Overview of Diffuse Emission results from the first 6 months of the Fermi LAT mission

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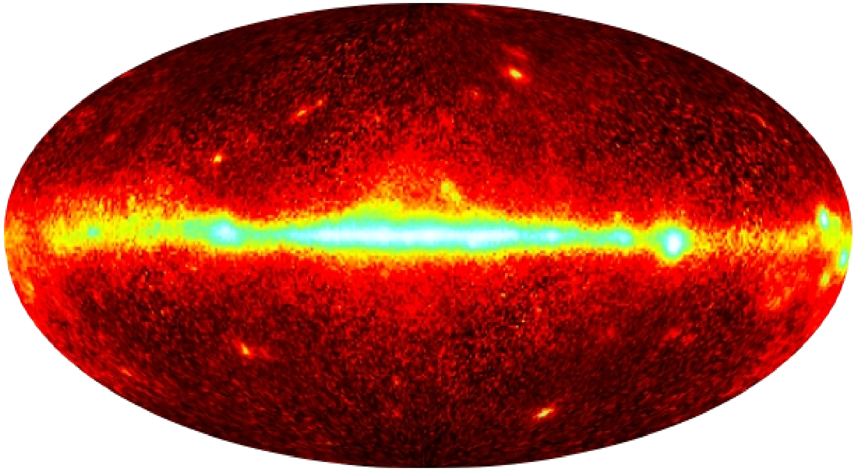
On behalf of the LAT instrument team

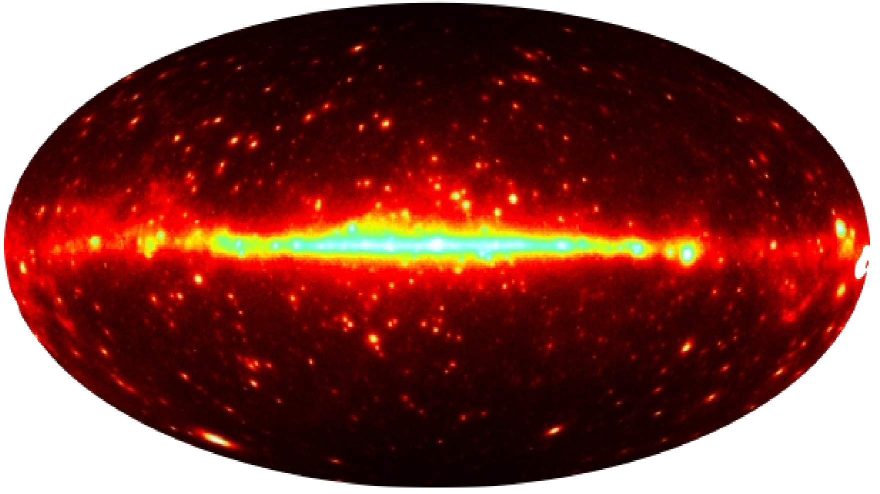
LAT Scientific Program

- Active galactic nuclei
- Gamma ray bursts
- Supernova remnants
- Pulsars
- Solar system objects
- Unidentified sources/new populations
- Galaxies, clusters of galaxies, X-ray binaries
- Study of diffuse gamma-ray emission
- Cosmic-ray acceleration & propagation
- Study of Extra-galactic background light (EBL)
- Search for Particle Dark matter/ tests of new physics

Gamma-ray sky from 5 years of EGRET



1 year simulation of Fermi LAT



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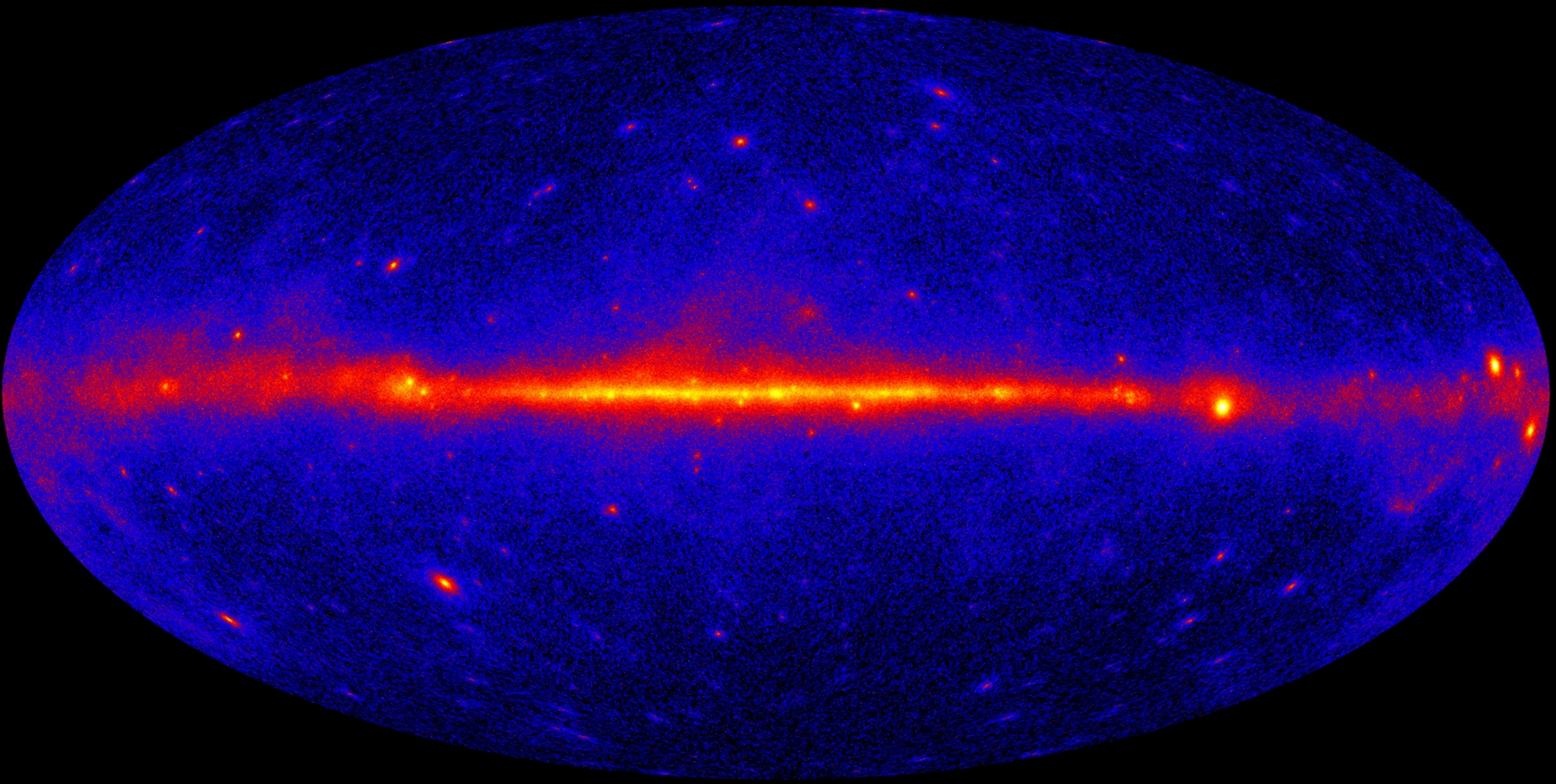
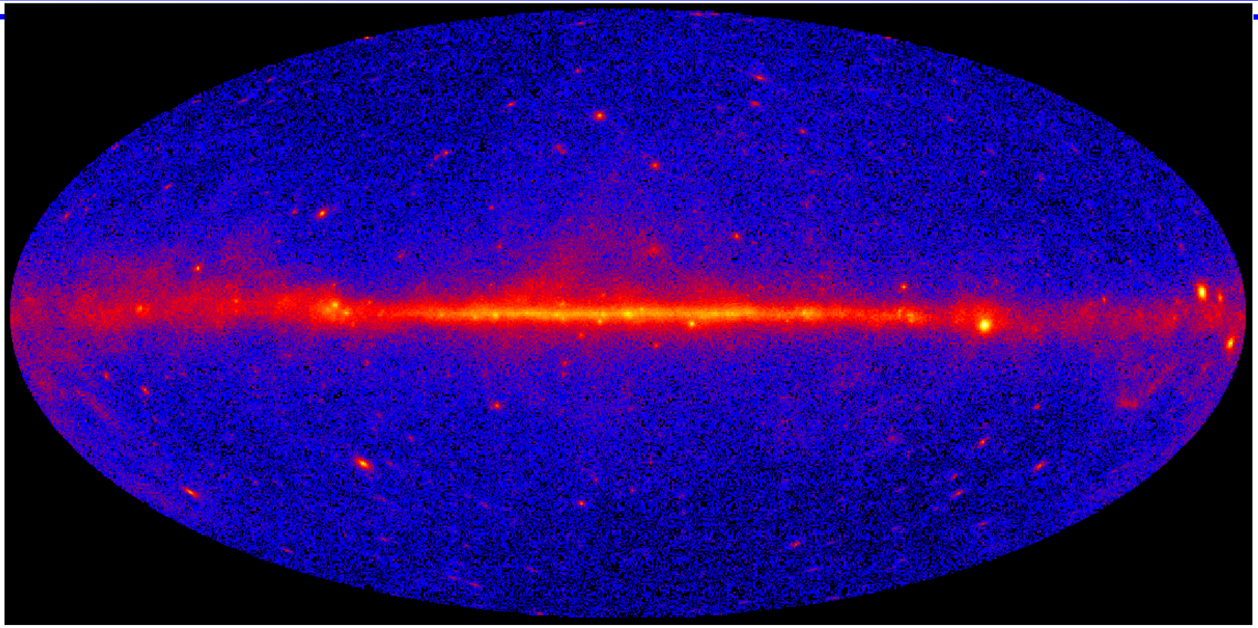
3-Month All-Sky Rate Map



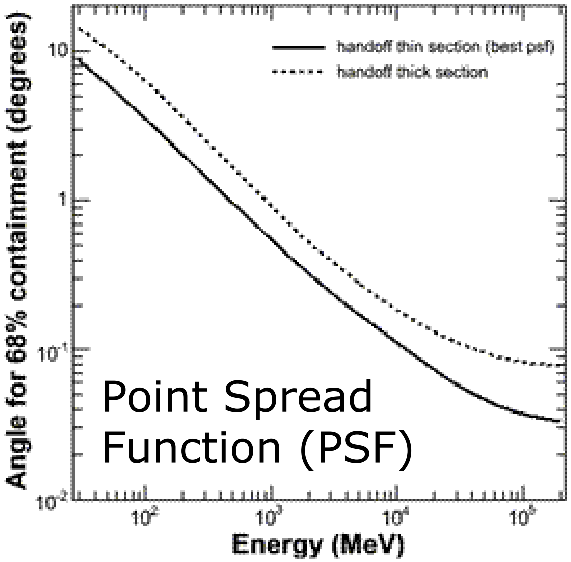
Diffuse emission ~80% total γ-ray flux!

