DIFFUSE LOW-FREQUENCY GALACTIC COMPONENTS

Foreground components include :--

..Synchrotron emission from relativistic electrons in magnetic fields.

..Free-free emission from ionized hydrogen (and helium).

..Anomalous emission from small spinning dust grains

..Thermal (vibrational) emission from larger dust grains.

..The emission associated with the gamma-ray bubbles.

We consider the structure of the emission at :--

..intermediate and higher latitudes including the Gould Belt system, the spurs, the haze/bubbles and the local matter (HI, dust, CO etc.).

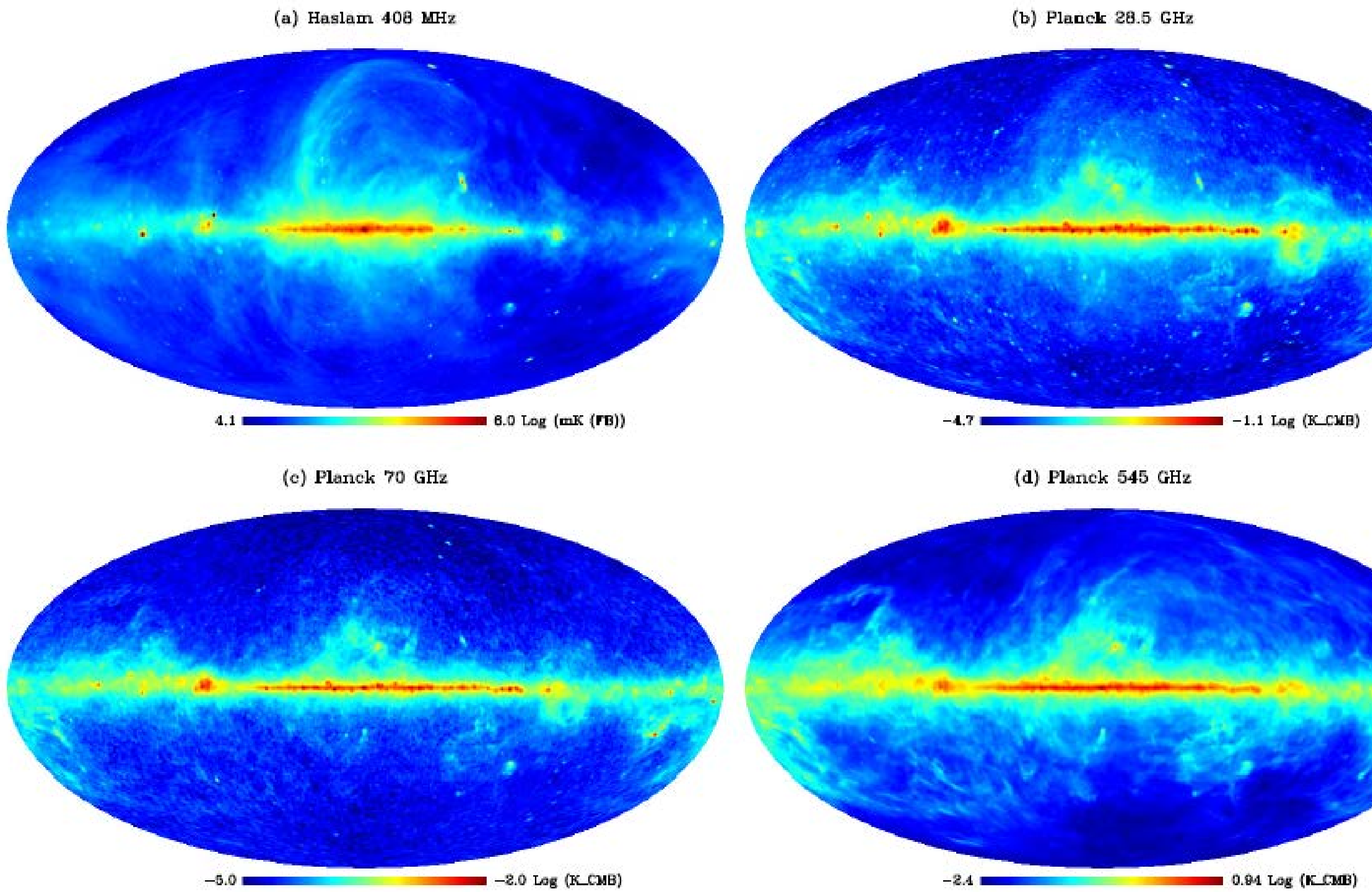
..the Galactic plane within the inner Galaxy in all components.

..We show how the Planck data are improving our knowledge in these areas.

Rodney Davies, Jodrell Bank Centre for Astrophysics,
University of Manchester, U.K.

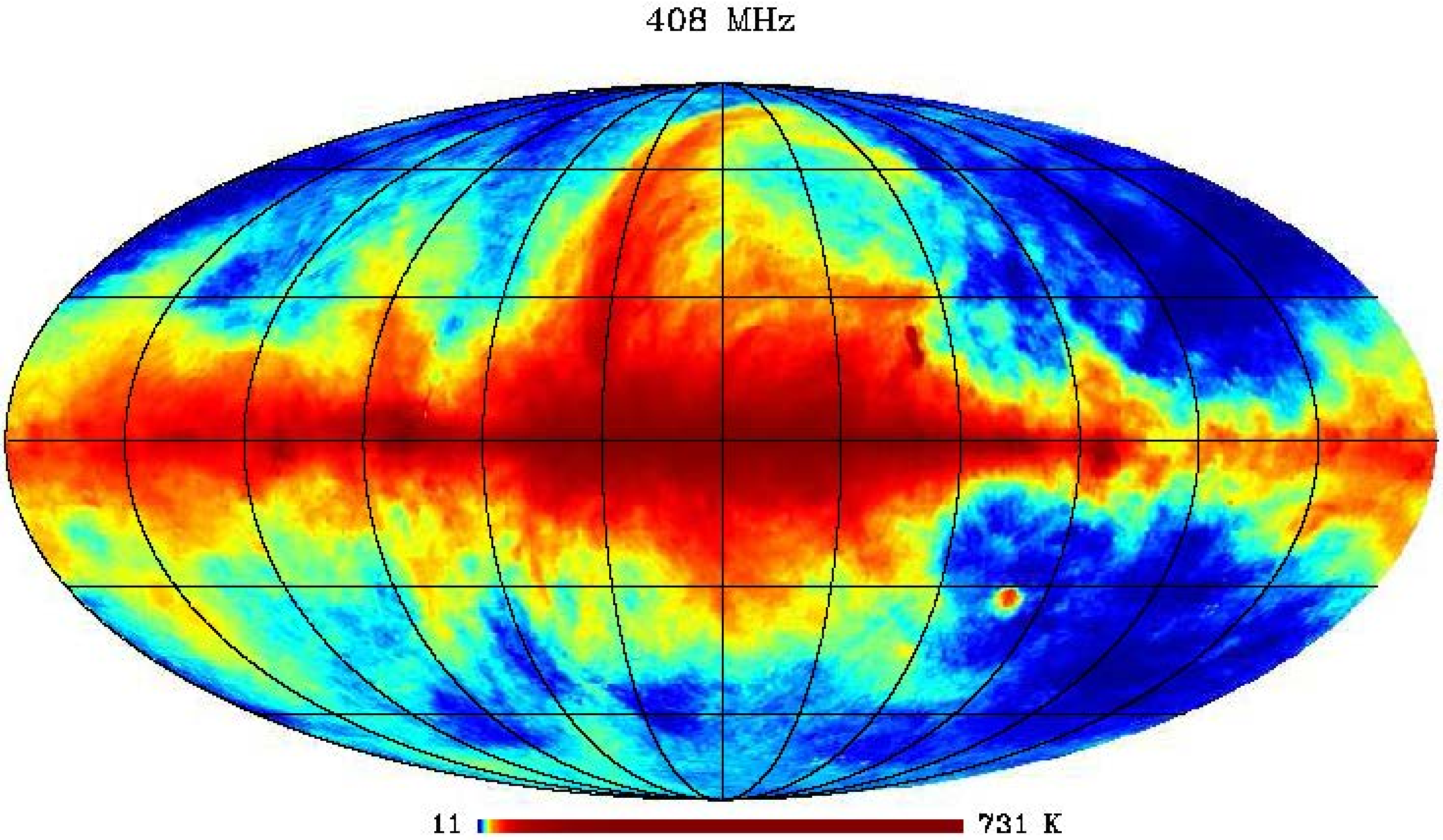
Planck Collaboration

The Galactic emission components as seen by Planck



In progressing from 408 MHz through the <u>Planck</u> frequencies we see synchrotron, free-free plus spinning dust (AME) and finally thermal dust emission.

FULL-SKY SYNCHROTRON EMISSION(1)

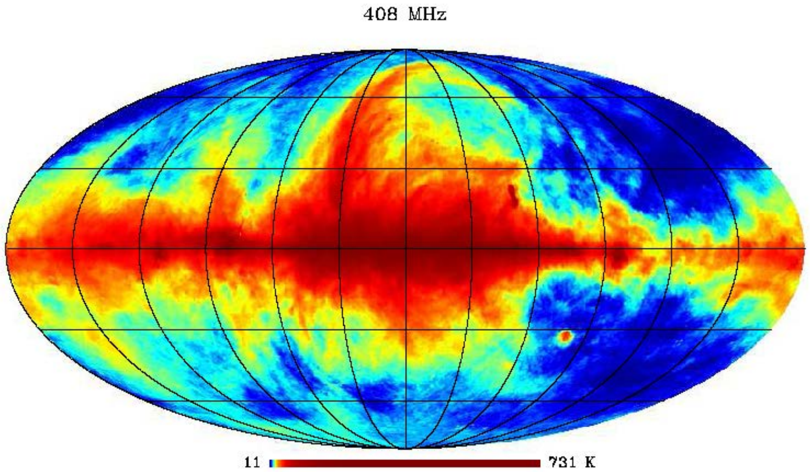


•At 408 MHz most of the emission is synchrotron.

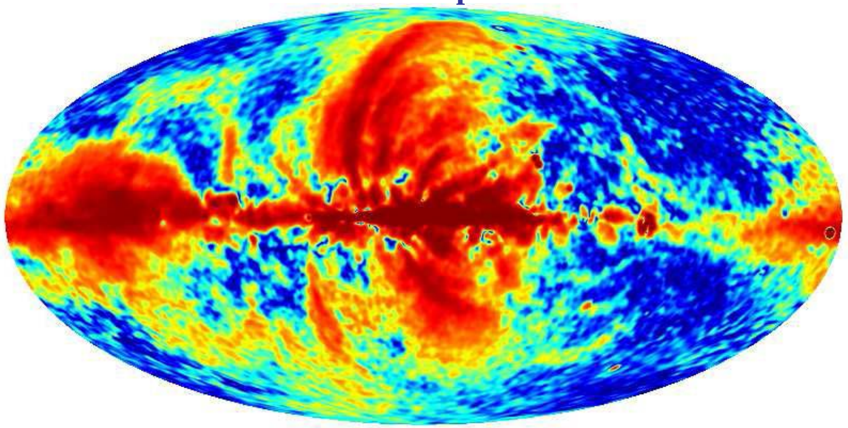
•In some areas there is significant free-free emission eg. the Gould Belt system, the Gum Nebula and the Galactic plane.

•A free-free – corrected map can be constructed.

