The Galactic ISM in the era of Planck

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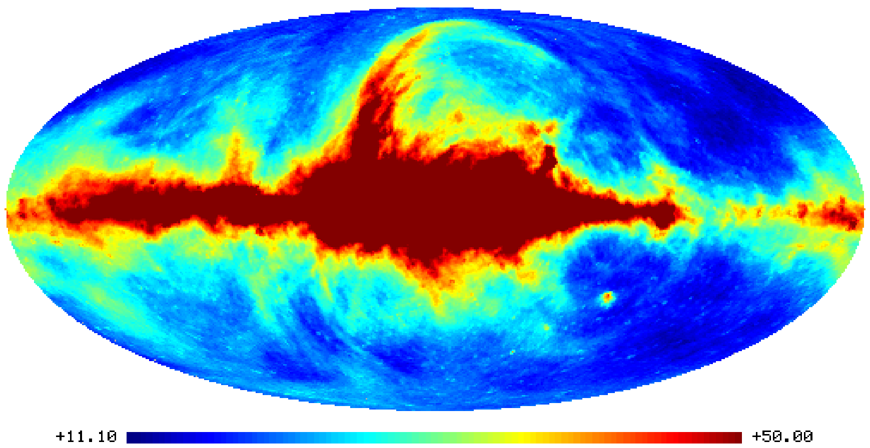
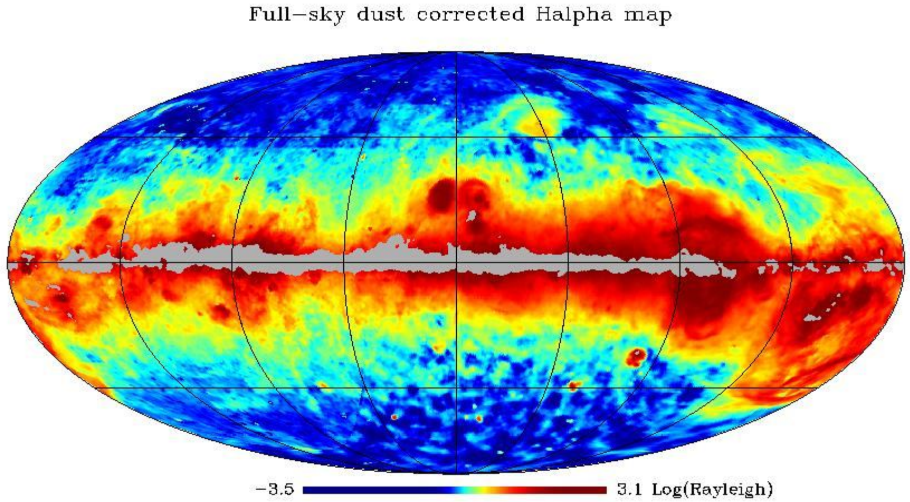
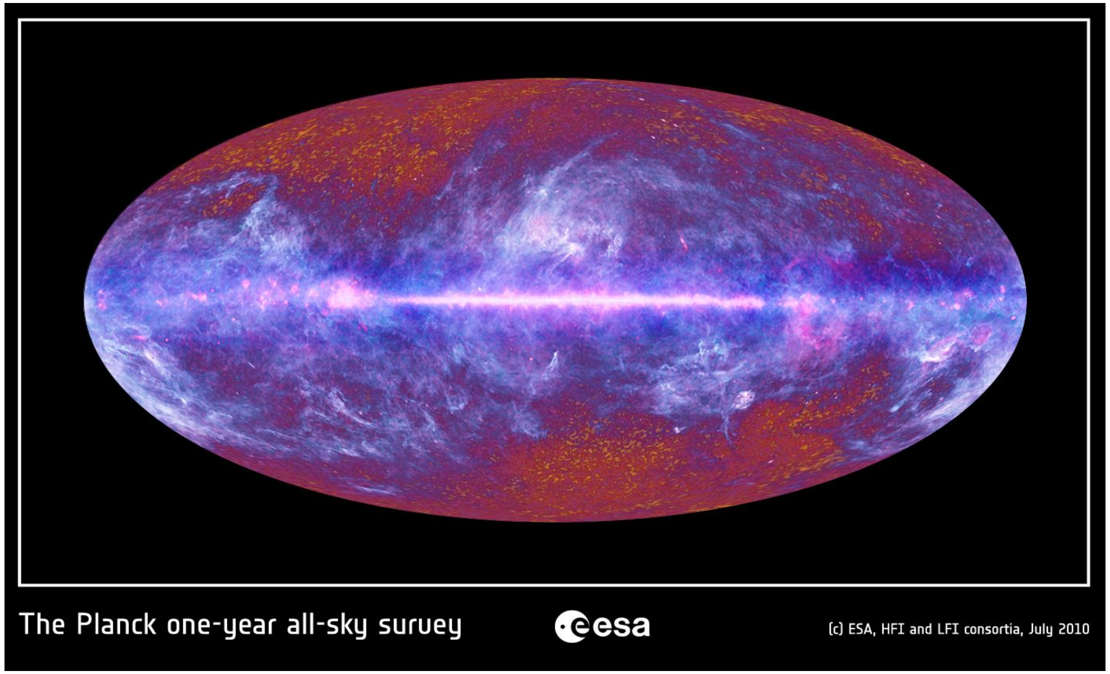
408 MHz – mainly synchrotron



