Interstellar gamma rays and cosmic rays

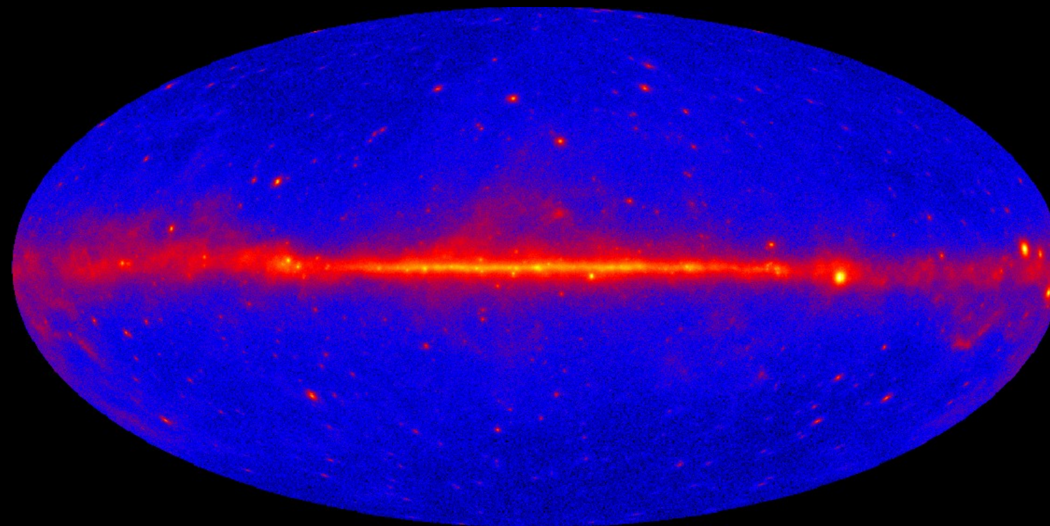
New insights from Fermi and INTEGRAL and …..

Andy Strong

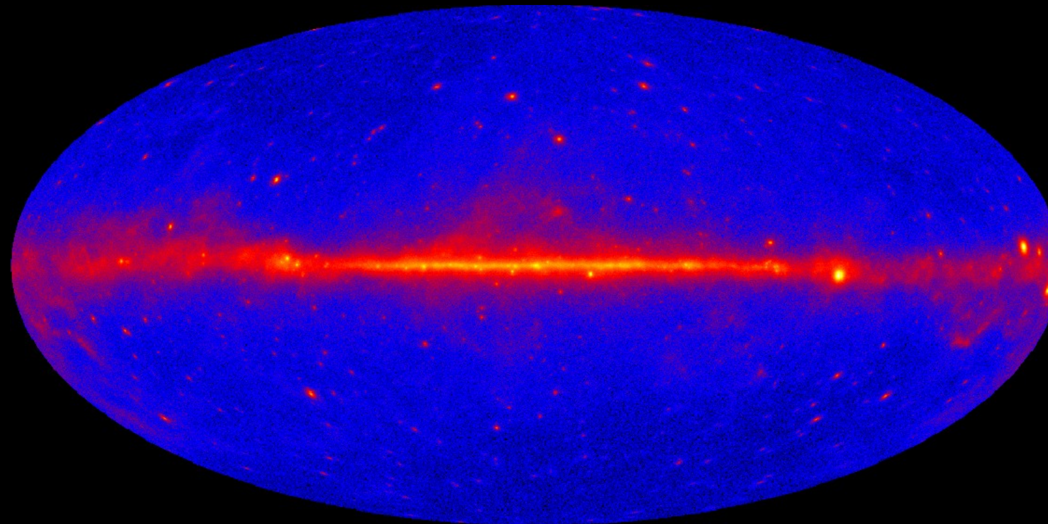
on behalf of Fermi-LAT collaboration

ICATPP, Villa Olmo, 7-8 October 2010

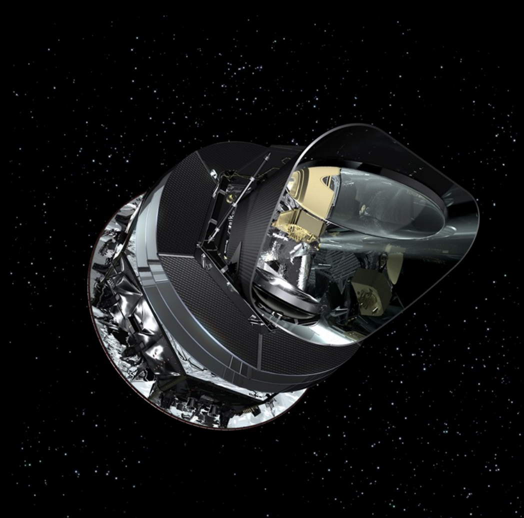

National Aeronautics and Space Administration
Fermi
Gamma-ray Space Telescope
www.nasa.gov/fermi

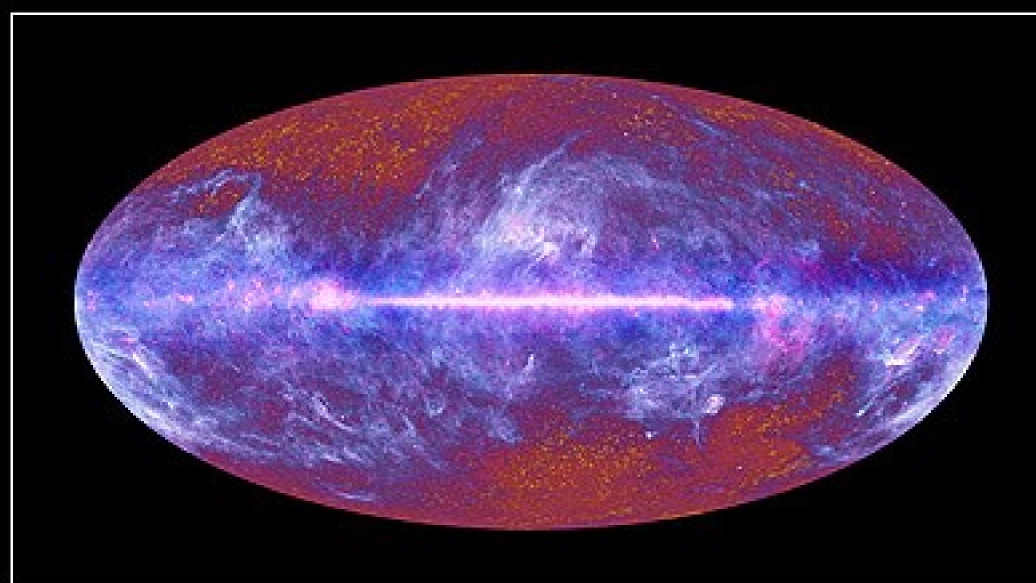


1 year



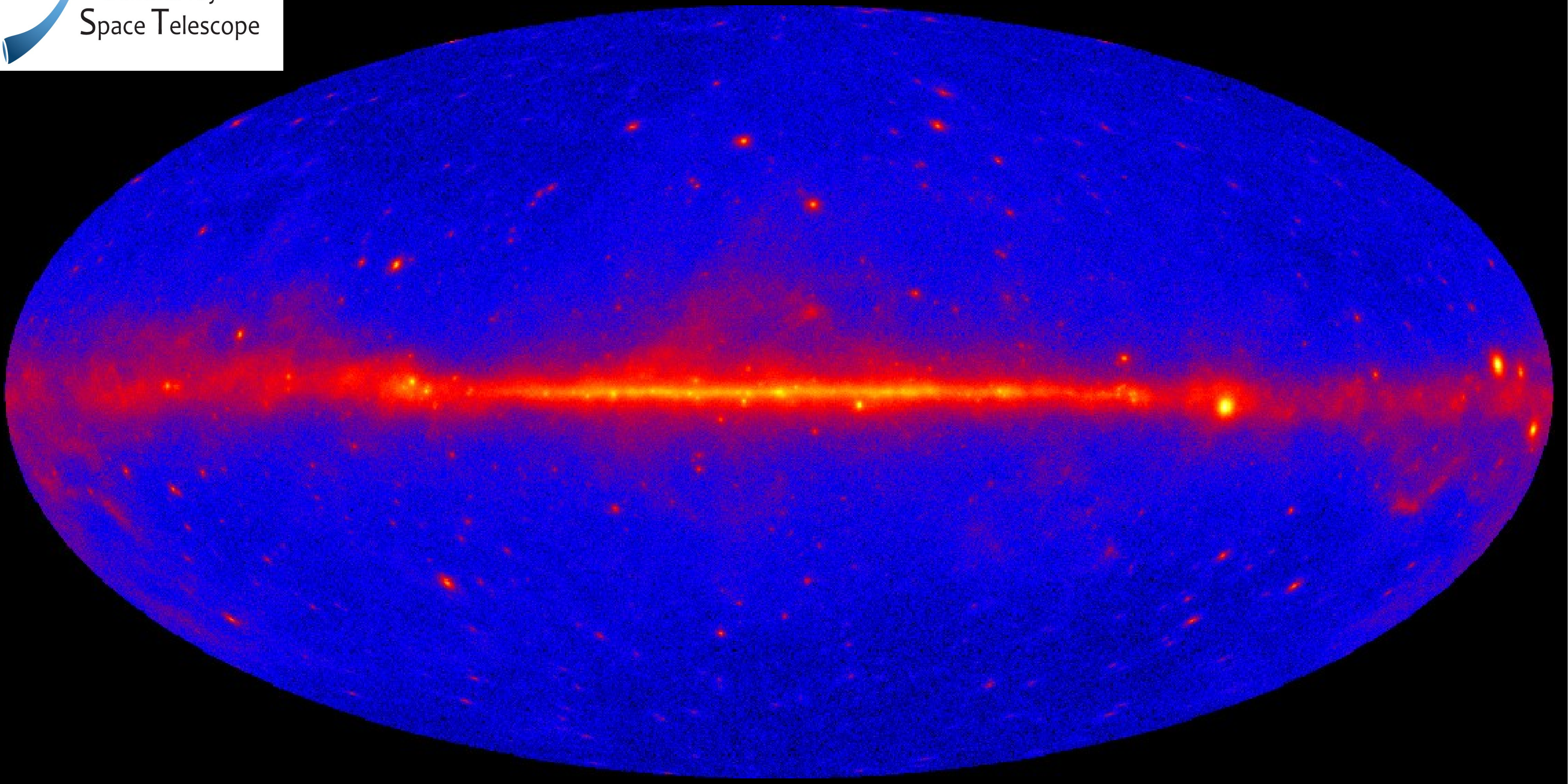
1 year





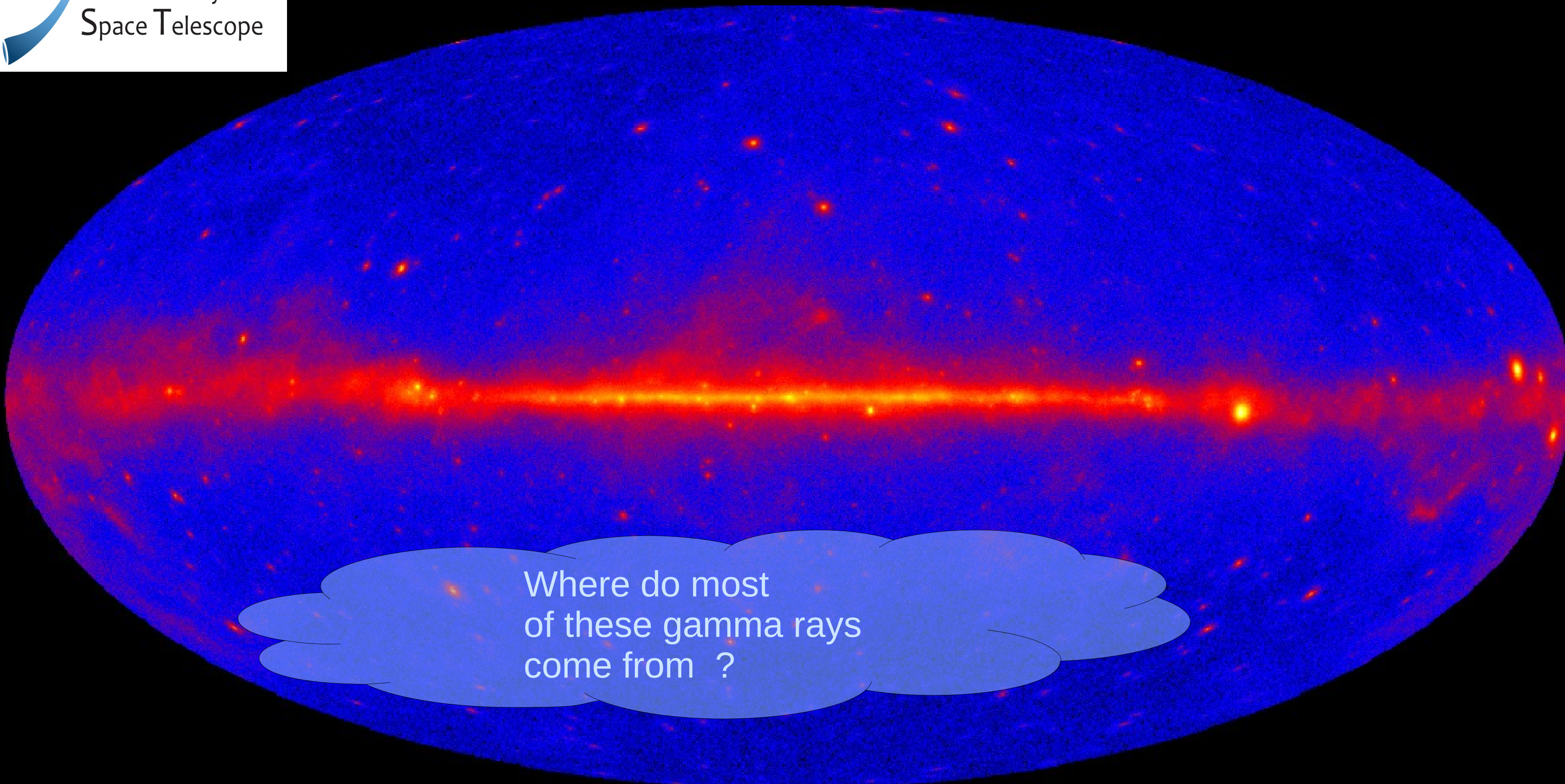
The Planck one-year all-sky survey esa (c) ESA, HFI and LFI consortia, July 2010

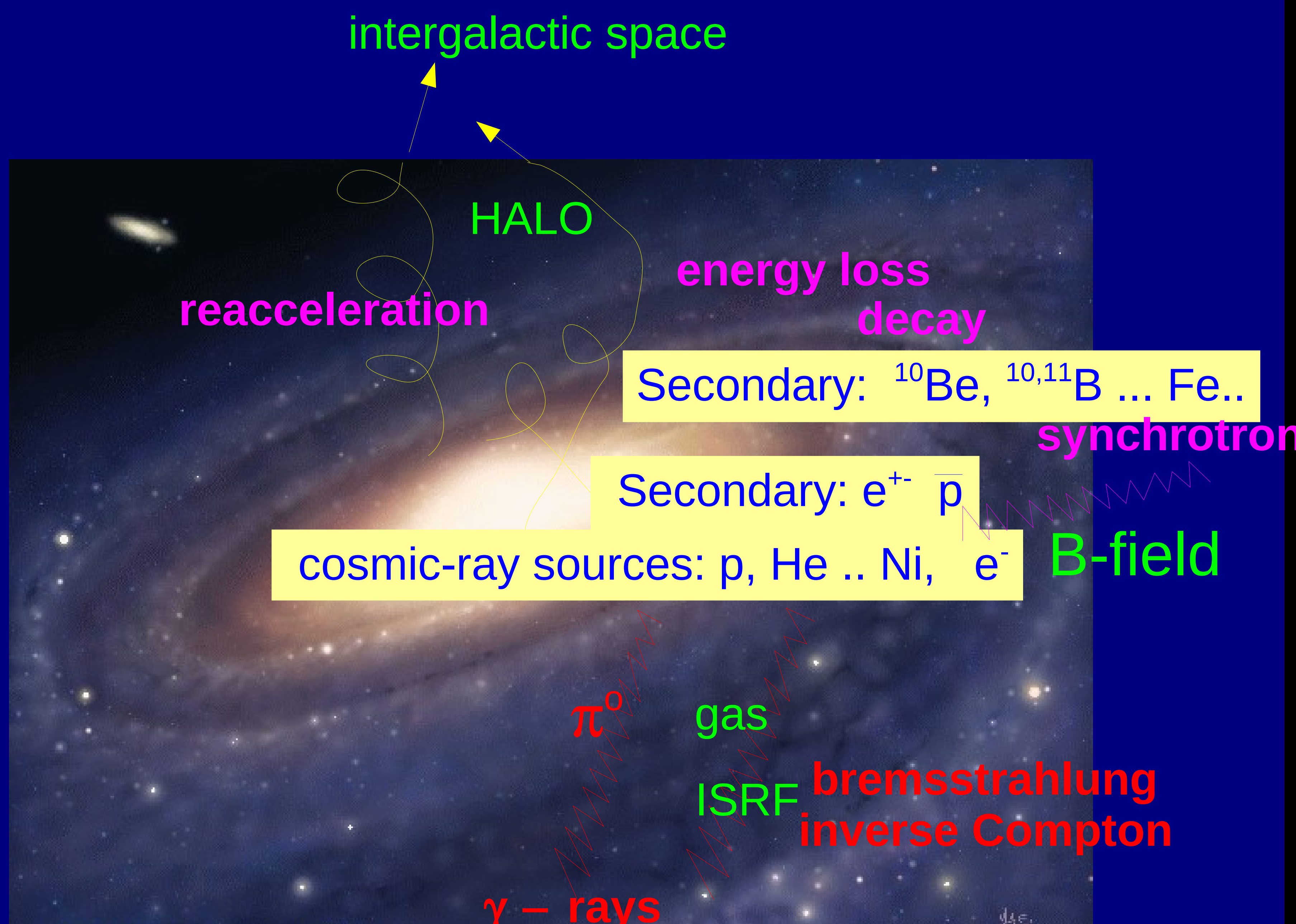
1 year



1st year skymap

Fermi
Gamma-ray
Space Telescope

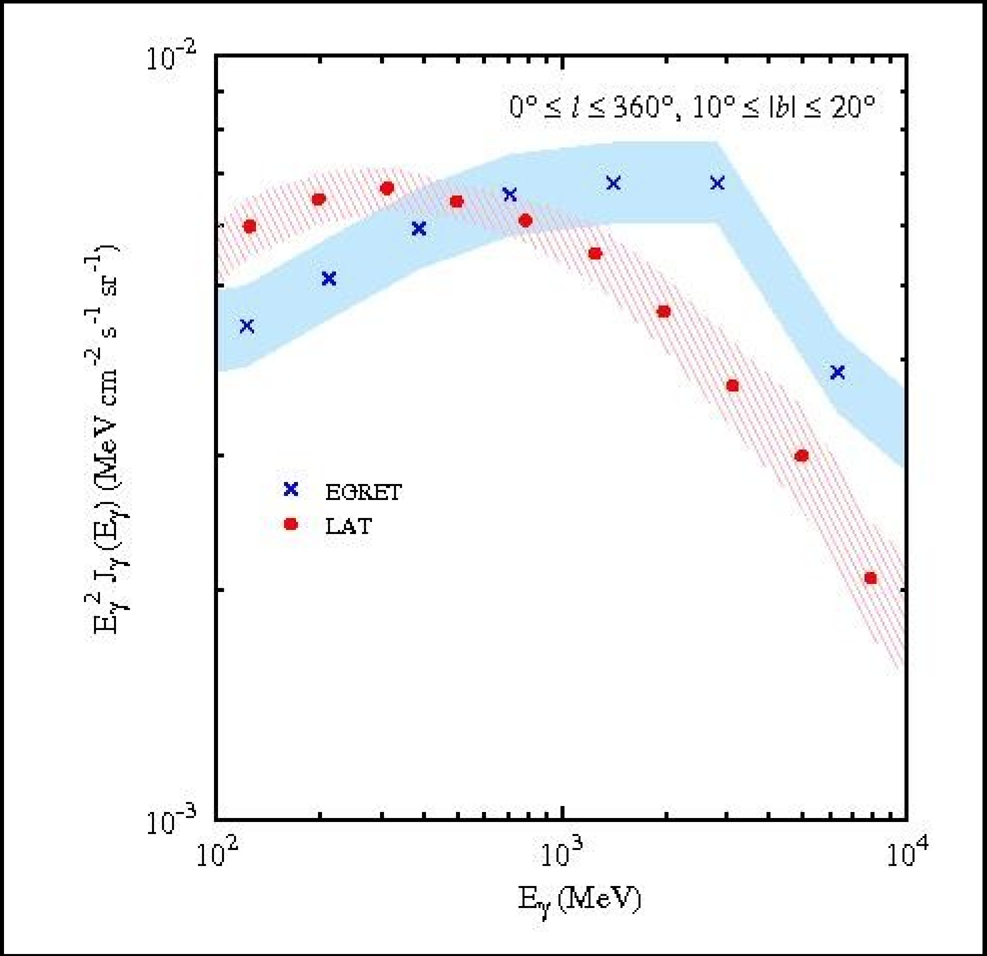




intergalactic space
HALO
reacceleration
energy loss
decay
Secondary: ^{10}Be, $^{10,11}B$ ... Fe..
synchrotron
Secondary: e^{+-} $\bar{p}$
cosmic-ray sources: p, He .. Ni, e^{-}
B-field
π^{o}
gas
ISRF
bremsstrahlung
inverse Compton
γ – rays

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 GeV excess !

