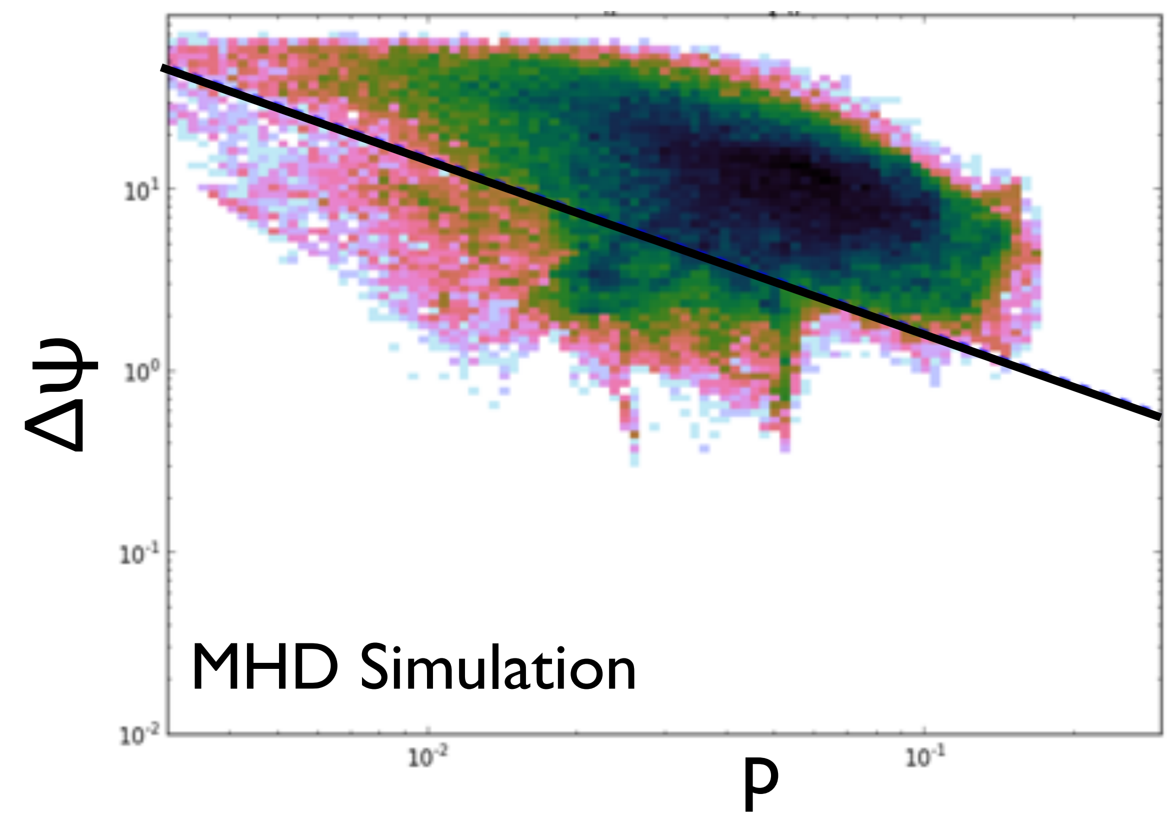
$$\Delta\psi^2(l) = \frac{1}{N}\sum_{i=1}^{N}\left[\psi(\mathbf{r}) - \psi(\mathbf{r}+\mathbf{l}_i)\right]^2$$ (Hildebrand et al. 2009)