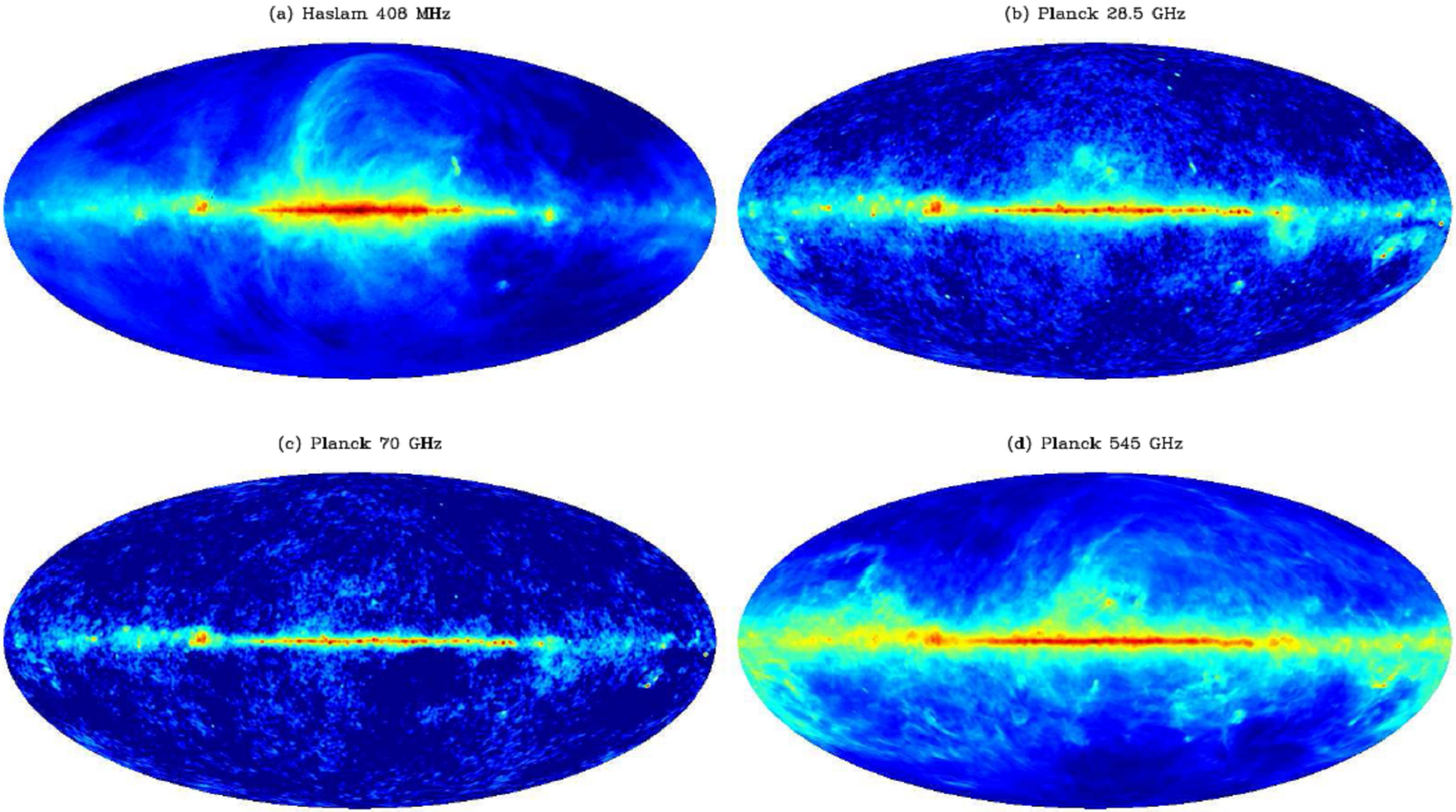


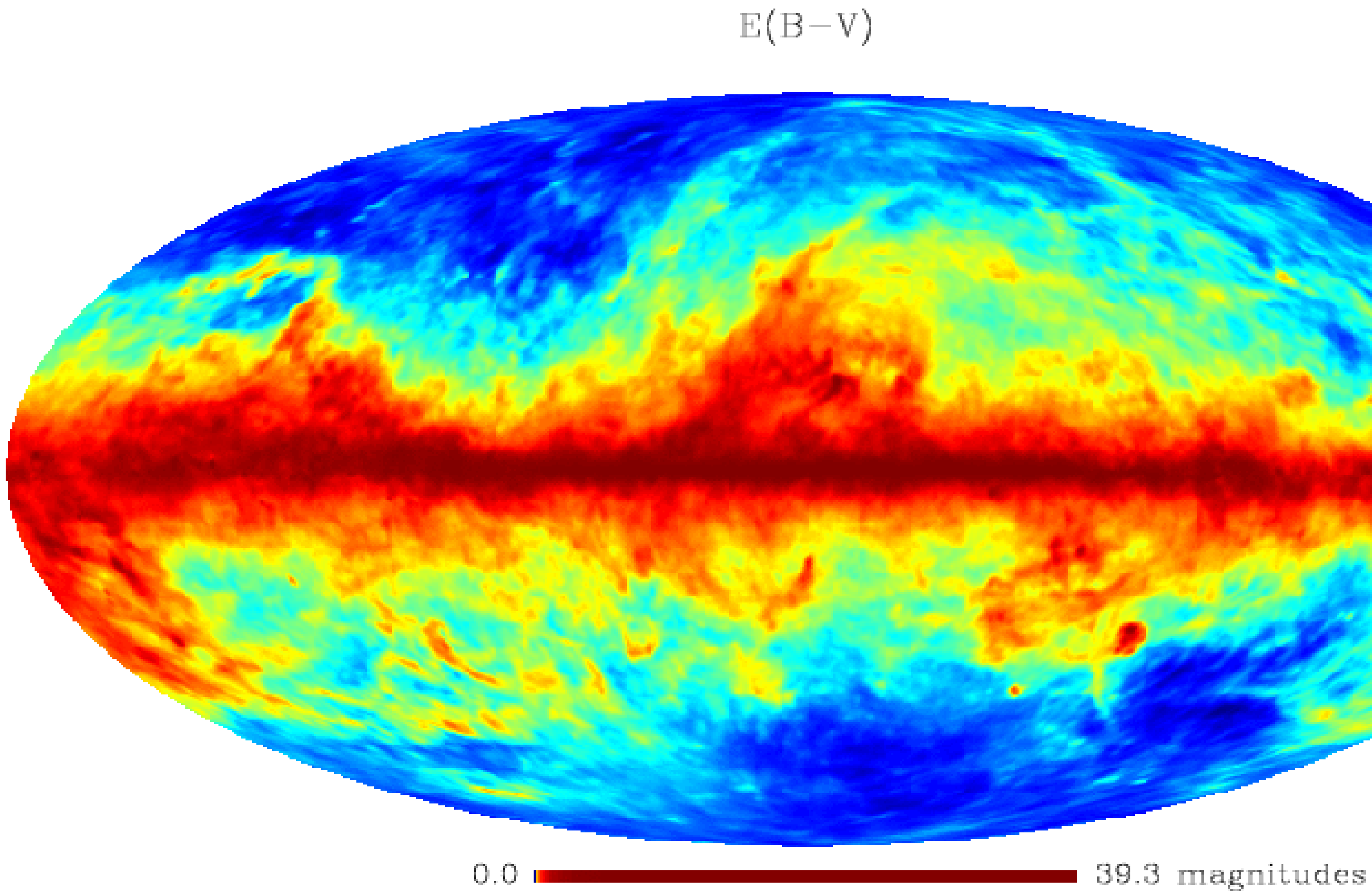


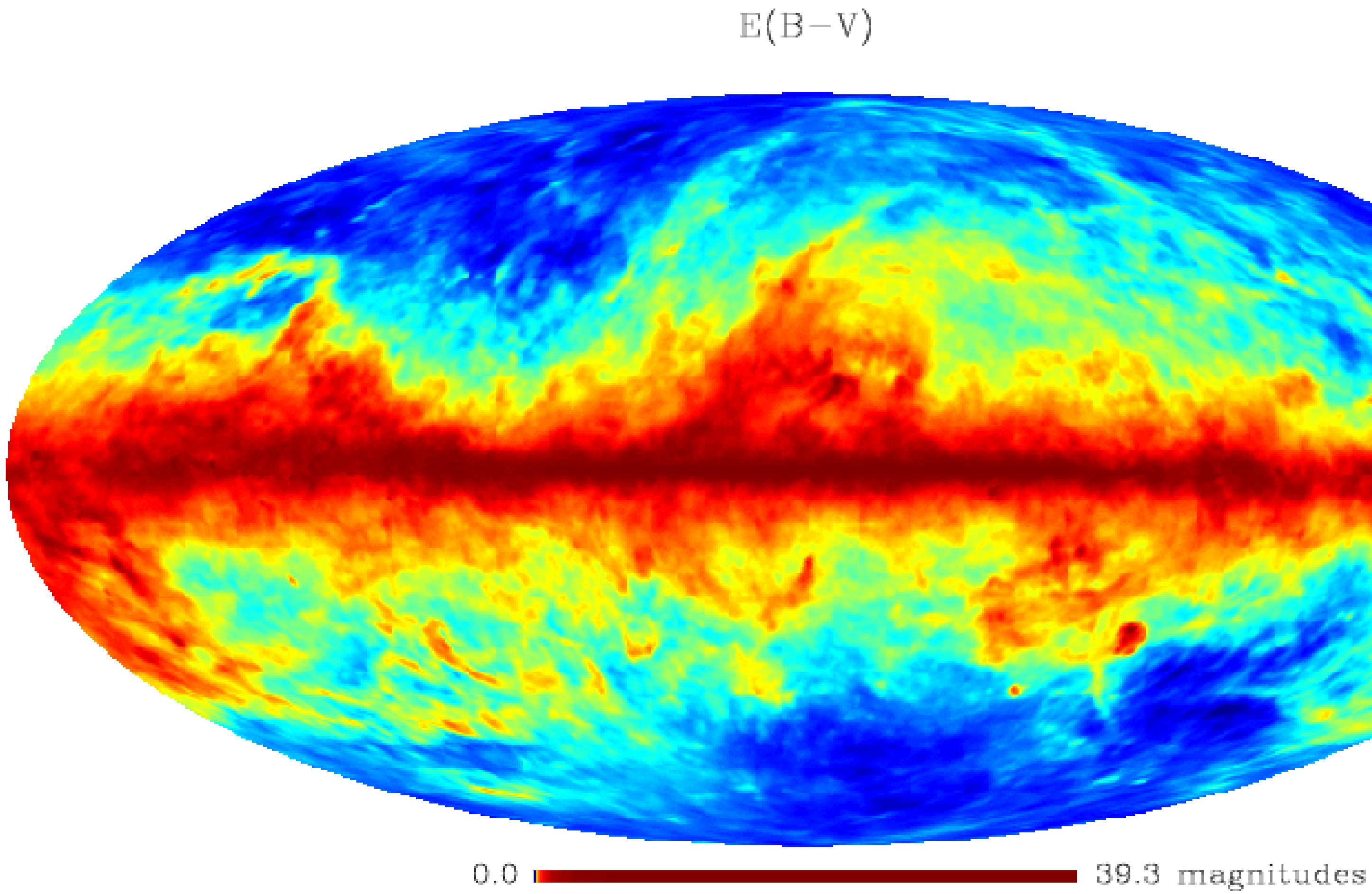
A road map of the Galaxy

- **The narrow Galactic plane** of width $1^{o} – 2^{o}$. A diffuse star-formation disc producing OB stars, Pulsars, PNe, SNRs etc.
- **The broader distribution** – populated with older stars, synchrotron, gamma-rays, X-rays, etc.
- **Local environment** extending to higher Galactic latitudes. Neutral, molecular and ionized gas, dust, etc.
- **Major features**. Regions of active star formation such as the Gould Belt extending 500 pc from the Sun inclined 20^{o} to the plane. Similar systems –Cygnus-X, Gum nebula. North Polar Spur (SNR?), Vela X,Y,Z etc.

Guides to the road map




E(B−V)
0.0
39.3 magnitudes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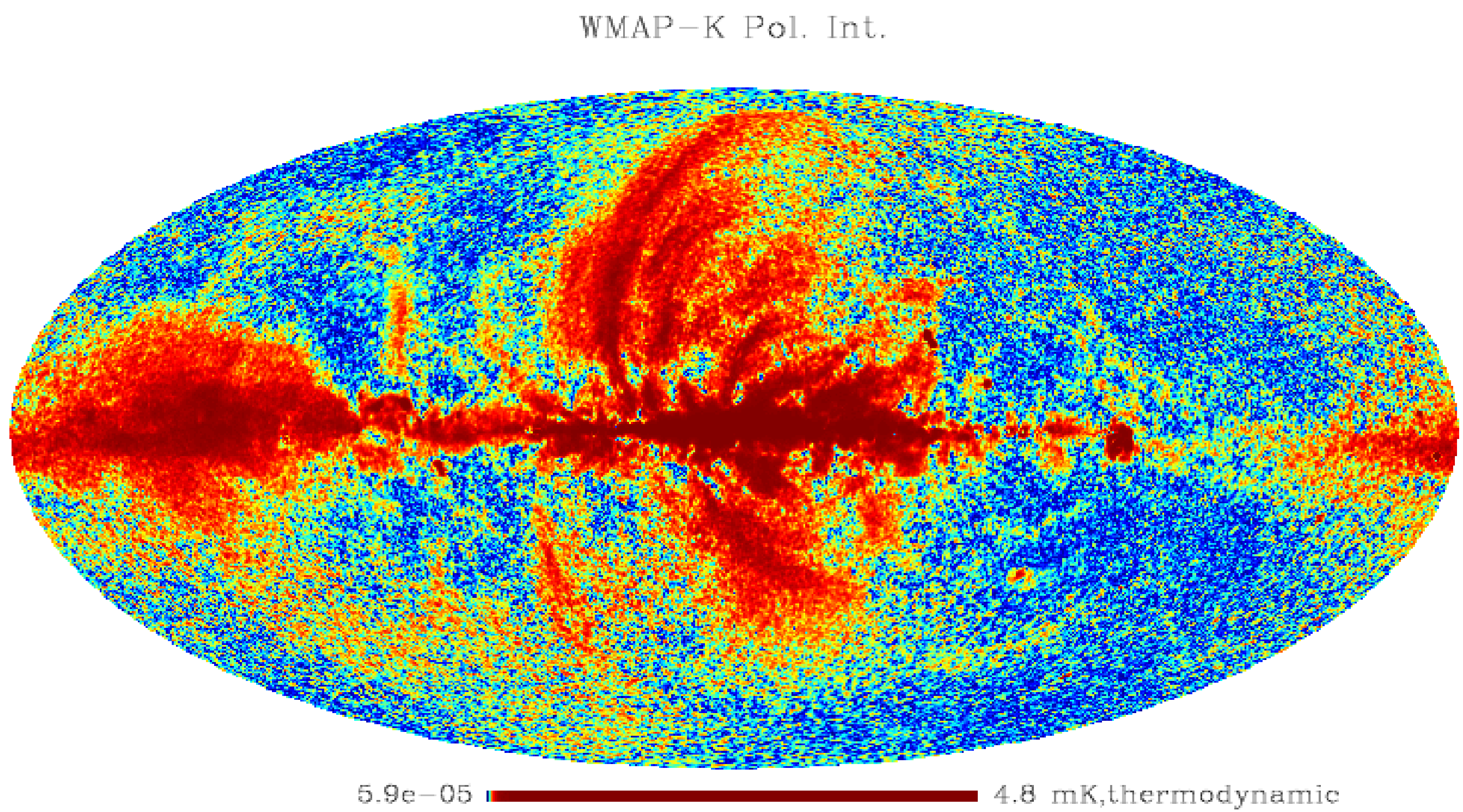
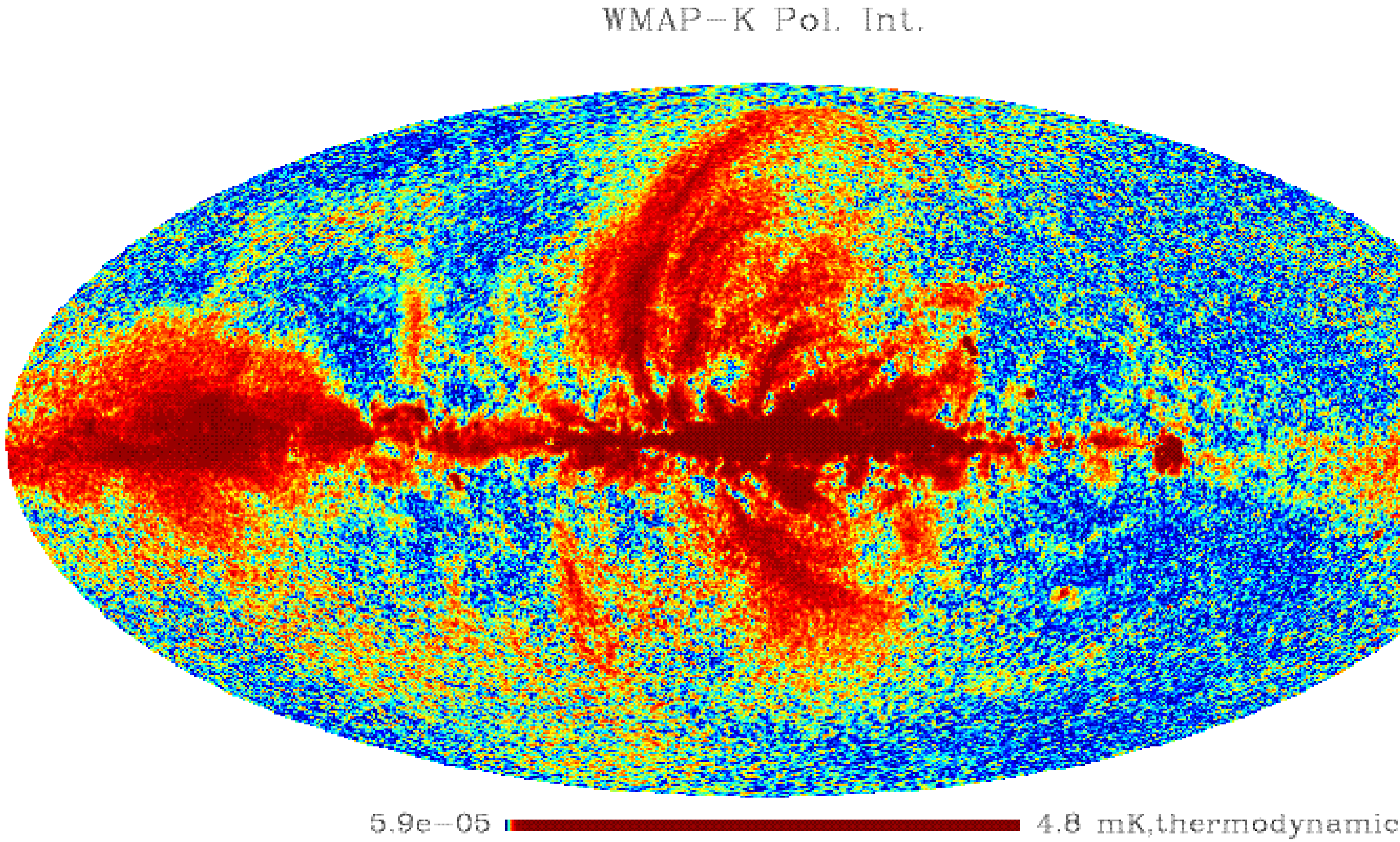

