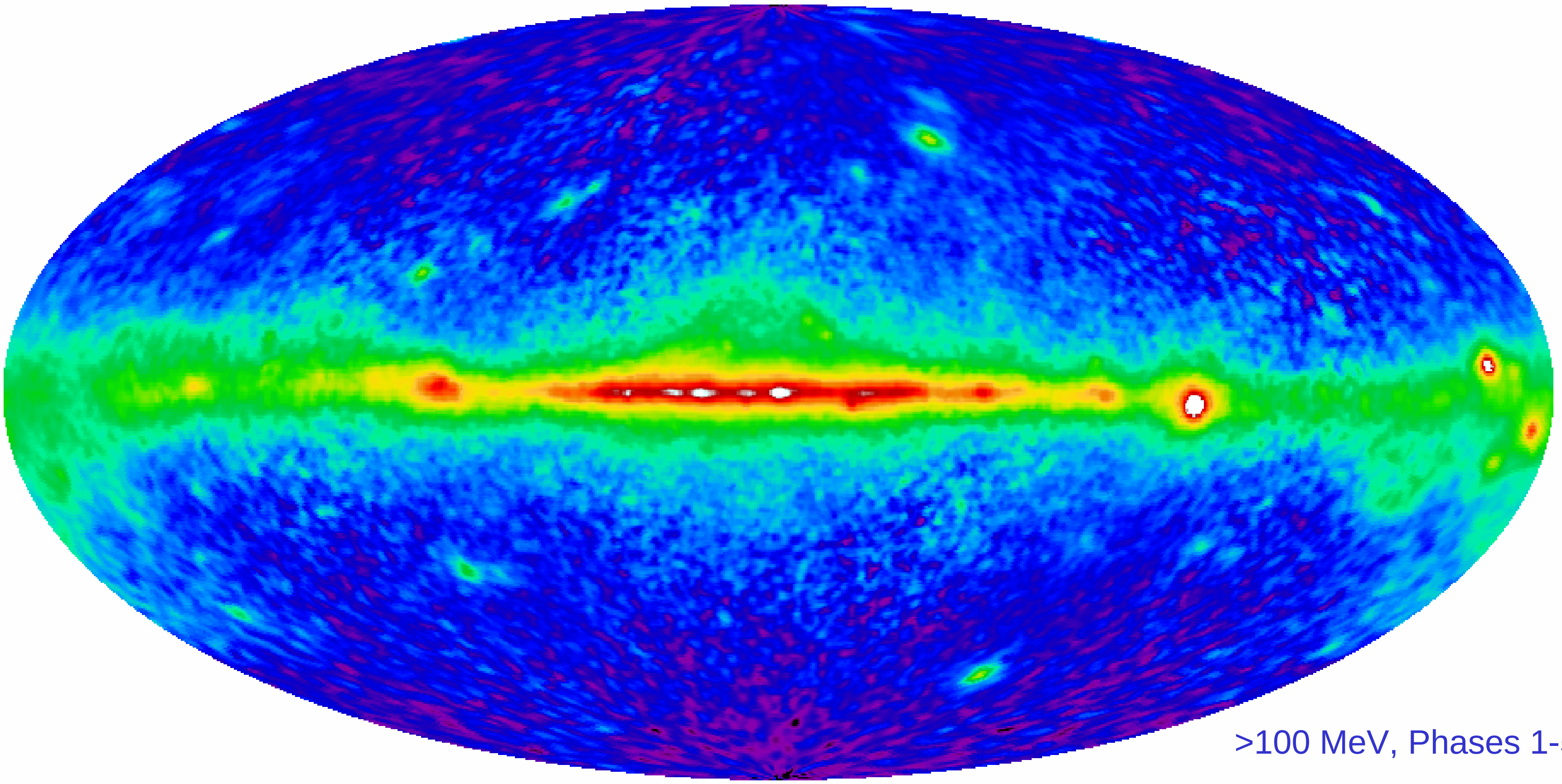
Gamma-ray Large Area Space Telescope

Galactic Diffuse Emissions

S. W. Digel

Is the Milky Way a diffuse γ-ray source?



