Planck's view on the Galactic Interstellar Medium

Planck Collaboration
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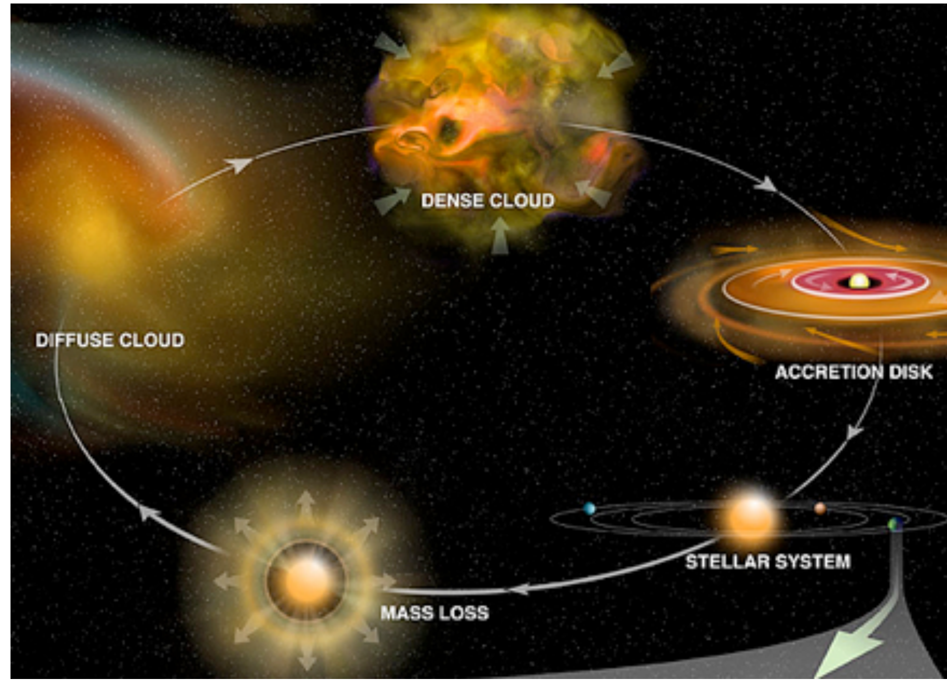
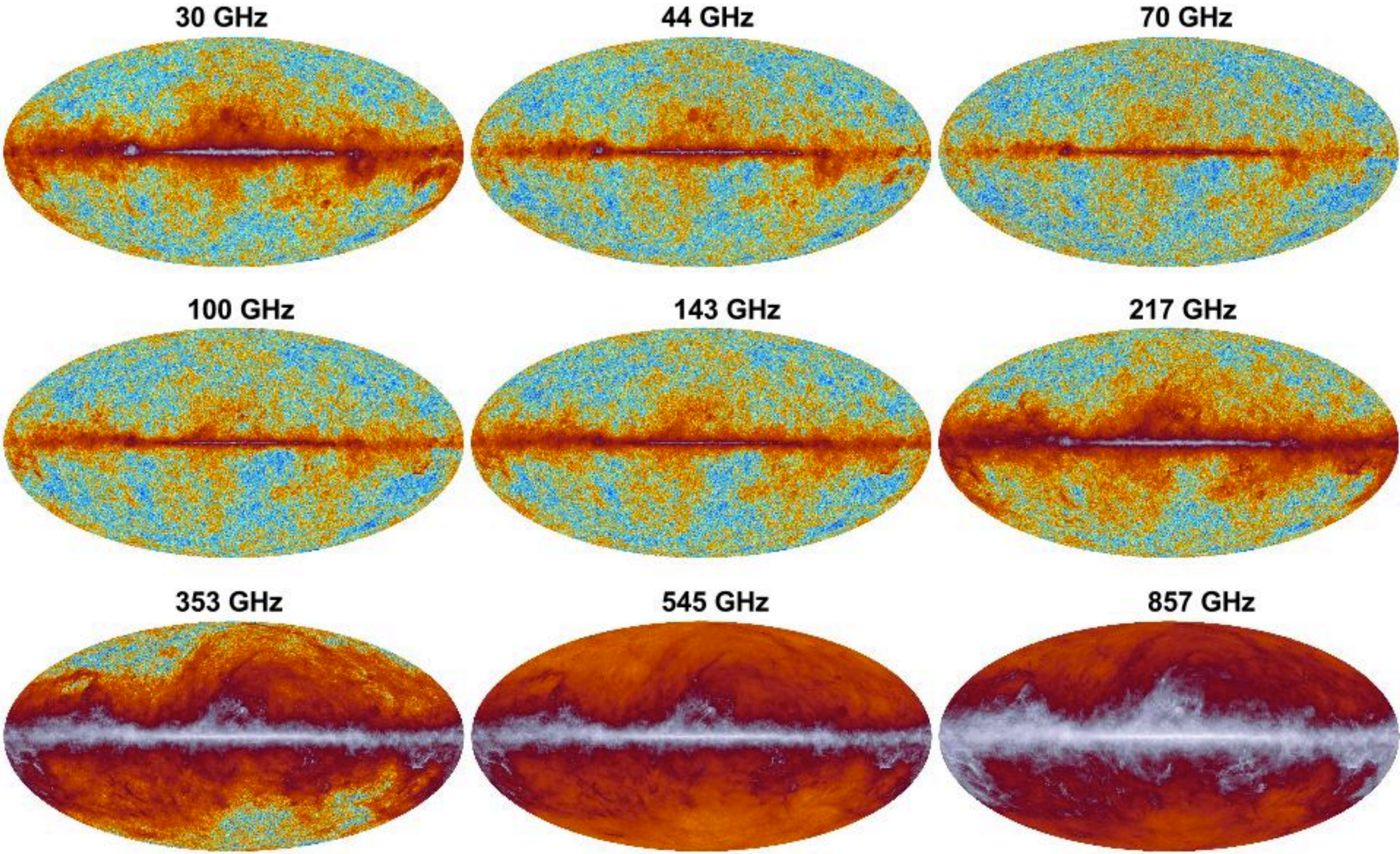
Interstellar Medium

- Interstellar gas: ions, atoms and molecules in the gas phase
- Interstellar dust: small solid particles mixed with the gas



✧ Energy in the ISM: thermal, kinetic (turbulent), gravitational, cosmic ray, magnetic and in photons (CMB, FIR and starlight) – in near equipartition.

The ISM probed by *Planck*



Outline

- Interstellar dust emission
  Tracing the structure of interstellar matter

- Anomalous Microwave Emission
  New perspective on interstellar matter

- Galactic (synchrotron) Haze
  Energetics of the Galactic centre

- Dust polarization
  Structure of the Galactic magnetic field

Dust emission

Planck and Herschel

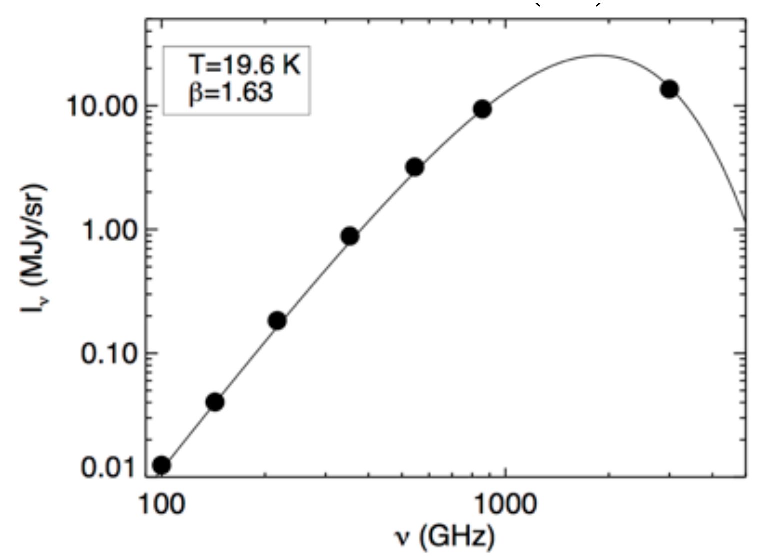
$$I_\nu = N_H \, B_\nu(T) \, \alpha \nu^\beta$$