WMAP-K Pol. Int.
5.9e-05
4.8 mK,thermodynamic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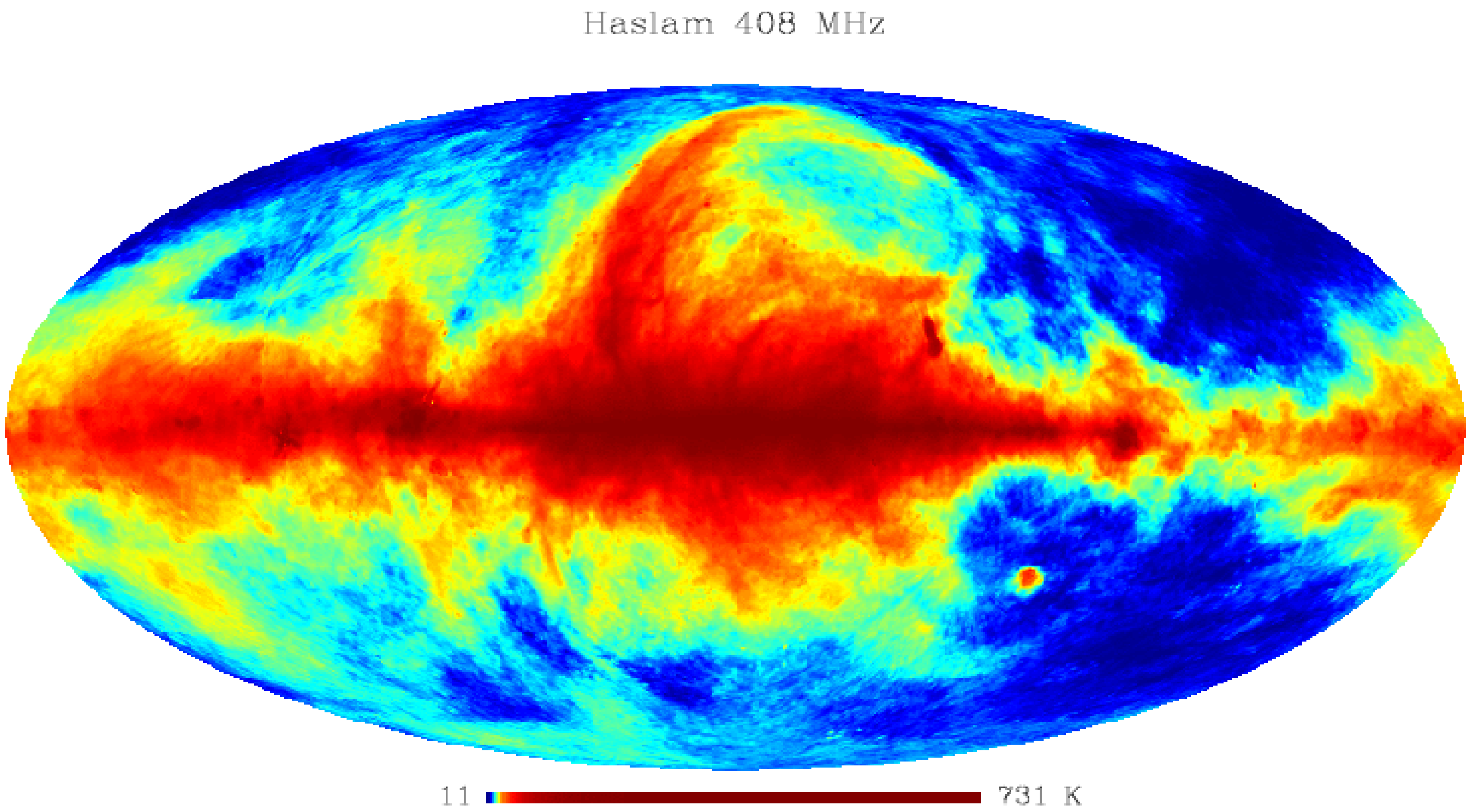
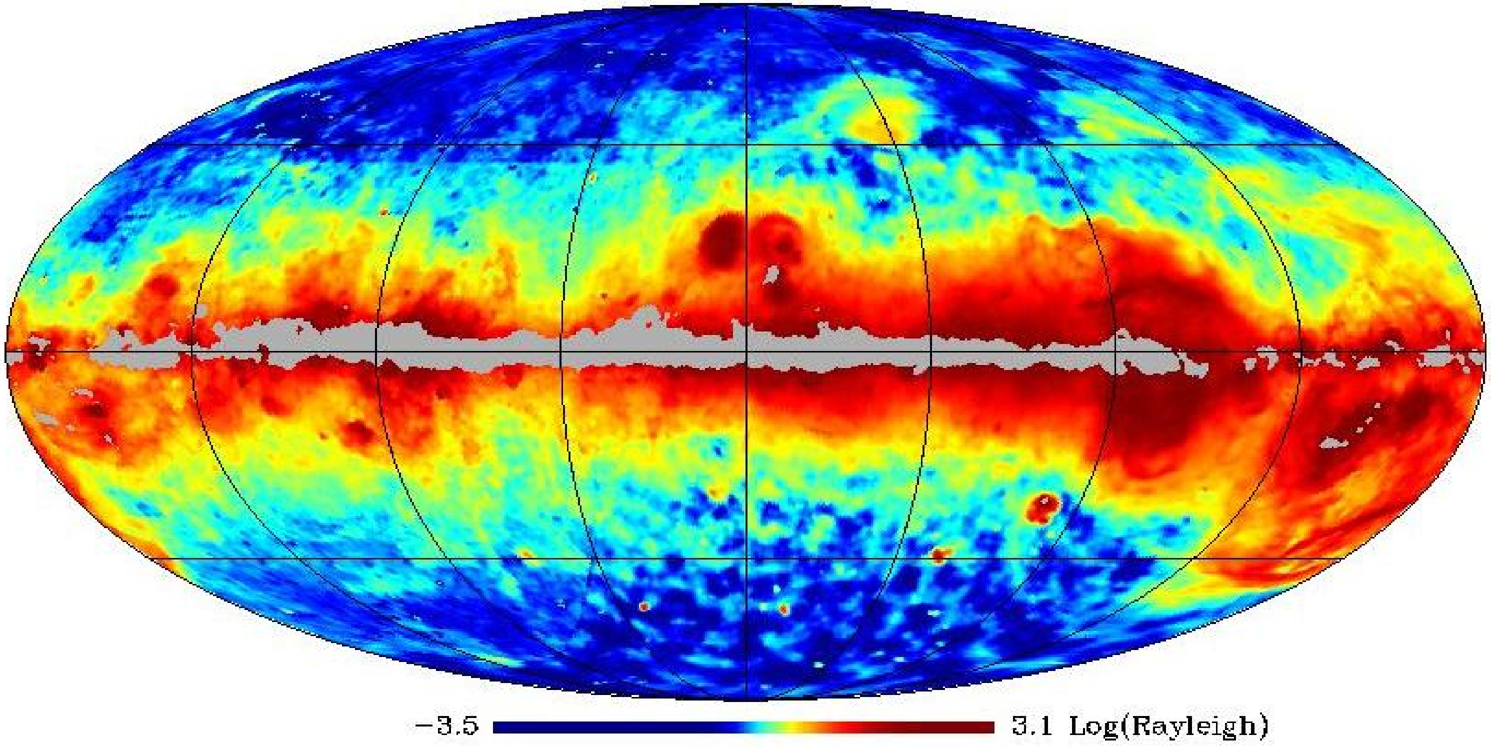

Haslam 408 MHz
11
731 K



H-alpha sky dust –corrected D^3 (2003)

<u>H-alpha absorbed by interstellar dust</u>

(a) A correction is required for the foreground dust.

(b) A value of 0.5 results from uniform mixing of ionized gas and dust.

<u>H-alpha scattered from interstellar dust</u>

(a) Witt et al 2010; 10 to 40% of H-alpha at intermediate latitudes is scattered.

(b) Brandt & Draine 2012: 19+/-4% at high latitudes.