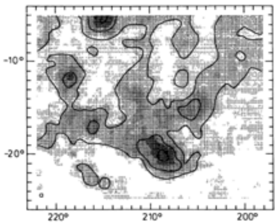
YES

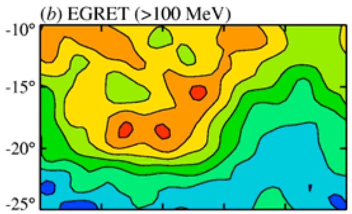
Gamma rays from atomic and molecular gas in the large complex of clouds in Orion and Monoceros

J.B.G.M. Bloemen[1,9], P.A. Caraveo[2], W. Hermsen[1], F. Lebrun[5], R.J. Maddalena[7], A.W. Strong[4], and P. Thaddeus[7,8]

The Caravane Collaboration for the COS-B satellite

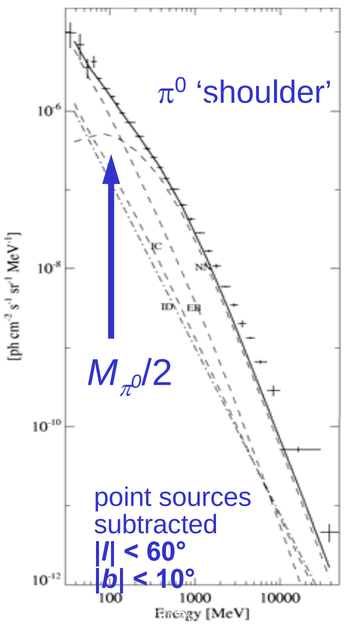
(1984)



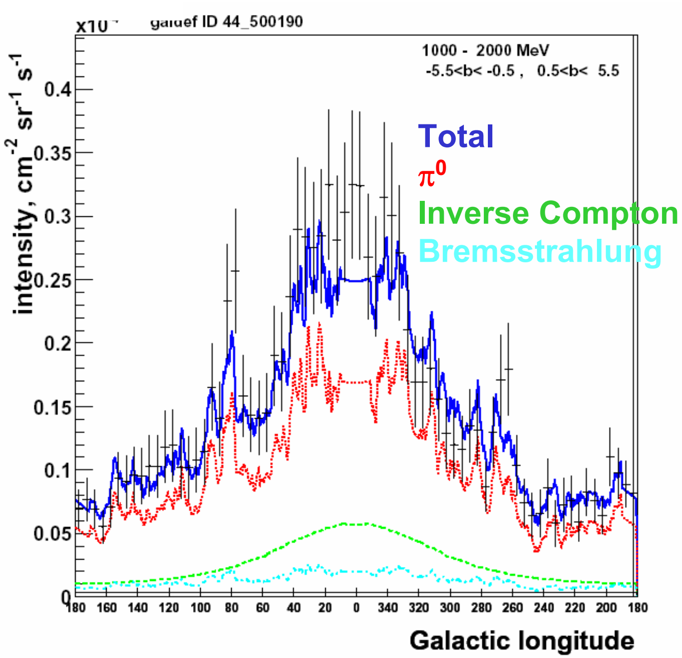


Digel et al. (1999)

YES



Hunter et al. (1997)



Strong, Moskalenko, & Reimer (2004)

So what’s left to talk about?

- Why are the answers yes? What makes the gamma rays?
- What do we know about diffuse emission and what would we like to learn about the Milky Way with the Large Area Telescope?
- Some current issues in understanding the diffuse emission
  - GeV excess
  - Details at intermediate latitudes
  - ‘Dark gas’
  - Galactic center diffuse
  - Metallicity gradient and distribution of CR sources
  - Interstellar radiation field
  - Point source contribution
- Will not discuss: nuclear lines