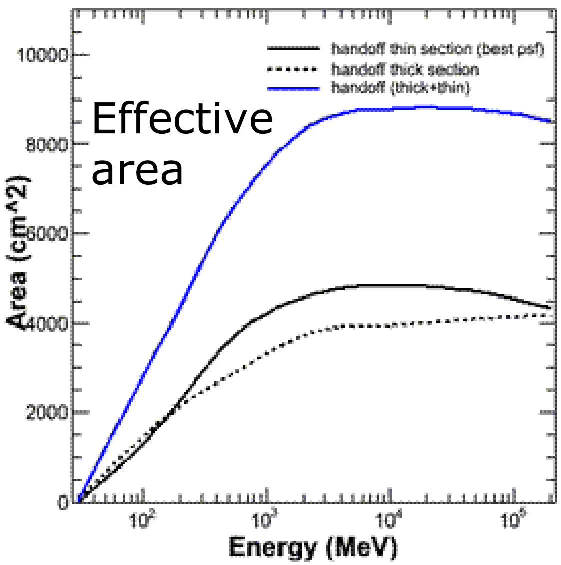
Galactic Diffuse Emission is ...

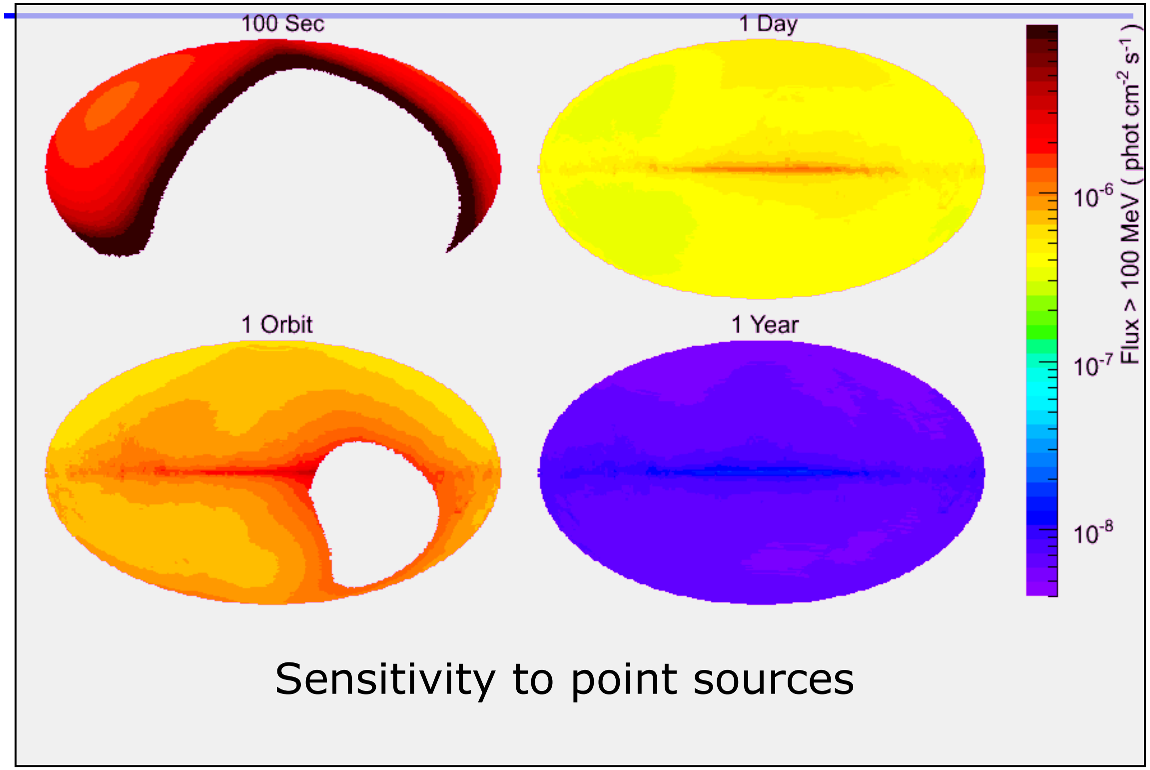


- Useful for studying cosmic-rays on Galactic scales.
  - Direct cosmic-ray observation are limited to local environment.
- Supplementary probe of gas in the Galaxy.
- Bright background for sources in the Galactic plane.
  - Observation of faint or soft sources in the plane are affected.
- Foreground to extragalactic background.

Observatory Performance







Energy Resolution: ~10%

PSF (68%) at 100 MeV: ~ 3.5° (front)

