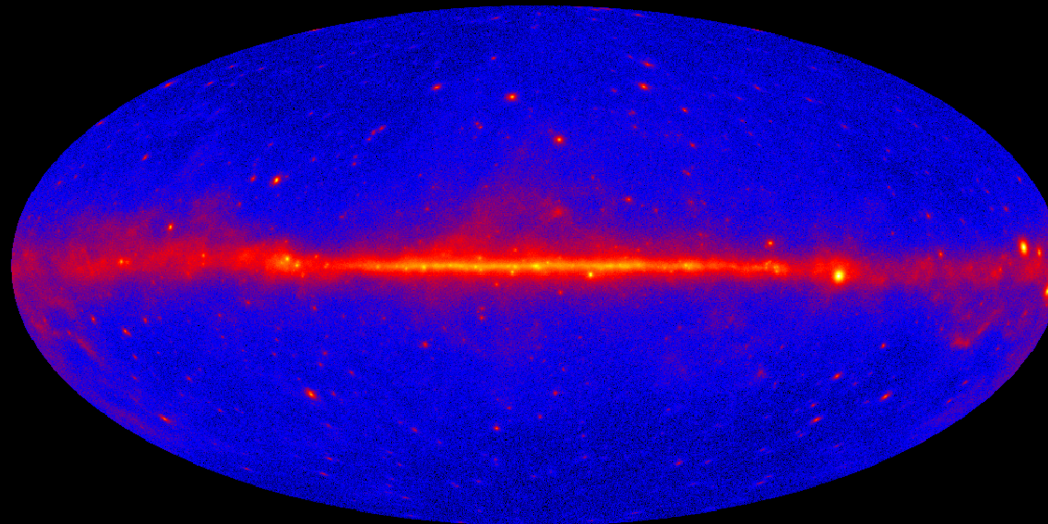
The cosmic-ray, gamma-ray, synchrotron, B-field connection

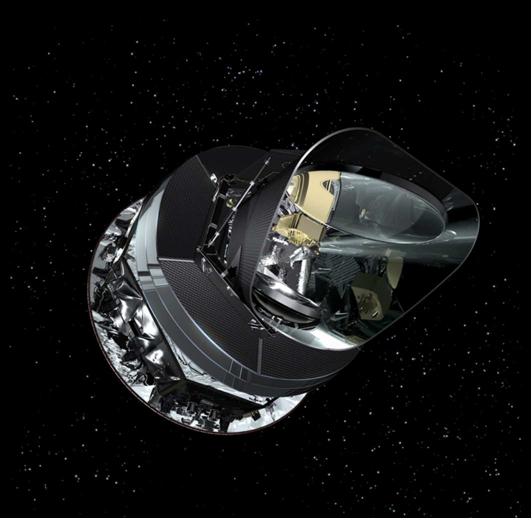
Andy Strong

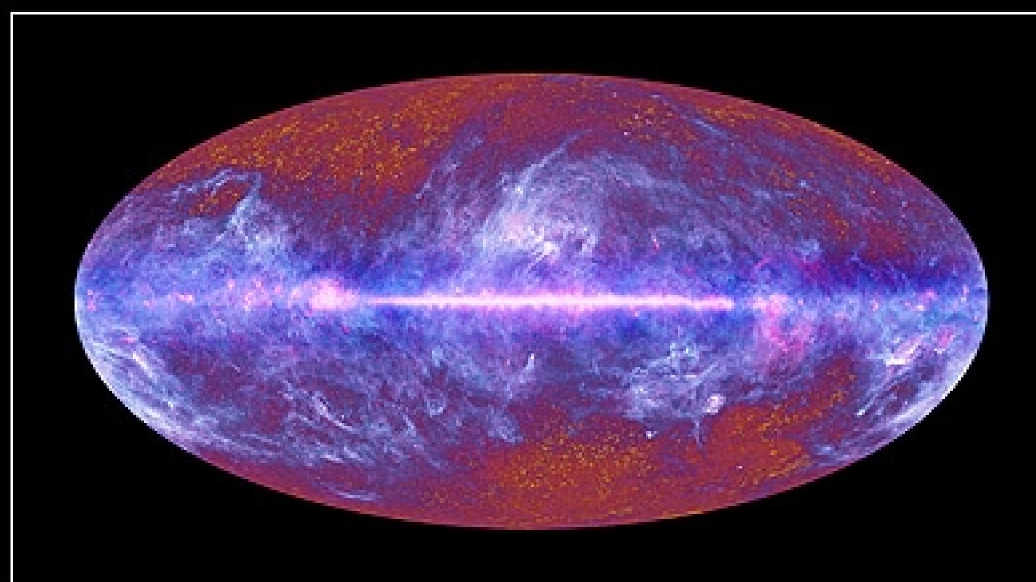
on behalf of Fermi-LAT collaboration

Workshop on Extragalactic Magnetic Fields,
APC, Paris, 13-15 Dec 2010



1 year



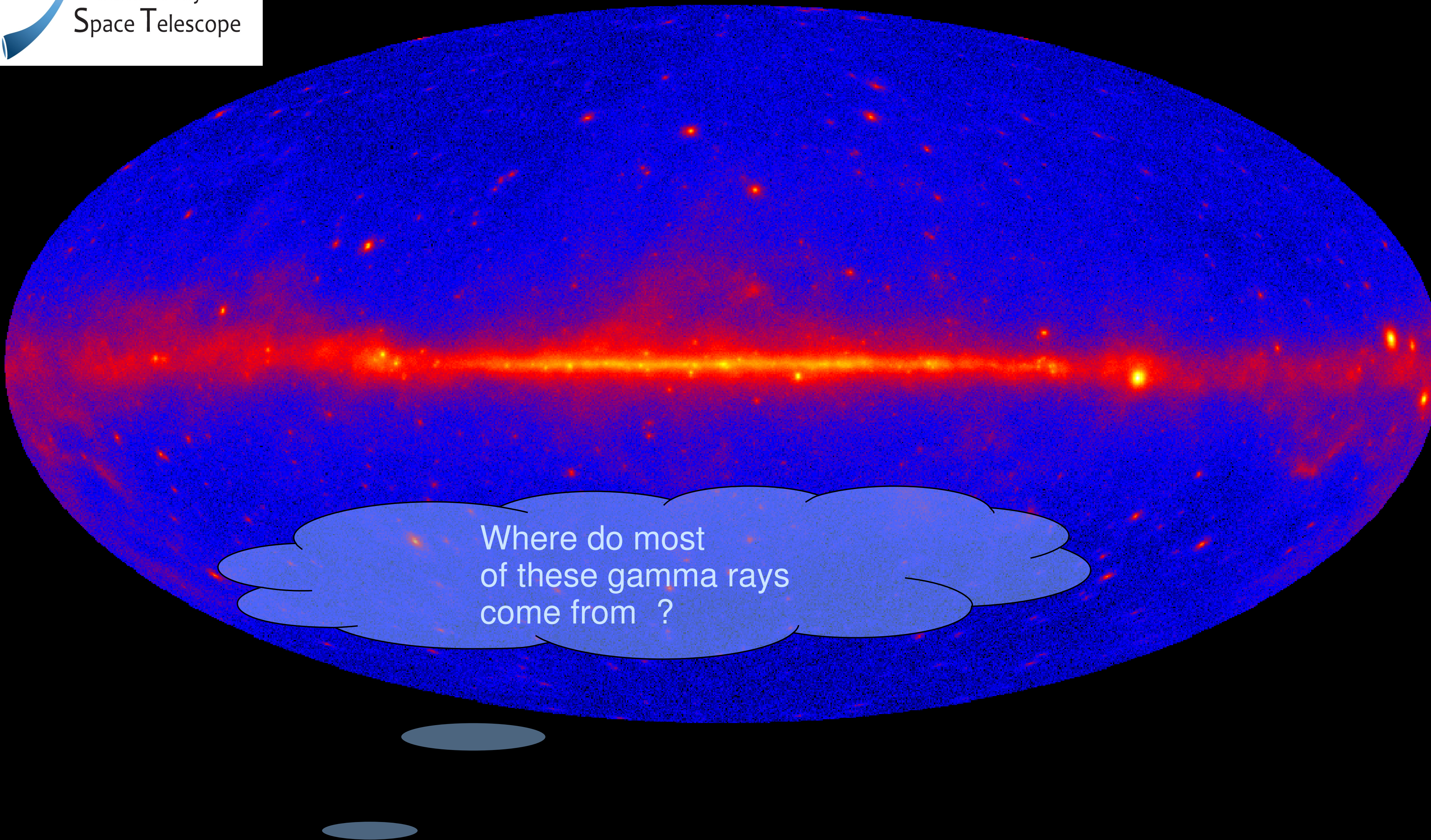


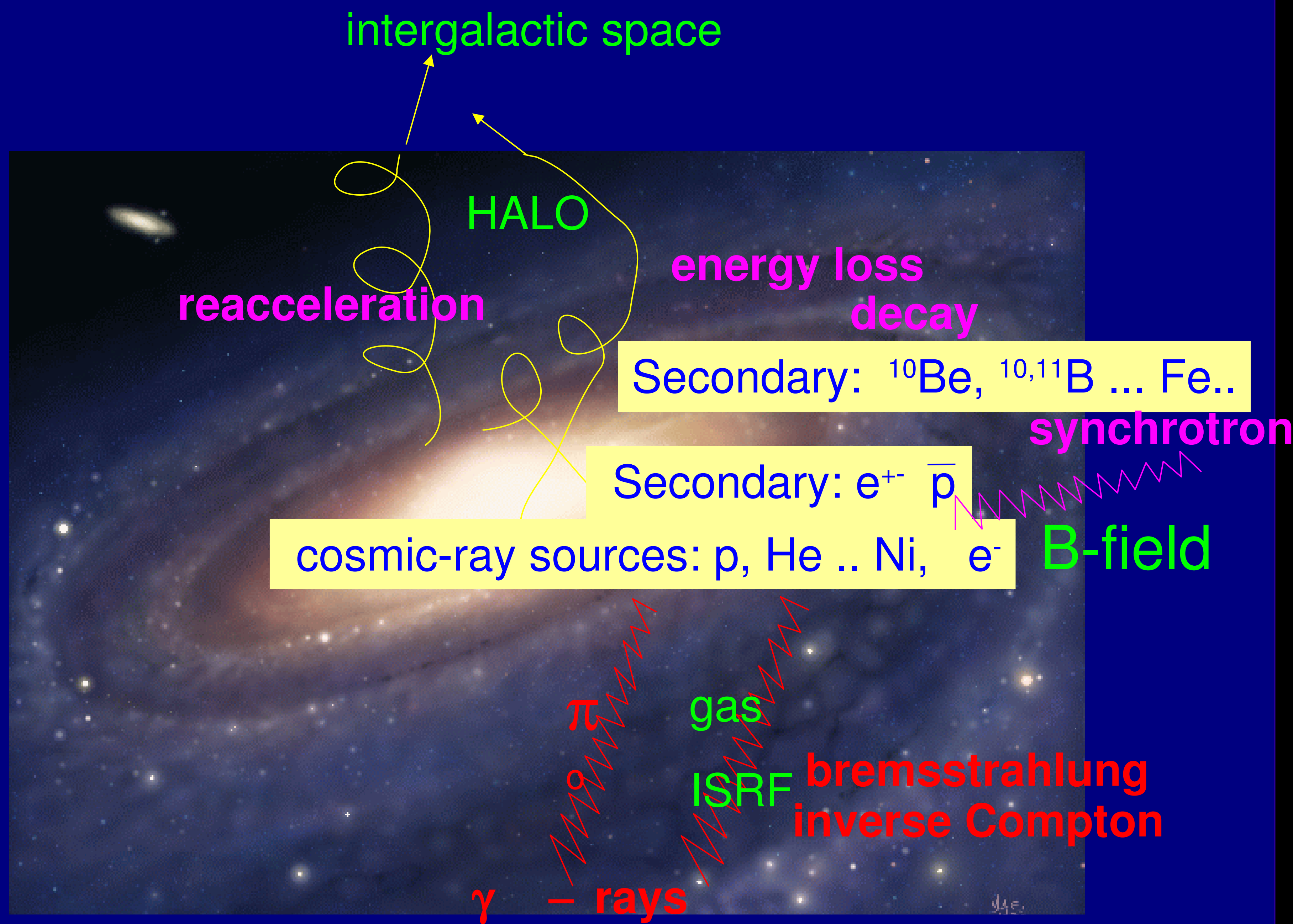
The Planck one-year all-sky survey   esa   (c) ESA, HFI and LFI consortia, July 2010

1 year

Both flying now. A lot of common astrophysics !

Fermi
Gamma-ray Space Telescope

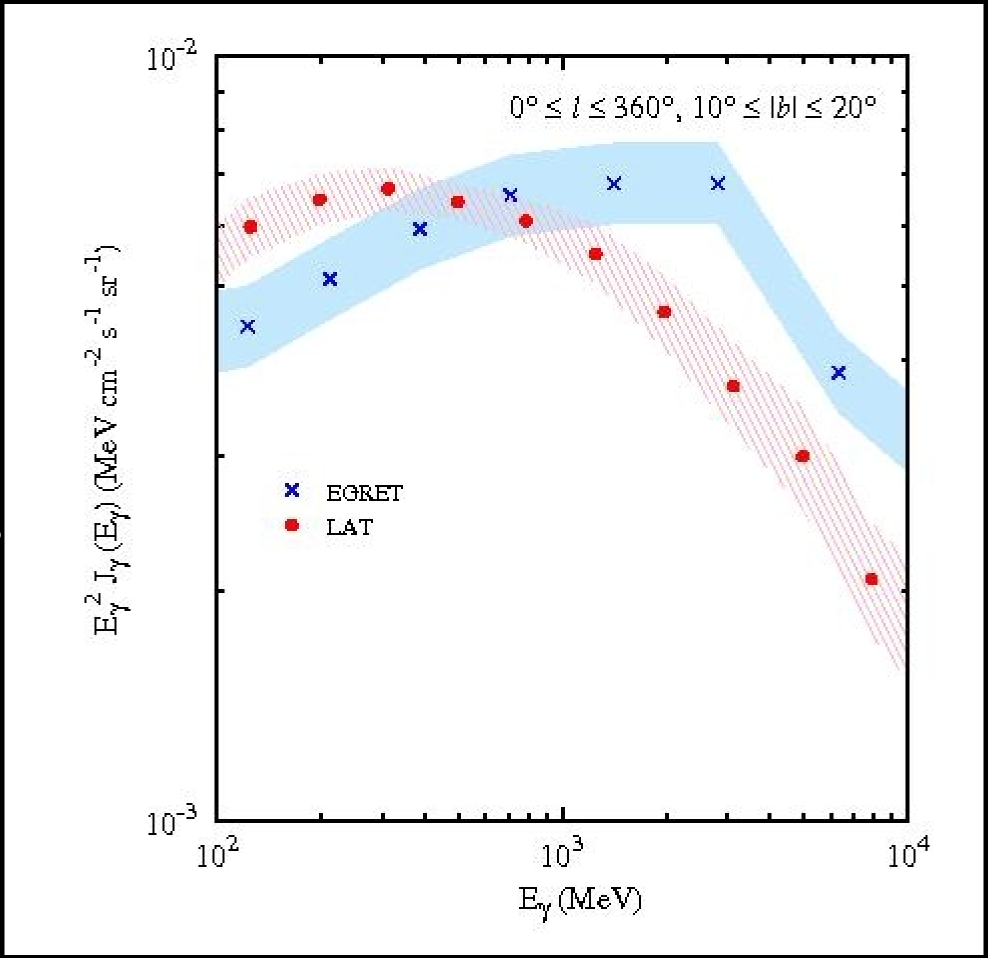




Magnetic field is part of the puzzle, hence this talk !

EARLY CONCLUSIONS from Fermi-LAT

Fermi does *not* confirm EGRET GeV excess



Abdo et al (2009) PRL 103, .251101

so back to the drawing board for models based on EGRET GeV excess !

DIFFUSE EMISSION RESULTS FROM FERMI-LAT

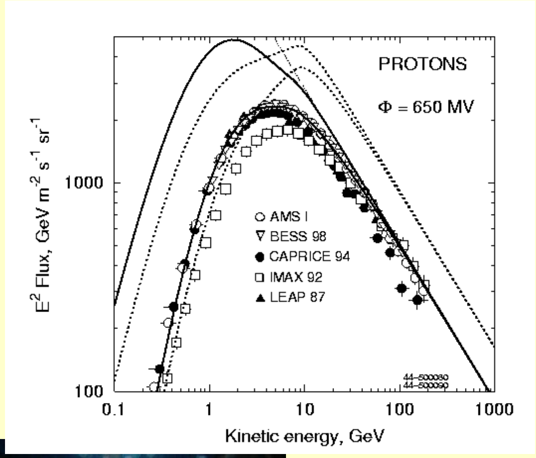
New:

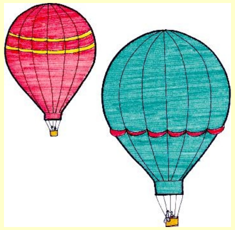
- >1 year of data
- low background event class (developed for extragalactic background study)
- Fermi-measured electron spectrum
- Improved gas tracer: dust emission

The **goal** : use *all* types of data in self-consistent way to test models of cosmic-ray propagation.

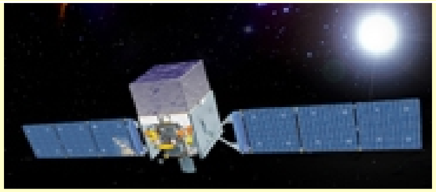
Observed *directly, near Sun:*

- primary spectra (p, He ... Fe; e^-)
- secondary/primary (B/C etc)
- secondary e^+ , antiprotons...

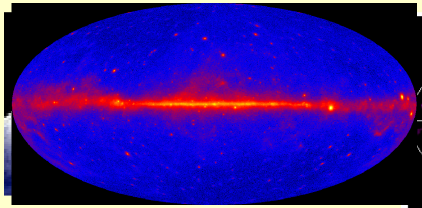


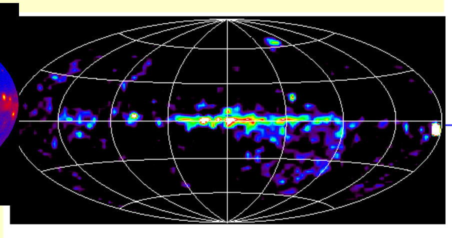


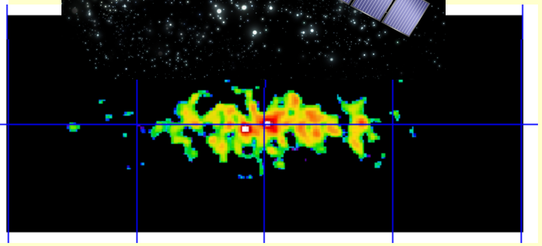
Observed *from whole Galaxy:*



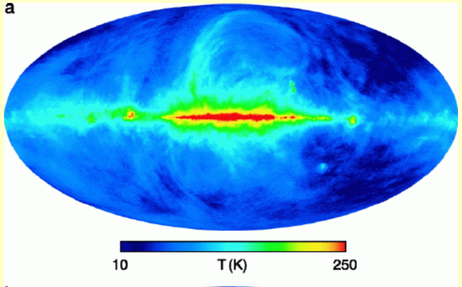
γ







synchrotron



Modelling the gamma-ray sky

Main ingredients of GALPROP model

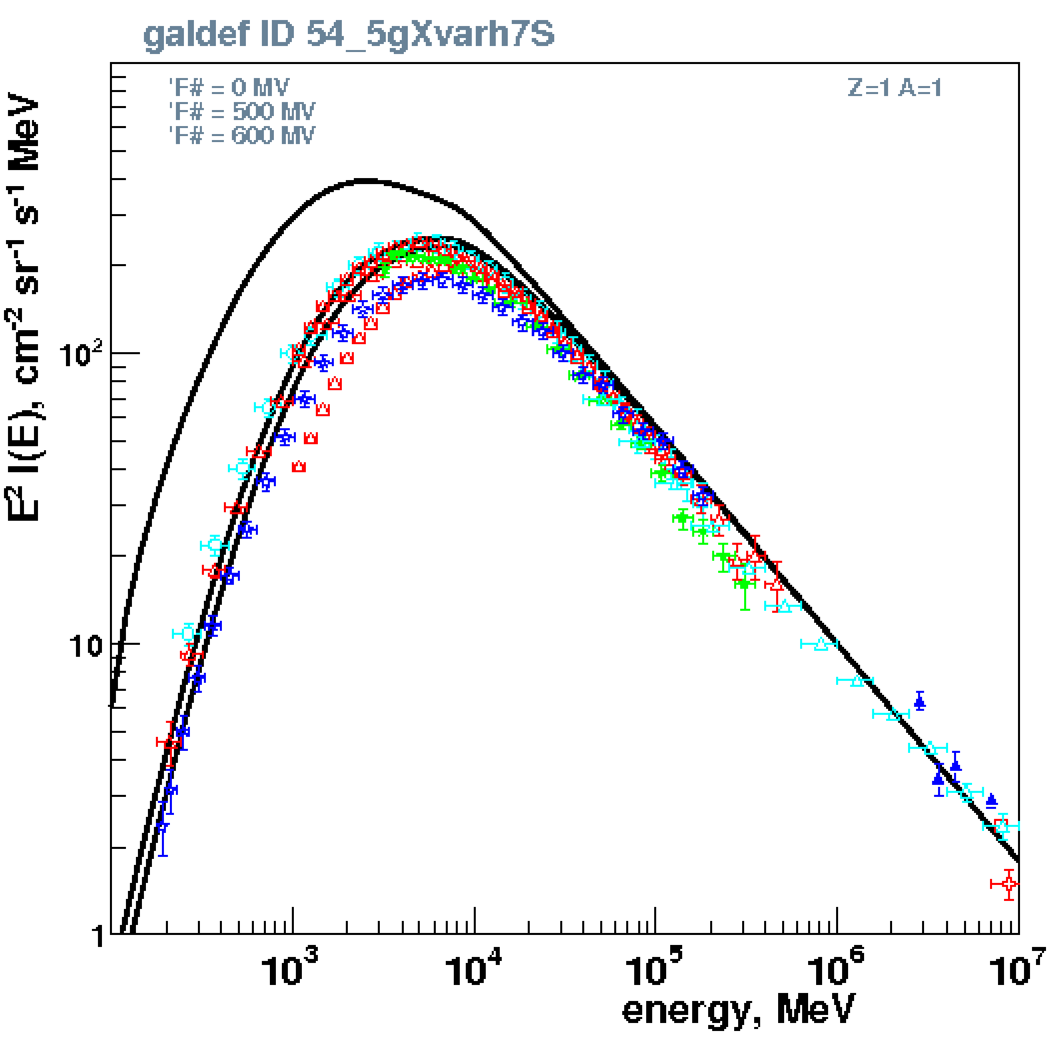
cosmic-ray spectra p , He , e- , e+ (including secondaries)
(including *Fermi-measured* electrons)
cosmic-ray source distribution follow e.g. SNR/pulsars

secondary/primary (B/C etc) for propagation parameters
halo height = 4 - 10 kpc (from radioactive cosmic-ray nuclei)