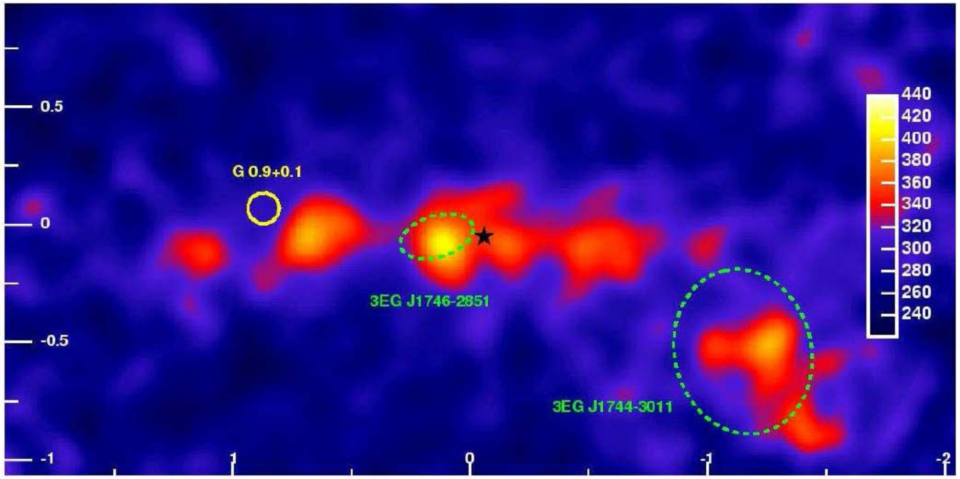
N.B. 100 MeV–100 GeV diffuse emission

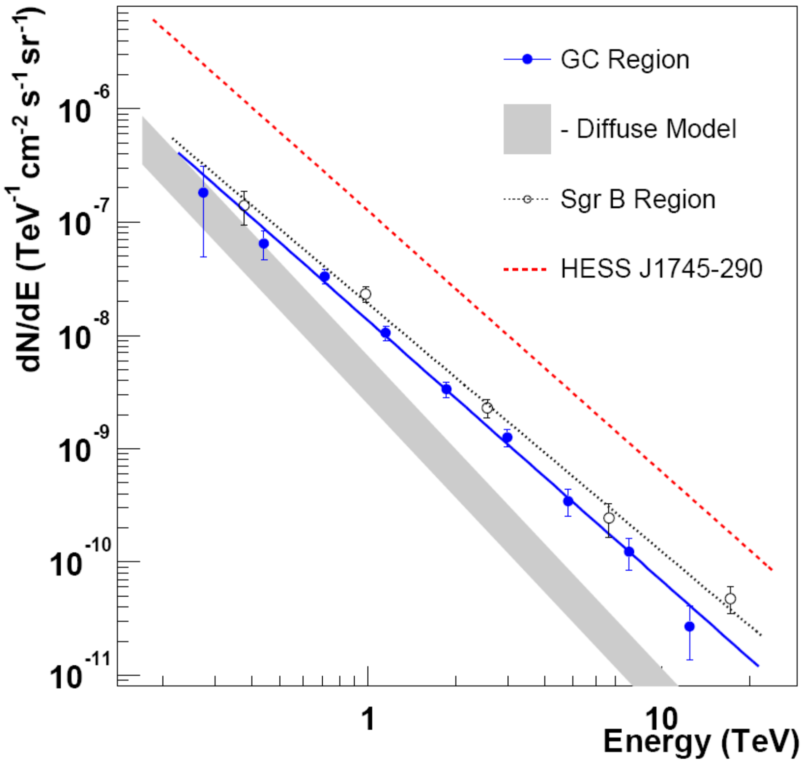
- **As we have seen this week, that although the central energy range for pair conversion gamma-ray telescopes (like the LAT) is blessed with bright diffuse emission – *other gamma-ray energy ranges have to do without***
- **At lower energies, INTEGRAL is resolving much of the emission into point sources (although a diffuse continuum probably remains below 1 MeV)**
  - **Talk by J. Knödlseder, this session**

TeV diffuse emission

- **At higher energies, point sources dominate over diffuse emission, or nearly so**
- **For H.E.S.S., diffuse emission is seen only in the Galactic Center so far**

H.E.S.S. would not have seen diffuse emission if the CR spectrum were not more intense and harder in the G.C. than locally
N.B. TeV electrons do not diffuse far, ~200 pc





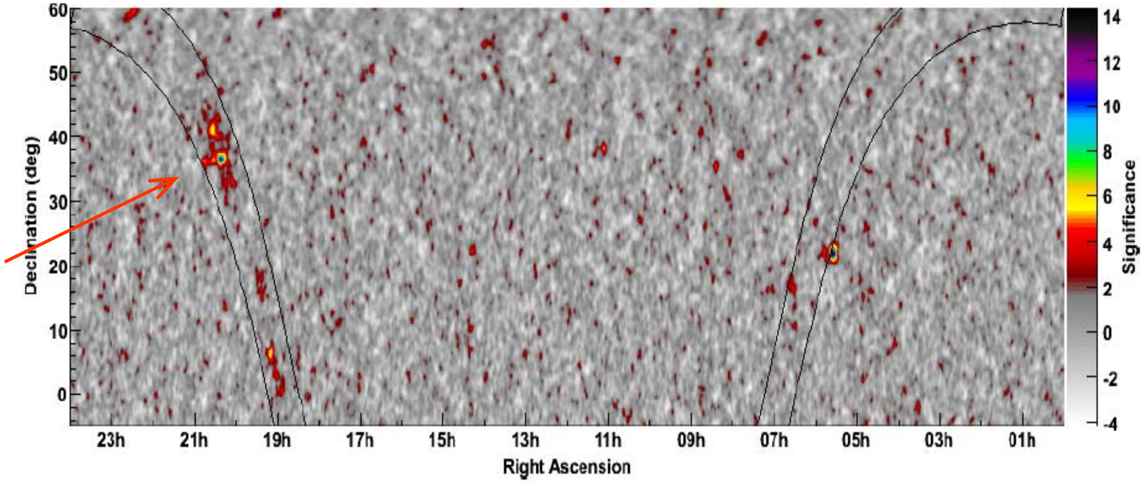
Aharonian et al. (2006); Hinton et al. (2006)

