# Galactic Diffuse Emission: Models and Interpretation

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on behalf of the **Fermi LAT collaboration**
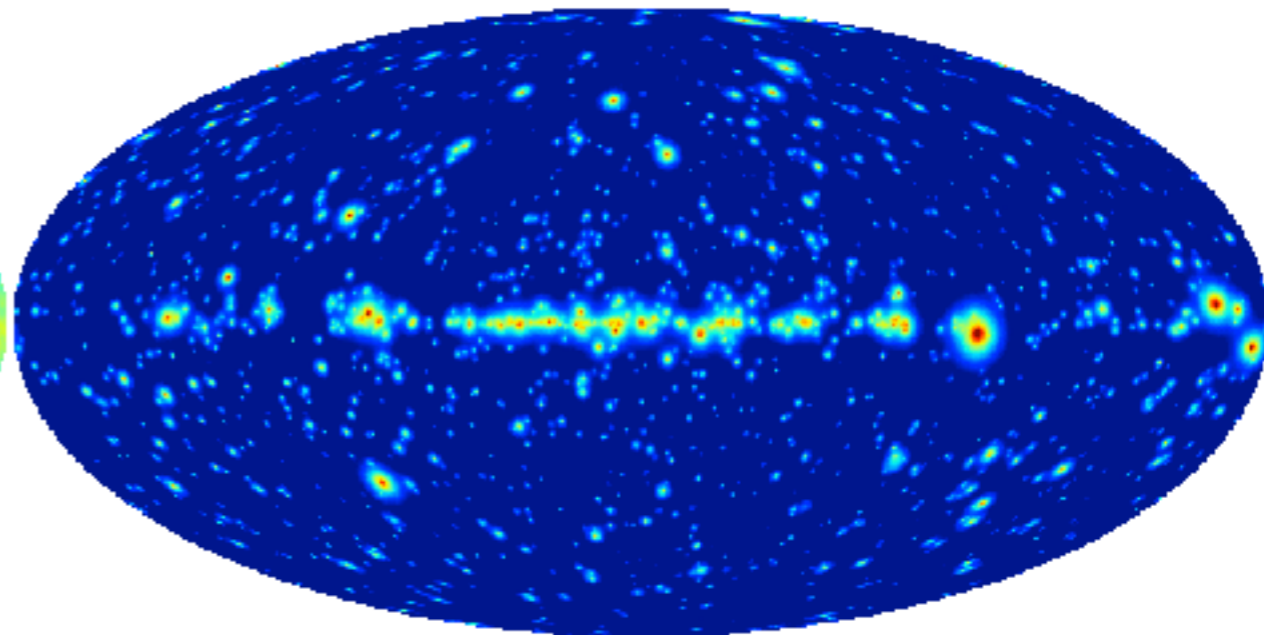
2011 Fermi Symposium
Rome
May 9, 2011

I   *LAT view of the Galactic interstellar emission*

II   *Work performed inside and outside the LAT collaboration related to the diffuse emission*

III   *How to predict the Galactic emission*

IV   *The next public model*

LAT view of the Galactic interstellar emission
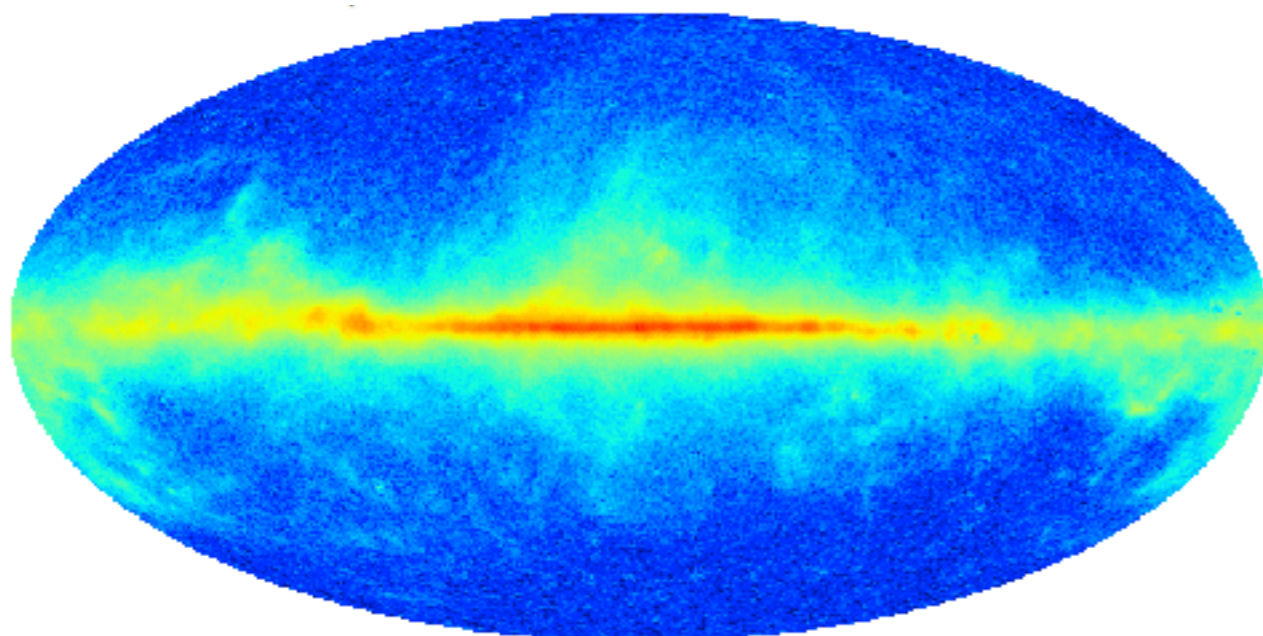
LAT counts above 300 MeV
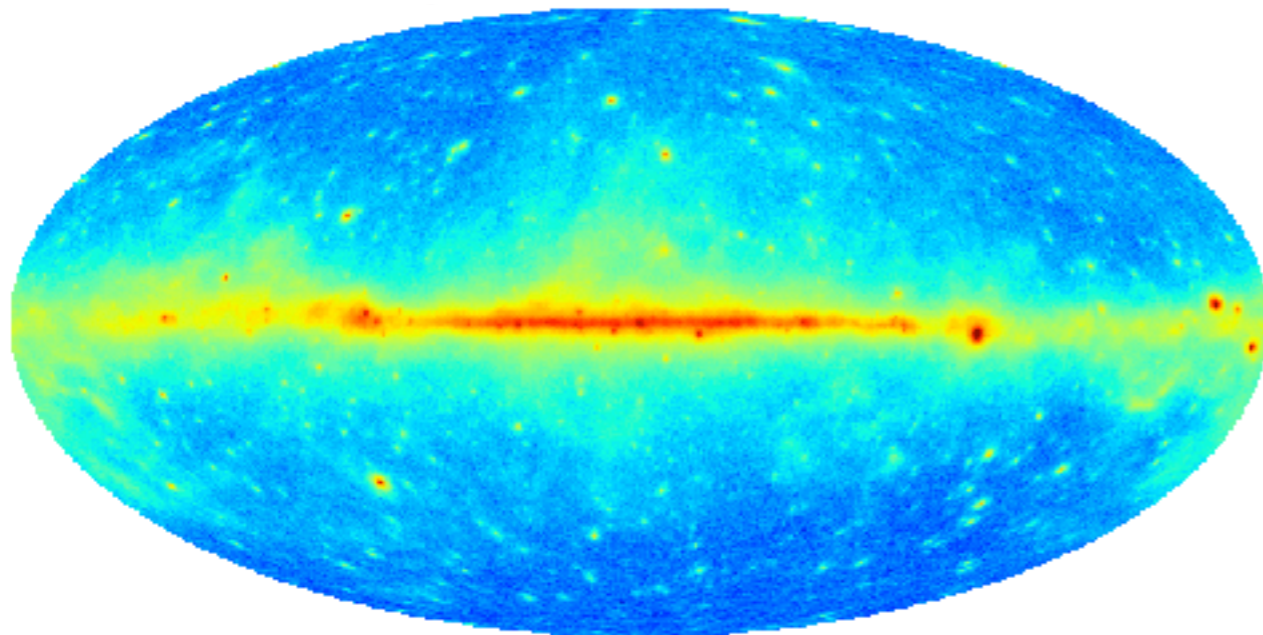
Sources, 2FGL early version

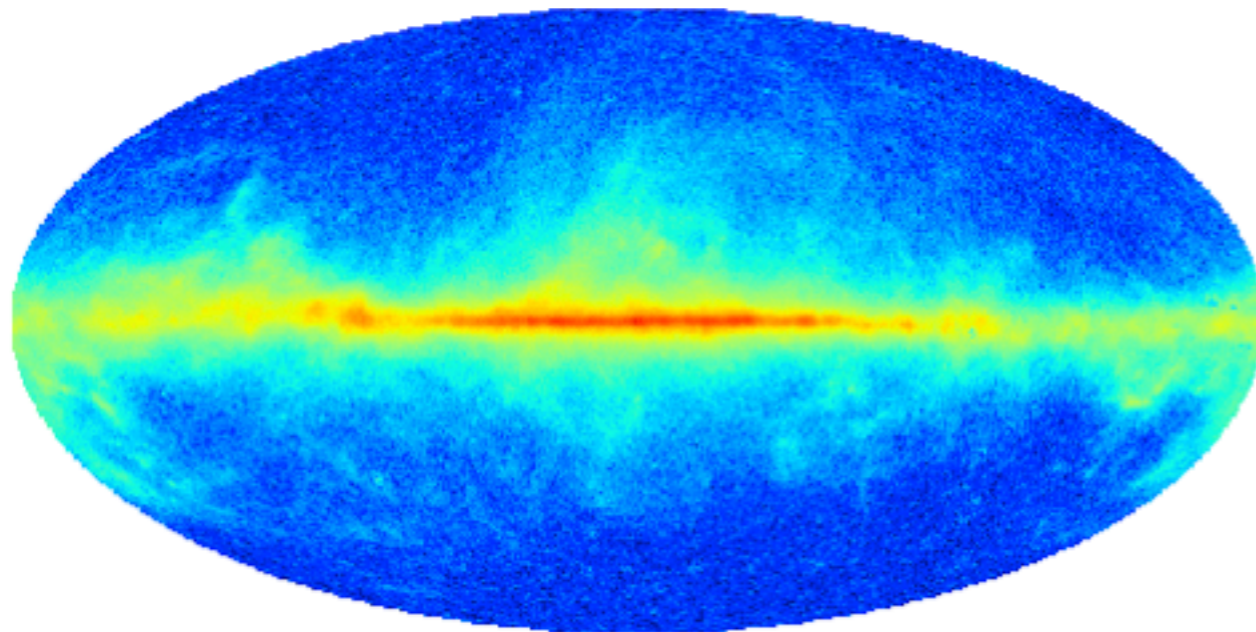LAT counts minus sources and isotropic
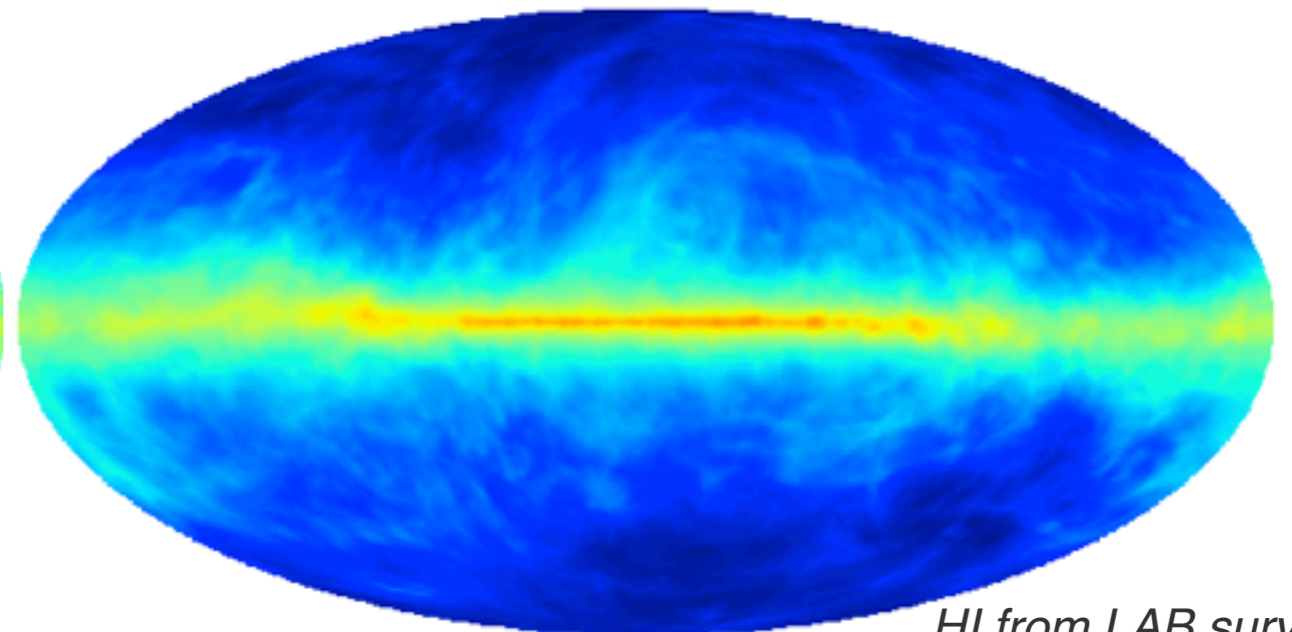
scale: log(counts)

0   3

24 months of data

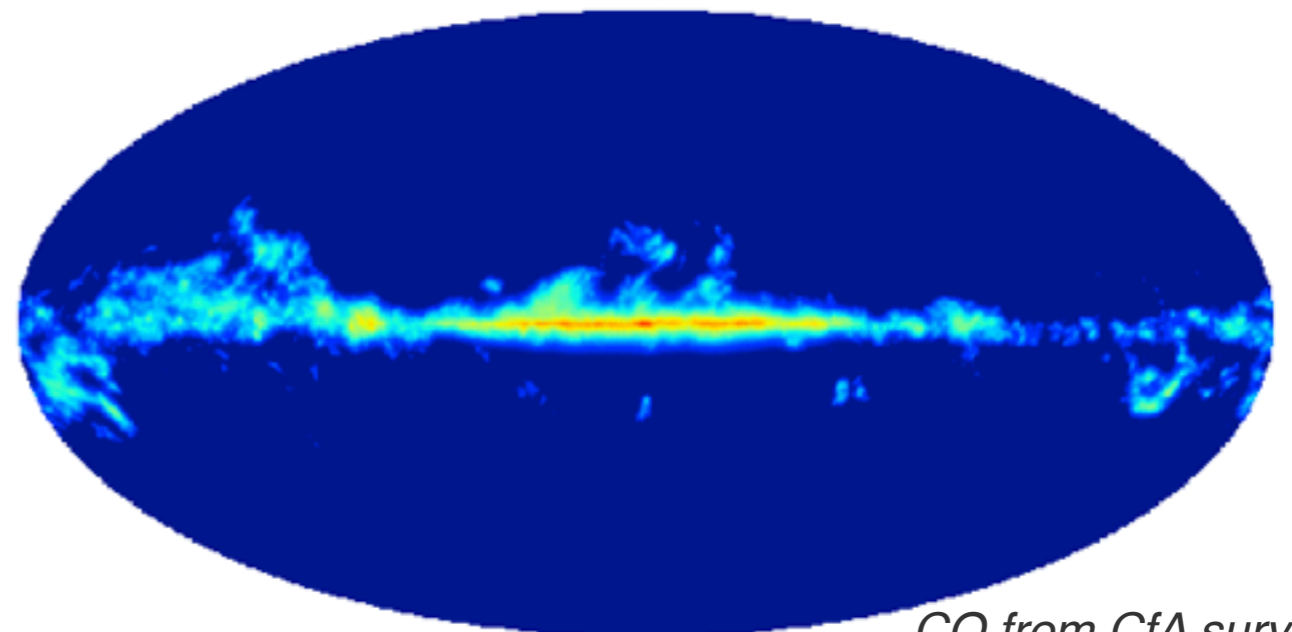# LAT view of the Galactic interstellar emission