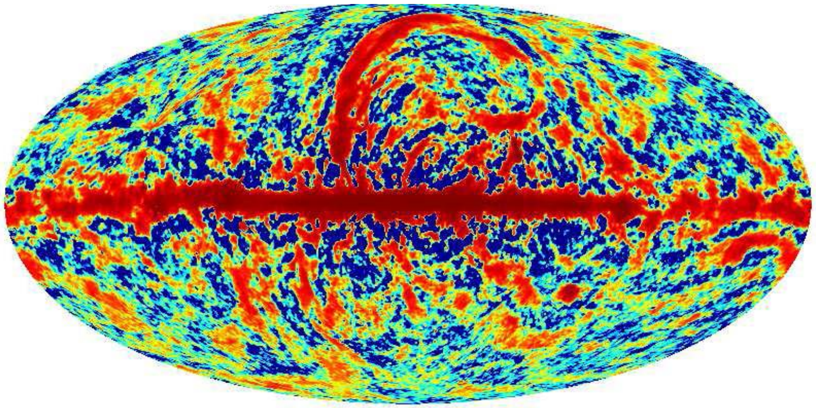
FULL-SKY SYNCHROTRON EMISSION (2)



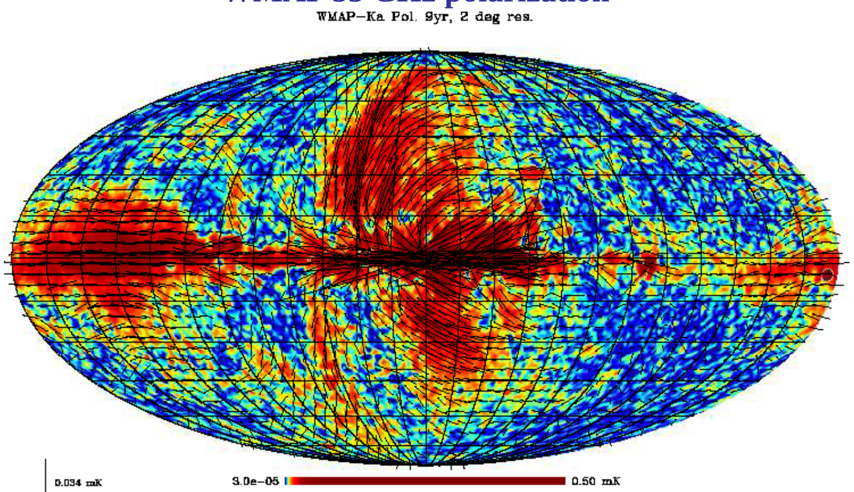
WMAP 23 GHz polarization



408 MHz 5º unsharp mask

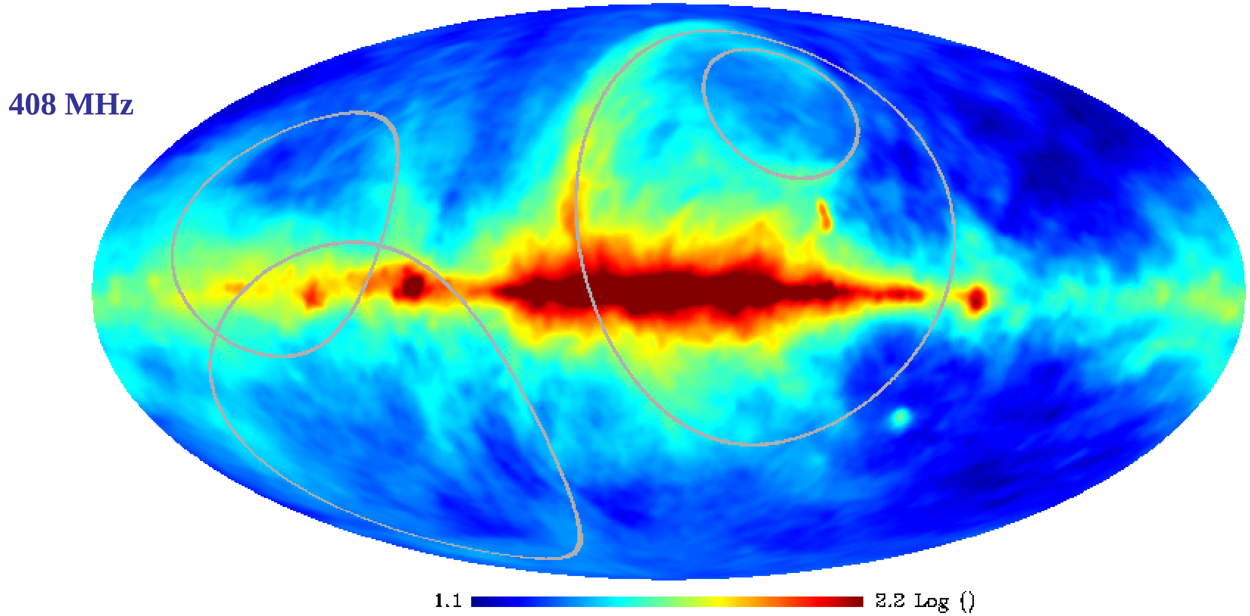


WMAP 33 GHz polarization



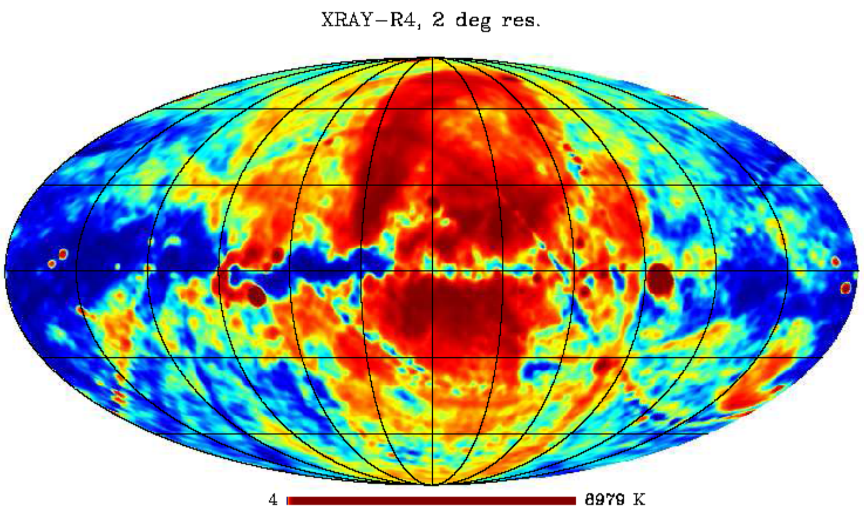
- **The 408 MHz features are clearly seen in the 23 & 33 GHz polarization data.**
- **Polarization cancellation due to orthogonal overlying fields is evident near the plane**
- **<u>Planck LFI</u> polarization data are still to come. They will clarify this structure.**

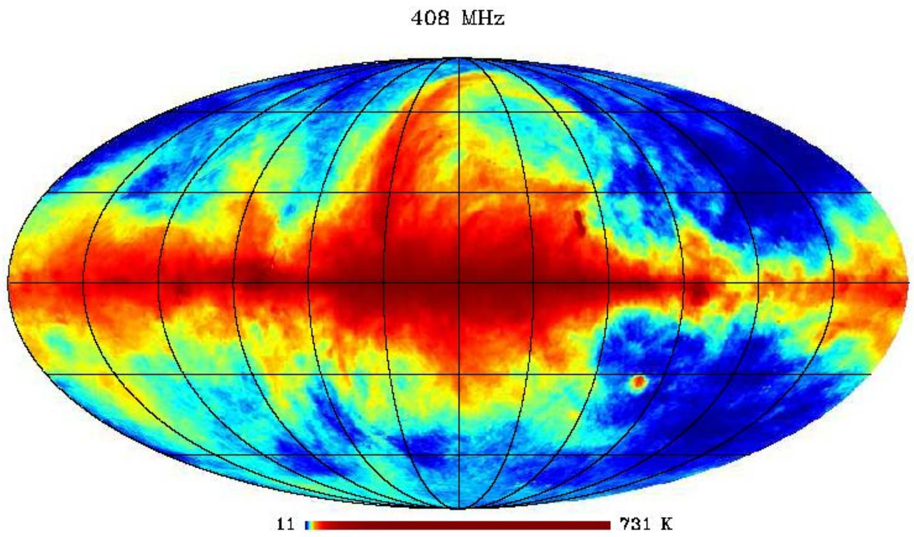
SYNCHROTRON EMISSION – ITS ORIGINS (1)

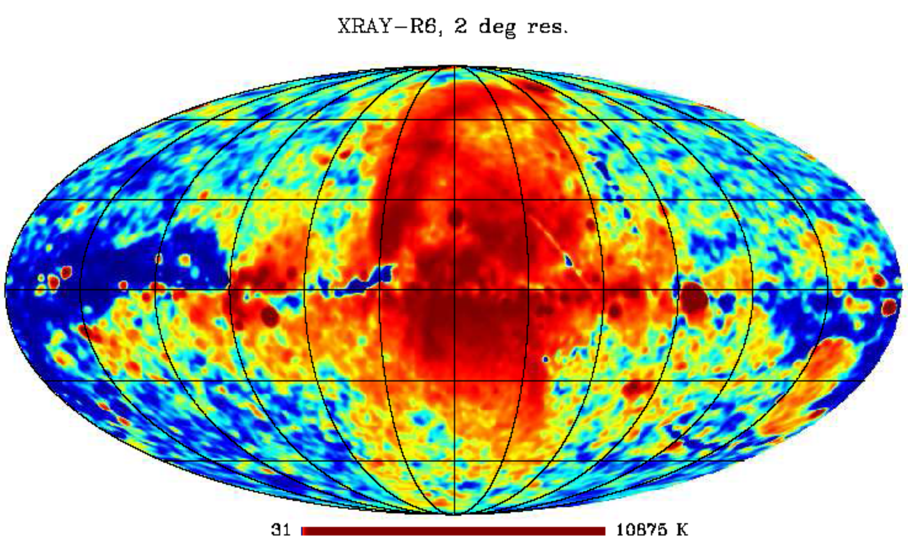


- **Large-scale loops have been identified in low frequency surveys such as that at 408 MHz (Berkhuijsen 1971).**
- **This picture has changed radically with more recent surveys and particularly the WMAP polarization data. Planck polarization data will improve it further.**
- **The polarization information on the magnetic field direction enables many more features to be identified. The field is everywhere tangential to the loops at WMAP/Planck frequencies where the Faraday rotation is a few degrees at most.**
- **The loops appear to be expanding shells - most likely old SNRs.**

SYNCHROTRON EMISSION –ITS ORIGINS (2).







- **The NP Spur is a nearby (100 – 200 pc) SNR lying within the Gould belt system.**
- **The bright outer edge of the NPS is clearly defined in the higher energy X-rays**
- **The associated X-ray emission shows absorption near the plane as expected for the GB system.**
- **This radio emission is superposed on any emission towards the Galactic Centre such as the haze/bubbles (<u>Planck collaboration</u> 2012 arXiv 1208.5483P) and any GC outflows (Carretti et al. 2013 and this meeting).**

Gamma-ray and radio haze/bubbles

•Fermi Gamma-ray Space Telescope found an Inverse-Compton haze signal extending above and below the Galactic centre.

•A radio haze with the same energy spectrum had a similar morphology (Dobler et al. 2010, Su et al. 2010).

•This was thought to imply a new mechanism for cosmic ray acceleration in the centre of the Galaxy. Many mechanisms have been proposed including a high SN rate (Biermann 2010).