Trace the structure of the ISM from all gas phases

$$\tau_{353} = \frac{I_{353}}{B_{353}(T)}$$

Spectral coverage to derive the opacity accounting for temperature variations

- All-sky map of dust optical depth
- Estimate mass of objects (of known distance)
- All-sky map of dust reddening



Dust optical depth

Tracer of N_H (dust-to-gas ratio, absorption cross-section)

Herschel – zooming in

Orion B – Gould Belt survey (André et al. 2010, Schneider et al. 2003)

Cygnus X - HOBBYS project (Motte et al. 2010, Henneman et al. 2012)

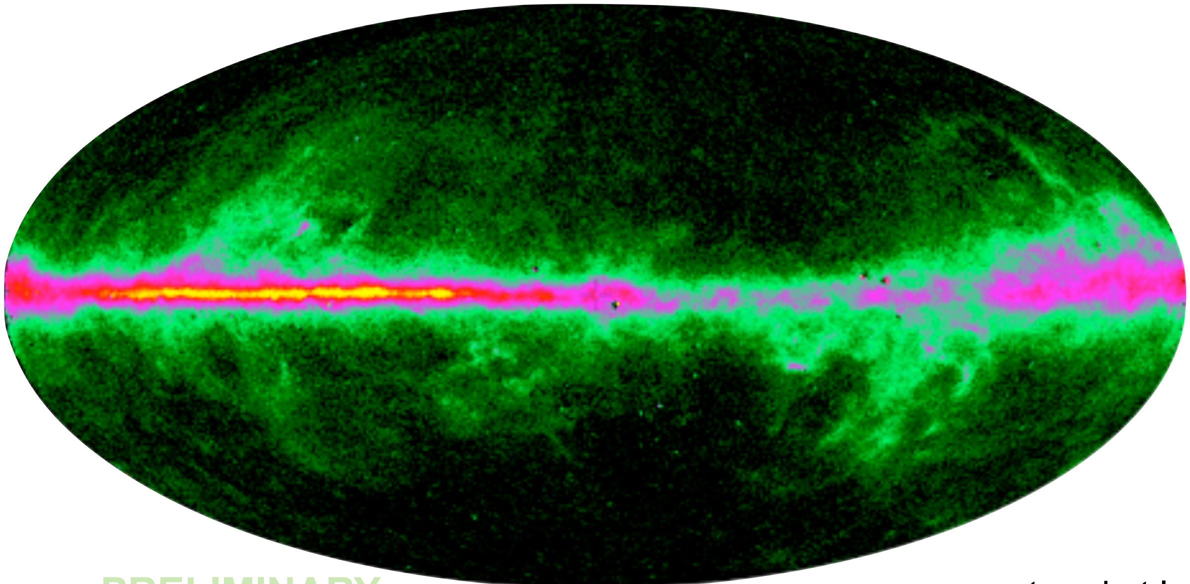
Radiance - Luminosity

Tracer of N_H (ISRF, absorption cross-section)

Observed dust temperature

Extinction from *Planck*: E(B-V)

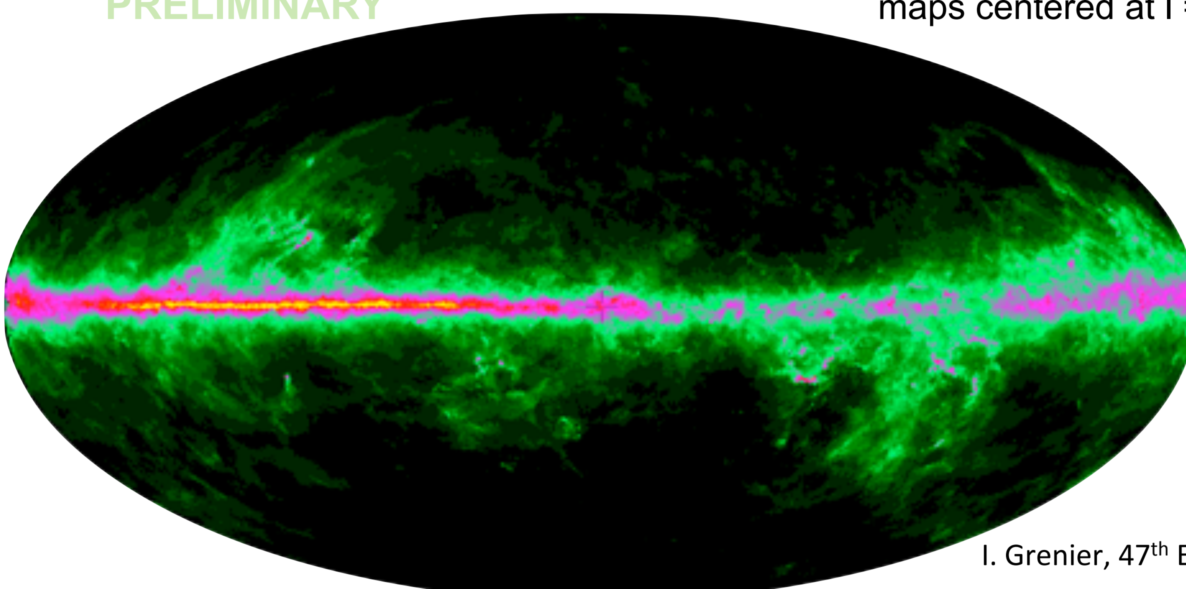
Synergies with Fermi



0.6 - 7 GeV photons
Fermi LAT diffuse model, in prep.

PRELIMINARY

maps centered at l = 270°



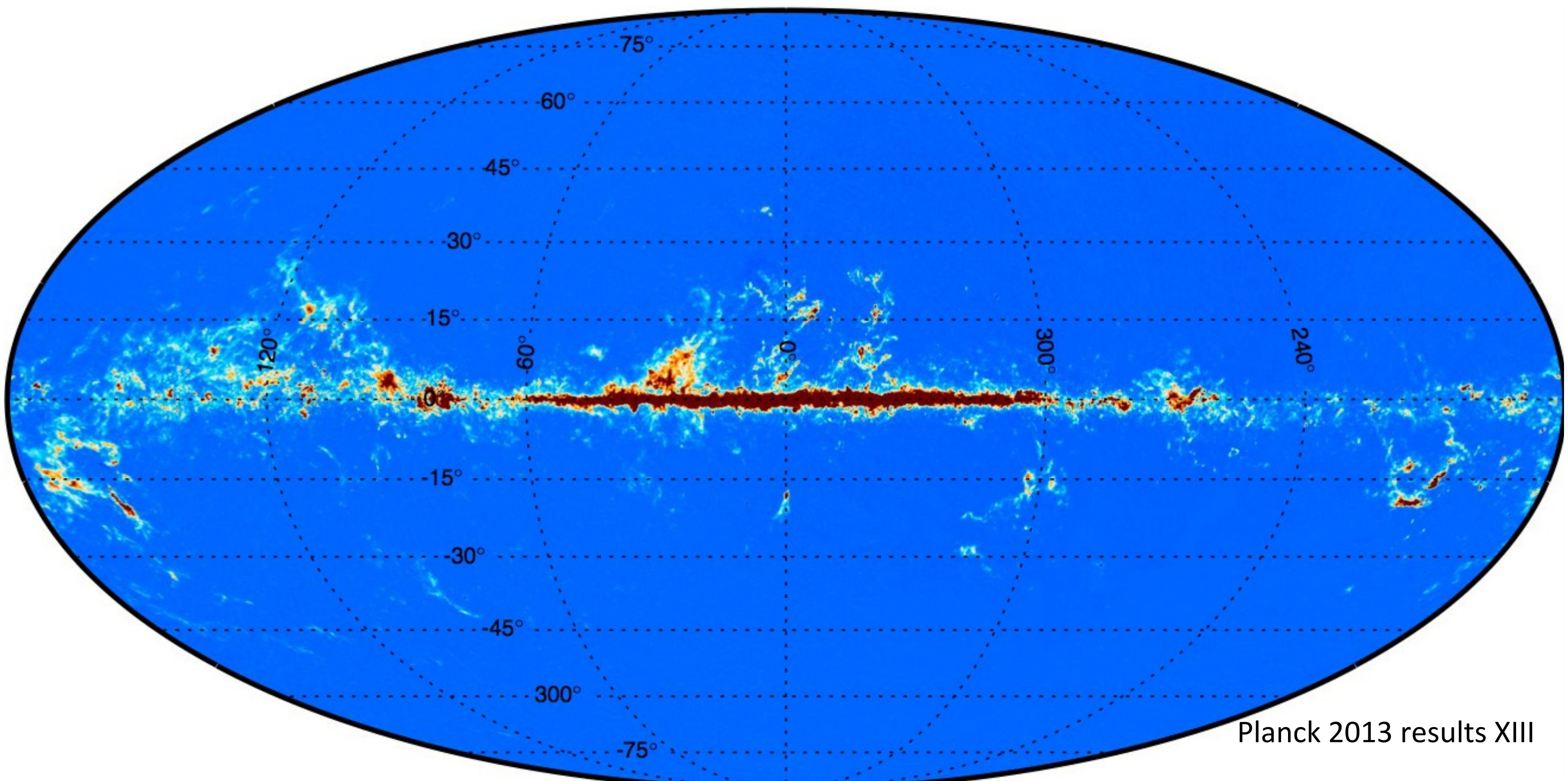
dust optical depth
Planck et al. 2013, in prep