LAT counts minus sources and isotropic

Counts map derived from HI and CO radio surveys. The gas column density distributed in Galactocentric rings was scaled to reproduce the LAT counts
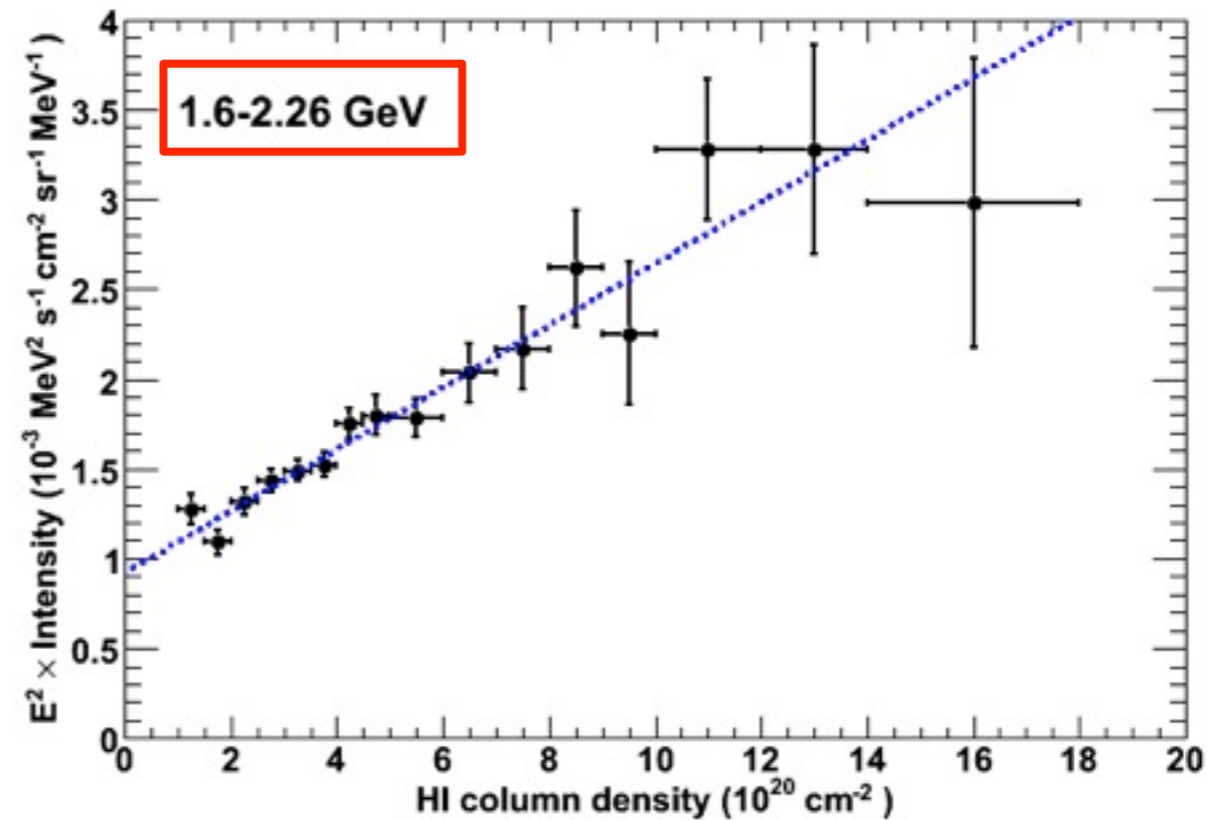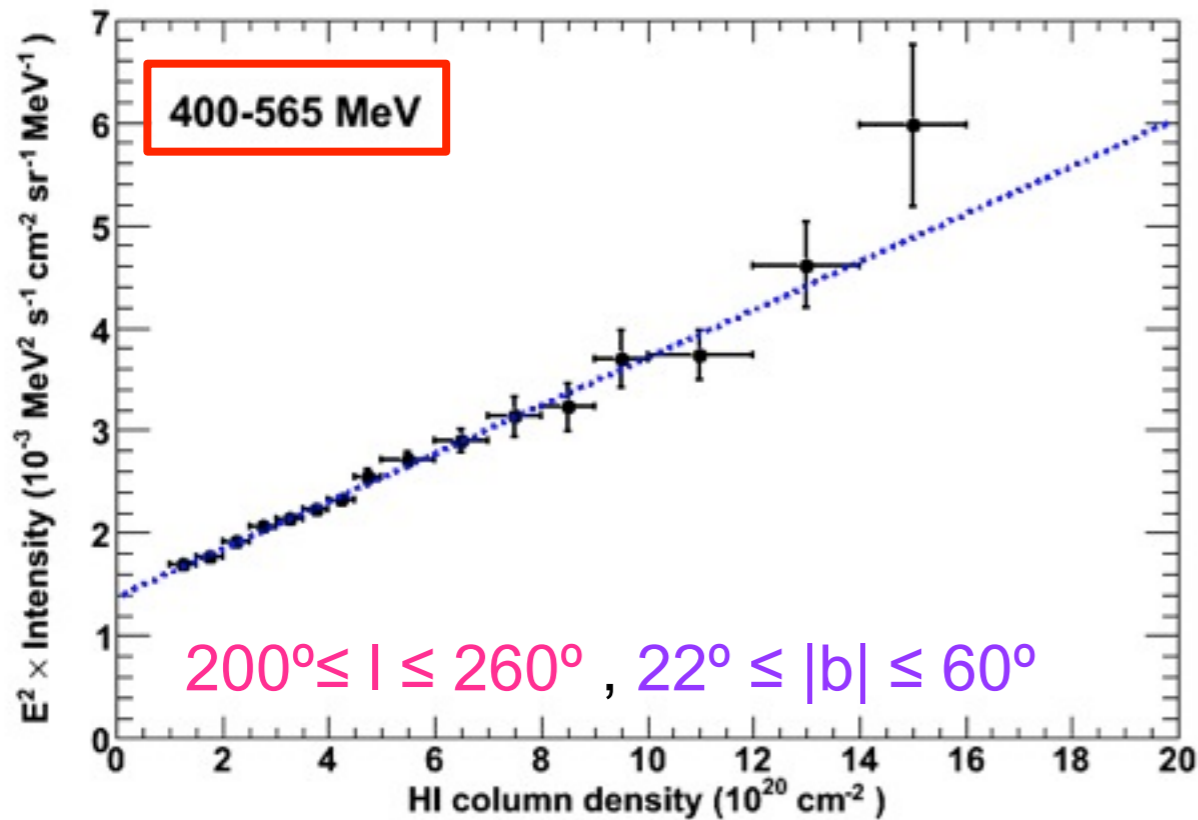
HI from LAB survey

CO from CfA survey

No H₂, γ intensity is proportional to HI column density

γ-ray intensities (sources and IC removed) versus HI column densities

400-565 MeV

1.6-2.26 GeV

200° ≤ l ≤ 260° , 22° ≤ |b| ≤ 60°

Abdo et al., ApJ 703, 1249 (2009), C.A.: T. Mizuno

The origins of the high energy Milky-Way γ-ray diffuse emission are mainly:
- *decay of π⁰ produced in protons/gas collisions*
- *Bremsstrahlung of relativistic electrons in gas*
- *Inverse-Compton of relativistic electrons with ISRF*

Diffuse Emission :   study of CR, ISM and ISRF

Fermi Gamma-ray Space Telescope

Work performed inside and outside the LAT collaboration related to the diffuse emission

I *Analysis software like the Science Tools or GaRDiAn packages*

II *Lots and lots of systematics studies related to the HI spin temperature, the $H_2\_to\_CO$ ratio, Dark Gas, Galaxy halo size, unresolved sources ..*

Effect of the spin temperature in the extraction of HI column density from radio survey.
See Poster of Guðlaugur (Gulli) Jóhannesson
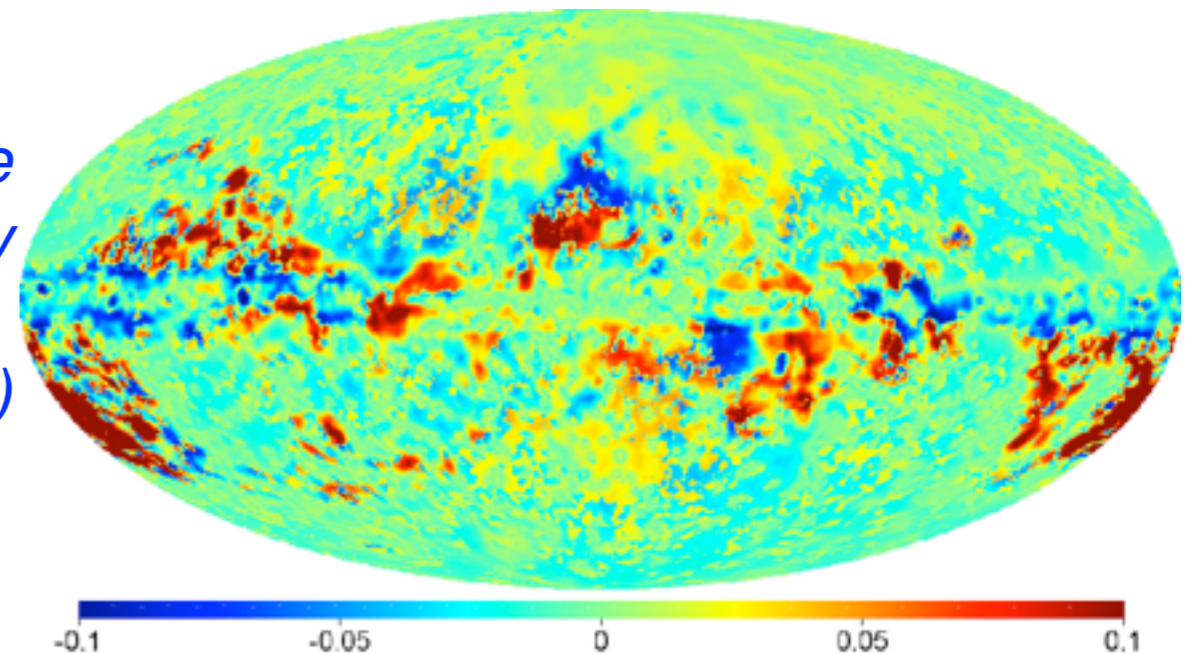
III *Derivation of CR contamination-clean classes dedicated to Galactic or extra-Galactic diffuse studies (see poster of Markus Ackermann)*

IV *Study of less-confused regions:*
- *Local gas at less than1 kpc, outside the plane*
- *Second and third quadrant*
- *Molecular clouds: Orion, Chamaeleon, RCrA*
- *Local group galaxies: LMC, SMC, M31*
- *Isotropic Diffuse Emission* *(see Marco Ajello's talk, Tonia Venters' poster)*

V *Starting to study confused regions:*
- *Inner Galaxy* *(Troy Porter's talk)*
- *Cygnus region* *(Luigi Tibaldo's talk and posters)*

- *Star-forming galaxies outside the Local Group*

VI *Also, very interesting works from outside the collaboration*
(see Meng Su's talk)

Is the cosmic ray density uniform within ~1 kpc from the sun ?

3 regions were investigated:

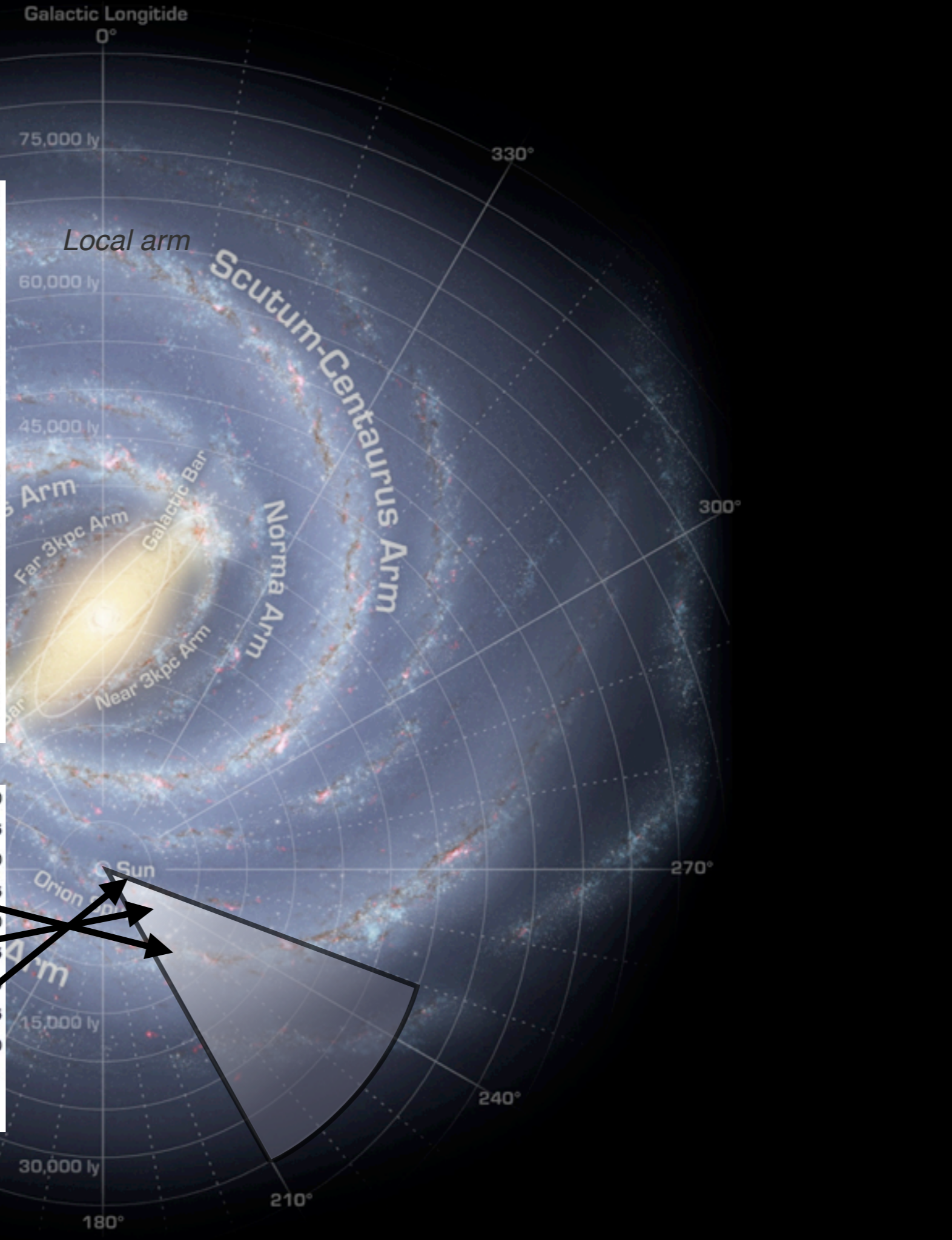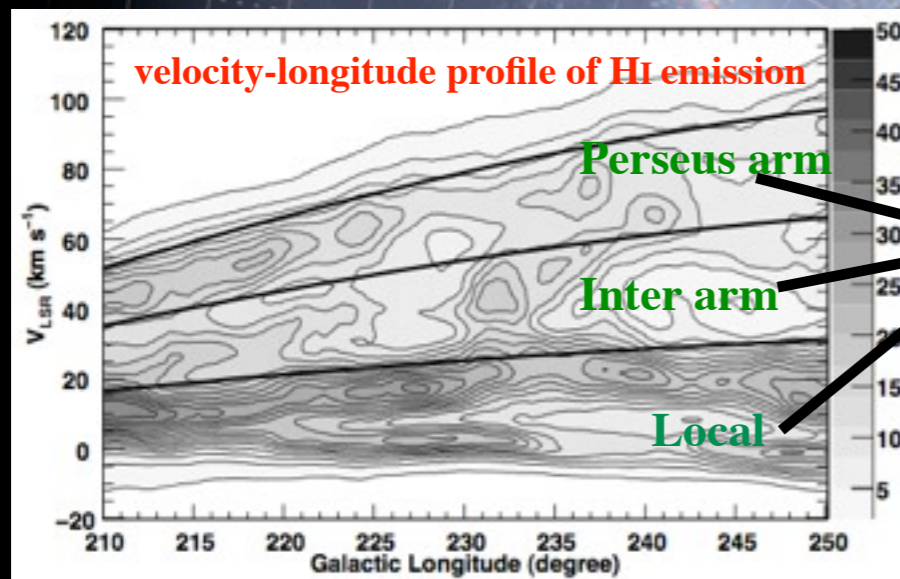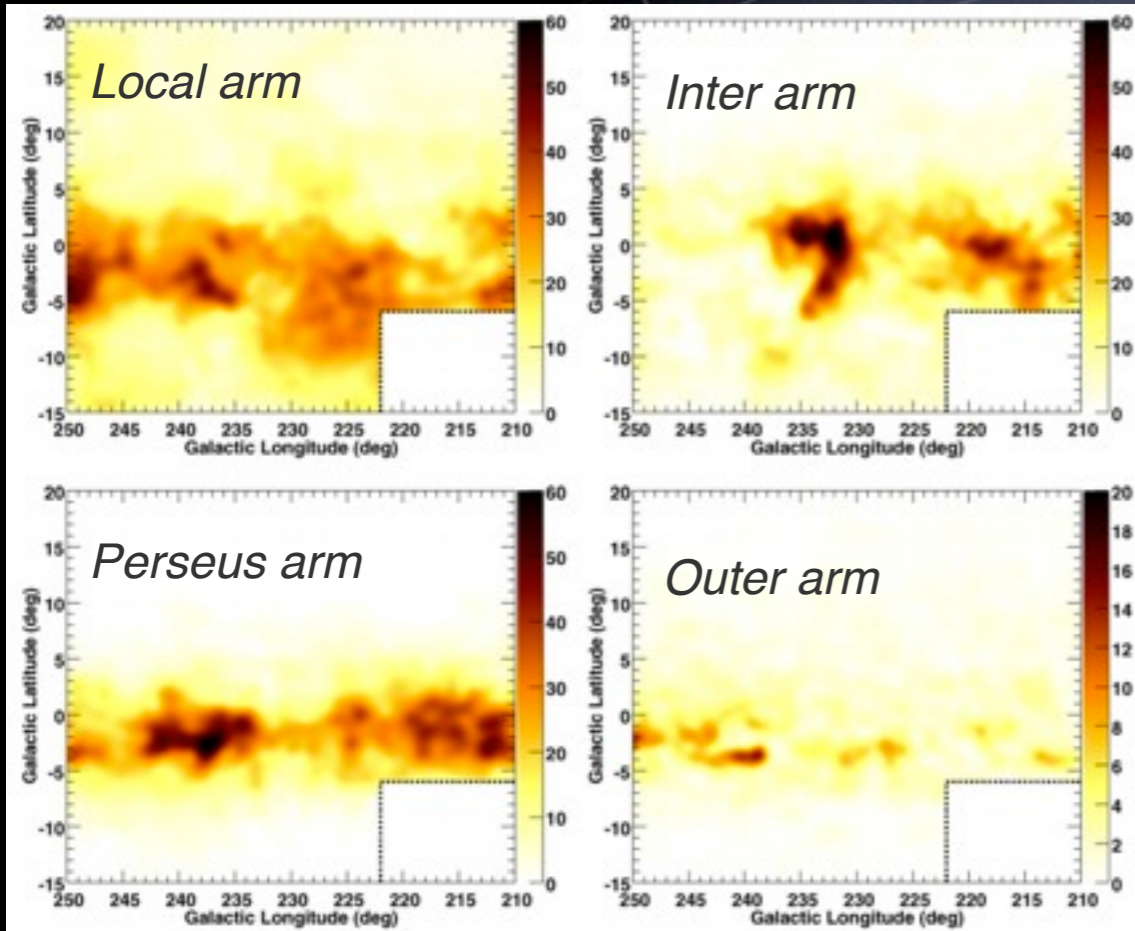➡ *Local HI: $200° \leq l \leq 260°$, $22° \leq lbl \leq 60°$* Abdo et al., ApJ 703, 1249 (2009),
C.A.: T. Mizuno

➡ *II quadrant: $100° \leq l \leq 145°$, $-15° \leq b \leq 30°$ (local arm)* Abdo et al., ApJ 710, 133 (2010)
C.A.: L. Tibaldo, I. Grenier