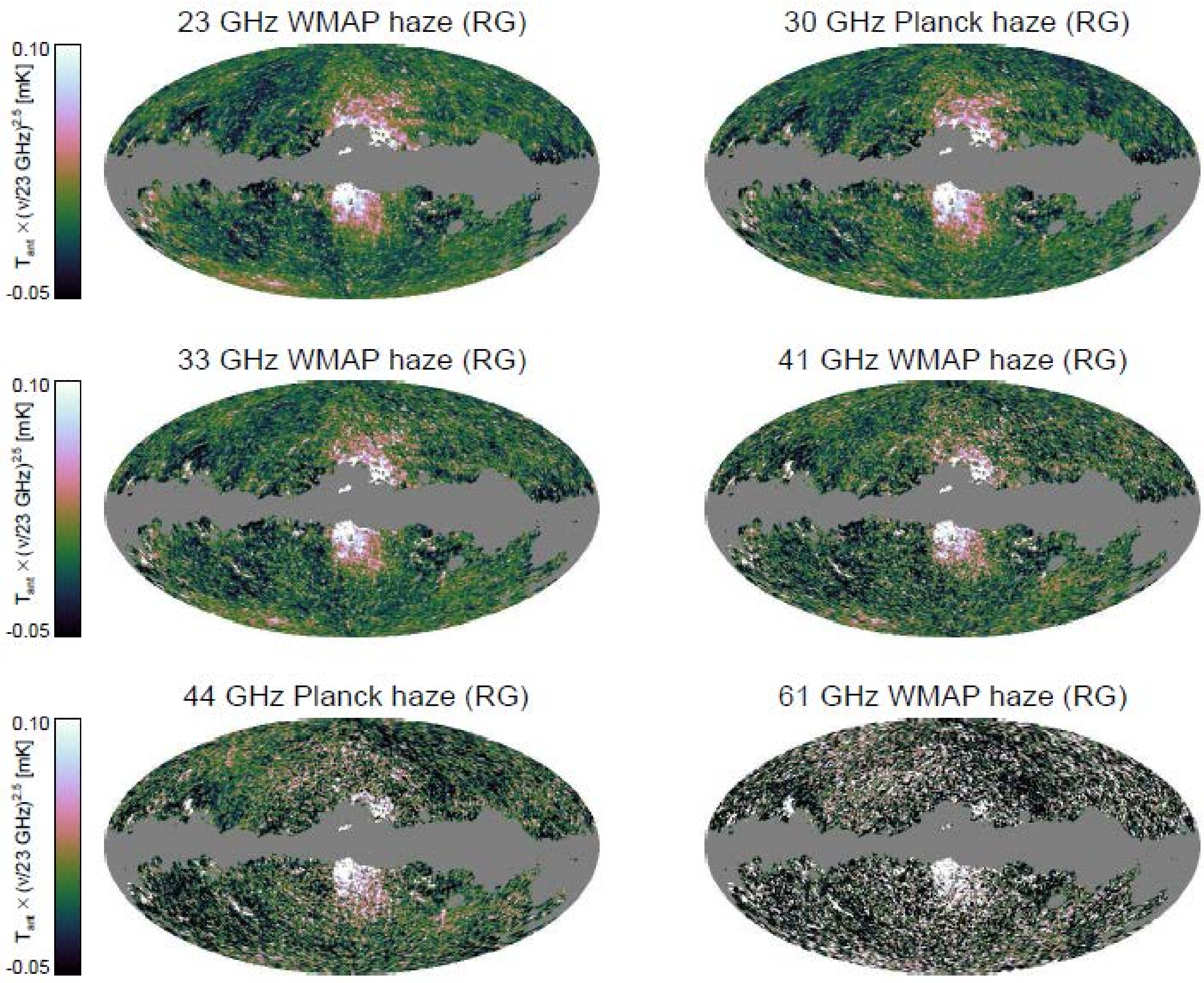
•The wide frequency coverage of <u>Planck</u> allows a more secure component separation to be made (<u>Planck</u> Collaboration 2012arXiv 1208.5483P).

•The brightness of the haze, when scaled to a spectral index of -2.5, is constant at frequencies of 23 to 61 GHz; elsewhere the index is -3.1.

•The morphologies of the radio and the gamma-rays are similar.

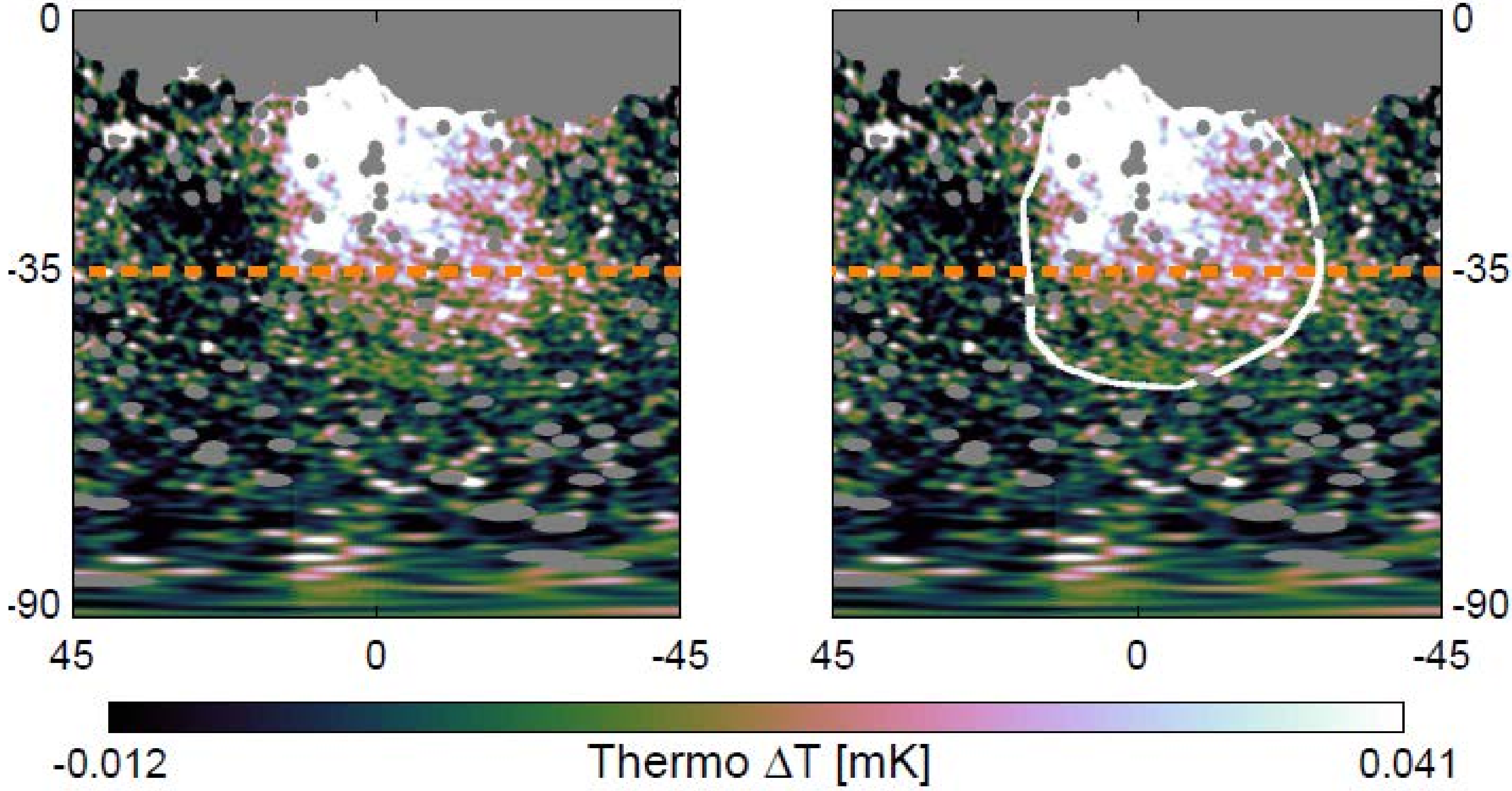
•The CR electron acceleration mechanism is still to be understood.

THE HAZE AS SEEN BY PLANCK AND WMAP

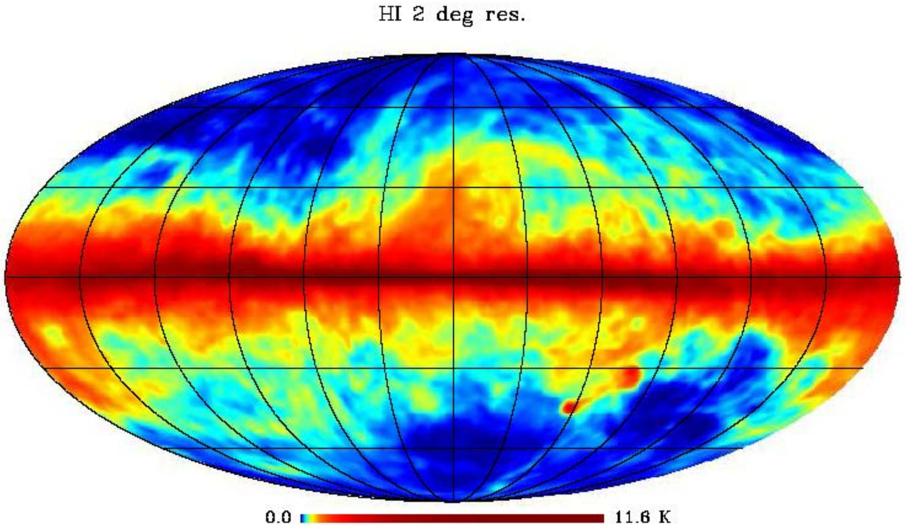


THE PLANCK VIEW OF THE SOUTHERN HAZE

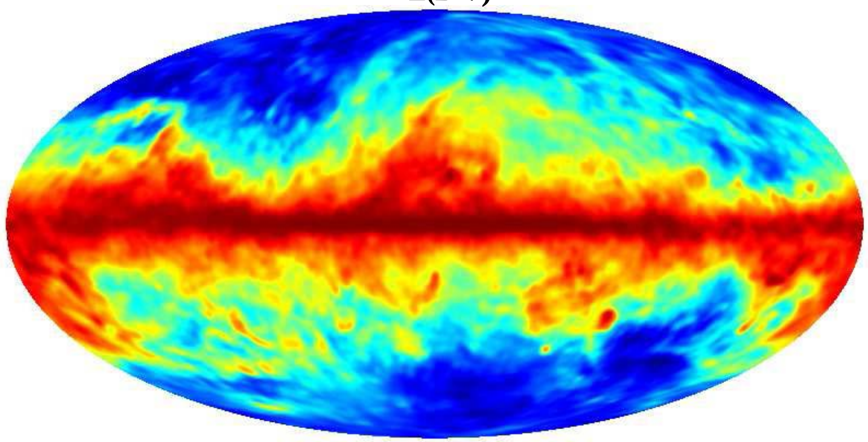
30 GHz haze - South | **Gamma-ray bubble – white line**