TeV diffuse emission (2)

- **Milagro is also seeing Galactic emission at >1 TeV energies – mostly point sources (Casanaova & Dingus 2006)**
  - **Talk by A. Abdo in this session (and C. Lansdell yesterday)**

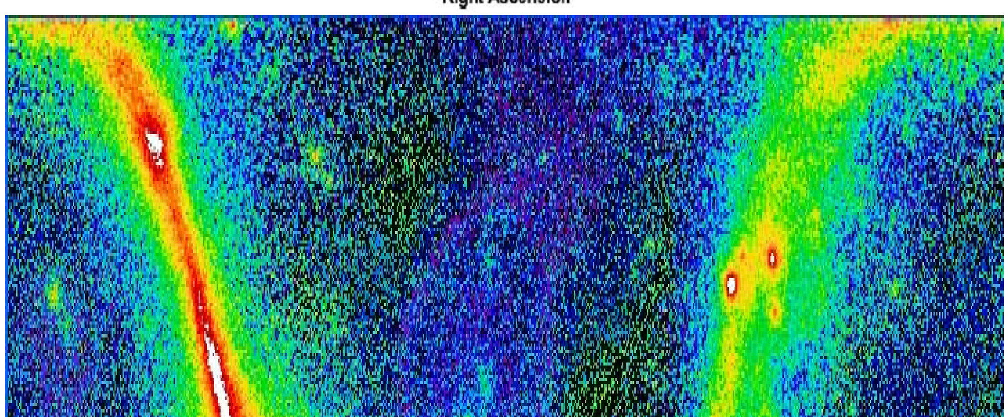
Milagro map of significance

Cygnus region
4 'hot spots'



Abdo et al. (2006)

EGRET intensity (>100 MeV) in ~same projection



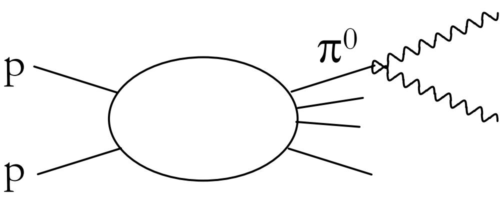
Living with diffuse emission

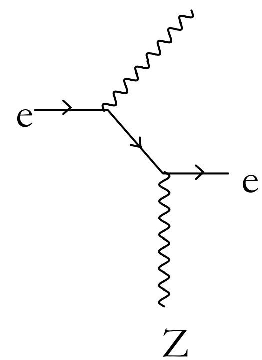
- **In the GeV range, if you don't care about the diffuse emission as a diagnostic tool, you might want to care about having it modeled accurately anyway**
  - **Discriminate between point sources and interstellar emission***
  - **Get coordinates correct for sources***
  - **Accurately measure the extragalactic component (talk by C. Dermer, this session)**

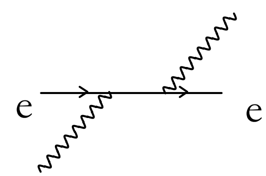
* As you recall from P13.2 by Casandjian & Grenier, the implications from adoption of a new component for diffuse emission were serious for the detections of faint point sources in the EGRET data.

Production mechanisms for high-energy γ-rays

- π^0 decay – secondaries from CR proton-nucleon collisions
- Bremsstrahlung – scattering of CR electrons by protons/nuclei
- Inverse Compton scattering of low-energy photons by CR electrons