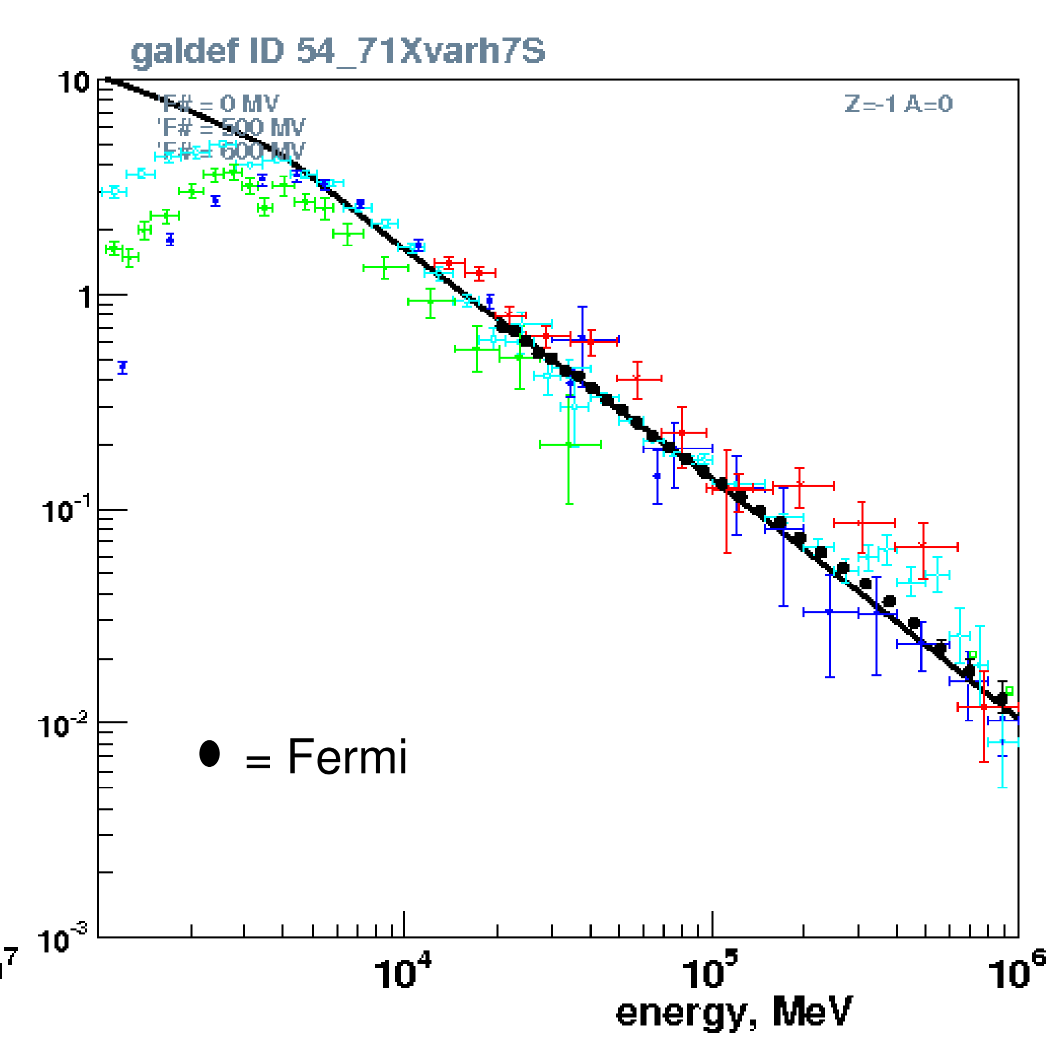
Interstellar radiation field (-> inverse Compton)
B-field (electron energy losses, synchrotron)
HI, CO, dust surveys
CO-to-H_2 conversion a function of position in Galaxy
Fermi 1st Year Source Catalogue

First use a model based on *locally-measured* cosmic rays

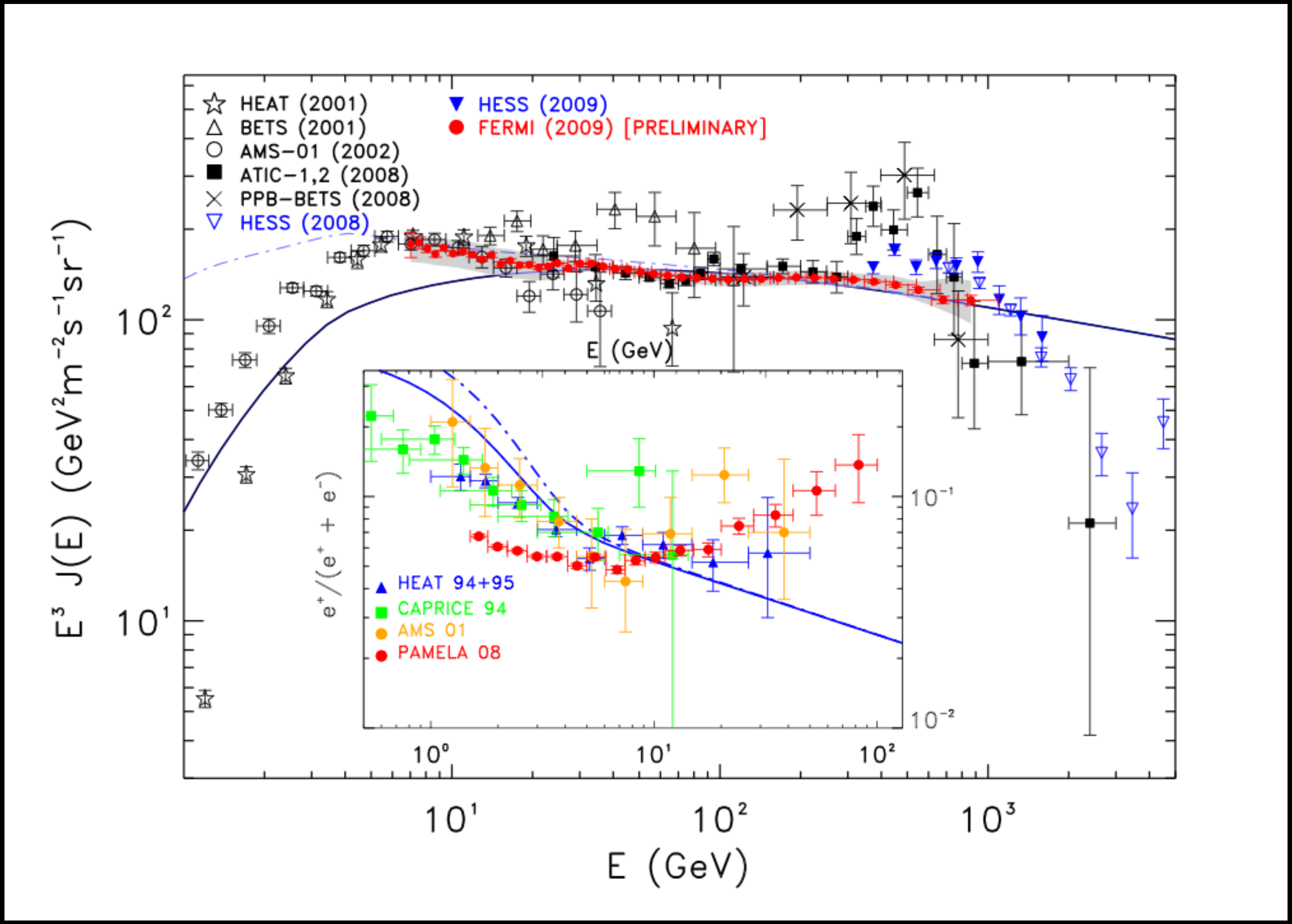
PROTONS



ELECTRONS



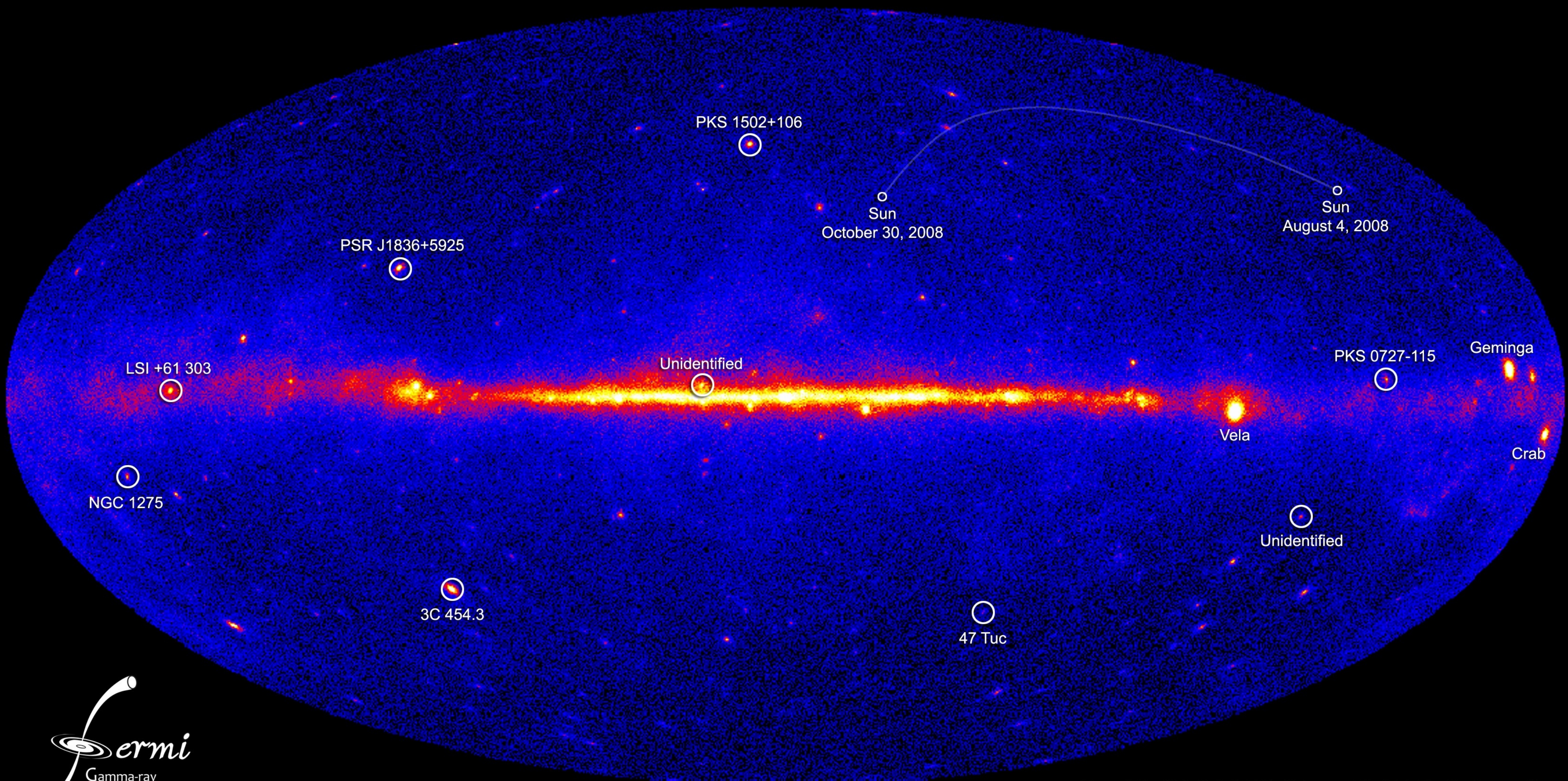
Electron spectrum measured by Fermi-LAT extended down to 7 GeV



Abdo etal 2010

Abdo et al 2009 PRL.102, 181101, Grasso et al 2009 Astropart.Ph. 32, 140

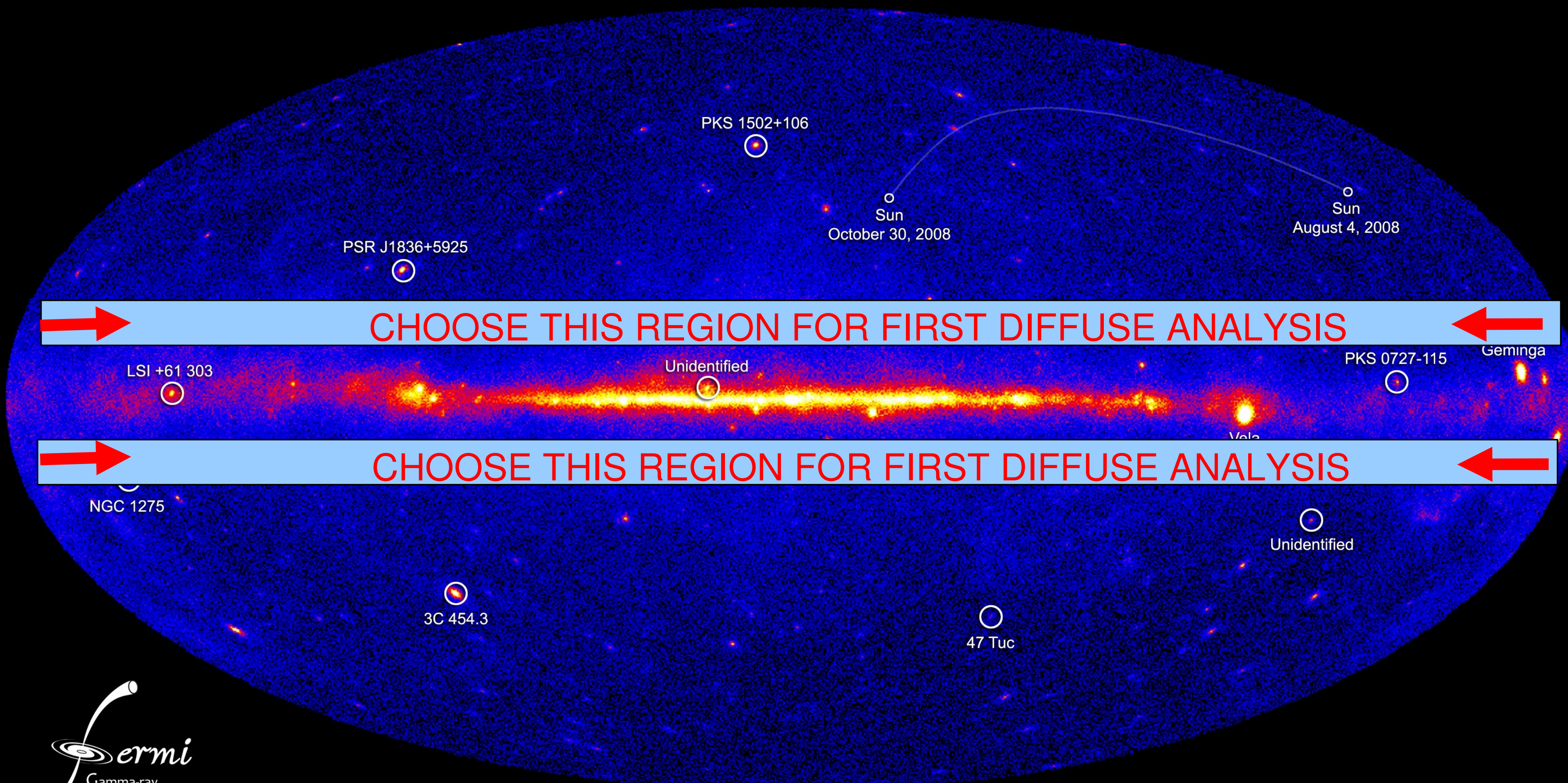
NASA's Fermi telescope reveals best-ever view of the gamma-ray sky



Fermi Gamma-ray Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

NASA's Fermi telescope reveals best-ever view of the gamma-ray sky

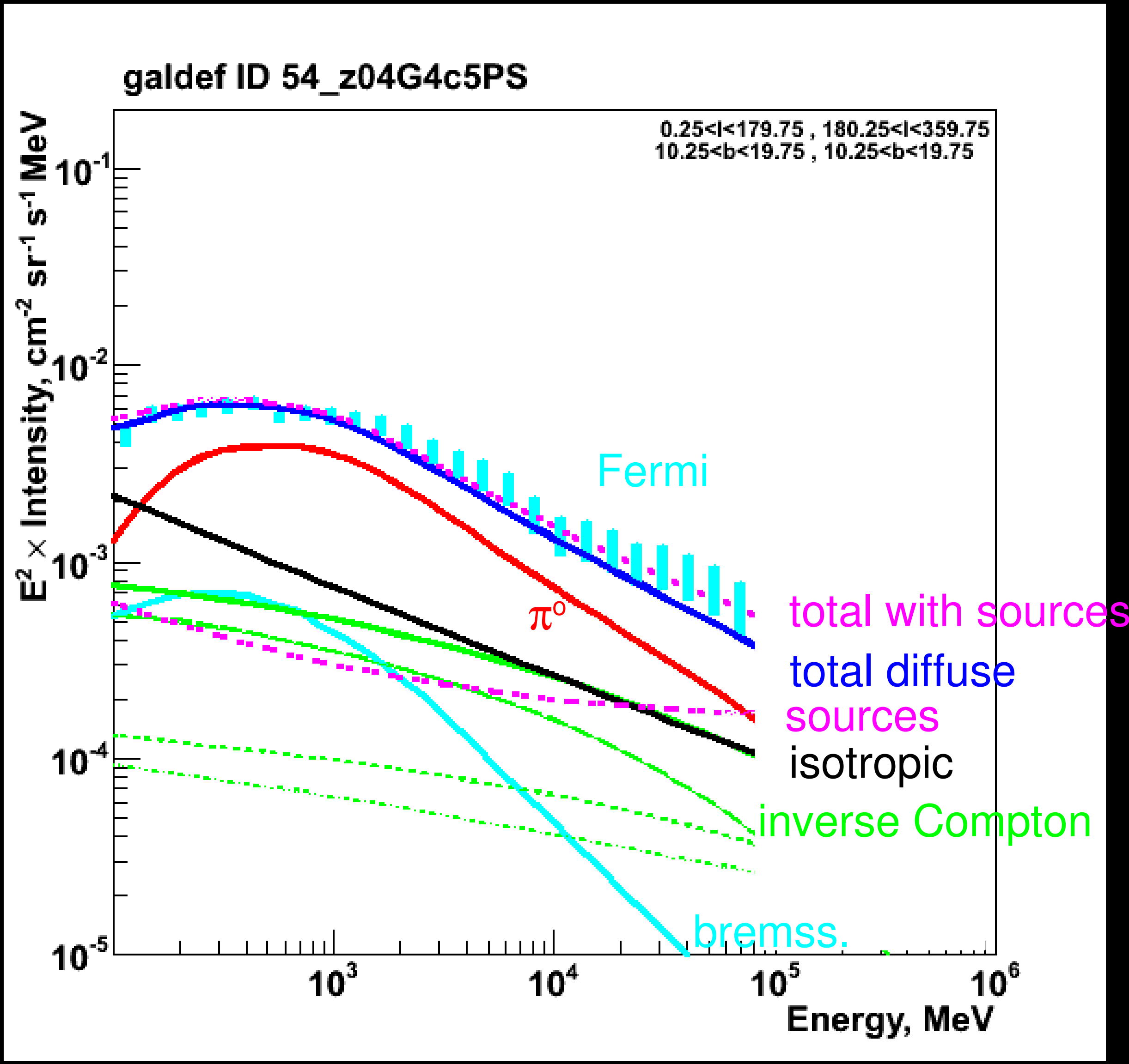


Fermi
Gamma-ray
Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

INTERMEDIATE LATITUDES
+10 < b < +20

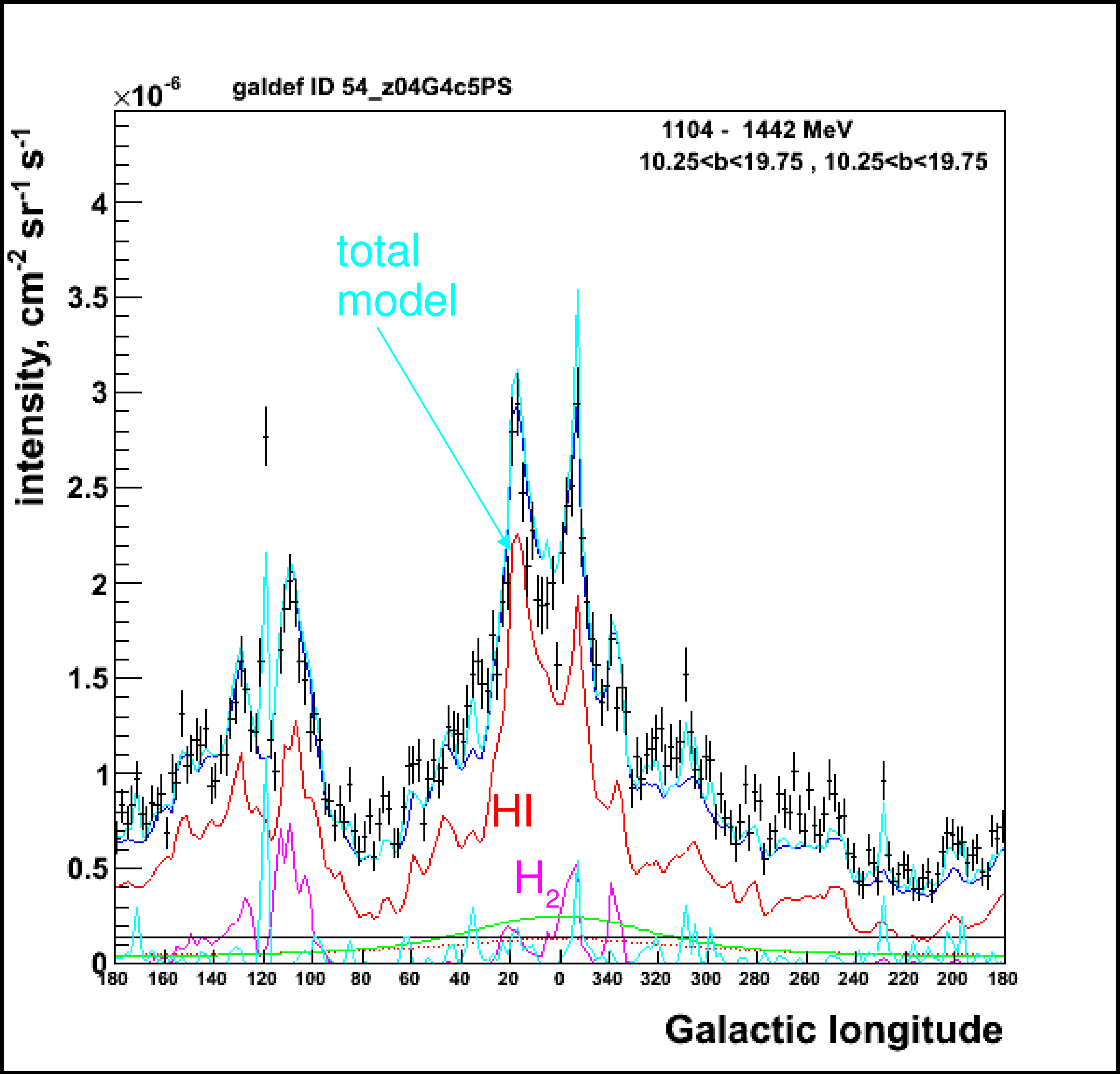
good
agreement
with
basic
model



PRELIMINARY

INTERMEDIATE LATITUDES
+10 < b < +20
1 GeV

total gas
traced by
dust from
IRAS+DIRBE



Remarkable agreement. Confirms that dust is a better tracer of local gas than HI+CO
(Grenier, Casandjian: found this in EGRET data)