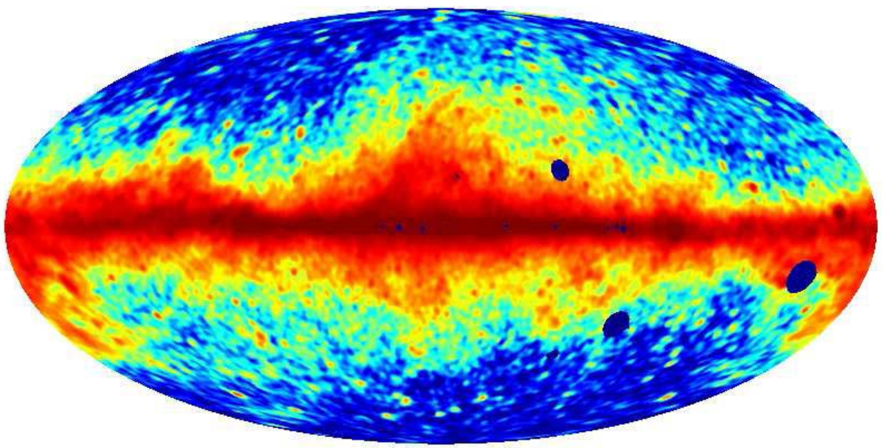
THE TOTAL GASEOUS MATTER

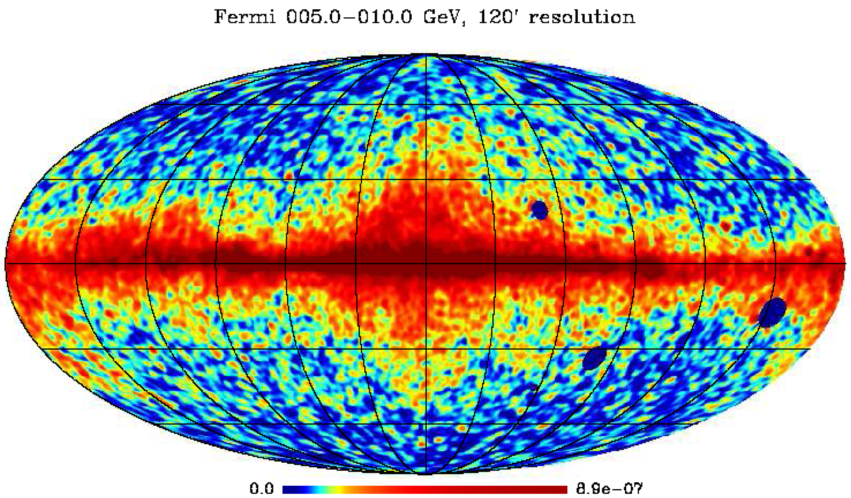


E(B-V)



Fermi 1.0 – 2.0 GeV

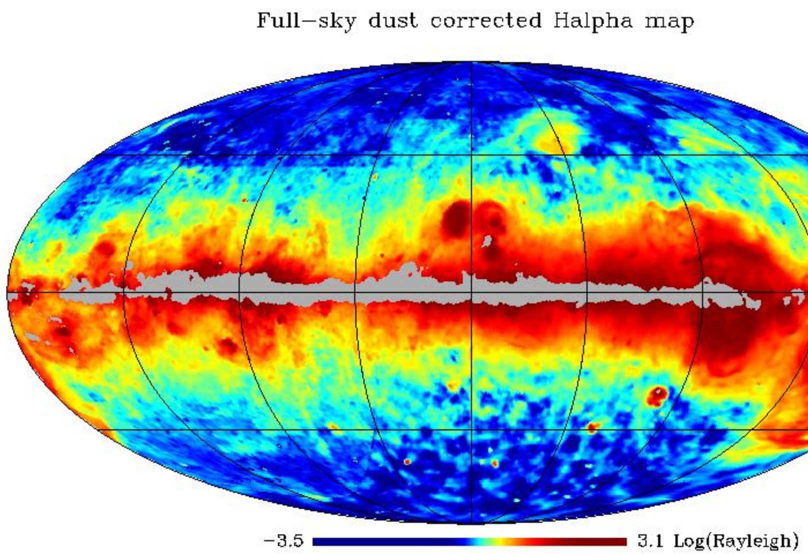


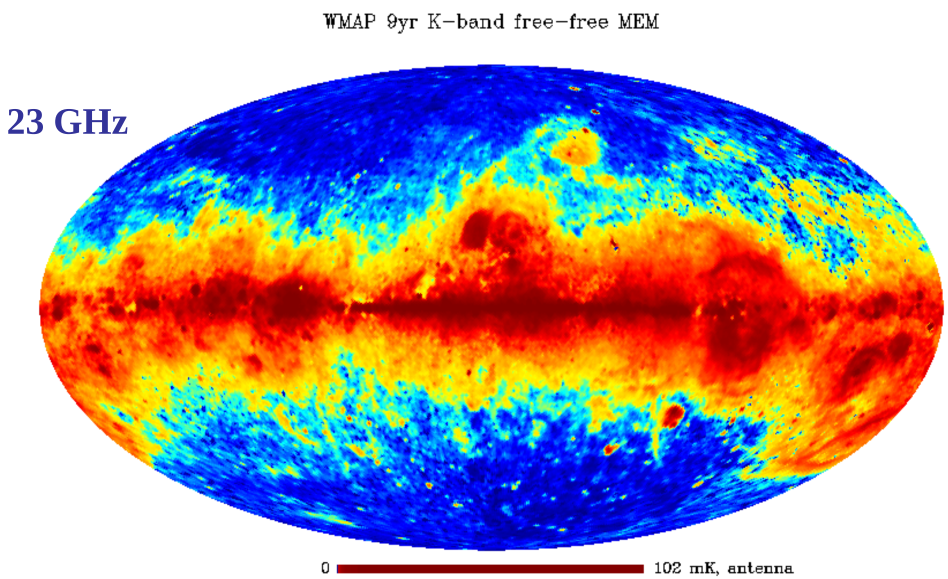


Note the filamentary structure in HI and dust at high latitudes – particularly the NP Spur region.

•The gamma-rays (particularly 1.0 – 2.0 GeV) follow the Gould Belt matter distribution.

ALL-SKY FREE-FREE EMISSION





- **Halpha data give a good estimate of the free-free emission over most of the sky (D^3 2003).**
- **A correction is required to account for absorption by dust in the line of sight.**
- **An electron temperature is needed for the free-free estimate.**
- **Some account is needed for the scattering of the Halpha by dust.**

- **Radio observations can cover the regions where absorption makes the Halpha measure unreliable.**
- **This is important on the Galactic plane and in the Gould Belt with use of RRLs.**
- **Here component separation is necessary. See next slide re Planck.**

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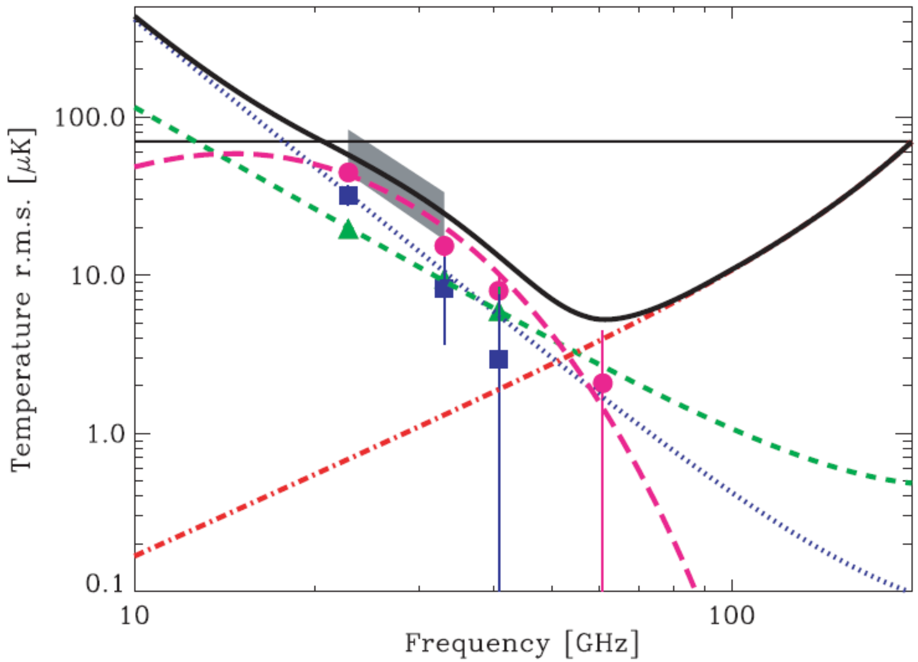
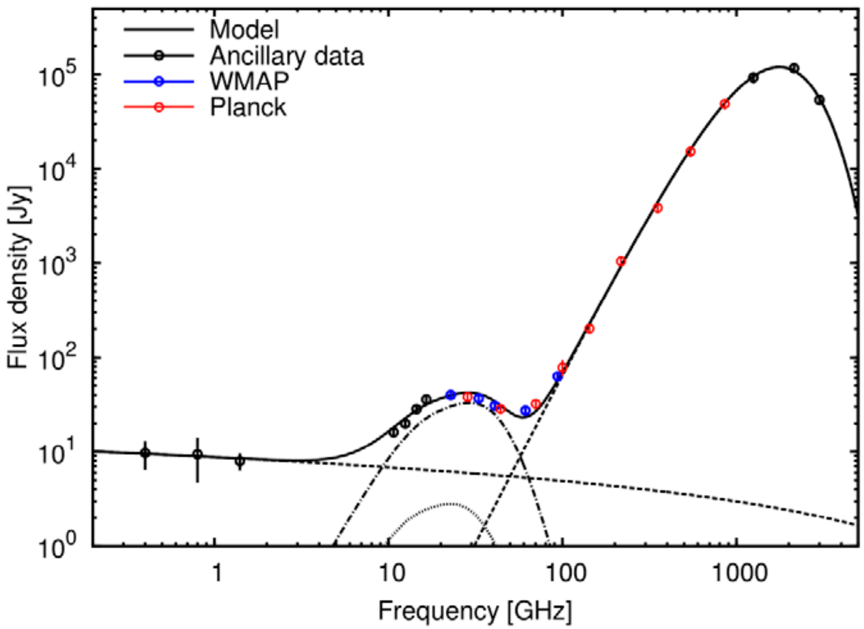
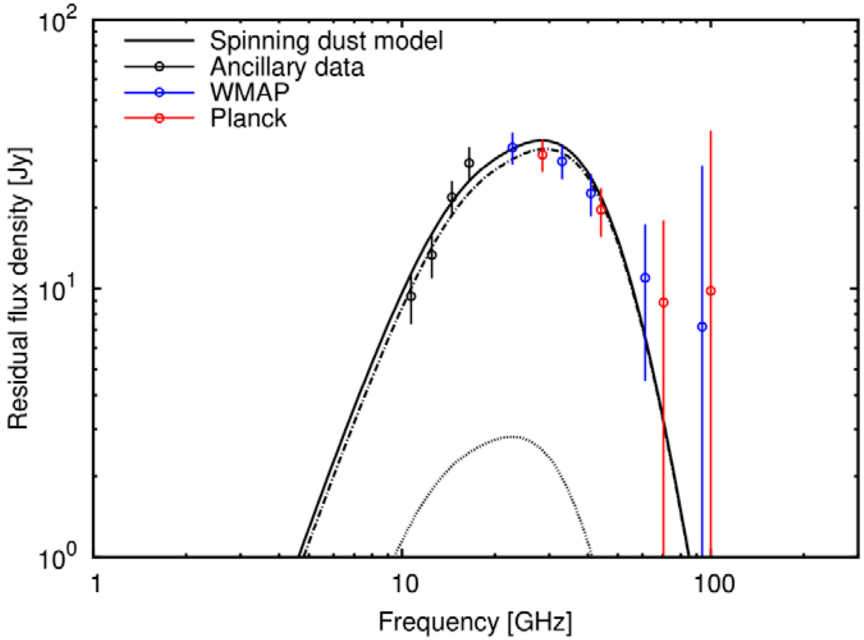
ALL-SKY SPINNING DUST - ANOMALOUS MICROWAVE EMISSION



- **The approximate amplitudes of the 4 emission components as found with cross-correlation analysis on the WMAP full-sky data using a Kp2 mask (Davies et al.2006) .**
- **The CMB is 70 microK, corresponding to 1º resolution.**
- **The spectral indices are -3.1. -2.14 and +1.7 for synchrotron. free-free and thermal dust. The spinning dust emission is a Draine & Lazarian model.**
- **Planck, with its wide frequency coverage, greatly improves the separation.**