LATEST 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

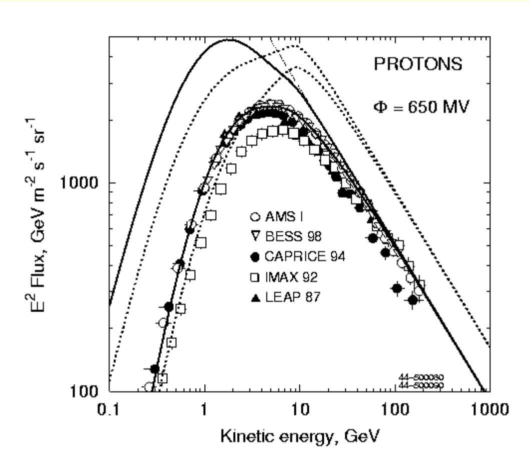
The **goal** : use *all* types of data in self-consistent way to test models of cosmic-ray propagation.

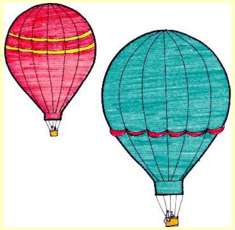
Observed *directly, near Sun:*

primary spectra (p, He ... Fe; e^-)

secondary/primary (B/C etc)

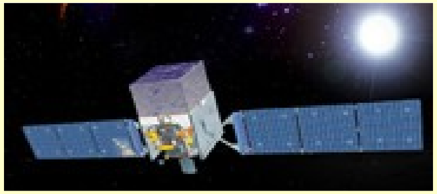
secondary e^+ , antiprotons...

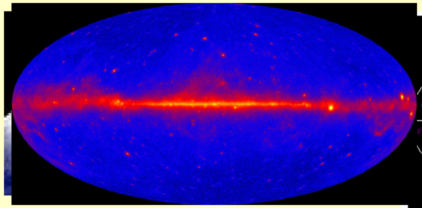


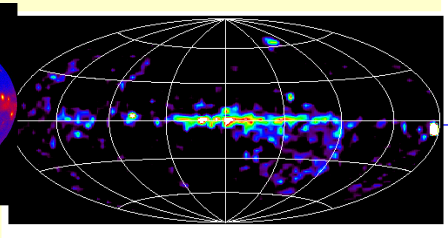


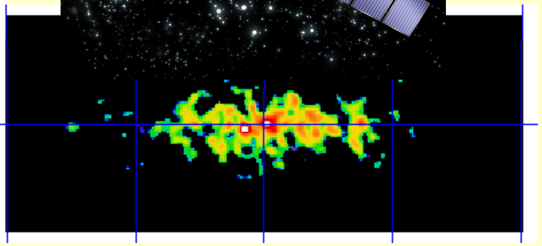
Observed *from whole Galaxy:*

γ - rays

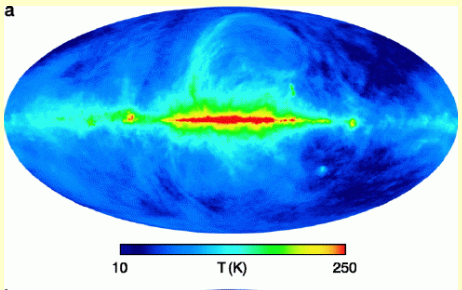








synchrotron



Modelling the gamma-ray sky

See talk by Troy Porter at this conference.

Main ingredients of GALPROP model

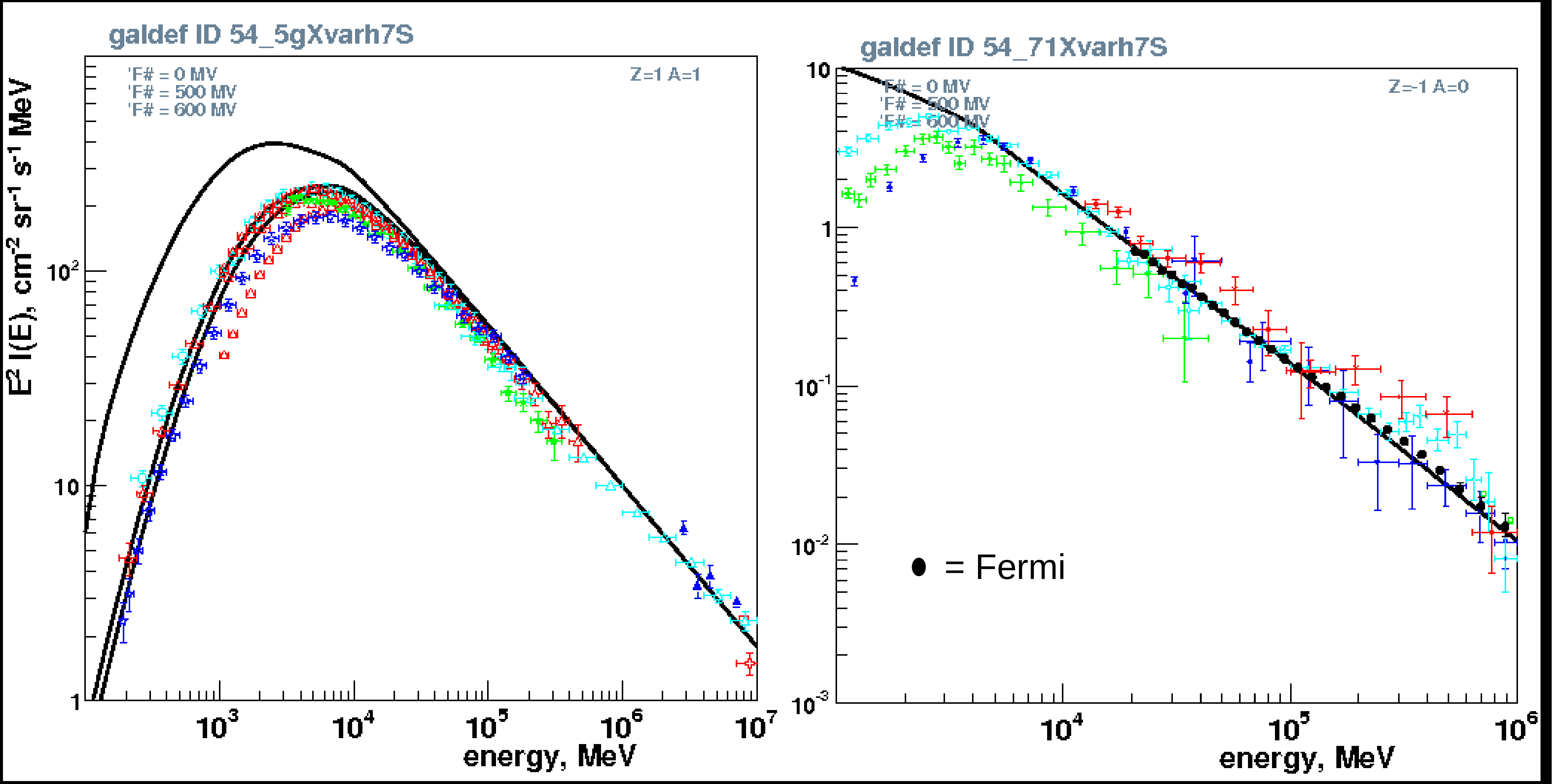
cosmic-ray spectra p , He , e- , e+ (including secondaries)
(including *Fermi-measured* electrons)
cosmic-ray source distribution follow e.g. SNR/pulsars

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

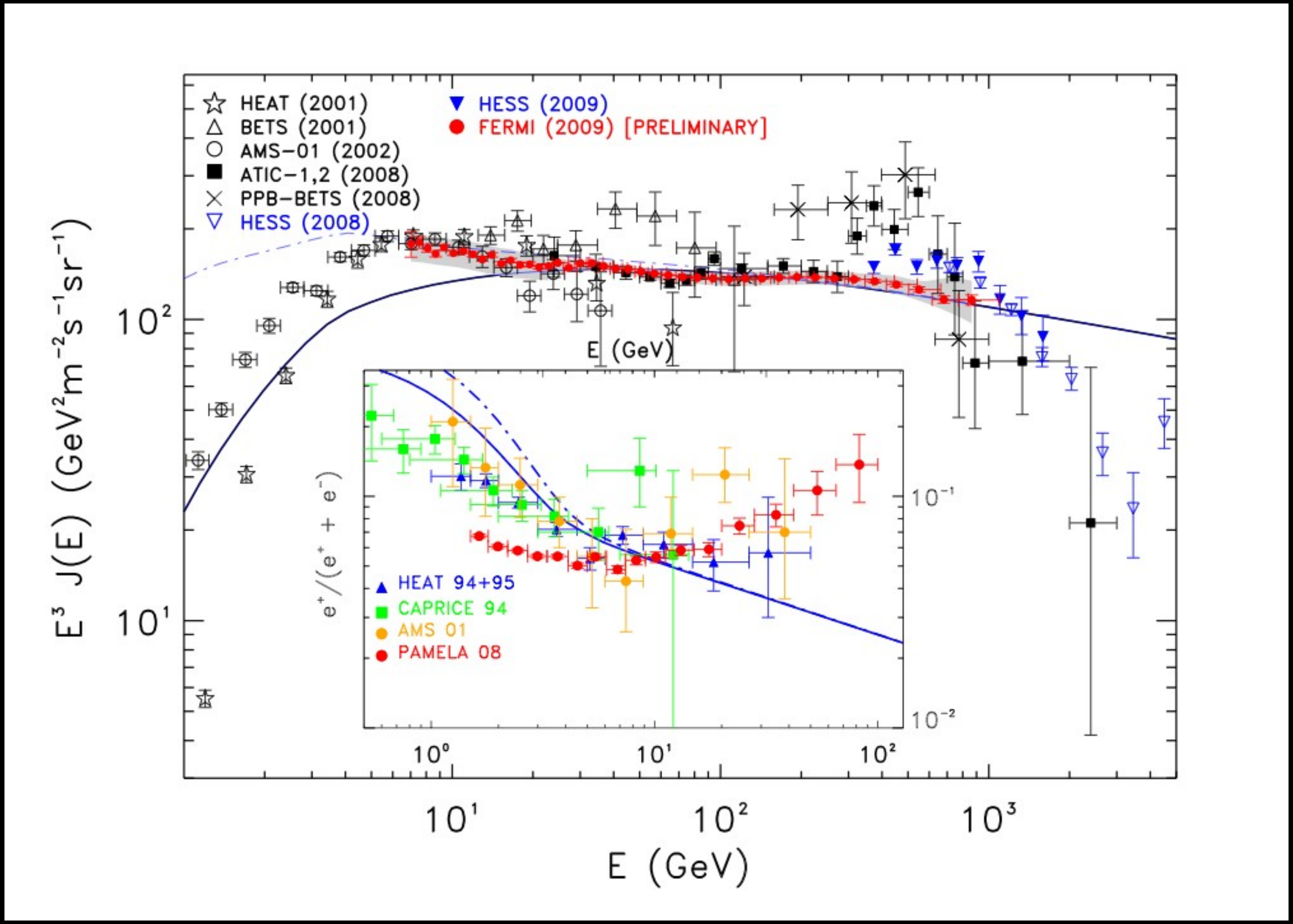
Interstellar radiation field (-> inverse Compton)
HI, CO, dust surveys
CO-to-H_2 conversion a function of position in Galaxy
Fermi 1st Year Source Catalogue

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

PROTONS **ELECTRONS**



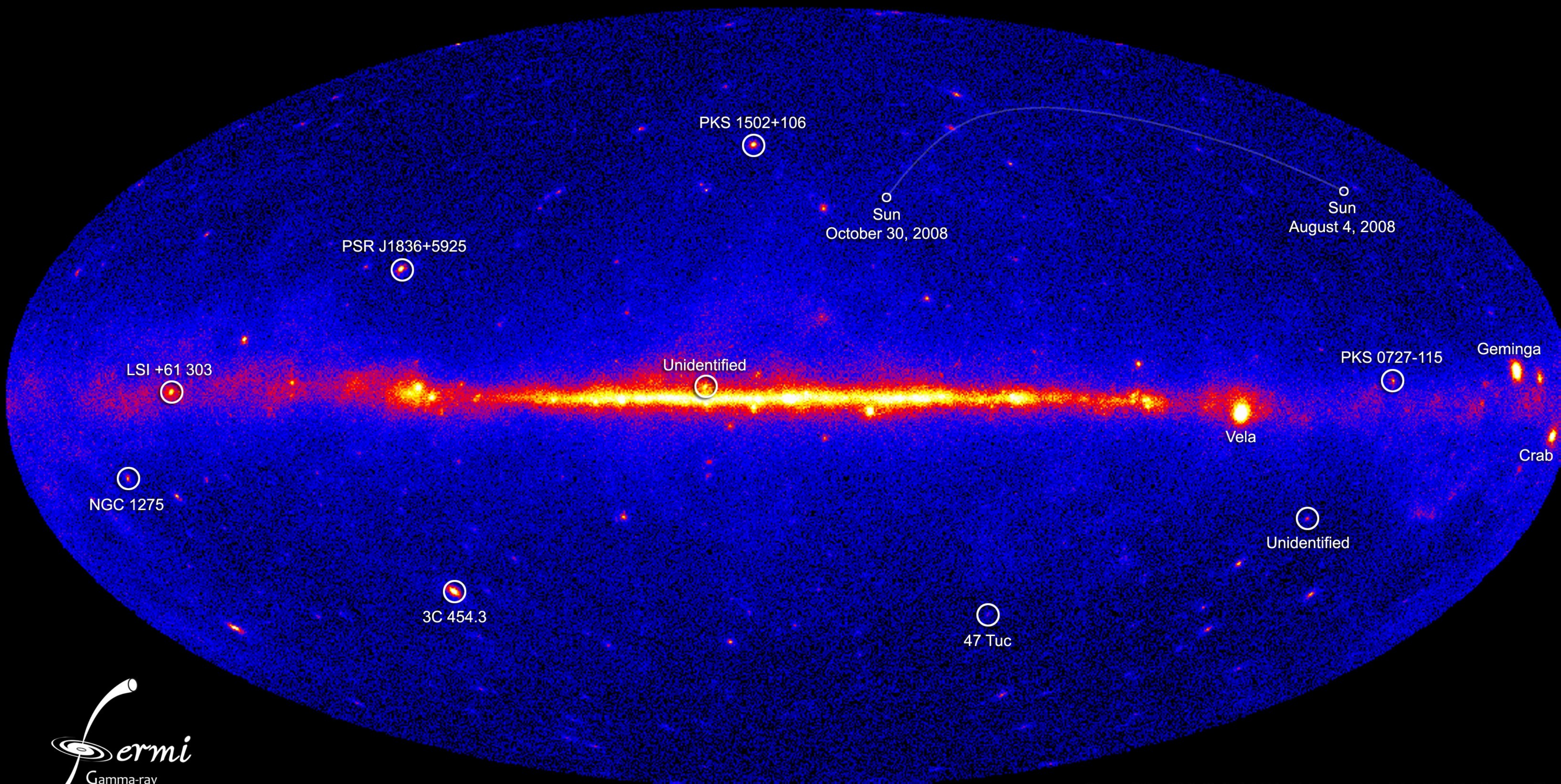
Electron spectrum measured by Fermi-LAT extended down to 7 GeV



Abdo etal in preparation

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

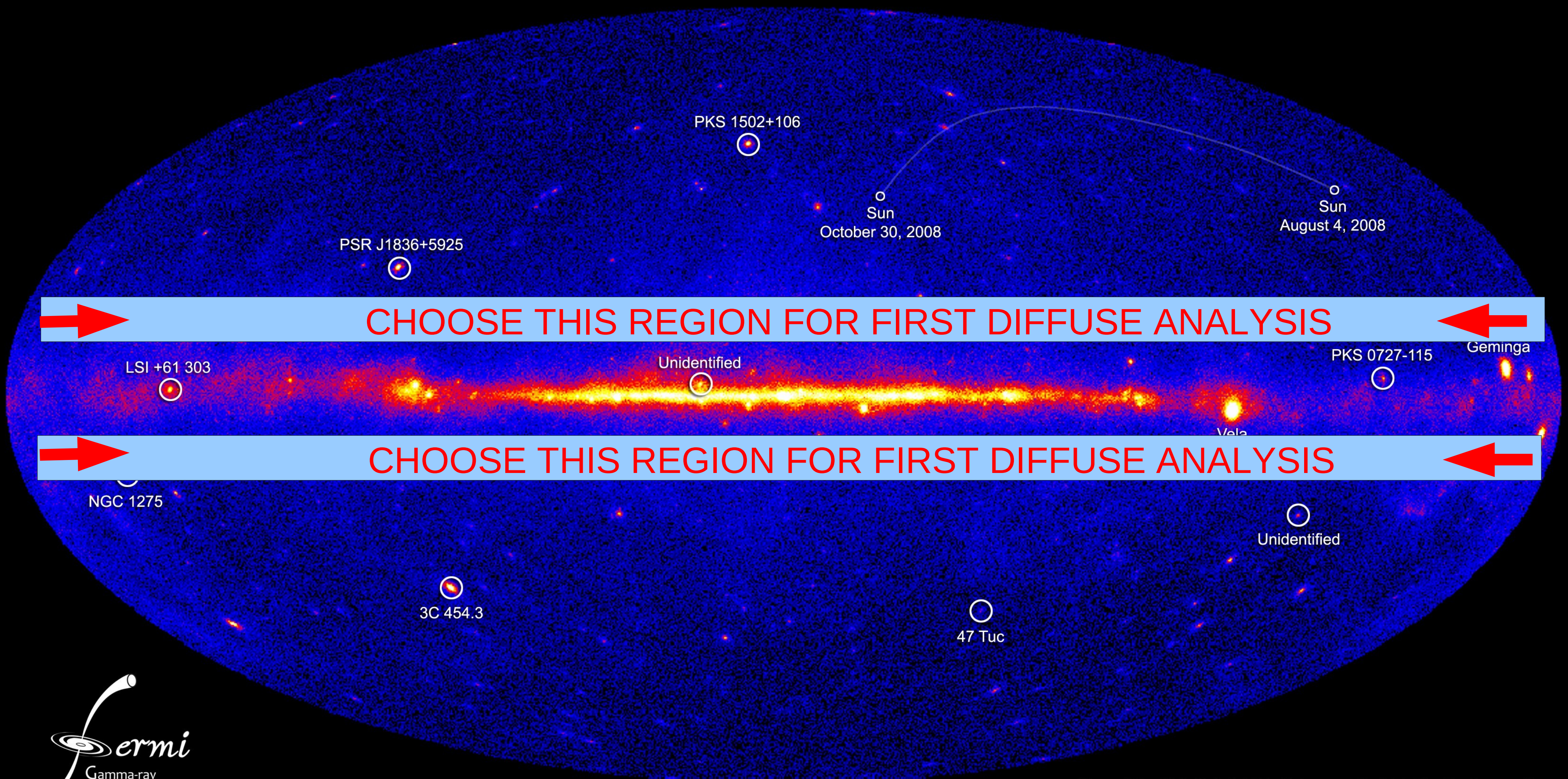
NASA's Fermi telescope reveals best-ever view of the gamma-ray sky