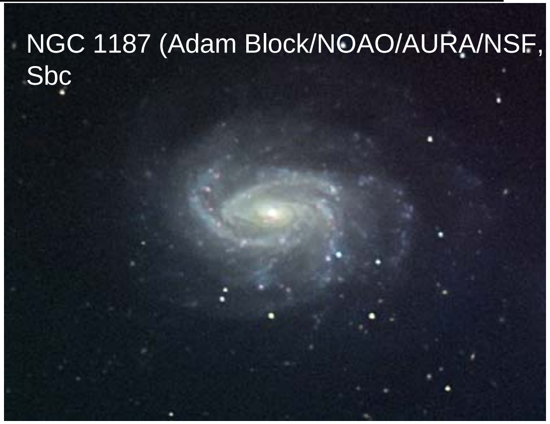


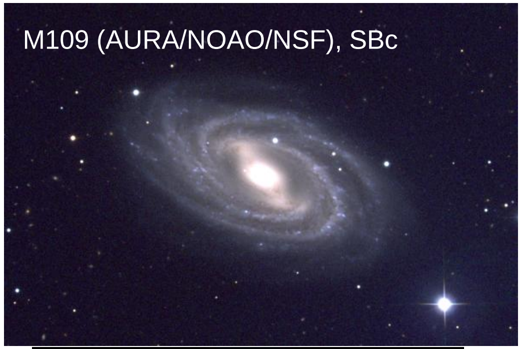


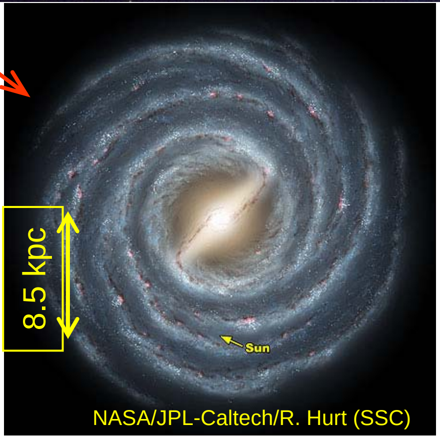
- The nuclei that matter are in interstellar gas – stars do not have a large filling factor and also absorb the great majority of γ-rays produced by CR interactions
  - Good thing! Decreases solar flux by factor 10^{14}!
- Of course to have CRs in the first place in a galaxy you want to have interstellar gas to form massive stars out of
- And you want the galaxy to keep its CRs

Milky Way as a Galaxy

- So the best galaxies (short of starbursts, merging galaxies) for diffuse γ-ray emission are massive spirals, probably barred
- Milky Way: A large SBbc spiral galaxy
- Semi-idealized diagram of Milky Way - don't take this too literally
  - From an in-plane perspective tracing arms, gas distribution, CR sources in far side is hard *


NGC 1187 (Adam Block/NOAO/AURA/NSF, Sbc


M109 (AURA/NOAO/NSF), SBc



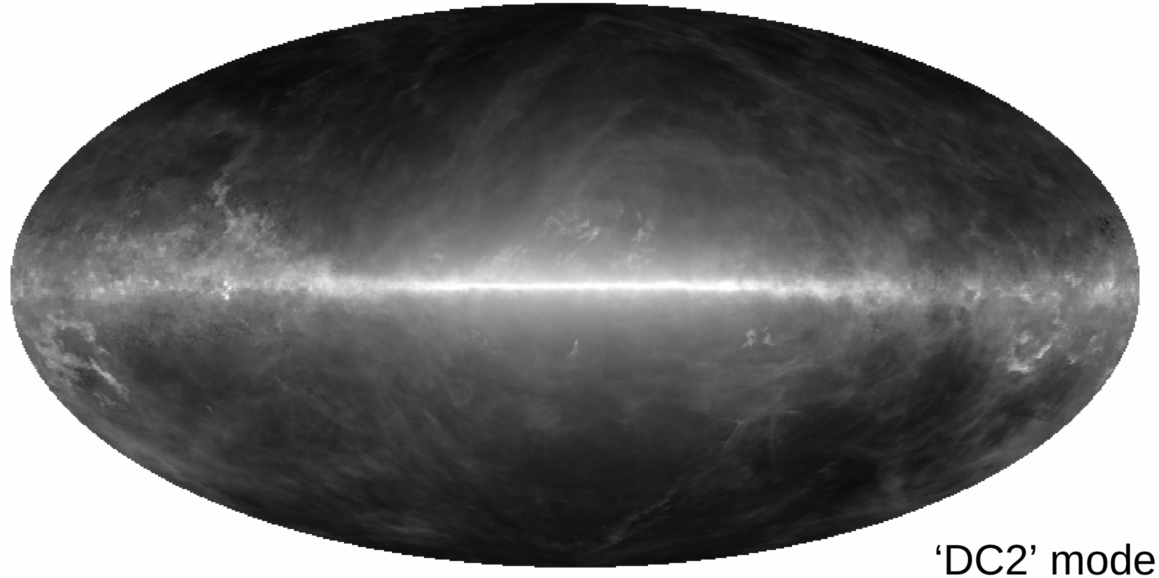
NASA/JPL-Caltech/R. Hurt (SSC)