PRELIMINARY

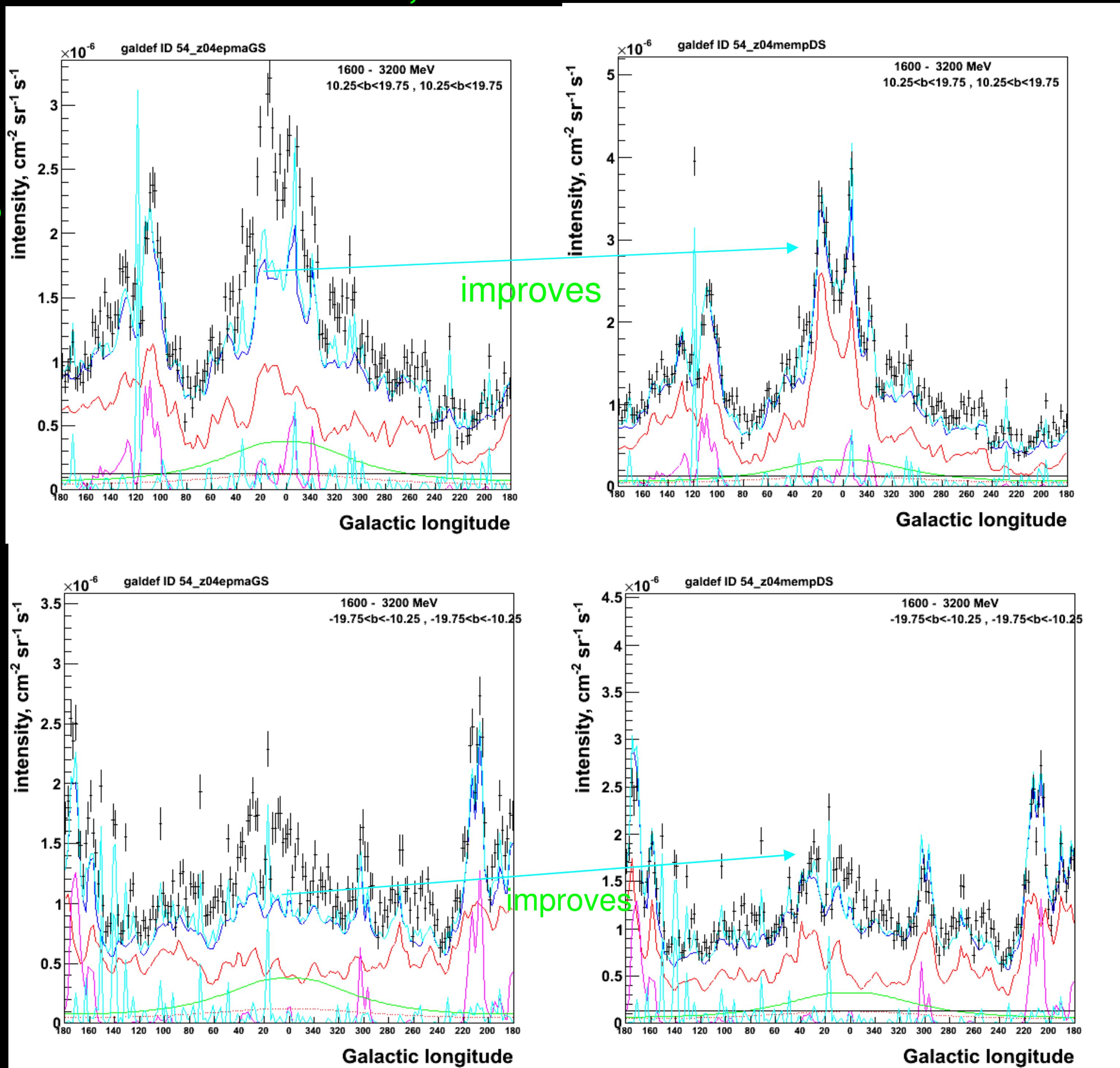
GAS TRACER: HI, CO — GAS TRACER: dust

North

$+10^o < b < +20^o$

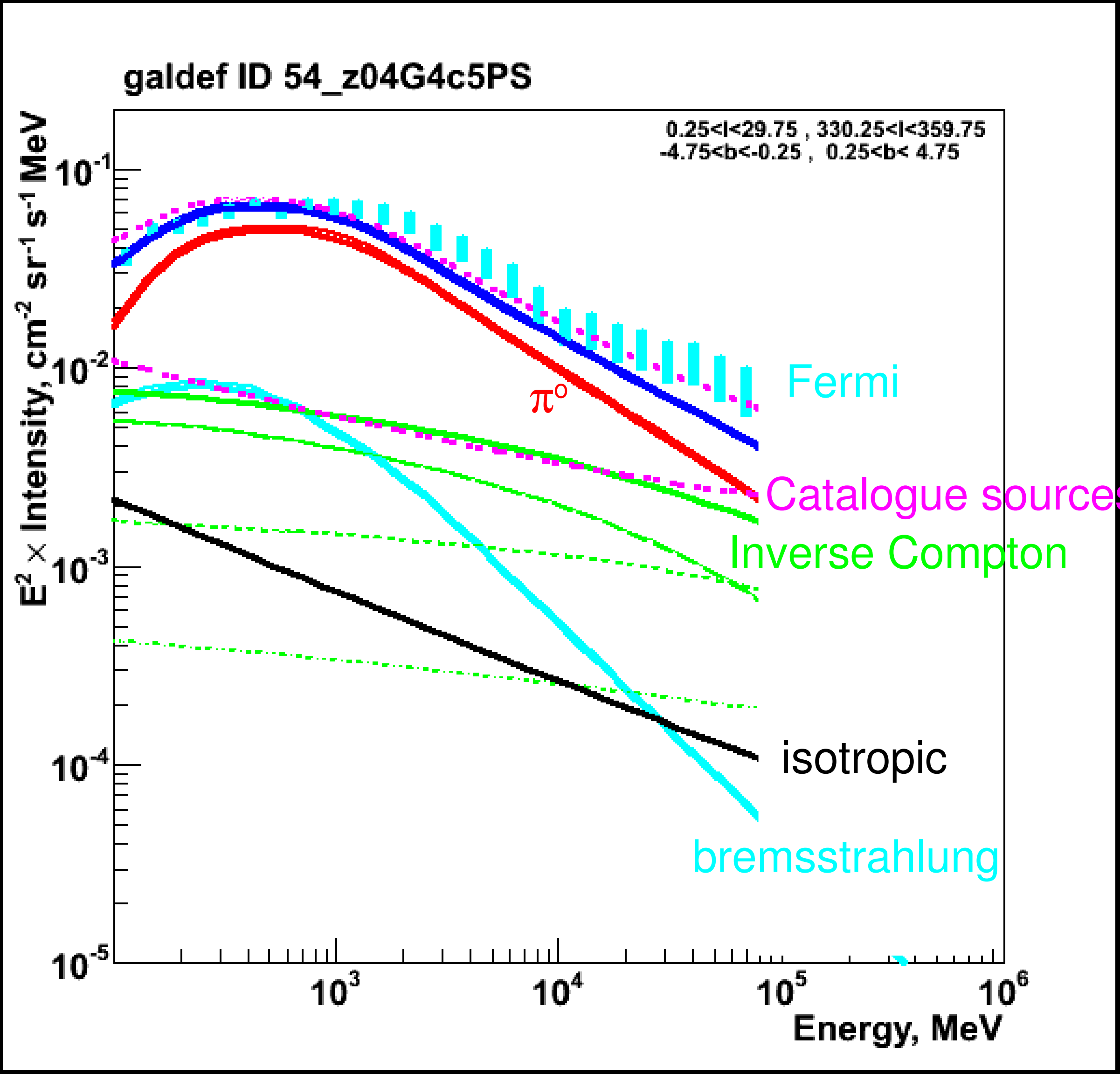
South

$-20^o < b < -10^o$



Dust emission is a better tracer of local gas than HI+CO !

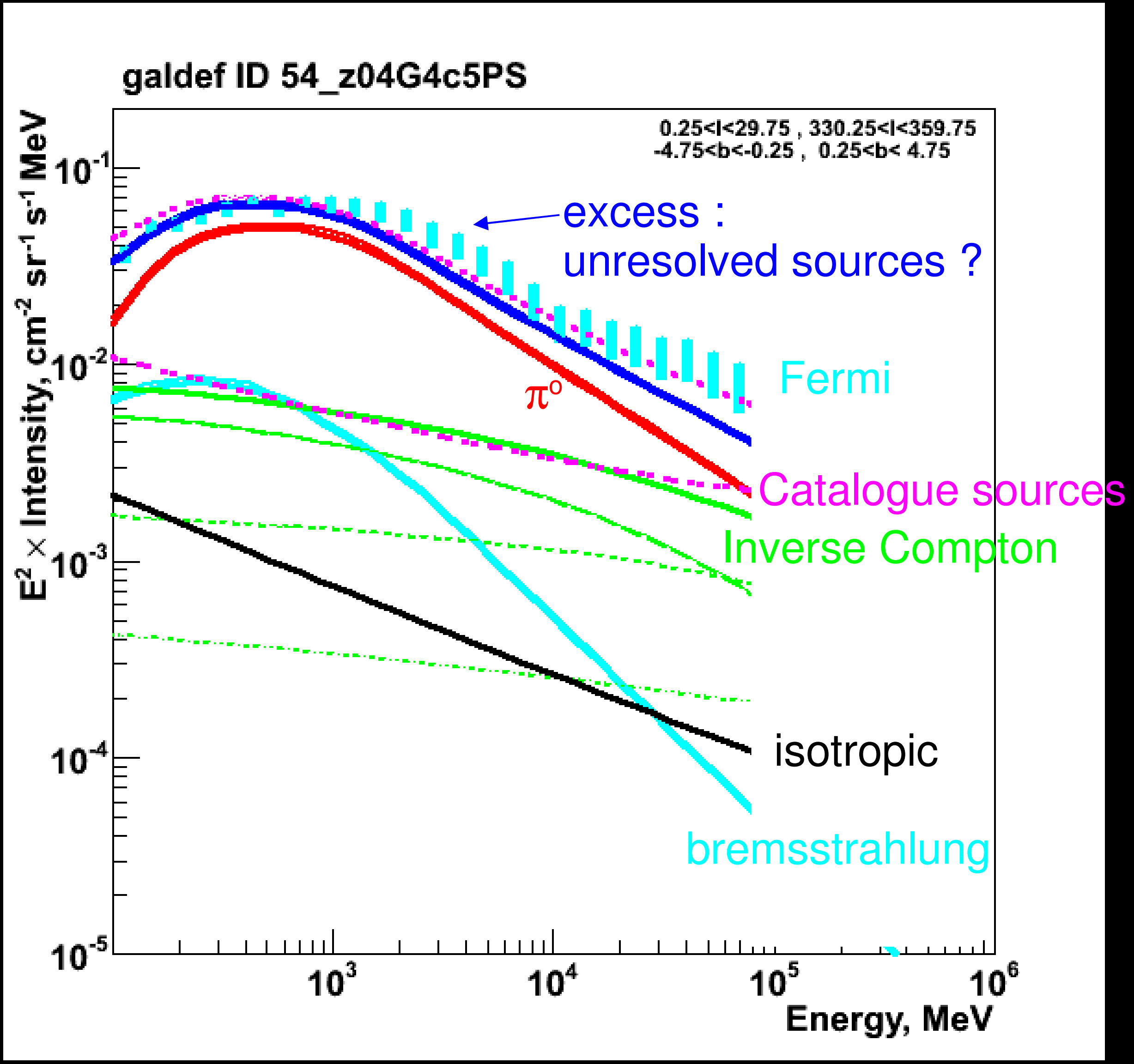
Inner Galaxy
330° < l < 30°, |b|<5°



PRELIMINARY

Good agreement overall with basic model

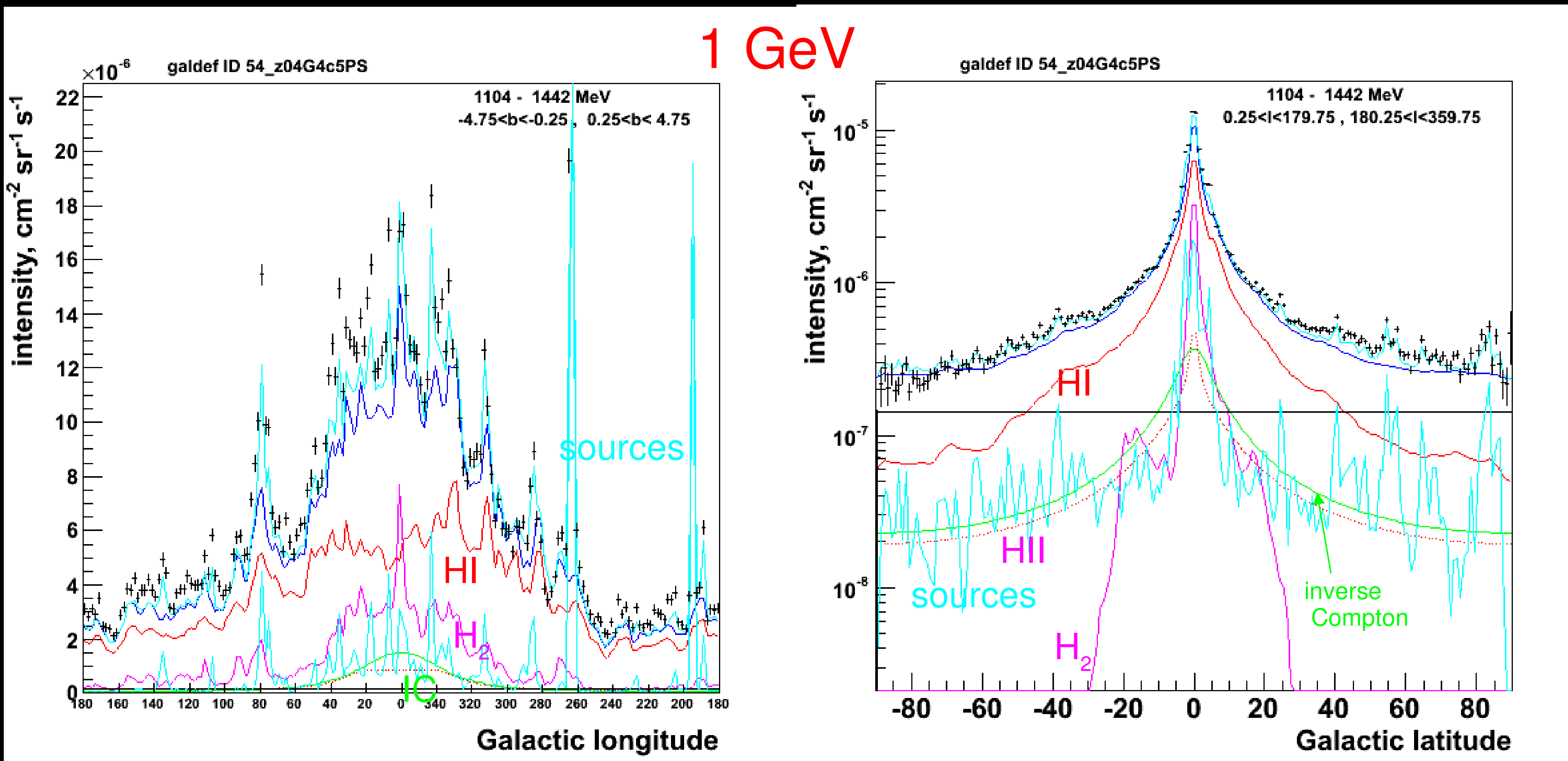
Inner Galaxy
330° < l < 30°, |b|<5°



PRELIMINARY

LONGITUDE PROFILE LOW LATITUDES

LATITUDE PROFILE ALL LONGITUDES

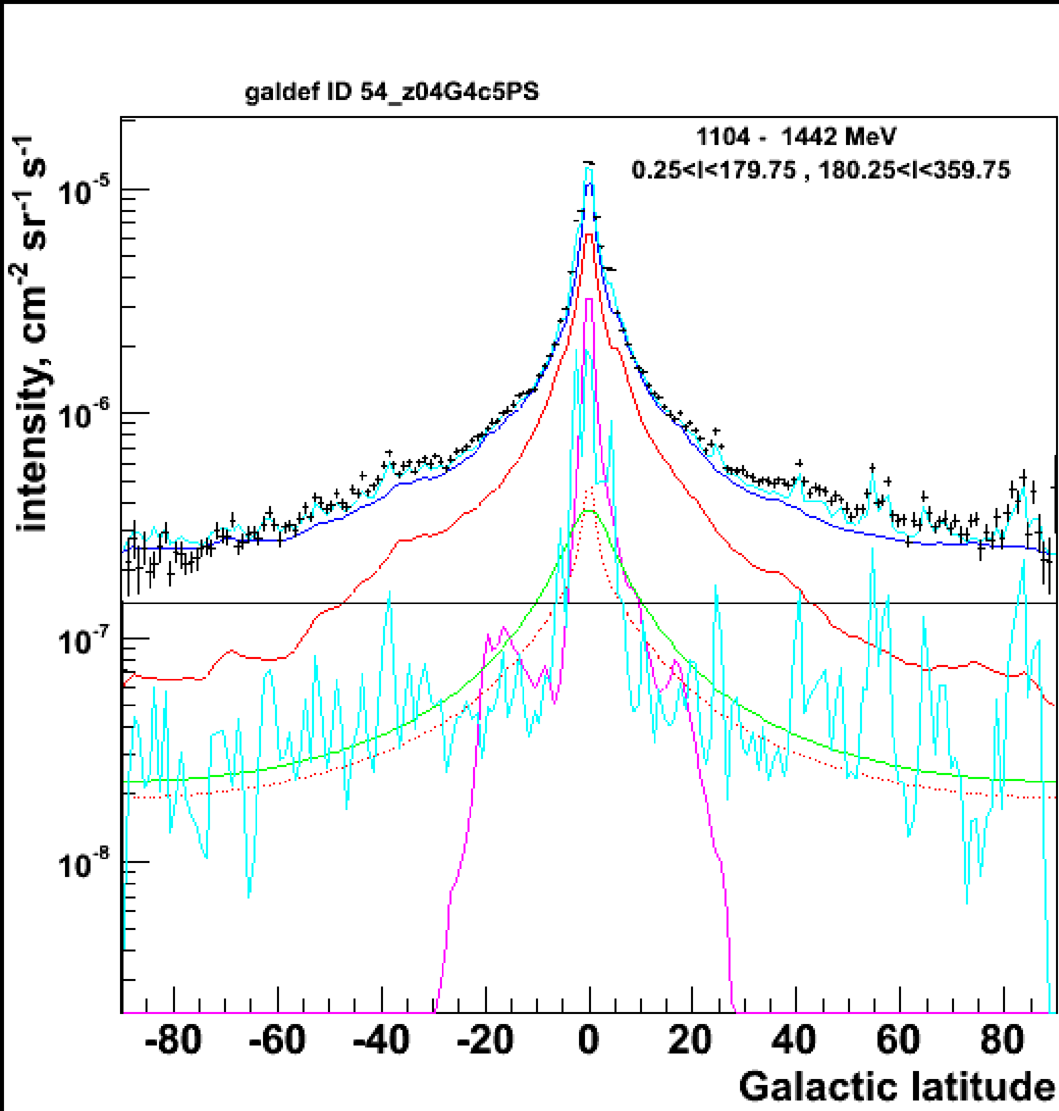


Agrees within 15% over 2 decades of dynamic range
The observed flux is the sum of many components:
importance of modelling them all !