Fermi Gamma-ray Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

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

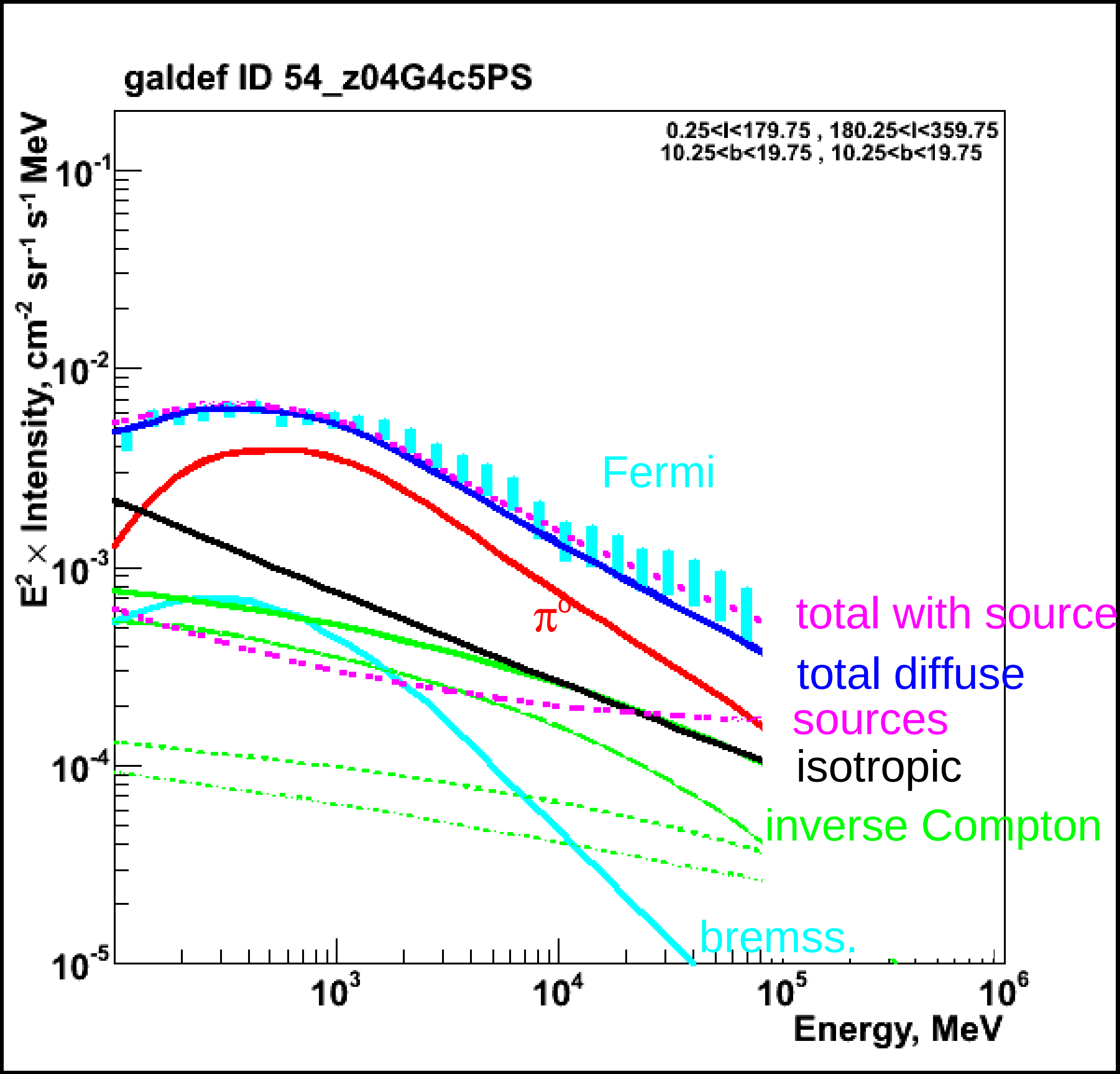


Gamma-ray
Space Telescope

Credit: NASA/DOE/Fermi/LAT Collaboration

INTERMEDIATE LATITUDES
+10 < b < +20

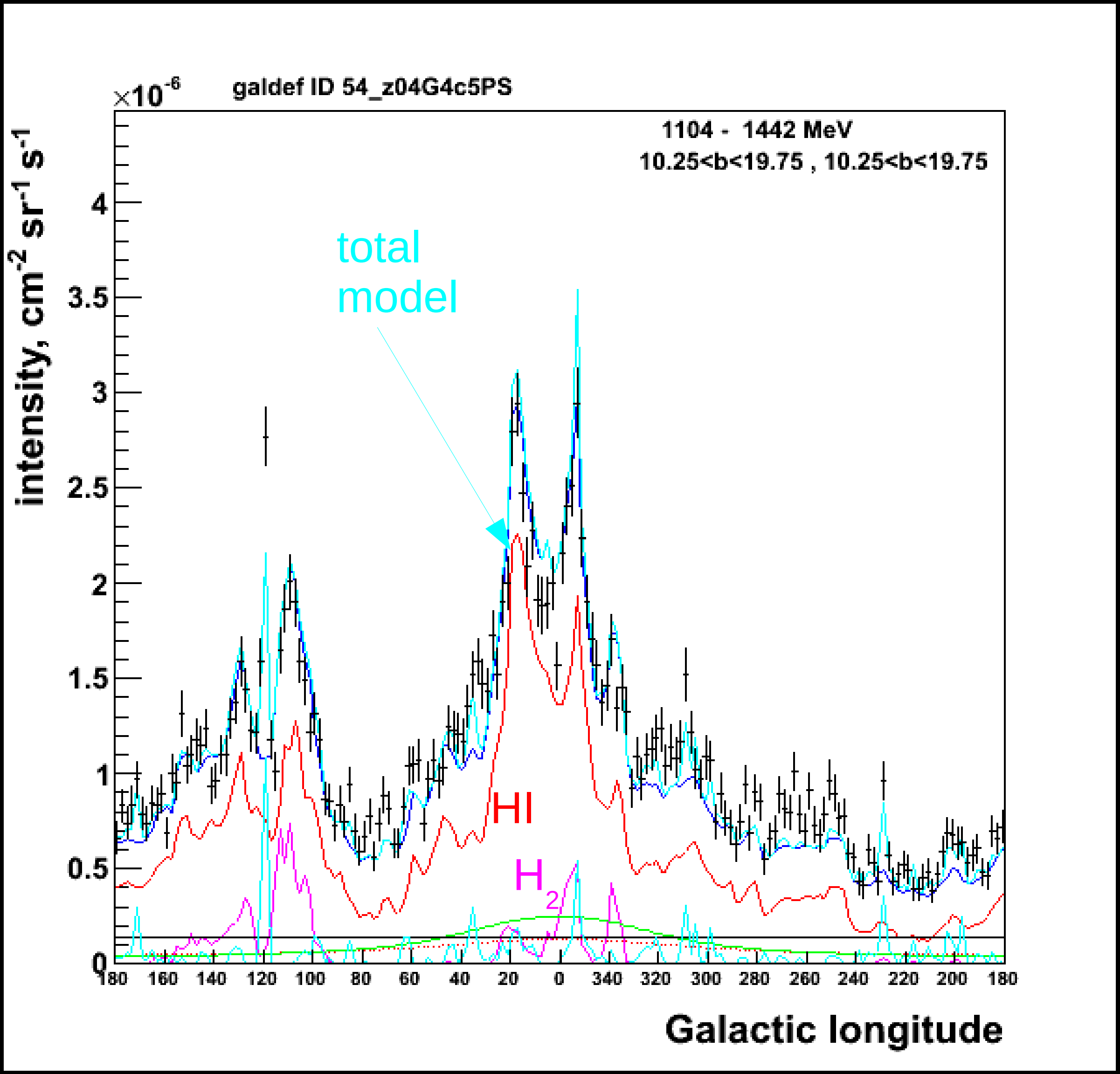
good
agreement
with
basic
 model



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

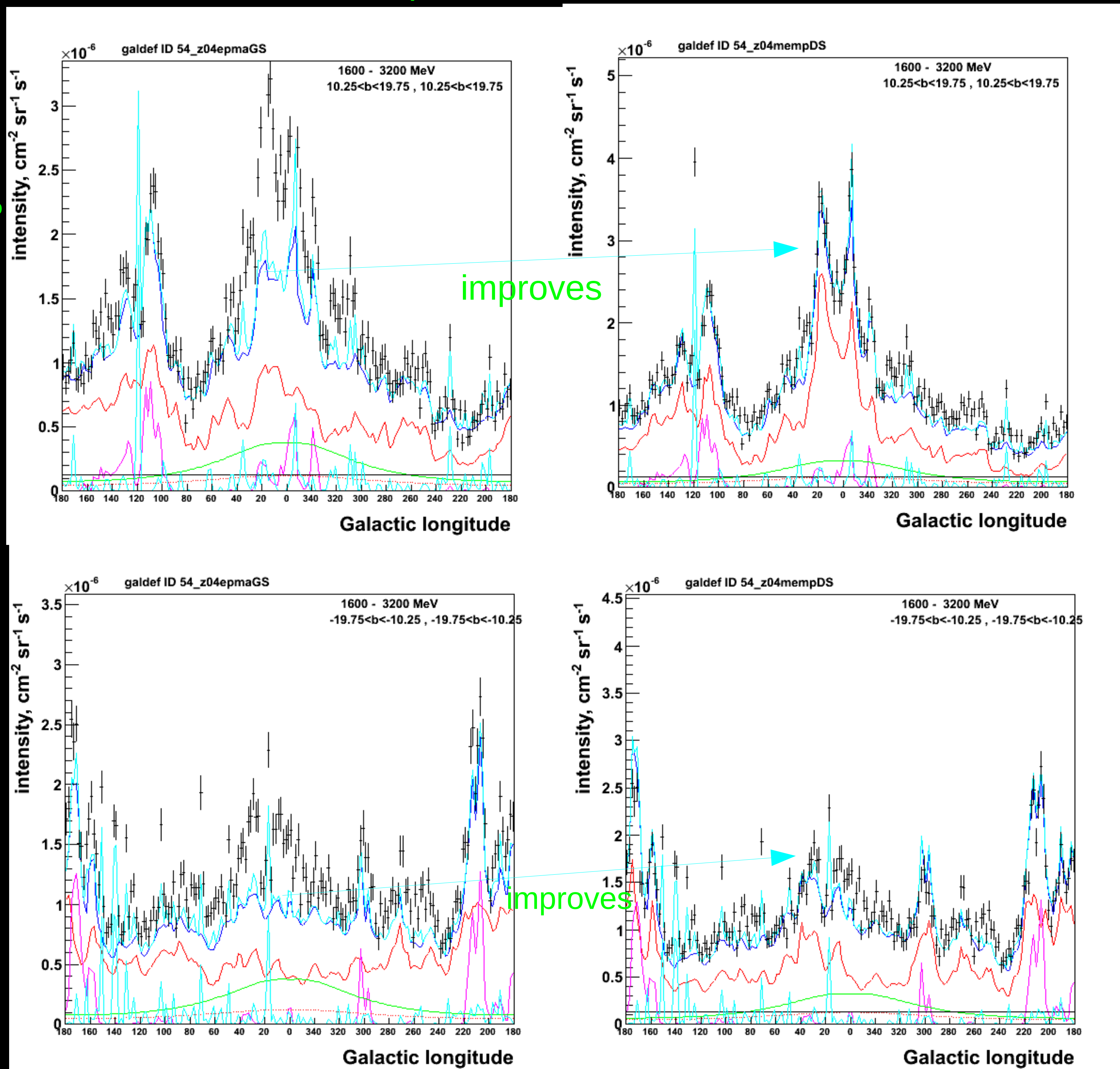
GAS TRACER: HI, CO | GAS TRACER: dust

North

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

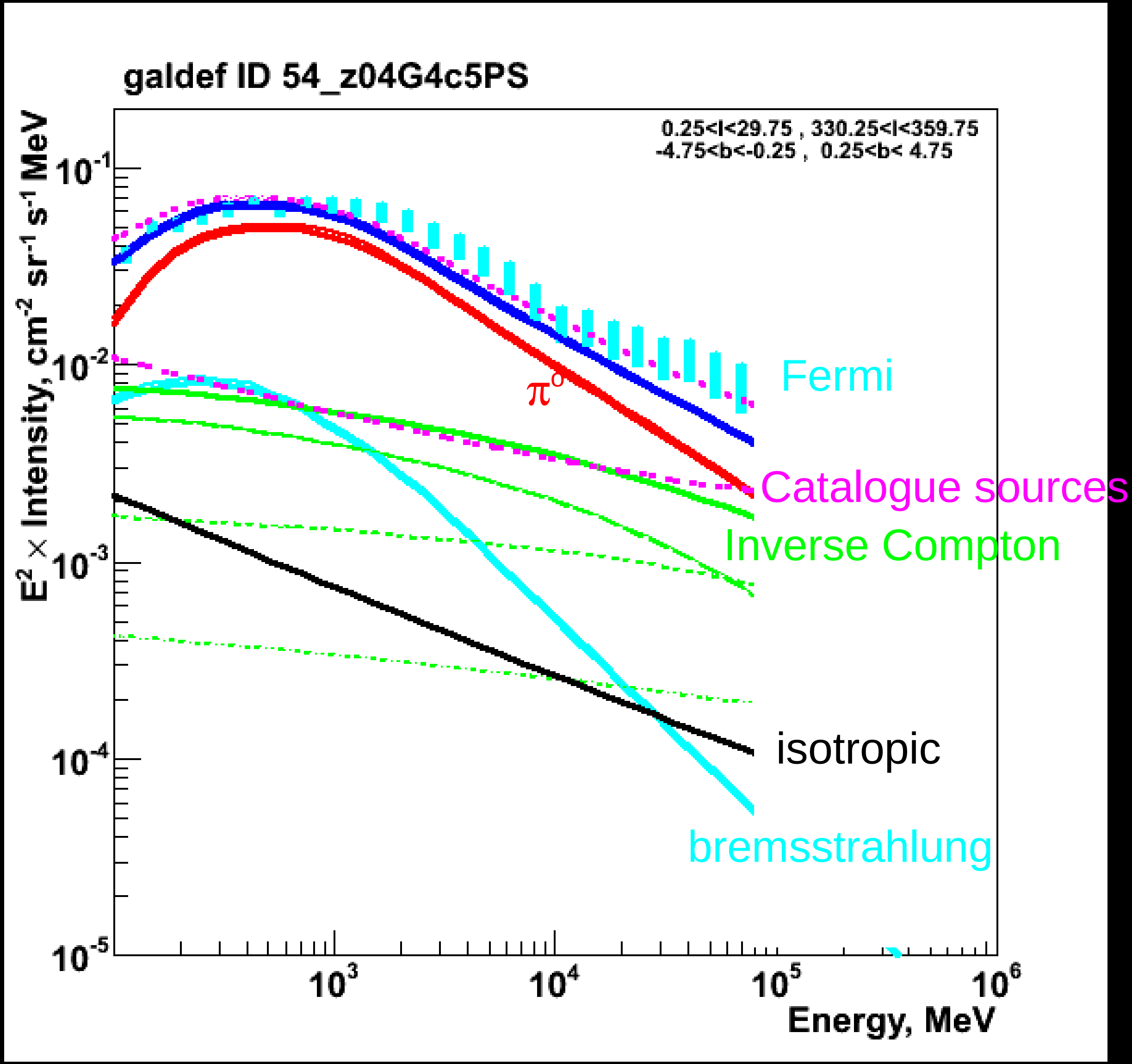
South

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



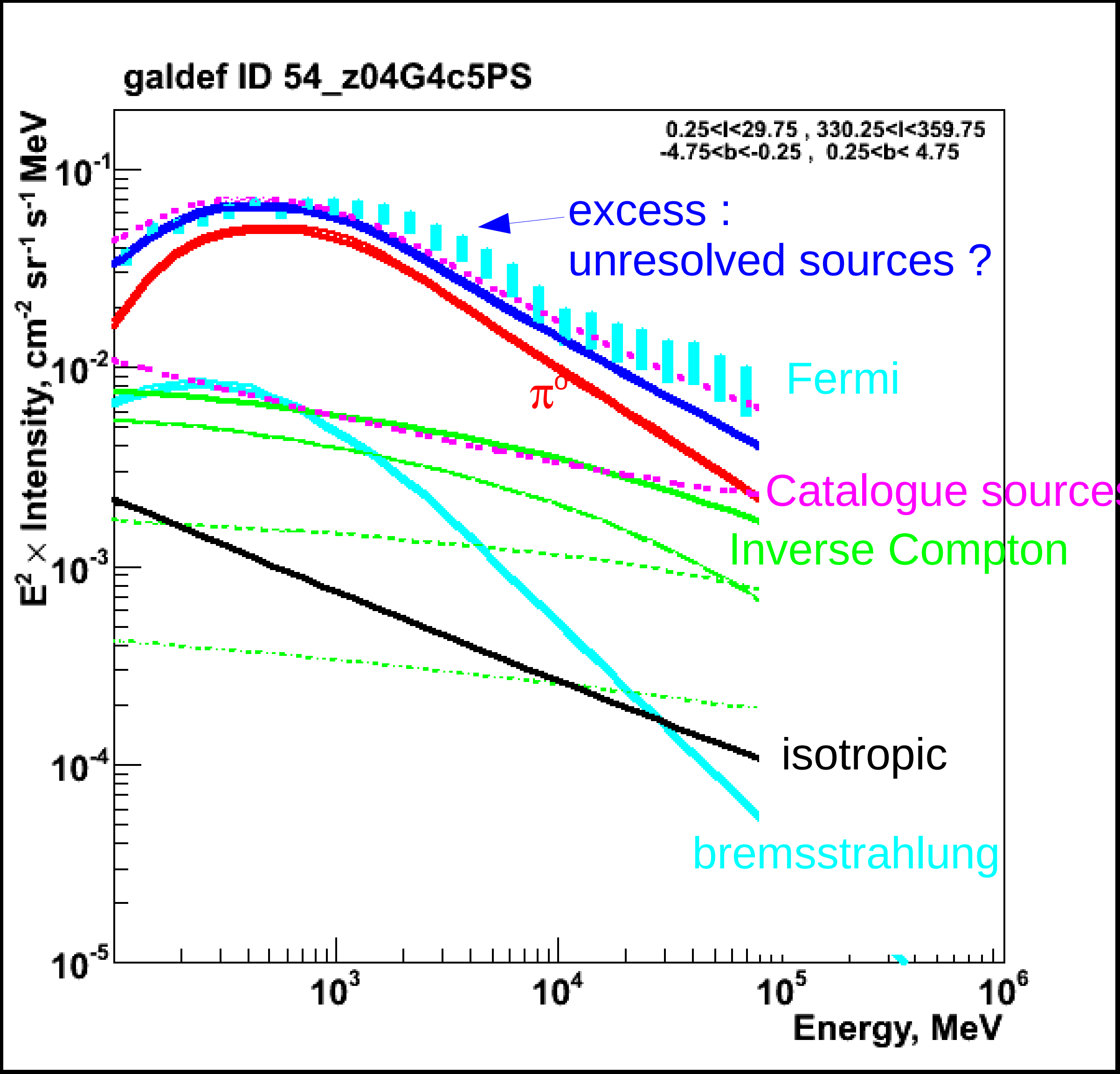
Dust emission is a better tracer of local gas than HI+CO !