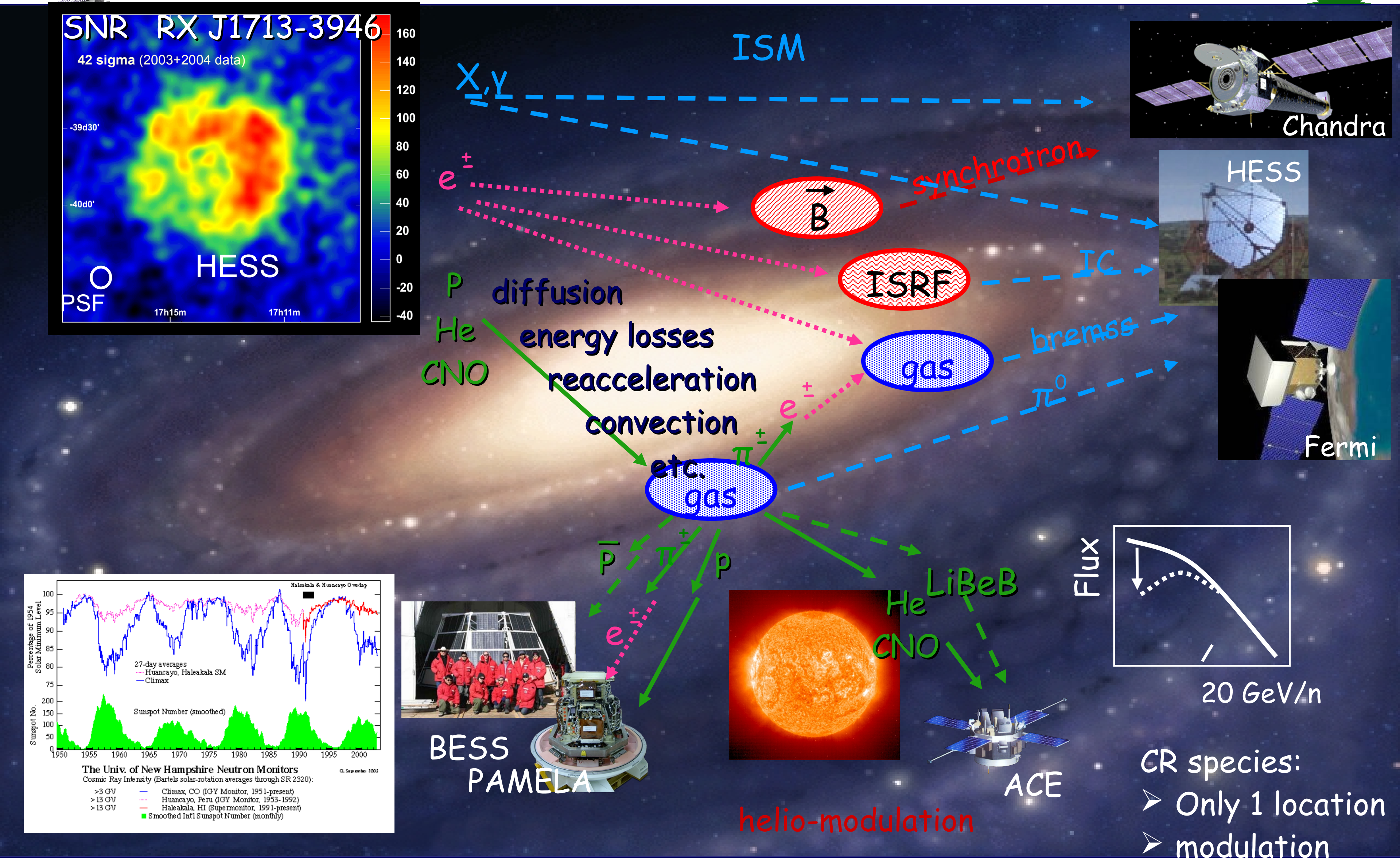
PSF (68%) at 10 GeV: ~ 0.1°

Field Of View: 2.4 sr

Point Source sens. (>100 MeV): 3×10^{-9} cm^{-2} s^{-1}

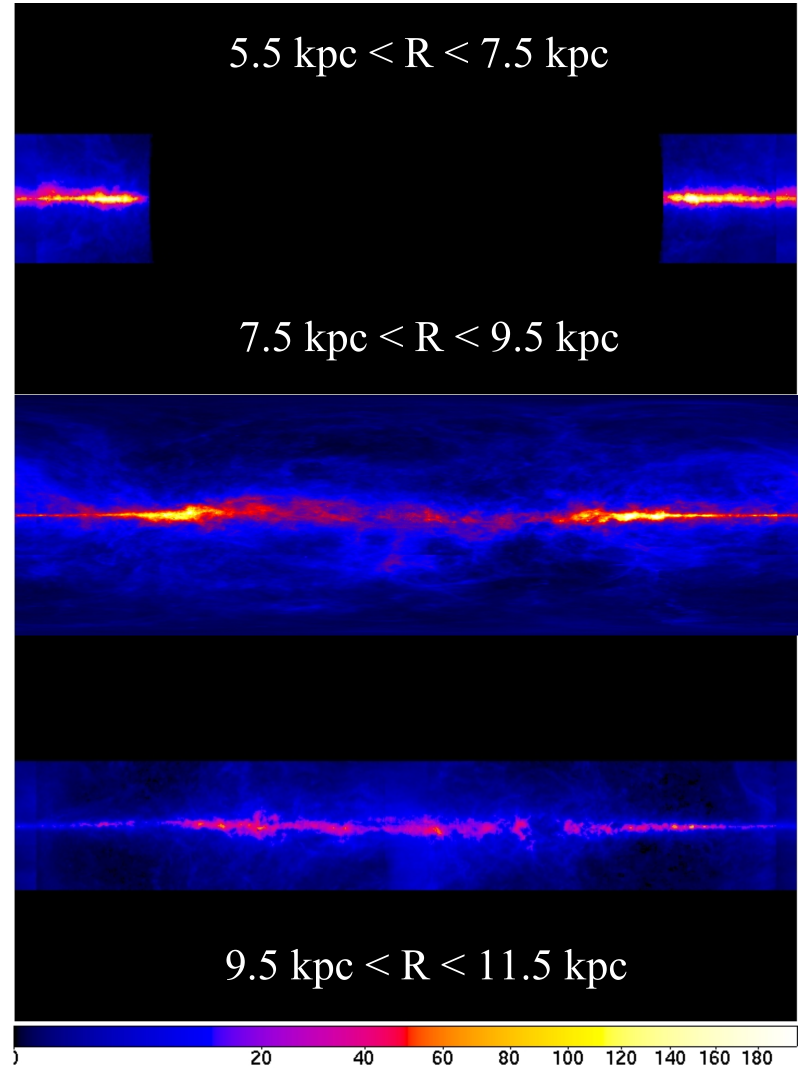
(1-year survey, assuming dN/dE~E^{-2})

Cosmic-Ray Propagation in the Galaxy



Local Galactic Diffuse emission

- Outside of the Galactic plane, most of the gas is local.
- Galactic diffuse emission dominated by π^0-decay emission around 1 GeV.
- Isotropic background dominates at high latitudes.
- Diffuse emission should follow prediction of local cosmic-ray observations at intermediate latitudes.



Column density of HI in different galactocentric rings. CAR projection with *l* increasing to right and the galactic center at the edge.

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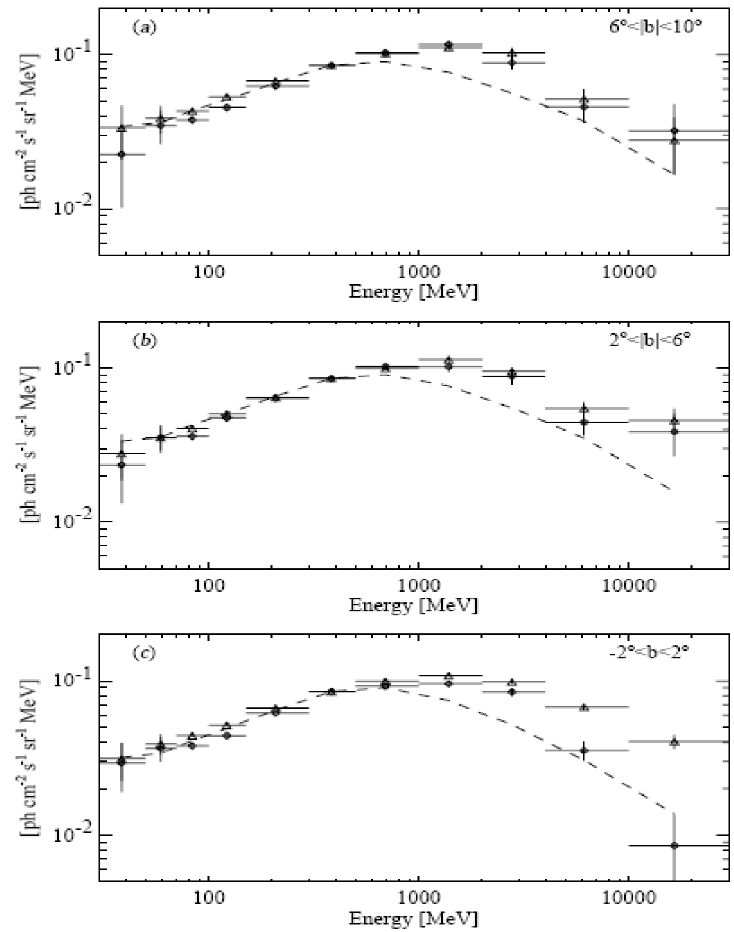
EGRET GeV Excess

- EGRET observations showed excess emission > 1 GeV when compared with conventional model consistent with local cosmic-ray nuclei and electron spectra
- Potential explanations
  - Variations in cosmic-ray spectra over Galaxy
  - Unresolved sources (pulsars, SNRs, …)
  - Dark matter
  - Instrumental



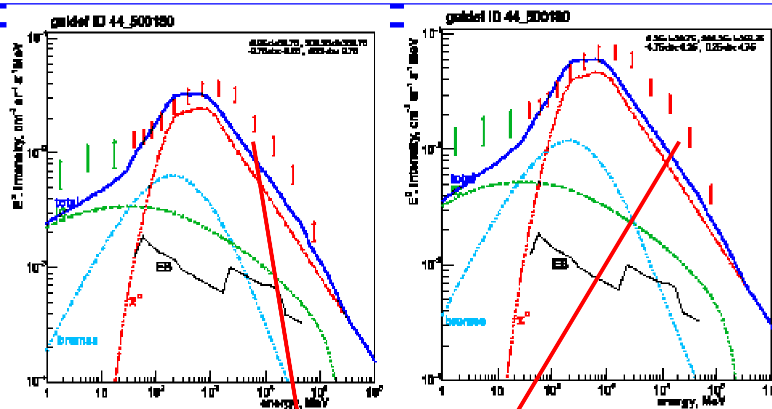
~100% Discrepancy above 1 GeV!

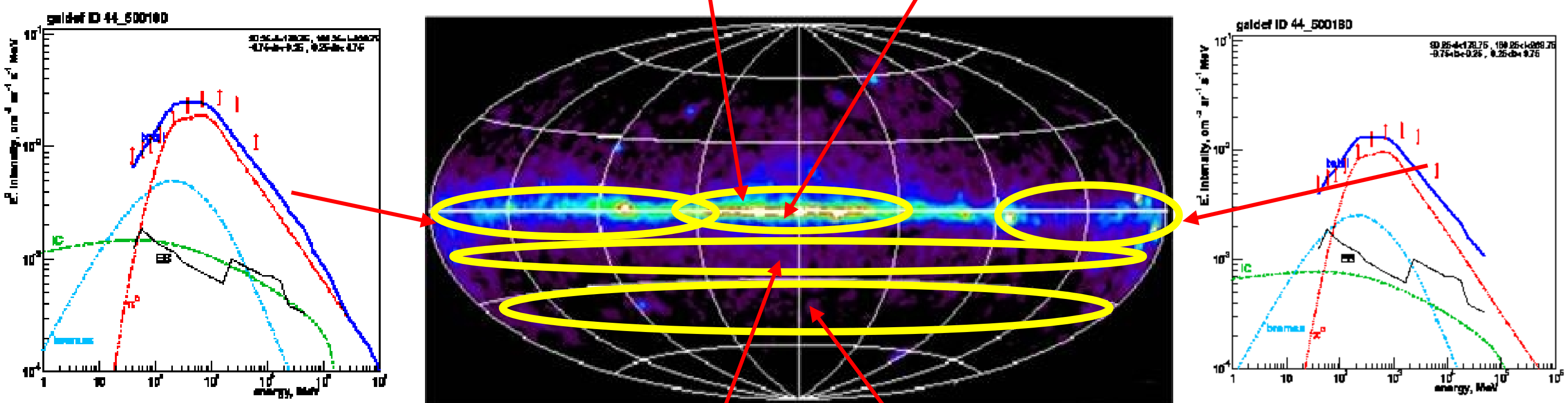
Hunter et al. (1997)

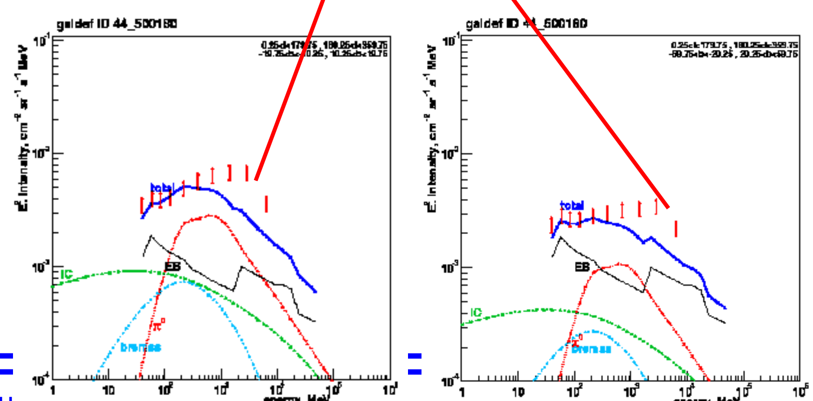
EGRET GeV Excess

EGRET data.