I. Grenier, 47th ESLAB symposium 2013

"Dark" gas

Transition between bright-HI and bright-H_2 gas: opaque HI and H_2 gas with little or no CO (predicted theoretically by van Dishoeck & Black 1988)

Discovered as an excess in dust emission above the neutral and molecular gas tracers:
$\tau = a_{HI}\, N_{HI} + a_{CO}\, W_{CO}$ + **dark gas** (e.g. Blitz et al. 1990, Grenier et al. 2005, Lee et al. 2012)



Planck 2013 results XIII

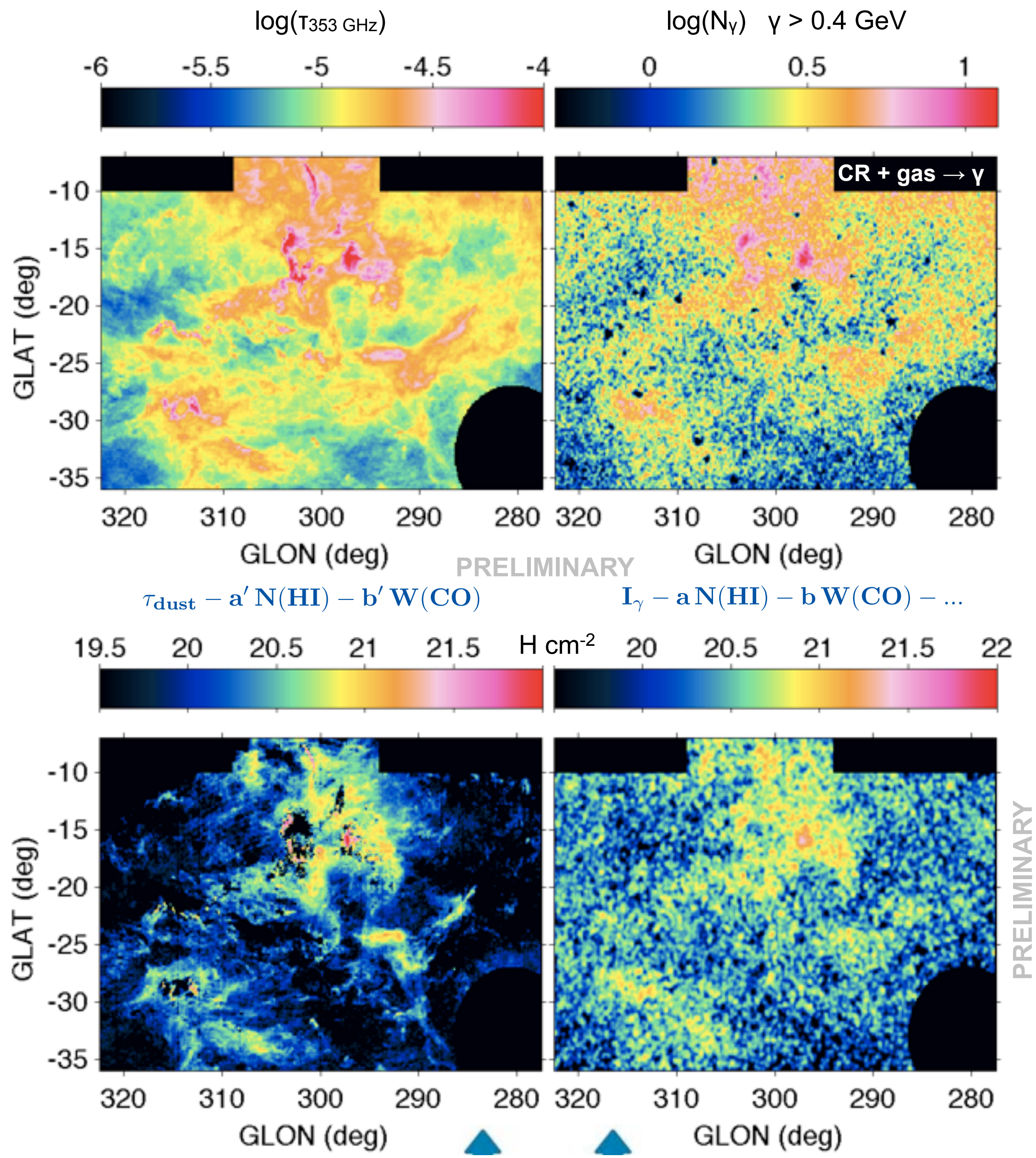
“Dark” gas – *Planck* and Fermi

Chamaeleon region:

- Dark gas contains ¼ of the HI mass and twice the CO-bright mass

→ Important constituent of the ISM!

- Located between the diffuse HI and the compact CO gas



I. Grenier, 47th ESLAB symposium 2013
Planck Collaboration (in prep.)

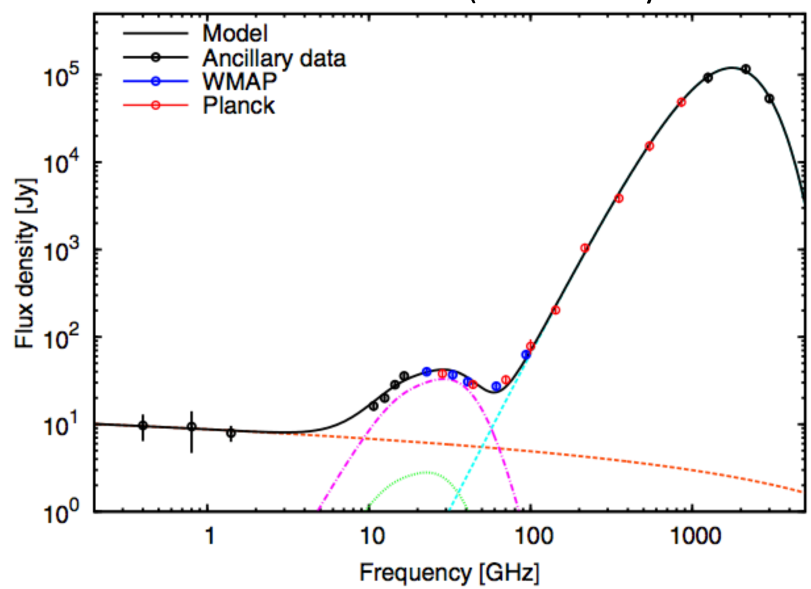
Anomalous Microwave Emission

Kogut (1996), Banday et al. (2003), Davies et al. (2006)

- Additional source of diffuse radio emission at frequencies ~ 10-60 GHz
  → Most likely electric dipole radiation from spinning dust grains - First predicted by W.C. Erickson in 1957