Inner Galaxy
330° < l < 30°, |b|<5°



PRELIMINARY

Inner Galaxy
330° < l < 30°, |b|<5°

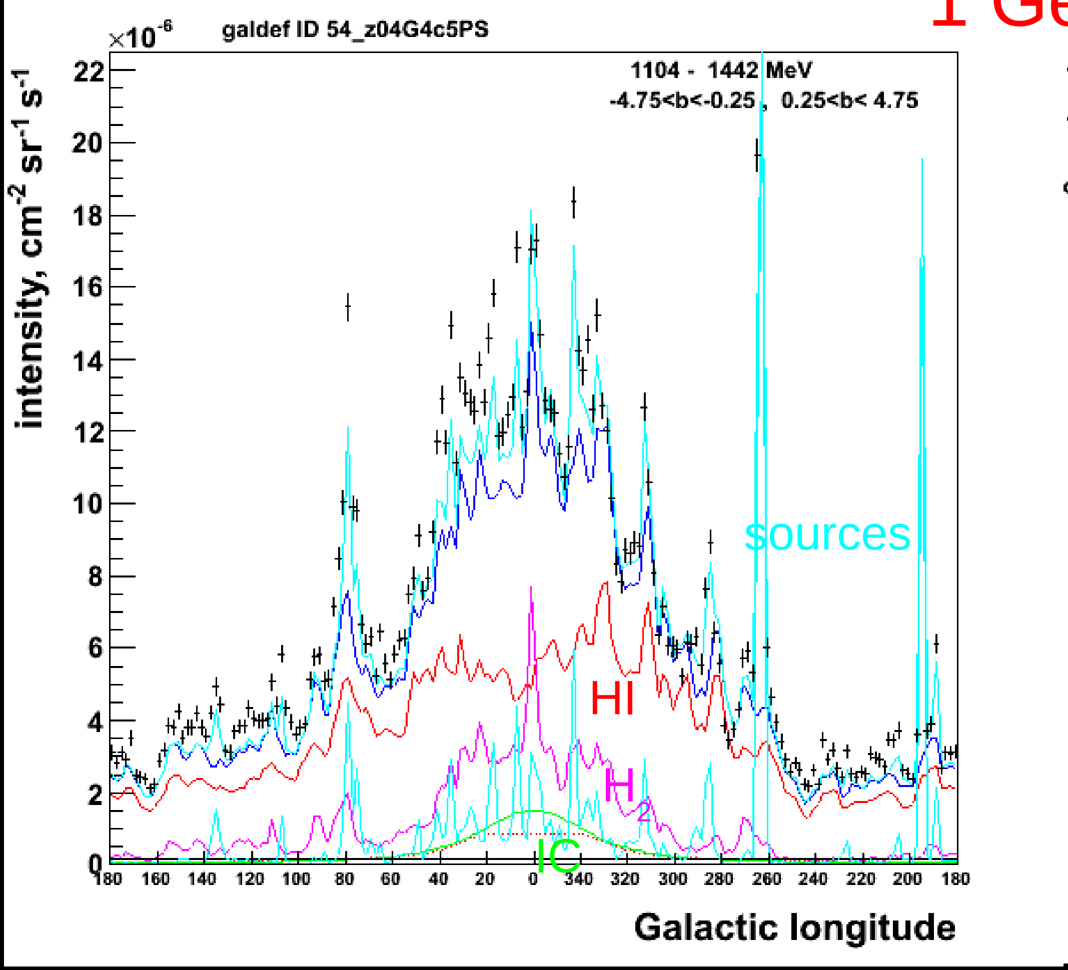


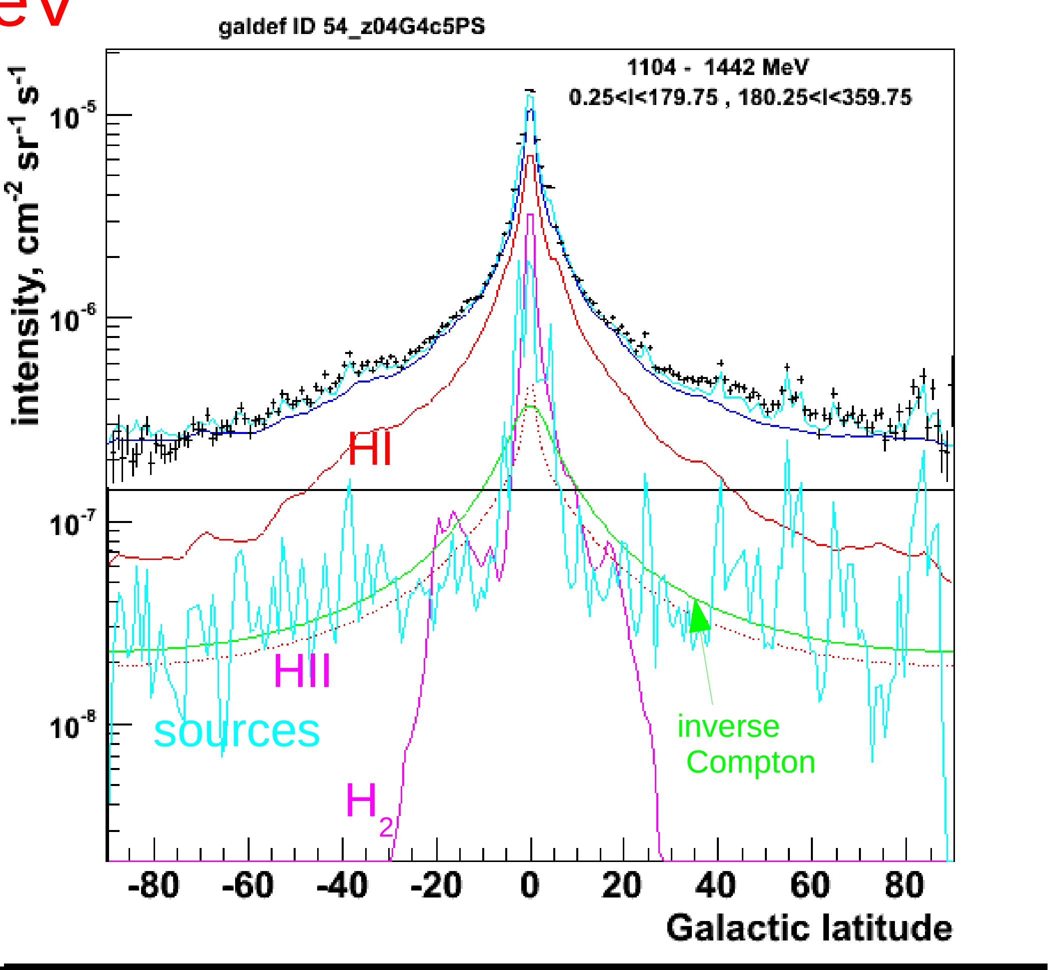
PRELIMINARY

LONGITUDE PROFILE LOW LATITUDES

LATITUDE PROFILE ALL LONGITUDES

1 GeV



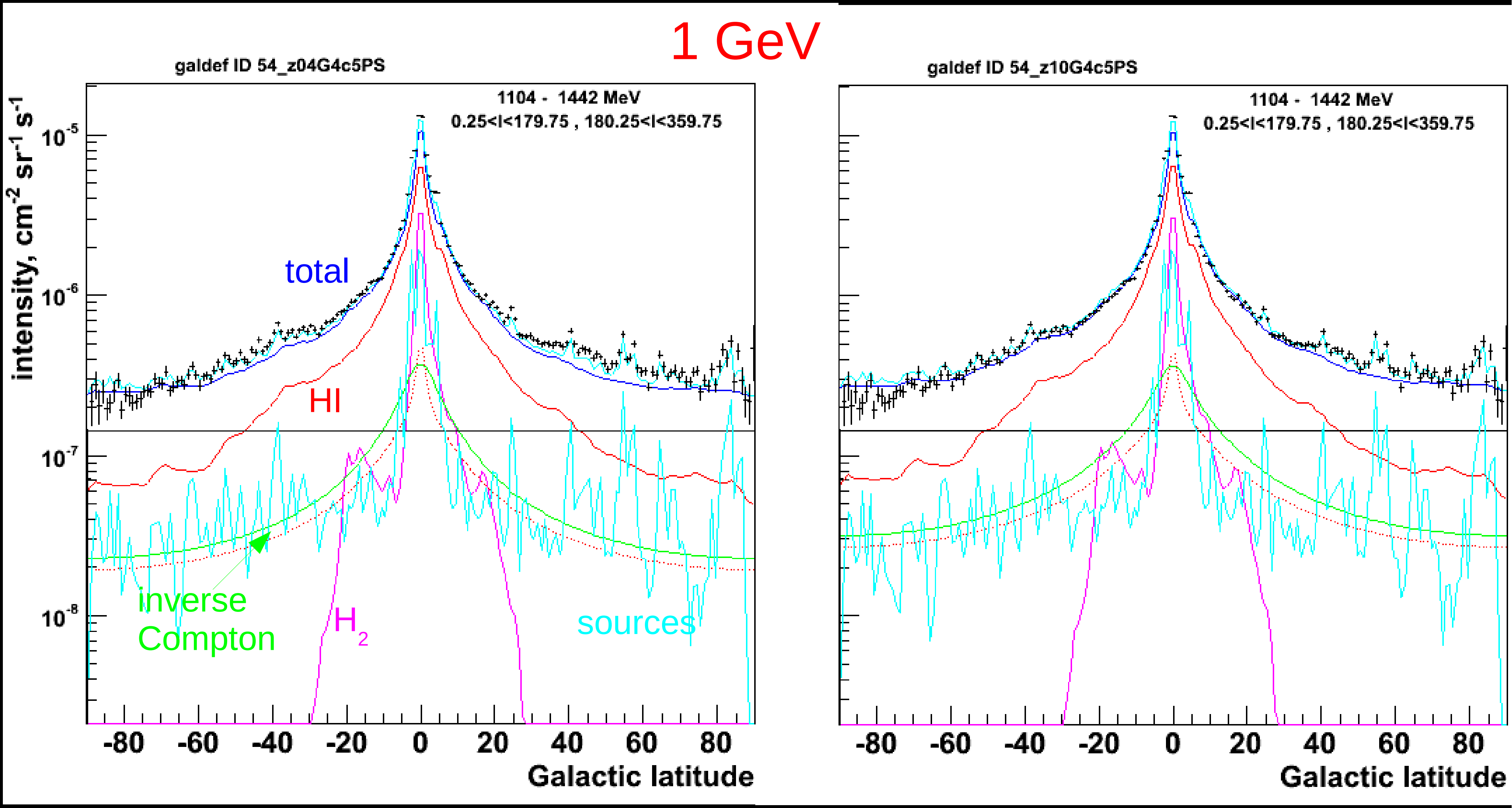


Agrees within 15% over 2 decades of dynamic range
The observed flux is the sum of many components:
importance of modelling them all !

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*

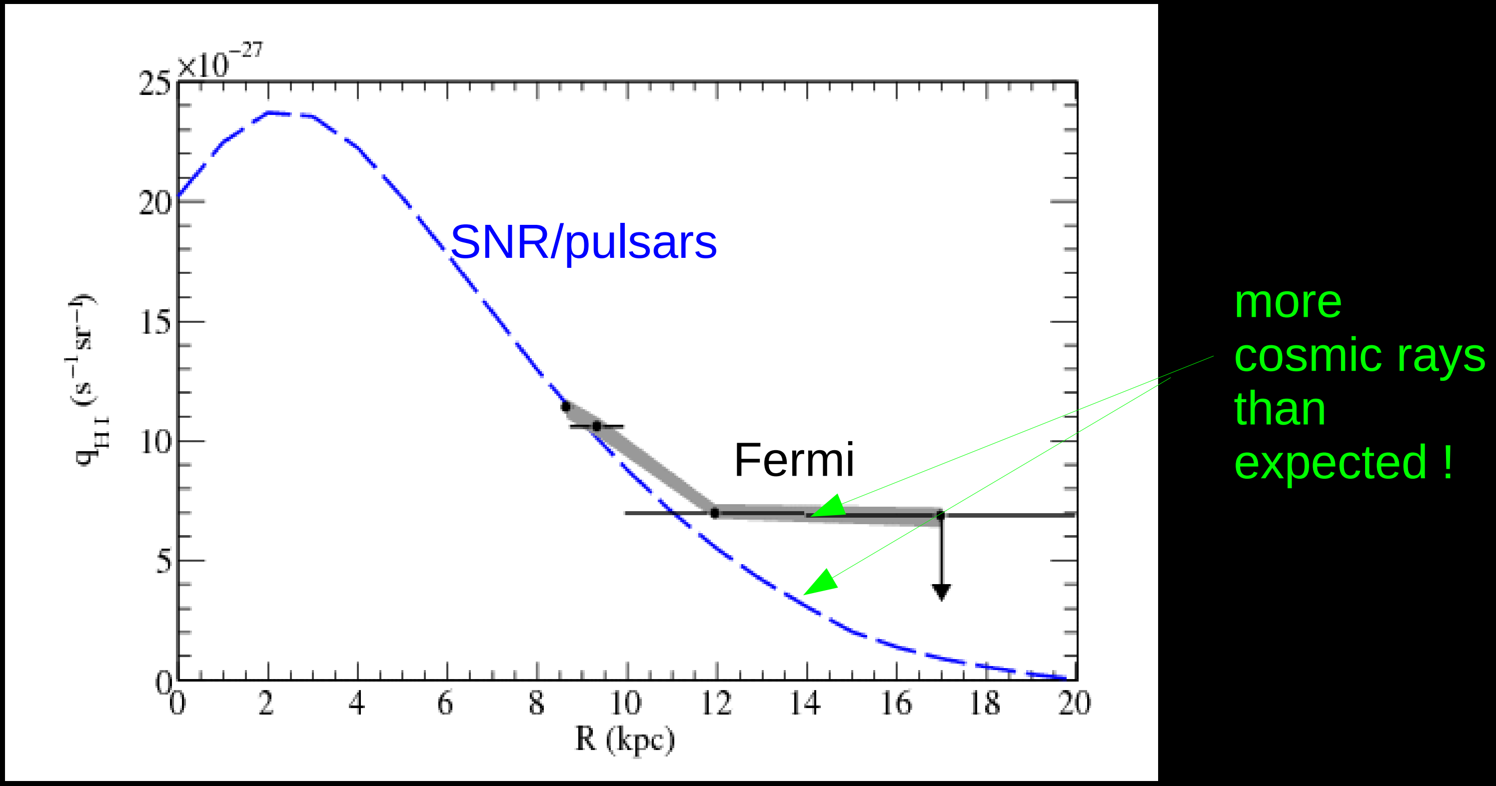
PRELIMINARY

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

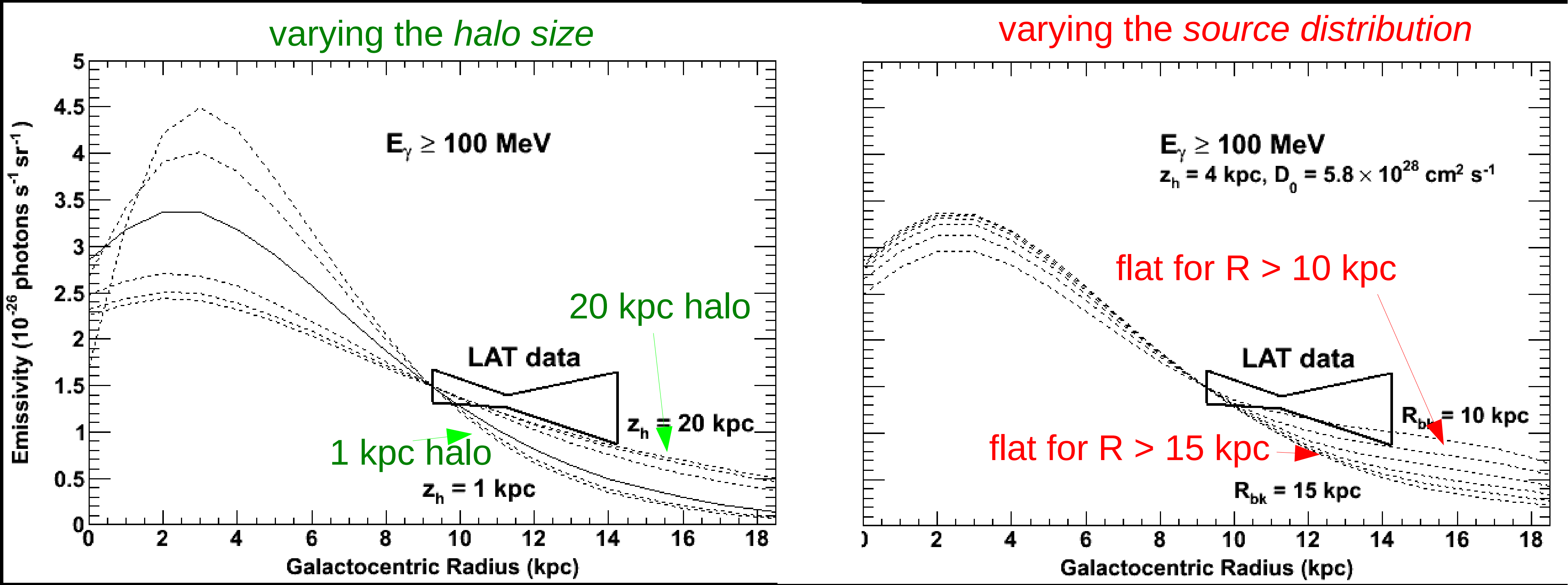
2^{nd} Galactic quadrant



Abdo etal (2010) ApJ 710, 133

Gamma-ray emissivity distribution in outer Galaxy

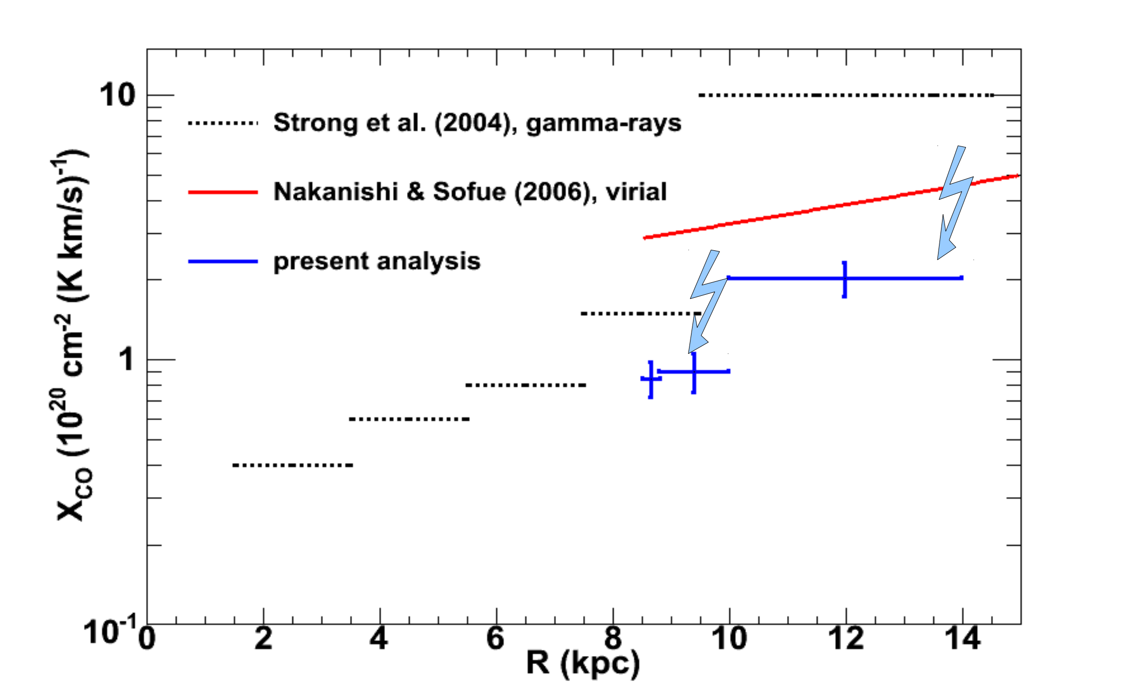
3^{rd} Galactic Quadrant



Abdo etal 2010, ApJ submitted

NEW: PRELIMINARY

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



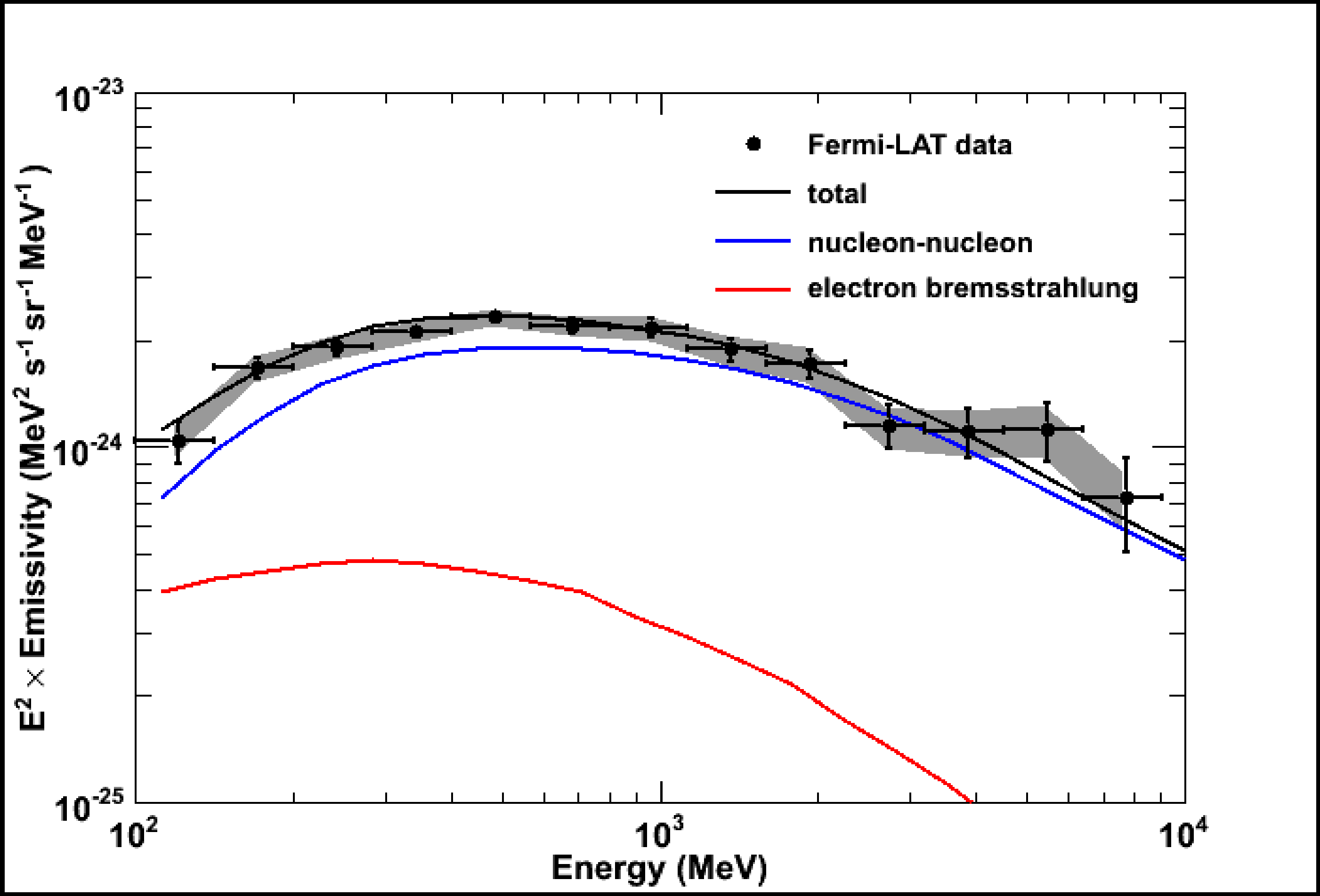
Scaling factor Xco from ^{12}CO to H_2

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 !