SPINNING DUST in the Perseus Molecular Cloud



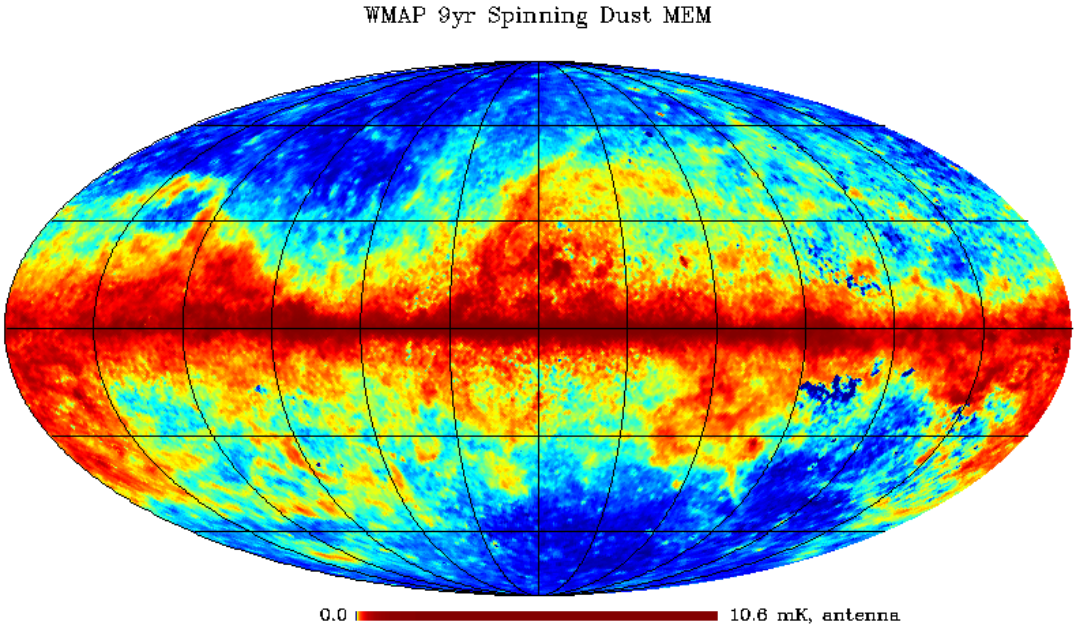


•A combination of Planck and WMAP data with higher and lower frequency data provides a well-defined spectrum of spinning dust (Planck collaboration 2011 A&A, 536 A20) for the Perseus Molecular Cloud.

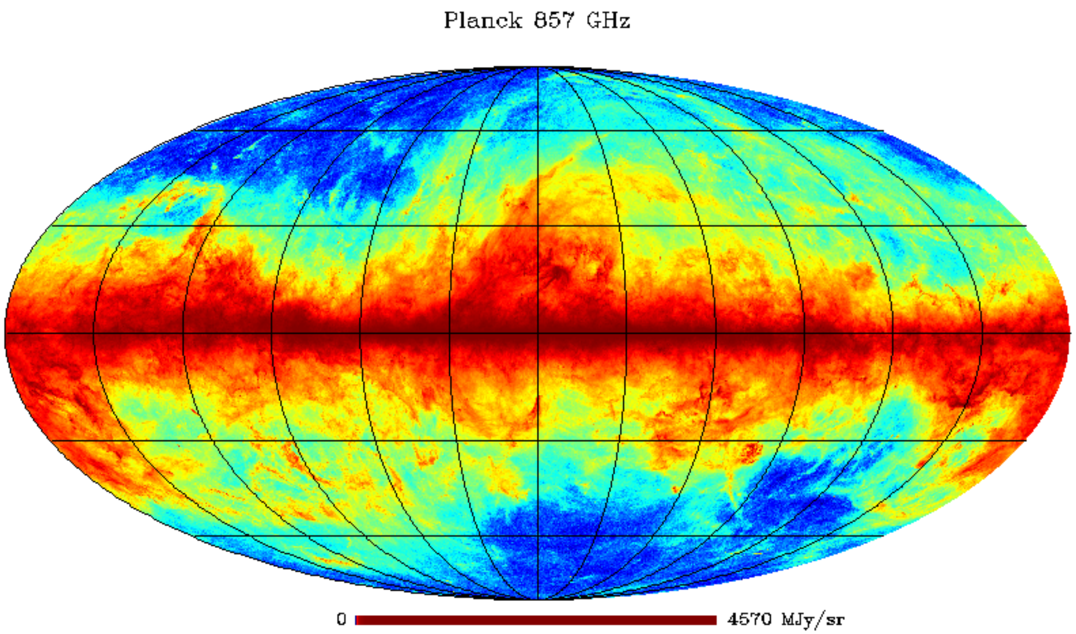
•The shape of this spectrum is a function of the dust properties and the ambient conditions (Draine & Lazarian 1998).

•An extensive study of individual spinning dust clouds using Planck data is presented at this meeting (Planck Collaboration 2013 -Clive Dickinson).

ALL-SKY SPINNING DUST



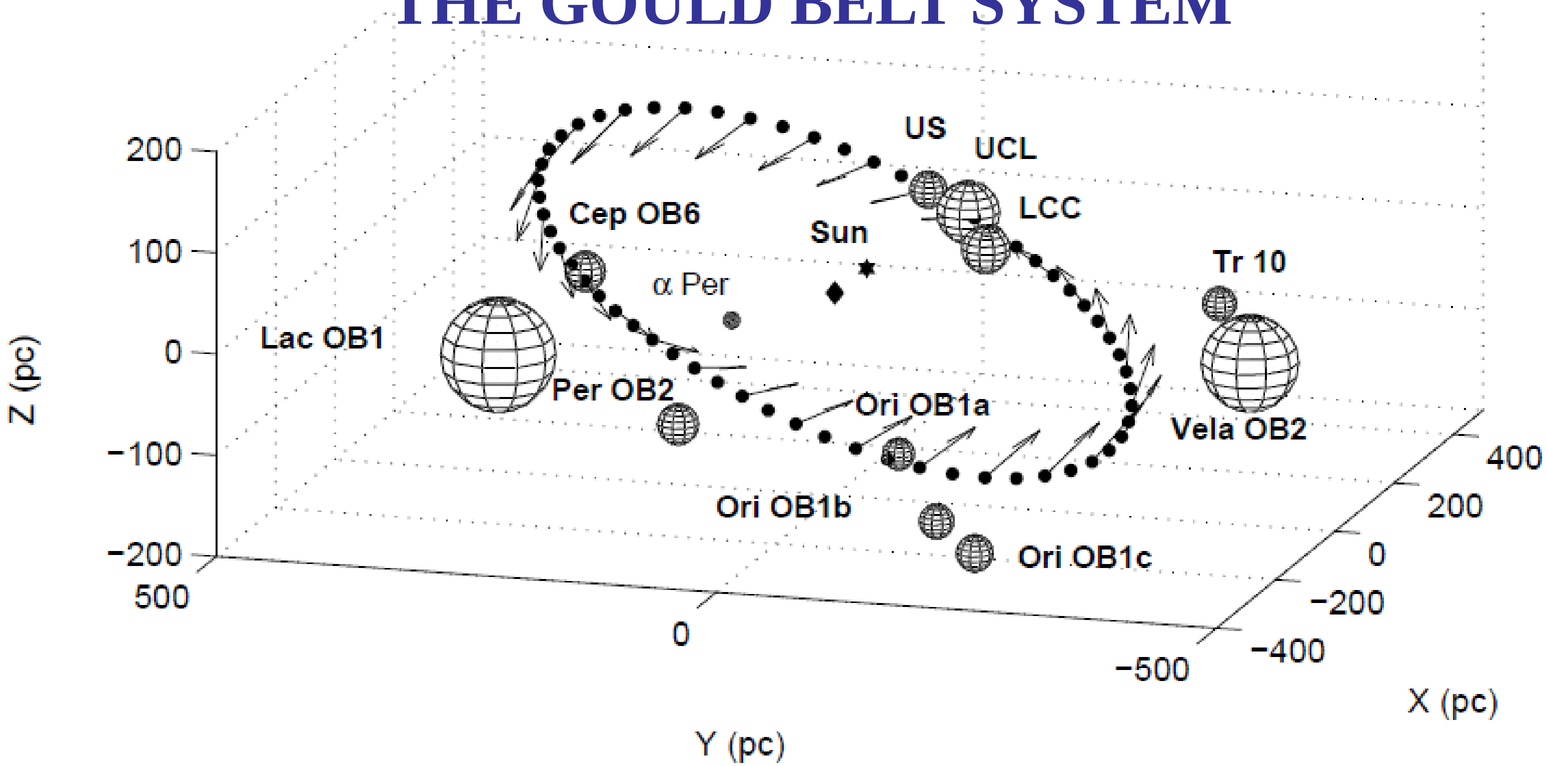
The WMAP (Bennett et al. arXiv 1212.5225) MEM spinning dust solution uses the 100 micron IRIS map as a prior since it is a good indicator of the dust distribution. Although the 100 micron emission refers to the larger dust grains, the smaller grains responsible for AME have a similar distribution. Note the prior in the weaker areas.



The 857 GHz Planck map is, not surprisingly, similar to the spinning dust distribution down to the finest detail because of the use of a dust prior.

The determination of AME in the Gould Belt System using Planck data will be discussed by Anna Bonaldi at this meeting (Planck Collaboration 2013 arXiv 1301.5839P)

STRUCTURE AT INTERMEDIATE LATITUDES
THE GOULD BELT SYSTEM



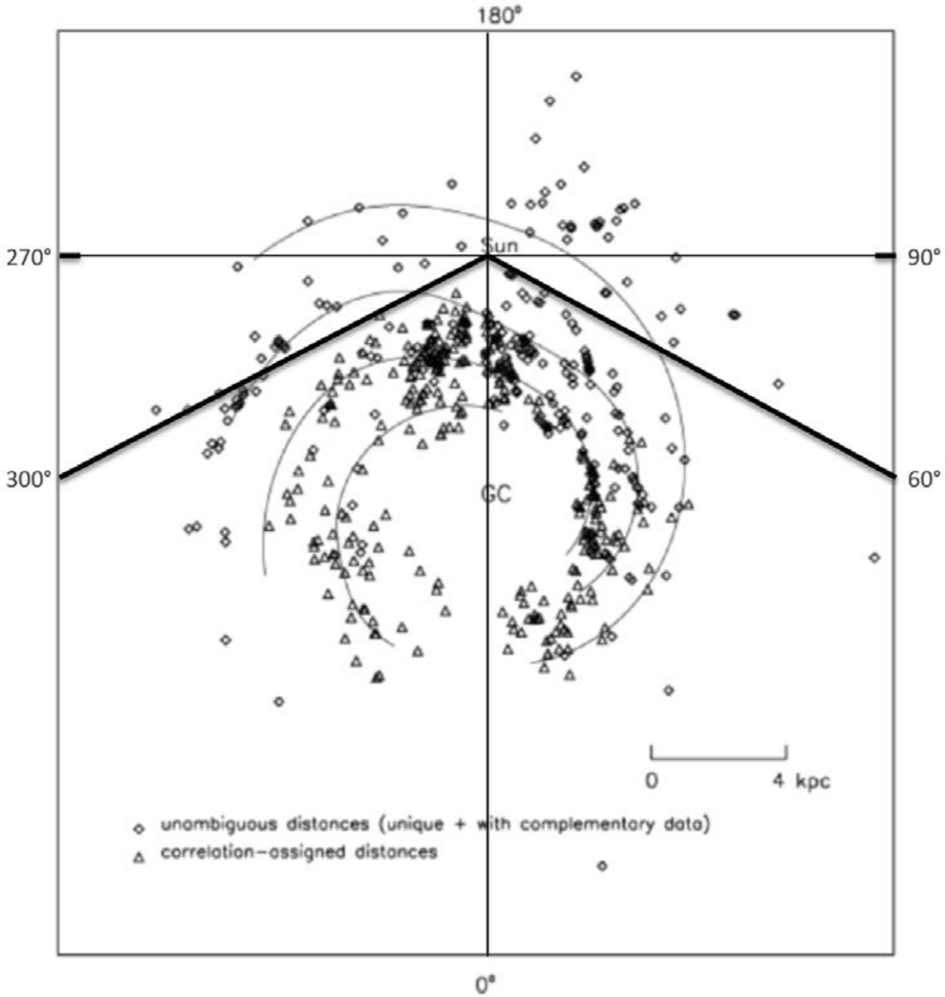
•The Gould Belt System is a rotating region of gas and stars born 30 x 10^6 yrs ago (Lindblad et al. 1997). Accurate distances of OB associations from Hipparcos.