* My proposal: *Out Of Plane Super Gamma-ray Observatory Next-gen Explorer:* OOPS-GONE

Components of an interstellar emission model

- **Interstellar gas** (molecular, atomic, and ionized)
  - Molecular gas (H_2) in ISM is indirectly measured via CO $J = 1 \rightarrow 0$ line; even N(H I) can be tricky [will not discuss]
  - Distance ambiguity, velocity dispersion, & non-circular velocity field of Milky Way [will not discuss]
- **Interstellar radiation field**
  - Dependence on position, wavelength, and direction
- **Cosmic rays**
  - Spatial distribution of sources, effects of propagation and interaction [will not discuss]
- ***Difficult or impossible to get unique answers for any of the above***

But it is semi-ok

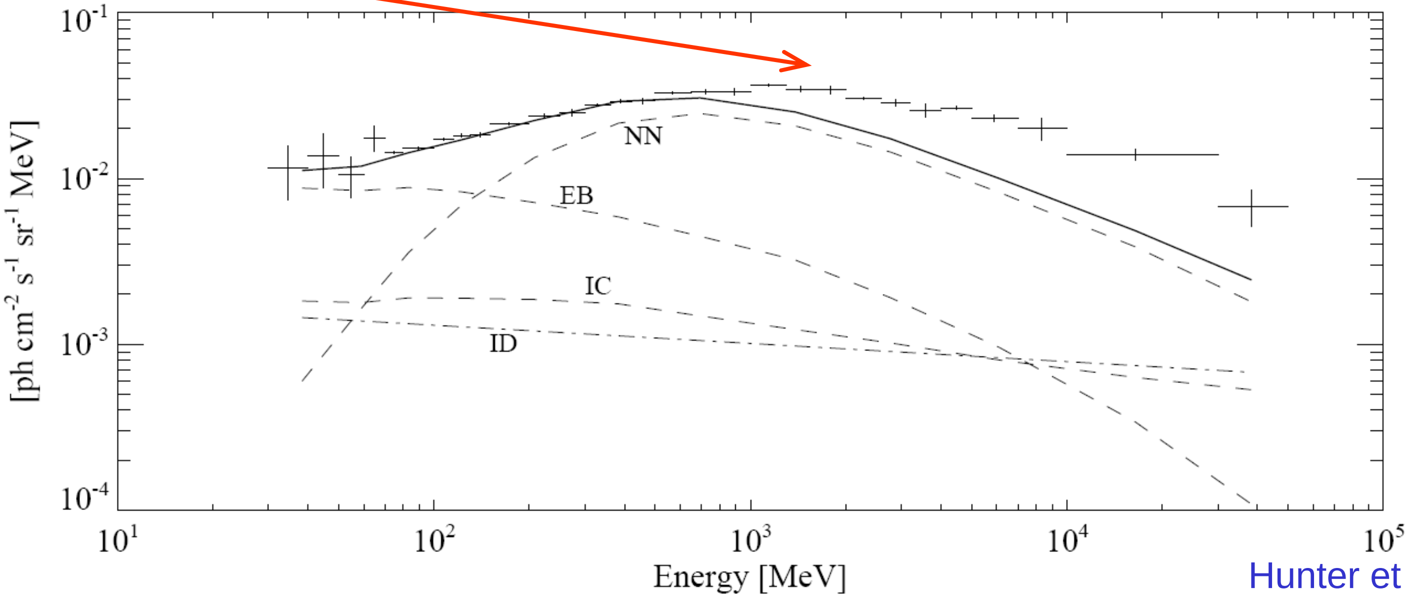


'DC2' model @ 160 MeV

- **Some saving aspects**
  - **The distribution of CRs is much smoother than the dist, of the interstellar gas, especially the molecular gas**
  - **Cosmic-ray data, e.g., B/C ratio, place real constraints on the CR propagation parameters**

Spectral aspects of models: GeV excess

- The EGRET team's model (Hunter et al. 1997), has overall a reasonably good fit to the EGRET data, with few tunable parameters
- 'GeV excess' is significant and has been a subject of intense study