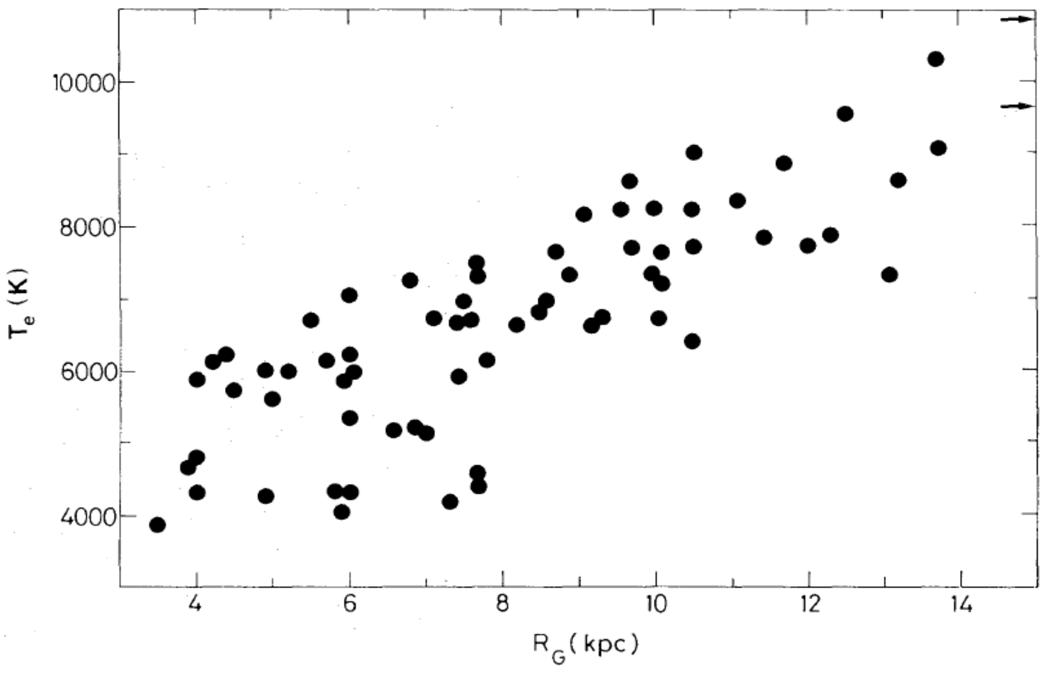
As a consequence, the measured Te is 20% higher.- ie 8000K

The Galactic T_e gradient

To obtain a free-free brightness temperature, a Te is required.

T_e from RRLs (Shaver et al. 1983).

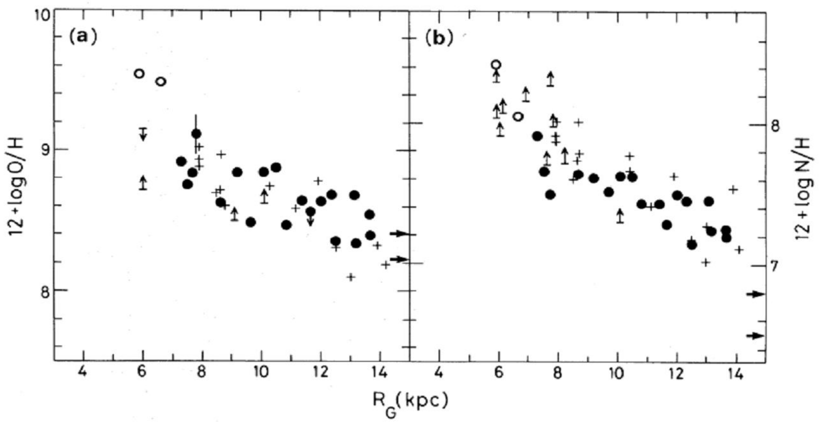
Data from bright HII regions at different galactocentric distances



Optical data.

Element abundances vs R_G.

Oxygen is one of principal coolants

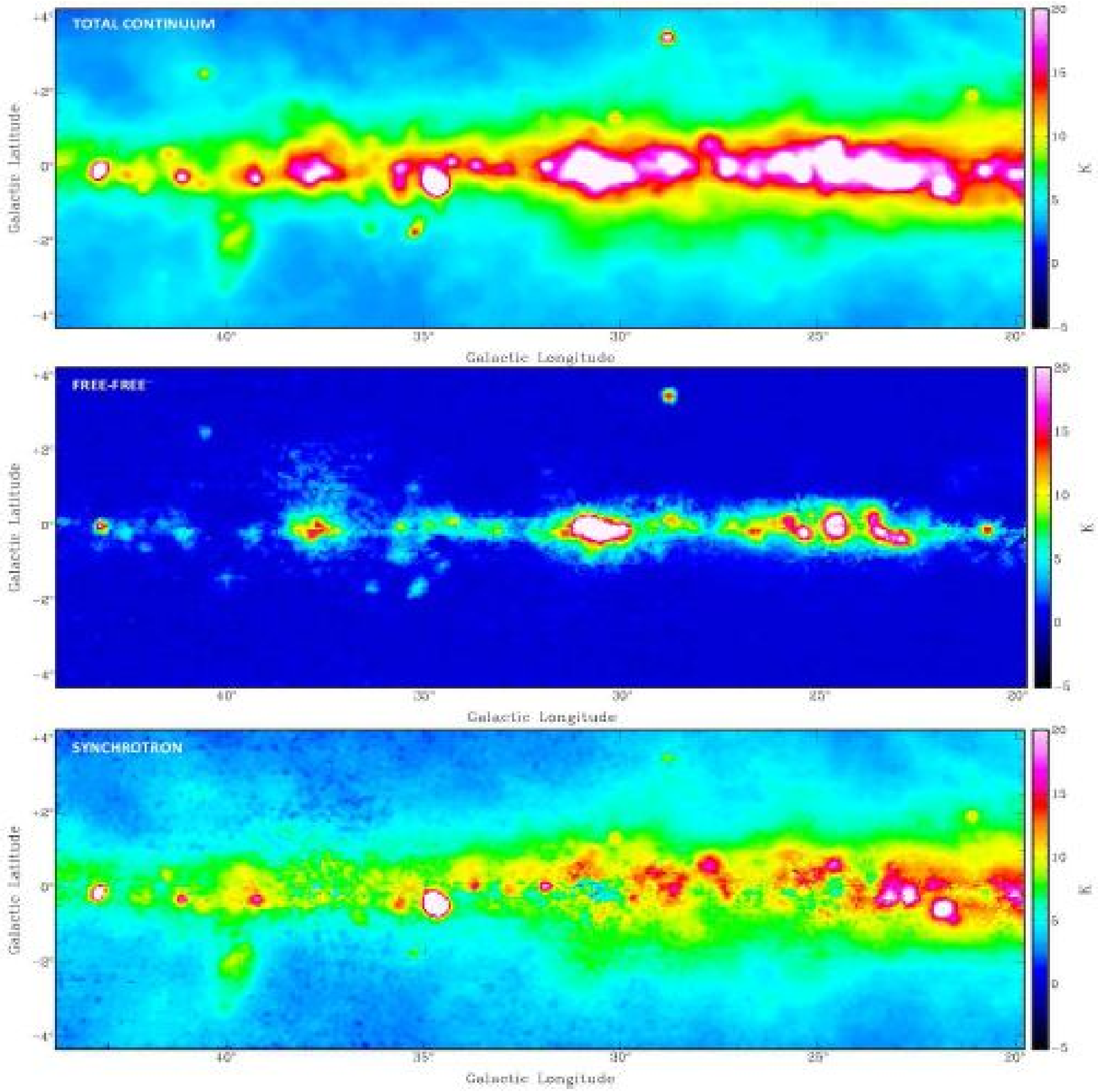


$$\int T_L d\nu = 1.92 \times 10^3 T_e^{-1.5} \mathrm{EM}$$

$$T_b = 8.235 \times 10^{-2} a(T_e) T_e^{-0.35} \nu_{\mathrm{GHz}}^{-2.1} (1 + 0.08) \mathrm{EM}$$

$$\frac{\int T_L dV}{T_b} = 6.985 \times 10^3 \frac{1}{a(T_e)} \frac{1}{(1 + 0.08)} T_e^{-1.15} \nu_{\mathrm{GHz}}^{1.1}$$

The separation of free-free and synchrotron at 1.4 GHz using RRLs



Total continuum at 1.4 GHz

L = 20º -44º

B = -4º - +4º

Free-Free

Synchrotron

(Alves et al. 2011, 2012)

Anomalous Microwave Emission (AME)

•Very small dust grains transiently heated to several l00K by neutrals and ion collisions will emit dipole radiation at the GHz frequencies at which these grains spin (Draine & Lazarian 1998).

•Discovered in the last decade in the 10 to 70 GHz band associated with dust seen in the FIR.

•Their characteristic spectrum peaks in the range 20 – 60 GHz. Only weak (<5%) polarization is expected.

•The AME spectrum provides a probe of the dust and its environmental properties.

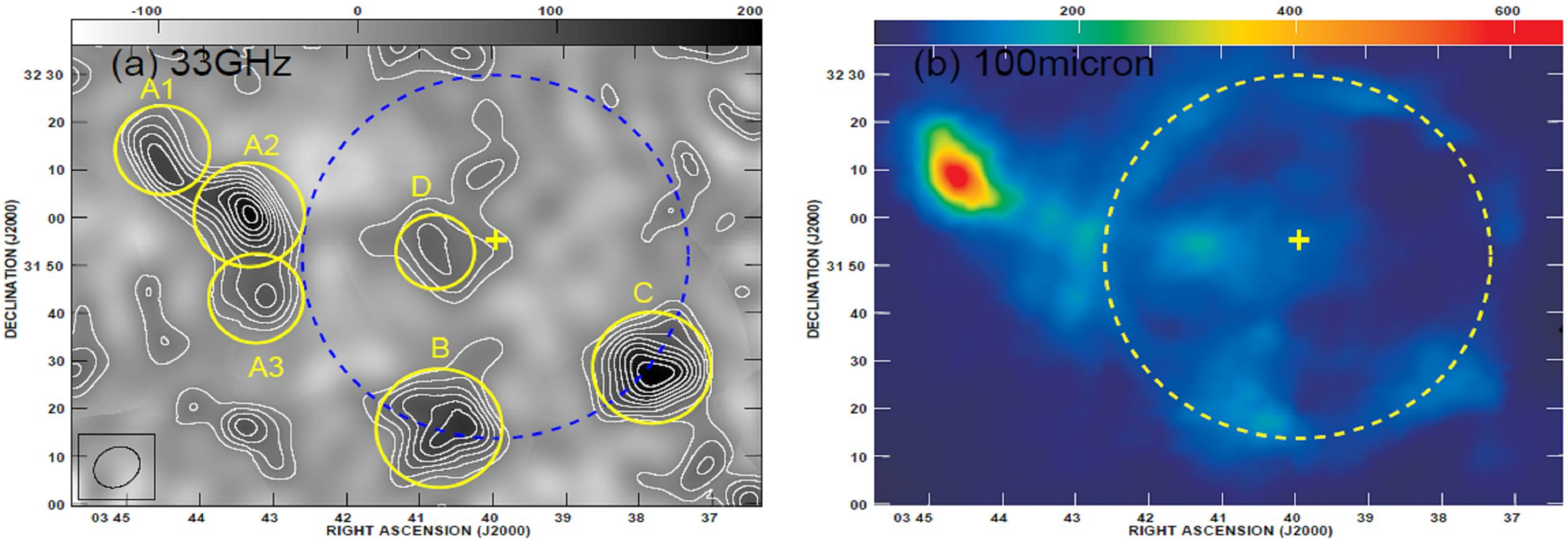
•PAH molecules emitting in the 3 - 15 micron range could be responsible. The understanding of the AME data is at an early stage.

• Planck will make a significant contribution since it covers all the relevant frequencies and it covers a wide range of ISM environments.

AME in the Perseus Molecular Cloud

•AME in this region was first detected at 12 - 18 GHz by COSMOSOMAS with a 1.3º beam. It appeared to be centred on the 100 micron ring surrounding a low excitation star.