•It includes an expanding shock wave containing a population of gamma-ray sources (Perrot & Grenier 2003) with an age of 26 x 10^6 yr.

•Semi-axes of 370 x 230pc inclined at $17^o.2$ +/-$0^o.5$ to the galactic plane and offset 104pc towards l = 180^o.

•The supernova rate is 3-5 times that of the nearby disc at ~25 per 10^6 yr.

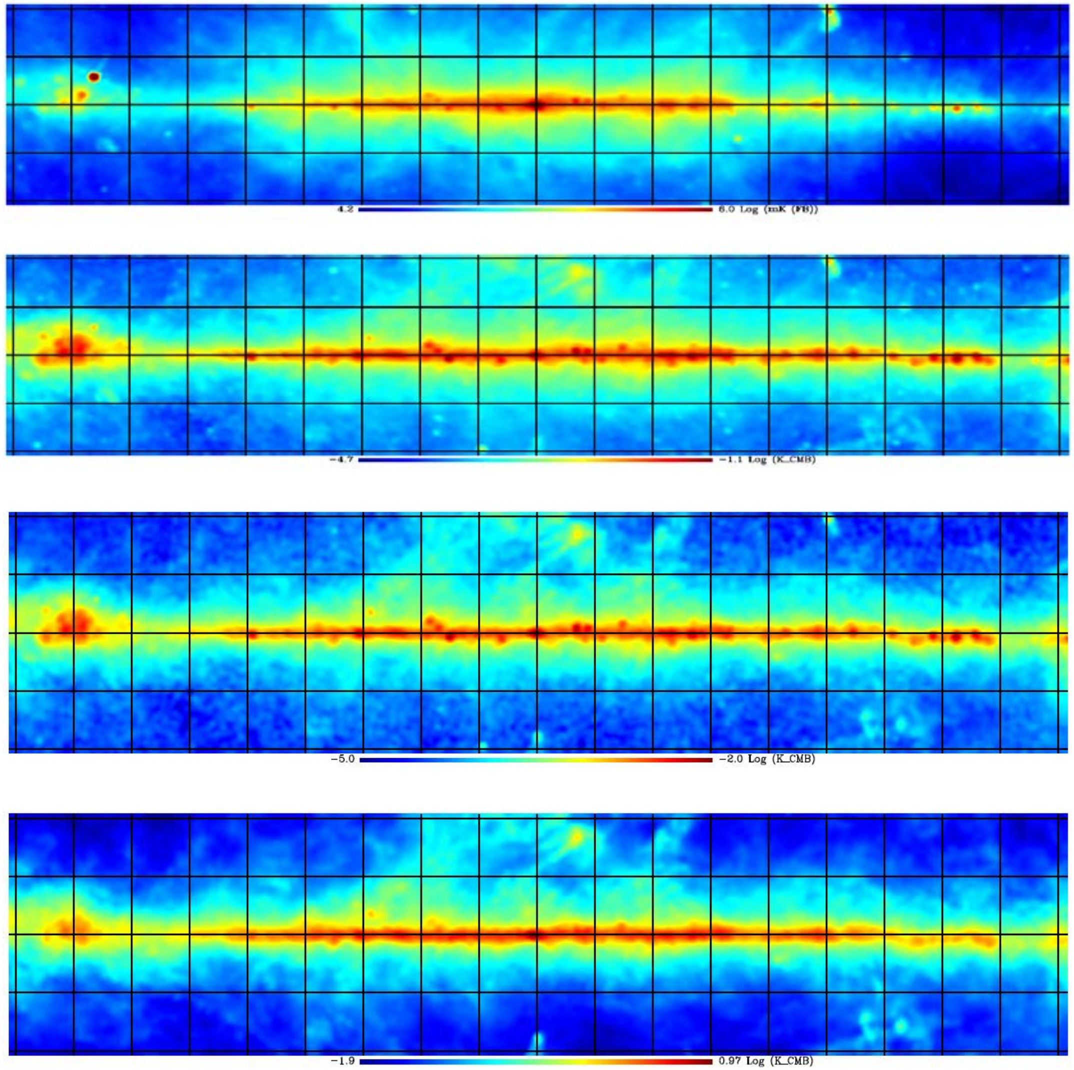
The Galactic plane region of the inner Galaxy



•The map shows the positions of HII regions in the inner Galaxy (Paladini et al. 2004).

•This is the region of highest star formation in the Galaxy.

THE INNER GALAXY



0.408 GHz

Mainly synchrotron. Note the narrow and broader latitude components.

28.5 GHz

Planck

Mainly free-free and AME

70 GHz

Planck

Mainly free-free

545 GHz

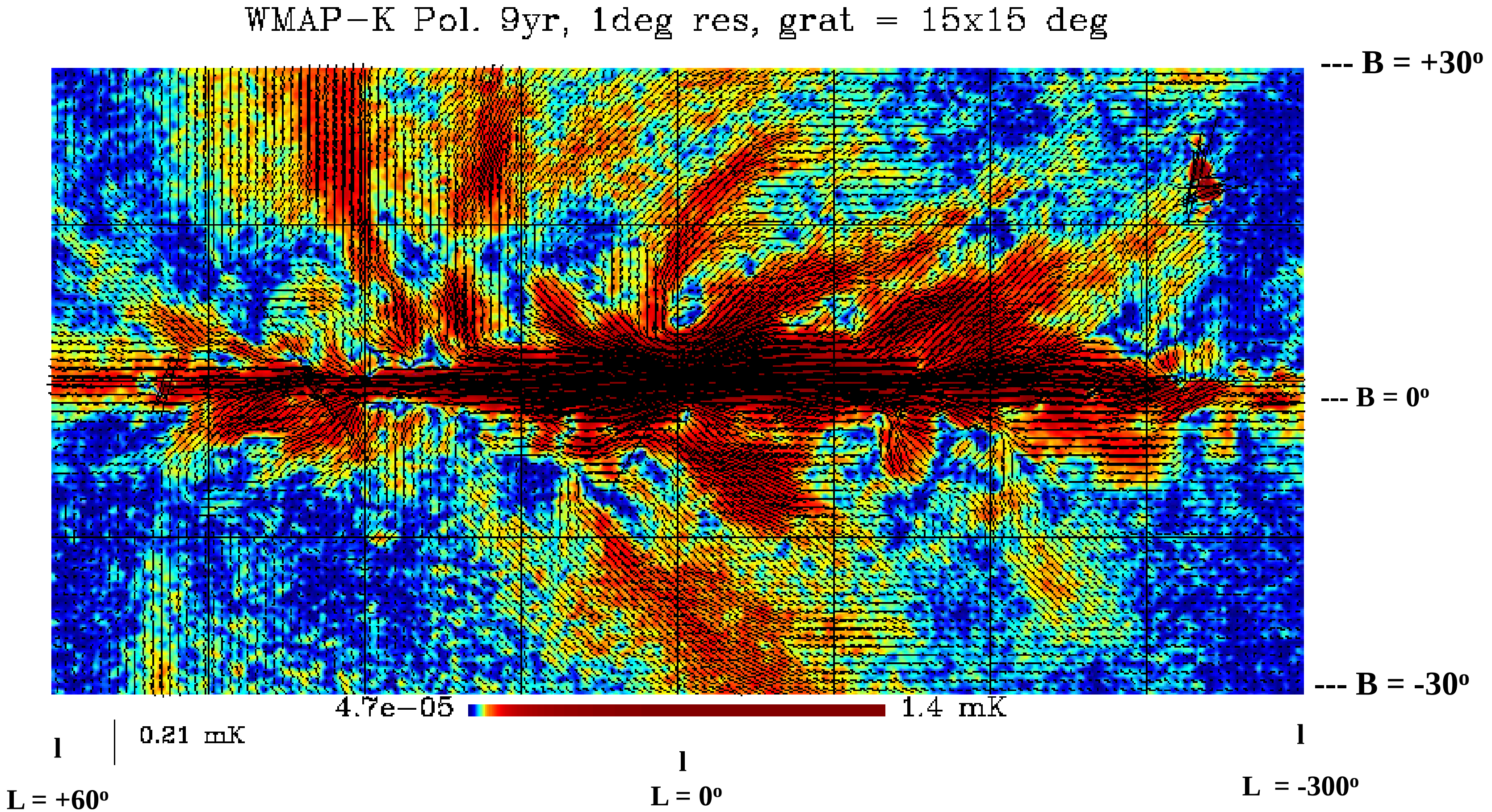
Planck

Thermal dust

l +90^o | l 0^o | l - 90^o

Galactic Longitude

THE INNER GALAXY- SYNCHROTRON POLARIZATION



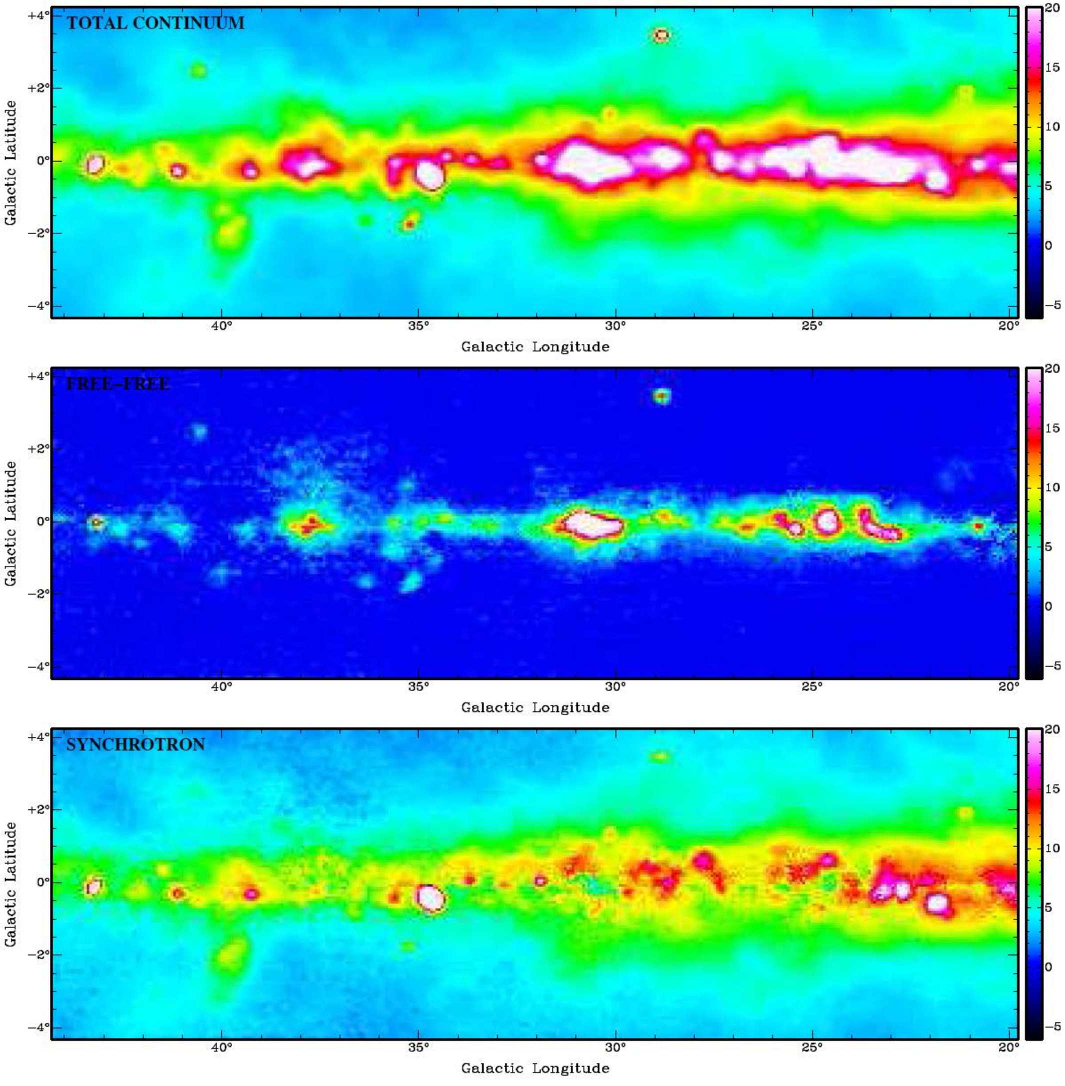
•The magnetic fields are parallel to the curved structures of the elongated features.