➡ *III quadrant: $210° \leq l \leq 250°$, $-15° \leq b \leq 20°$ (local arm)* Abdo et al., ApJ 726, 81A (2011)
C.A.: T. Mizuno, L. Tibaldo, I. Grenier

It is uniform within 20% (large systematics due to HI spin temperature).
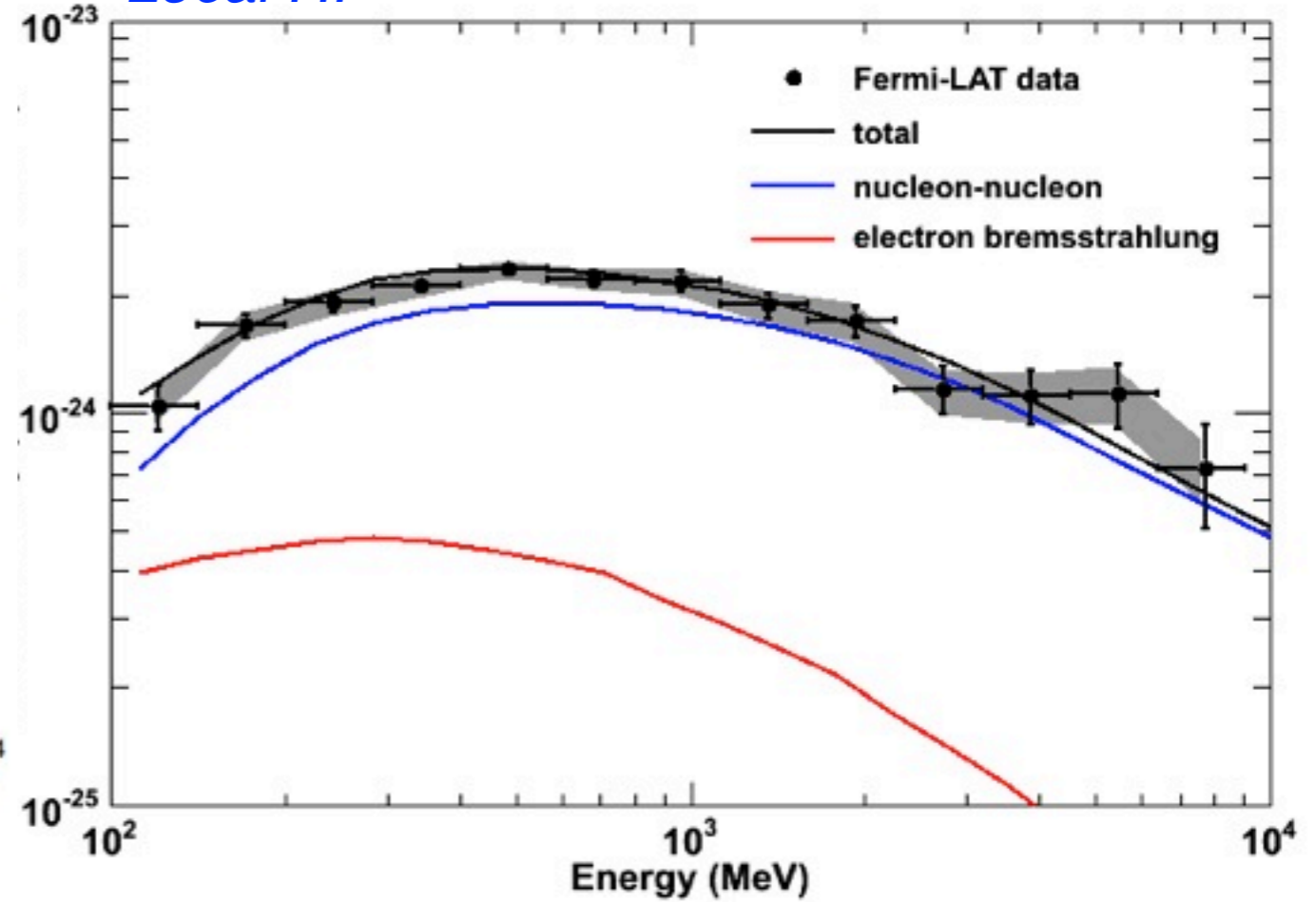*The local CR nuclei spectra are close to those directly measured at the Earth.*

Maps of N(HI) (in unit of 10^{20} atoms cm^{-2})

Local arm

Inter arm
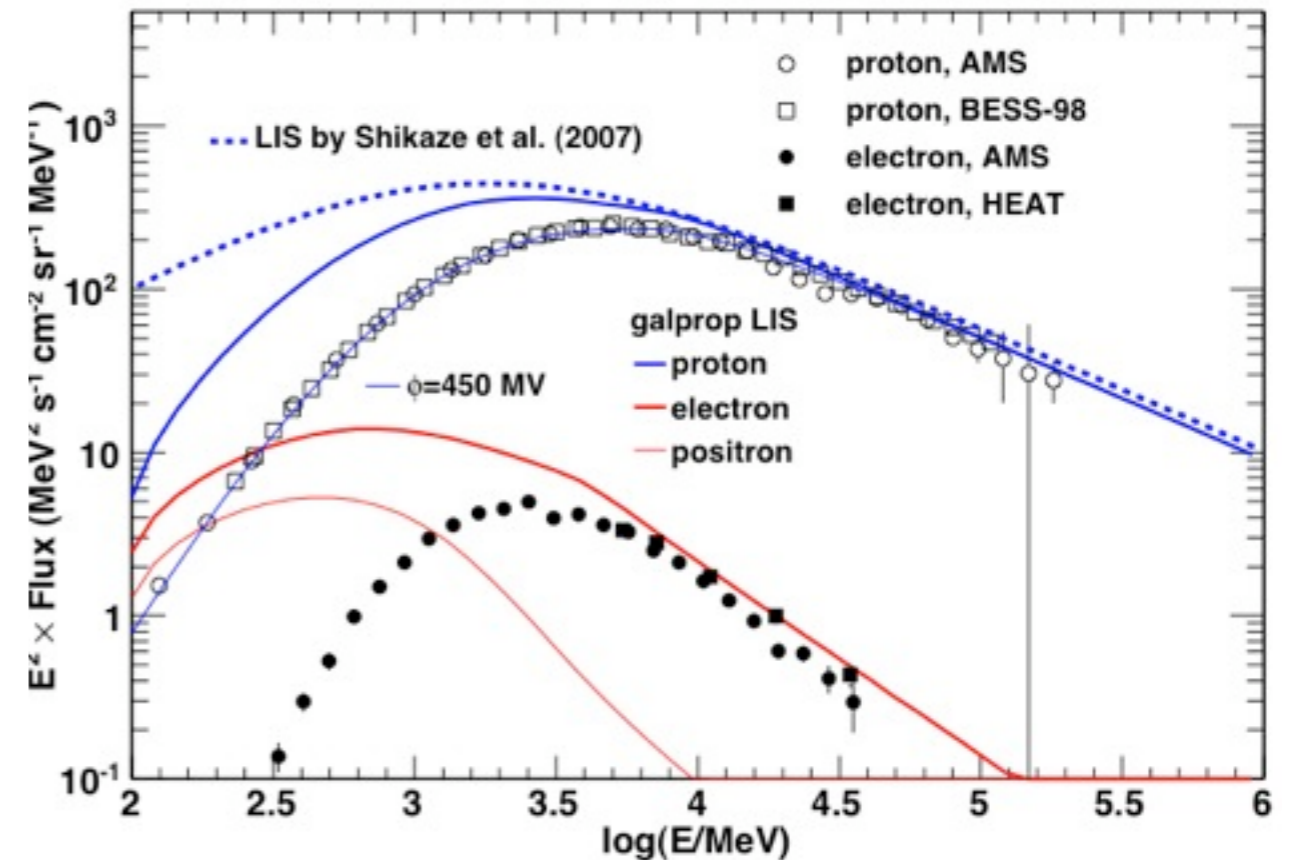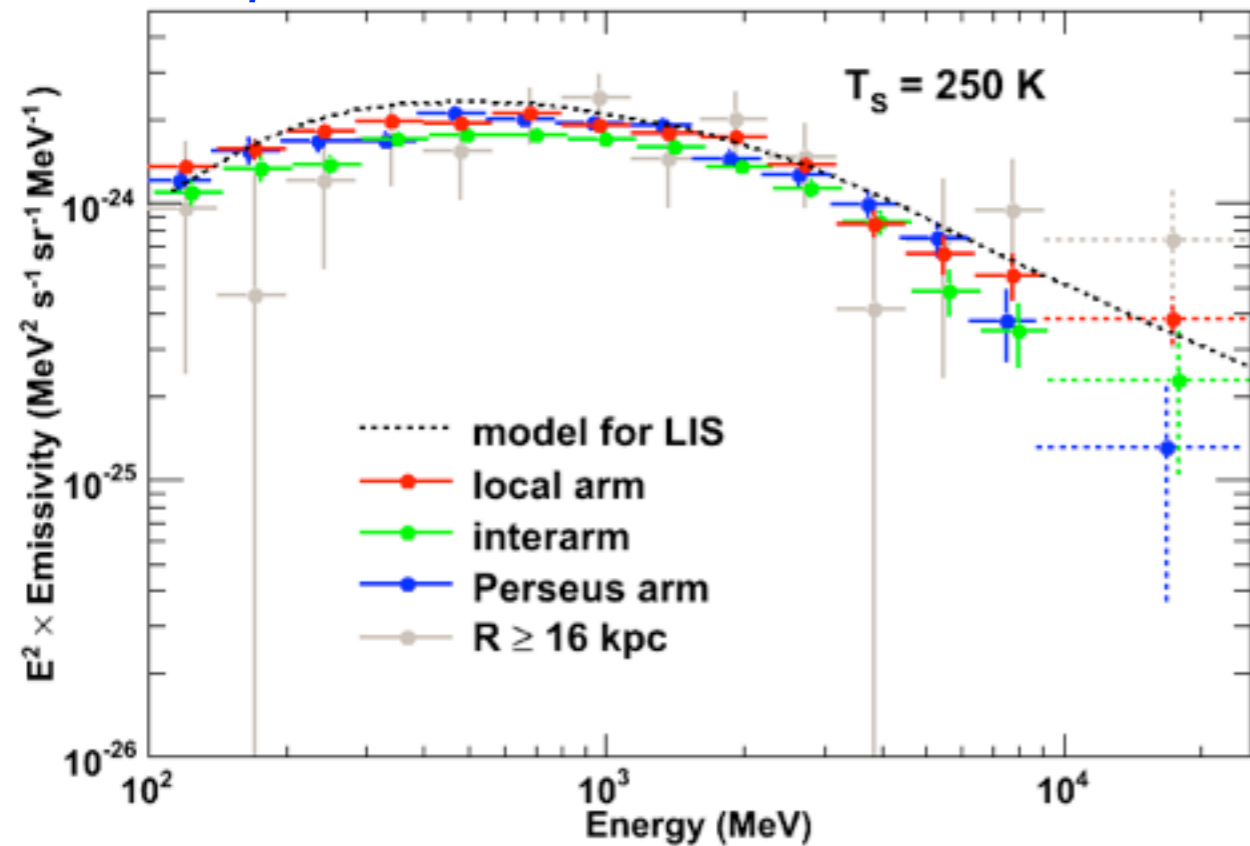
Perseus arm

Outer arm

velocity-longitude profile of HI emission

Perseus arm

Inter arm

Local

Local arm

Scutum-Centaurus Arm

Norma Arm

Galactic Longitide
0°

II quadrant   local arm
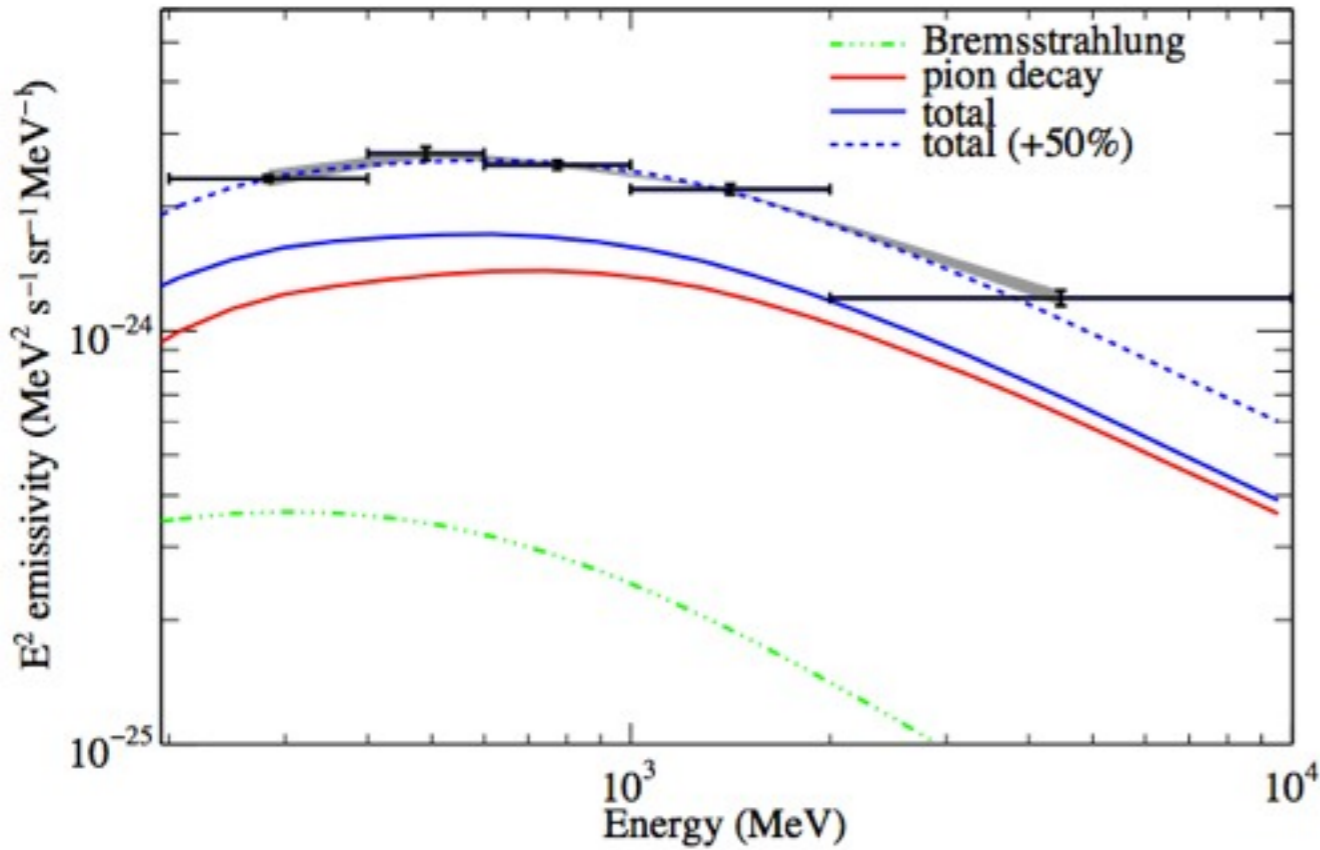
Local HI

III quadrant

$T_S = 250$ K

Electron and proton spectrum used to fit the data

ermi
Gamma-ray
Space Telescope

How does the CR density vary with the Galactocentric distance ?

2 regions were investigated:

➡ *II quadrant: $100° \leq l \leq 145°$, $-15° \leq b \leq 30°$ (local arm) Abdo et al., ApJ 710, 133 (2010)*
   C.A.: L. Tibaldo, I. Grenier

➡ *III quadrant: $210° \leq l \leq 250°$, $-15° \leq b \leq 20°$ (local arm) Abdo et al., ApJ 726, 81A (2011)*
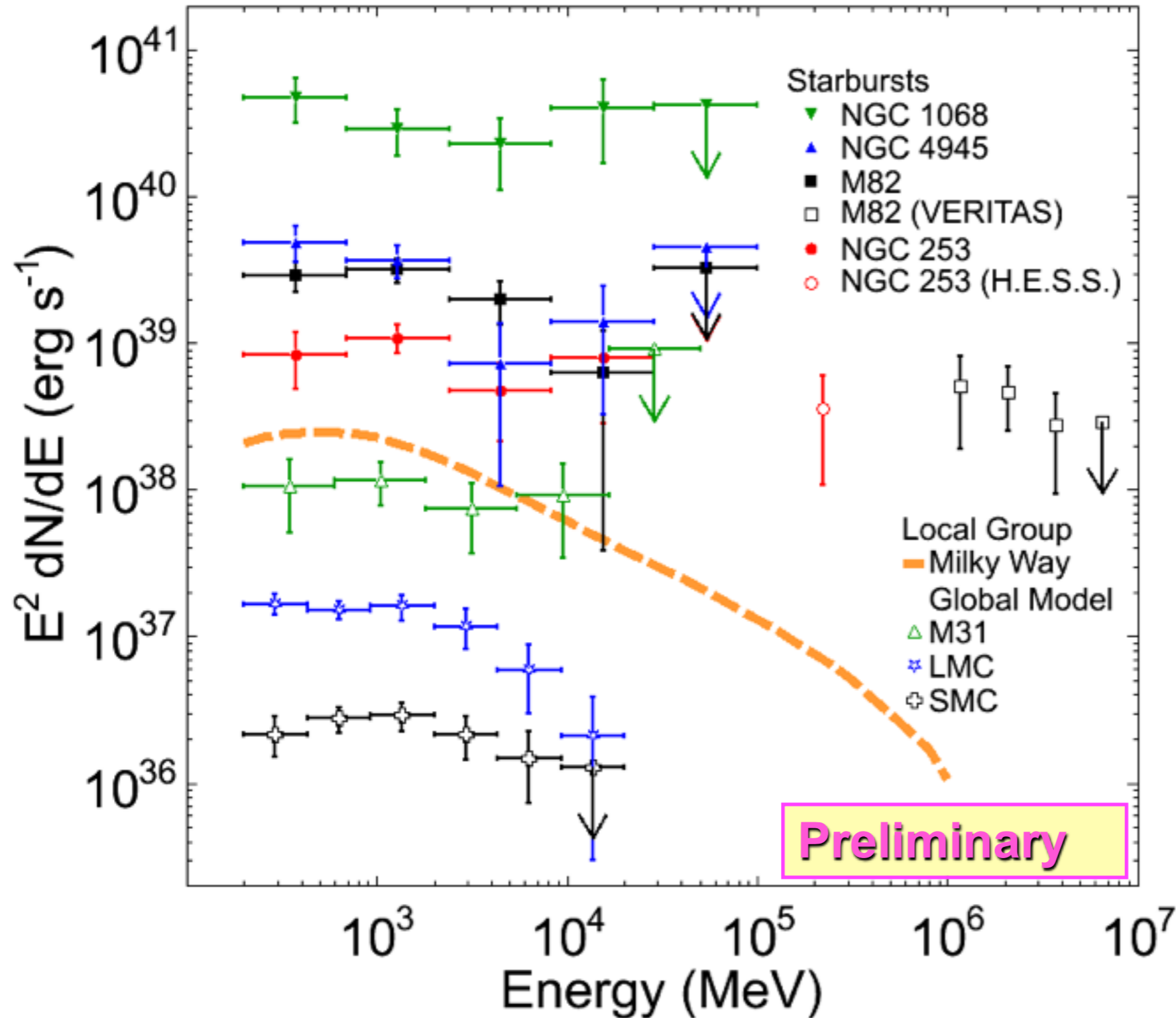   *C.A.: T. Mizuno, L. Tibaldo, I. Grenier*