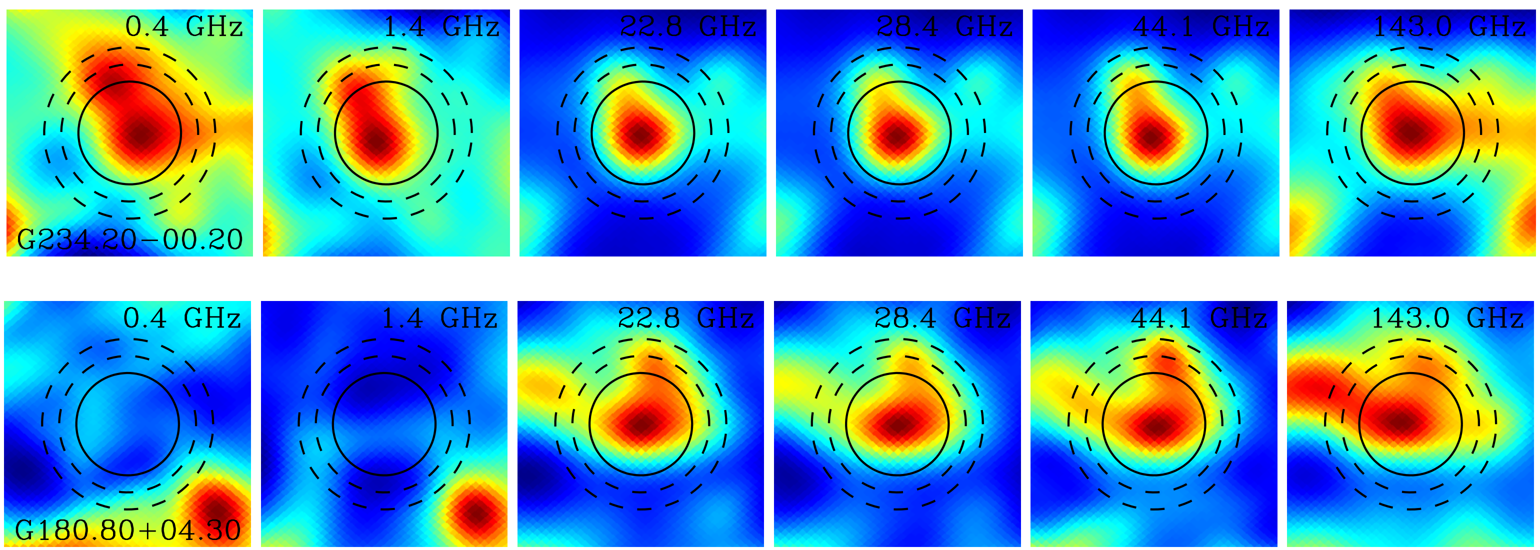
- Strongly correlated with far-infrared emission
- Does not appear to be strongly polarized
- Observed in a range of environments
- Before *Planck* only a very few convincing detections in star-forming regions
- Planck intermediate results XII studies AME in the diffuse ISM
- Planck intermediate results XV studies AME in individual objects (HII regions, dust clouds)

Perseus molecular cloud (Planck early results XX)

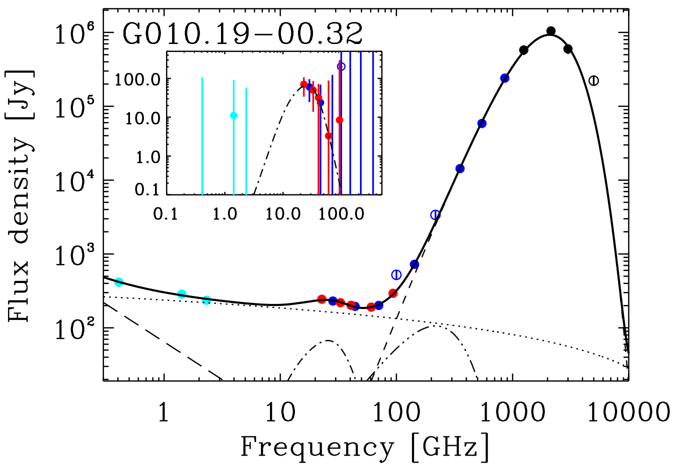


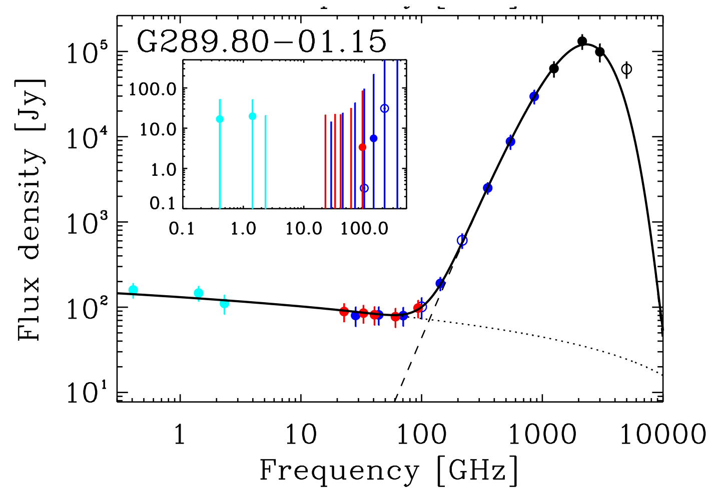
AME – Planck intermediate results XV

- Sample of **98 sources** (not a complete sample!)
- SEDs constructed from aperture photometry, combining Planck with WMAP, IRAS/DIRBE, low frequency radio data (at 1 degree resolution)
- Fit simple models of optically thin free-free, CMB, thermal dust, synchrotron and spinning dust

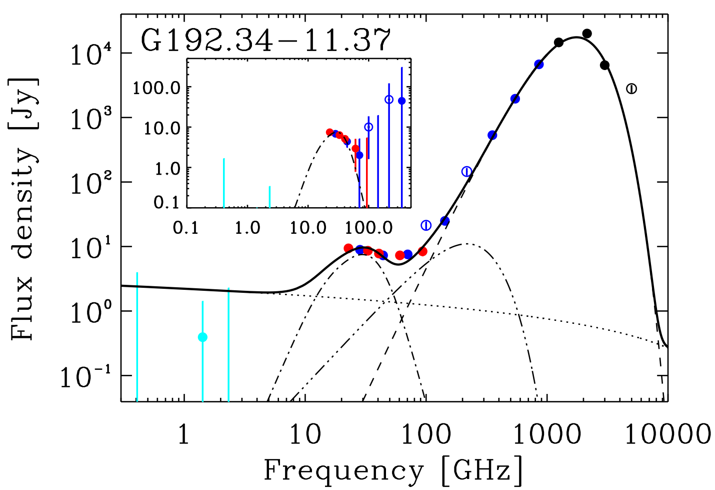


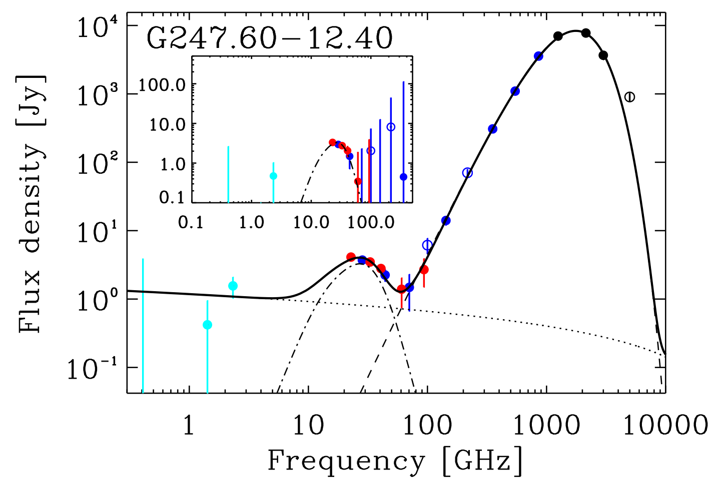
AME – Planck intermediate results XV





A significant number of sources (28) have a very strong "detection" of excess emission at ~40-60 GHz that is well-fitted by spinning dust emission



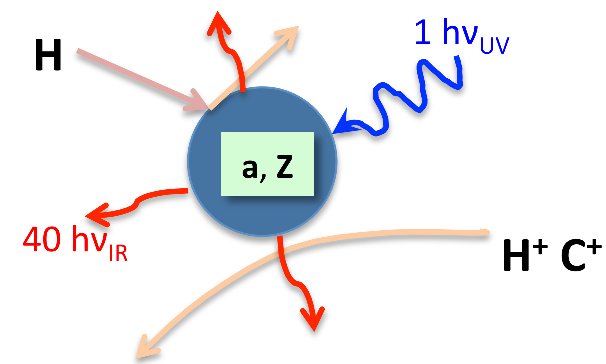


AME – Physical model

- SpDUST (Ali-Haïmoud et al. 2009, Silsbee et al. 2011)
- Hoang et al. (2010,2011)