•Some features cross the plane – foreground features? <u>Planck LFI</u> polarization data will substantially improve this intriguing picture.

•Only a few features appear to emanate from the Galactic nucleus. See the contribution at this meeting by Carretti et al. (also 2013 Nature 493, 66).

THE INNER GALAXY

The separation of free-free and synchrotron emission

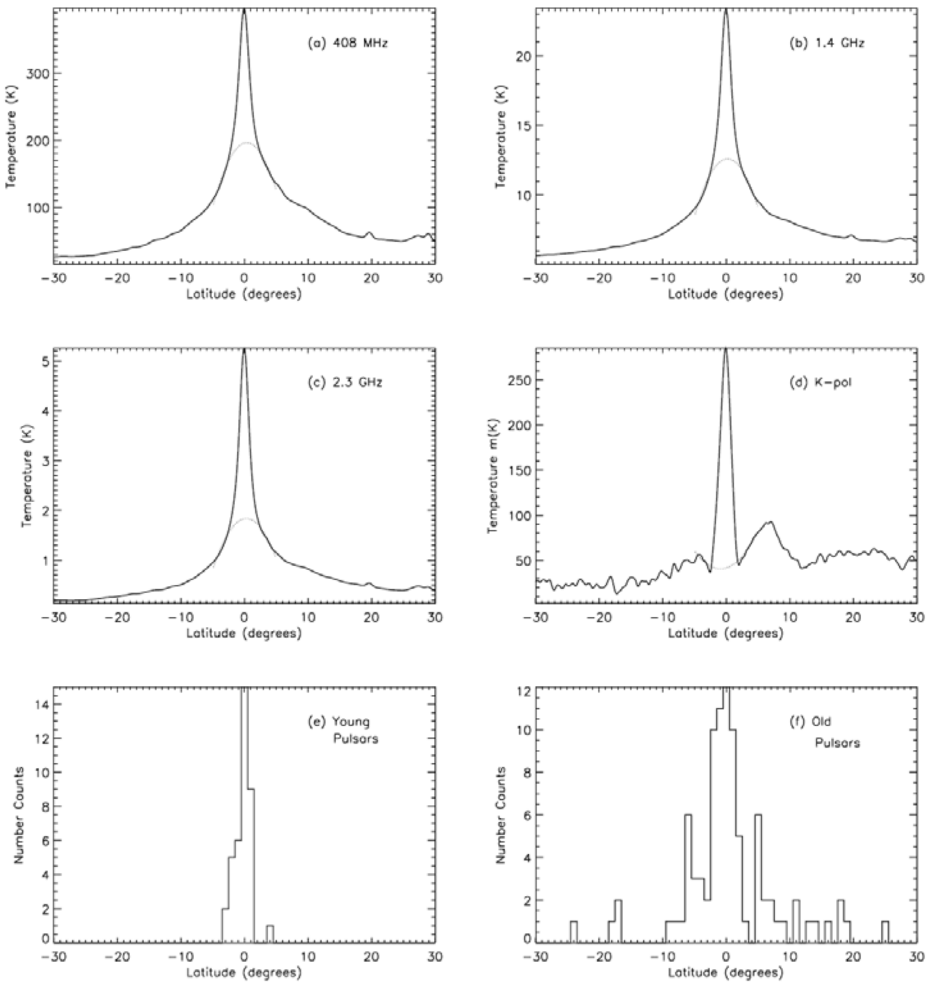


- At 1.4 GHz a substantial fraction of the emission is free-free.
- Radio recombination line (RRL) observations can be used to derive the free emission at 1.4 GHz on the assumption of an electron temperature which for the inner Galaxy is ~6000K (Alves et al. 2012).
- The synchrotron emission at 1.4 GHz is the difference between the total emission and the free-free emission.
- The free-free emission at Planck frequencies can be estimated assuming a spectral index of -2.14.
- The synchrotron spectral index at Planck frequencies estimated from 1.4 GHz is -3.0 to -3.3 for most regions.

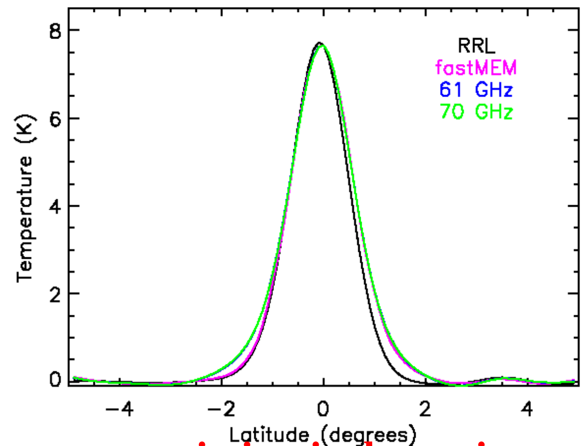
LATITUDE PROFILES

Longitude range = 20^{o} – 30^{o}.

SYNCHROTRON-RELATED



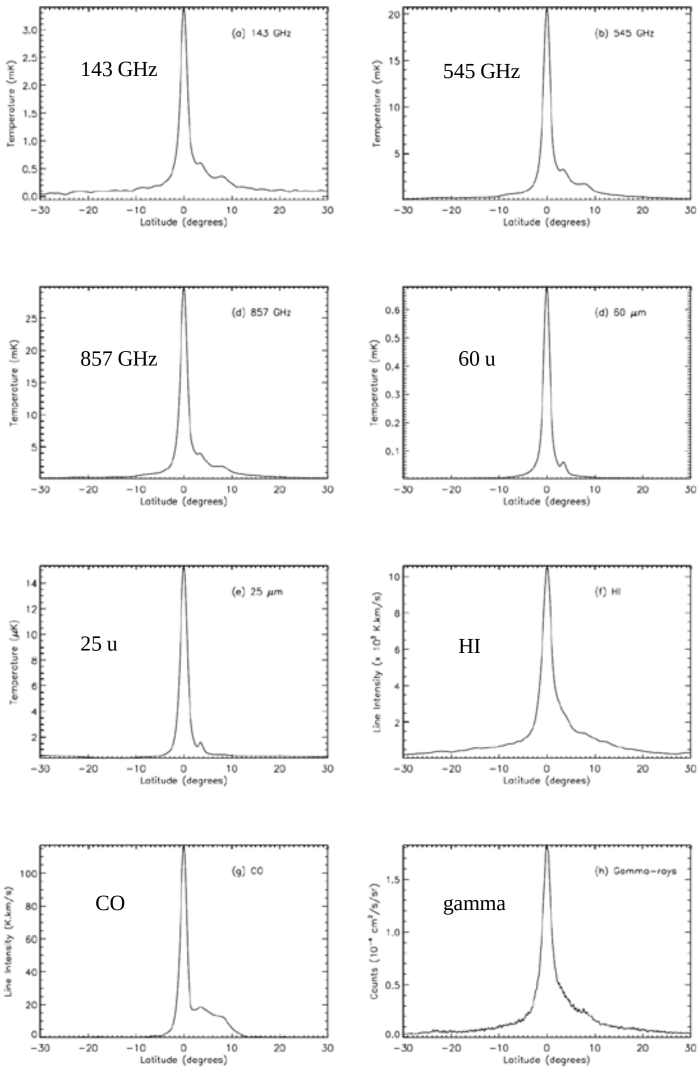
FREE-FREE RELATED



- **Synchrotron emission is the major component at 0.408, 1.4 and 2.3 GHz**
- **Synchrotron has a narrow (1.^{o}7) and a broad (~15^{o}) latitude component.**
- **Narrow synchrotron component clearly seen in polarization. <u>Planck LFI</u> polarization data will strengthen this picture.**
- **The free-free is well-defined in all data - and it follows the RRLs. The fastMEM free-free solution using <u>Planck</u> data agrees closely with the observed RRL data.**

LATITUDE PROFILES – GAS- AND DUST-RELATED

Longitude range = 20^{o} – 30^{o}.



• **A narrow ($1.^{o}2$) component is seen in all <u>Planck HFI</u> channels. In addition there is emission from the Gould Belt at b ~ +8^{o}.**

•**The Gould Belt emission is seen in HI, CO, and gamma-rays.**

•**The Gould Belt emission is relatively weak at 25 and 60 microns.**

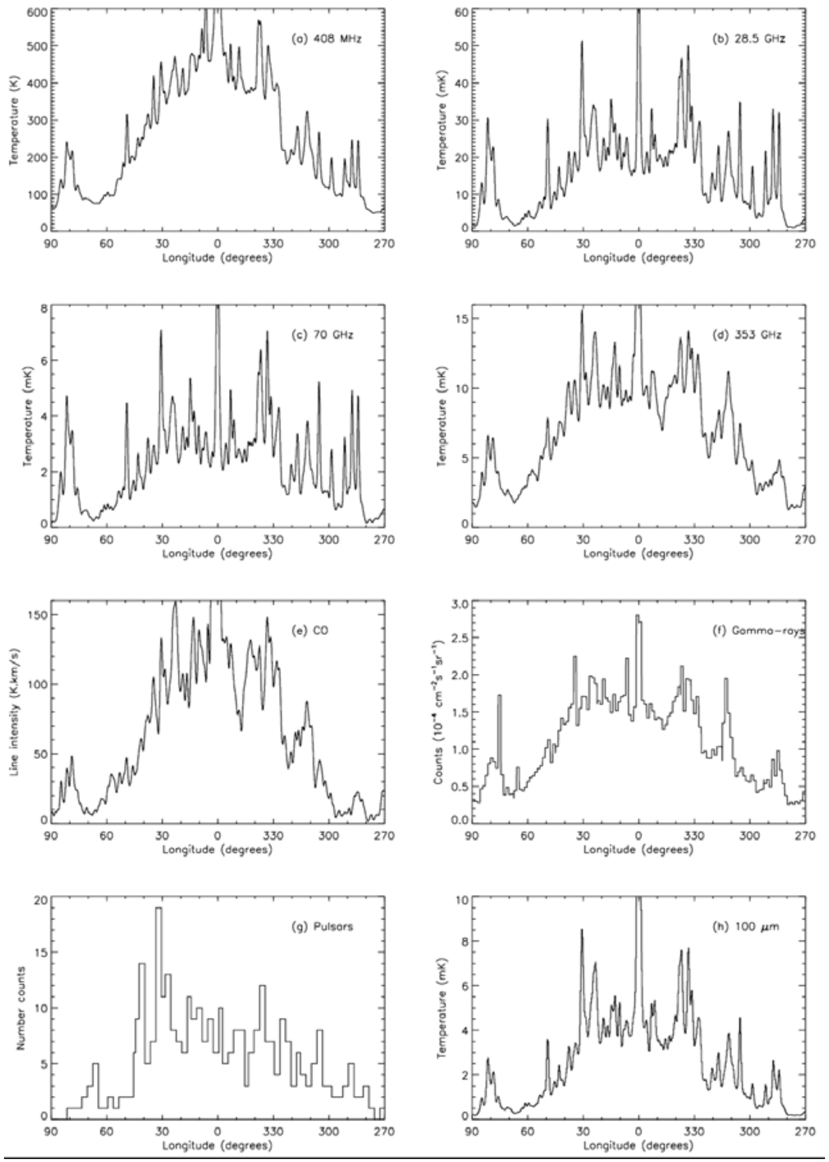
Latitude widths of Galactic components

(Longitudes 320^o – 340^o and 20^o - 40^o.)