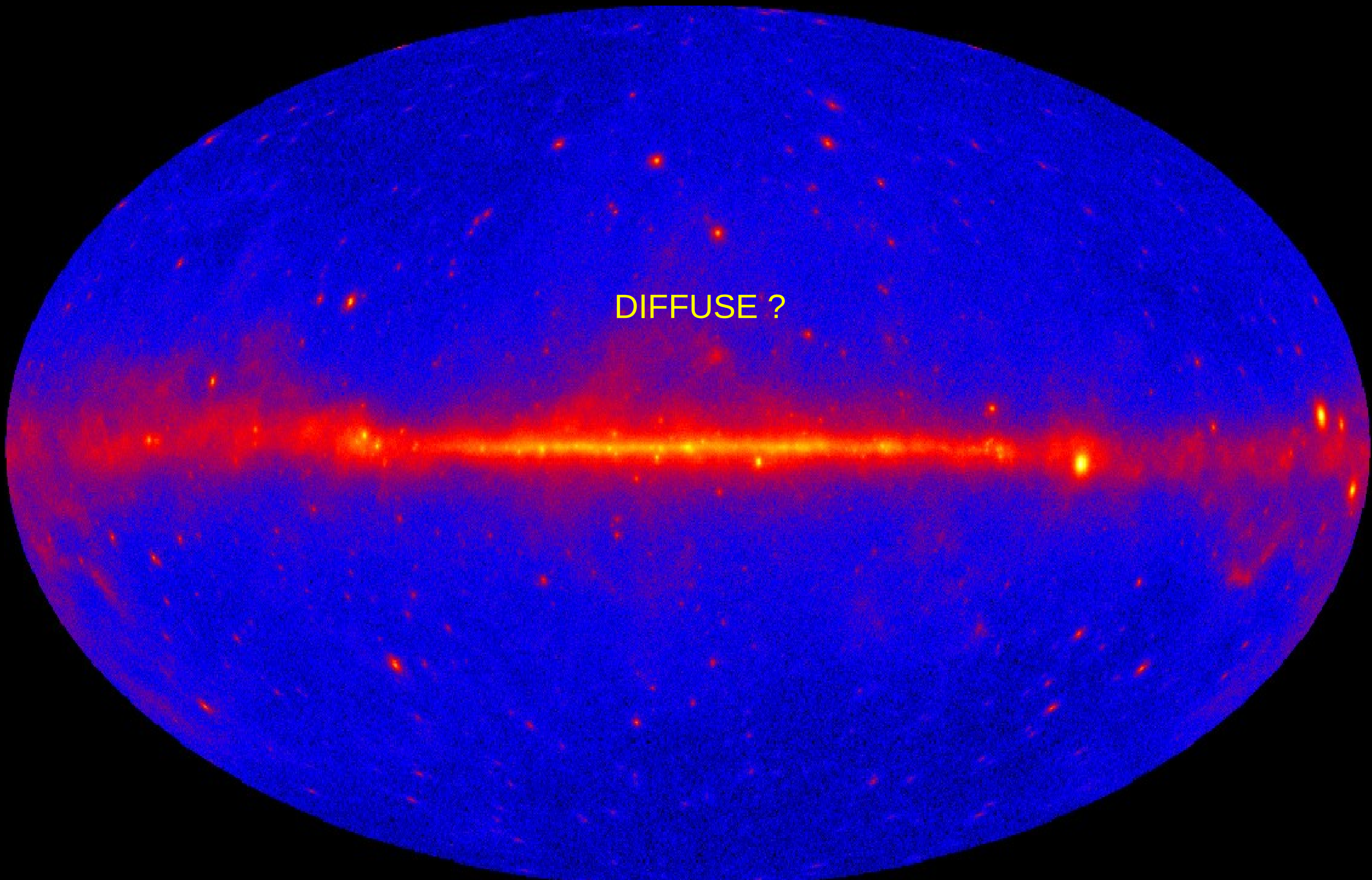
Abdo et al. ApJ 2009

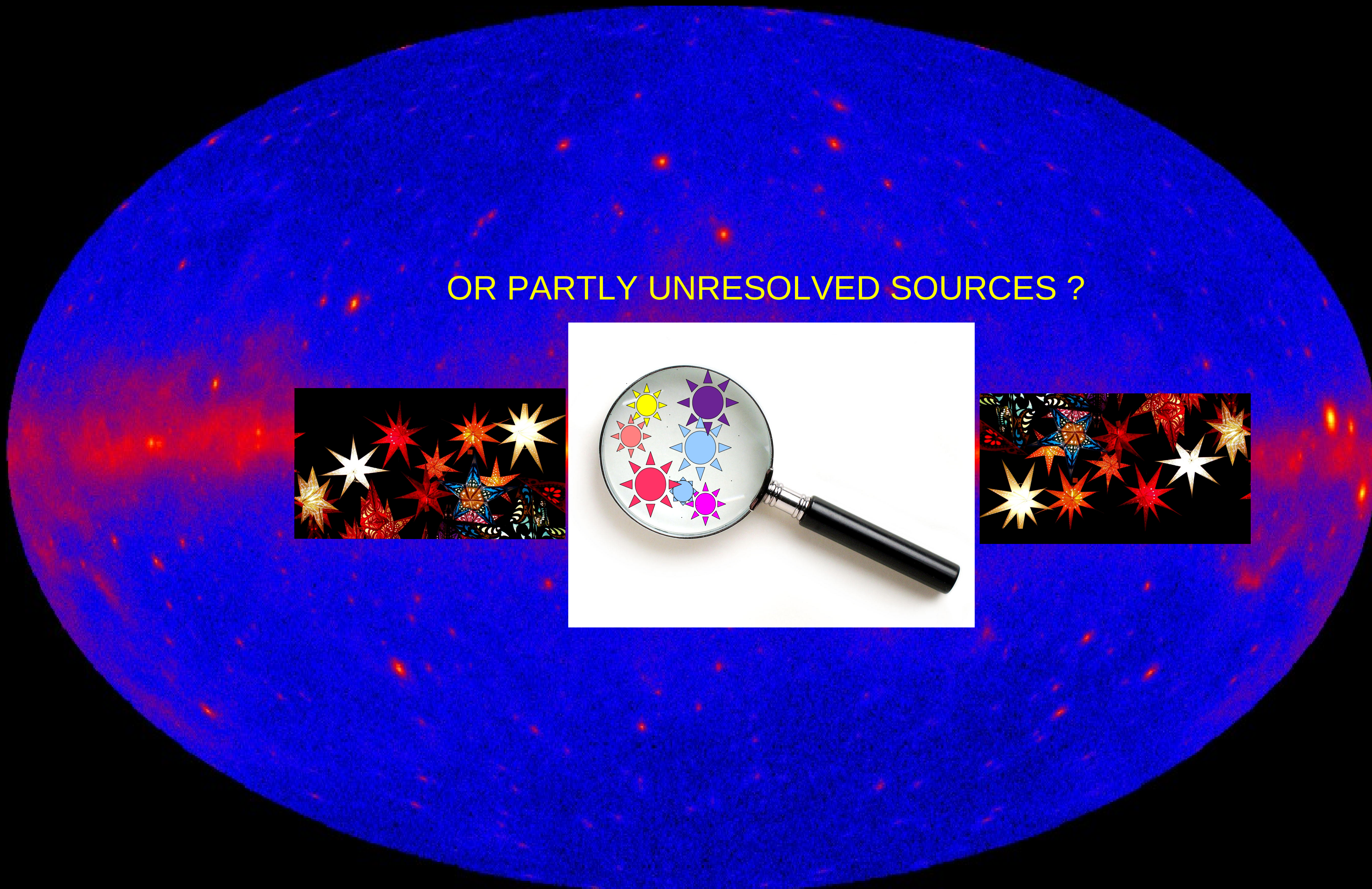
Facit

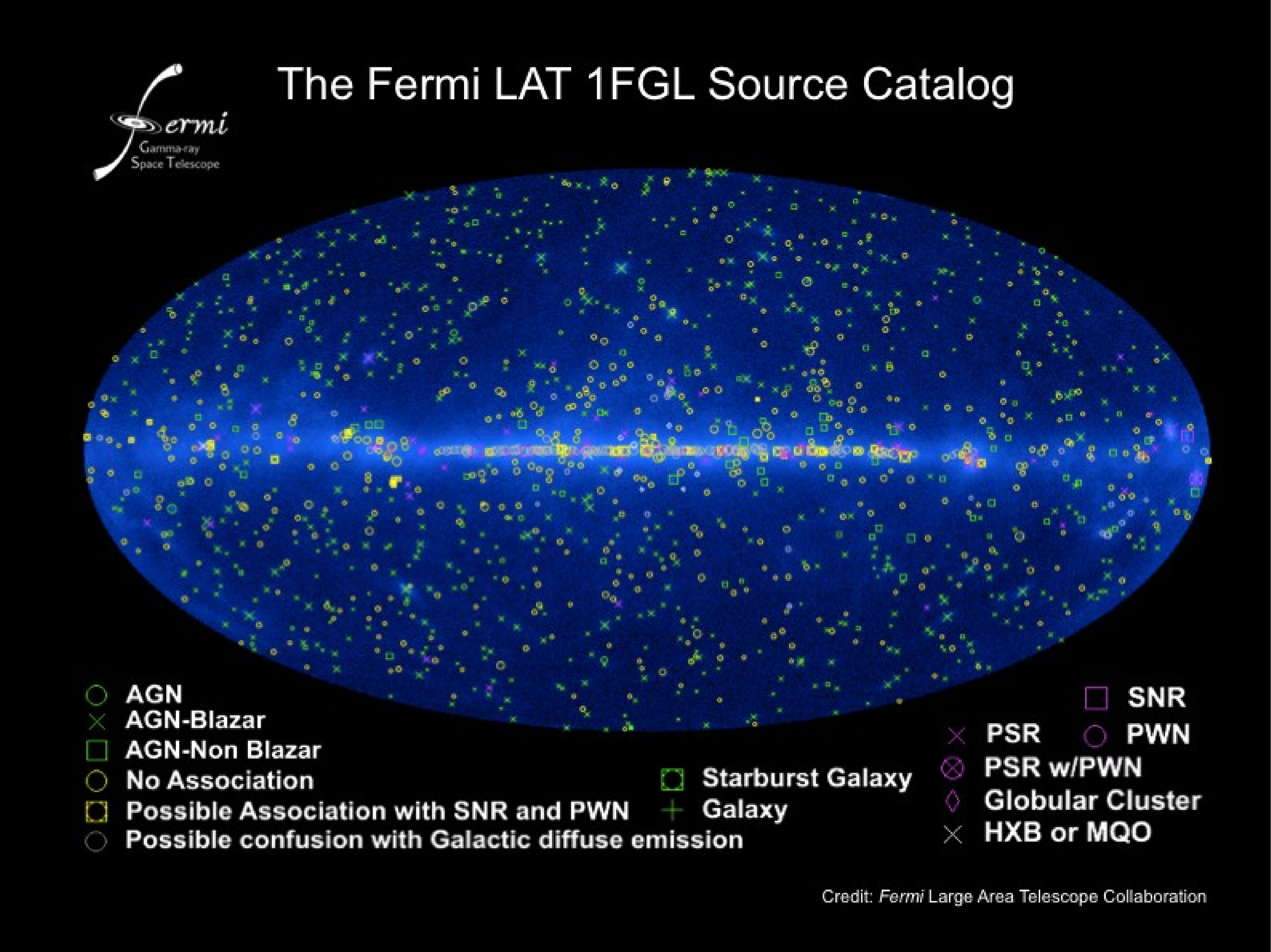
Large Scale Diffuse Gamma Ray Emission:

The diffuse emission model reproduces the Fermi data remarkably well.

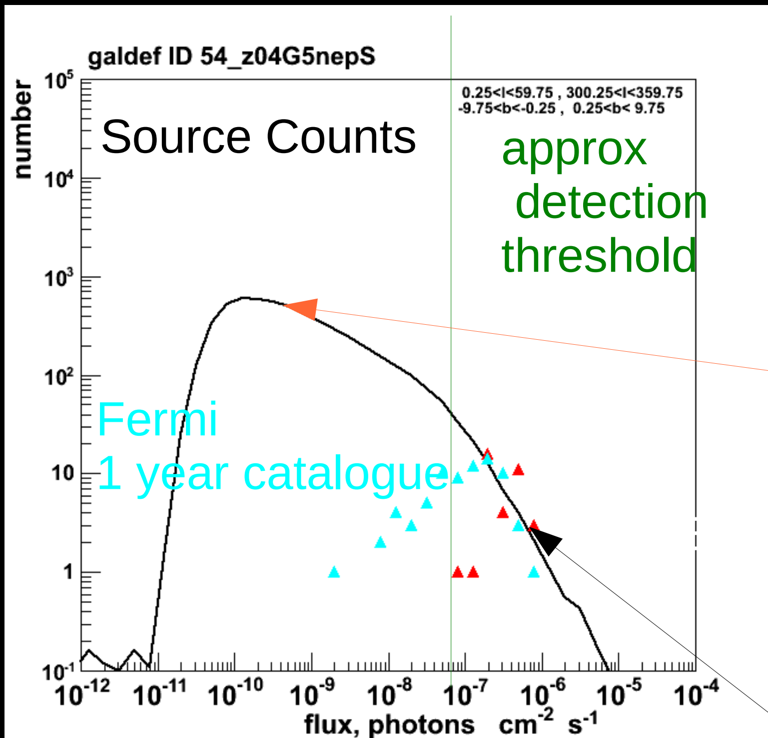
The remaining residuals have many possible origins: this is where the current action and interest is focussed.


DIFFUSE ?

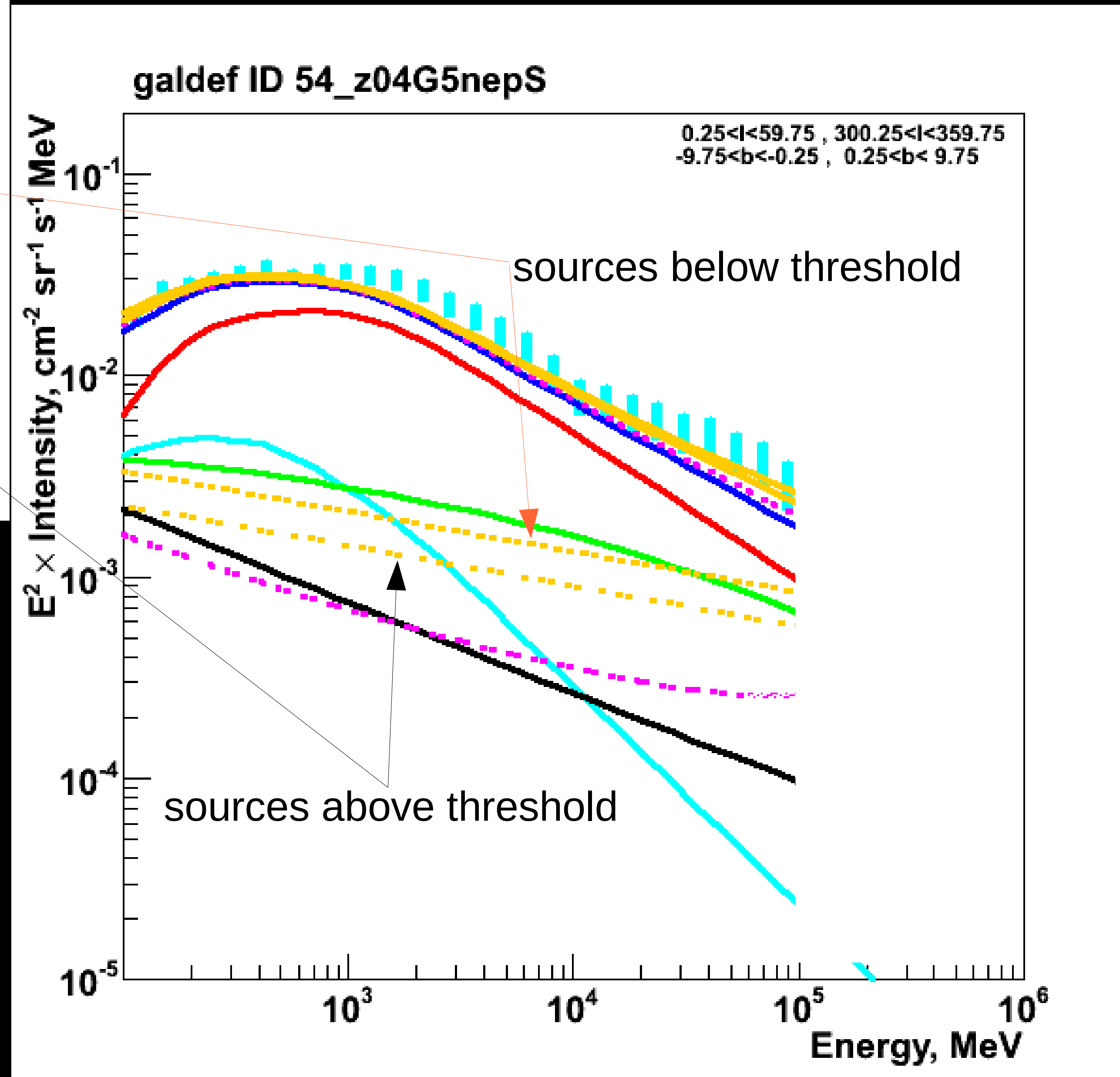

OR PARTLY UNRESOLVED SOURCES ?