No significant decrease of CR densities toward the outer Galaxy

Larger halo, more sources, more gas, non uniform diffusion parameter ? *(see Daniele Gaggero's poster)*
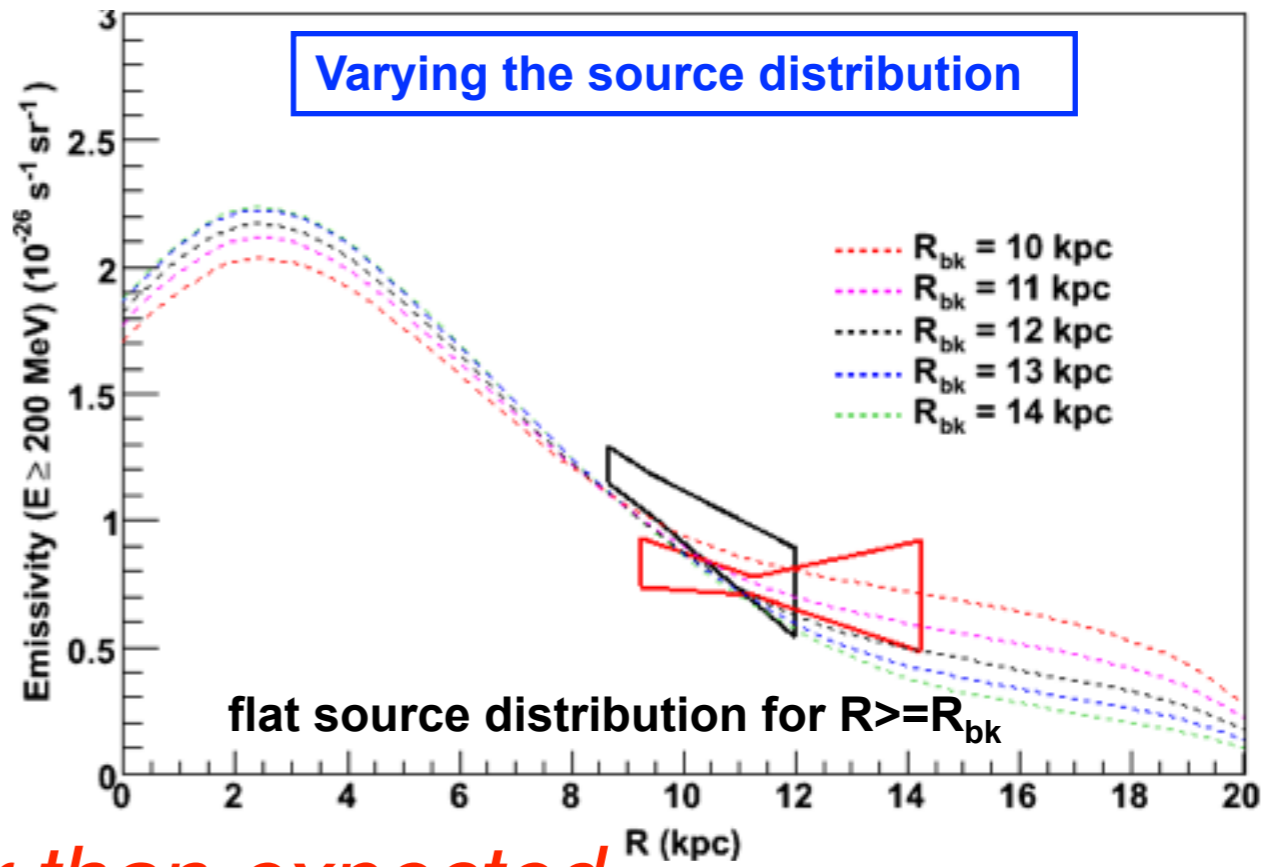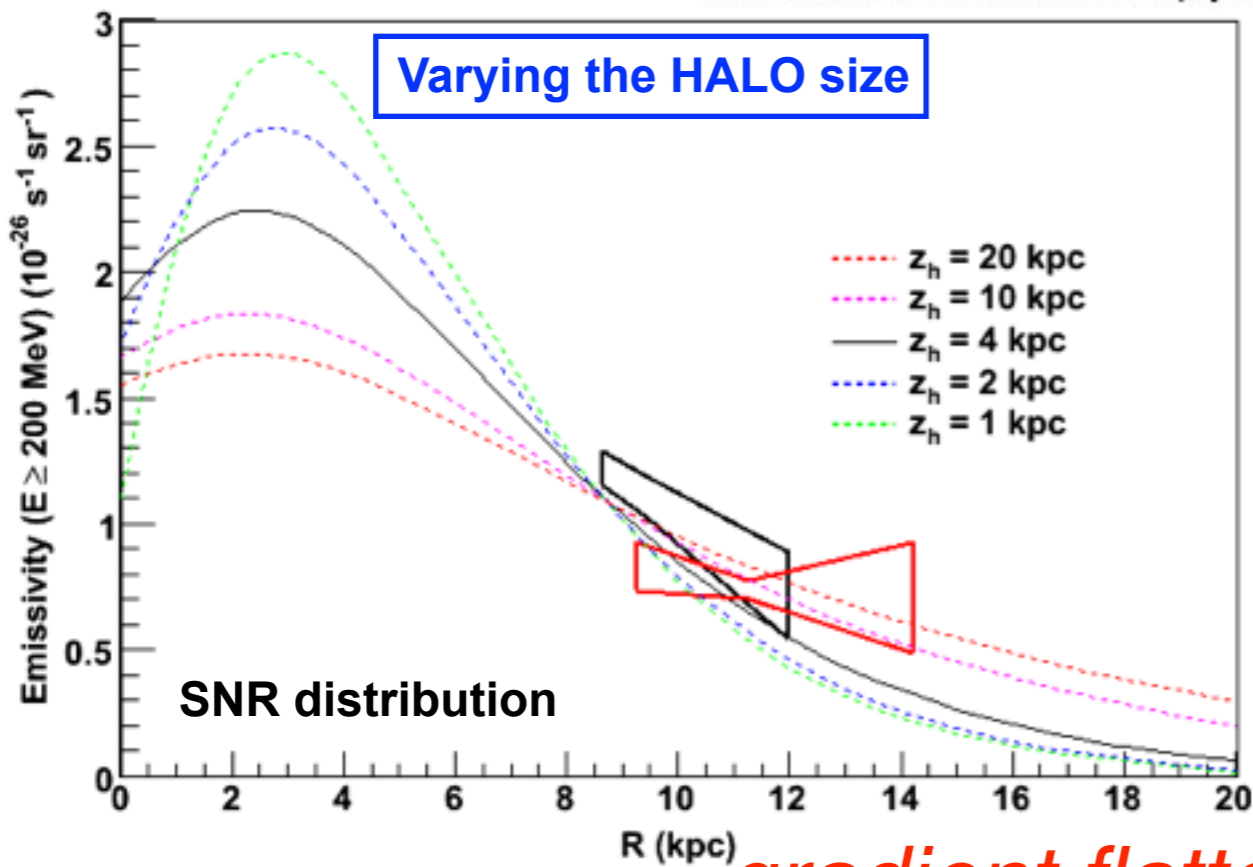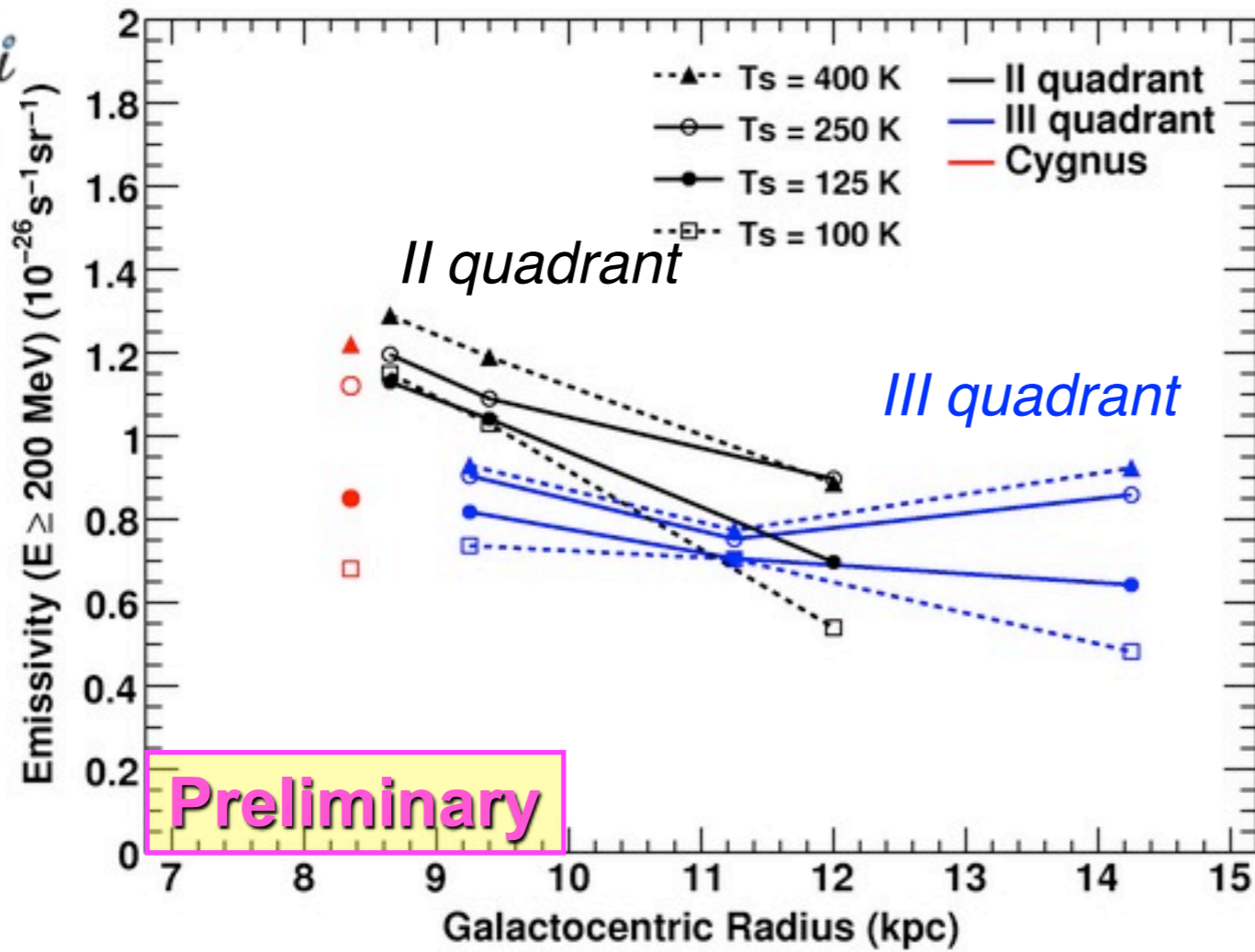
gradient flatter than expected

Star-forming galaxies

Luminosity Spectra of All LAT-detected Star-forming Galaxies

Starbursts
- ▼ NGC 1068
- ▲ NGC 4945
- ■ M82
- □ M82 (VERITAS)
- ● NGC 253
- ○ NGC 253 (H.E.S.S.)

Local Group
- ━ Milky Way

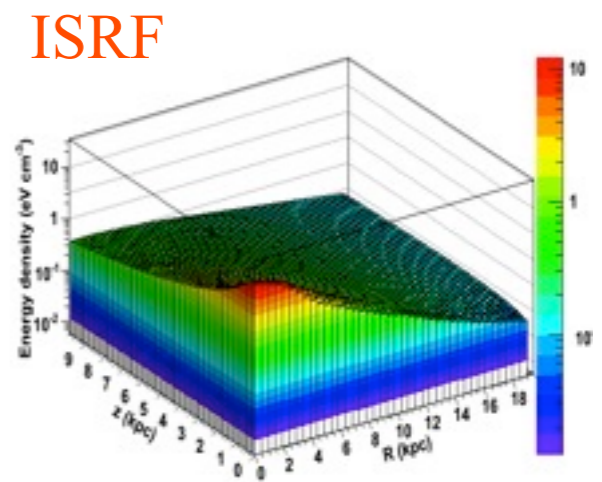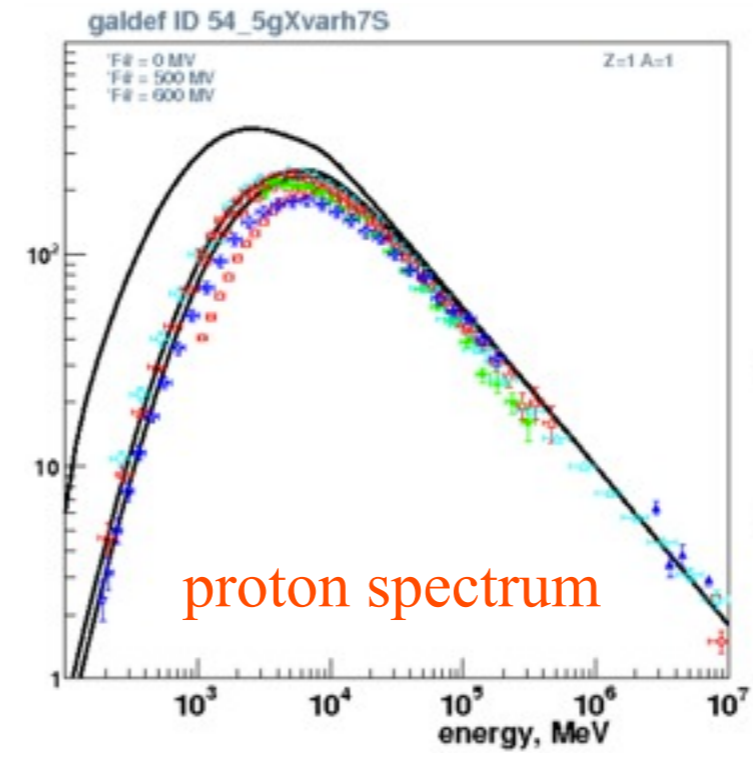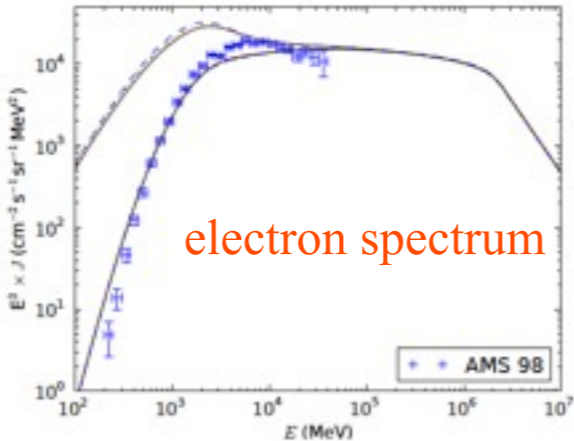**Global Model**
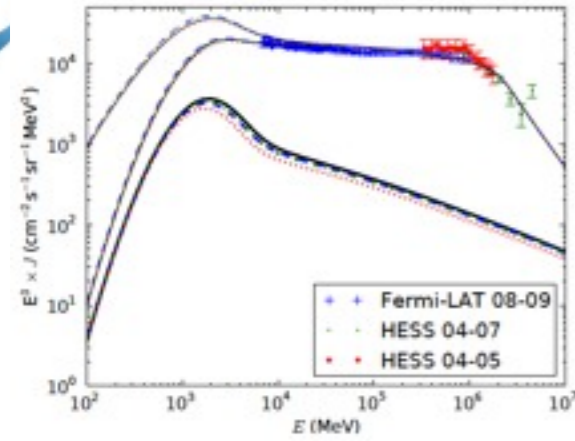- △ M31
- ✳ LMC
- ✥ SMC

Preliminary

Can we predict the large scale structures of the Galactic interstellar emission ?