•OB stars (Wood & Churchwell 1989)	$0^o.83$ +/-$0^o.05$
•Dense CS clouds (Bronfman et al. 2000)	$0^o.90$ +/-$0^o.05$
•Free-free from RRLs (n_e^2)	$0^o.92$ +/-$0^o.04$
•Free-free from fastMEM on Planck data	$1^o.07$+/-$0^o.05$
•CO	$1^o.19$+/-$0^o.08$
•Thermal dust – FIR(100 micron)	$1^o.24$+/-$0^o.02$
•Thermal dust – Planck 353, 545 & 857GHz	$1^o.30$+/-$0^o.04$
•Gamma-rays (representing total matter)	$1^o.26$+/-$0^o.05$
•Synchrotron, GHz frequencies	$1^o.65$+/-$0^o.05$
•Synchrotron, K-band polarization (WMAP)	$1^o.67$+/-$0^o.13$
•Neutral hydrogen (partially optically thick)	$1^o.98$+/-$0^o.05$

LONGITUDE DISTRIBUTION AT B = 0º

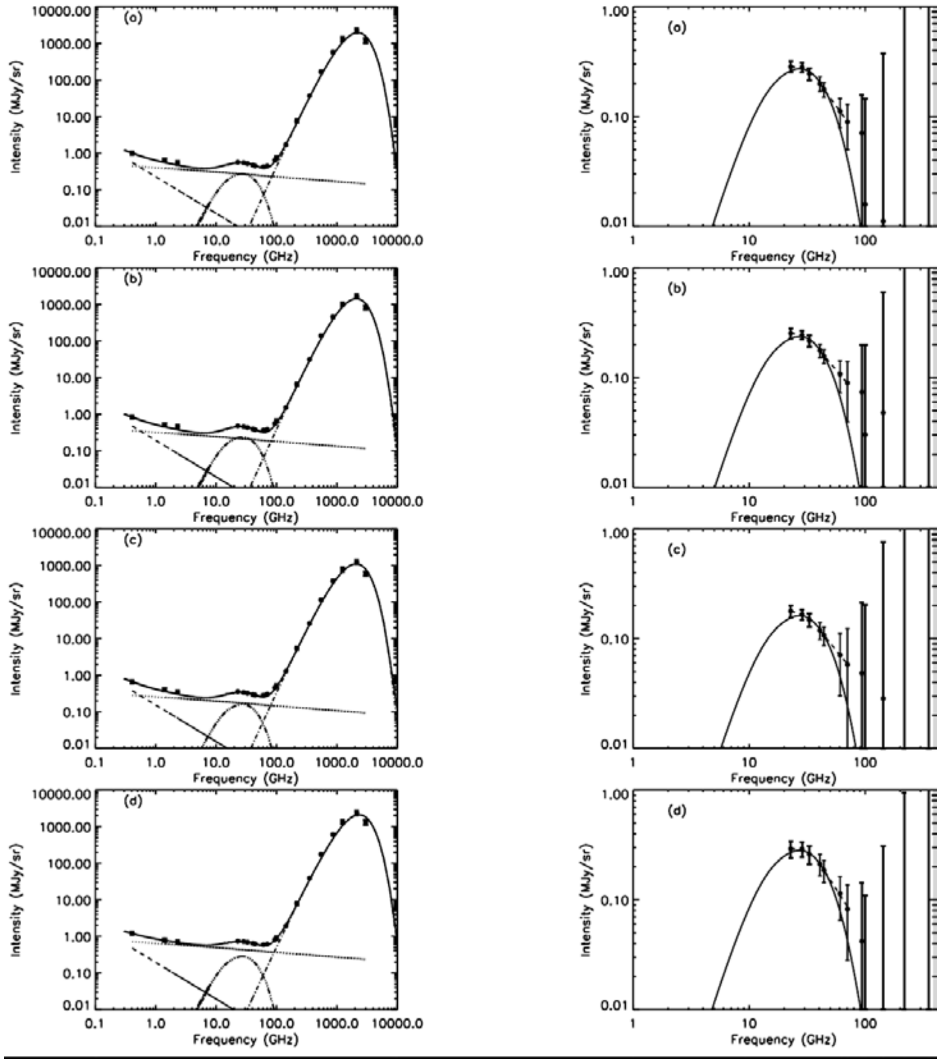
Galactic latitude = 0º with 1º resolution



- **The emission, ranging from radio through <u>Planck</u> frequencies to the FIR, show remarkably similar features - a consequence of recent star-formation on the Galactic plane.**
- **This is in spite their origin in different emission mechanisms.**
- **Such features are the tangents to the Norma-Scutum arm, the Cygnus-X complex, the Gum Nebula.**
- **CO and gamma-rays (plus pulsars?) are similar.**

SEDs IN THE INNER GALAXY AT B = 0º

Longitude ranges 20º – 30º, 30º – 40º, 320º – 330º and 330º – 340º.

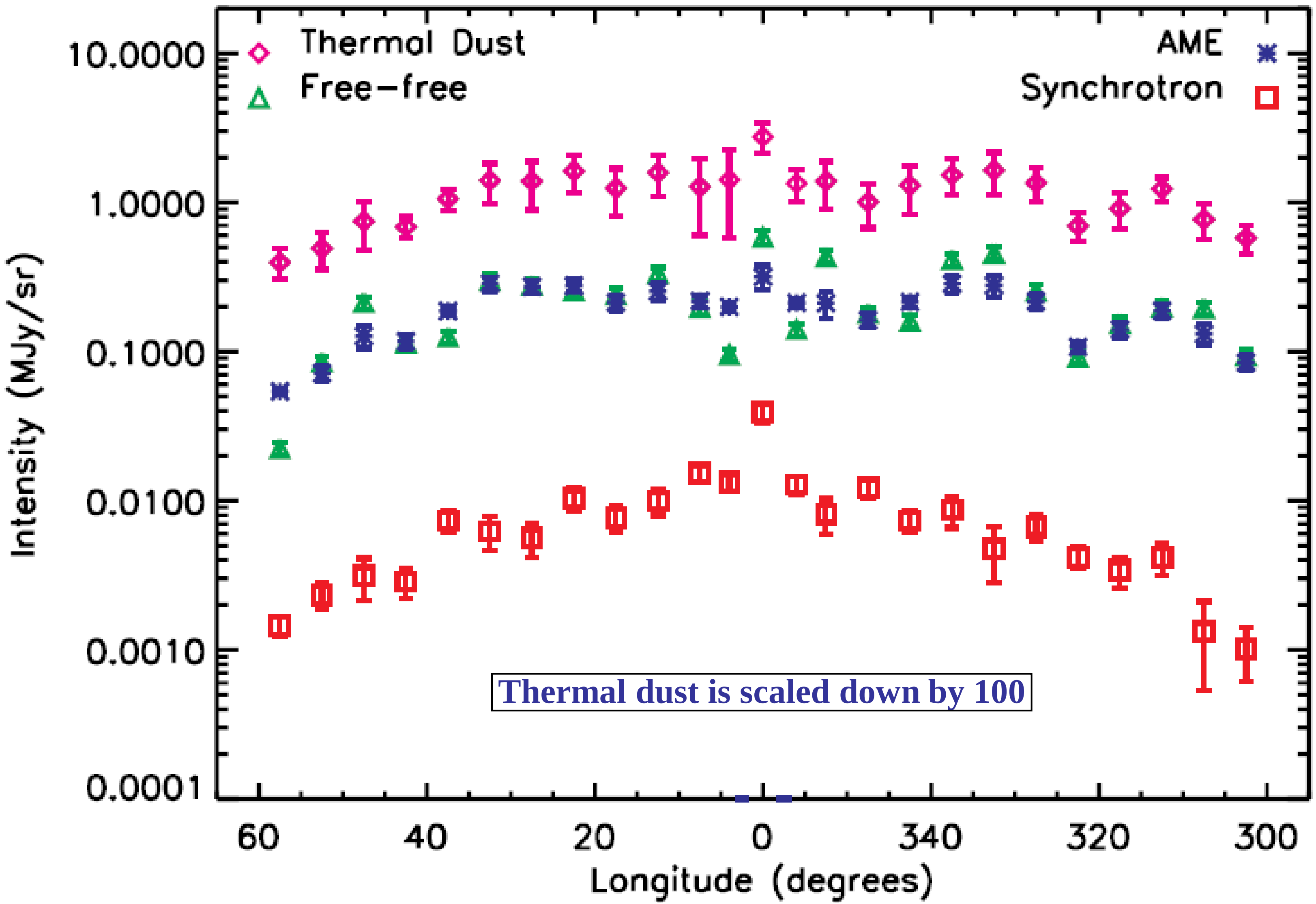


- **Because of the similarity of the distribution of the different emission components, it is necessary to derive Spectral Energy Distributions in the regions of interest.**
- **The SEDs using fastMEM on <u>Planck</u> data for four longitude intervals each 1º wide in latitude are shown.**
- **AME is clearly identified.**
- **In the longitude interval l = 300º - 0º - 60º, the AME is 42 +/-4% of the total emission at 28.5 GHz. This may be compared with 25 +/- 5% for a broader latitude range by <u>Planck</u> Collaboration (2011 A&A, 536 A21.**
- **See next slide.**

LONGITUDE DISTRIBUTION OF THE 4 COMPONENTS

Thermal dust, synchrotron, free-free and spinning dust at 5º x 1º resolution.

Frequency = 28.5 GHz. Analysis based on <u>Planck</u> data.



DIFFUSE LOW-FREQUENCY GALACTIC COMPONENTS

We have seen that foreground components include :--

..Synchrotron emission from relativistic electrons in magnetic fields.

..Free-free emission from ionized hydrogen (and helium).

..Anomalous emission from small spinning dust grains

..Thermal (vibrating) emission from larger dust grains.

..The emission associated with the gamma-ray bubbles.

We have considered the structure of the emission at :--

..intermediate and higher latitudes including the Gould Belt system, the spurs, the haze/bubbles and the local matter (HI, dust, CO etc.).

..the Galactic plane within the inner Galaxy in all components.

Planck is improving our knowledge of all these areas.

Further Planck results will be shown in the parallel sessions.

esa

planck

cnes

agenzia spaziale italiana

NASA

CNRS

DTU Space
National Space Institute

INAF ISTITUTO NAZIONALE DI ASTROFISICA

HFI PLANCK
a look back to the birth of Universe

PLANCK LFI

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CSA ASC

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.

UK SPACE AGENCY

MAX-PLANCK-GESELLSCHAFT

A" Aalto University

APC

ioa

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CESR

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IASF

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CNRS IN2P3 Les deux infinis

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NUI MAYNOOTH

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UBC

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