Above 1 GeV, data are above the Galprop prediction everywhere in the sky.



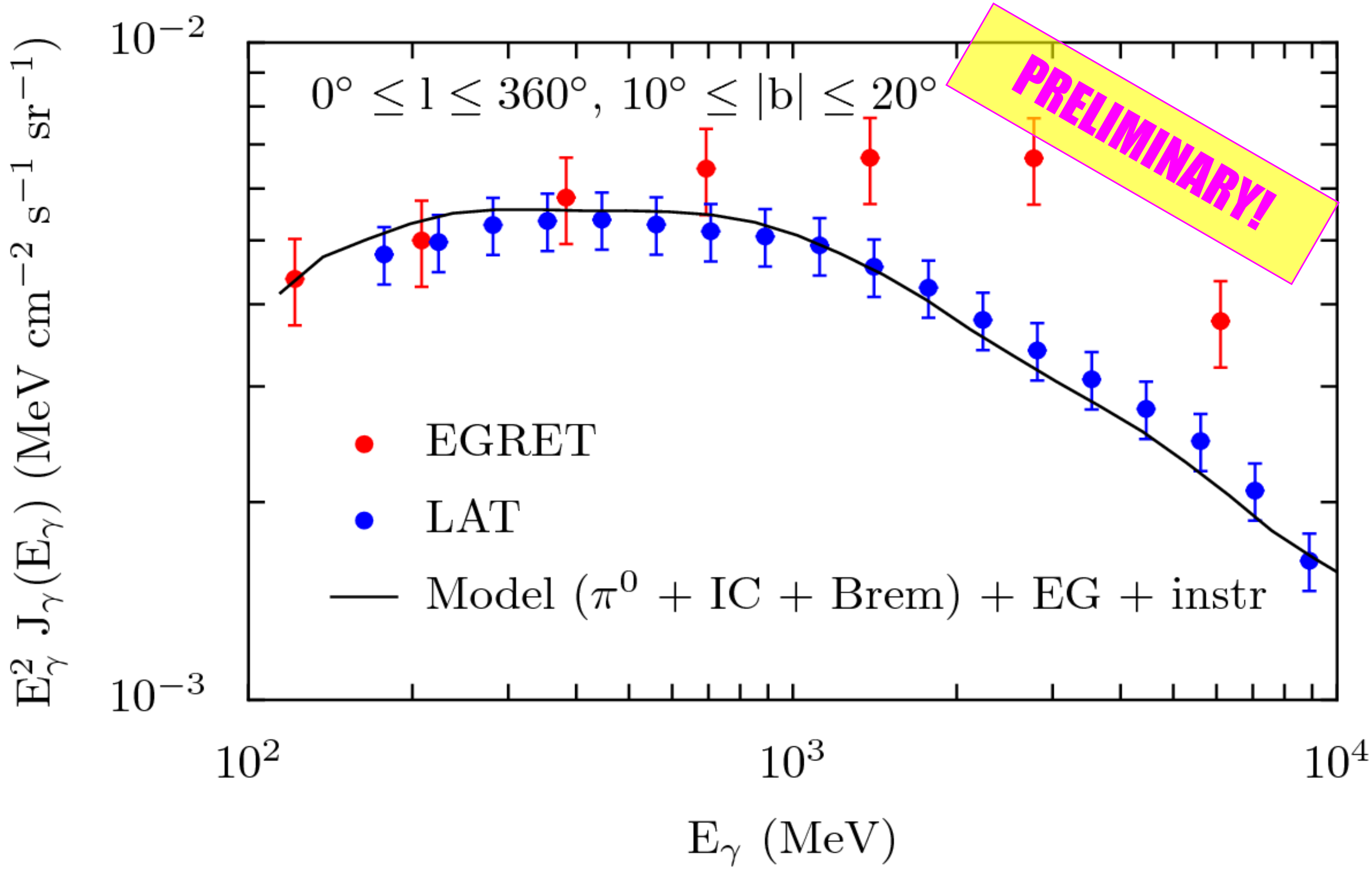




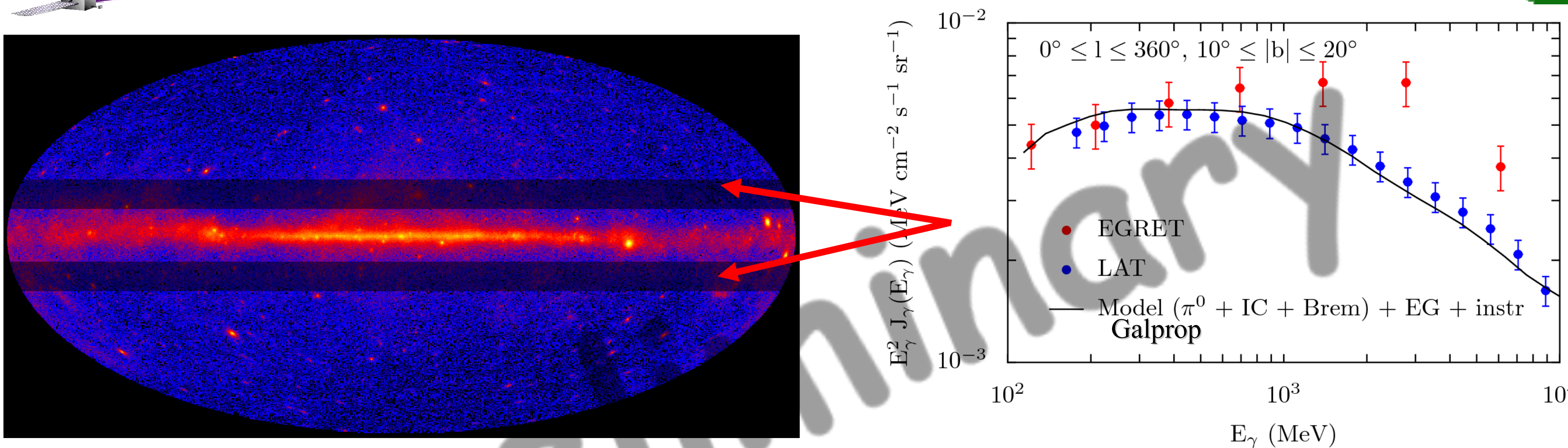
Strong, Moskalenko & Reimer ApJ 613, 962 (2004)

LAT statistics already good enough to confirm/refute all-sky nature of this excess emission

Fermi LAT mid-latitude close up



The Fermi LAT View



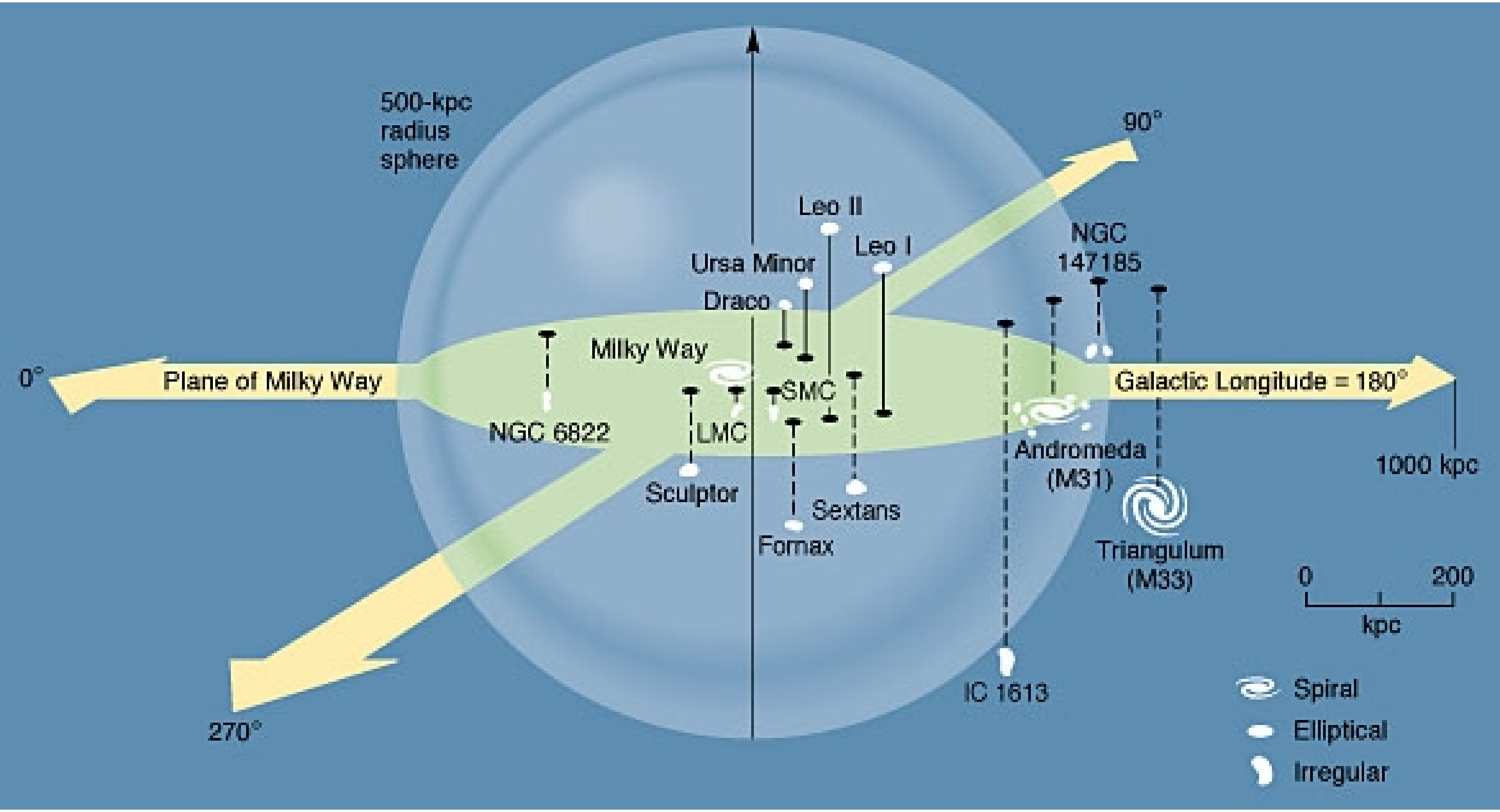
- Spectra shown for mid-latitude range → GeV excess in this region of the sky is not confirmed.
- Sources are not subtracted but are a minor component.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% → this is preliminary.
- EGRET data are prepared as in Strong, et al. 2004 with a 15% systematic error assumed to dominate (Esposito, et al. 1996).
- EG + instrumental is assumed to be isotropic and determined from fitting the data at $|b| > 30^\circ$.