With GALPROP we can

Strong et al., Annual Reviews of Nuclear and Particle Science, 2007
http://galprop.stanford.edu/

Some ingredients

electron spectrum

proton spectrum

ISRF

Z=0, R=0 kpc

Gas   HI   CO

source distribution
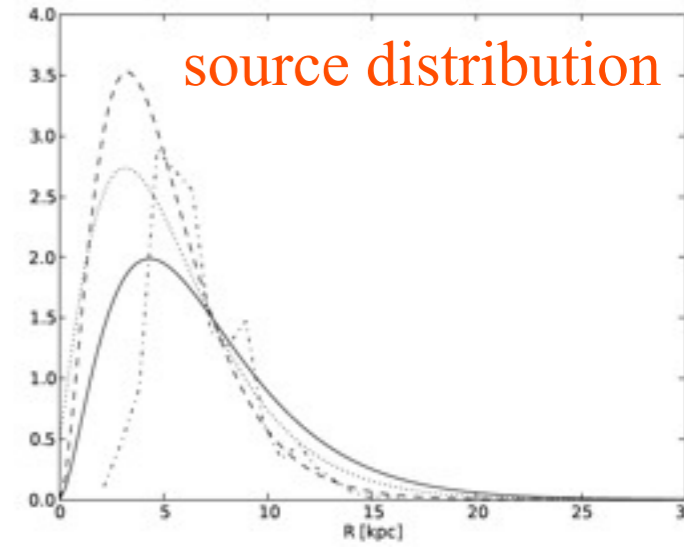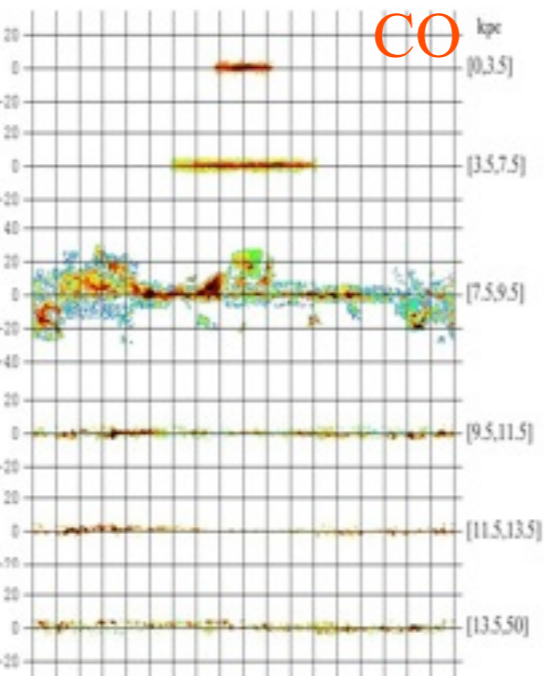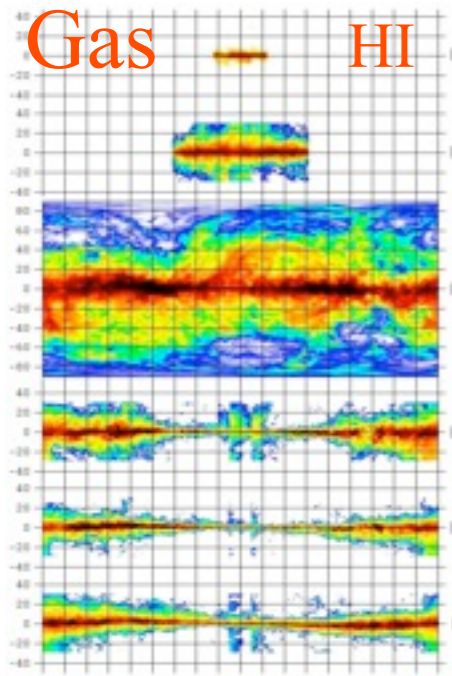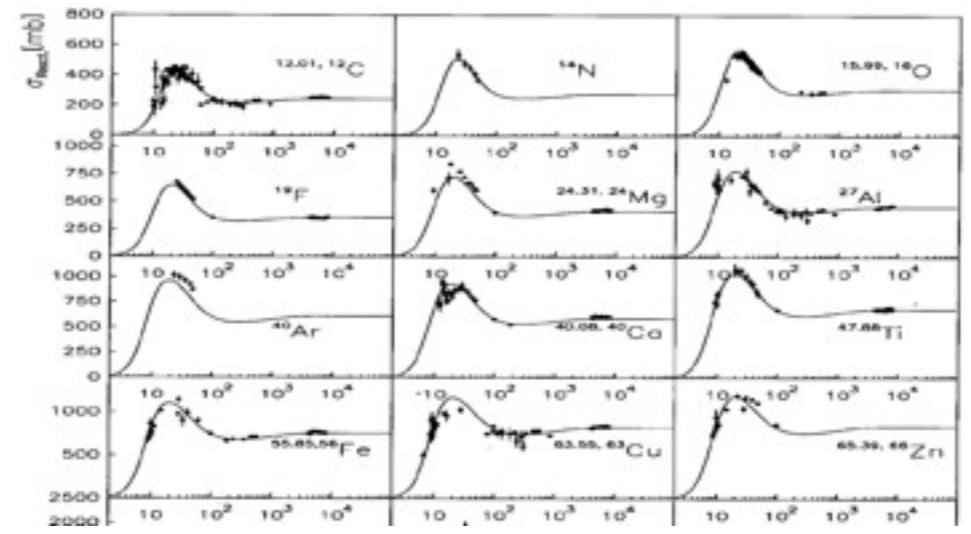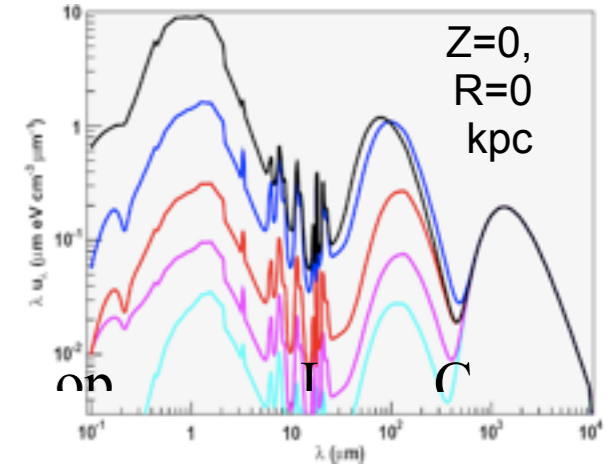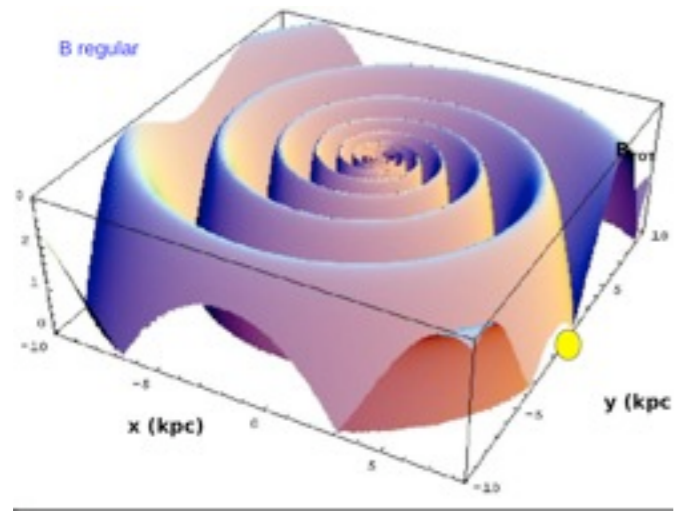
A transport equation

$$\frac{\partial \psi (\vec{r}, p, t)}{\partial t} = q(\vec{r}, p)$$ *sources (SNR, nuclear reactions…)*

diffusion $+ \vec{\nabla} \cdot [D_{xx} \vec{\nabla} \psi - \vec{V} \psi]$

diffusive reacceleration (diffusion in the momentum space) $+ \frac{\partial}{\partial p} \left[p^2 D_{pp} \frac{\partial}{\partial p} \frac{\psi}{p^2} \right]$ *convection (Galactic wind)*

E-loss $- \frac{\partial}{\partial p} \left[\frac{dp}{dt} \psi - \frac{1}{3} p \vec{\nabla} \cdot \vec{V} \psi \right]$
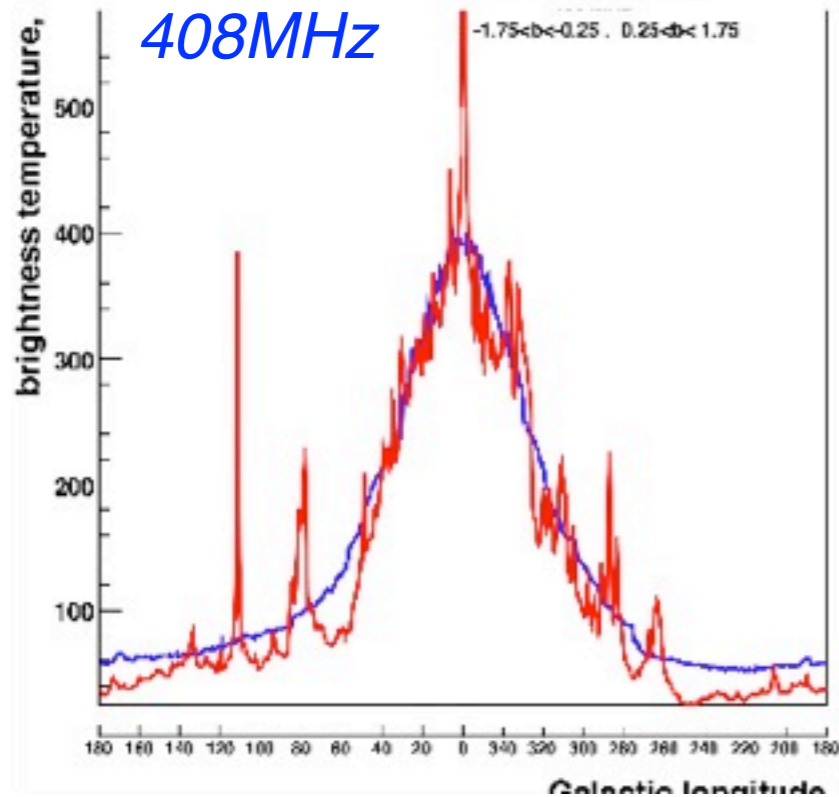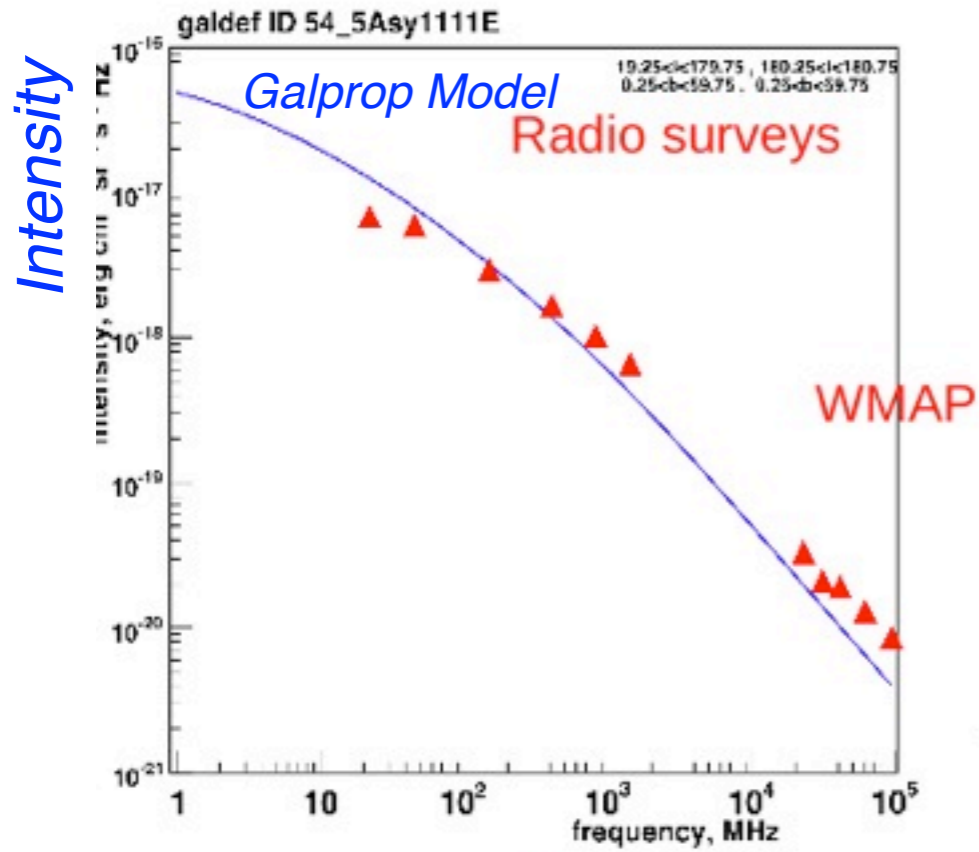
fragmentation $- \frac{\psi}{\tau_f} - \frac{\psi}{\tau_d}$ *radioactive decay*
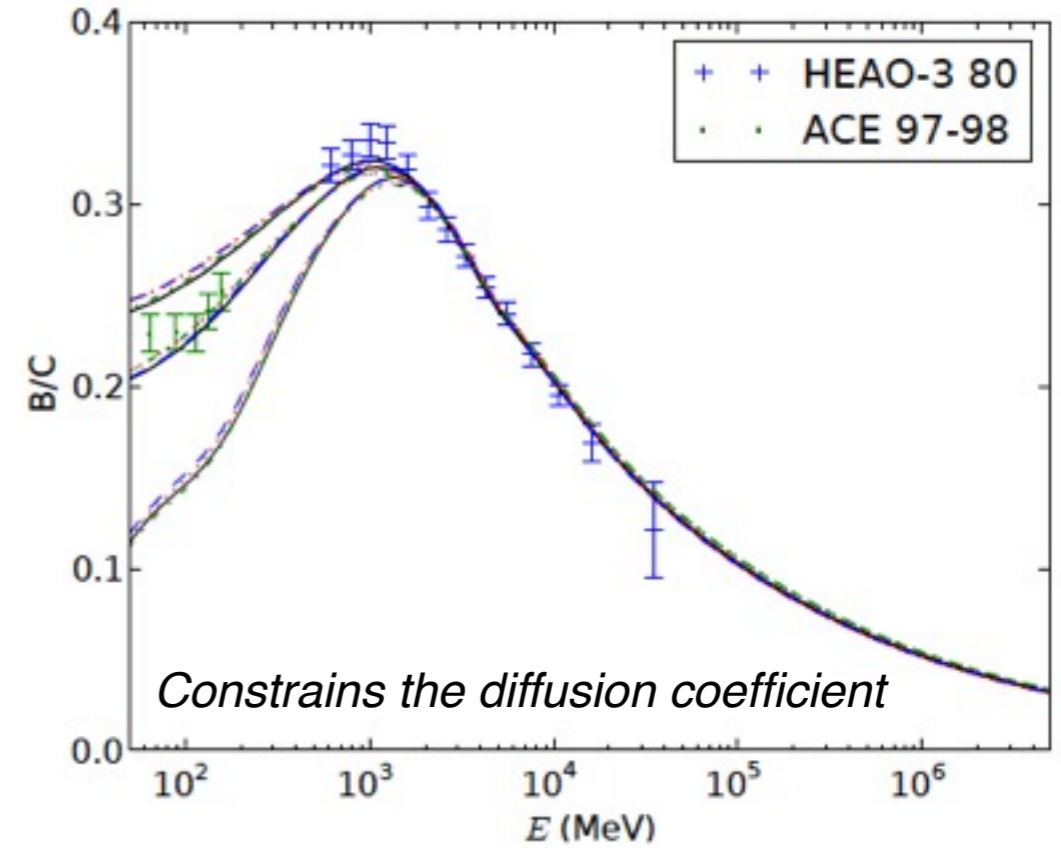
+ boundary conditions