  Grain properties and dipole moments – still with many simplifications

  Excitation of the particles: collisions, plasma drag, IR photons



Derived parameters include **density** and **ISRF**, also the dipole moment of PAHs

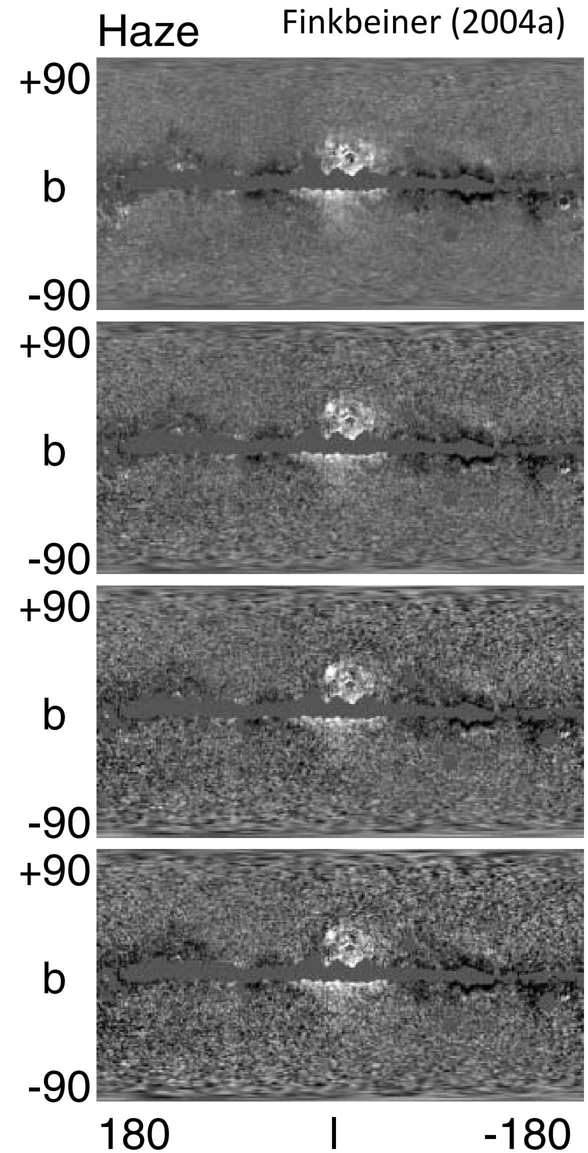
Spinning dust provides a potential diagnostic for interstellar dust properties – PAH abundance gradients
Small grains are important in the ISM (heating, chemistry, etc)

The Galactic Haze

"Haze"

- distinct component of diffuse emission, roughly centred on the Galactic centre and extending to |b|~35° and |l|~15°
- discovered by Finkbeiner (2004a) using WMAP data
- originally characterized as free-free emission due to its hard spectrum ($\sim\nu^{-2.1}$)

- Dobler & Finkbeiner (2008) re-estimated the spectral index →softer than free-free but harder than synchrotron elsewhere in the Galaxy



The Galactic Haze

Dobler et al. (2010) discovered gamma-ray counterpart with Fermi
→ **synchrotron nature** → electrons with hard spectrum

Proposed interpretations?

- Enhanced SN rates (Bierman et al. 2010)
- Galactic wind (Crocker & Aharonian 2011)
- Jet generated by accretion onto a central black hole (Guo & Mathews 2011, Guo et al. 2011)
- Co-annihilation of dark matter particles in the Galactic halo (Finkbeiner 2004b, Dobler et al. 2011)

With Planck we not only study the Haze with an independent experiment but also determine a more accurate spectrum.

The Haze with *Planck*

Two component separation methods:

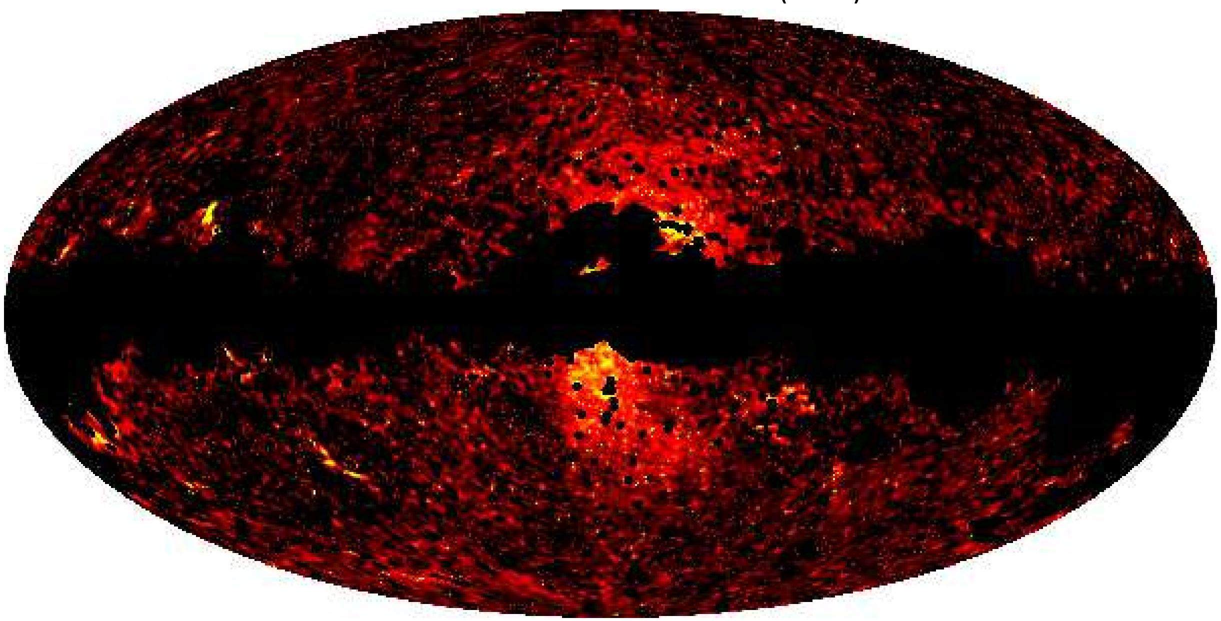
- Template fitting – needs CMB subtraction → Planck high frequency CMB estimation
- Gibbs sampling analysis (Commander) - It solves for the CMB simultaneously, with stronger priors on its parameterisation

Planck only and *Planck*+WMAP:

- Haze detected in the *Planck* maps
- Morphology and spectrum of the haze consistent between the two datasets

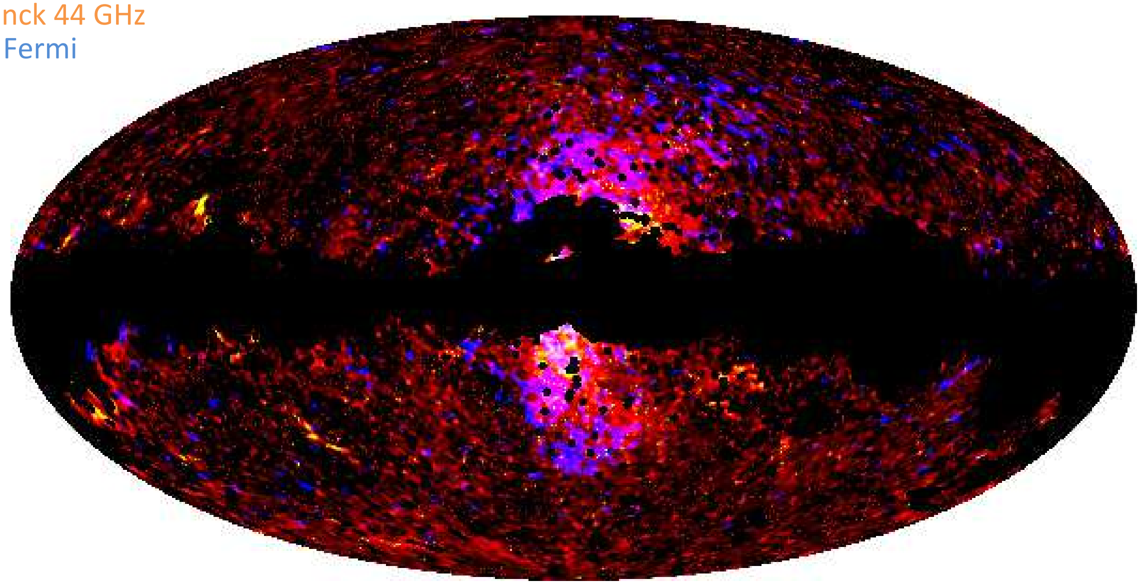
Planck intermediate results IX (2013)