Current View of Galactic Diffuse Emission

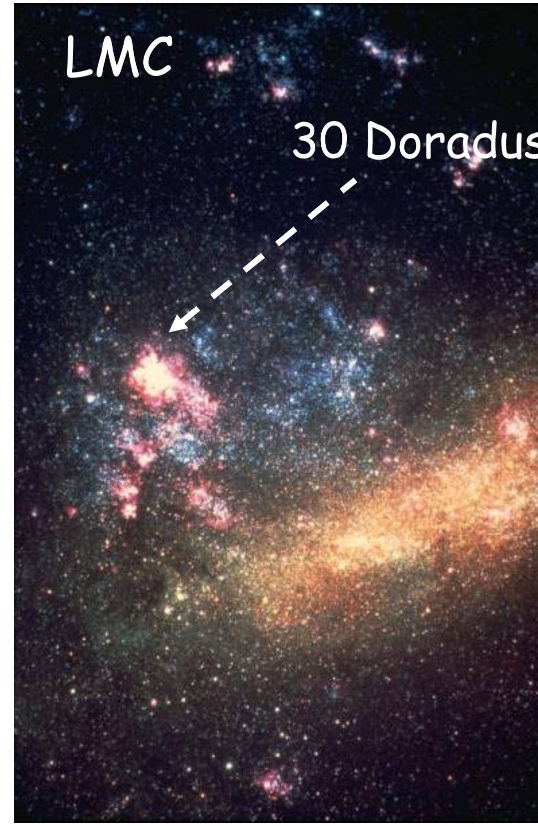
- Intermediate latitude γ-ray spectra can be explained by cosmic-ray propagation models based on local cosmic-ray nuclei and electron spectra. The EGRET GeV excess is not seen in this region of the sky with the LAT.

- Work to analyse and understand diffuse emission over the entire sky is in progress

Local Group Galaxies



Magellanic Clouds



Type: Im IV-V

Magnitude: 2.3

Size: 280 x 160 arcmin <kpc

Distance: ~60 kpc

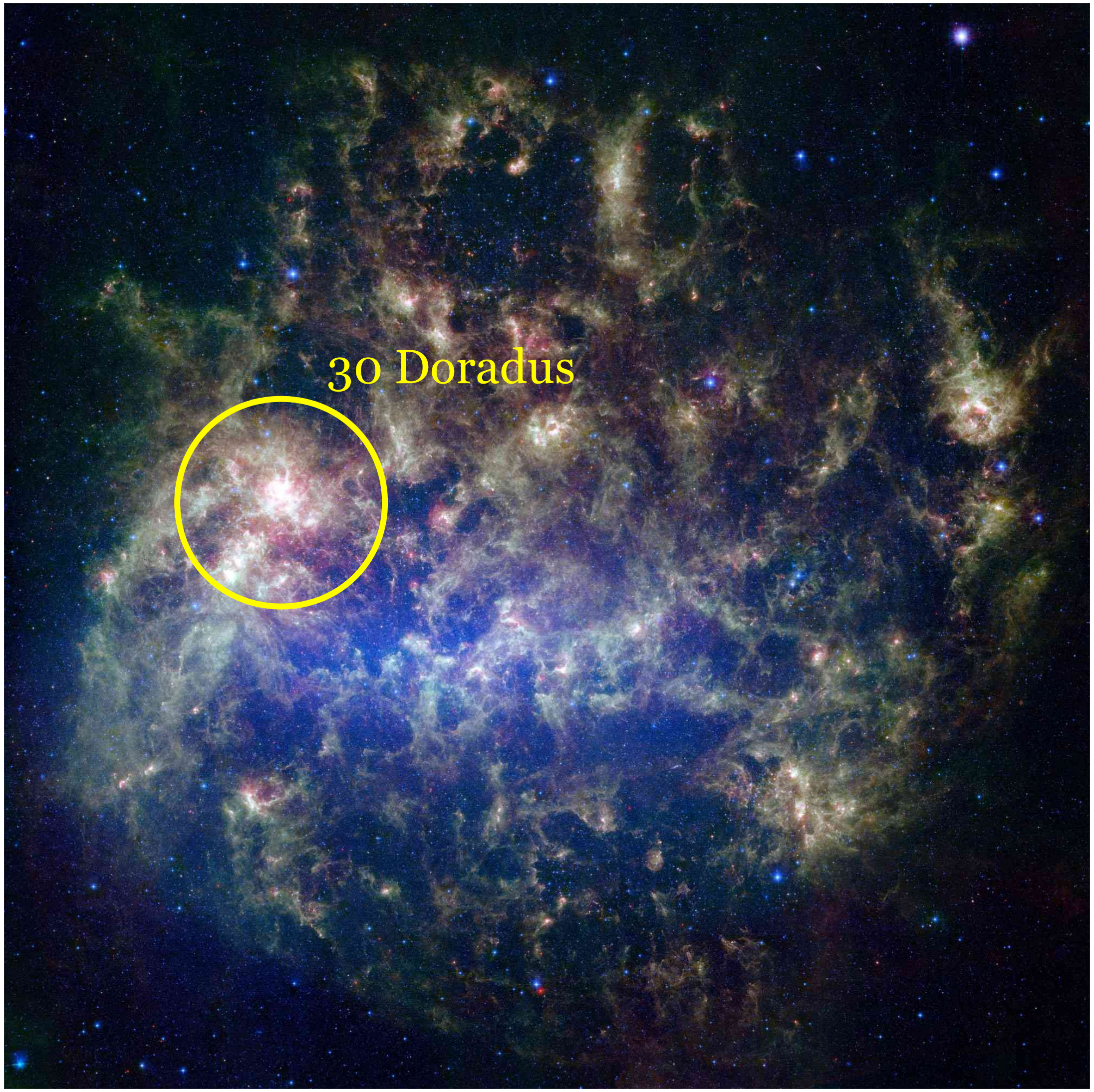
Type: Irr/SB(s)m

Magnitude: 0.9

Size: ~10°x10° ~few kpc

Distance: ~50 kpc

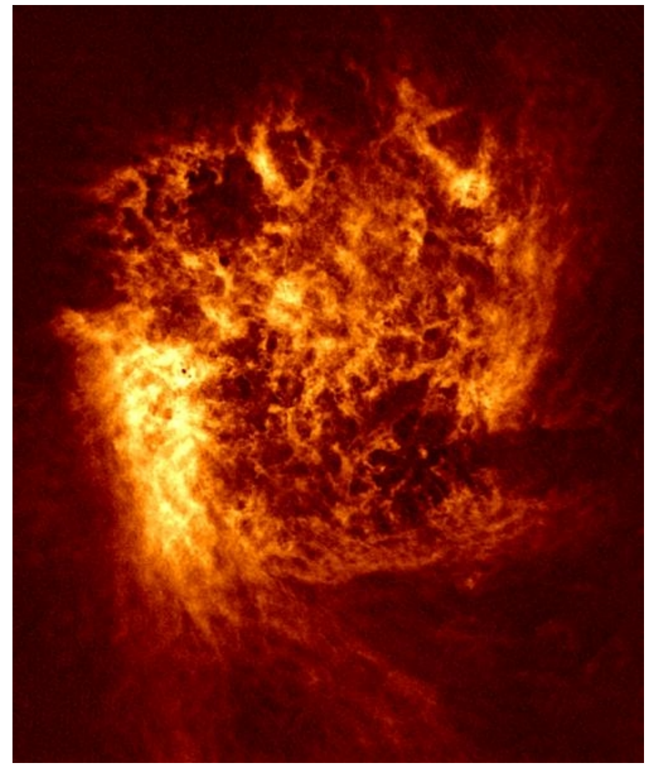
Why study the Large Magellanic Cloud?