Constraints

Synchrotron

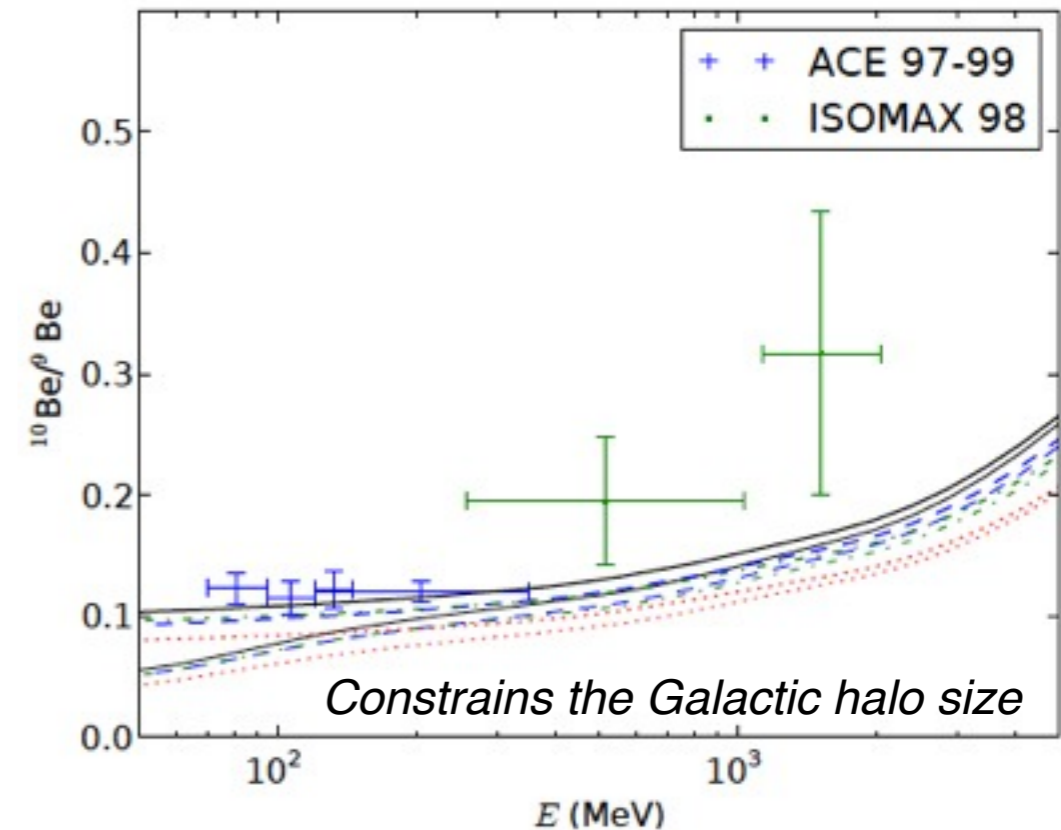*Boron to Carbon ratio*

Intensity

Galprop Model

Radio surveys

WMAP

Constrains the diffusion coefficient

^{10}Be / ^9Be ratio

408MHz

Constrains the Galactic halo size

see poster session 1, #122

Inner Galaxy spectrum

a priori model, no special fitting
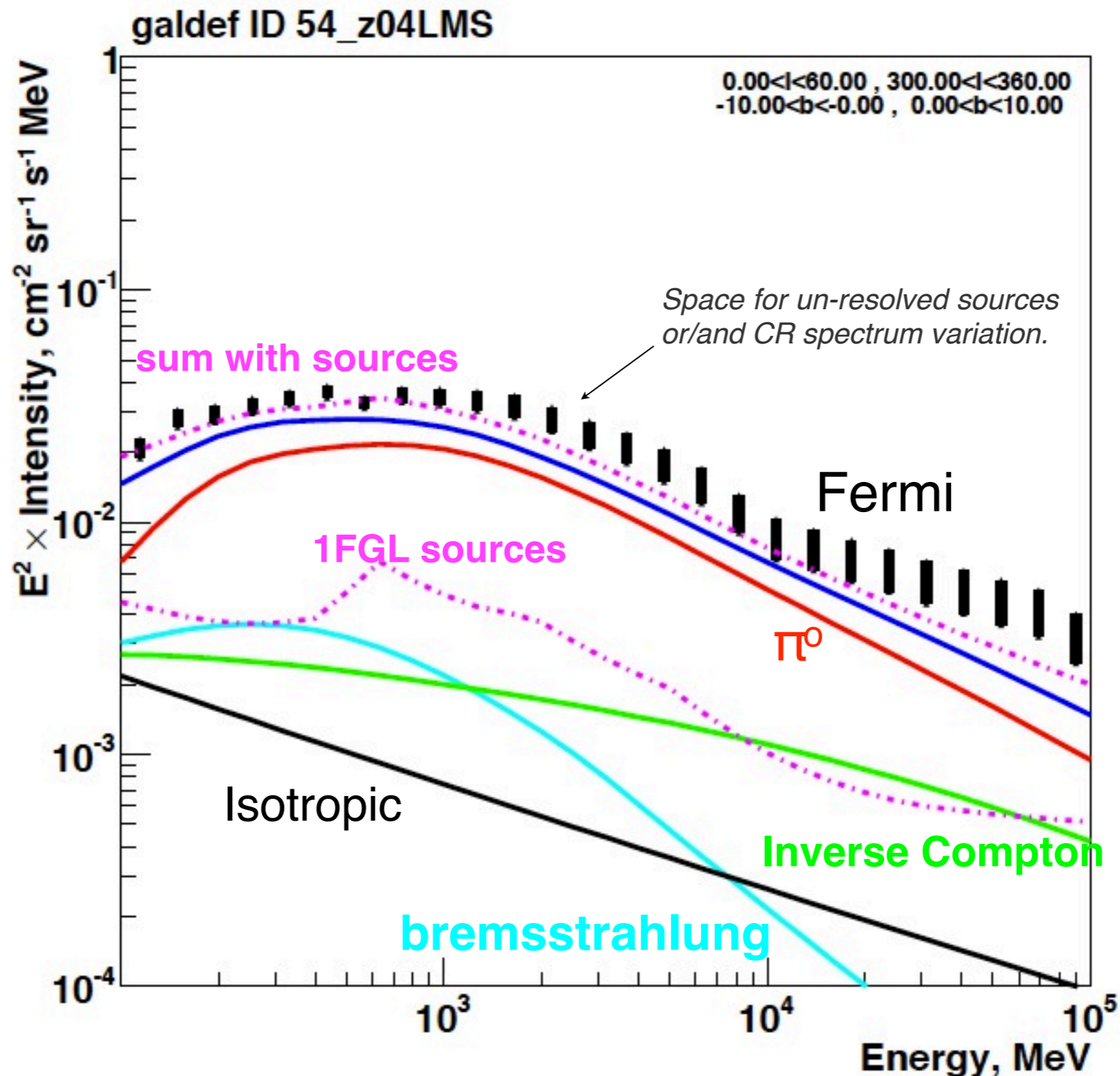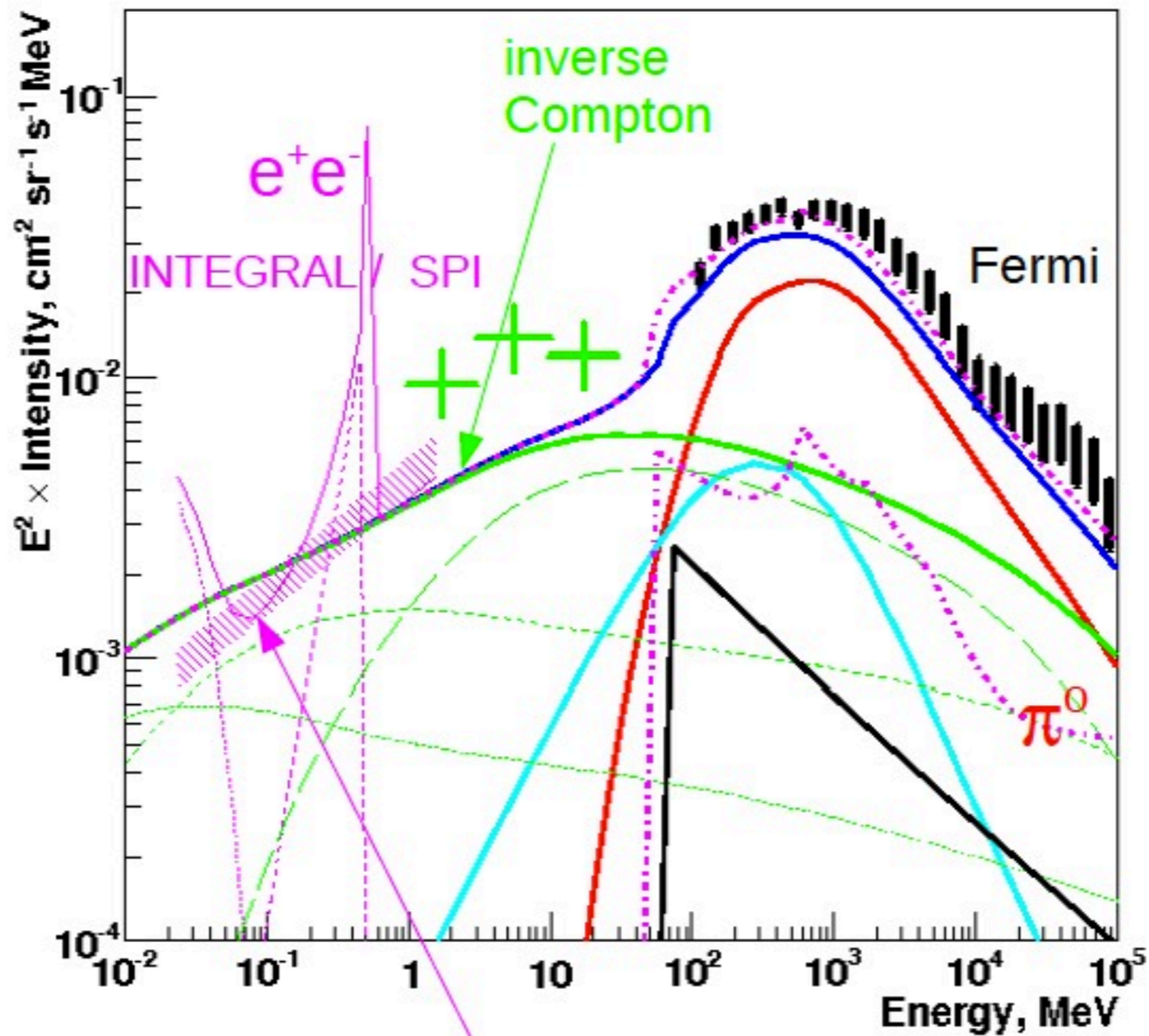
Inner Galaxy projections

1104-1442 MeV
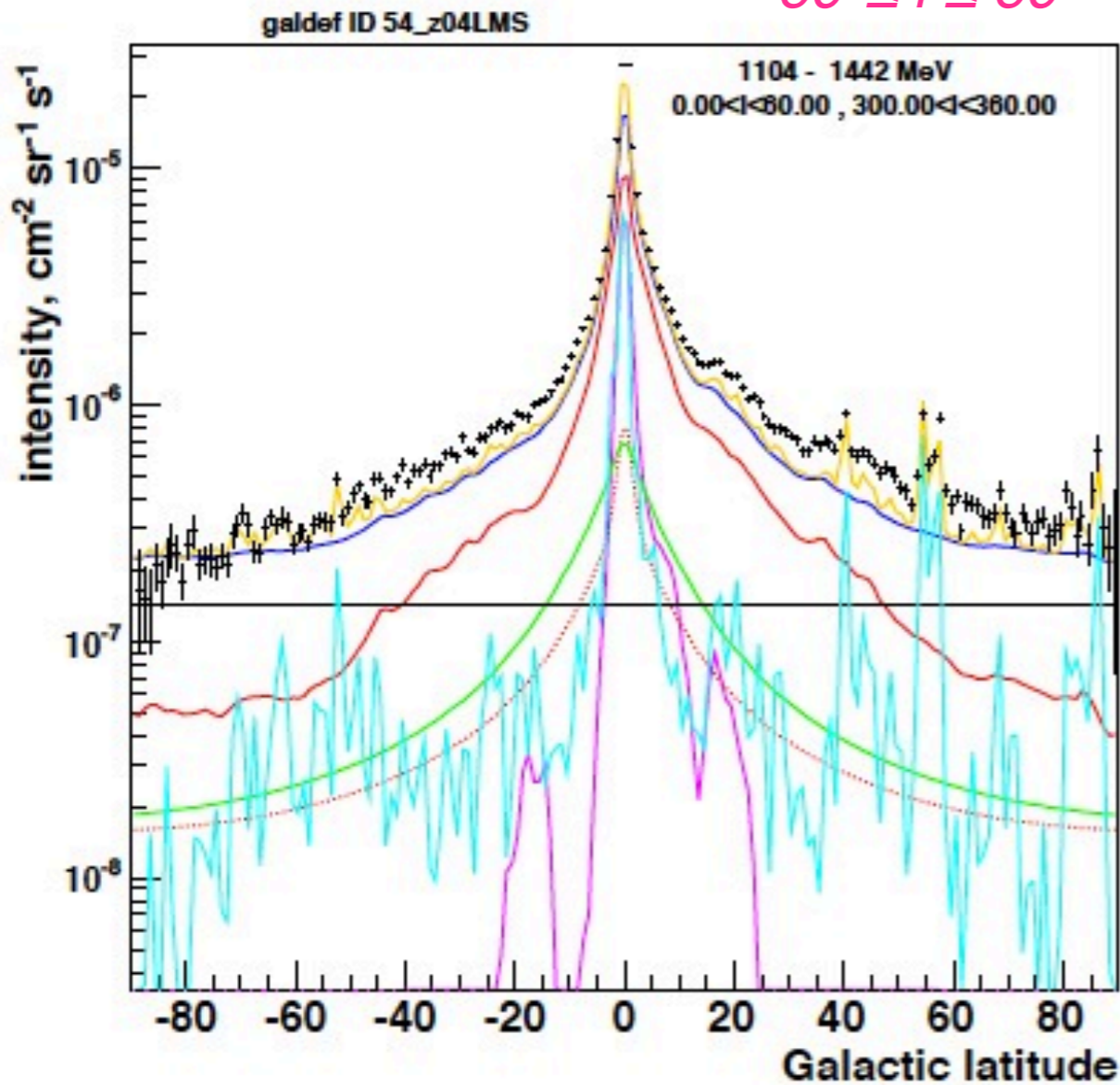
-60° ≤ l ≤ 60°   -5° ≤ b ≤ 5°
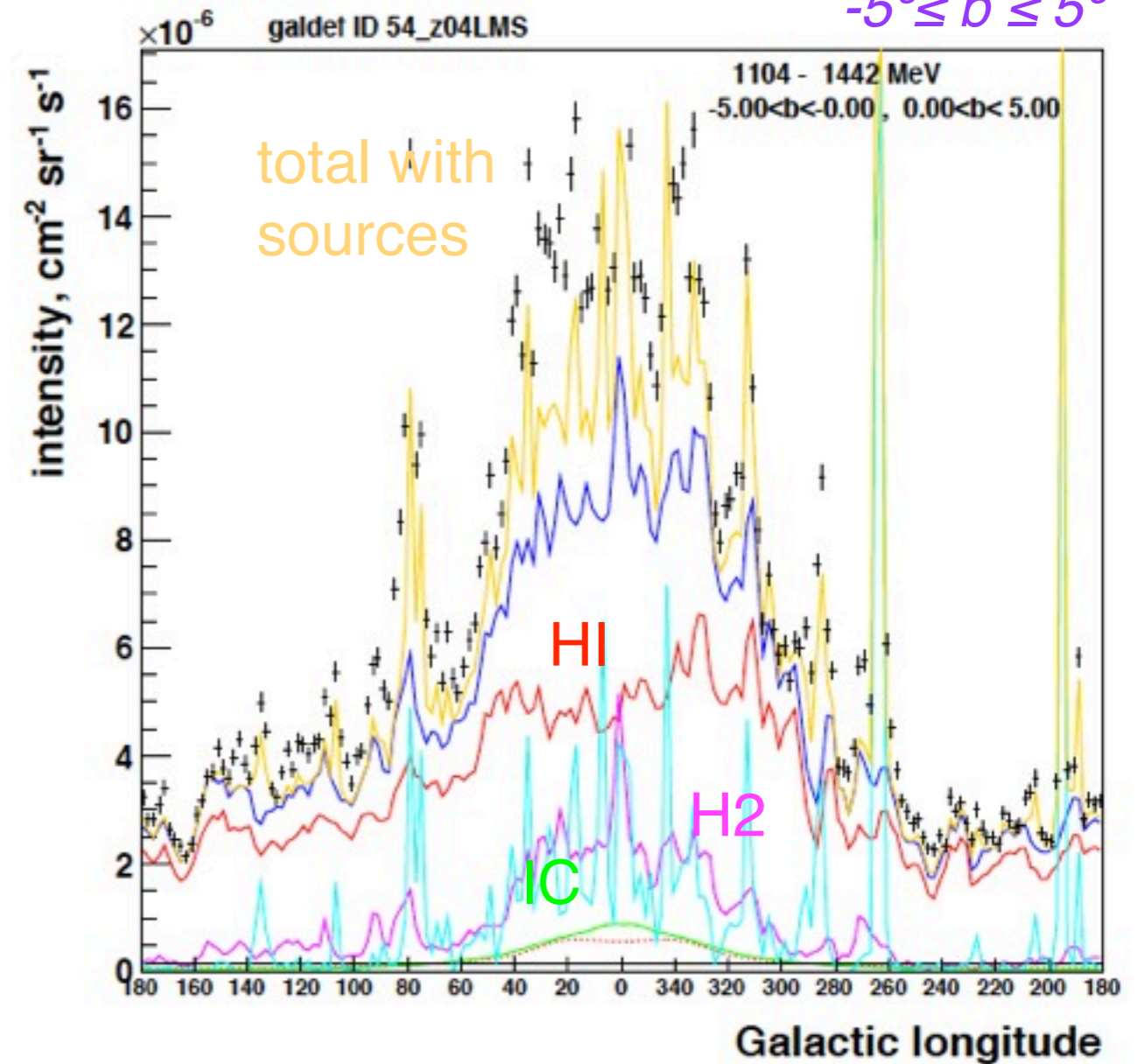
Andy Strong, Proceedings of the ICATPP Conference on Cosmic Rays for Particle and Astroparticle Physics, 2010

Inner Galaxy spectrum: lower energy range with Integral

power-law continuum measured by INTEGRAL / SPI

Andy Strong, Proceedings of the ICATPP Conference on Cosmic Rays for Particle and Astroparticle Physics, 2010

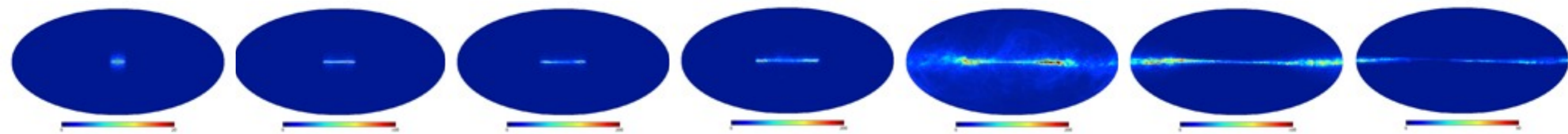*See Laurent Bouchet's talk*

The Template Approach

The diffuse emission can be modelled with a linear combination of various templates.
This approach was used to study selected regions of the sky.
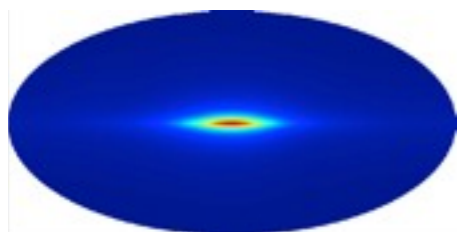*We can also apply it to the whole Galaxy.*

Principle:

$$\gamma = \sum_{r=1,} q_{hi} * NHI_r + \sum_{r=1,} q_{co} * WCO + q_{HI} * I_{IC} + Iso$$

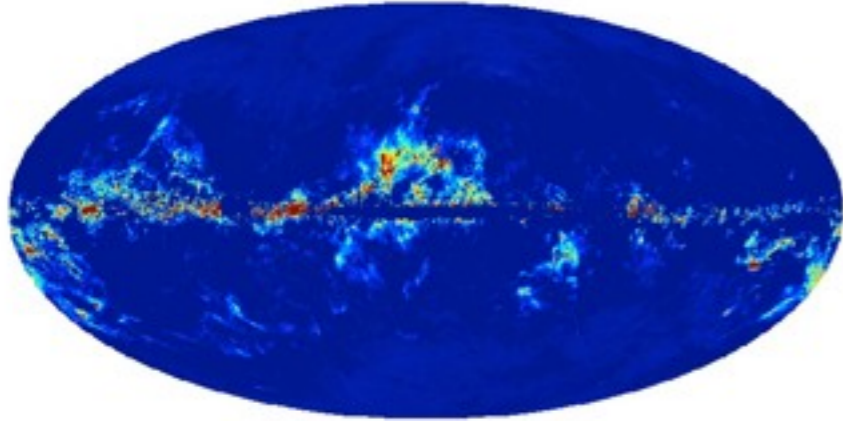*Templates: all-sky surveys or GALPROP IC*