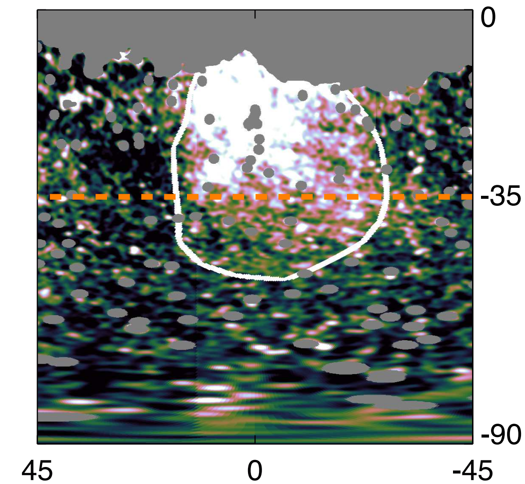
Power-law spectrum **β=-2.55±0.05**



Synchrotron emission elsewhere β=-3.1

Planck Haze and the Fermi bubbles



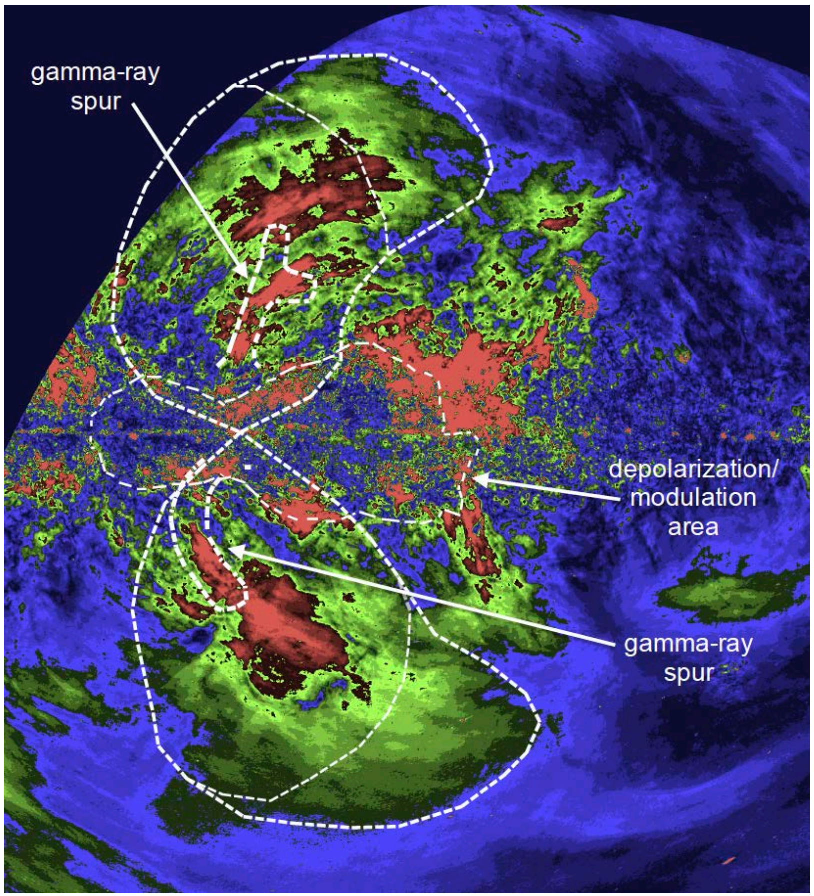


- Fermi bubbles consistent with IC from a population of electrons with energy spectrum required to reproduce β=-2.55, dN/dE α $E^{-2.1}$
- Strong spatial coincidence between Planck haze and Fermi bubbles at low latitude, b~35°

→ The magnetic field within the haze decreases ~5 kpc away from the Galactic plane, whereas the CR distribution extends to ~10 kpc

Polarization of the Haze

Planck **LFI** data → looking for the haze in polarization…



SPASS (Carretti et al. 2013): survey of the polarized emission at 2.3 GHz

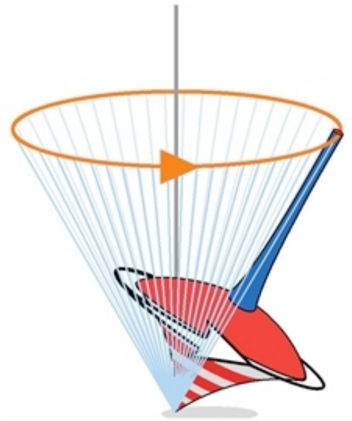
- Two giant linearly polarized radio lobes emanating from the Galactic centre
- Closely related to the Fermi bubbles

→ ***Star-formation driven origin:*** emission in the lobes is generated in the GC and transported by the magnetic field

Dust polarization

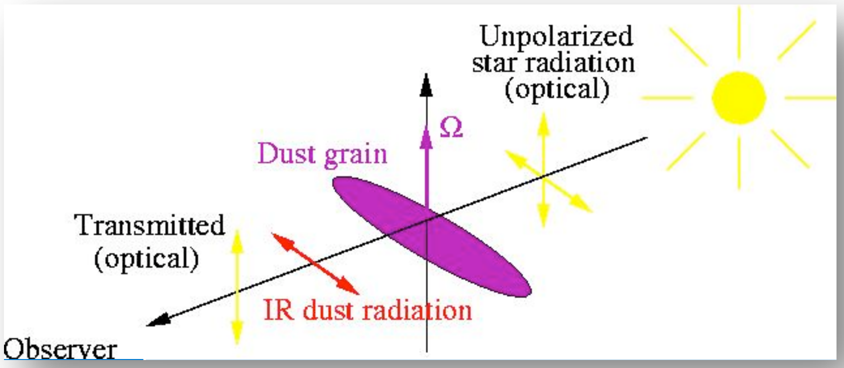
Dust polarization holds information on

- Dust properties & dust alignment efficiency:
- Which dust components contribute to polarization?
- Where in the ISM are grains aligned and with what efficiency?



- Galactic magnetic field:

What is the interplay between the structure of the magnetic field and that of interstellar matter?



Dust polarization

***Planck* gives, for the first time, the possibility to study the Galactic magnetic field through a tracer of the interstellar matter**