The Fermi LAT 1FGL Source Catalog
Fermi
Gamma-ray Space Telescope
AGN
AGN-Blazar
AGN-Non Blazar
No Association
Possible Association with SNR and PWN
Possible confusion with Galactic diffuse emission
Starburst Galaxy
Galaxy
SNR
PSR
PWN
PSR w/PWN
Globular Cluster
HXB or MQO
Credit: Fermi Large Area Telescope Collaboration

Source contribution from luminous (pulsars etc) sources



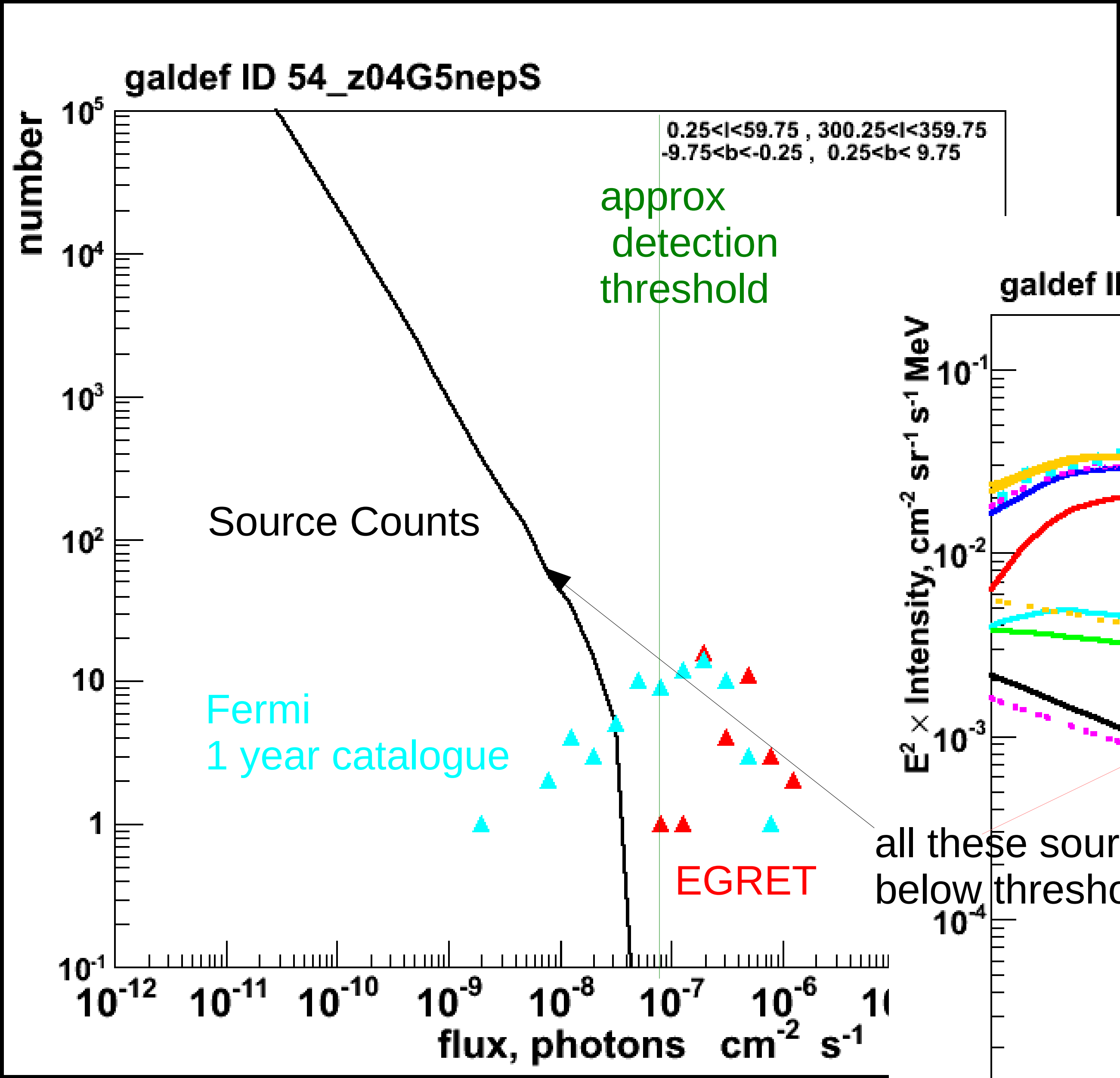
Due to Fermi sensitivity,
unresolved source flux will finally be at percent level



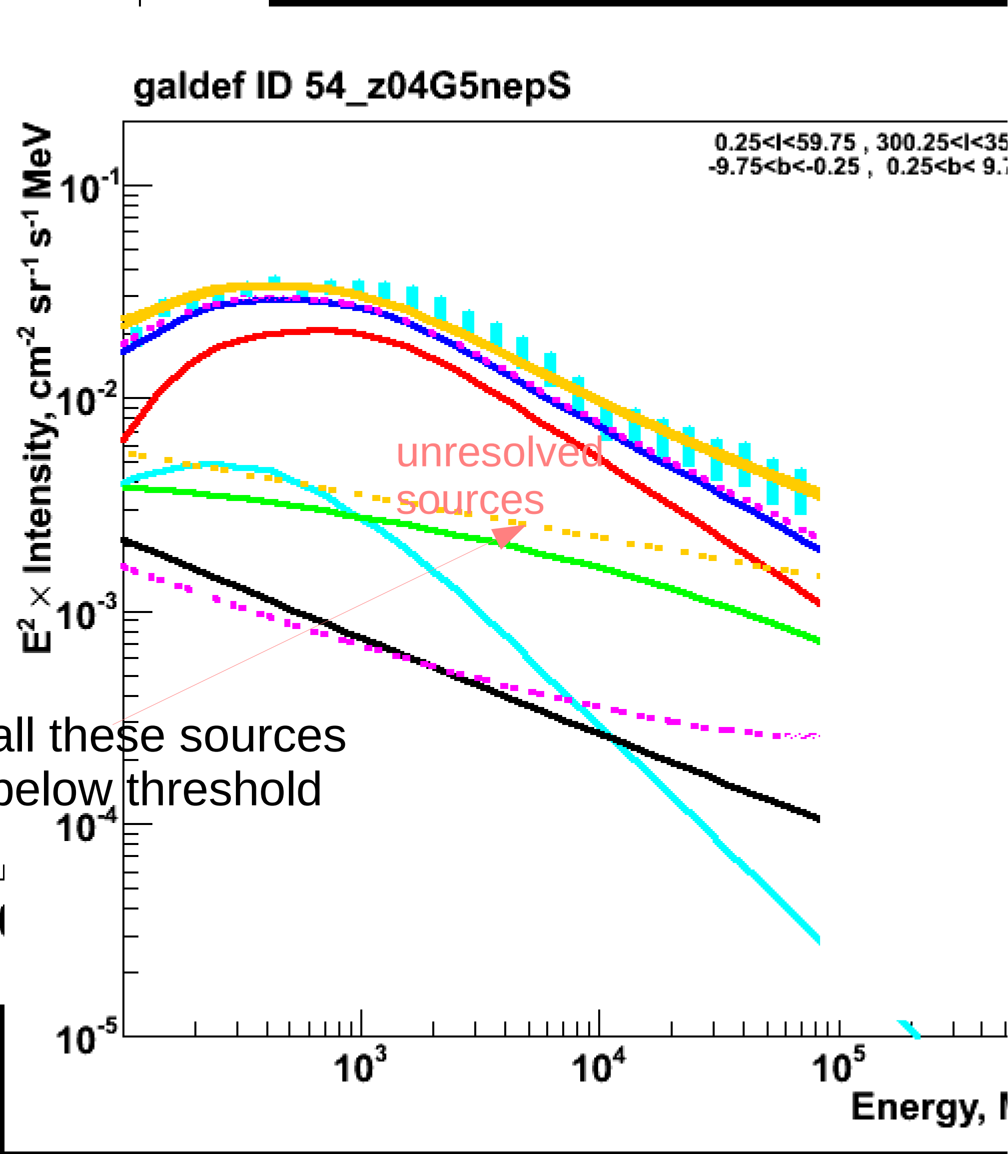
population synthesis
model consistent with
Fermi year 1 Catalogue

A .Strong, 2009 Fermi Symposium

Source contribution from possible low-luminosity sources

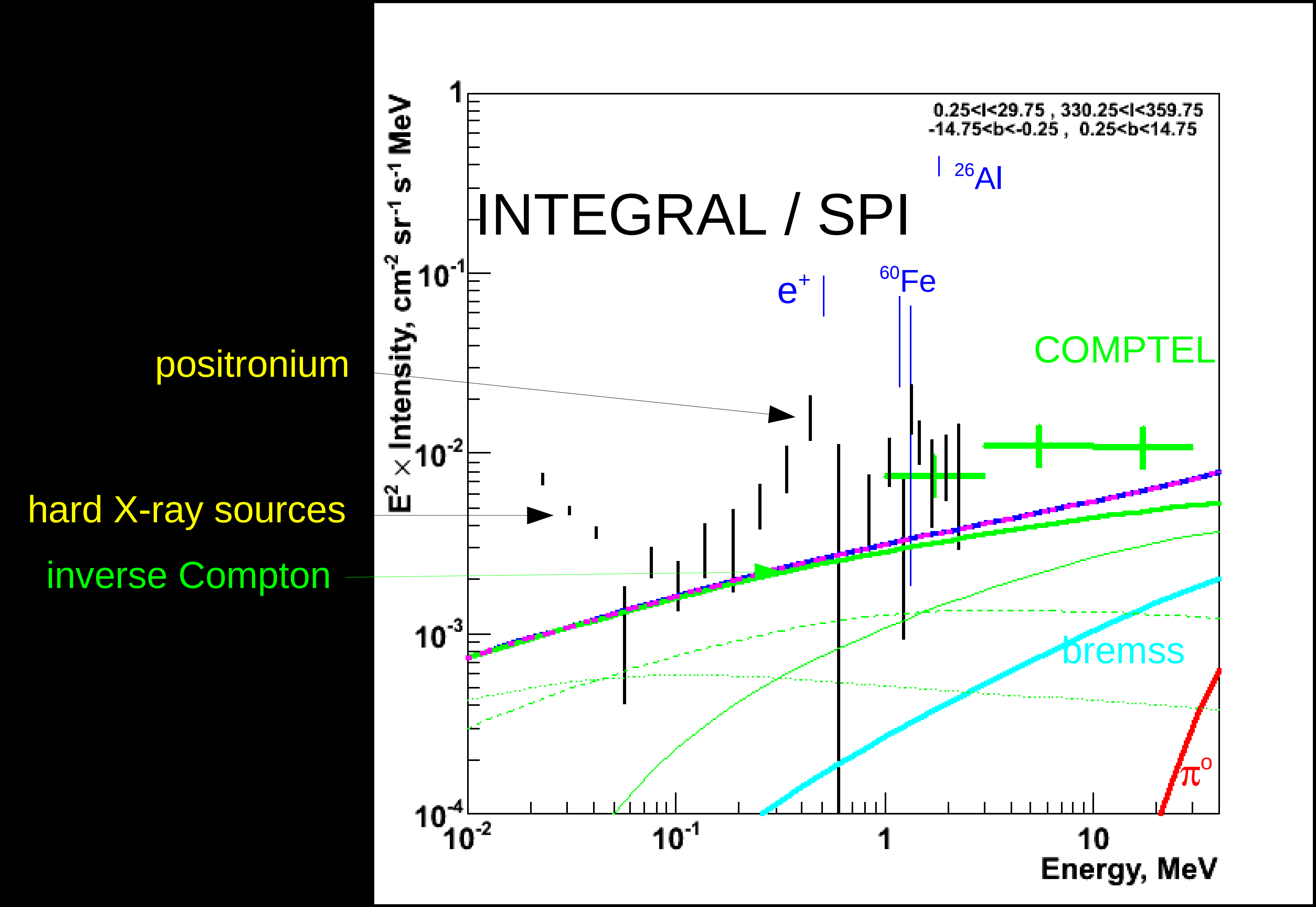


Many more dim sources can hide.
Just limits can be set on
their contribution.



A. Strong, 2009 Fermi Symposium

INTEGRAL / SPI
spectrum of inner Galaxy



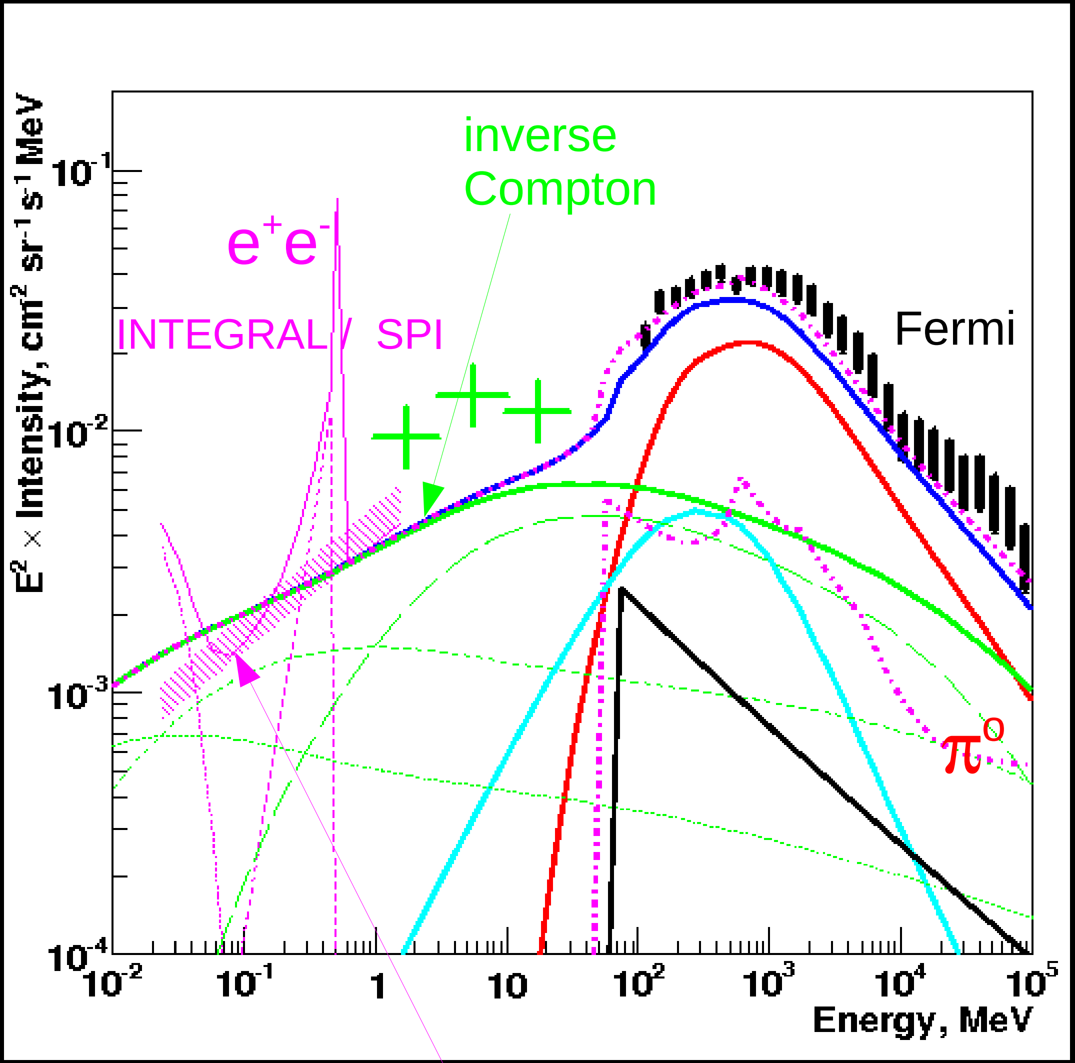
NEW

Bouchet etal 2010, in preparation
this conference: E18 Poster #65

Gamma-rays, inner Galaxy

inverse Compton
from primary electrons, secondary electrons + positrons

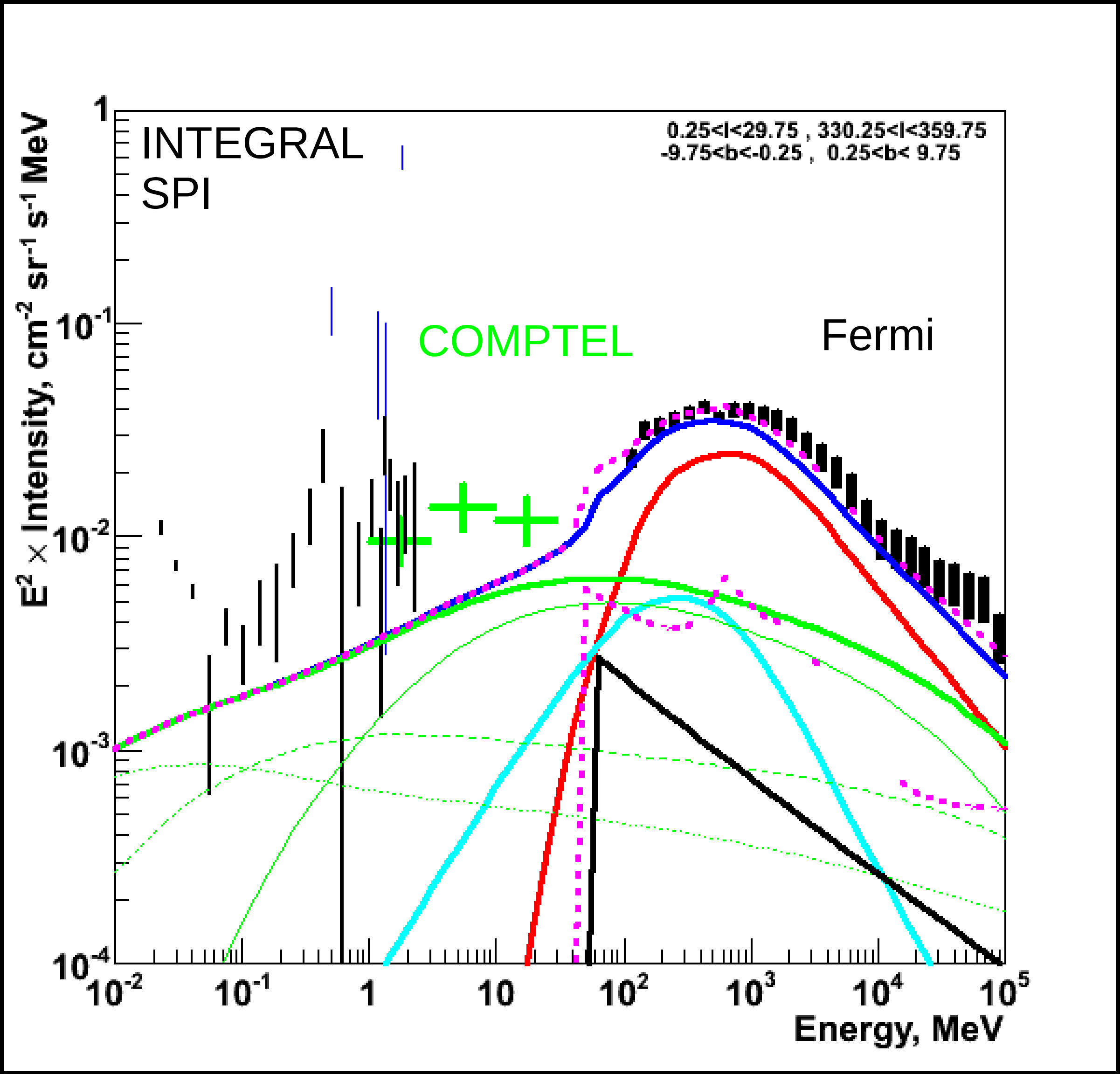
These processes are very relevant down to hard X-rays !



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

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

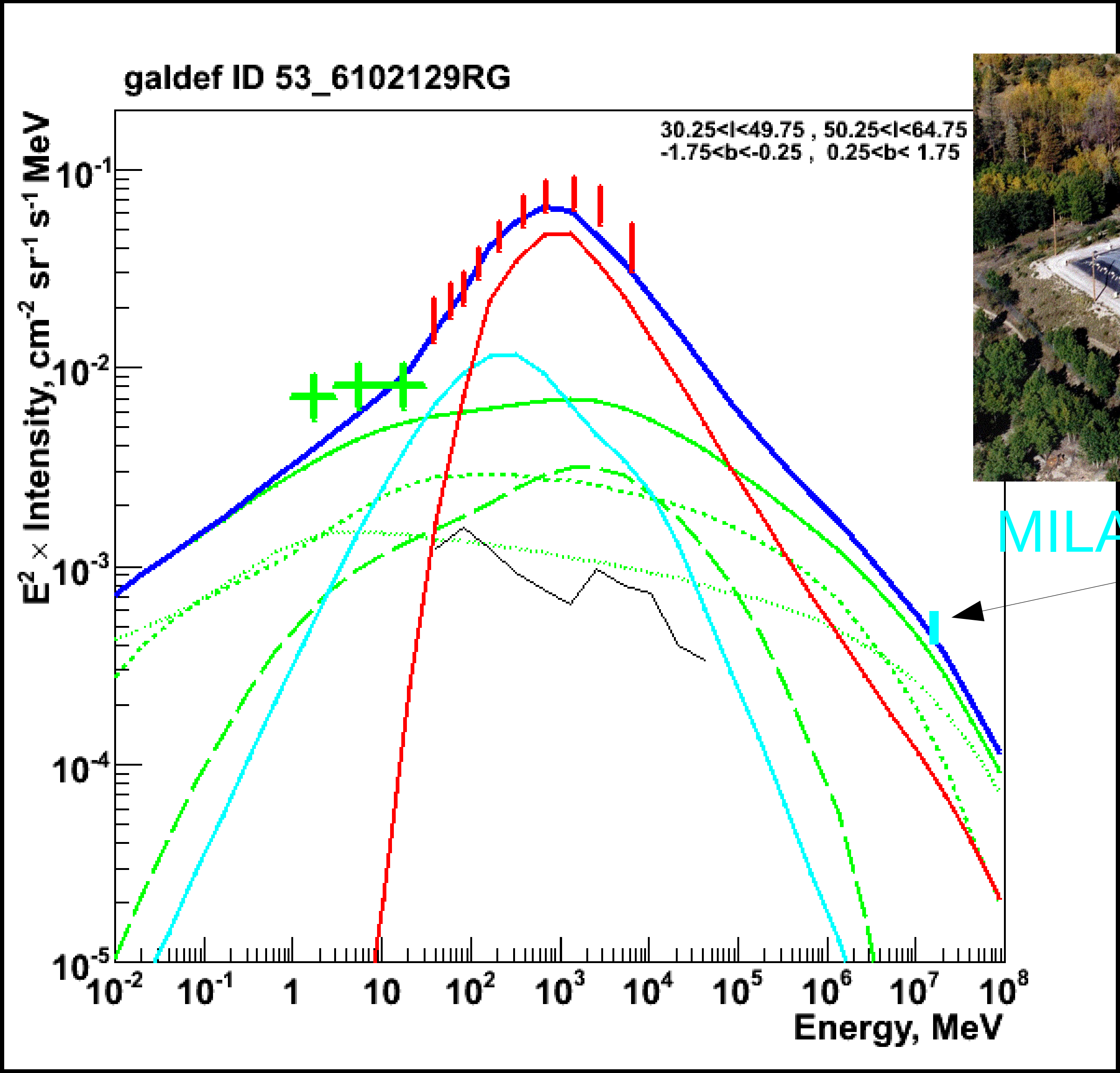
a glimpse of things to come....