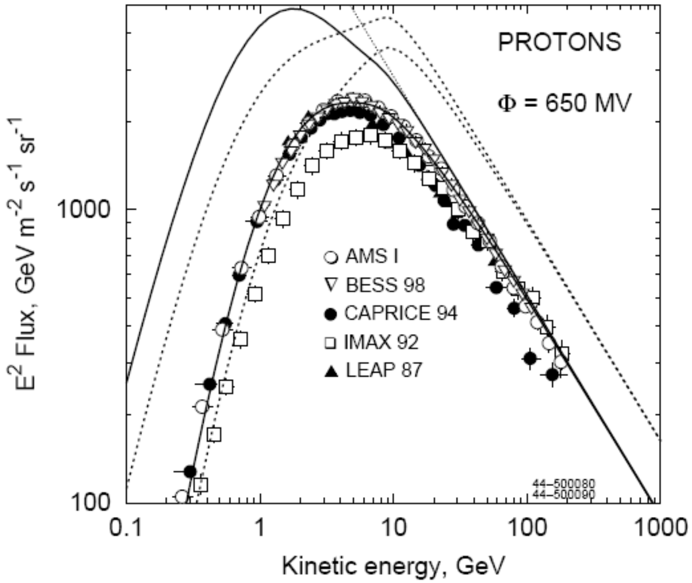


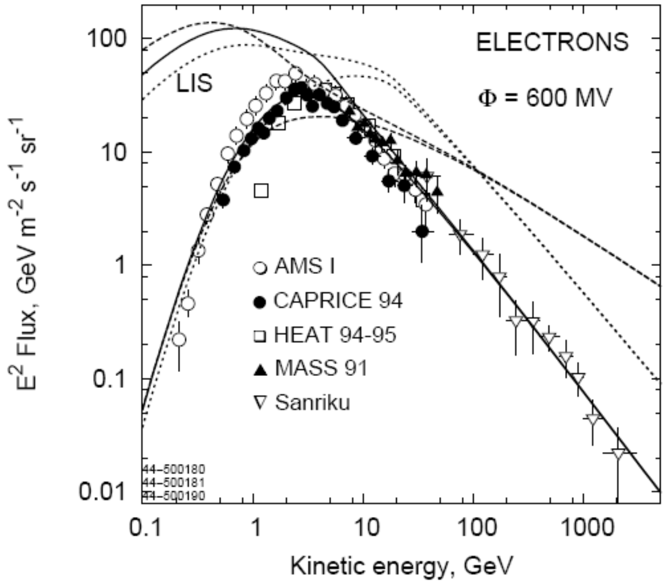
Hunter et al. (1997)

- **Origin:** Faulty production functions? (No – Mori 1997, Kamae et al. 2006) Miscalibration? (Probably not) Point sources (Probably not)

GeV excess (2)

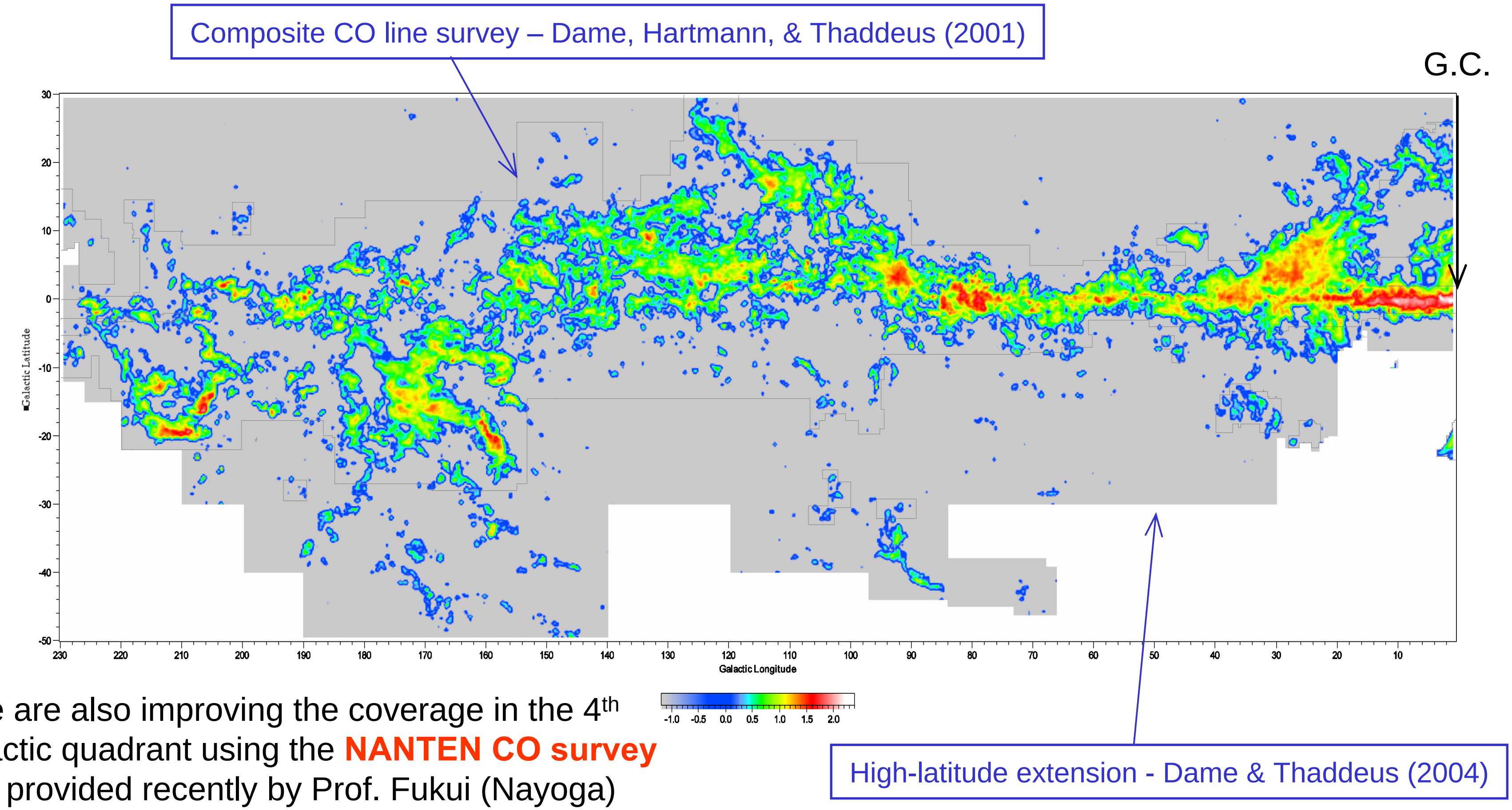
- **Strong et al. (2004) found that the cosmic-ray spectra could be tuned ('optimized') to make γ-ray intensities consistent with the GeV excess without violating the various other constraints (not including detailed agreement with the locally-measured CR spectra)**