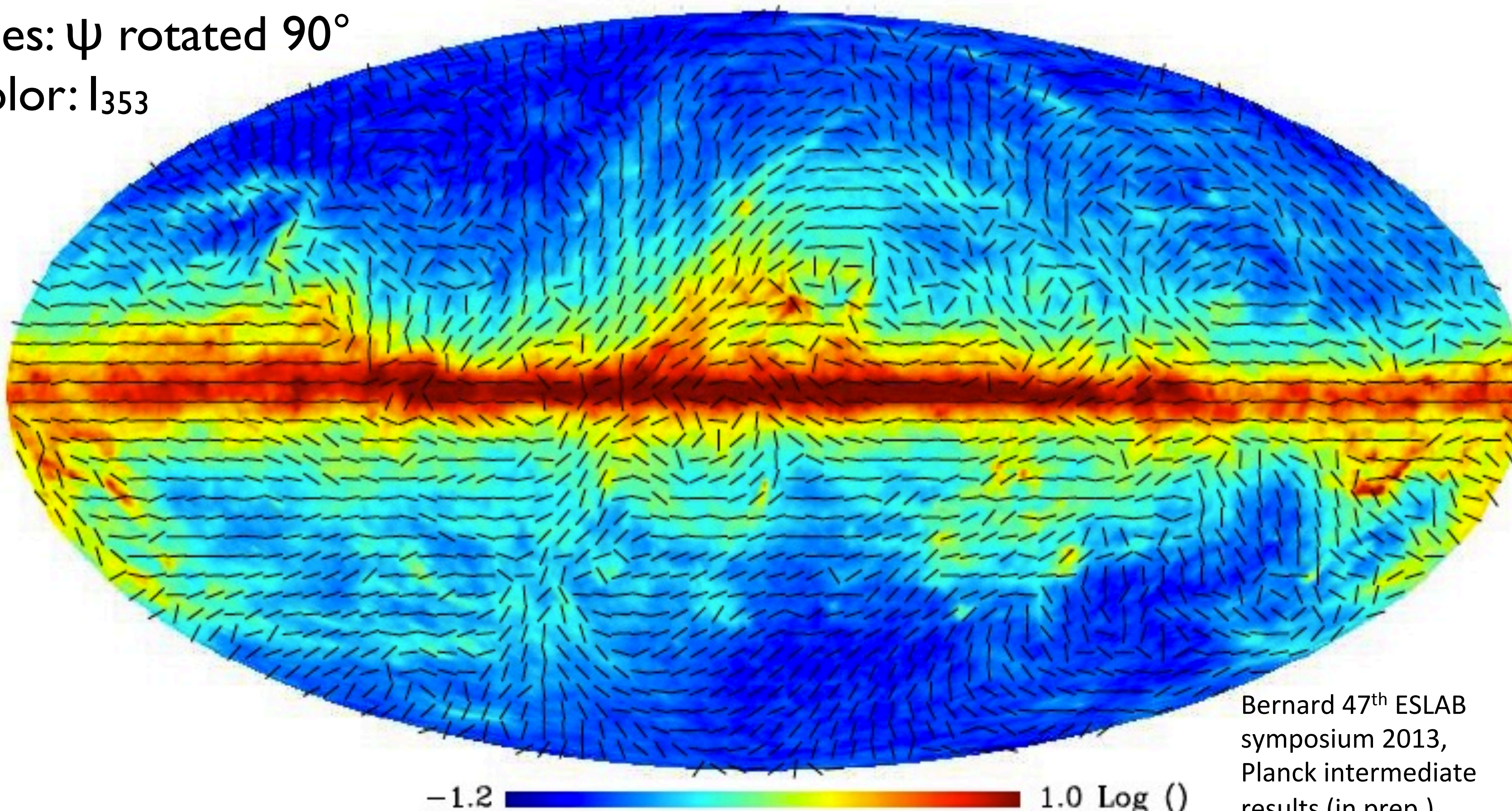
- **Synchrotron emission**: traces the field over the whole volume of the Galaxy including the thick disk and halo. The volume emissivity scales as $n_{cr} \times B_{\perp}^2$
- **Faraday Rotation**: traces the amplitude of BII in ionized gas. The RM scales as $\int n_e \times B_{//} \, ds$
- **Dust polarization**: traces the magnetic field over the thin disk where matter is concentrated. The volume emissivity scales as n_H. The observed polarization is the sum of two contributions:
  - The warm medium (WIM/WNM) with a significant volume filling factor (>0.2). This contribution traces the mean direction/structure of the field averaged along the line of sight.
  - The cold medium (CNM) with a small volume filling factor (< 0.01). This contribution traces the direction/structure of the field within localized clouds.

Dust polarization

B field direction at 353 GHz, 1° resolution

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

lines: ψ rotated 90°
color: I_{353}

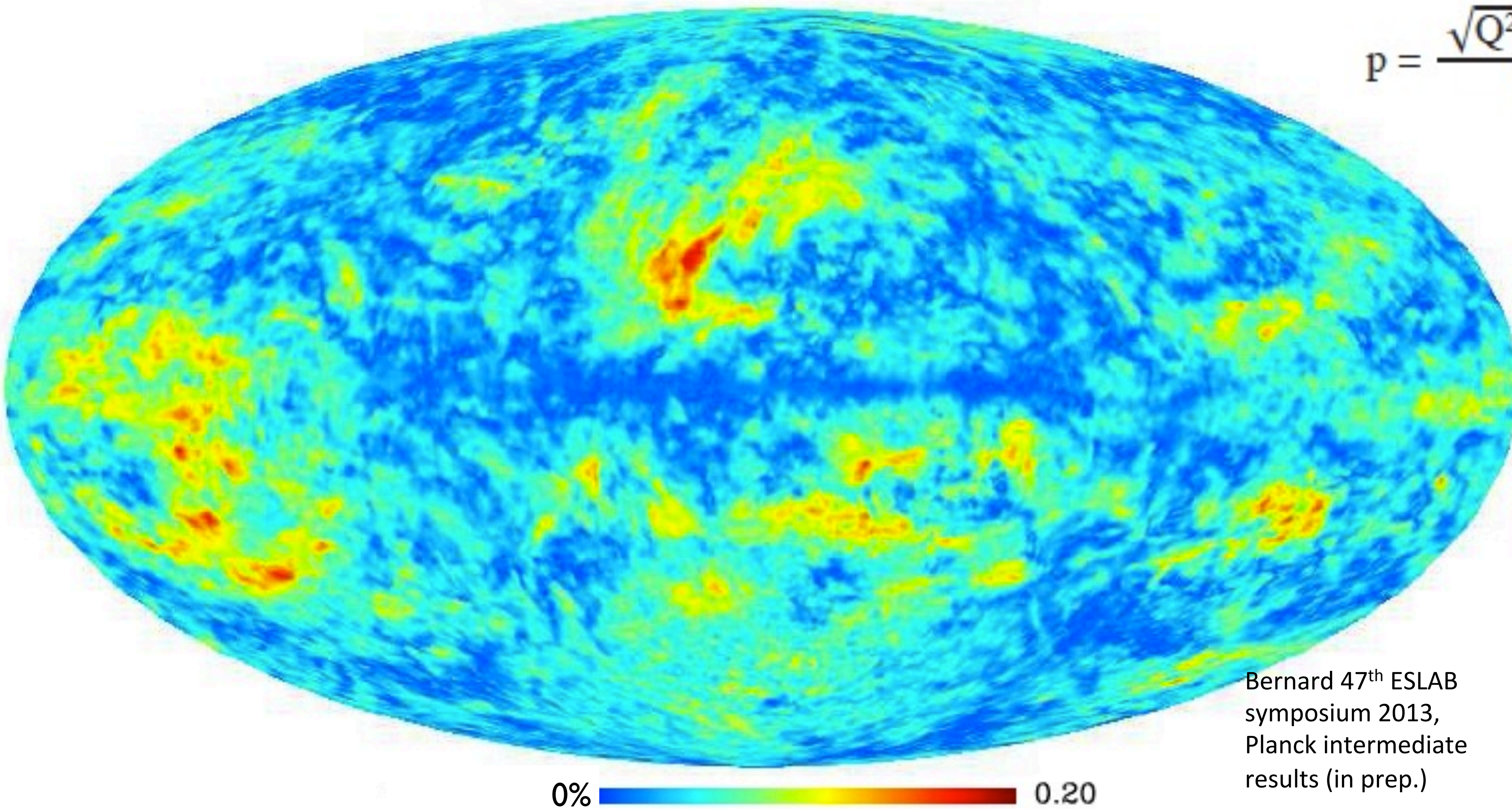


Bernard 47th ESLAB symposium 2013, Planck intermediate results (in prep.)

- Large scale direction consistent with magnetic field in the plane of the Galaxy.
- Field homogeneous over large regions, with strong polarization degree.