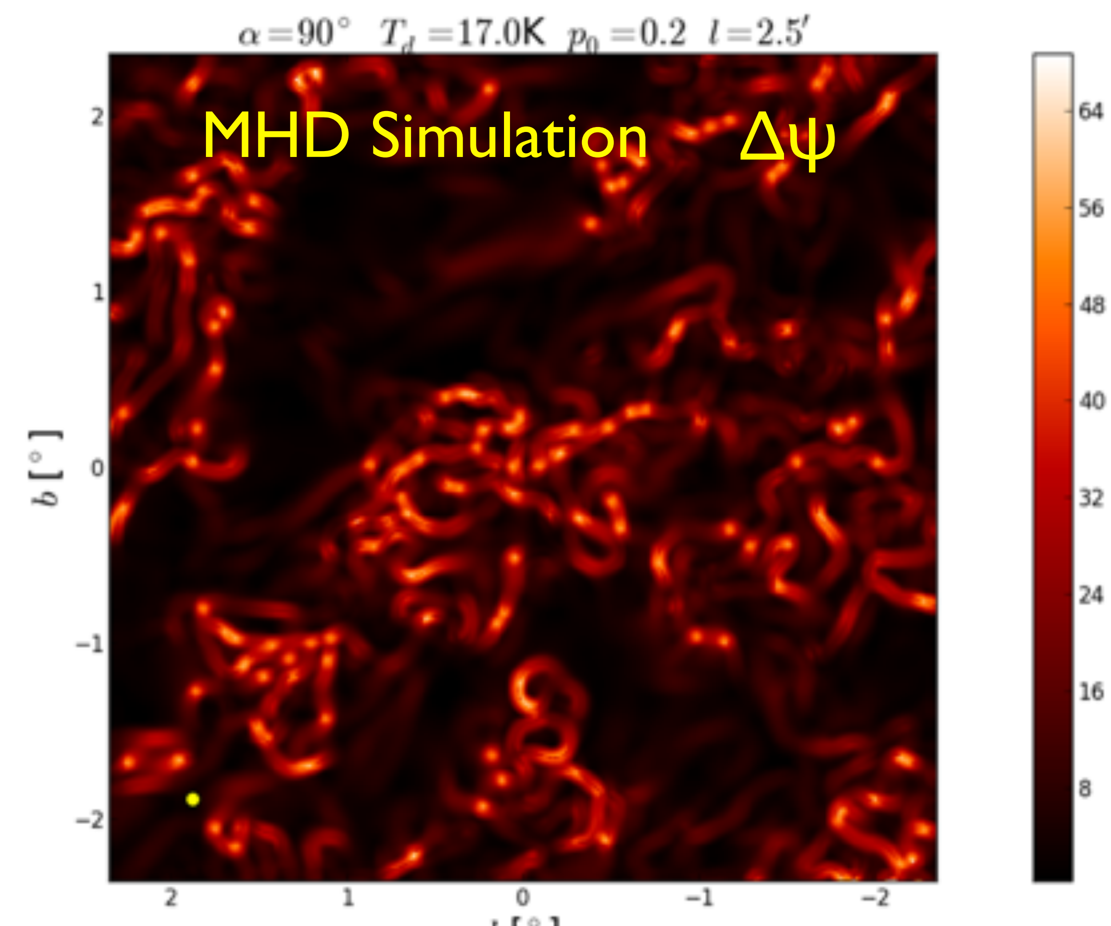


Angular Structure Function





- Δψ increases with scale l
- Δψ anticorrelates with p
- No clear correspondence with intensity filaments
- Similar behaviour observed in MHD simulations (see Poster by Levrier)
- MHD Δψ shows similar spaghetti structure
- Difference in absolute Δψ level can be due to fraction of diffuse emission in MHD cube