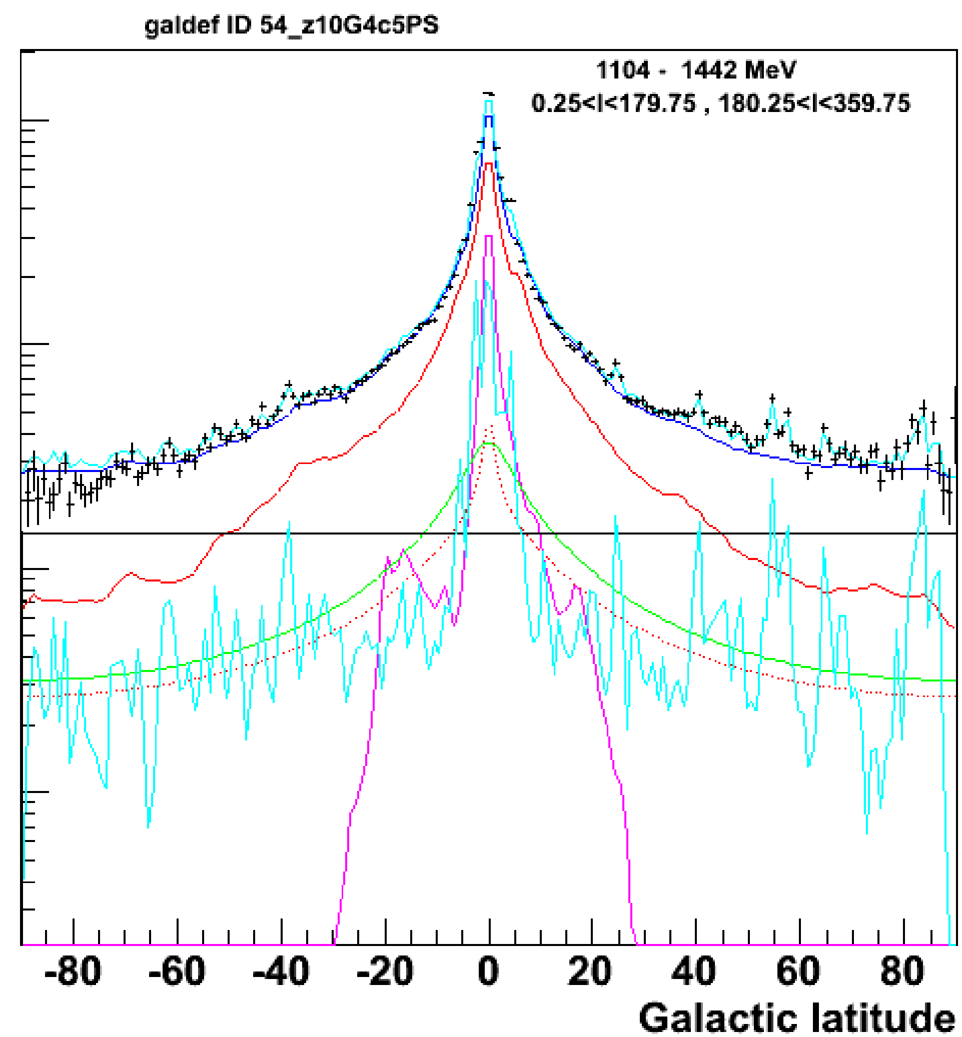
PRELIMINARY

EVIDENCE FOR LARGE COSMIC-RAY HALO

4 kpc halo height



10 kpc halo height



inverse Compton at high latitudes suggests a *large cosmic-ray halo*

Important for magnetic fields ! Relevant to this conference !

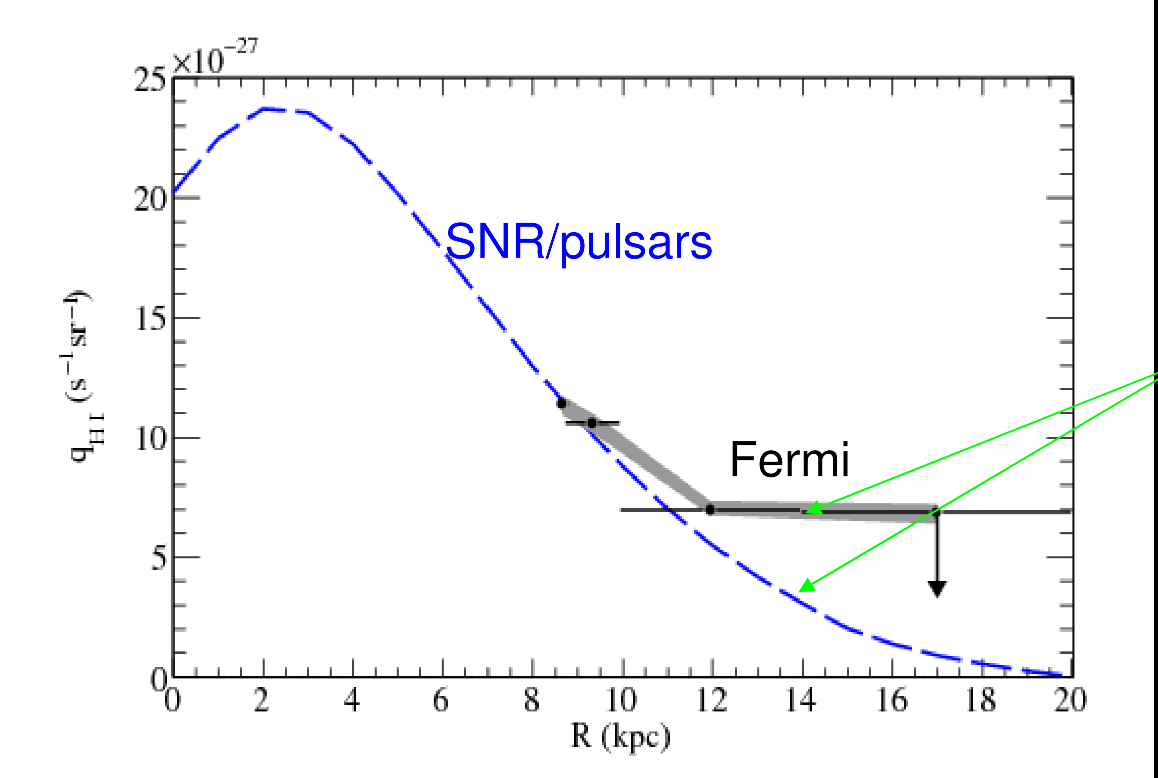
PRELIMINARY

Gamma-ray distribution in *outer* Galaxy

Gamma-ray emissivity falls off *slower than expected for SNR* source origin

Large halo will flatten it .... more evidence for large halo

2^{nd} Galactic quadrant



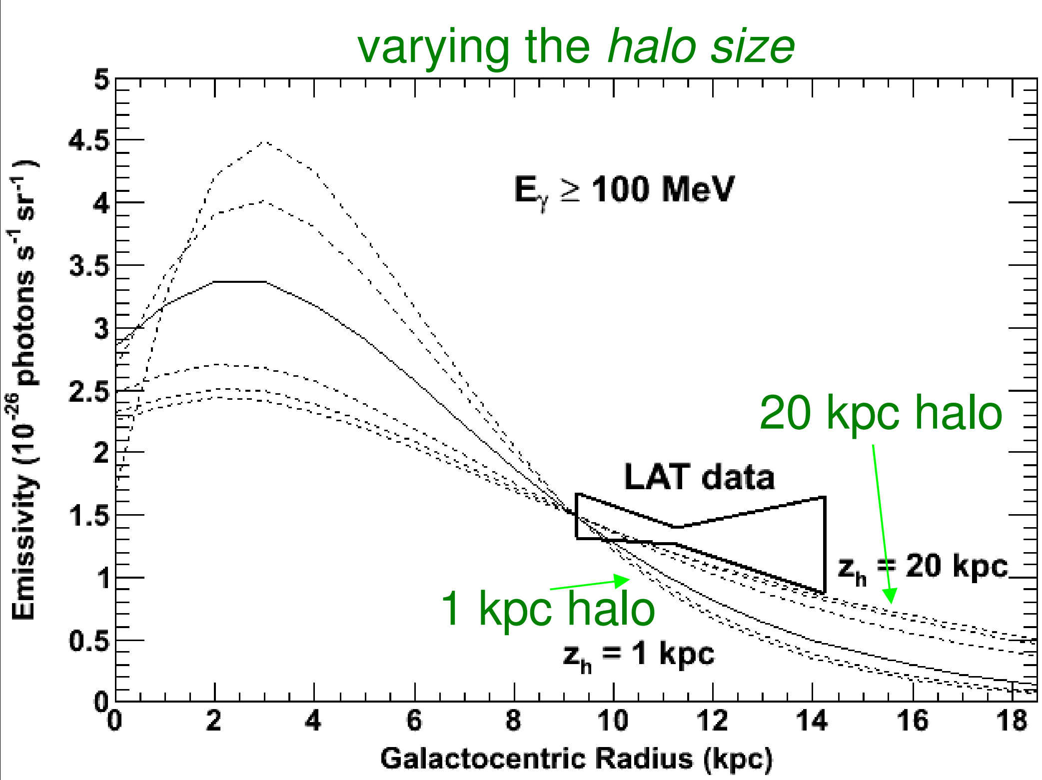
more cosmic rays than expected !

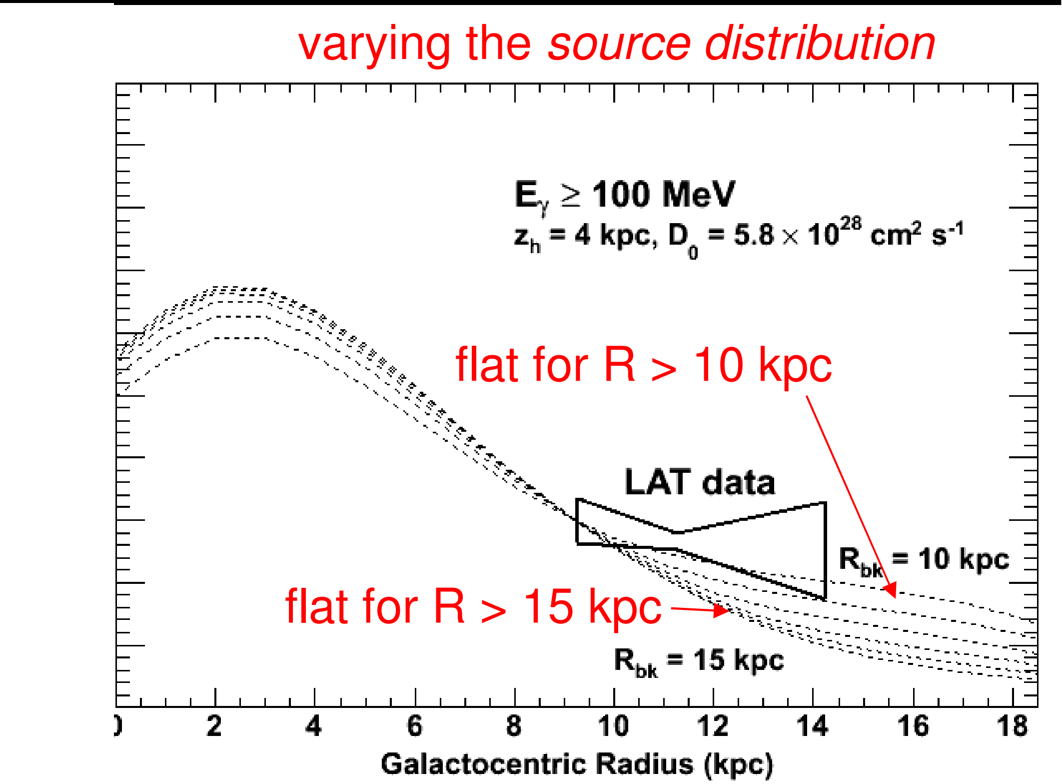
Or more gas than traced by HI, CO ?
e.g. diffuse H_2

Abdo etal (2010) ApJ 710, 133

Gamma-ray emissivity distribution in outer Galaxy

3^{rd} Galactic Quadrant



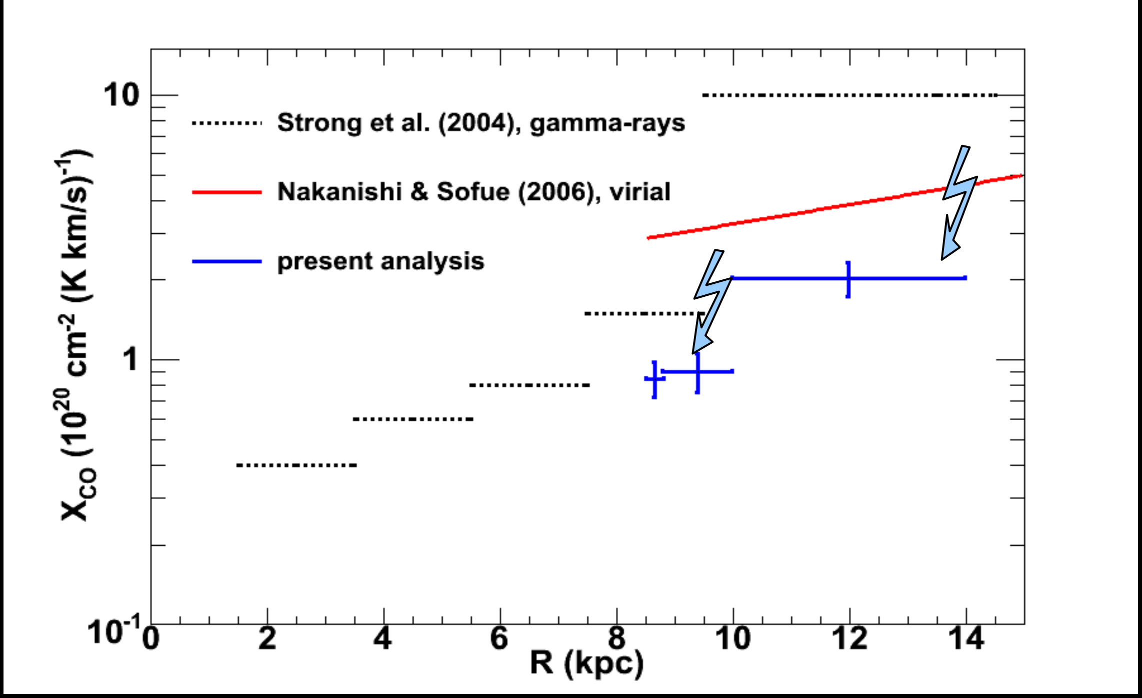


Abdo etal 2011, ApJ in press

Confirms 2^{nd} quadrant results.

Implications for synchrotron / B-field models : not yet investigated

Fermi measures molecular gas content of the outer Galaxy by comparing gamma-ray emissivities of molecular and atomic hydrogen

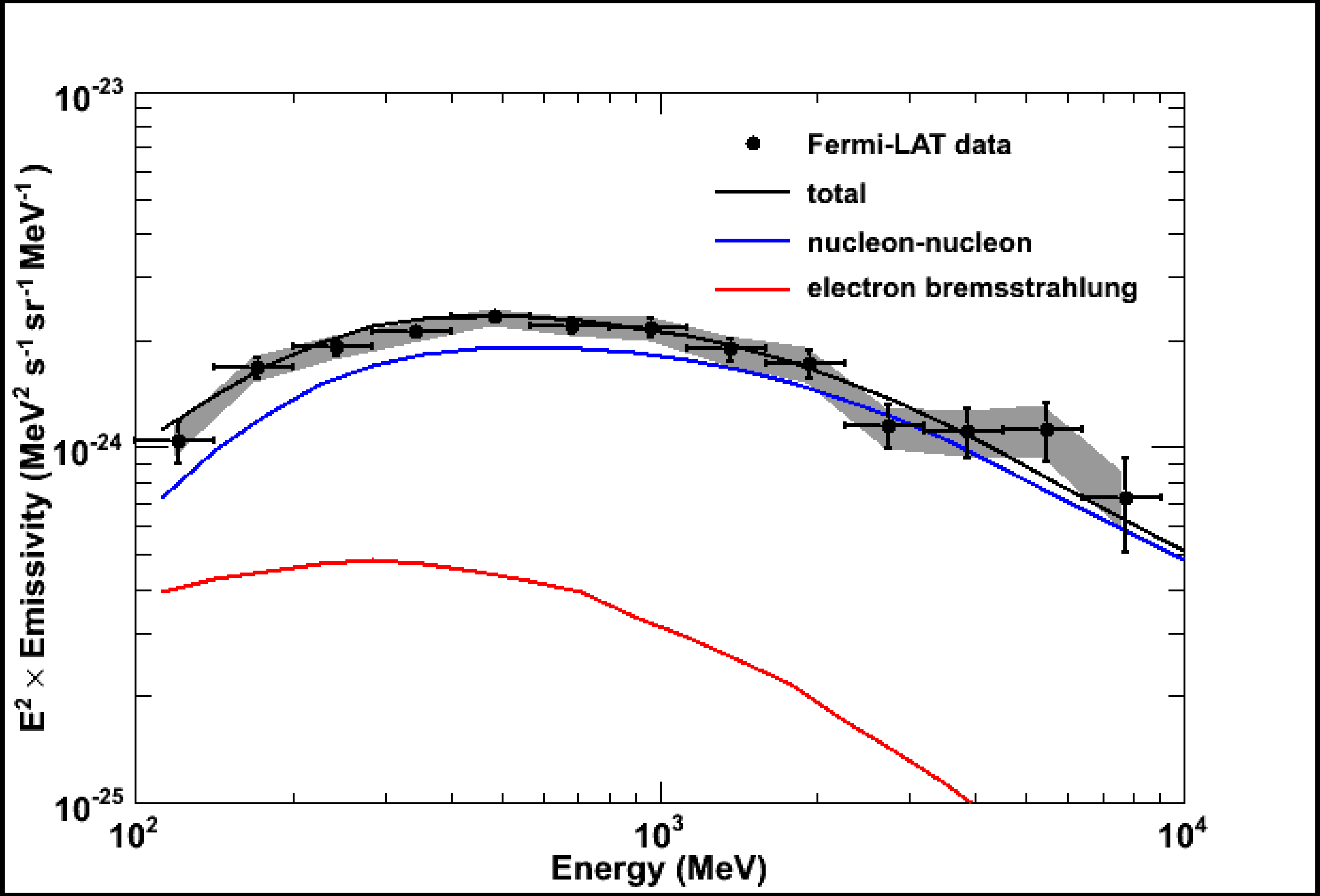


Scaling factor Xco from ^{12}CO to H_2
Local and Outer Galaxy (2nd quadrant)

Confirms *increase* from inner to outer Galaxy

Abdo etal (2010) ApJ 710, 133

Local HI gamma-ray emissivity



Agrees well with pion-decay calculation !