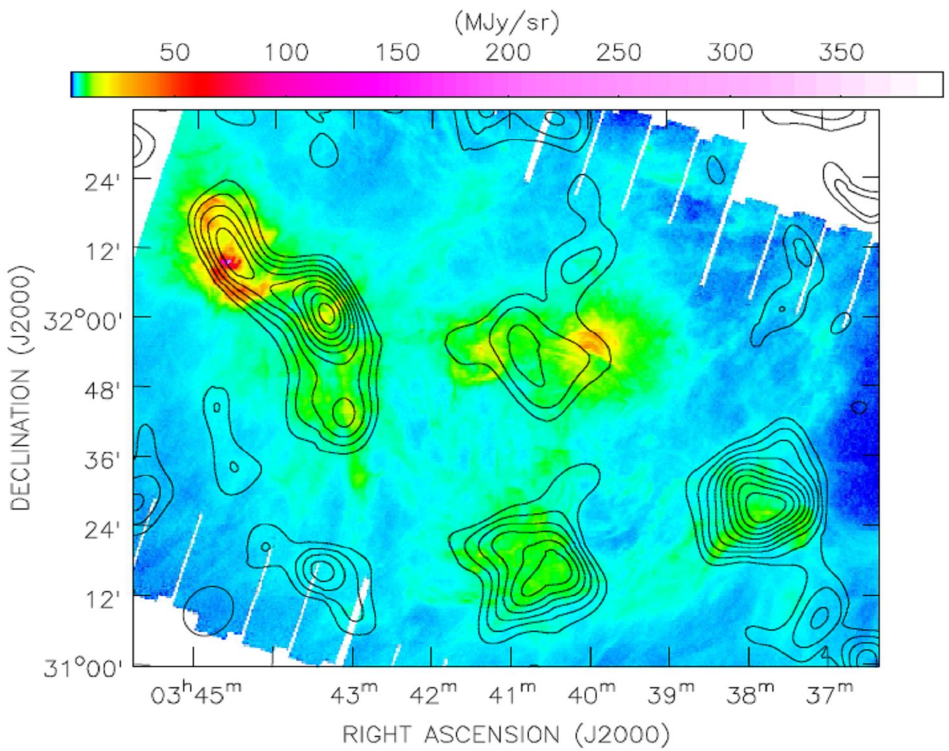
•Higher resolution data at 33 GHz showed compact AME sources within the region with a range of AME-to-FIR ratios. These made up only 10% of the total flux, indicating the presence of a dominant diffuse AME background.



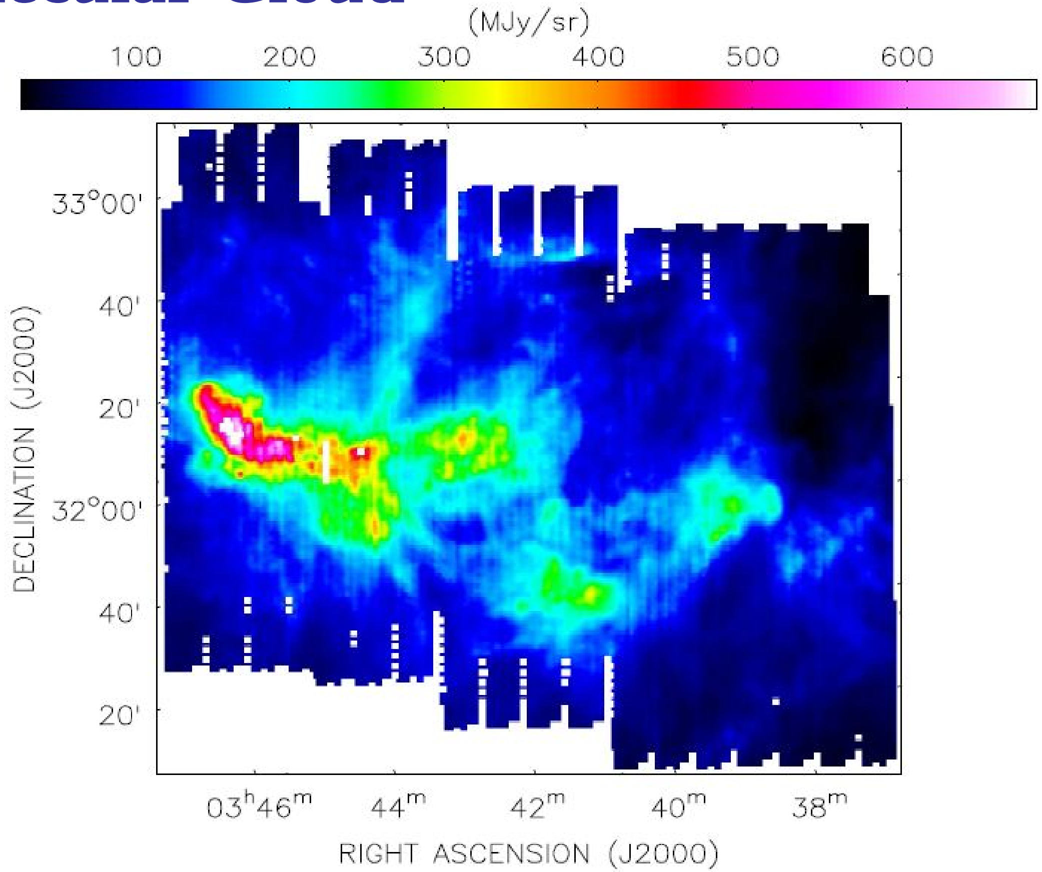
Perseus molecular cloud (VSA - 7’ resolution) Tibbs et al. 2010

Spitzer and VSA 33 GHz images of G159.6 -18.5

Perseus Molecular Cloud



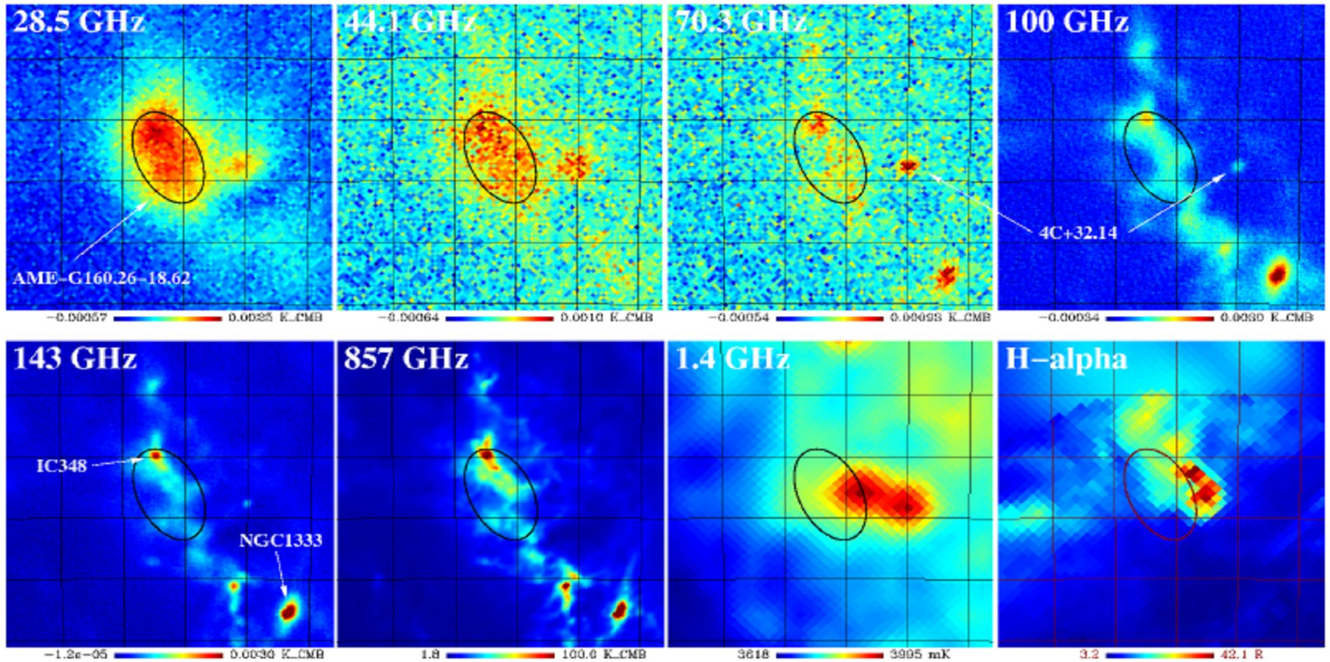
VSA 33 GHz image overlaid on Spitzer MIPS 24 micron image



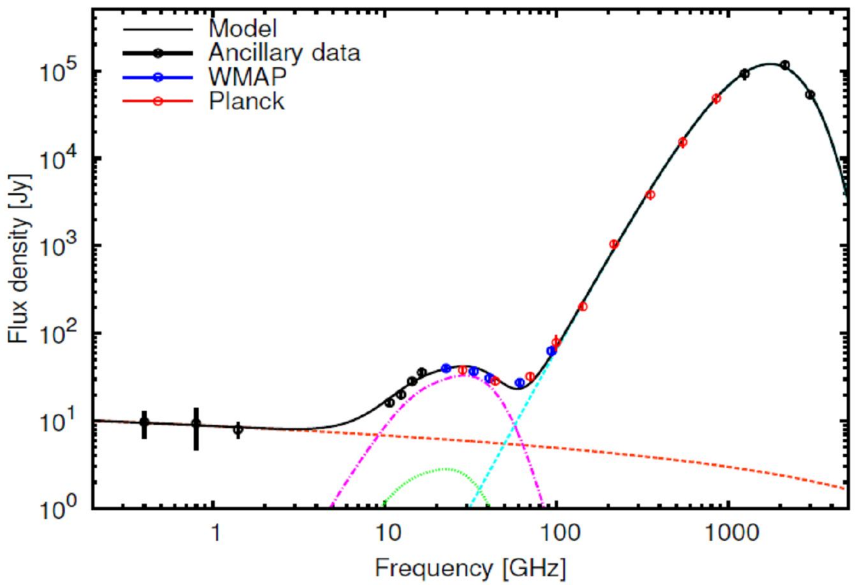
Spitzer MIPS 160 micron image

Perseus Molecular Cloud

Planck Early Paper



SED in 1.3°x1.0° ellipse.

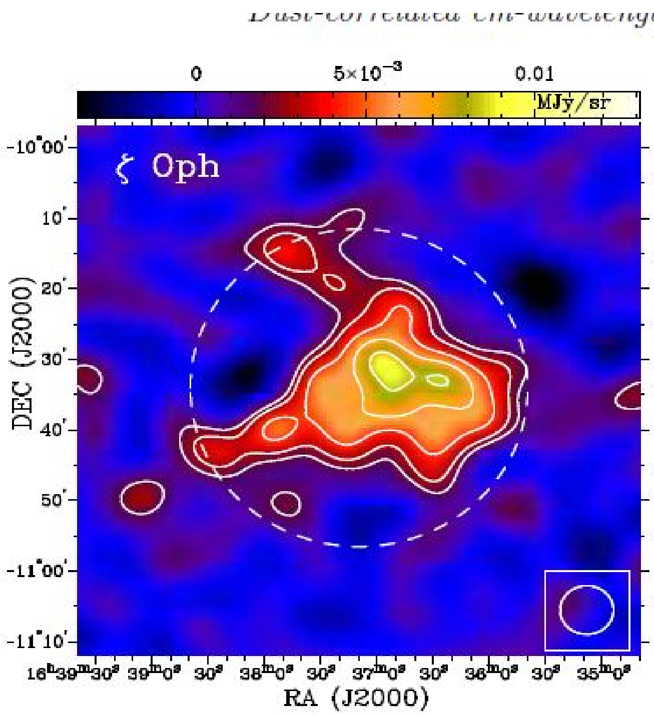


The diffuse (extended) emission seen by Planck is 5-10 times that of bright features seen in the VSA (7’).