Galactocentric HI rings

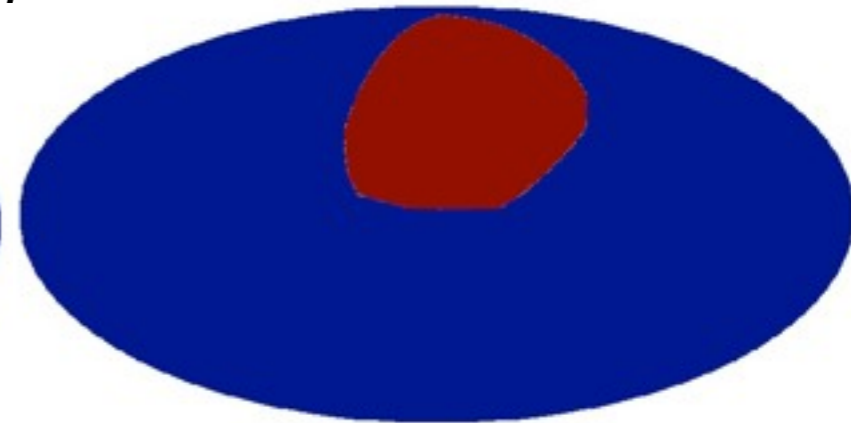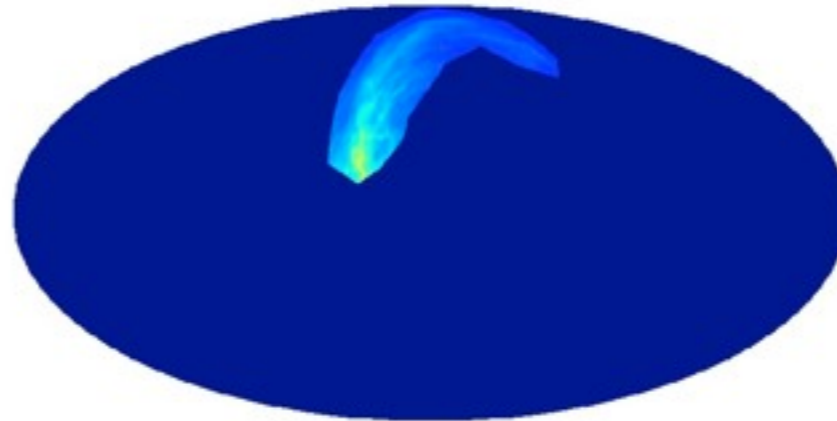*Example of Galprop IC prediction, depends on electron distribution and the ISRF*

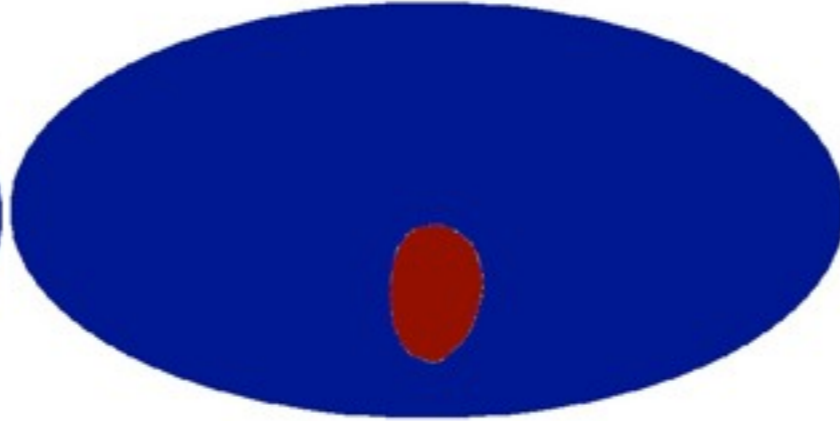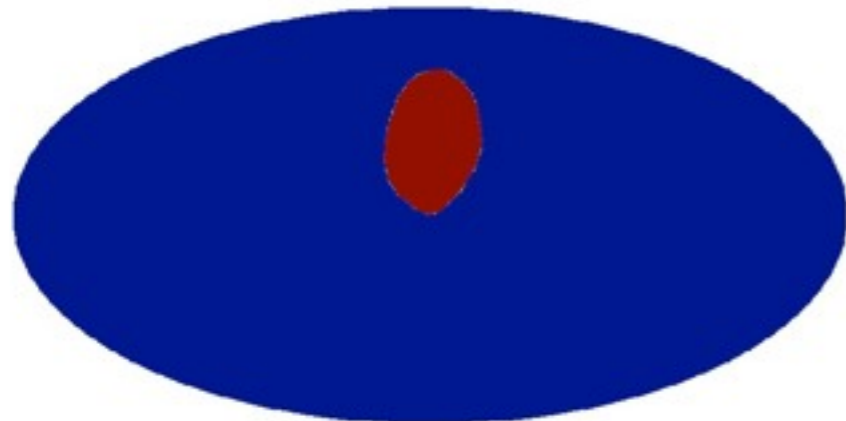# The Template Approach
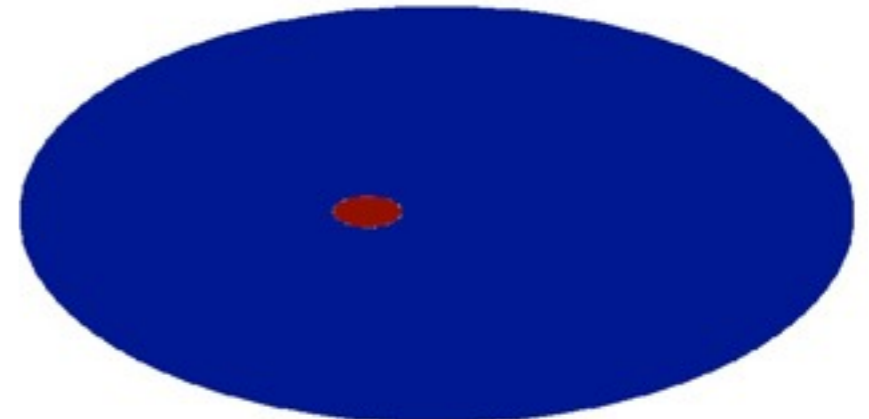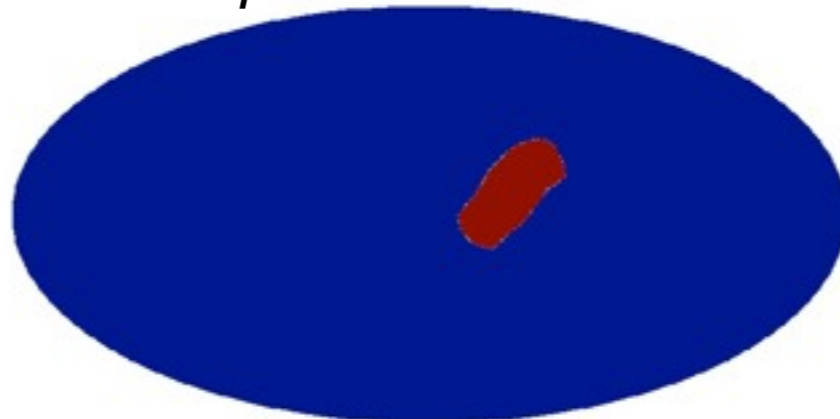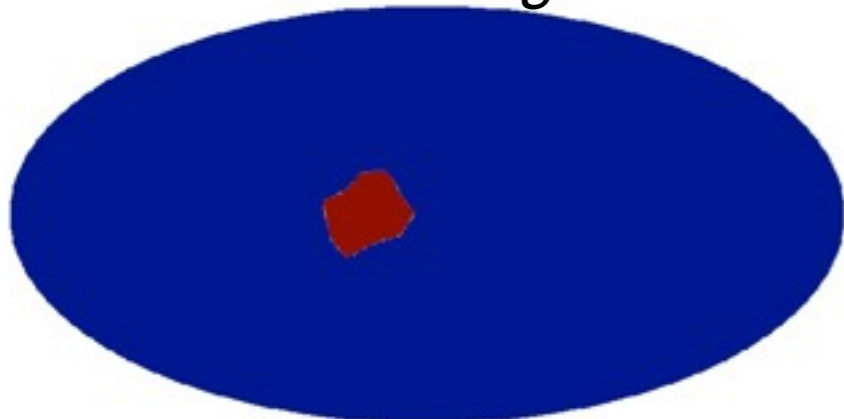
The reality is more complicated

Dark Gas

Loop I

Excess of photons possibly attributed to excess of CR or local spin temperature variation
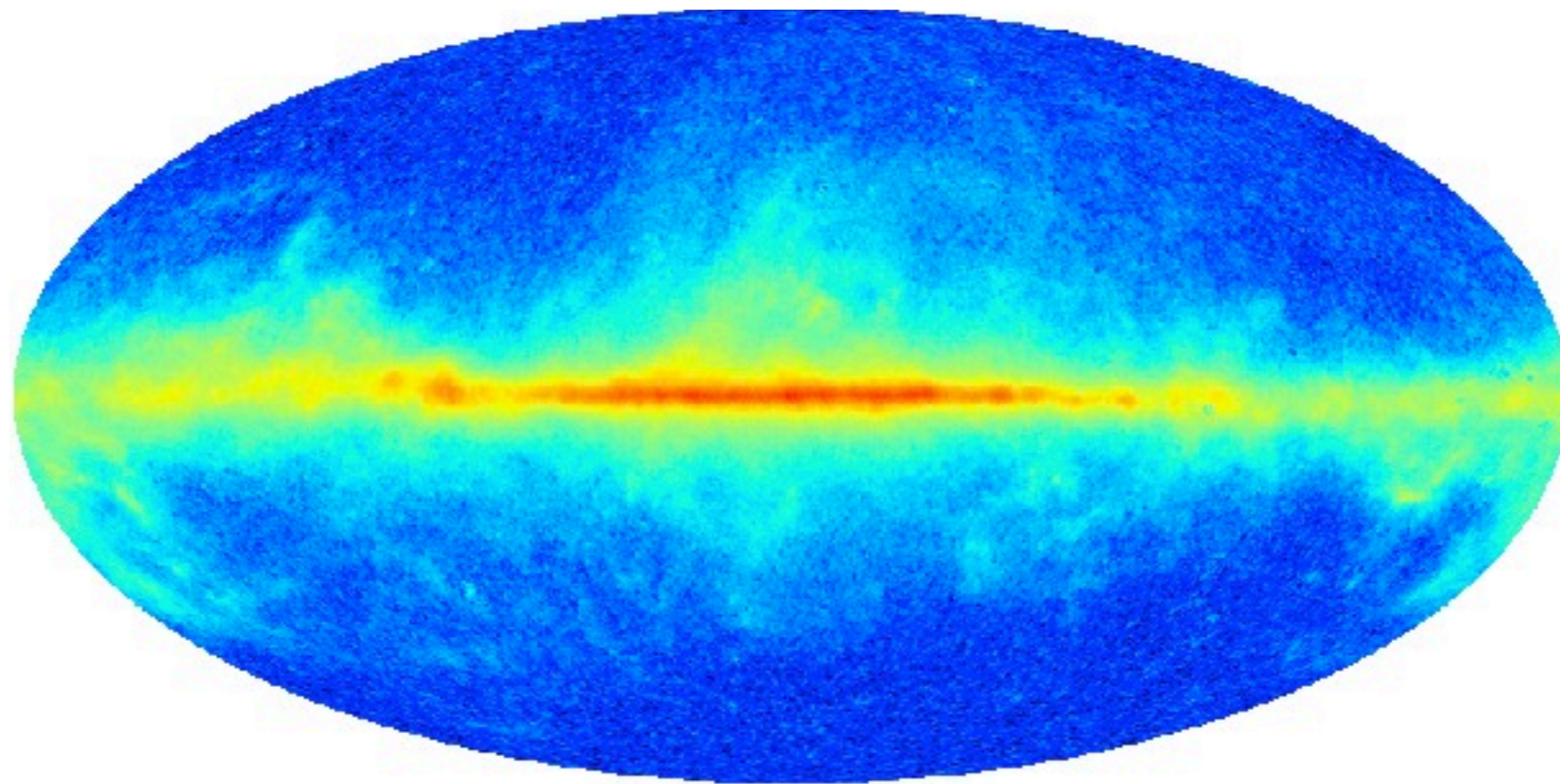
Hard spectrum residual toward the GC

See also Su, Slatyer, Finkbeiner 2010 ApJ 724 1044
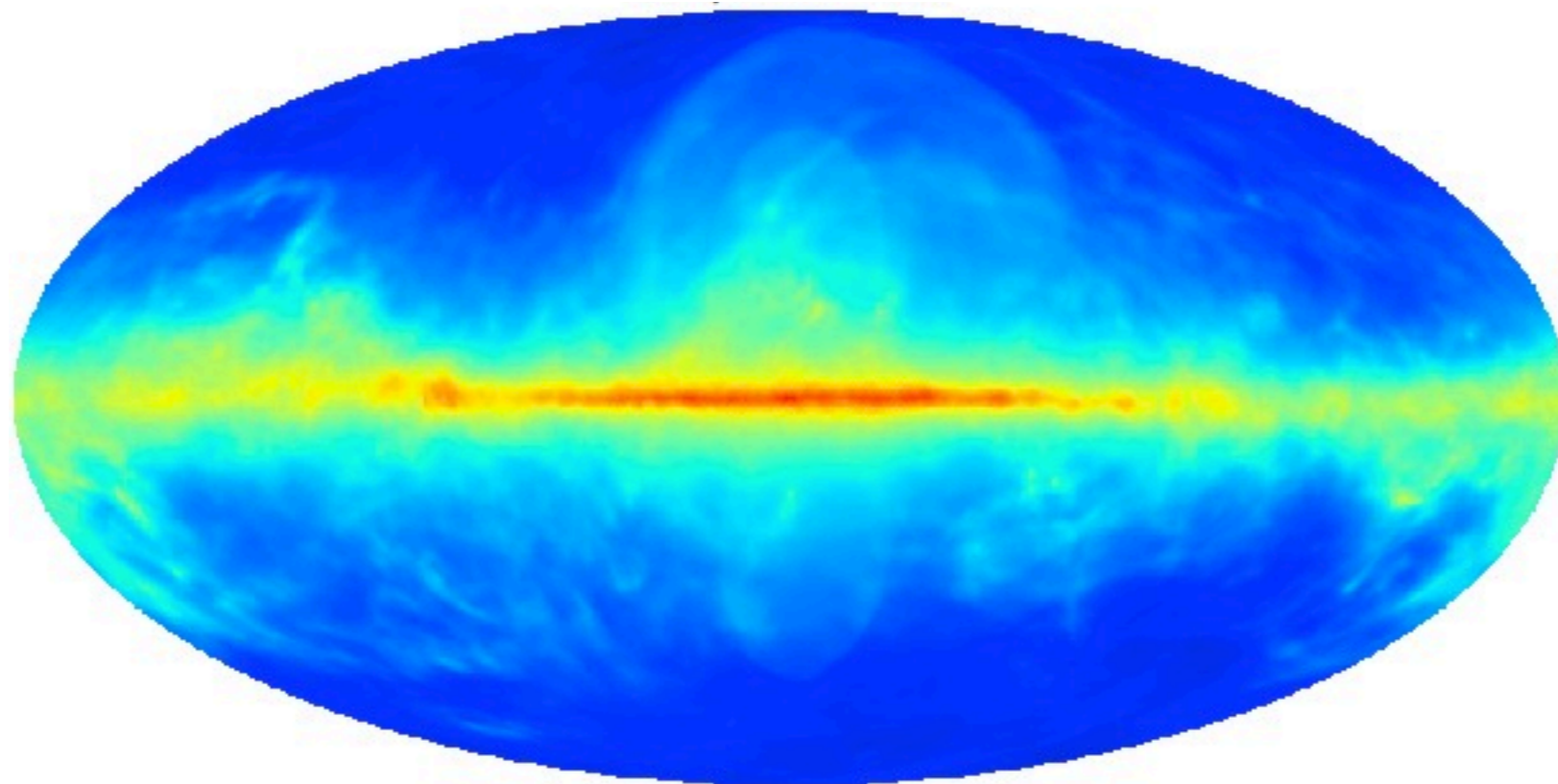
Other regions with excess of photons

LAT counts minus sources and isotropic above 300 MeV

scale: log(counts)

0   3

Template model

Next Public Model Characteristics

- *The grid for the model is 0.125°*

- *Cube with 30 energy planes from 50 MeV to 600 GeV.*

- *Size ~500 Mbyte.*

- *Fitted with 24 months of LAT data in 14 bands from 63 MeV to 40 GeV with 0.25° resolution.*

- *Based on P7.6 "clean" class with isotropic also provided for "source" class.*

- *Row centered on b=0°.*

- *New HI, CO column density map (no Magellanic stream for example).*

- *New GALPROP-derived template for IC*

- *Patches for unaccounted excess of photons*

The model is optimized for point and extended sources studies.

Conclusion

There are lots of interesting studies in the paradise of diffuse emission physics...