NASA/JPL-Caltech/M. Meixner (STScI) & the SAGE Legacy Team

LMC is

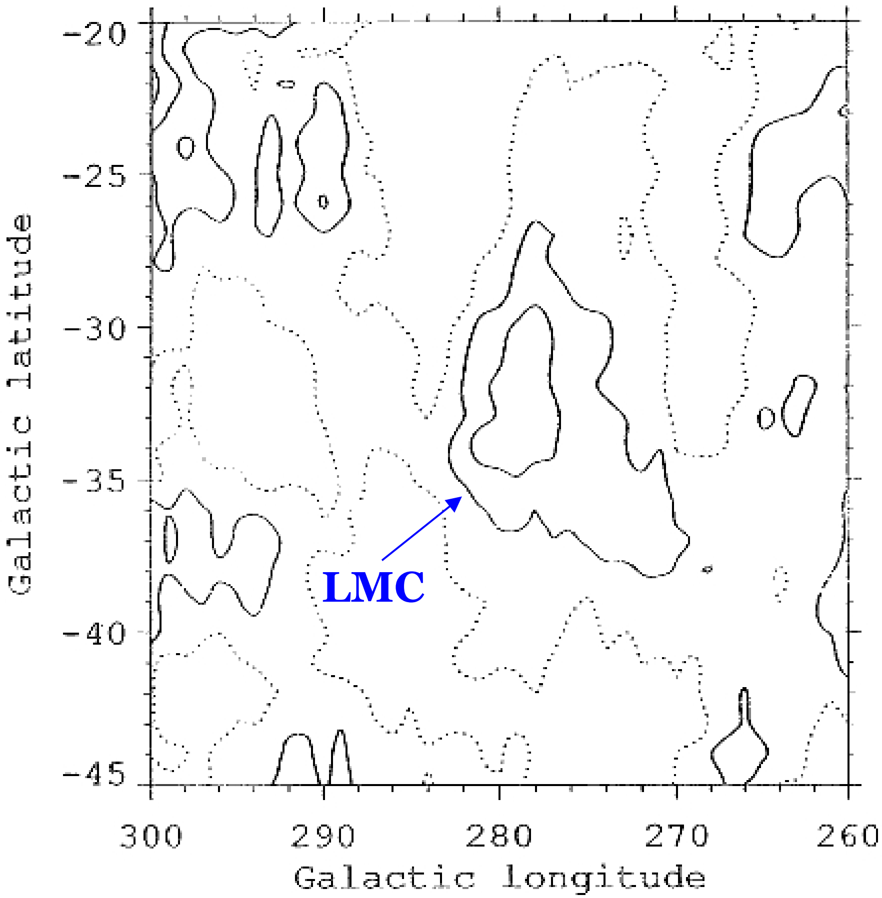
- seen ~ face-on (i ≈ 27°)
- nearby (~ 50 kpc)
- active (many massive star forming regions)

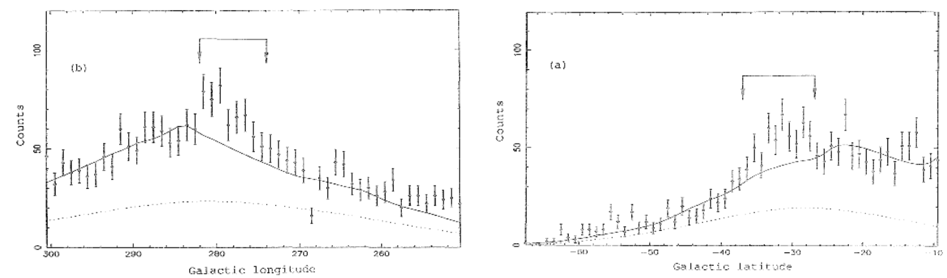


ATCA+Parkes H I (Kim et al. 2003)

EGRET View of the LMC

EGRET maps and profiles of LMC





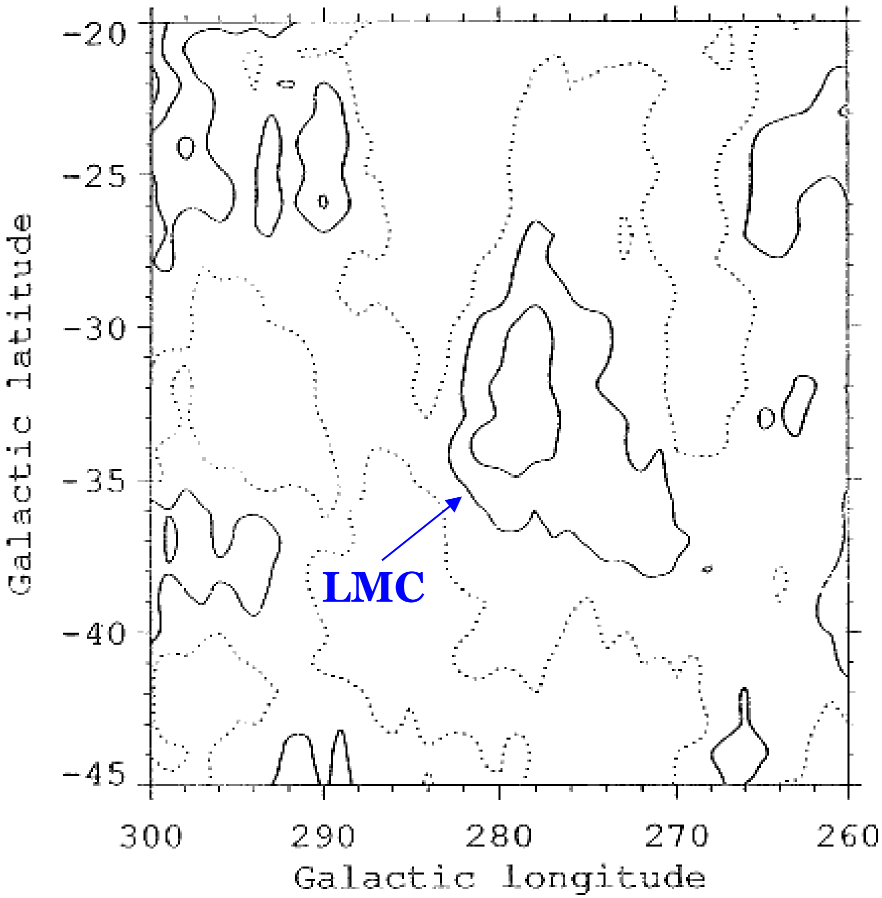
Sreekumar et al. (1992)

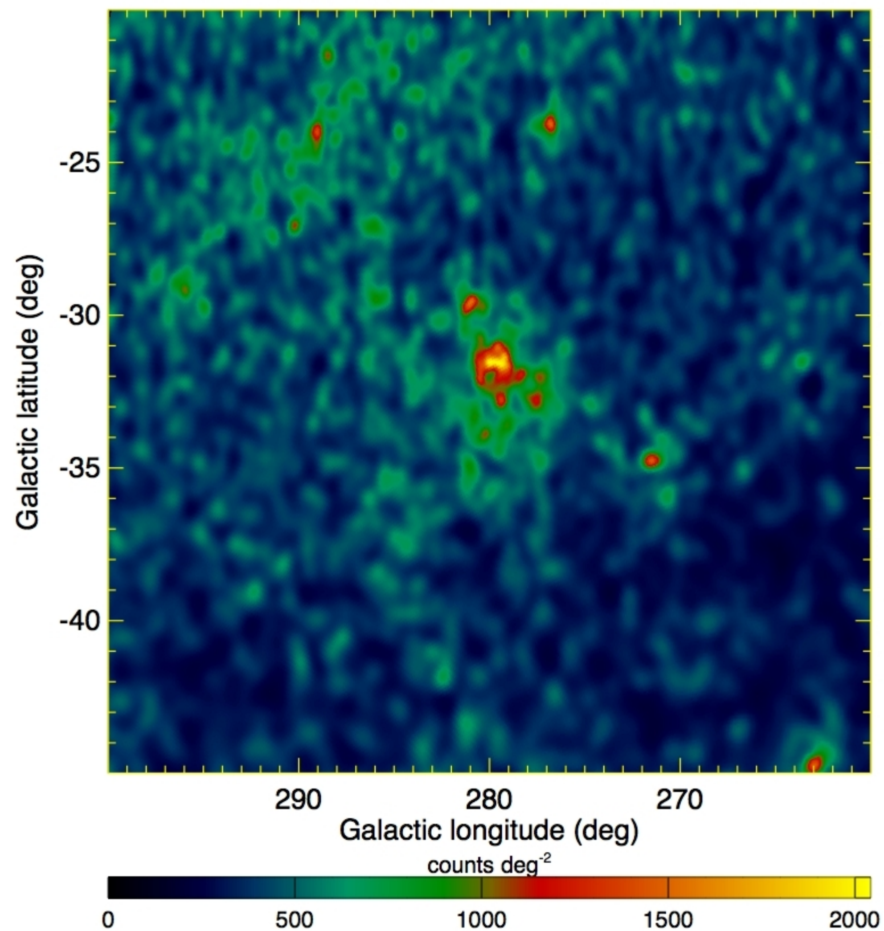
EGRET achievements

- first detection of LMC
- morphology consistent with radio data (yet no real spatial resolution of the emission)
- flux >100 MeV: (1.9 ± 0.4) 10^{-7} ph cm^{-2} s^{-1}
- flux consistent with either:
  - dynamic balance model
  - uniform CR density equal to that in solar neighborhood