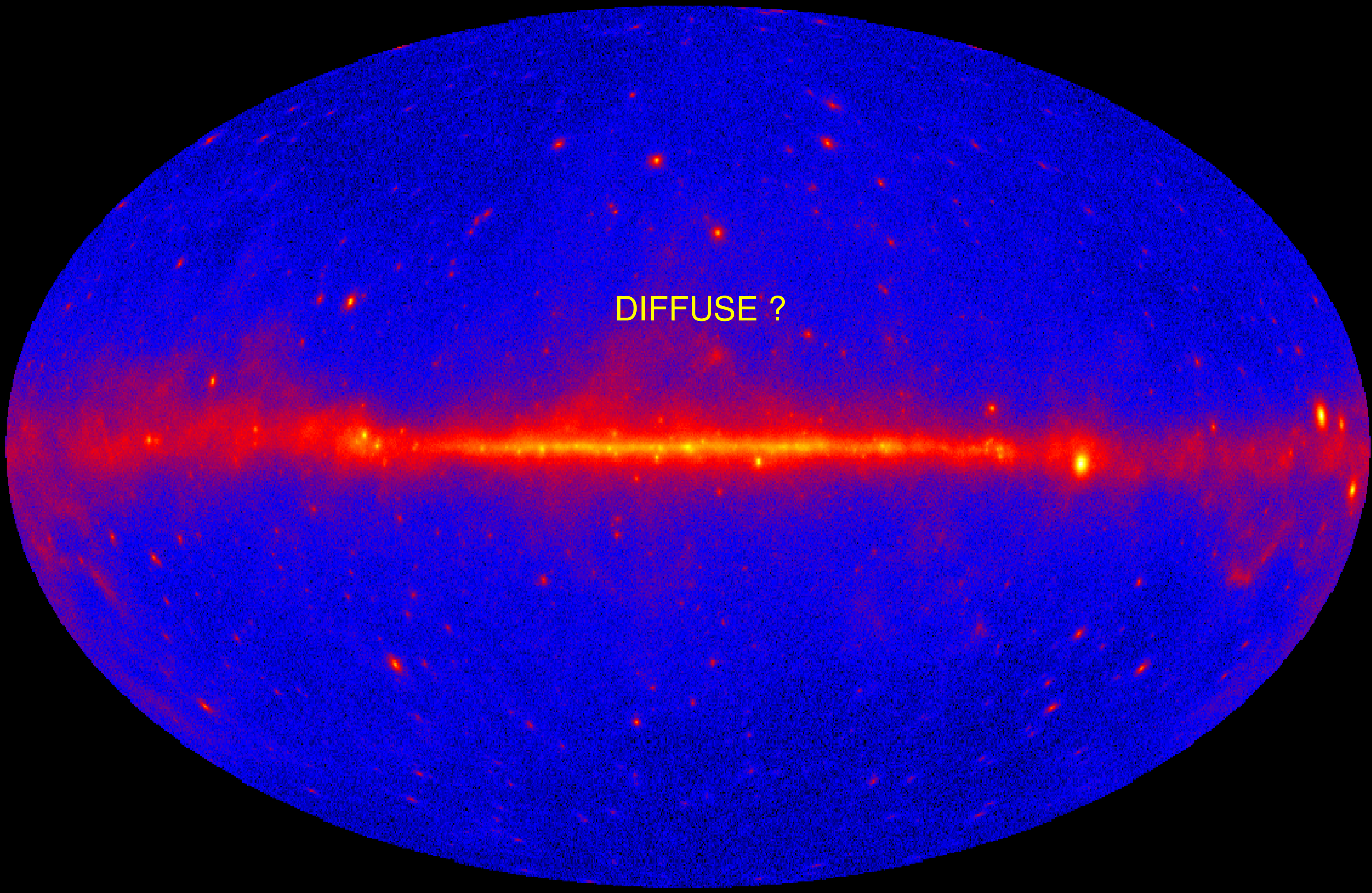
Abdo et al. ApJ 2009

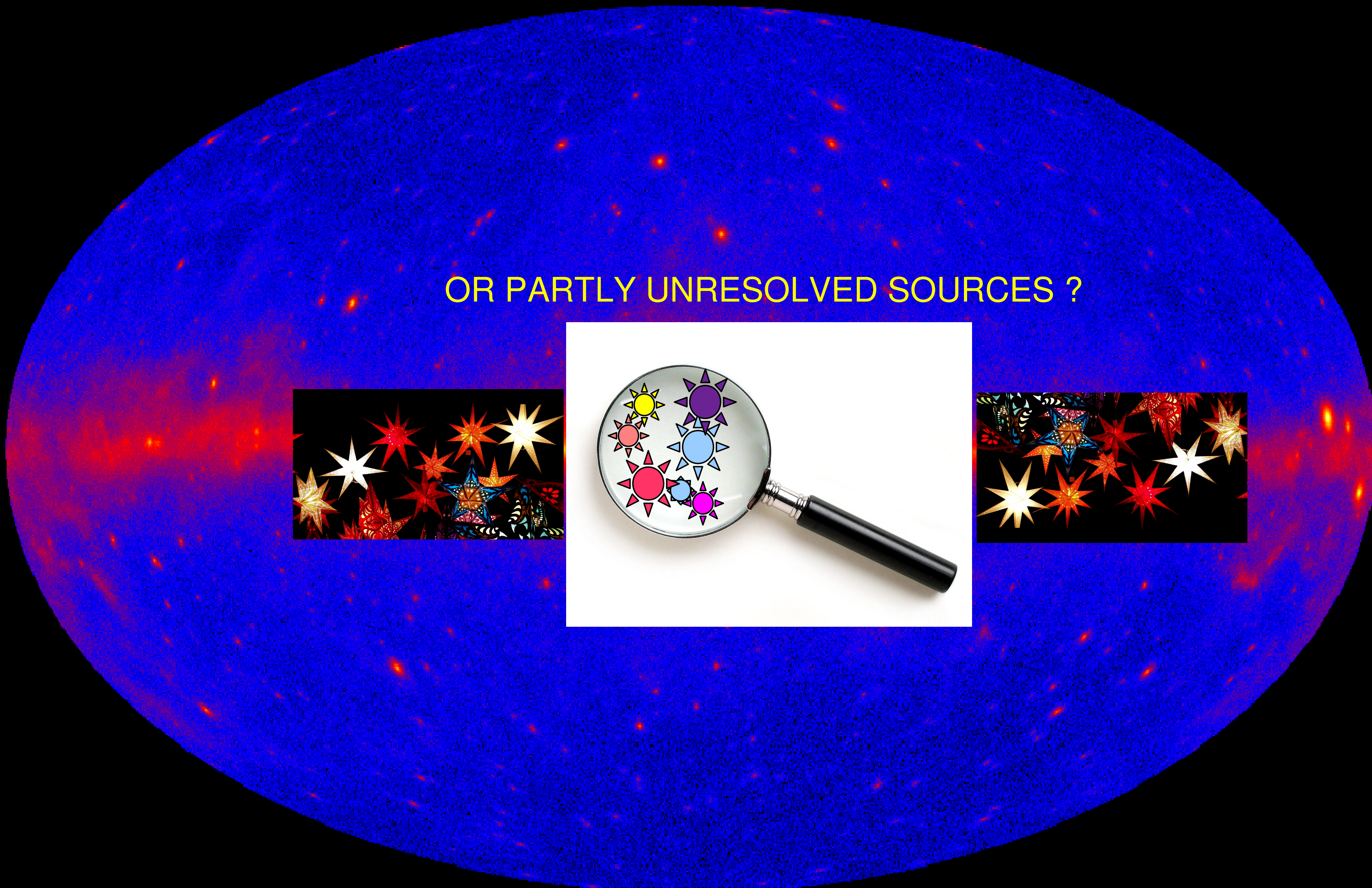
Facit

Large Scale Diffuse Gamma Ray Emission:

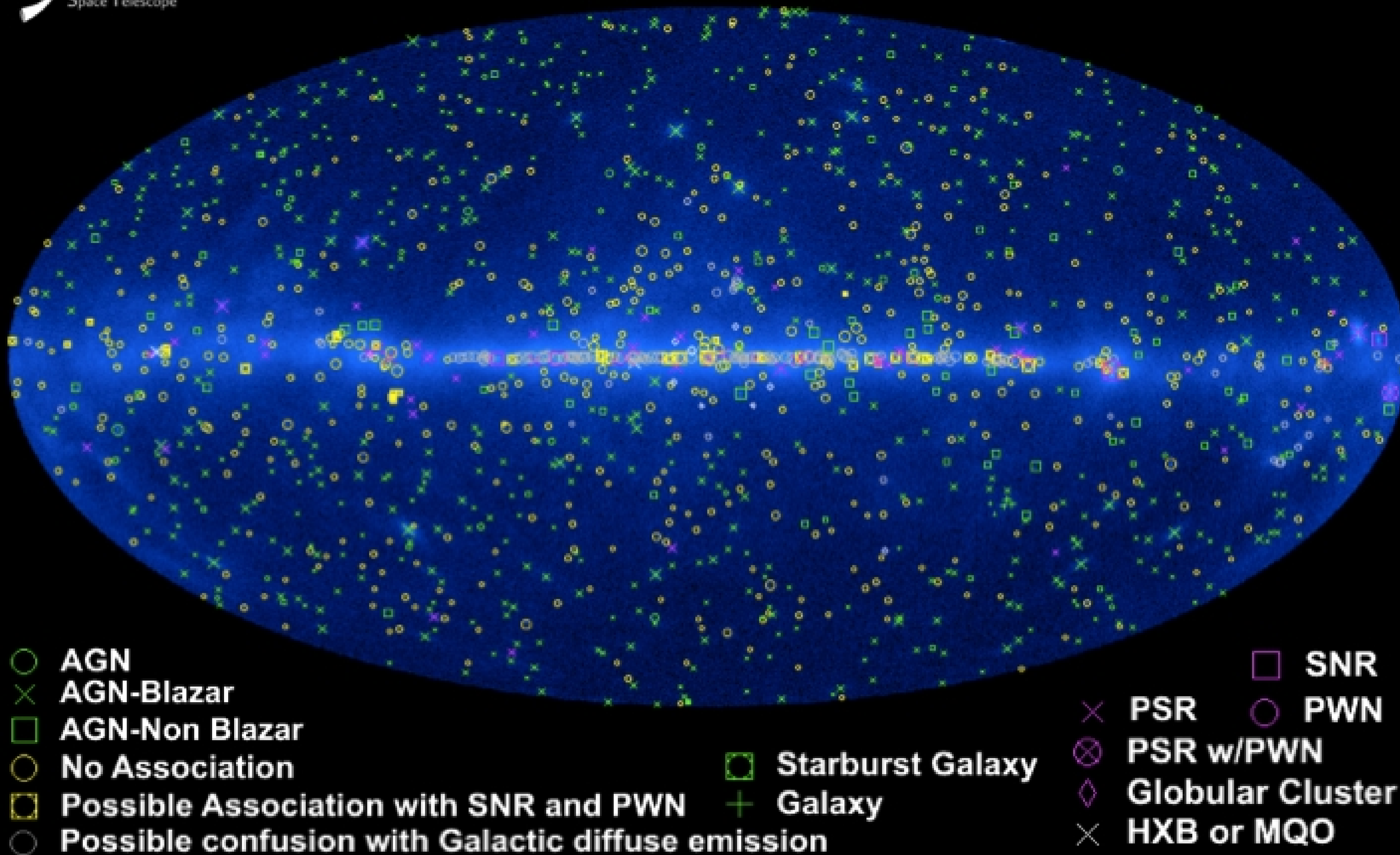
The diffuse emission model reproduces the Fermi data remarkably well.

The remaining residuals have many possible origins: this is where the current action and interest is focussed.


DIFFUSE ?

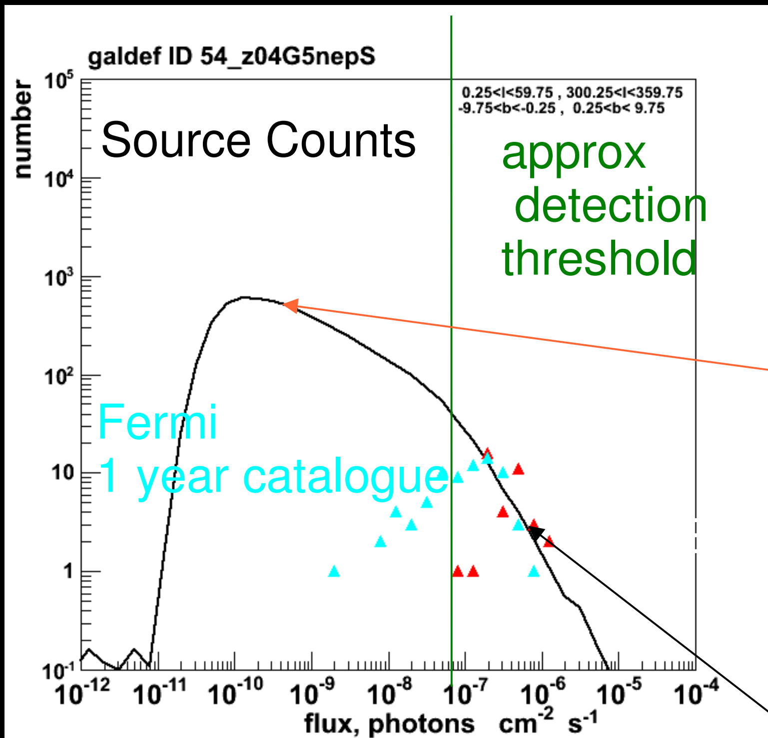

OR PARTLY UNRESOLVED SOURCES ?

The Fermi LAT 1FGL Source Catalog

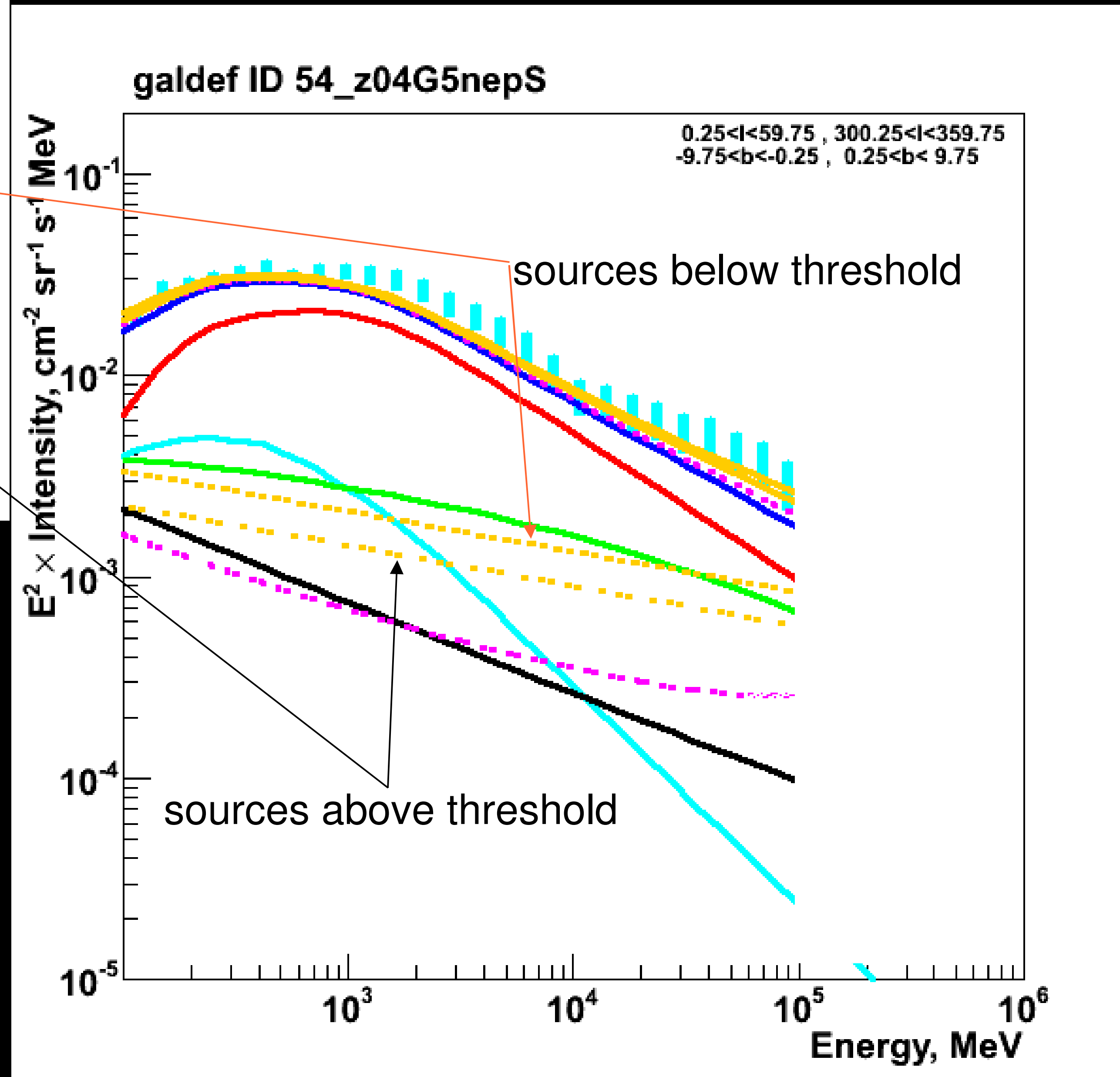


Credit: *Fermi* Large Area Telescope Collaboration

Source contribution from luminous (pulsars etc) sources



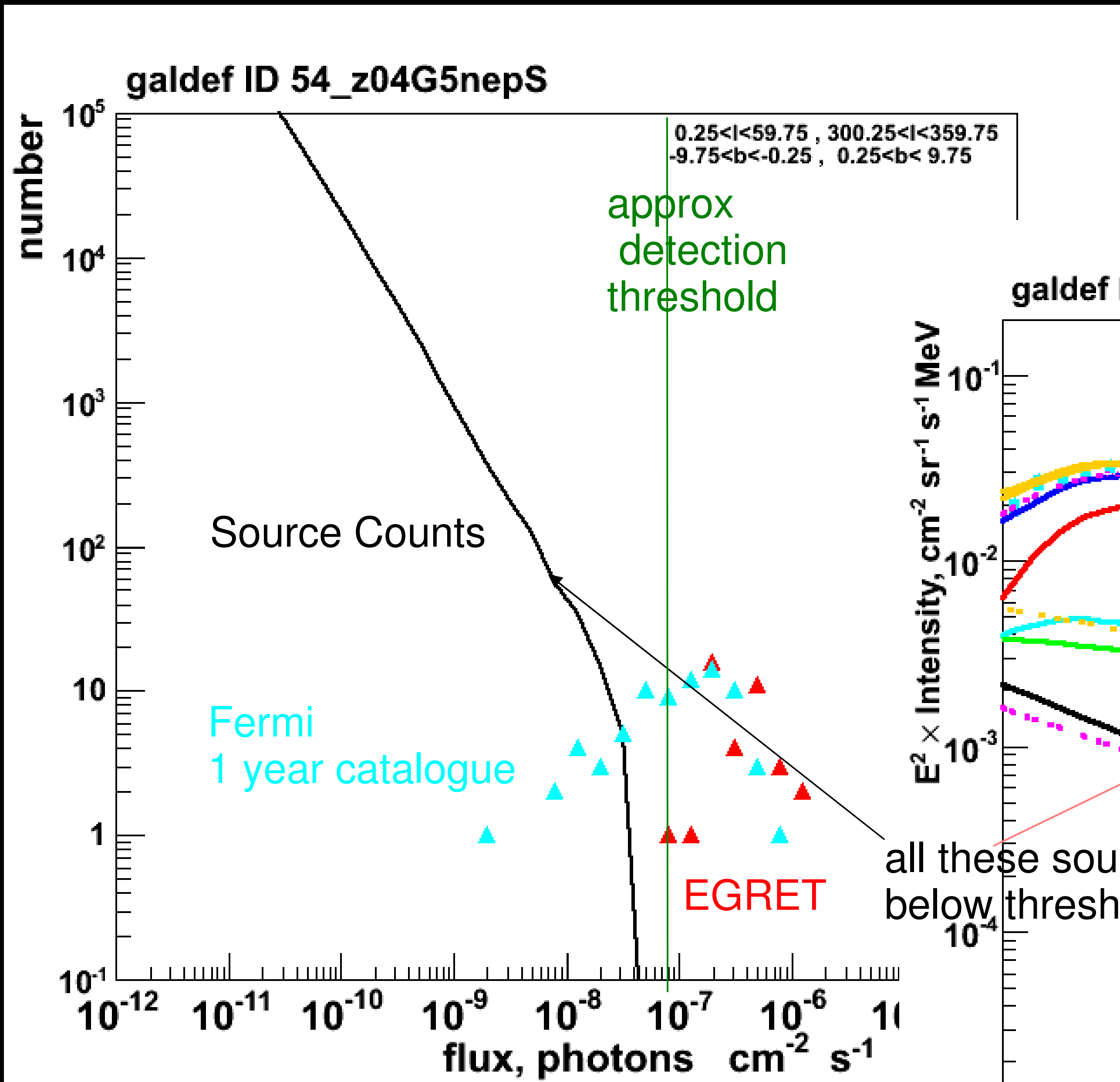
Due to Fermi sensitivity,
unresolved source flux will finally be at percent level



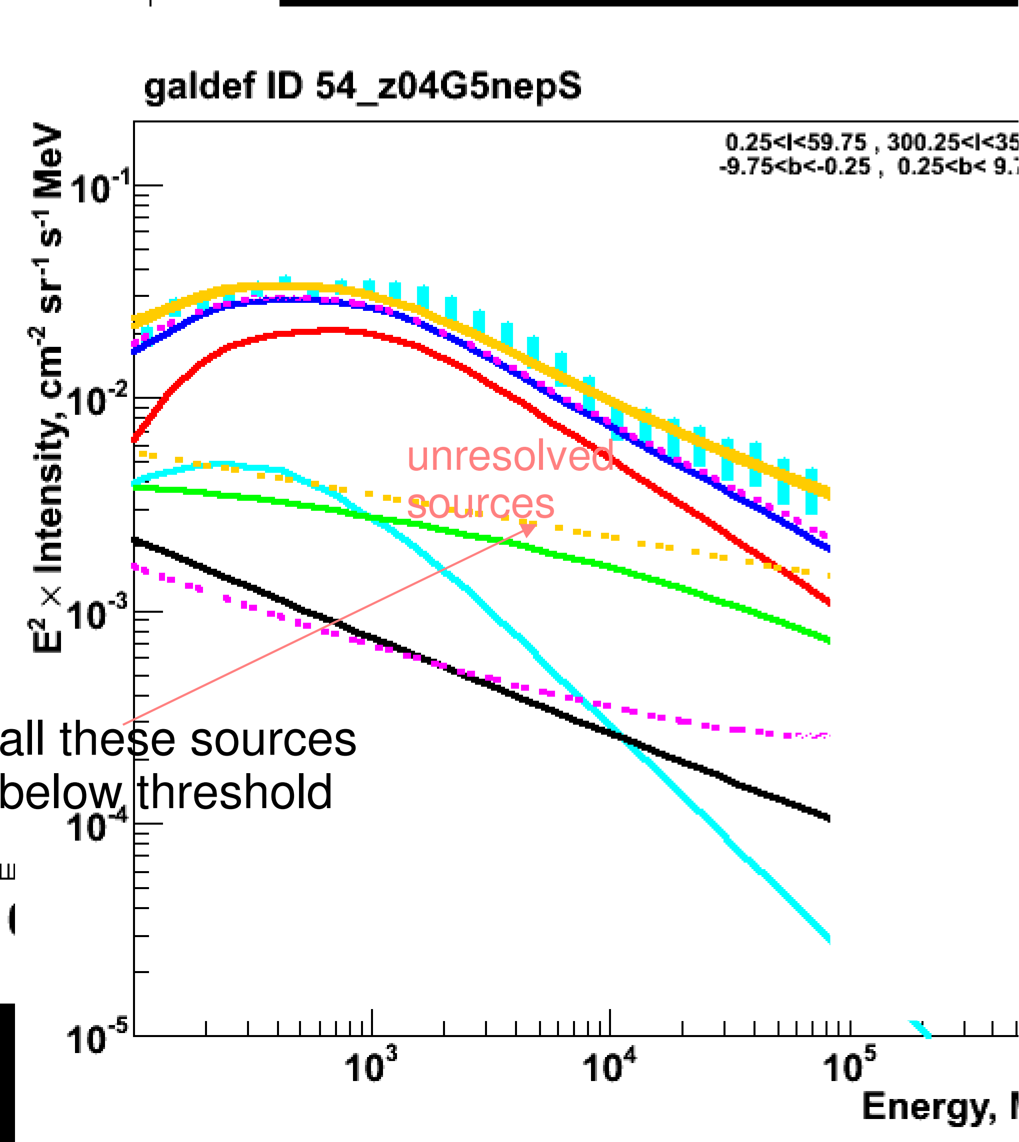
population synthesis
model consistent with
Fermi year 1 Catalogue

A .Strong, 2009 Fermi Symposium

Source contribution from possible low-luminosity sources



Many more dim sources can hide.
Just limits can be set on
their contribution.