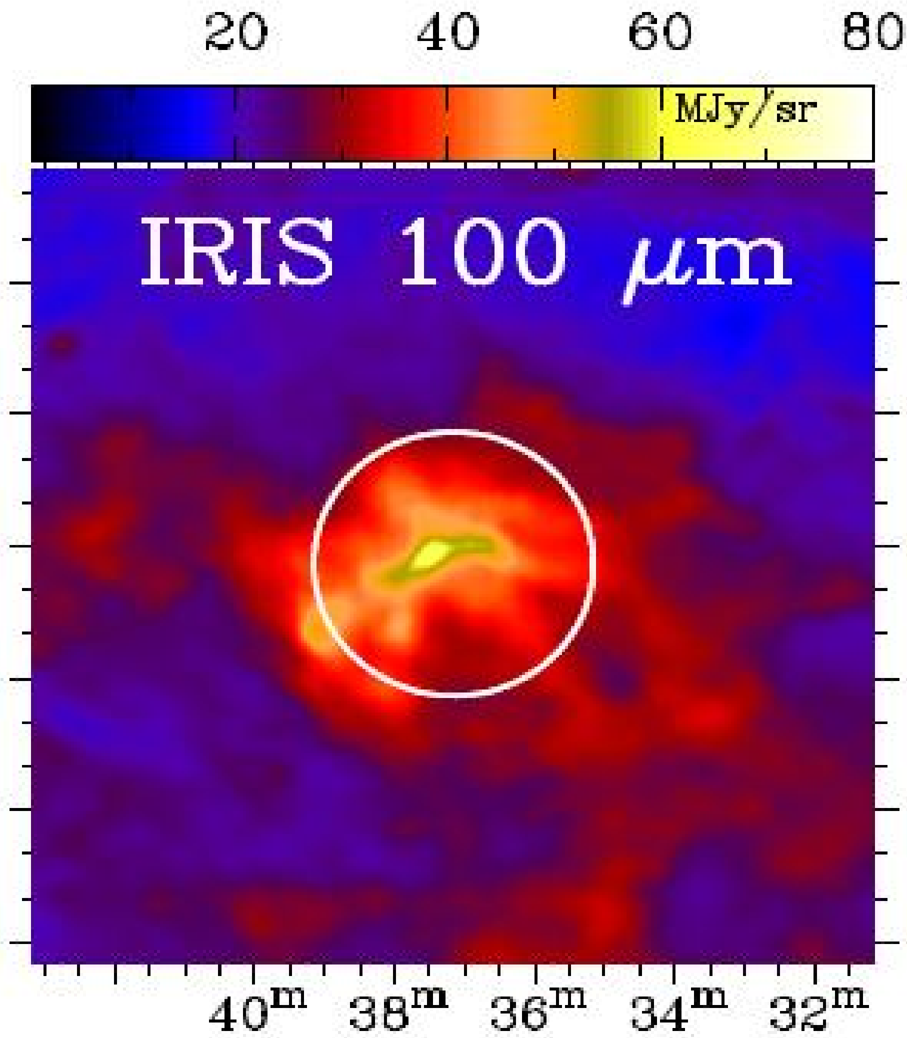
THE Planck contribution is finding the diffuse emission.

Rho Ophiuchi

As for G159.6 -18.5, Planck is sensitive to the extended emission



31 GHz CBI image at 6' resolution



The Gamma- ray sky

(1) CR protons on ISM giving pion decay gamma-rays of 1-5 GeV to give estimate of total matter content in ISM.

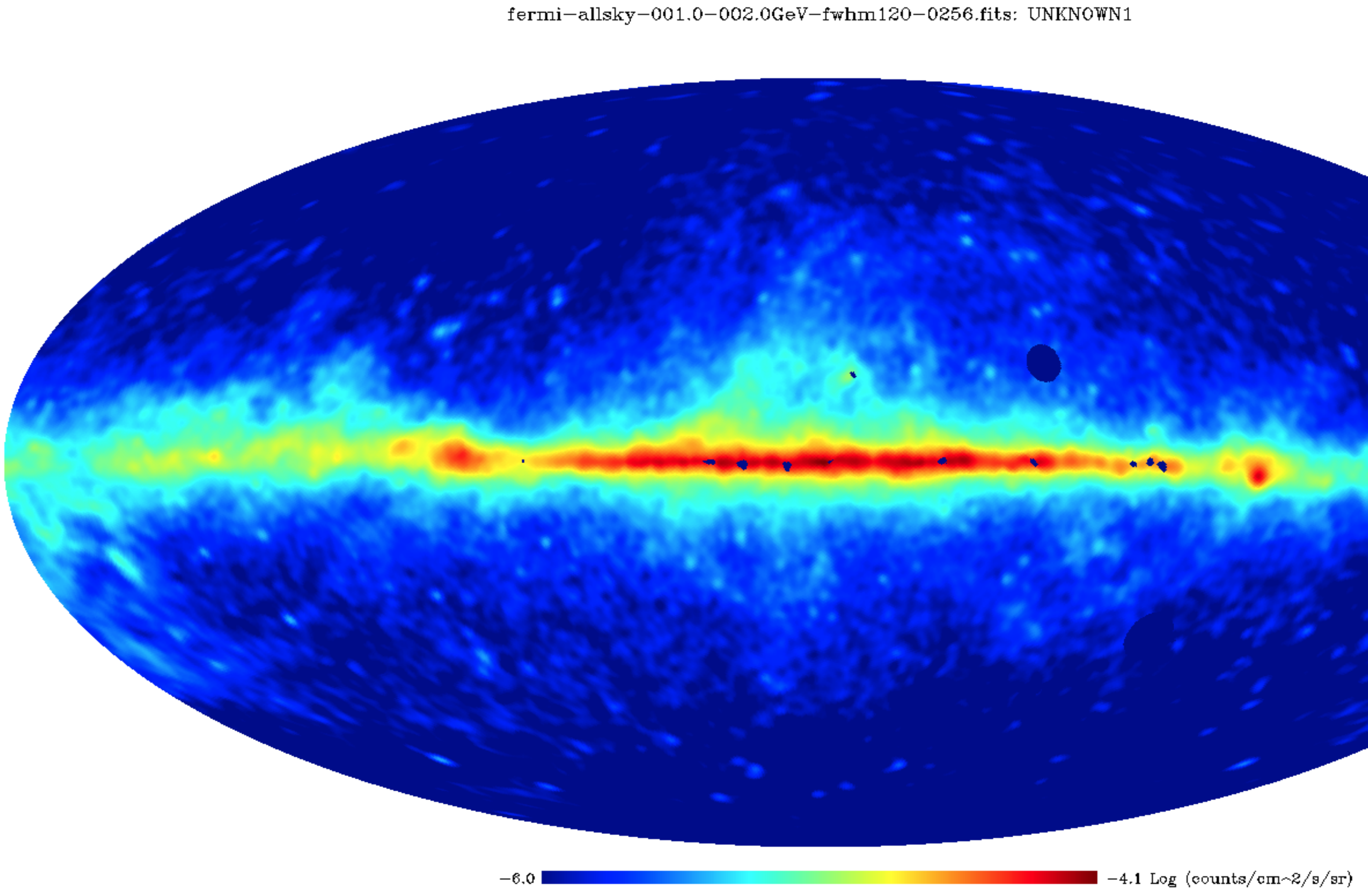
(2) CR electrons scatter on ISM giving Bremsstrahlung

(3) Inverse Compton of CR electrons on ISRF (CMB, IR, optical photons)

In the general ISM (1) is ~7x (2) and ~10x(3) at 1 GeV via GALPROP (Dobler et al. 2010; Strong et al. 2011).

Fermi-LAT is transforming our knowledge of the higher energy ISM, providing complementary information for Planck projects.

FermiLAT 1-2 GeV all-sky map



Polarization with Planck

- **Synchrotron** emission is strongly polarized in aligned magnetic fields. Maximum of 50-70%. Lower polarization in tangled fields.
- **Dust** - emission from aligned grains; dominates in Planck HFI bands. Typically 5-10 %.
- **AME** from aligned dust grains. Probably <5%. Only weak detections/limits so far.
- **Free-free** emission from brightness gradients.. Possibly no more than 1%. Not yet detected.
- **Planck will make a significant contribution in each of these fields.**

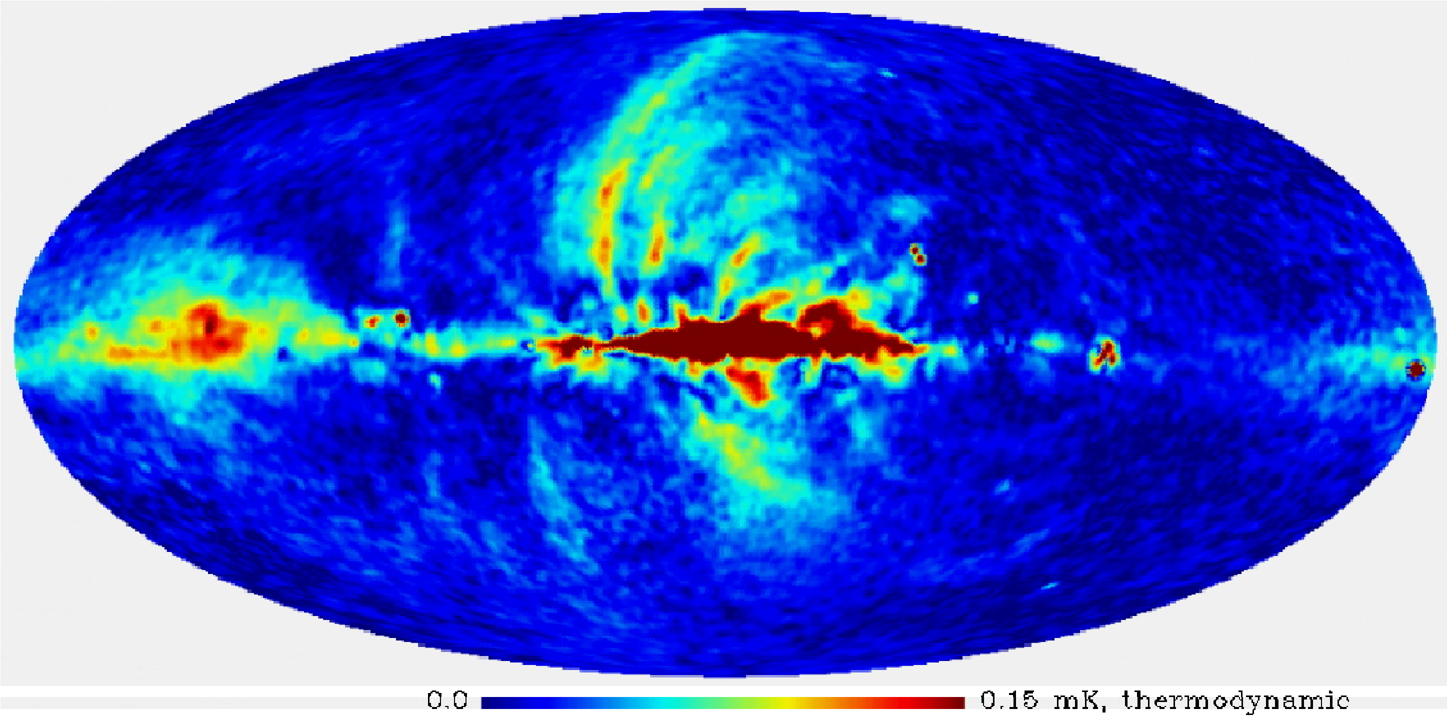
The Galactic magnetic field

Input data

- **All-sky radio polarization maps.** Low frequencies effected by Faraday depolarization near the Galactic plane. Planck data give a strong indication of the field configuration.