EGRET vs. Fermi View of LMC

PRELIMINARY

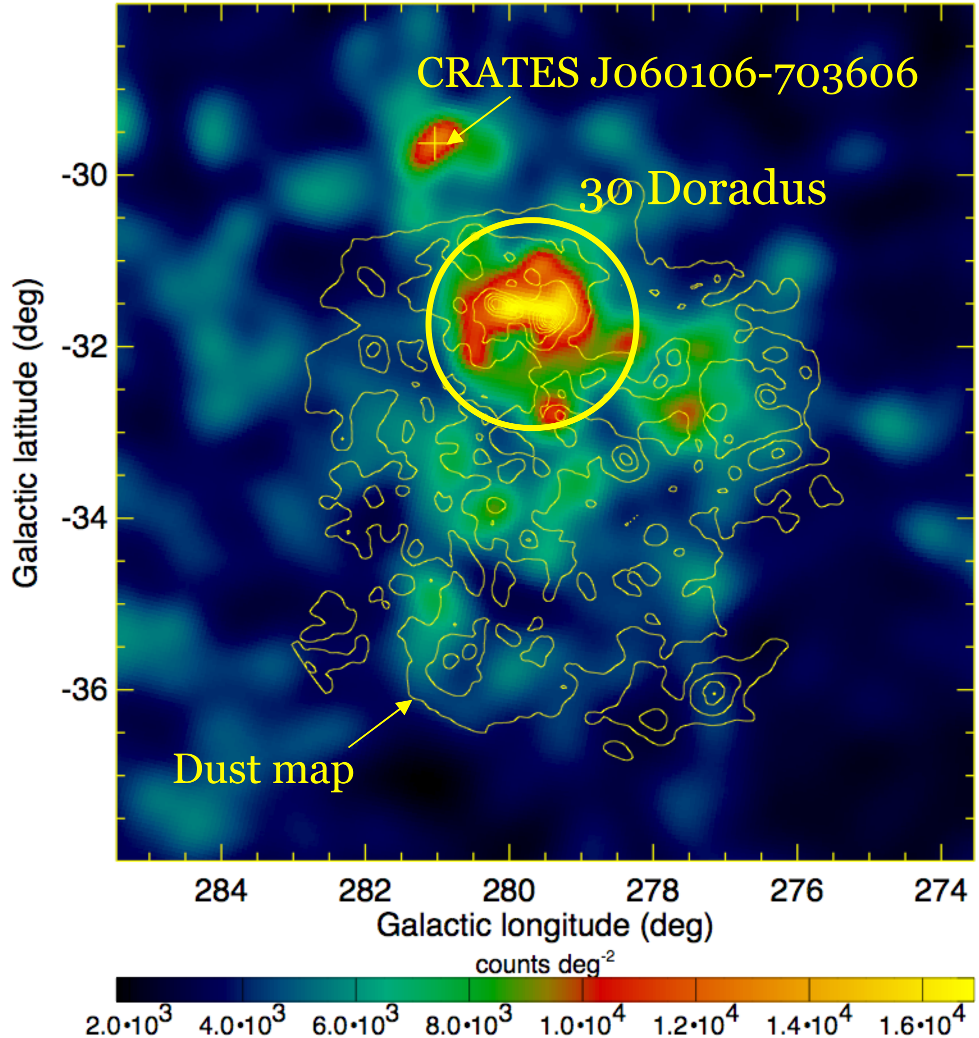




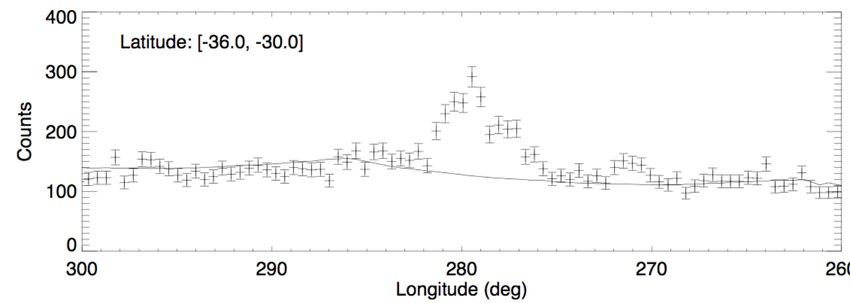
adaptively smoothed counts map (s.n.r. = 5)

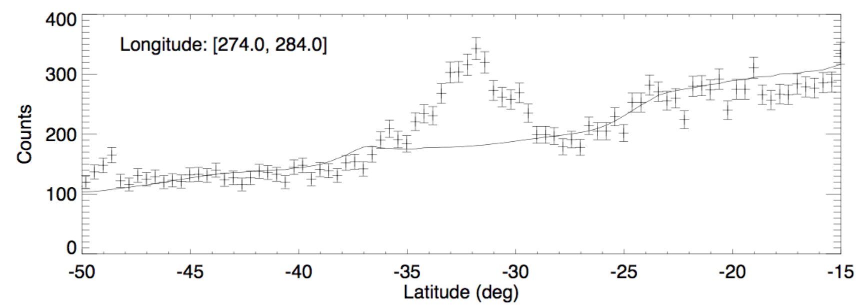
LAT/Fermi image of the LMC

PRELIMINARY



adaptively smoothed 100 MeV - 10 GeV counts map (s.n.r. = 5)





161 days of survey data
~ 1300 events above 100 MeV
Location (assuming point source):
$\alpha = 84.6 \pm 0.2$ (95%)
$\delta = -69.1 \pm 0.1$ (95%)

Consistent with 30 Doradus / R136 location (α=84.67, δ=-69.10)

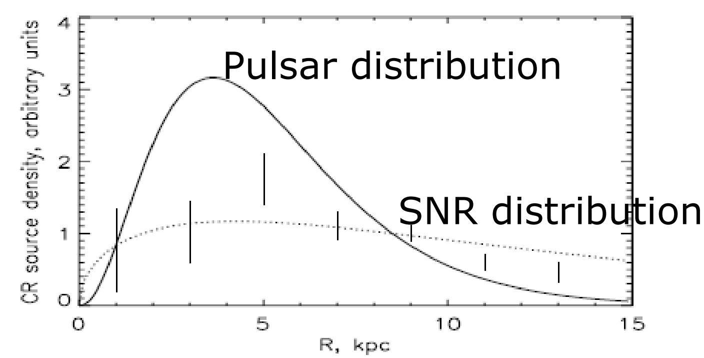
Summary and Outlook

- The LAT is a superb instrument for diffuse emission studies
  - Essentially uniform and deep coverage of the sky + very stable response over mission lifetime
- Have observed the Galactic diffuse emission with unprecedented resolution and statistics
- First results on mid-latitude Galactic emission show no evidence for EGRET feature > 1 GeV seen in same region of sky
- Easily detected diffuse emission from LMC
  - Emission resolved → 30 Doradus, host galaxy
  - More results very soon
- Stay tuned for further results on large-scale Galactic diffuse, other galaxies, EG at APS, ICRC, and later in the year

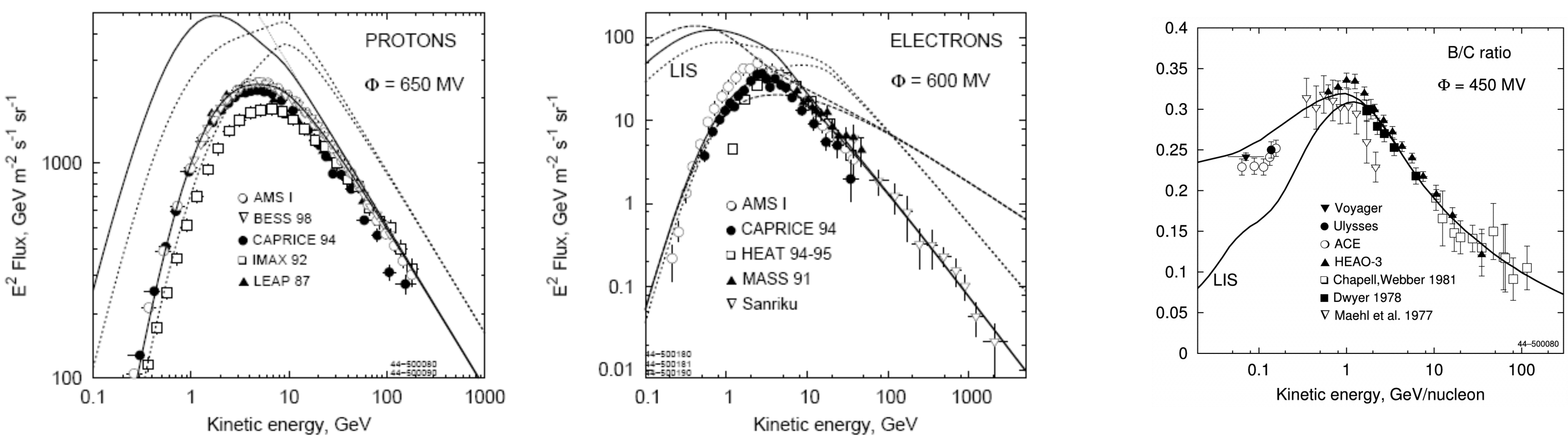
Fermi-LAT

Physical Input Needed

- The cosmic-rays have to be accelerated.
  - What are the accelerators ?
    - SNR, pulsars, ... ?
    - Affects the spatial distribution and spectra.



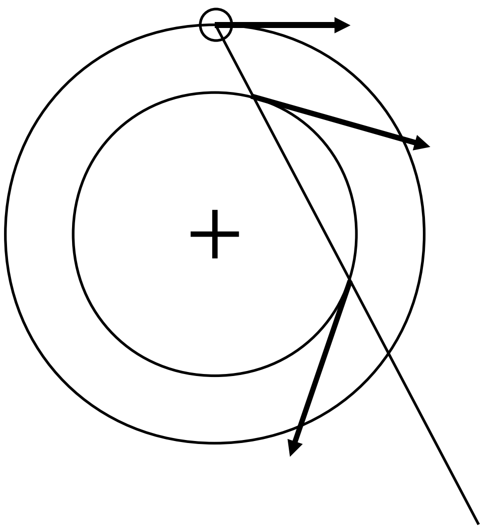
- Propagation through the galaxy.
  - Diffusion coefficients, secondary production, energy losses, ...
    - Determined from local observations of cosmic-rays.