Degree of dust polarization

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



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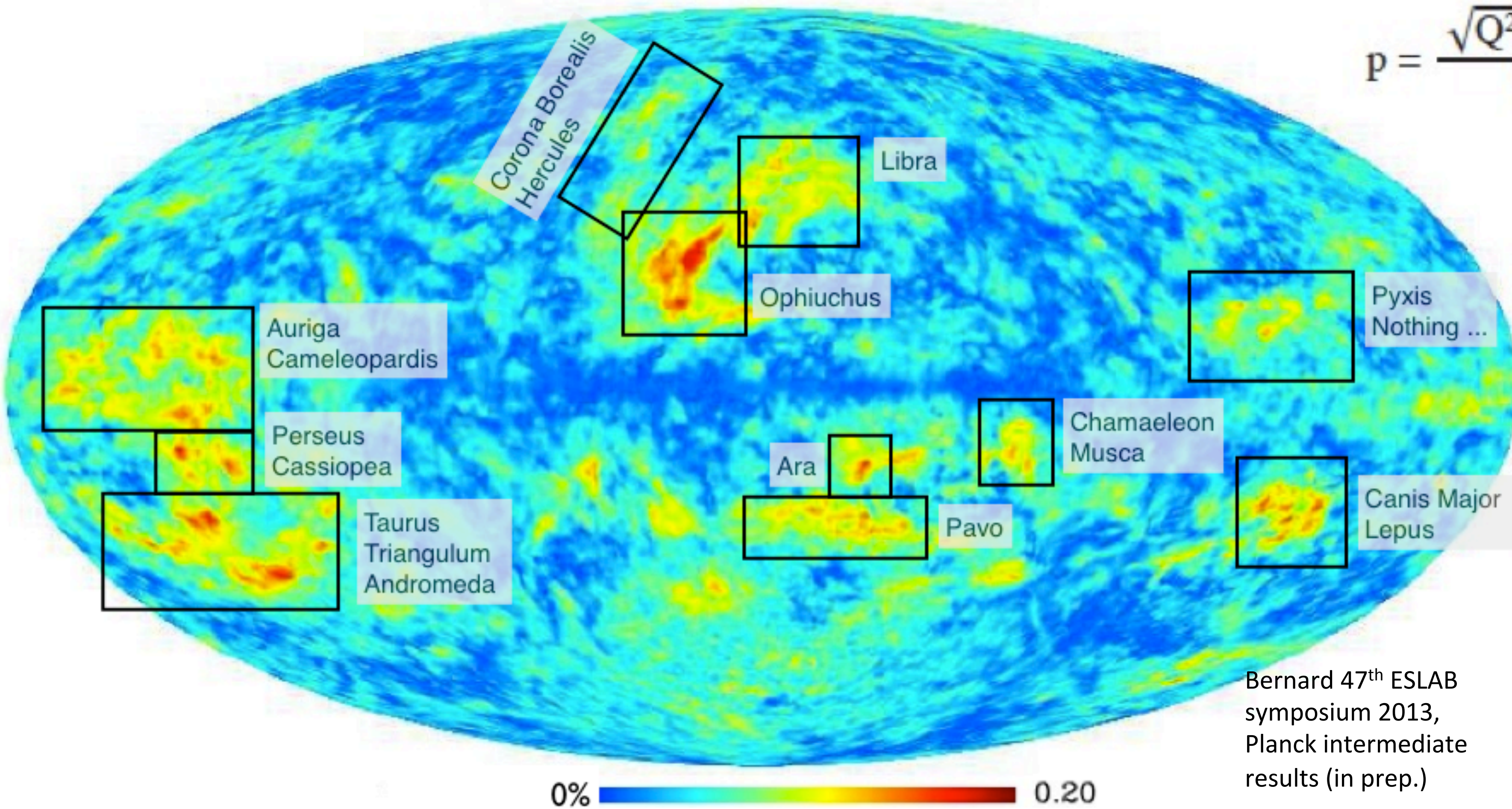
Dust polarization



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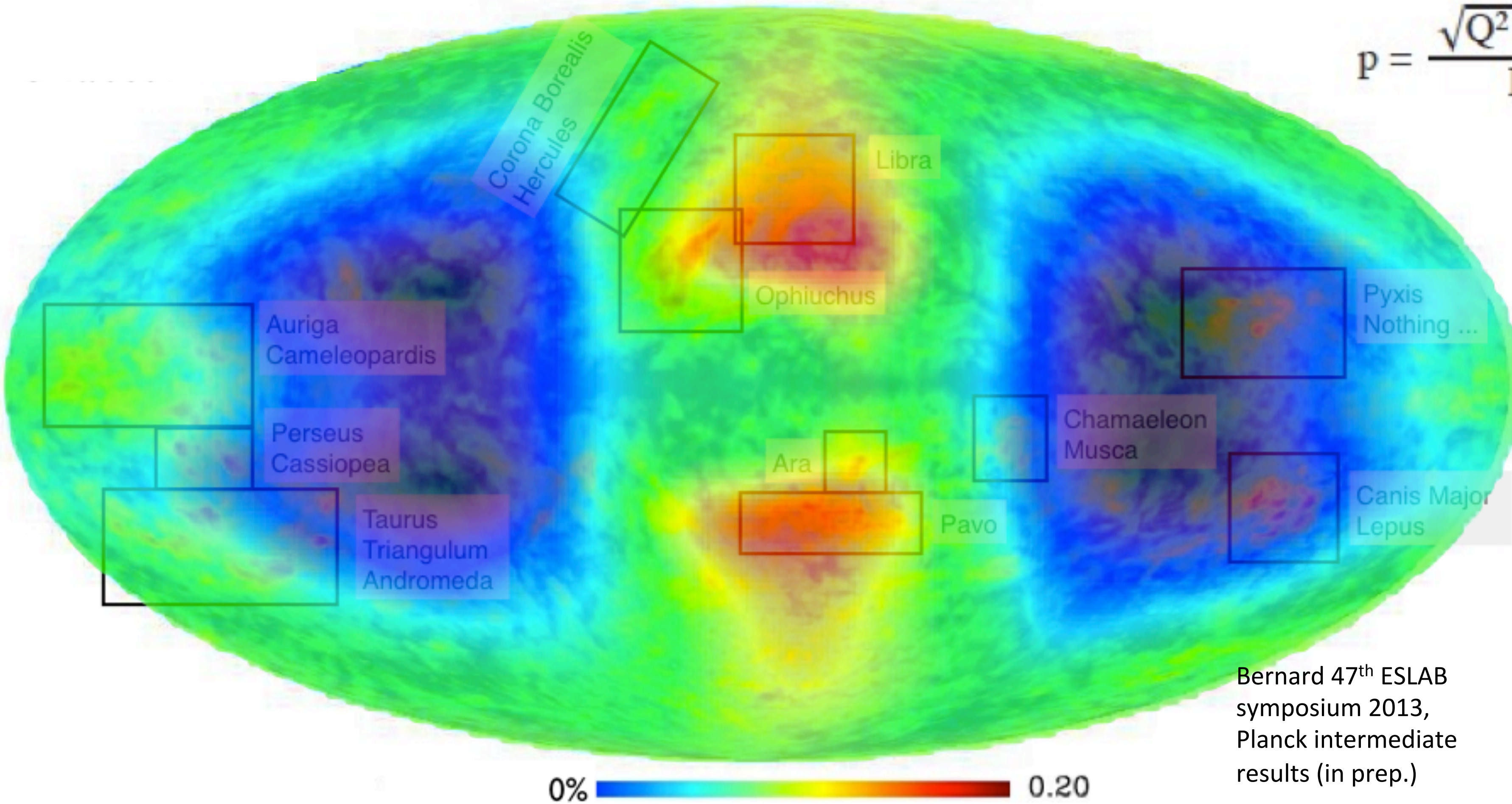
Dust polarization



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

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Dust polarization

- The map looks different in polarization!
- Regions of higher polarization degree have a fairly ordered magnetic field
- The field direction is seen to change within the dense structure – high $\Delta\psi$

Comparison with MHD simulations

Magnetic ←→ turbulent energies

Summary

Dust emission

- *Planck*'s optical depth map gives us an image of the Galaxy's reservoir for star formation
- Herschel provides the "details", the governing processes in the formation of cores and stars
- Extinction maps suited for extragalactic studies and diffuse Galactic ISM, as well as for the study of higher density Galactic medium
- There is still much to learn on the physics of dust particles and on the "dark" gas in our Galaxy – along with Fermi

Anomalous Microwave Emission

- New study of 98 regions – 28 high significance - gives definitive evidence for spinning dust
- Improved spinning dust models – take into account the complexity of grain structure and excitation mechanisms
- More data are needed – higher resolution and other frequencies

Summary

Galactic Haze

- Detection of the Galactic Haze with *Planck* and improved determination of its spectrum, from a combination with WMAP data, and owing to the improved CMB map from *Planck*
- β_{Haze}= - 2.55±0.05 confirming the hard synchrotron origin
- Morphology of the haze nearly identical from 23 to 44 GHz, indicating that the spectrum does not vary significantly with position
- Spatial correspondence with the Fermi bubbles indicates that an electron population with a spectrum dN/dE α $E^{-2.1}$ is responsible for the structure
- Origin? Star formation driven outflow (SPASS, Carretti et al.)? …

Dust polarization

- For the first time we the data needed to characterize the interplay between the structure of the magnetic field and the interstellar matter
- Need to disentangle the various intervening factors: dust properties, dust alignment and structure of the magnetic field
- Complement observations with simulations to understand the role of turbulent energy

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.