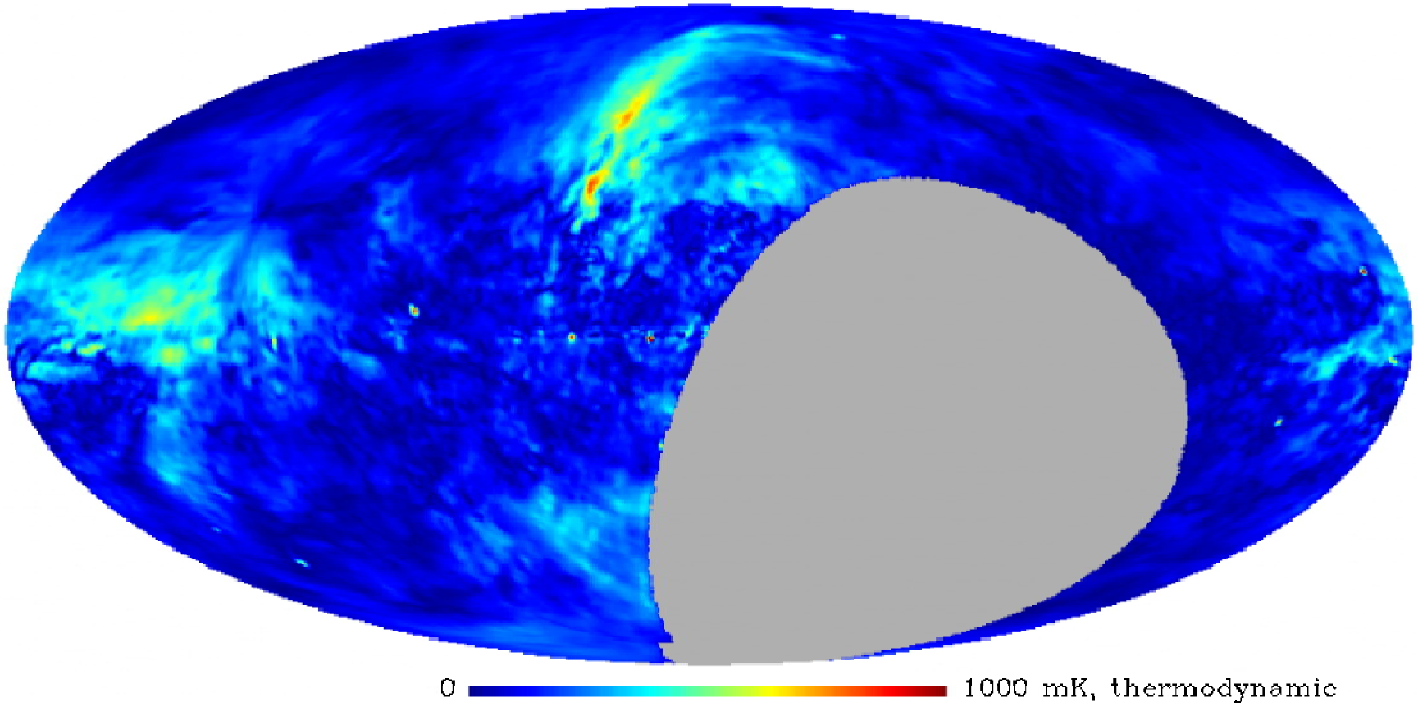
- **Fractional polarization** gives an indication of the level of field tangling.

- **Magnetic field strength** from pulsar data via Faraday Rotation and Dispersion Measure. Also from the CR propagation code GALPROP which uses synchrotron data along with the distribution of CR electrons derived from gamma-rays.



WMAP

23 GHz polarization intensity

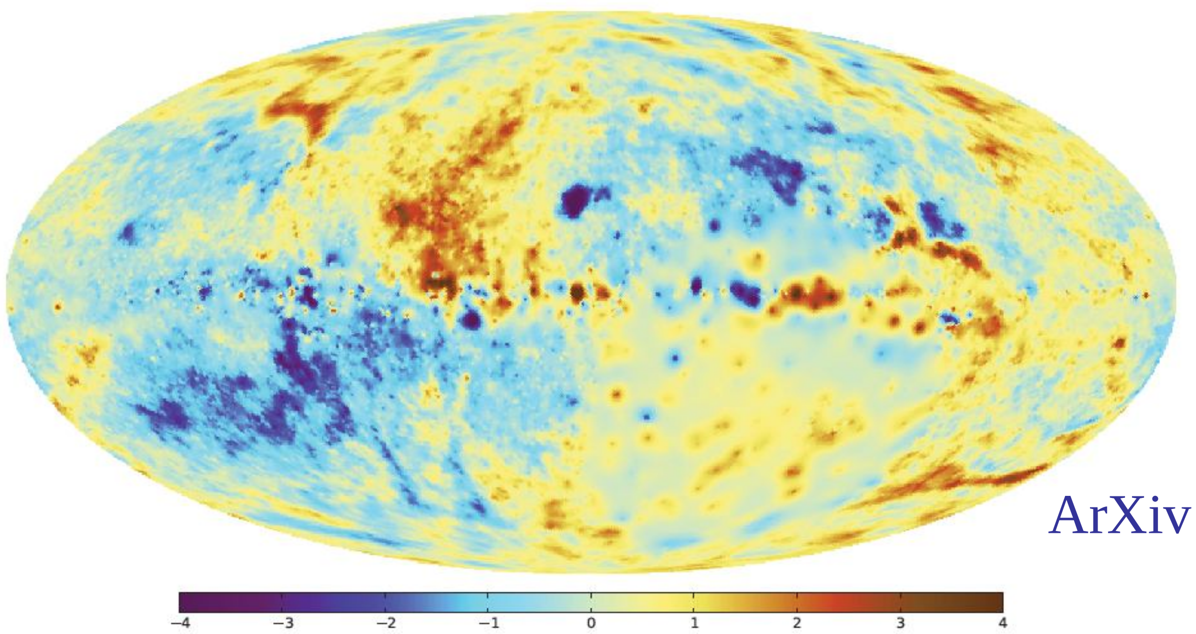


1.4 GHz polarization intensity

Note the depolarization at low latitudes

The Faraday Rotation Sky

Derived from extragalactic radio sources



ArXiv 1111.6186

- **Faraday rotation is proportional to the electron density multiplied by the magnetic field component integrated along the line of sight.**
- **FR gives field direction away from observer (blue) at positive longitudes and towards the observer (red) at negative longitudes.**
- **Note large-scale features at intermediate and high latitudes.**

The Galactic Centre haze and bubbles

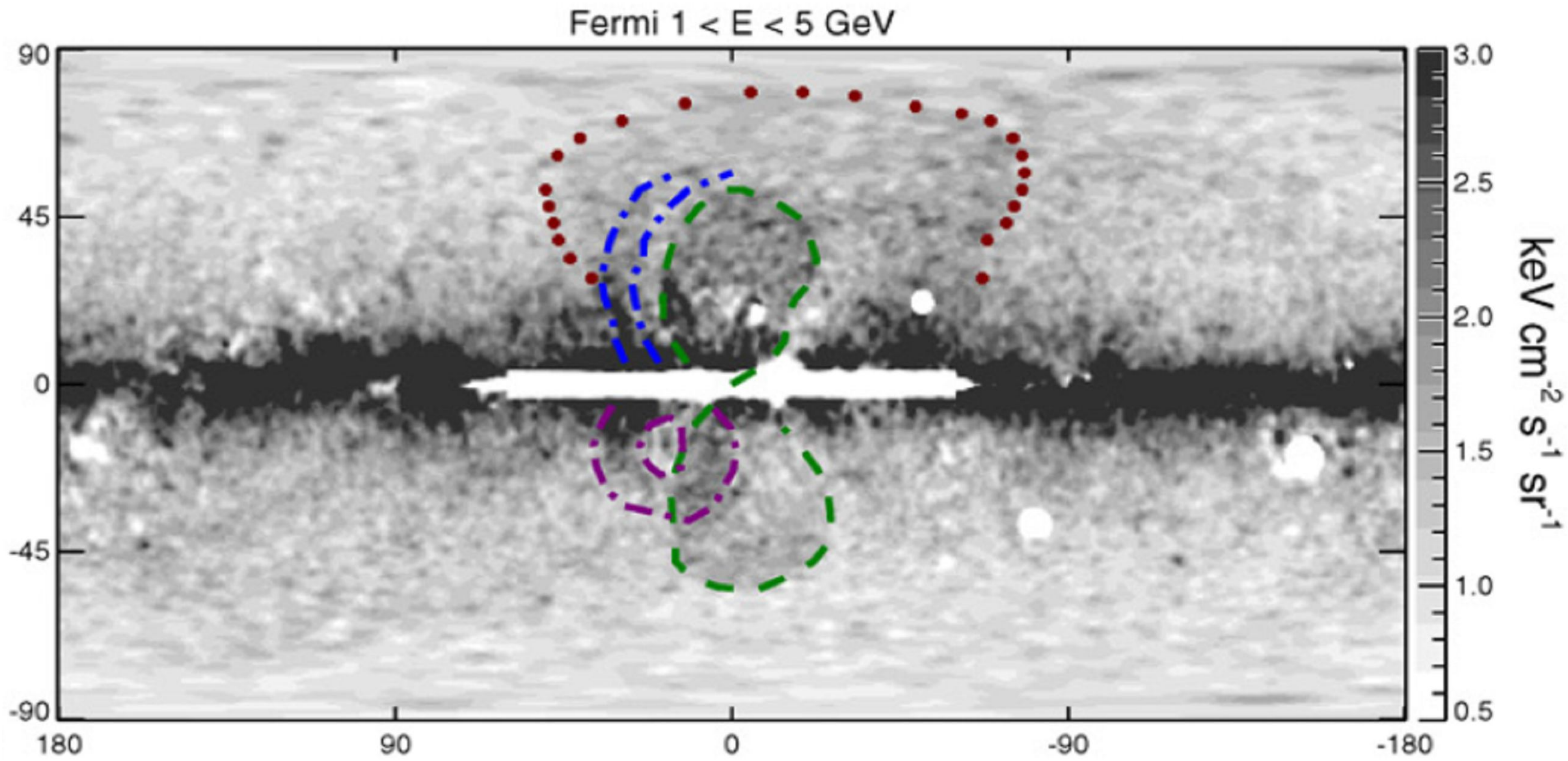
•Interest in the region around the Galactic centre was triggered by discovery of a component of hard spectrum (1 – 100GeV) gamma-rays in 50^{o} lobes above and below the plane - called “bubbles”.