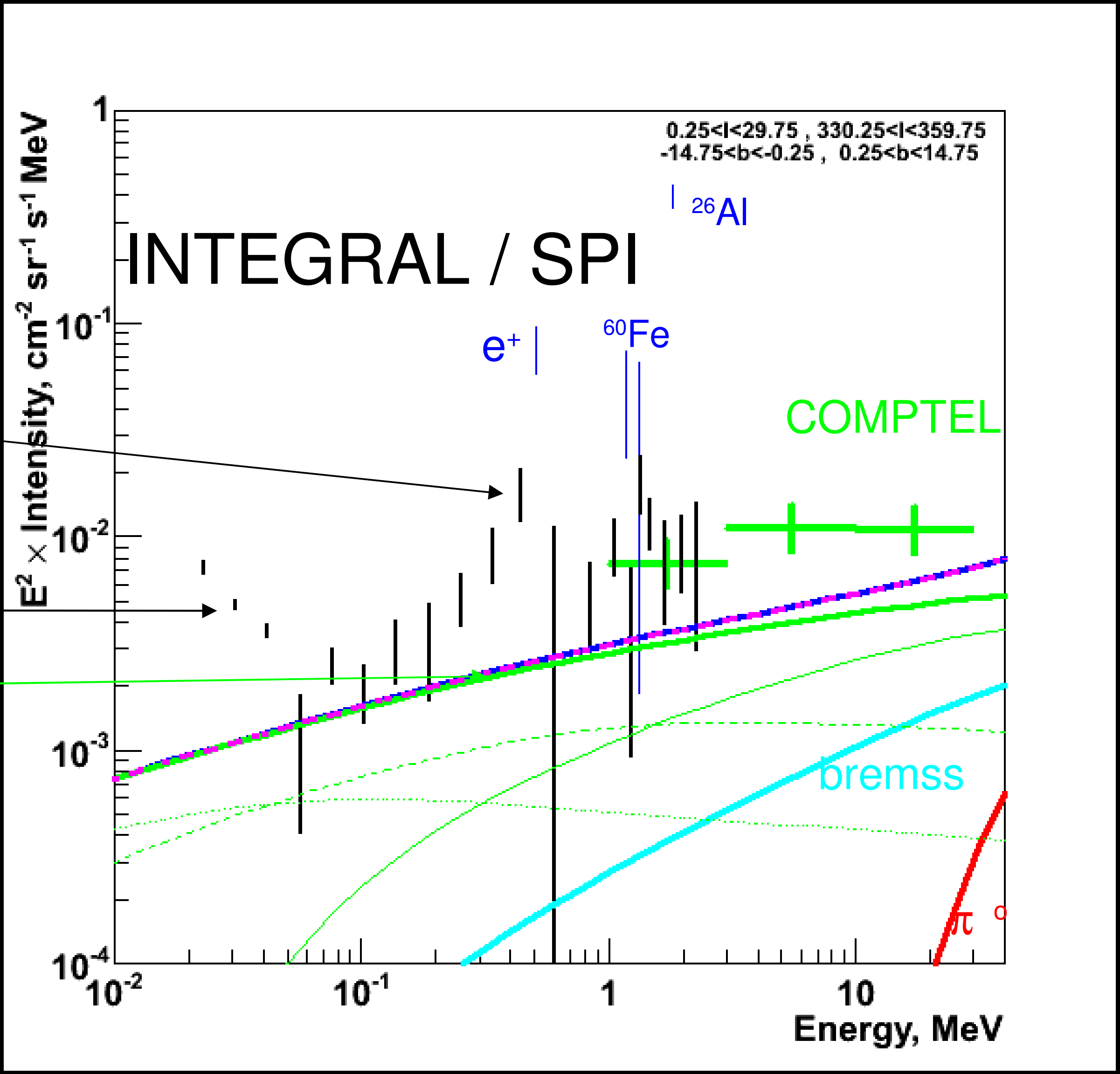
A. Strong, 2009 Fermi Symposium

INTEGRAL / SPI
spectrum of inner Galaxy

positronium

hard X-ray sources

inverse Compton



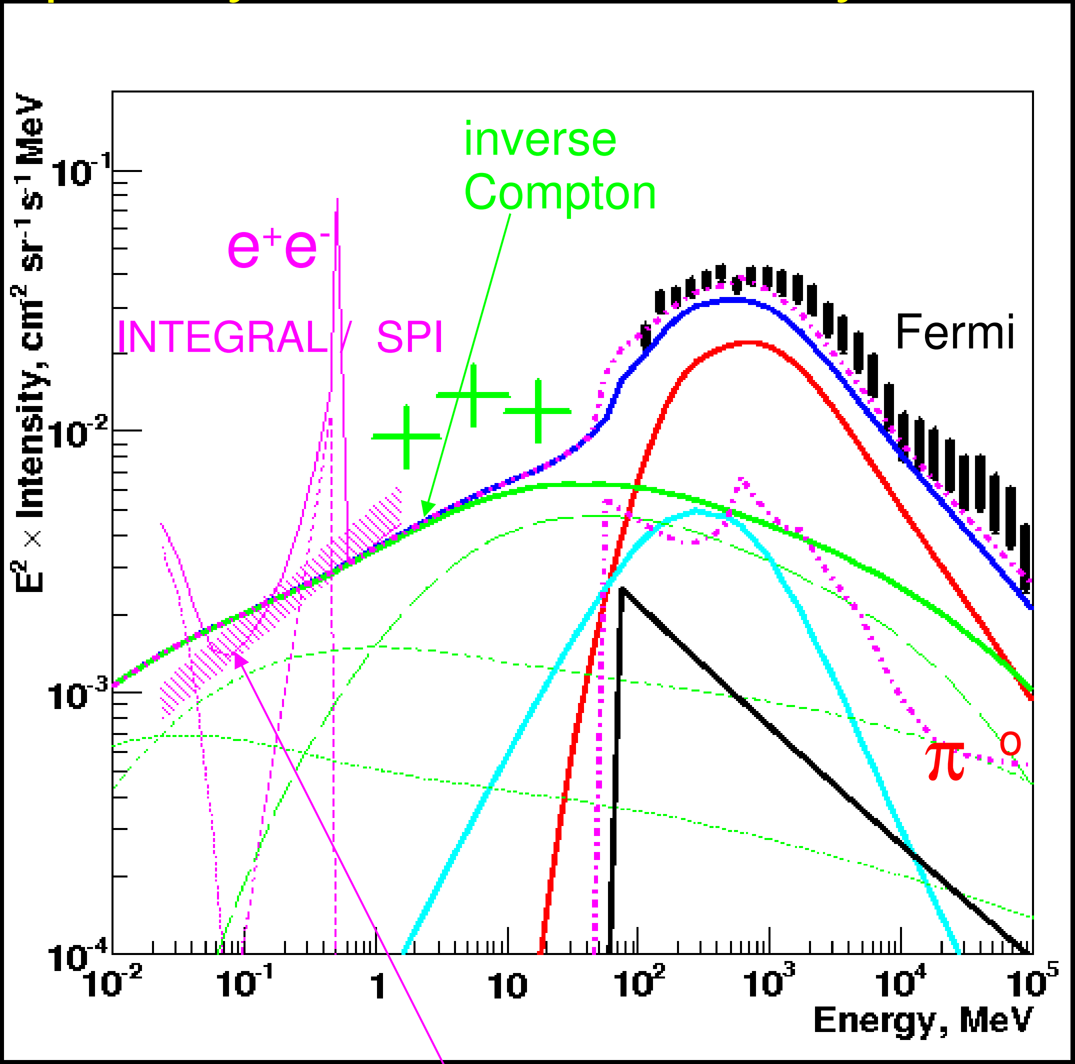
NEW

Bouchet etal 2011, in preparation

Gamma-rays, inner Galaxy

inverse Compton
from primary electrons, secondary electrons + positrons

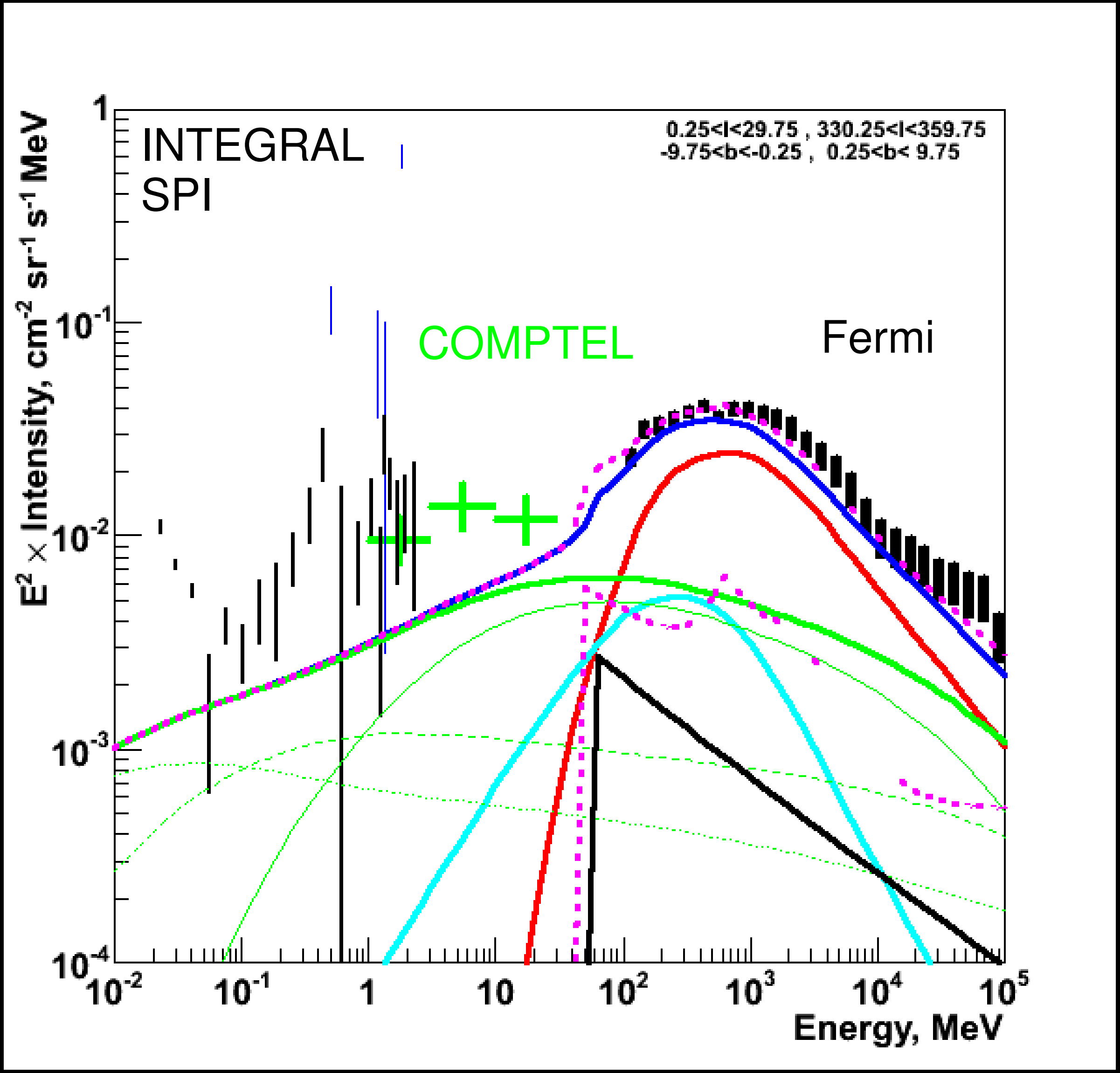
These processes are very relevant down to hard X-rays !



power-law continuum measured by INTEGRAL / SPI
Bouchet et al 2008, Porter et al 2008

large fraction of the inverse Compton power comes out in hard X-rays !

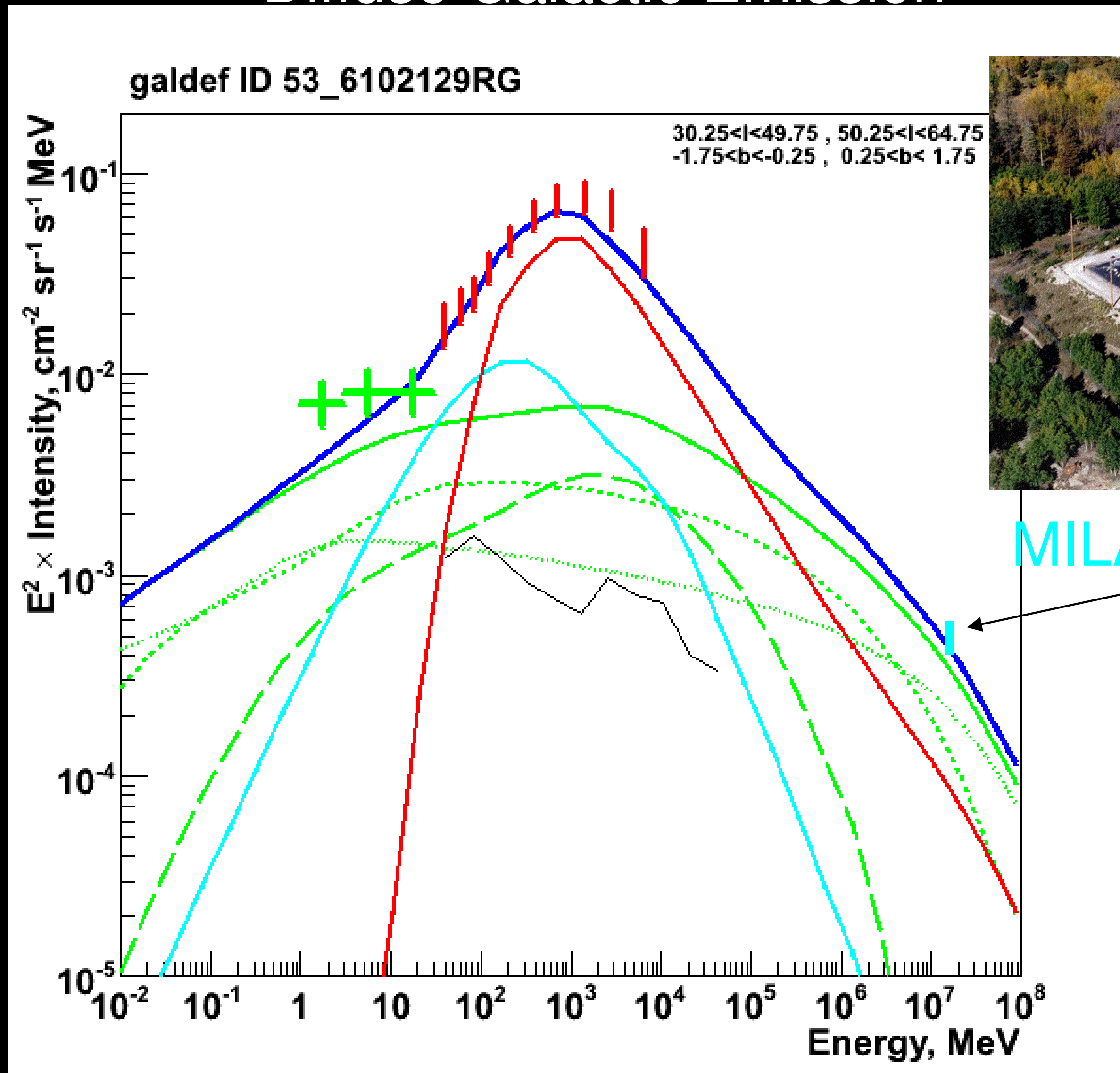
a glimpse of things to come.... putting it all together



PRELIMINARY

and towards the highest energies...

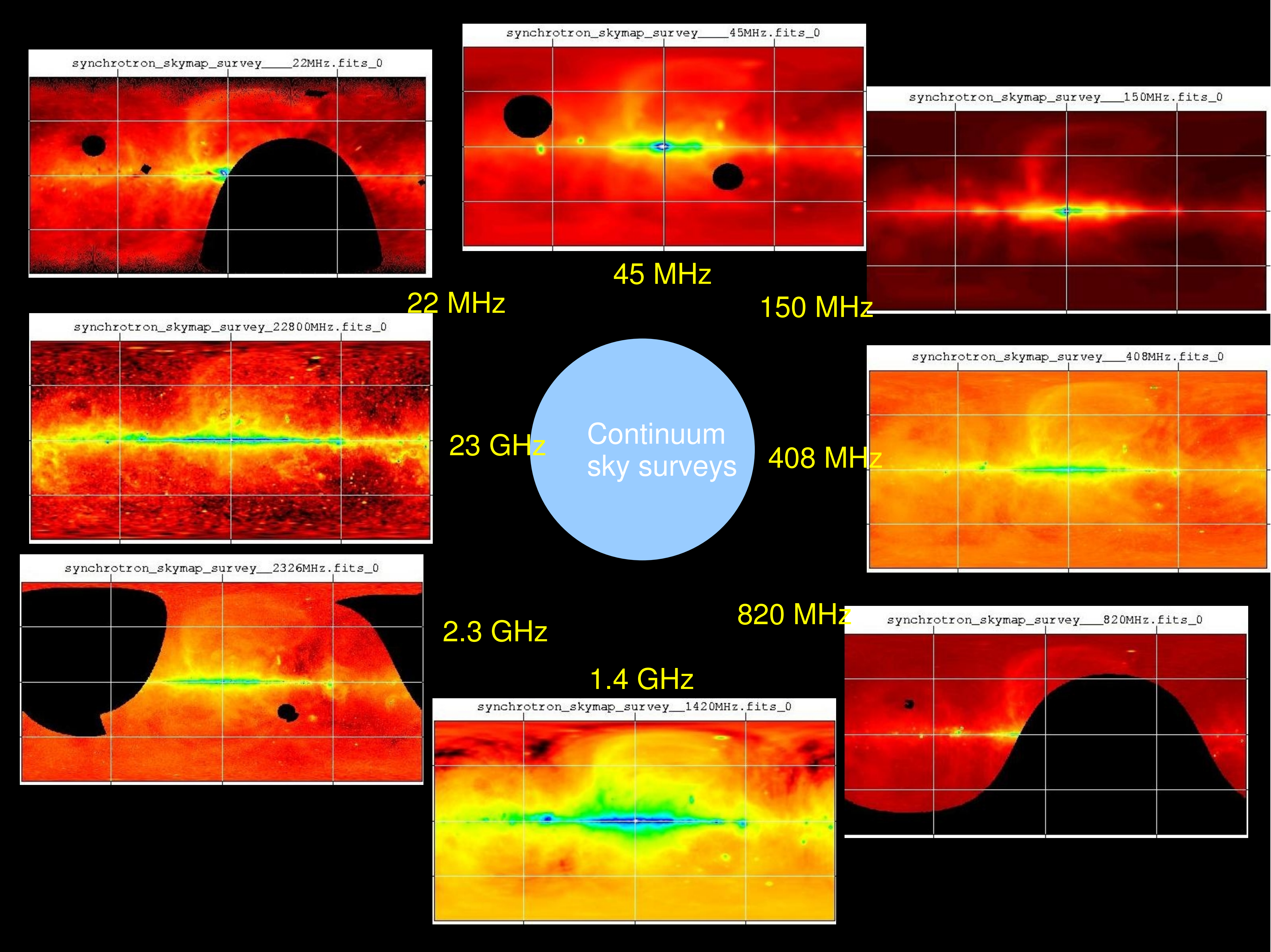
Diffuse Galactic Emission



Abdo et al. (2008) ApJ 688

This model was adapted to EGRET GeV-excess, gave a good fit to MILAGRO but now with Fermi situation has changed – prediction now too low !

Synchrotron and Magnetic Fields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45 MHz
22 MHz
150 MHz
synchrotron_skymap_survey_22800MHz.fits_0
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23 GHz
Continuum
sky surveys
408 MHz
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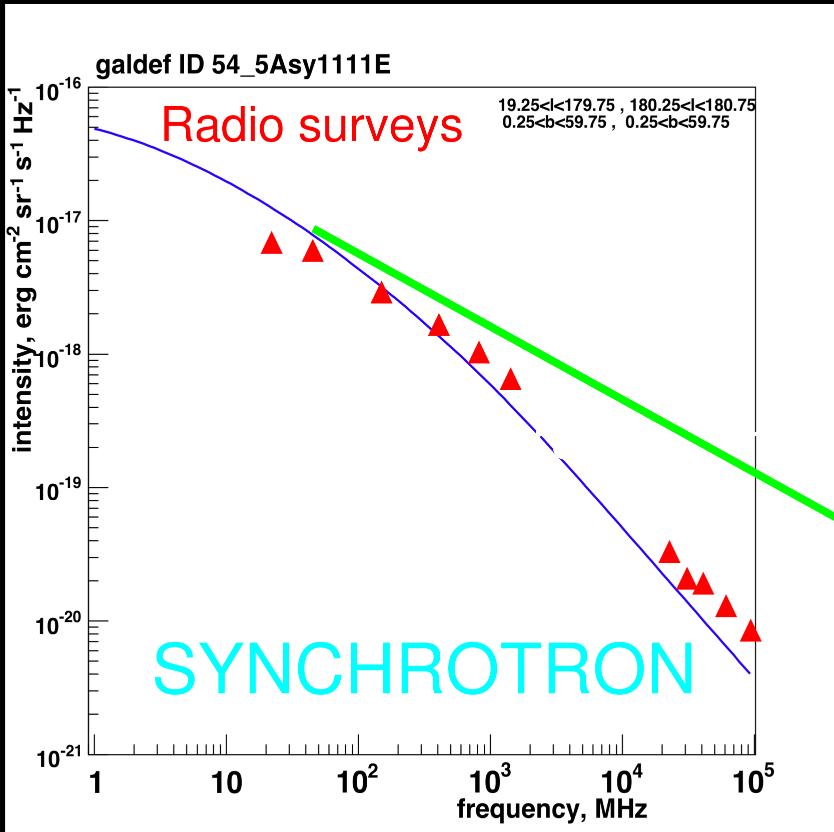
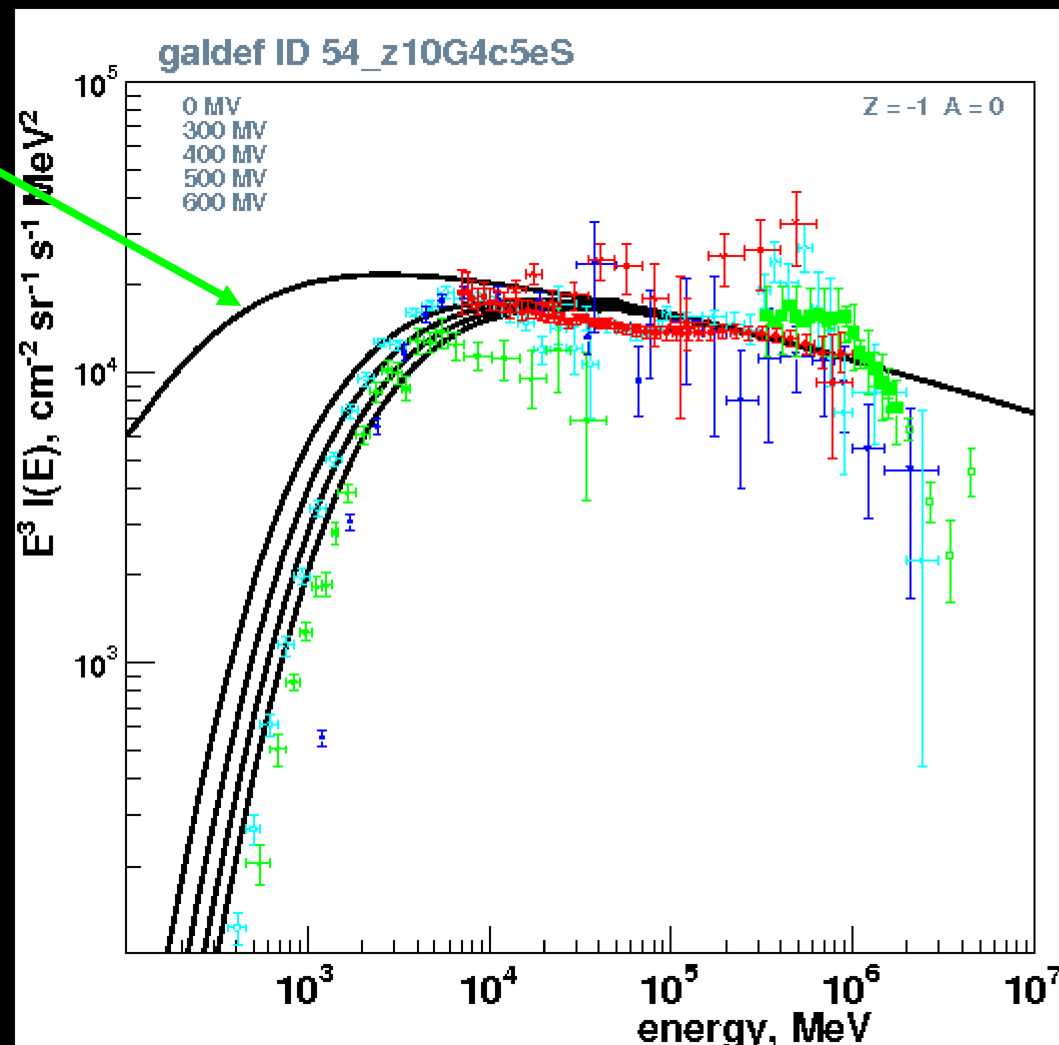