Torn Between Heaven and Hell
~golfiscool
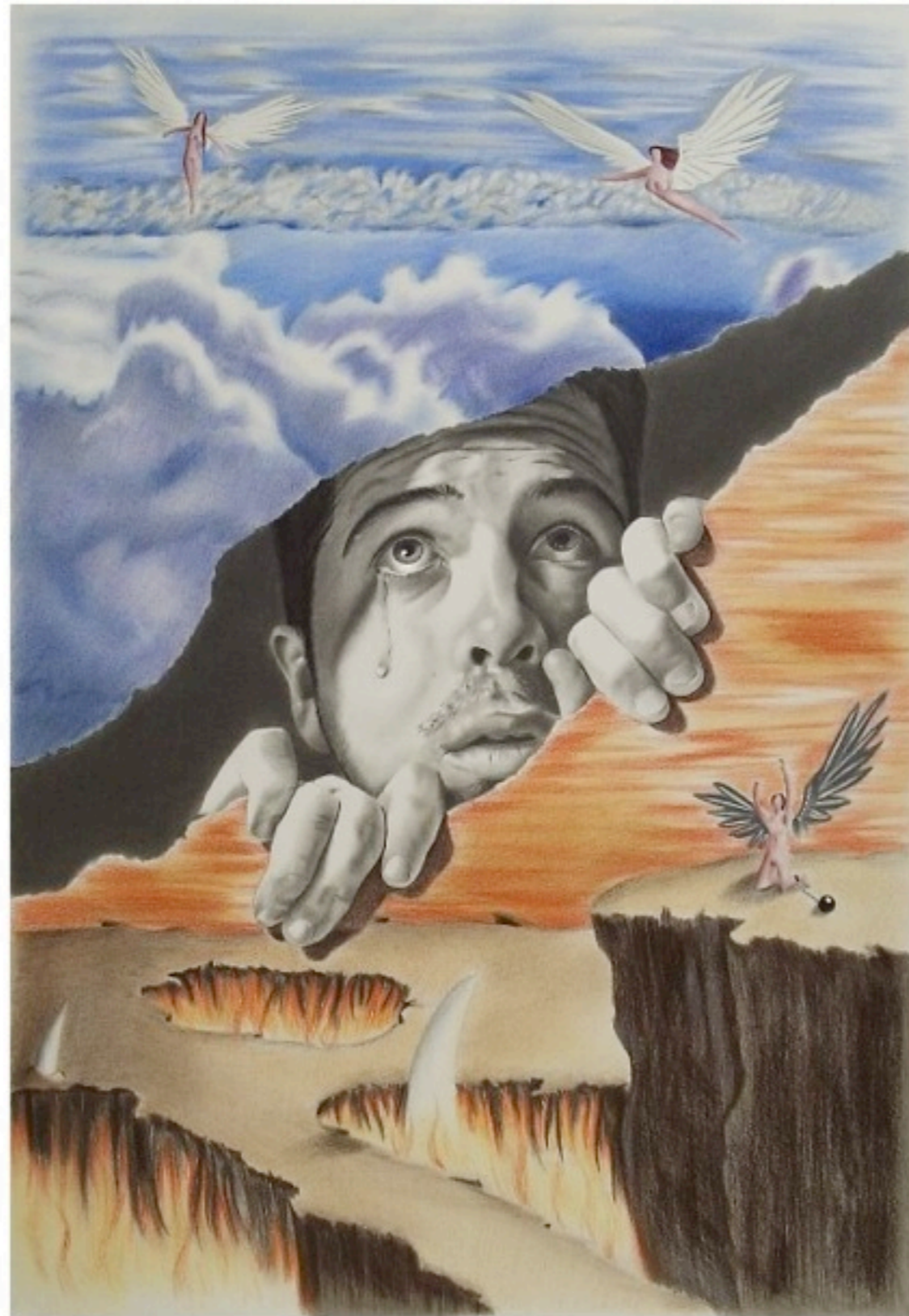
... but we still have to work like hell to make sure we understand the systematic errors.

Backup

Are the CR and ISM density coupled ?

Association of CR sources with regions of massive clouds ?
Confinement of CRs by magnetic fields associated with the gas ?

III quadrant: $210° \leq l \leq 250°$, $-15° \leq b \leq 20°$ *Abdo et al., ApJ 726, 81A (2011)*
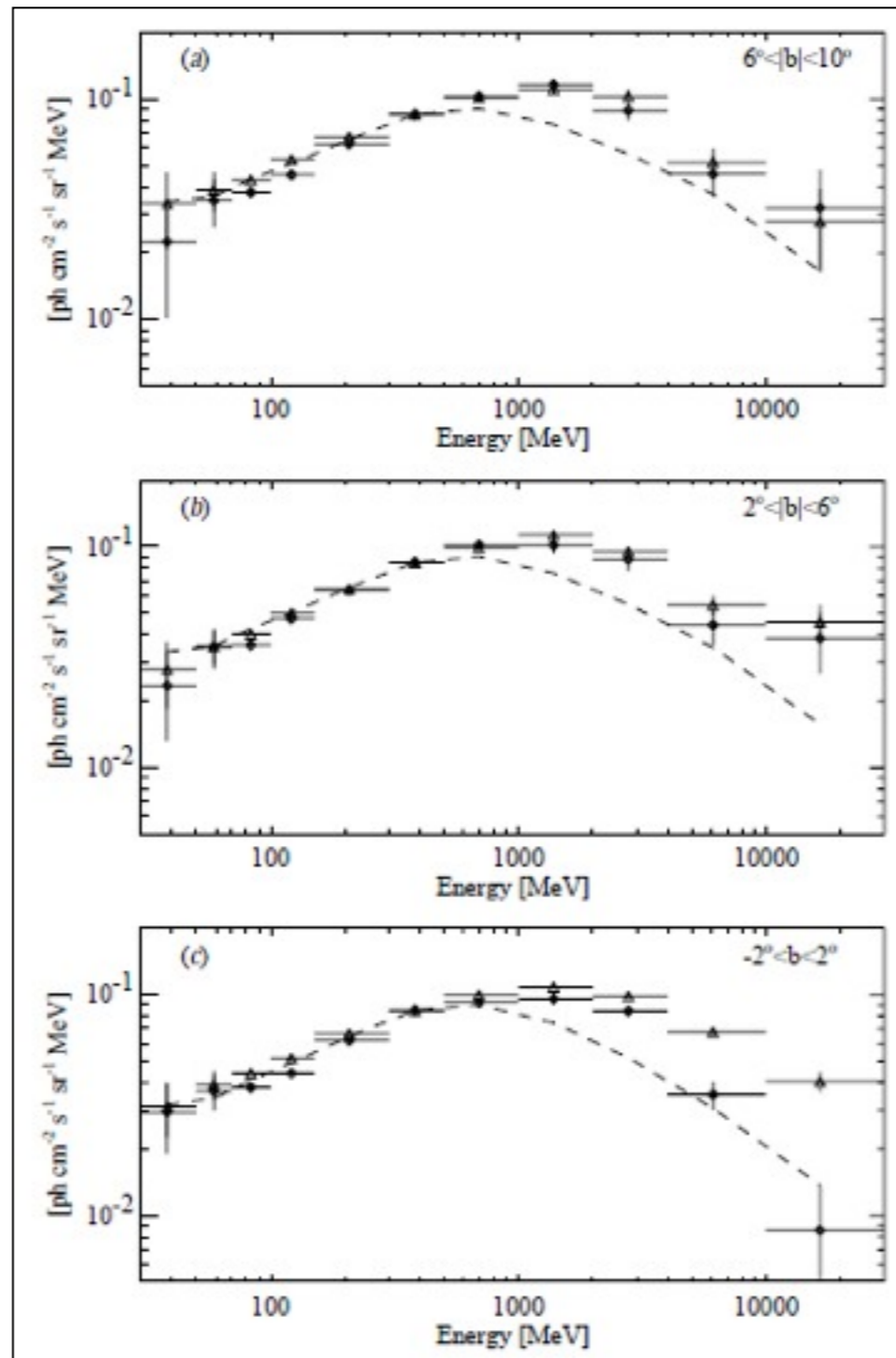*C.A.: T. Mizuno, L. Tibaldo, I. Grenier*

No large enhancement in the spiral arms with respect to the interarm region
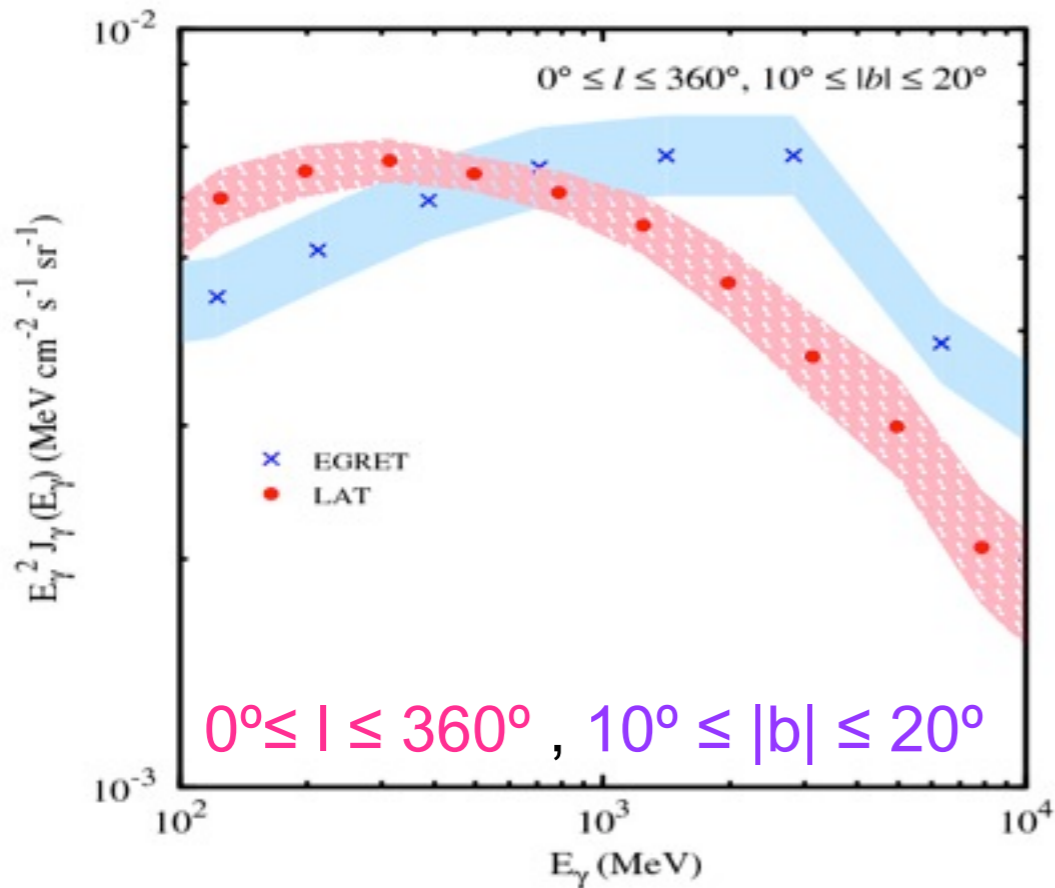
HI emissivity versus Galactocentric distance
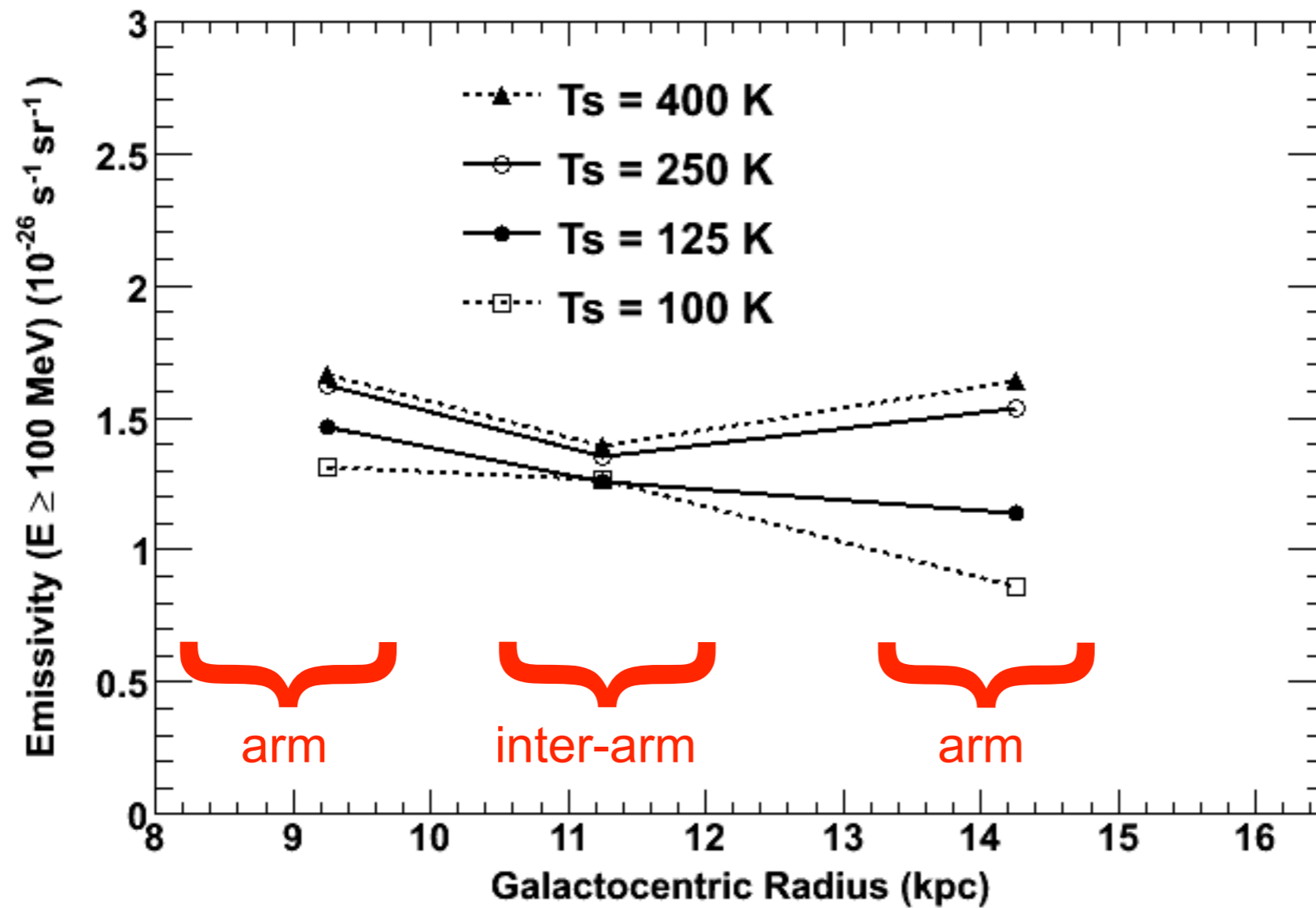
Abdo et al., ApJ 726, 81A (2011), C.A.: T. Mizuno, L. Tibaldo, I. Grenier
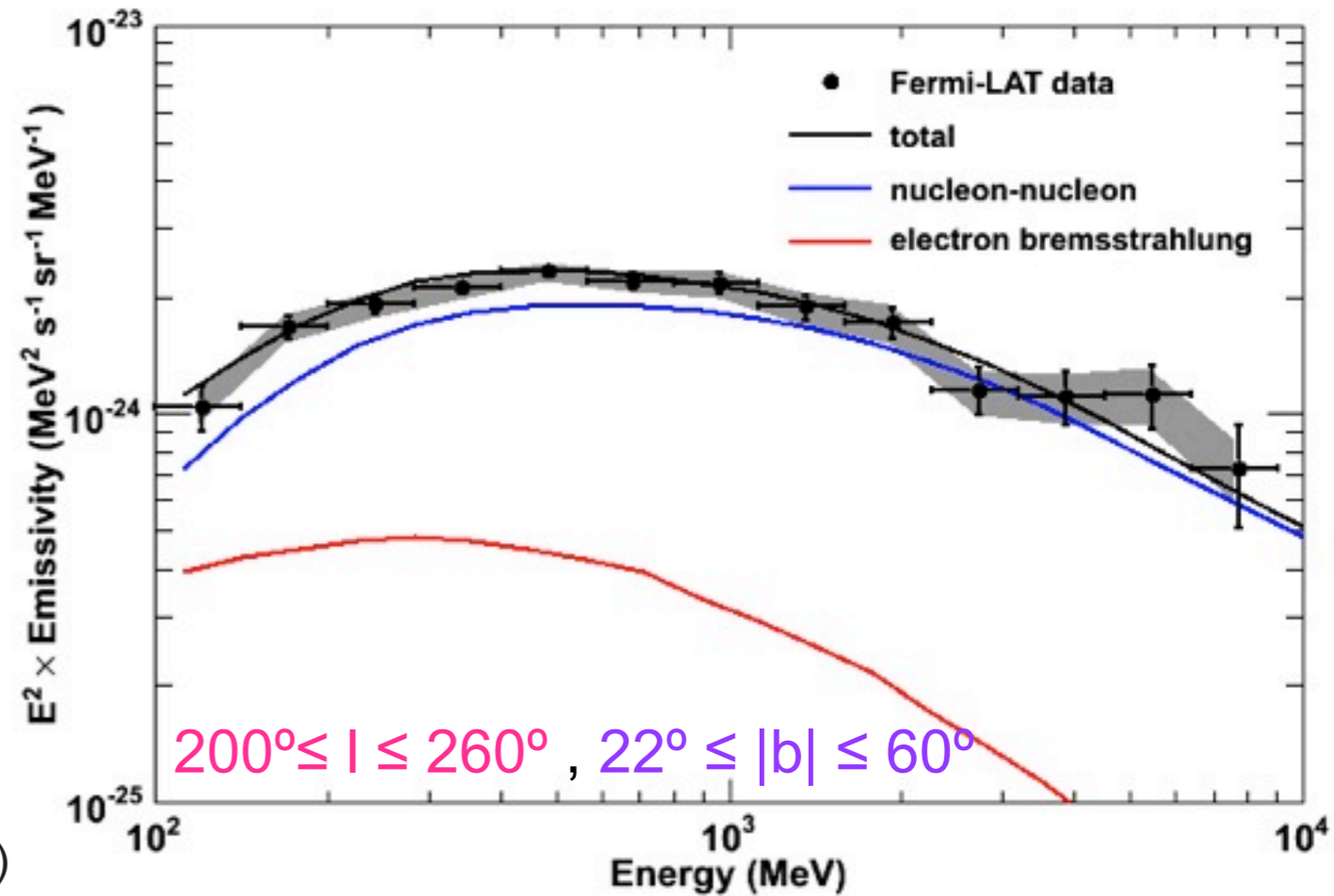
Does FERMI see the EGRET GeV excess ?

Hunter et al. 1997

Does FERMI see the EGRET GeV excess ?

$0° \leq l \leq 360°$, $10° \leq |b| \leq 20°$

Abdo *et al.*, Phys. Rev. Lett. 103, 251101 (2009)
C.A.: T. Porter, G. Johannesson

$200° \leq l \leq 260°$, $22° \leq |b| \leq 60°$

LAT spectrum does not confirm the EGRET GeV excess