PRELIMINARY

and towards the highest energies...

Diffuse Galactic Emission



MILAGRO : 15 TeV

Abdo etal,(2008) ApJ 688

This model was adapted to EGRET GeV-excess, gave a good fit to MILAGRO but now with Fermi situation will change !

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

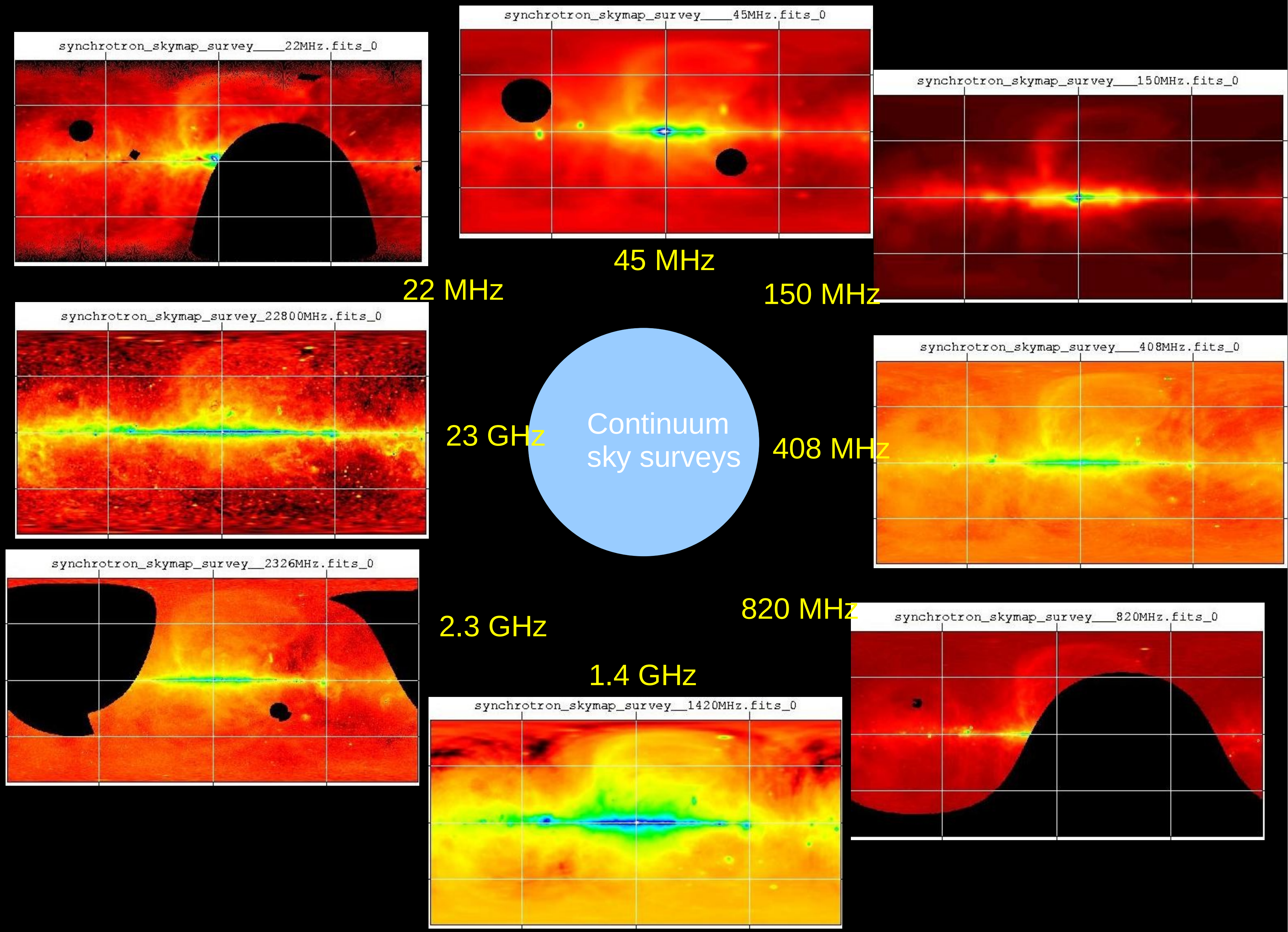
because ...

We know much more about our Galaxy than external galaxies:

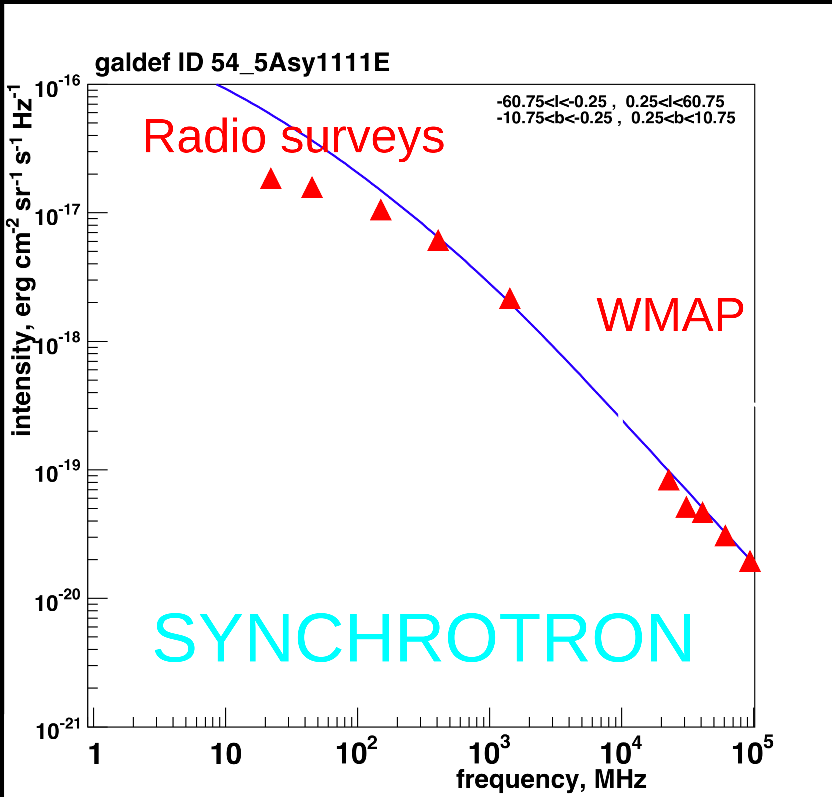
* cosmic rays *directly* measured
* gamma rays mapped in detail
* synchrotron mapped in detail
* magnetic fields measured

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

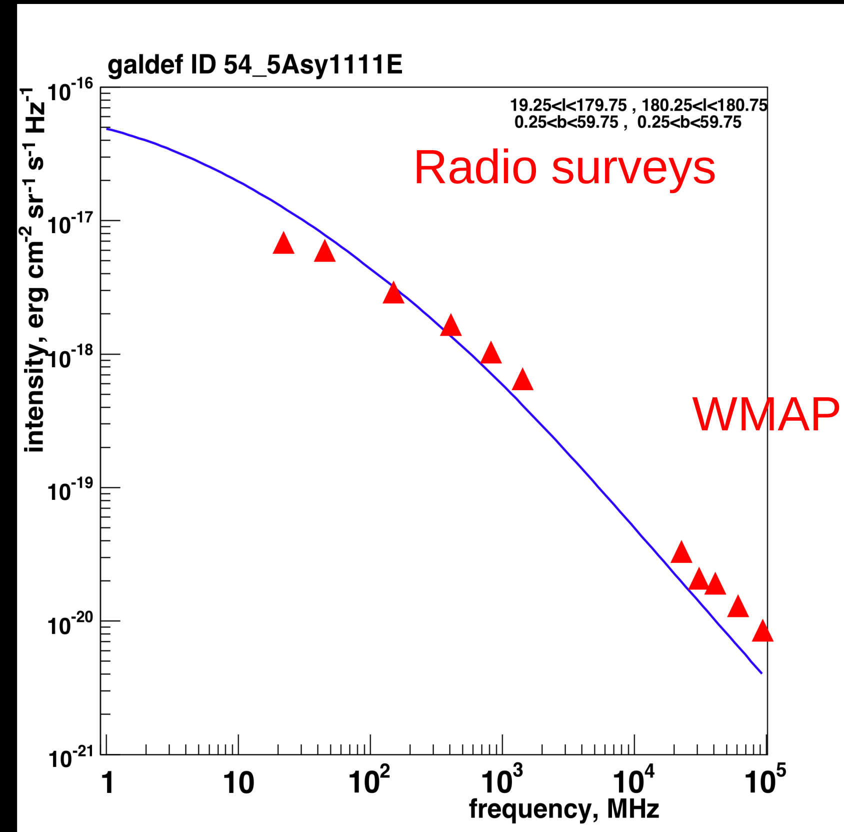
including e.g. cosmic-ray CALORIMETRY

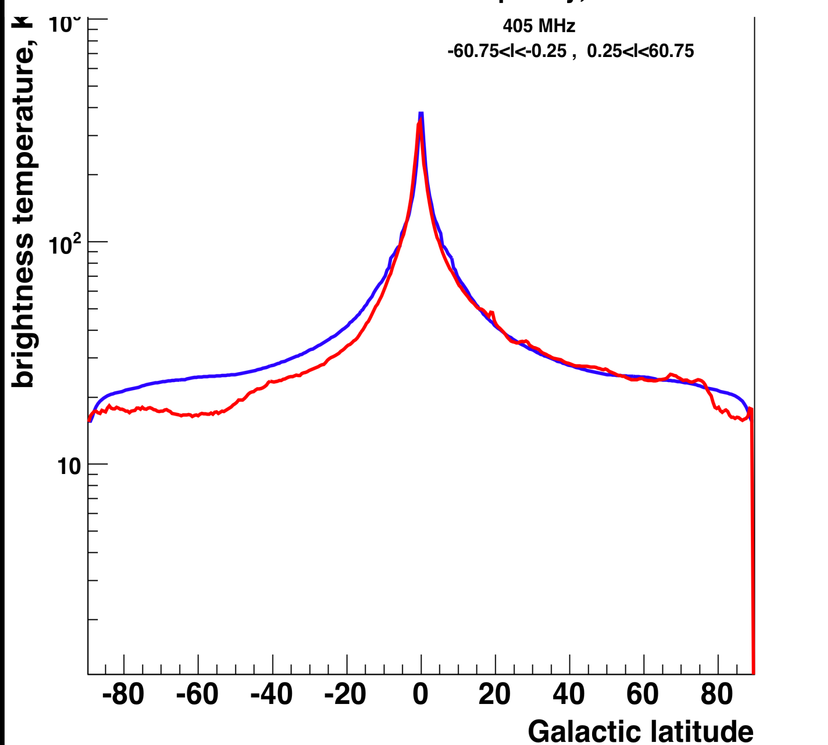


synchrotron_skymap_survey____22MHz.fits_0
22 MHz
synchrotron_skymap_survey____45MHz.fits_0
45 MHz
synchrotron_skymap_survey___150MHz.fits_0
150 MHz
synchrotron_skymap_survey_22800MHz.fits_0
23 GHz
Continuum
sky surveys
408 MHz
synchrotron_skymap_survey___408MHz.fits_0
synchrotron_skymap_survey__2326MHz.fits_0
2.3 GHz
820 MHz
synchrotron_skymap_survey___820MHz.fits_0
1.4 GHz
synchrotron_skymap_survey__1420MHz.fits_0

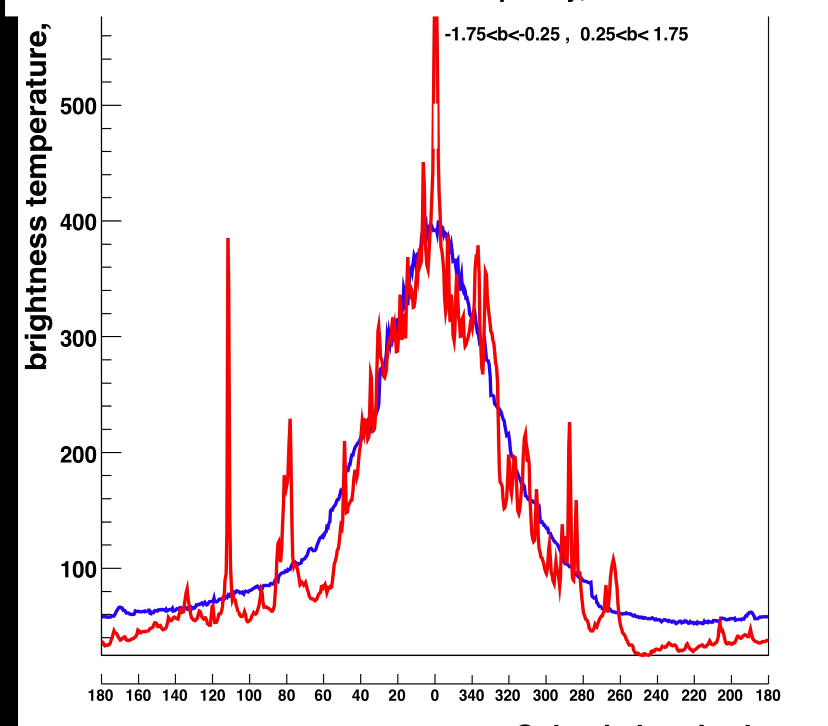


GALPROP model

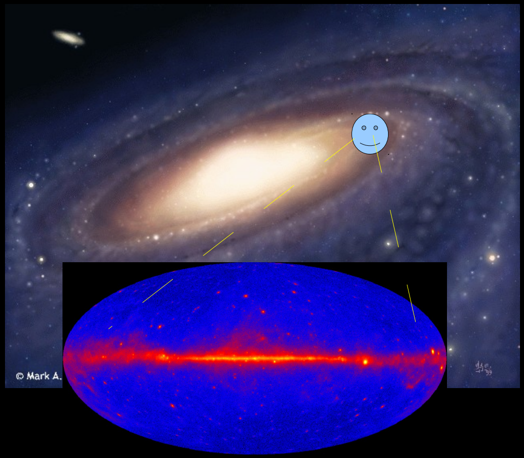




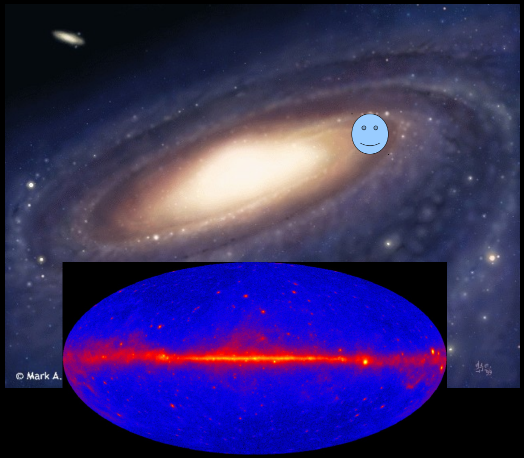
408 MHz



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

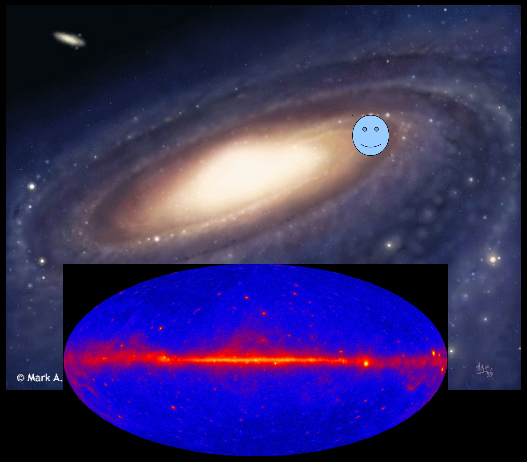


how does it look from out here ?

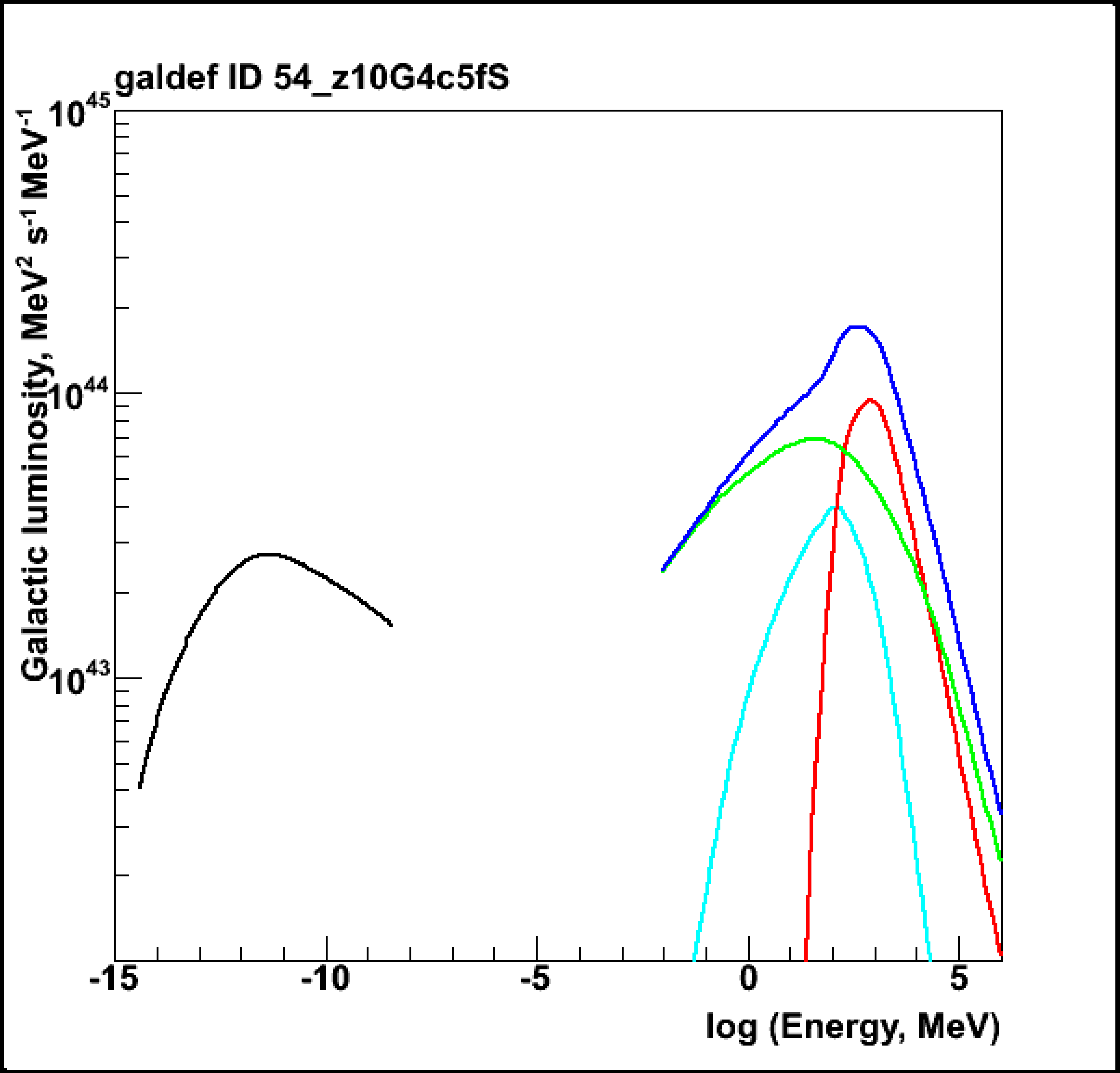


Model-dependent.