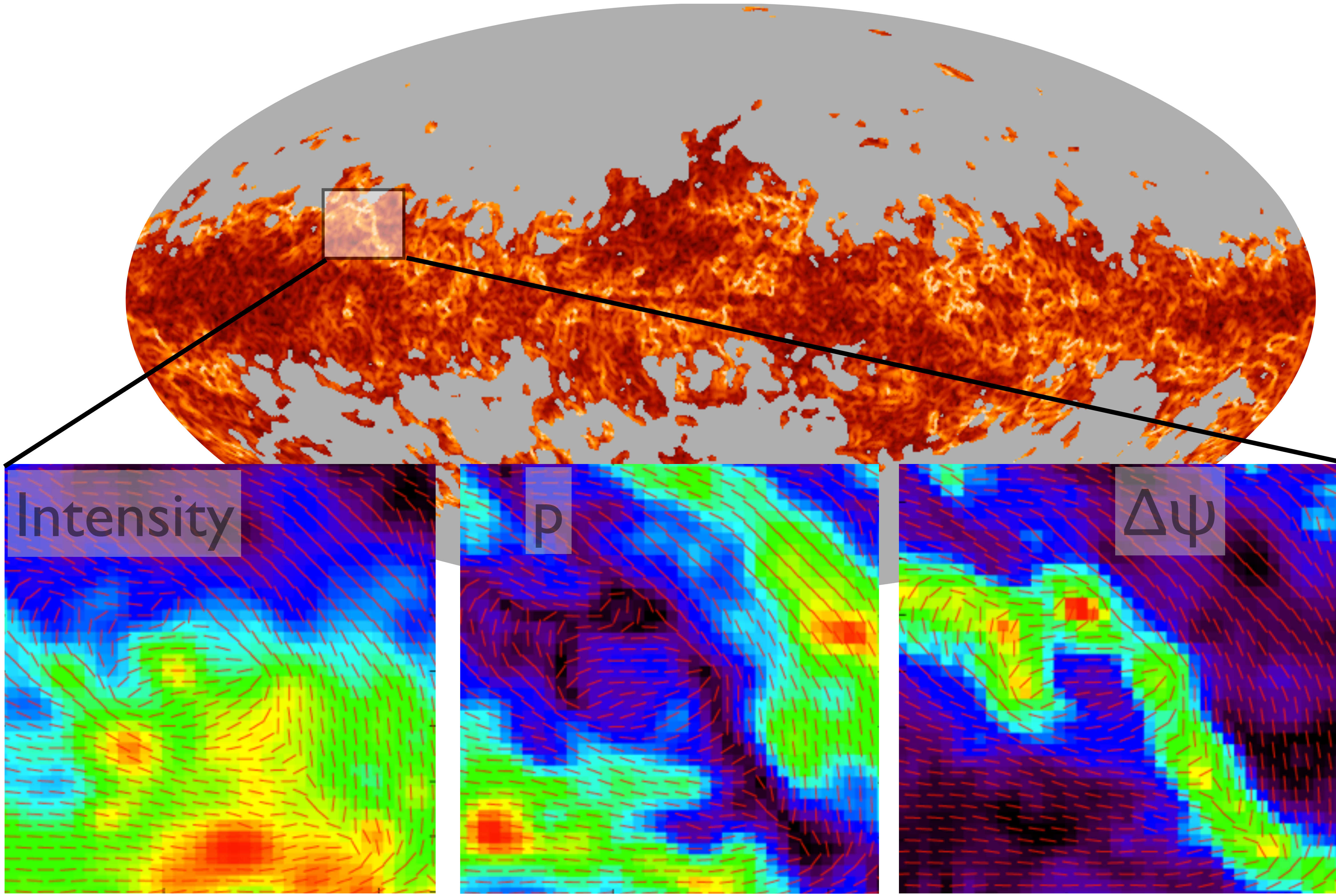


Angular Structure Function

Those structures avec very large: most likely nearby

They delineate the edges of regions with homogenous field of different directions

Similar to Synchrotron depolarization channels but different nature and positions



Conclusions

Observing dust with ALMA/Noema ?

Submm/mm <u>dust emission</u> is still full of mysteries :
- Investigate dust conditions in dense cores in our own MW
  (Have tried in cycle 1, not succesfuly ...)
- Investigate dust emissivity variations in other (more distant) galaxies
- What is the amount of Dark-Gas traced by dust in galaxies ?

<u>Dust linear polarization</u> offers a new dimension :
- Is polarization fraction truely constant with wavelength everywhere ?
- How does $p(N_H)$ behaves in different metalicity environments ?
  is the decrease due to B field structure or dust alignment ?
- What is the origin of dust depolarization spaghettis ?
- What is the magnetic field structure of different galaxies ?
  Only dust polarization traces B in the dense material.

Band	SPW1 (GHz)	SPW2 (GHz)	LO1 (GHz)	SPW3 (GHz)	SPW4 (GHz)
3	90.5	92.5	97.5	102.5	104.5
6	224.0	226.0	233.0	240.0	242.0
7	336.5	338.5	343.5	348.5	350.5

Such investigations cannot necessarily be obtained for free while observing lines.
Require dedicated ALMA/Noema observations.
Polarization will require observations at intermediate resolution (e.g. Nika2 30M)
In favor of high frequency bands for ALMA and polarization on NOEMA ...

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.