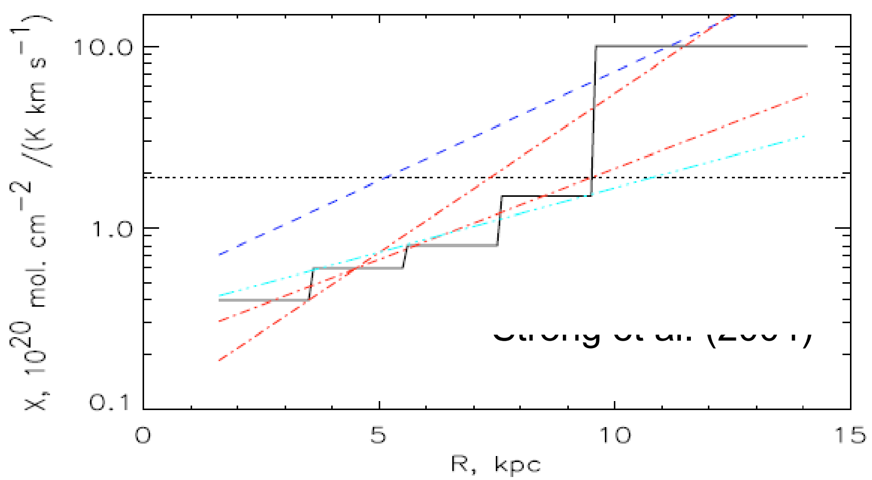


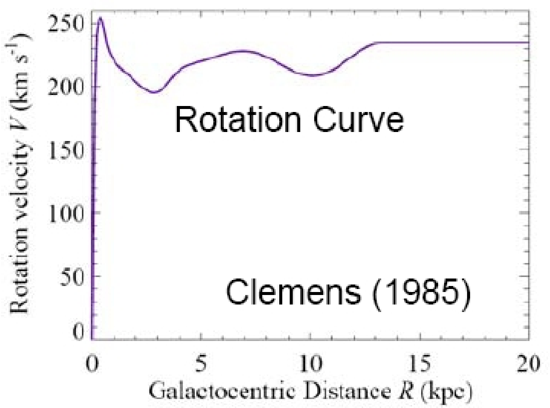
Strong, Moskalenko & Reimer, 2004

Physical Input Needed

- CR p, nuclei need targets to create γ-rays.
  - Gas distribution determined from radio and mm surveys, I (v,l,b).
    - Velocity => distance through a rotation curve.
  - HI density from 21 cm hyperfine line
    - Opacity correction needed
  - H_2 density from 2.6 mm CO 1-0 transition
    - Conversion factor not necessarily constant throughout Galaxy.





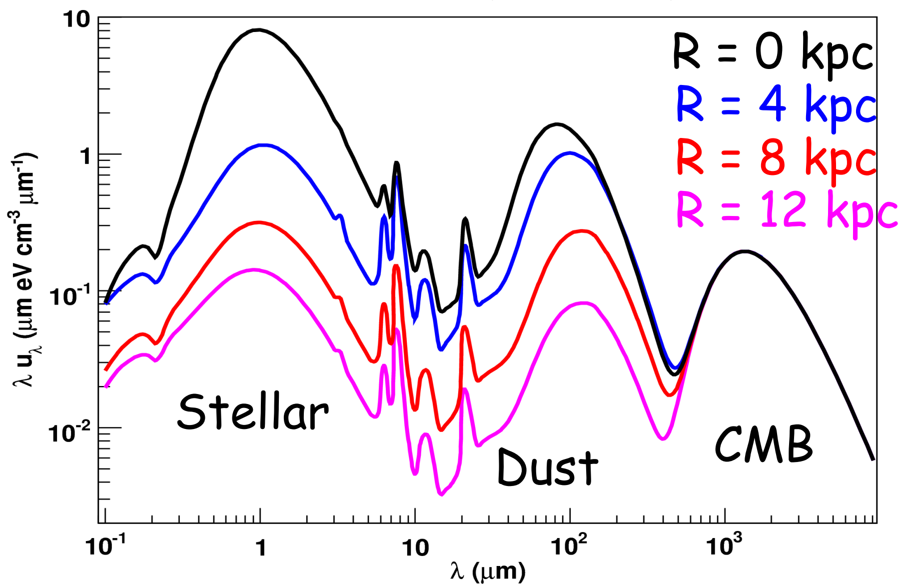


Physical Input Needed

- CR $e^{\pm}$ need targets to create γ-rays.
  - Interstellar radiation field determined from a realistic model taking into account stellar and dust distribution.
    - Starlight (~ 0.1 μm – 10 μm)
    - Dust (~ 10 μm – 300 μm)
    - CMB (> 300 μm)

There are uncertainties associated with gas and ISRF!

ISRF energy density



Porter et al. 2008

Fermi Diffuse Analysis

Distribution of ISM

HI/CO surveys, ISRF model

+ spatial mapping of ISM

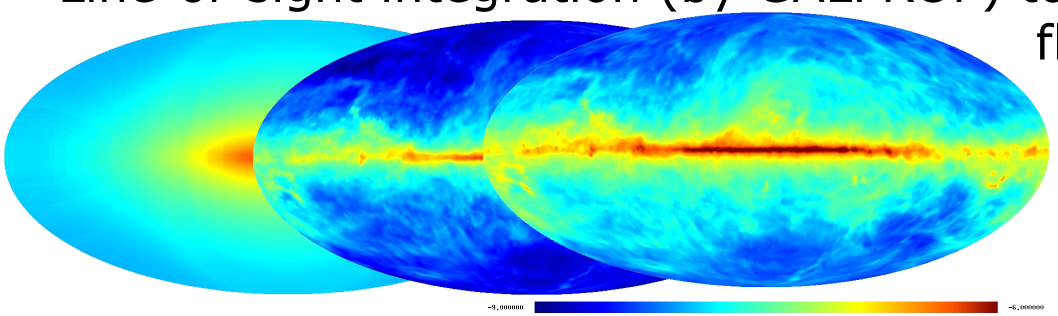
+ conversion to HI/H_2 column density

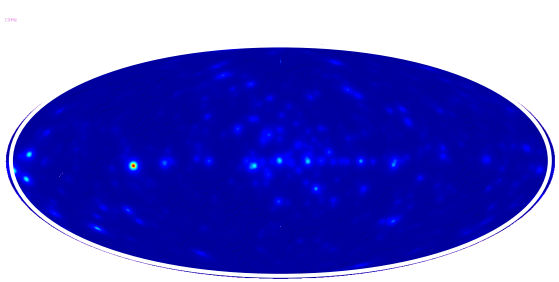
Galactic γ-ray emissivities

- from GALPROP cosmic-ray propagation
- derived from data for special regions

Line-of-sight integration (by GALPROP) to create template γ-ray flux maps for individual

- emission processes
- ISM components
- galactocentric annuli

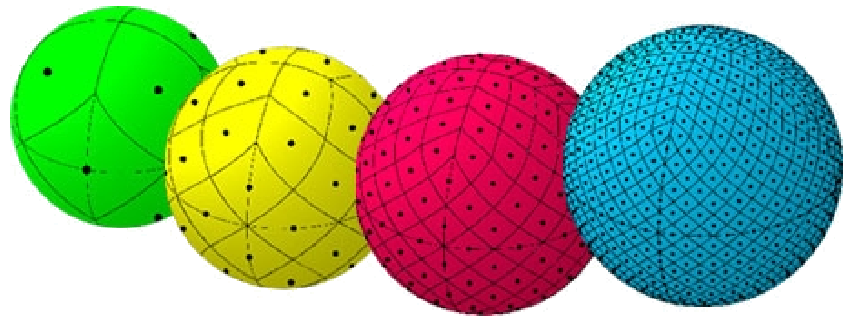




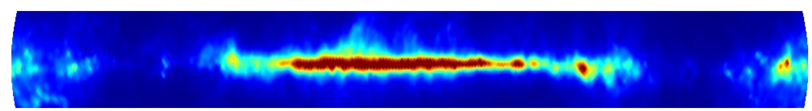
+ isotropic diffuse component (extragalactic + instrumental)
+ point sources
+ solar system / unresolved sources

Fermi Diffuse Analysis

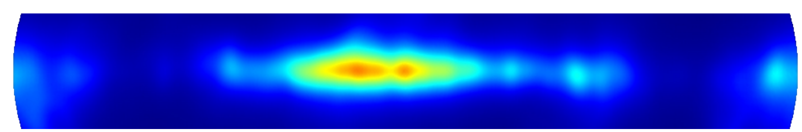
- Full-sky pixel-by-pixel maximum likelihood fit of template γ-ray maps to LAT data
- Usage of (equal area, iso-latitude) HEALPIX grid allows for fast convolution with energy dependent LAT instrument response
- Point source spectra are fitted in global scheme simultaneously with diffuse components
- Deviations from input model and analysis of residual map used to iteratively improve the diffuse model



HEALPIX grid (Gorski et al. 2005)



$$(k \star f)_l^m = \sqrt{\frac{4\pi}{2l+1}} k_l^0 f_l^m$$



Fast convolution with PSF using HEALPIX spherical harmonics decomposition

Summary: EGRET Observations

- LMC detection: CR density is similar to MW
- SMC non-detection: CR density is smaller than in the MW (otherwise it would have flux ~2×10^{-7} cm^{-2} s^{-1} > 100 MeV)
- First direct evidence:

  CRs are galactic and not universal !

  M31 non-detection: has to have smaller CR density than the MW (size M31>MW!)

Obs. Summary

Source	F(>100 MeV), cm^{-2} s^{-1}
LMC	$(1.9\pm0.4)\times10^{-7}$
SMC	$<0.5\times10^{-7}$
M31	$<0.8\times10^{-7}$

Sreekumar et al.(1992-94)