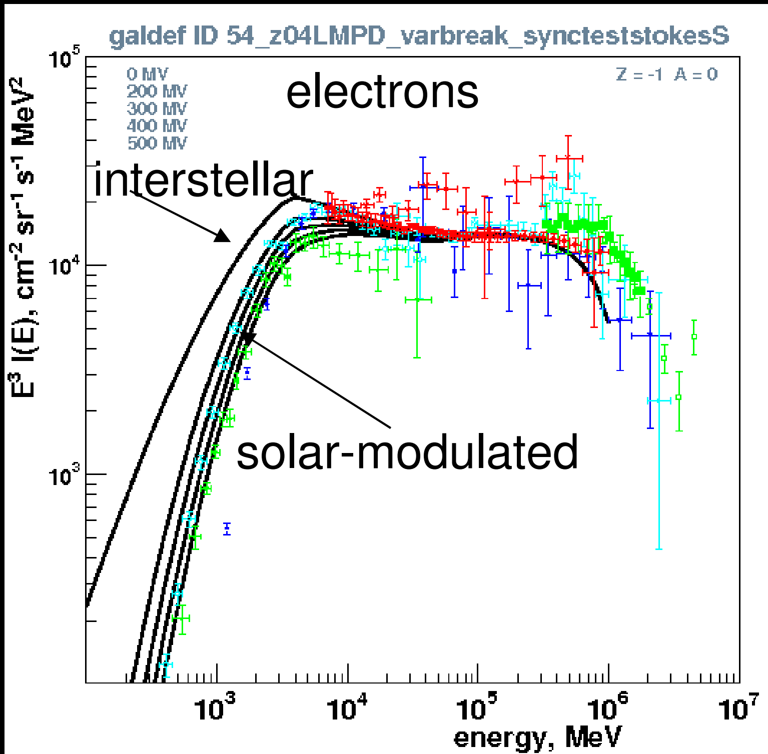
GALPROP
model

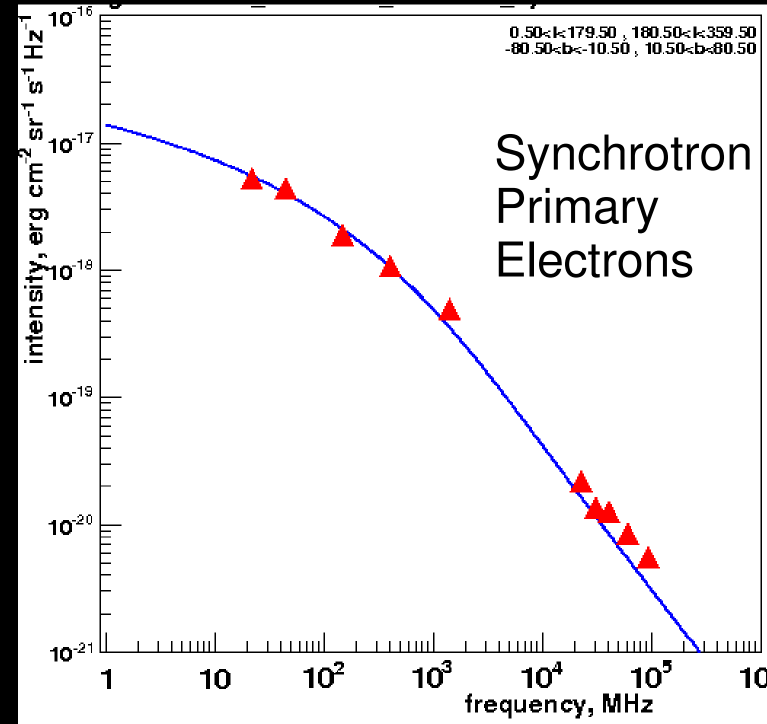


radio provides essential probe of interstellar electron spectrum at
E < few GeV
to complement direct measurments and determine solar modulation

electrons have huge uncertainty in modulation here

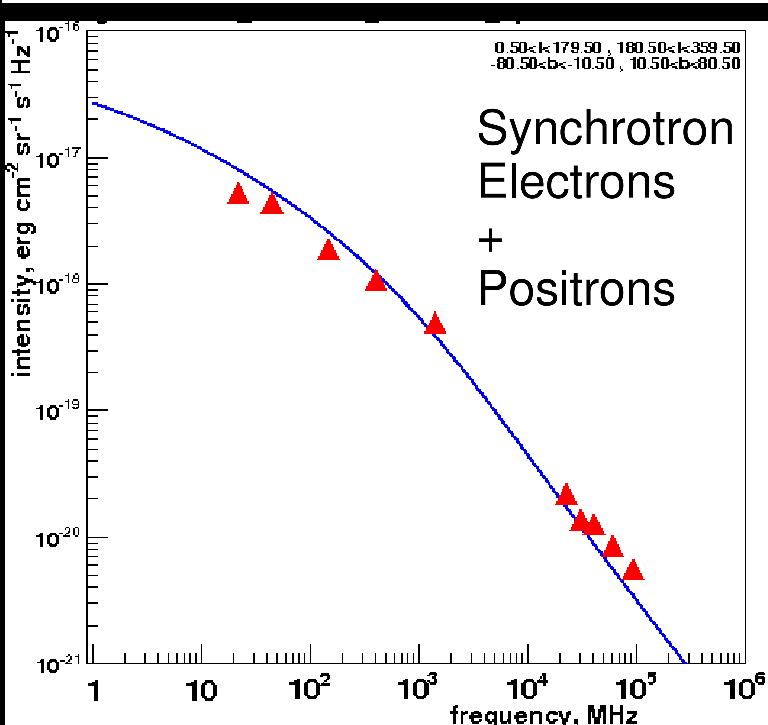
(NB synchrotron probes electrons but for nuclei no such probe !)



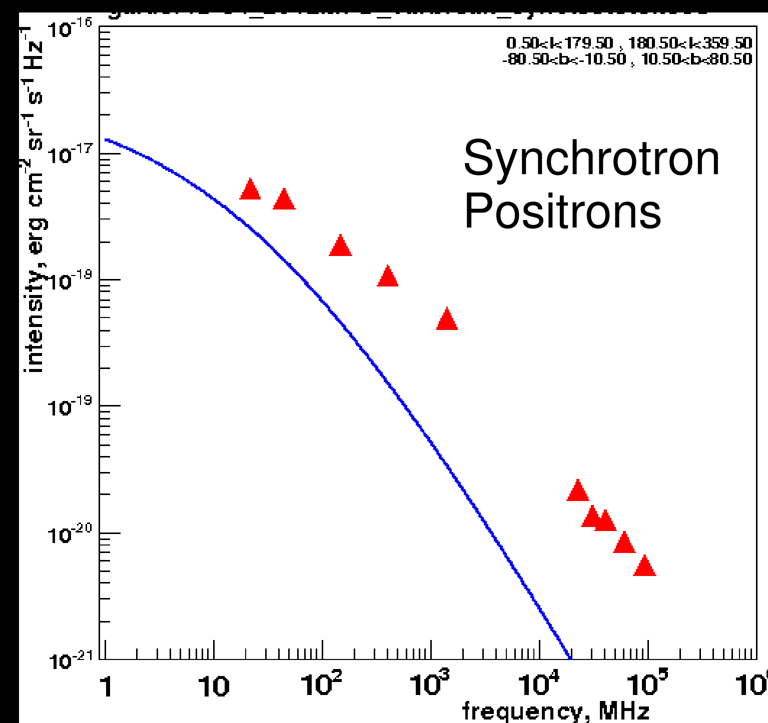


Synchrotron probes the interstellar electron spectrum.

Avoids solar modulation !



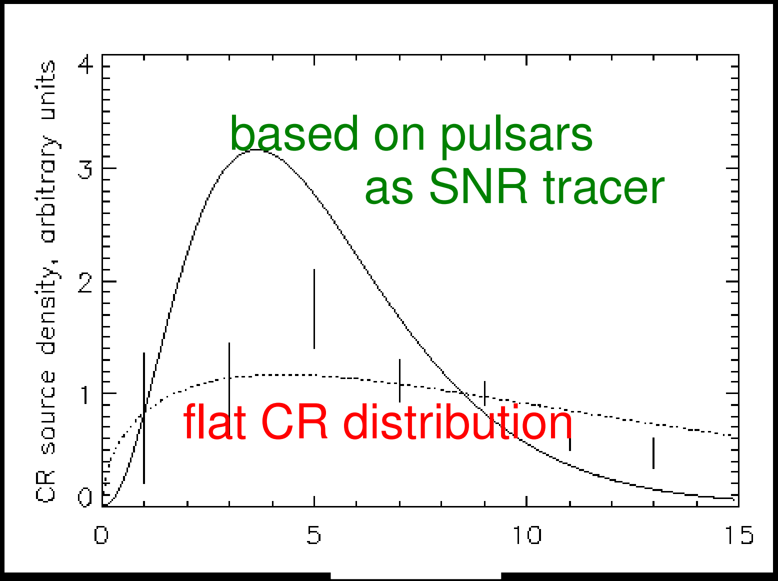
Secondary positrons (and secondary electrons) are important for synchrotron



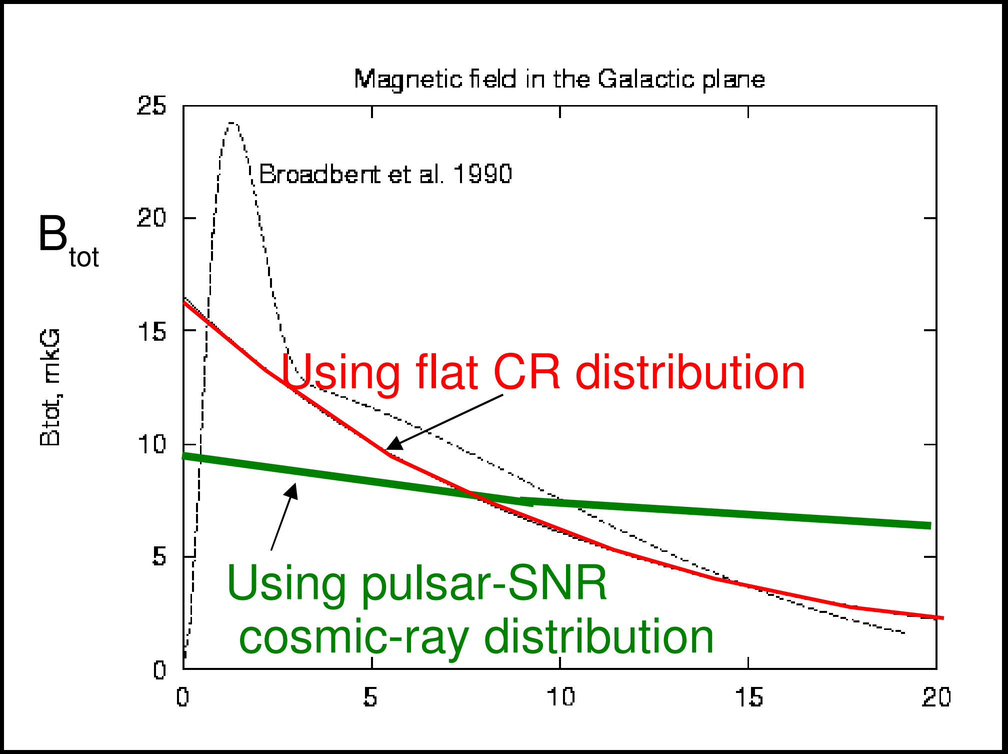
from synchrotron and cosmic-ray propagation model :

$$B_{tot}(\mu G) = 8\, e^{-(R - Ro)/50\,kpc\ -\ |z|/3\,kpc}$$

cosmic-ray source distribution



R, kpc

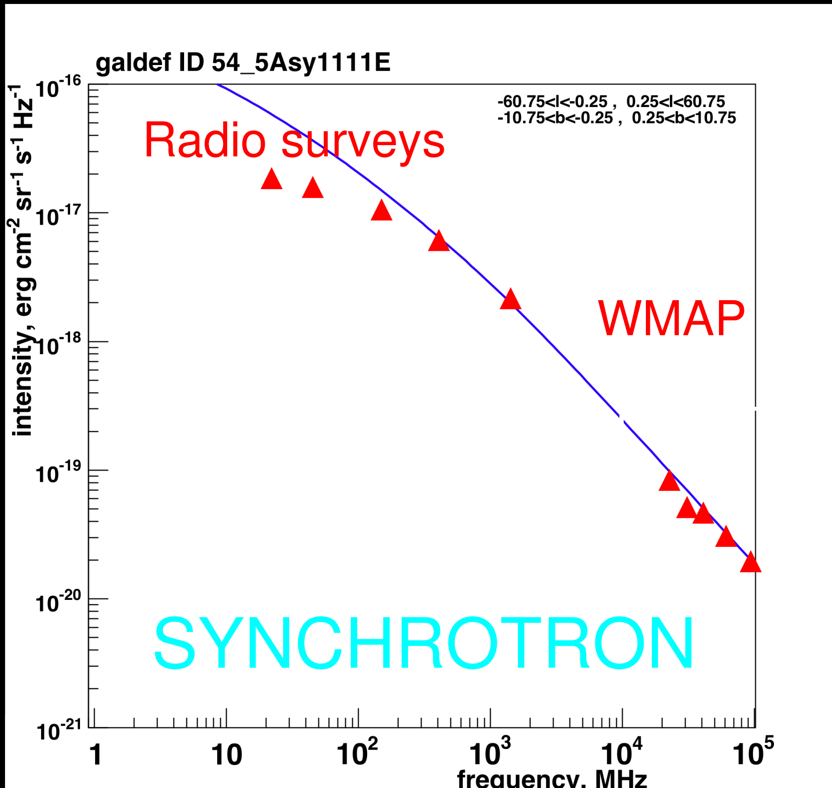


R, kpc

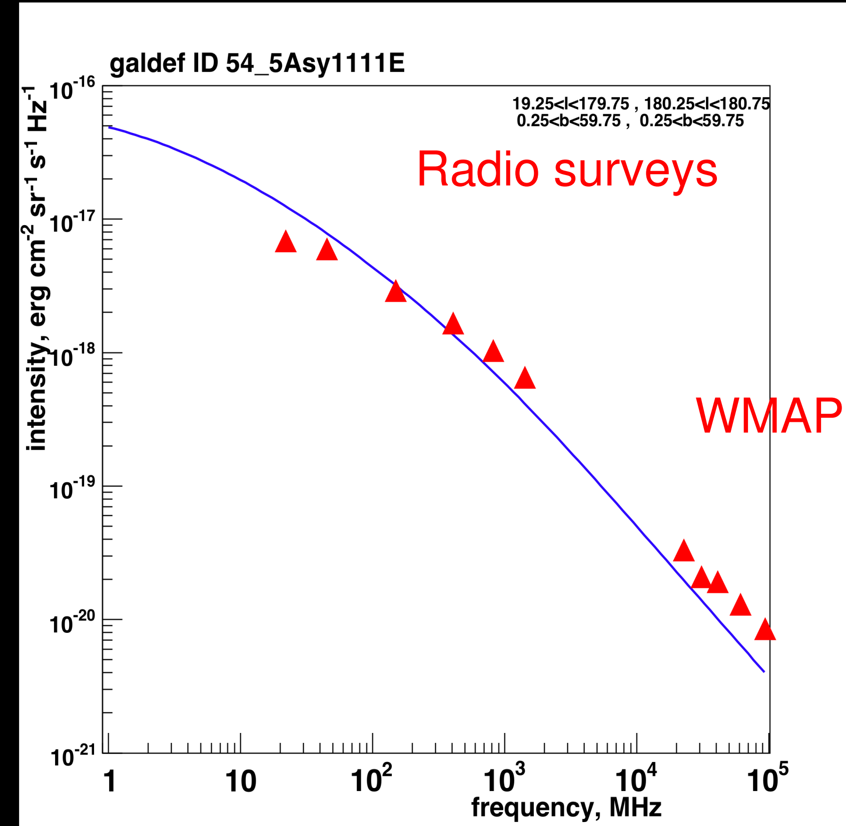
Using cosmic-ray distribution consistent with Fermi data, essentially no R- dependence of B_{tot}

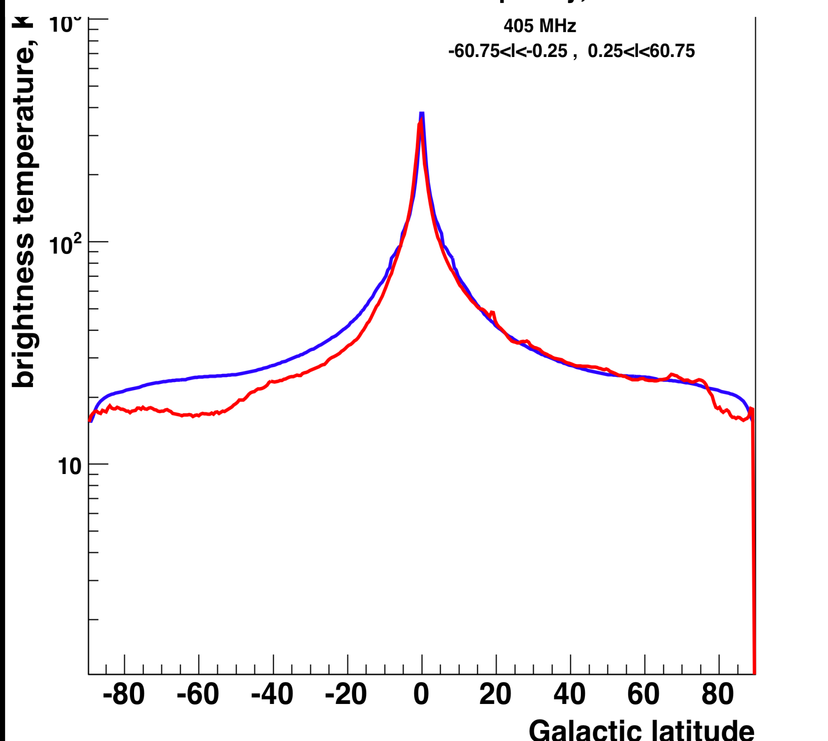
Only by combining gammas, electrons and synchrotron data can we get B_{tot} !

Relevevant to this conference !

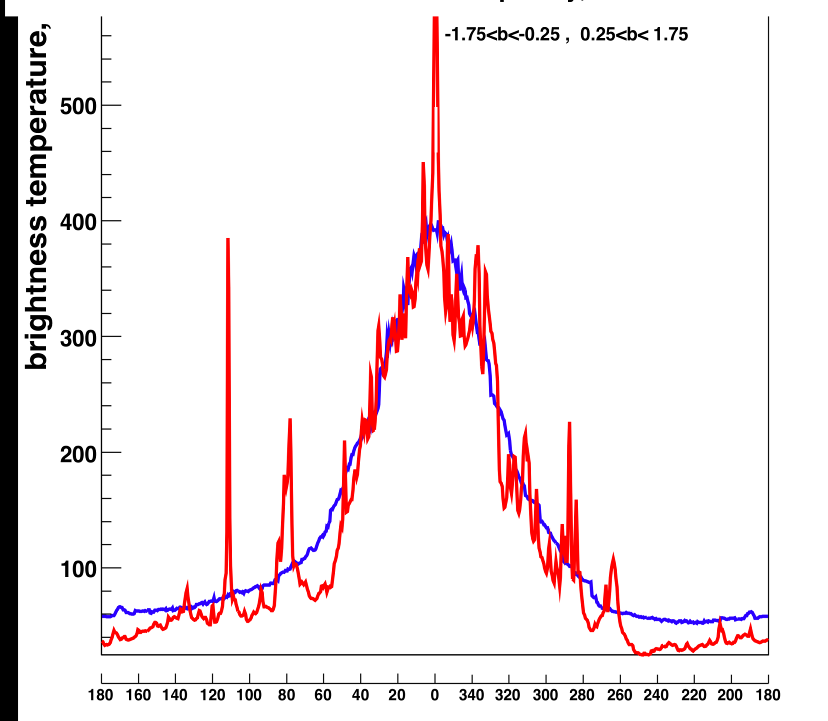


GALPROP model





408 MHz



Milky Way Galaxy is a special target for multi-wavelength studies

because ...