Need 3D models.



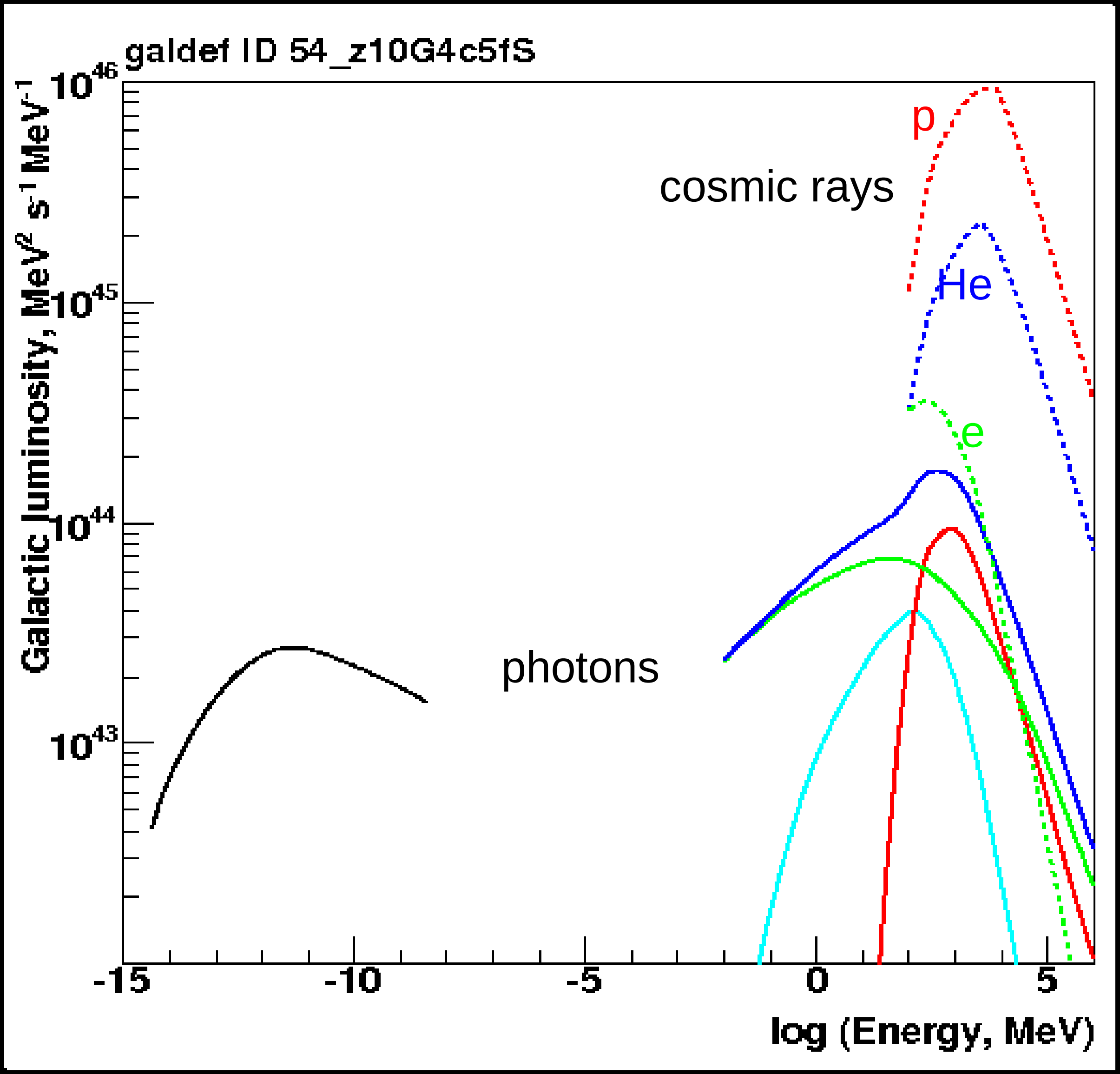
Galaxy luminosity over 20 decades of energy



radio CMB IR optical X γ

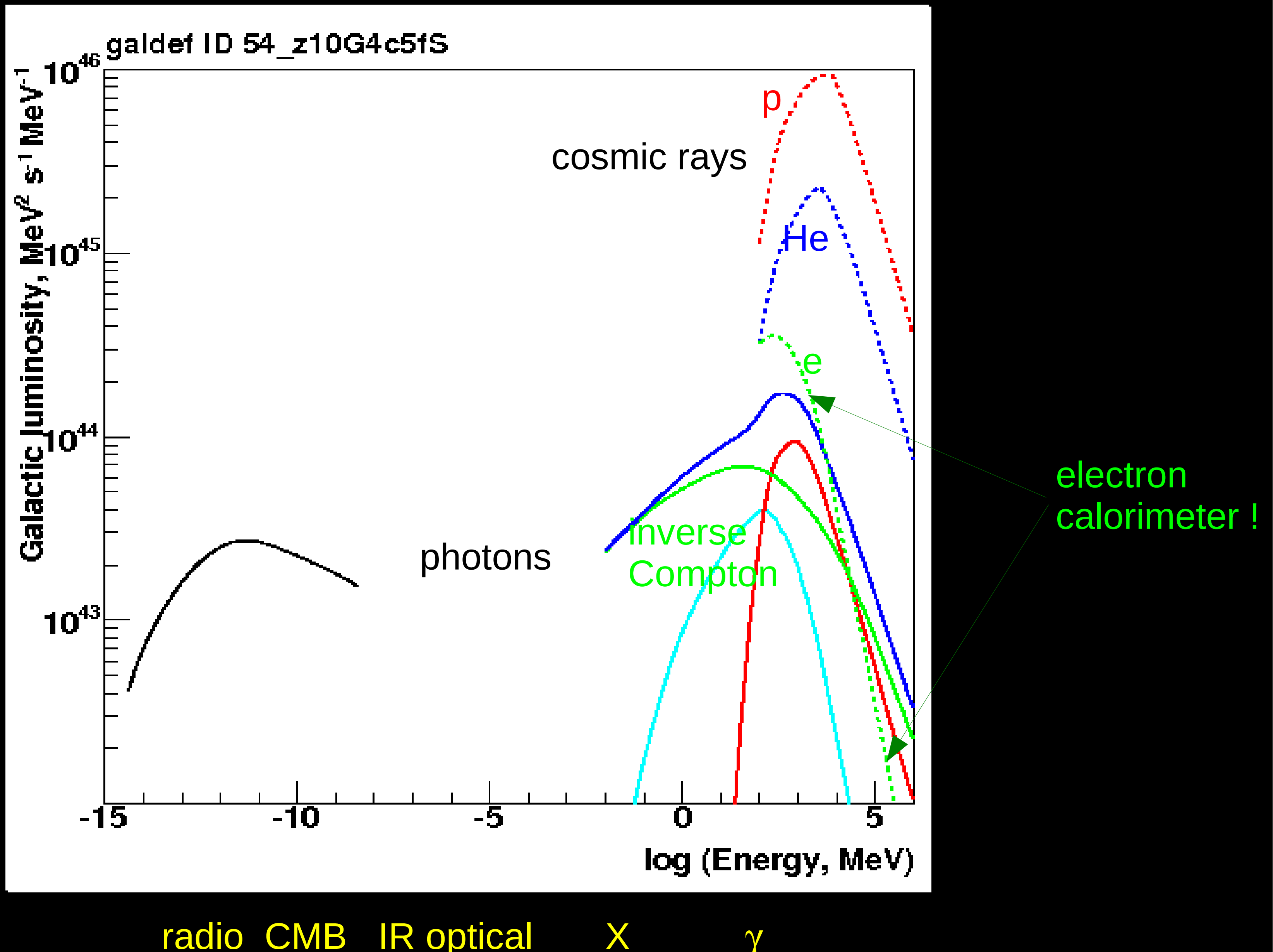
Strong etal, 2010 ApJL 722, L58

Galaxy luminosity over 20 decades of energy

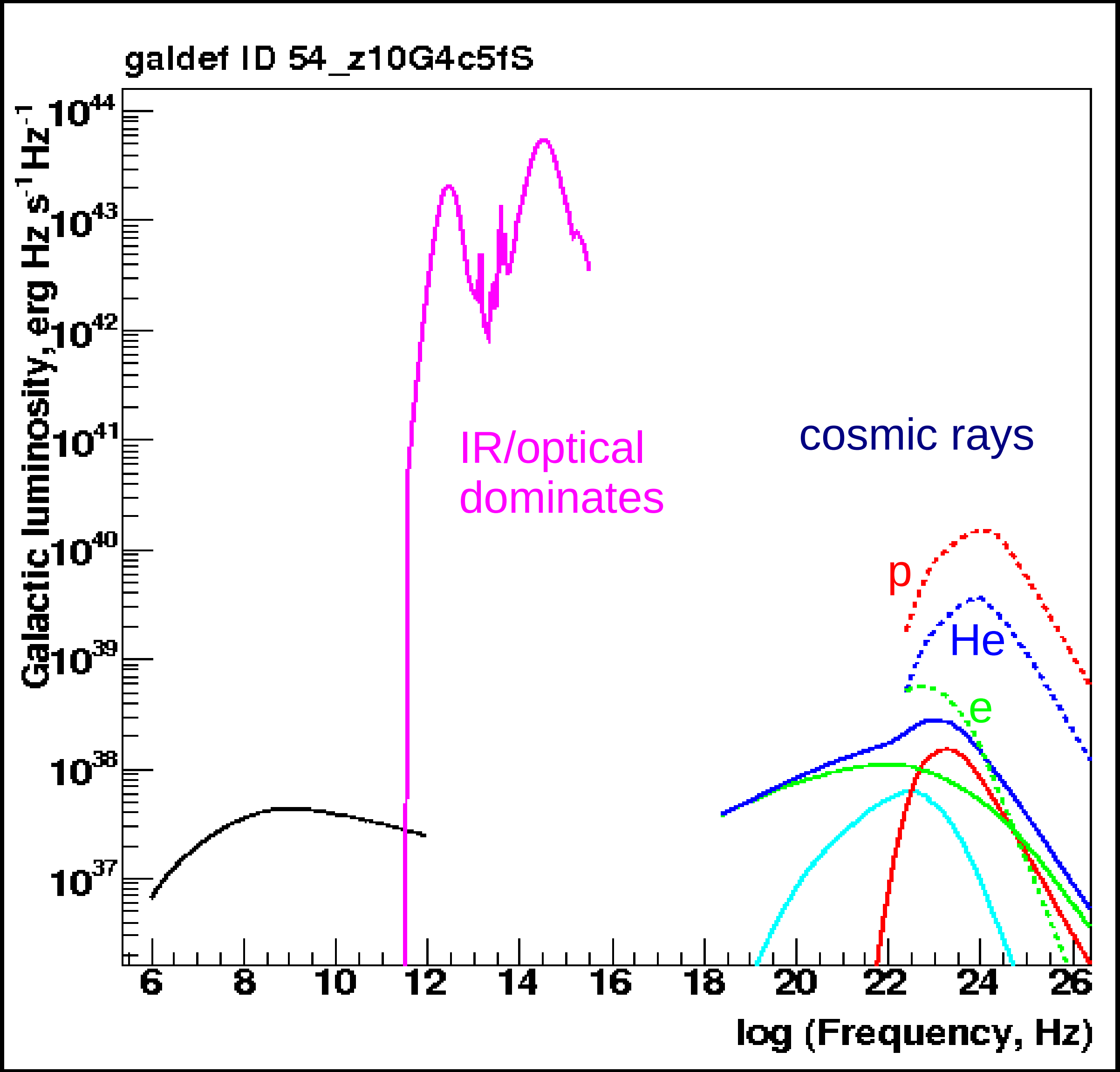


radio CMB IR optical X γ

Galaxy luminosity over 20 decades of energy



Galaxy luminosity over 20 decades of energy



radio CMB IR optical X γ

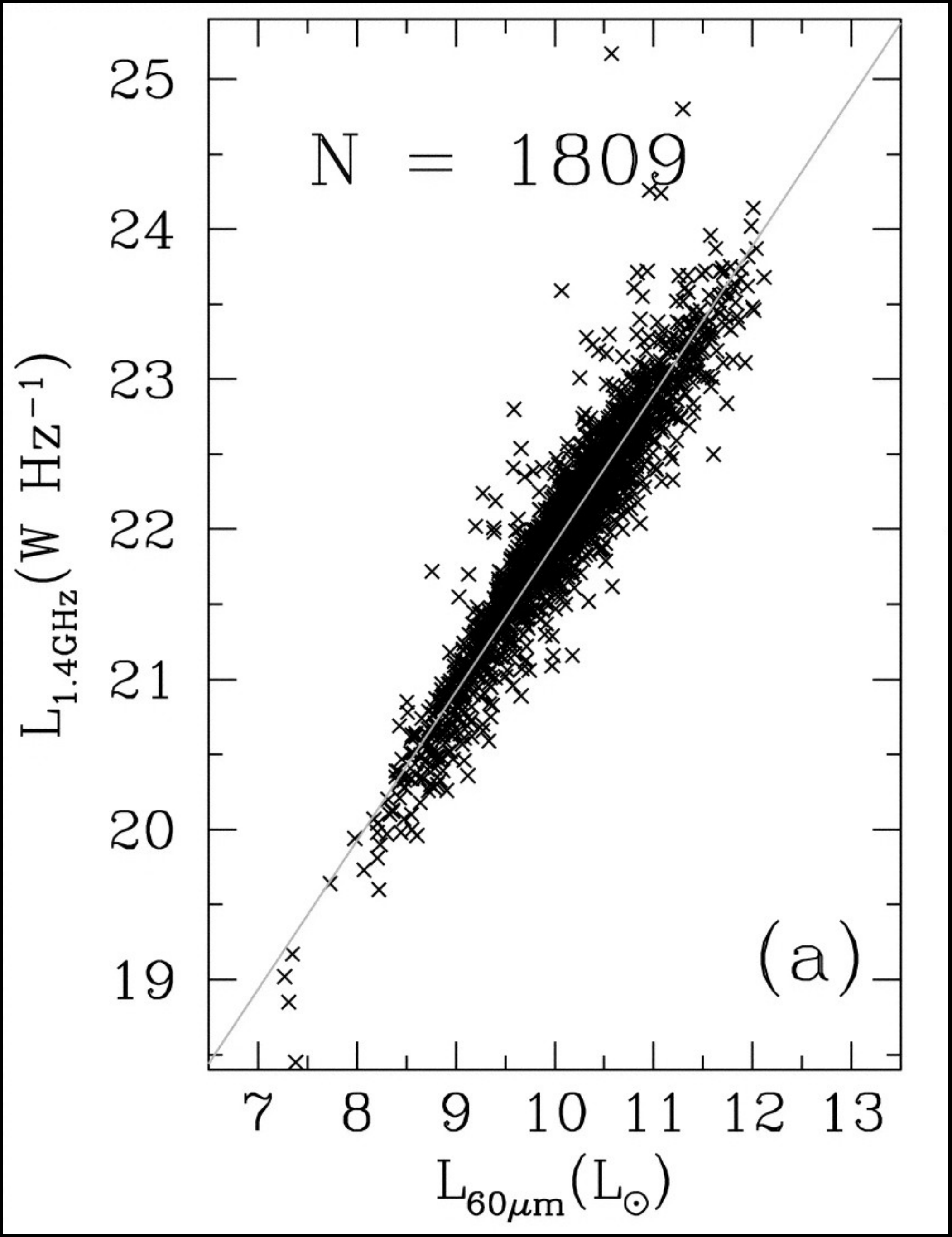
Galaxy luminosities

based on GALPROP model
Fermi gamma rays and electrons

Cosmic-ray nuclei	10^{41}	
Cosmic-ray electrons	$1.6\ 10^{39}$	erg s^{-1}
Gamma rays > 100 MeV	$1.2\ 10^{39}$	
π^o-decay	$7\ 10^{38}$	
bremsstrahlung	$1\ 10^{38}$	
inverse Compton	$4\ \ 10^{38}$	< 100 MeV: $8\ 10^{38}$
Synchrotron	$4\ 10^{38}$	
Optical + IR	10^{44}	

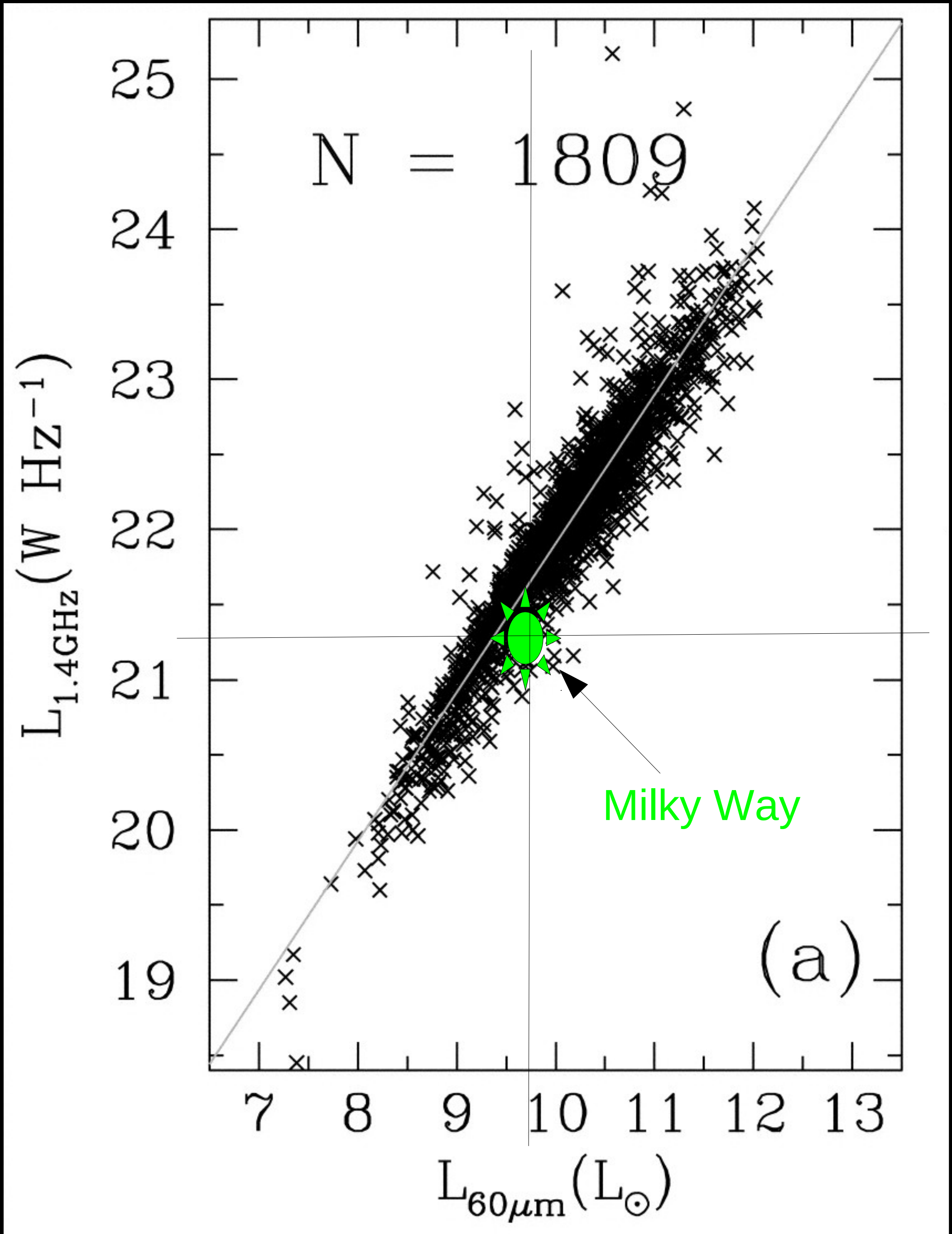
1% of nuclei energy converts to gamma rays
75% of electron energy converts to inverse Compton gamma rays
25% of electron energy converts to synchrotron radiation
Galaxy is electron calorimeter ! - but only if inverse Compton is included, not just synchrotron

FIR/radio correlation IRAS Galaxies



Yun etal 2001 ApJ 554, 803

FIR/radio correlation IRAS Galaxies



Outlook

Fermi operational, 2 years so far.
Diffuse emission results appearing.
The fine data challenges the models.

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