•These gamma-ray bubbles have a uniform brightness distribution with well-defined sharp edges.

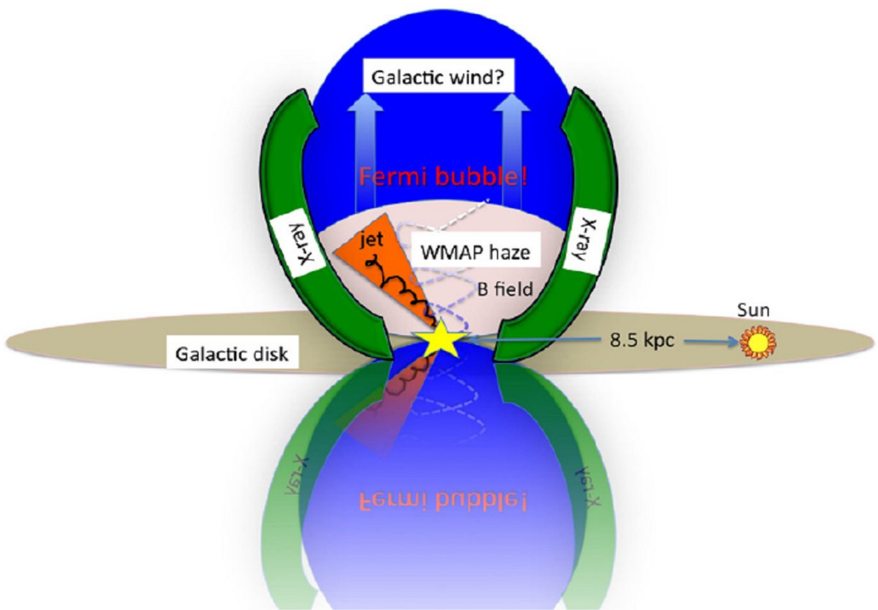
•A search for a hard-spectrum synchrotron counterpart revealed a “haze” in the WMAP data which appears to have a different morphology to the bubbles.

•Many explanations of these and other data (X-ray, IRAS) have been put forward – accretion onto GC BH, AGN-type jet, nuclear outburst, etc., etc.

•Planck has the potential with its higher sensitivity and frequency coverage to contribute to unravelling this enigma.

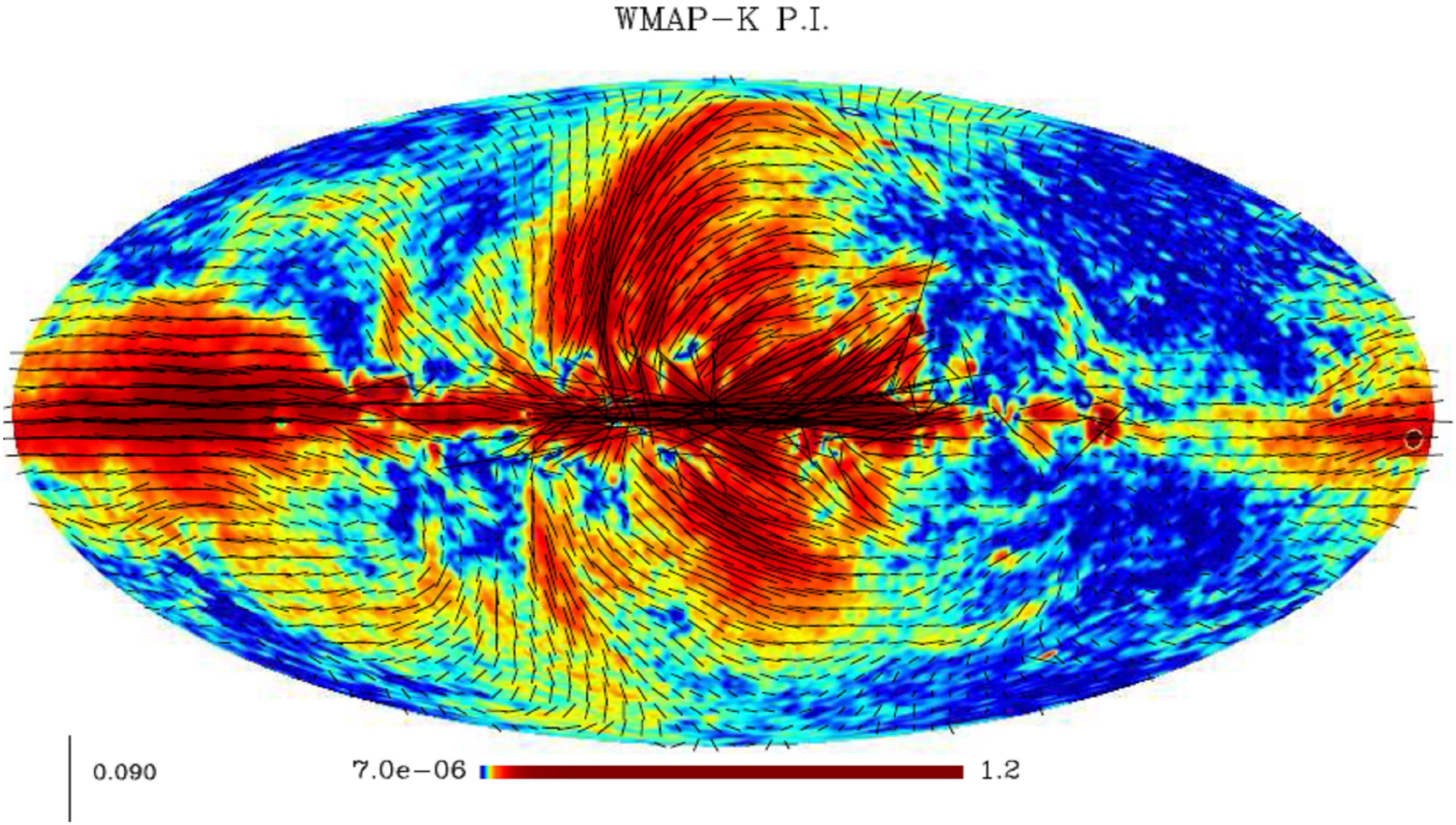


Fermi 1 < E < 5 GeV
90
45
0
-45
-90
180
90
0
-90
-180
3.0
2.5
2.0
1.5
1.0
0.5
keV cm^{-2} s^{-1} sr^{-1}



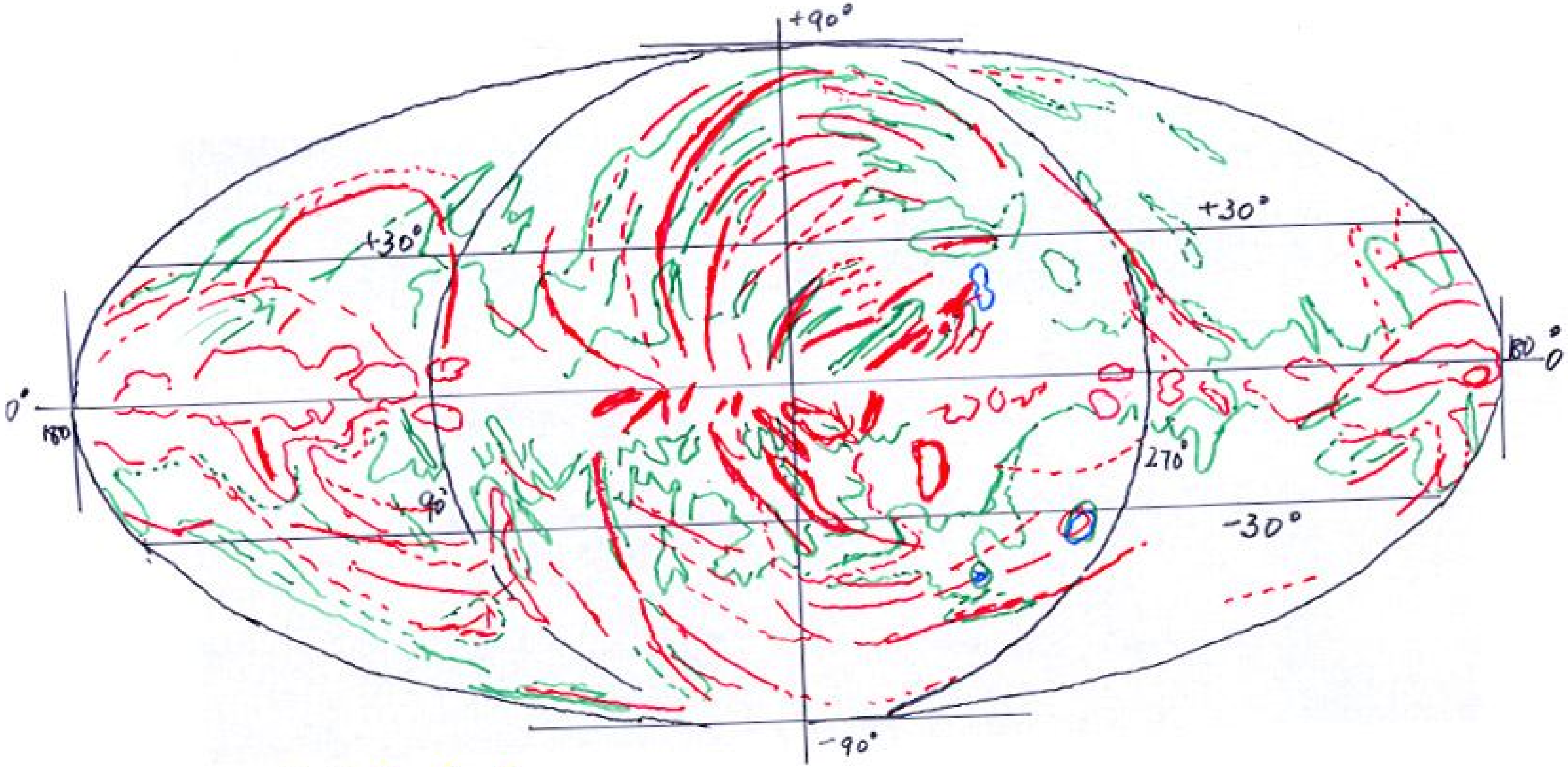
Galactic wind?
Fermi bubble!
X-ray
X-ray
jet
WMAP haze
B field
Sun
Galactic disk
8.5 kpc

WMAP K-band polarized intensity



The magnetic field configuration surrounding the centre (Vidal et al. 2012)

My sketchy road map of the polarized sky



— Magellanic Cl + Cen A

— K Polarization amplitude - mag. field aligned with each feature

— 408 MHz (Total - not HII-corrected)

I trust that my road map of the Interstellar Medium has brought us to some interesting destinations where Planck will be shedding exciting new illumination.

Will there also be by-ways not even dreamed of?