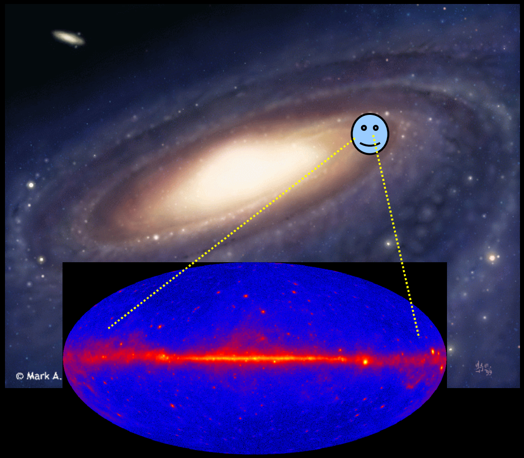
We know much more about our Galaxy than external galaxies:

* cosmic rays *directly* measured
* gamma rays mapped in detail
* synchrotron mapped in detail
* magnetic fields measured

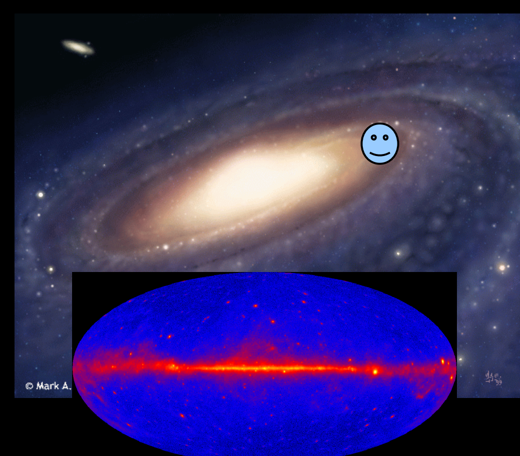
so study of the Galaxy allows a better understanding of the detailed inner workings to clarify the overall picture

including e.g. cosmic-ray CALORIMETRY

Since we live inside the Galaxy,
global properties e.g. luminosity
are not easy to deduce.

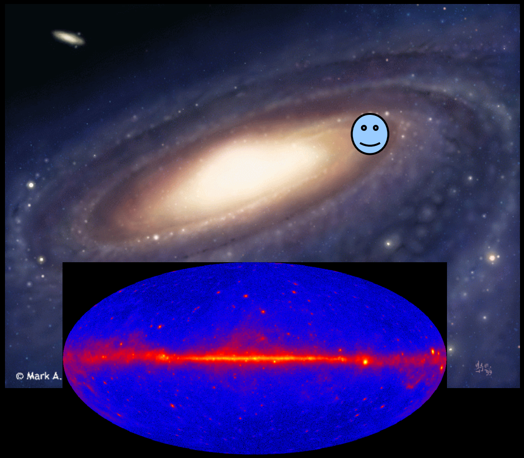



how does it
look from out
here ?

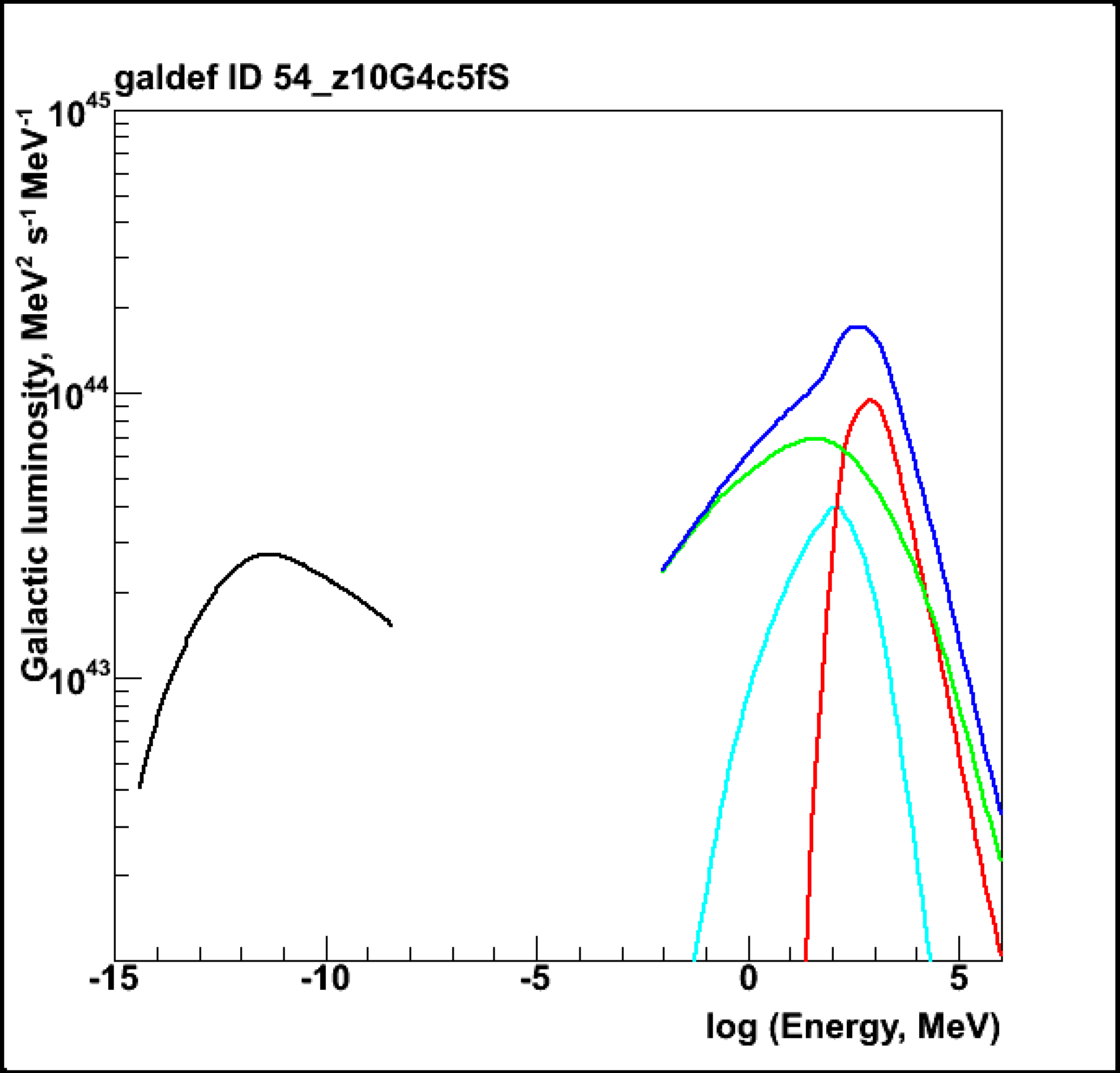


Model-dependent.

Need 3D models.



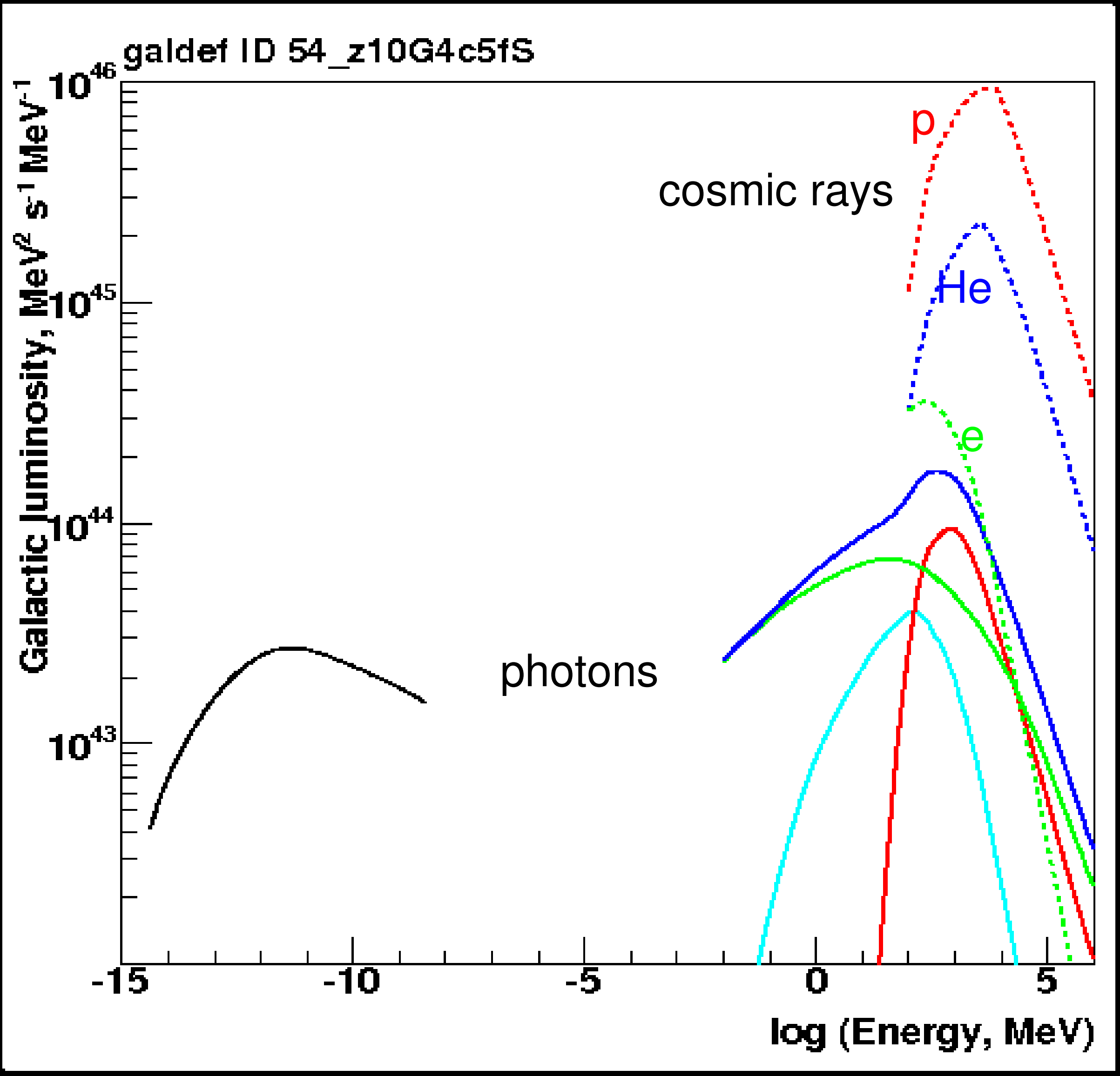
Galaxy luminosity over 20 decades of energy



radio CMB IR optical X γ

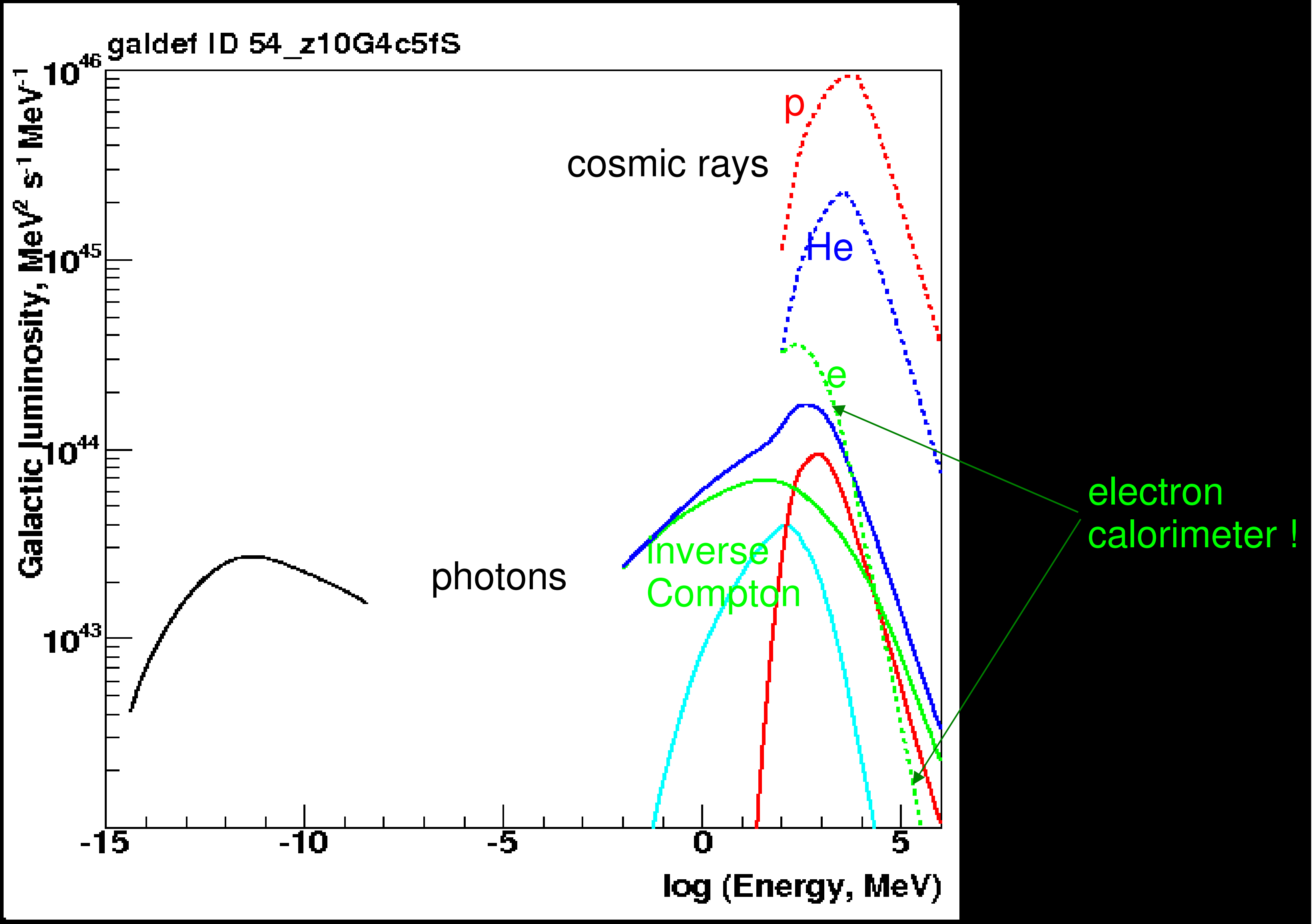
Strong etal, 2010 ApJL 722, L58

Galaxy luminosity over 20 decades of energy



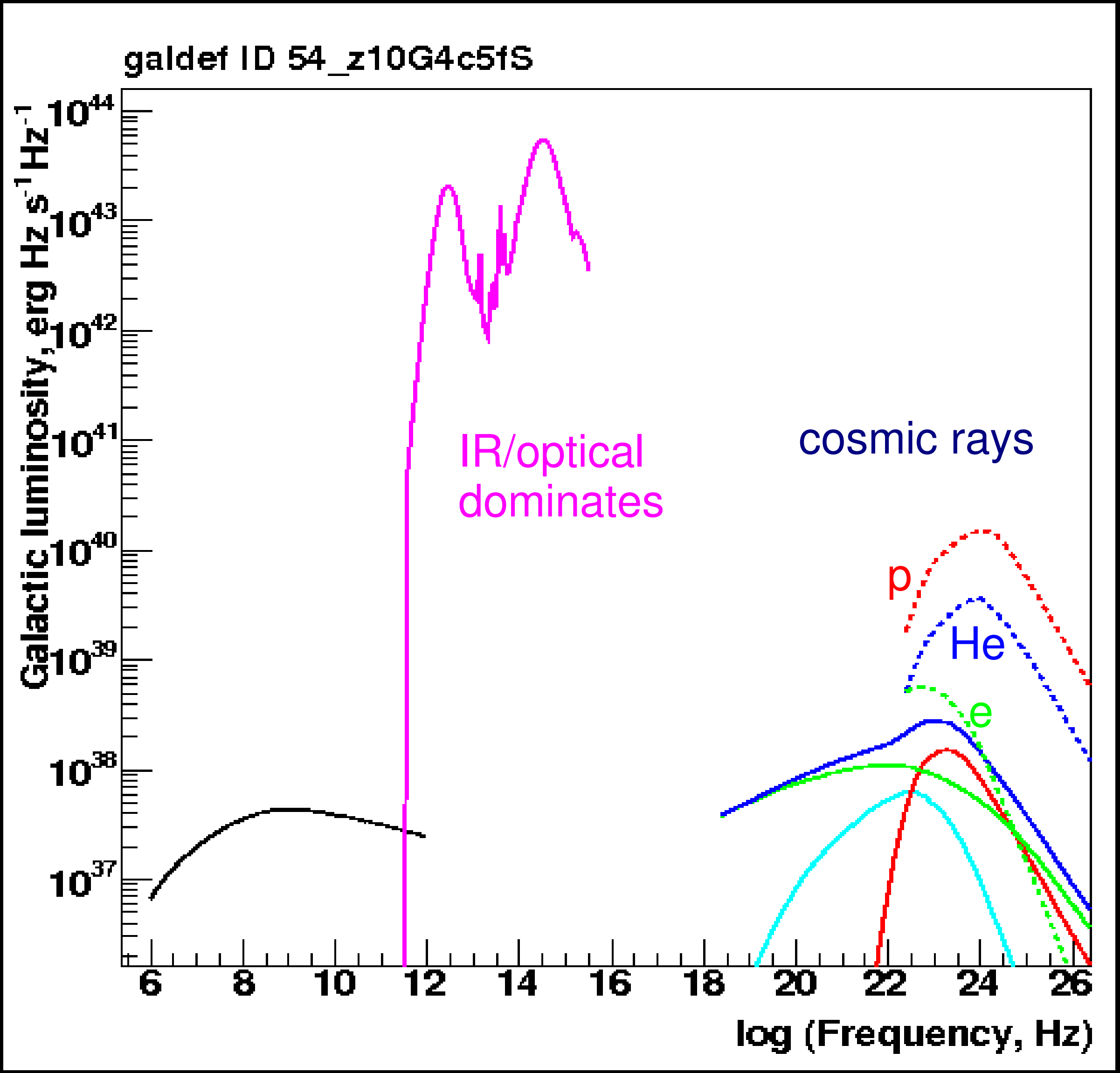
radio CMB IR optical X γ

Galaxy luminosity over 20 decades of energy



radio CMB IR optical X γ

Galaxy luminosity over 20 decades of energy



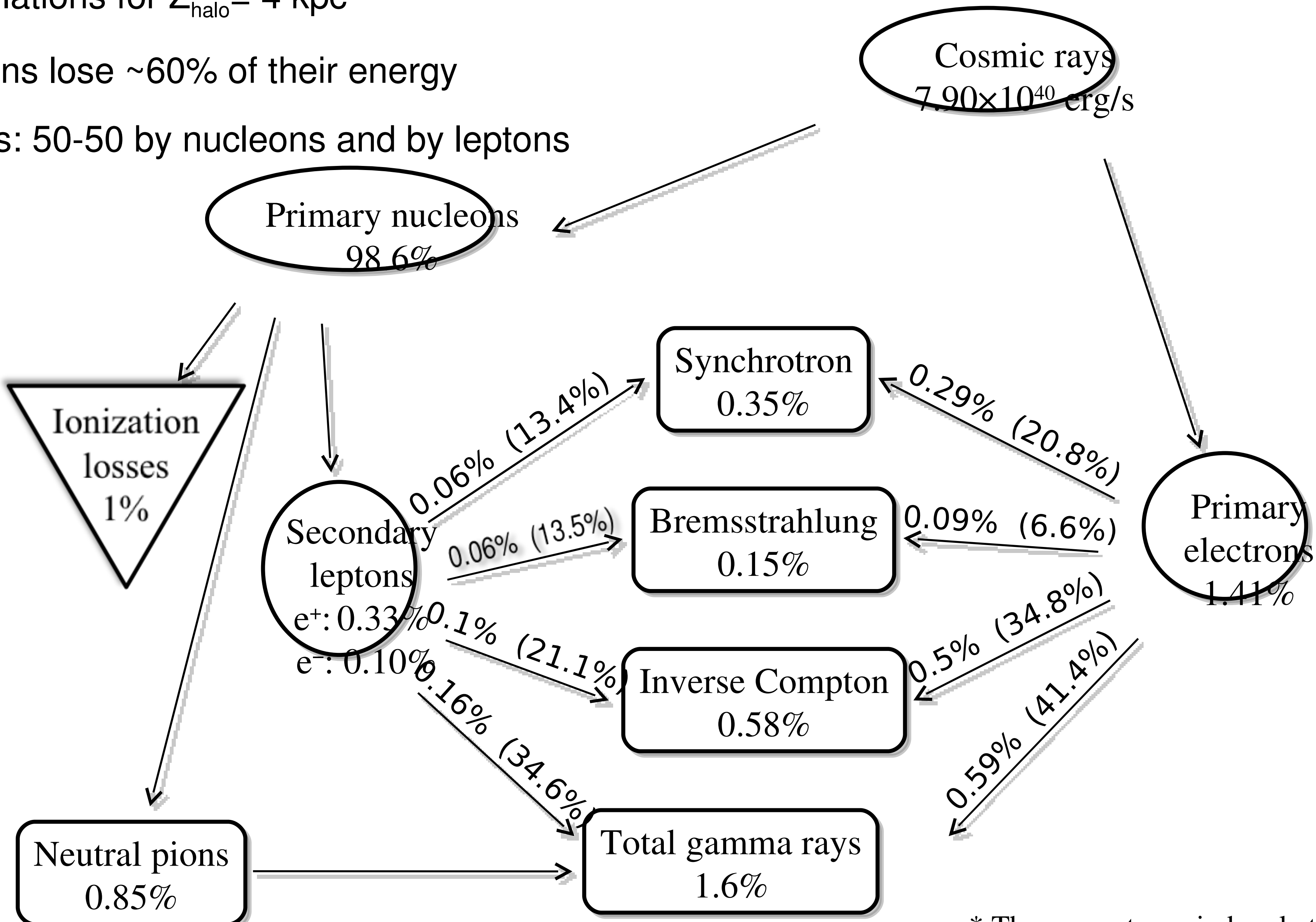
radio CMB IR optical X γ

Milky Way as electron calorimeter

Calculations for Z_{halo}= 4 kpc

Leptons lose ~60% of their energy

γ-rays: 50-50 by nucleons and by leptons



* The percentages in brackets show the values relative to the luminosity of their respective lepton populations

Outlook

Fermi operational, 2 years so far.
Diffuse emission results now appearing.
The fine data challenges the models.
Combining all data constrains B-field models.

Essential to exploit synergy between
cosmic-rays - gammas – microwave - radio