Details of nearby (|*b*| > 10°) interstellar gas

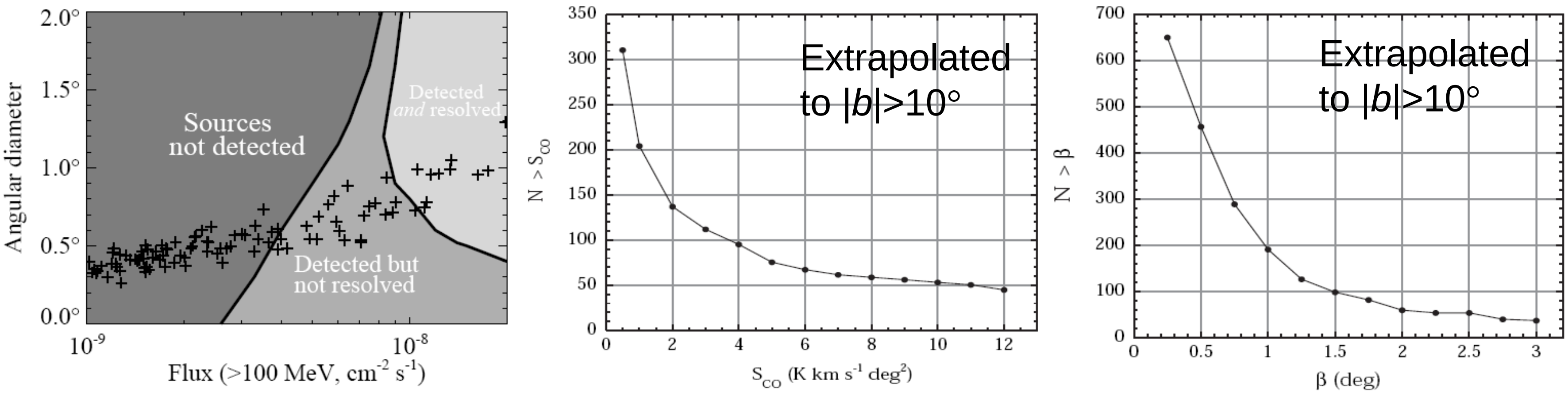
- **Dense (molecular), small interstellar clouds exist at high latitudes, with small filling factor**



* We are also improving the coverage in the 4th Galactic quadrant using the **NANTEN CO survey** data provided recently by Prof. Fukui (Nayoga)

Why details matter

- **Many are likely to be detectable with the LAT and some also have resolvable diameters – and would otherwise be unidentified steady sources**

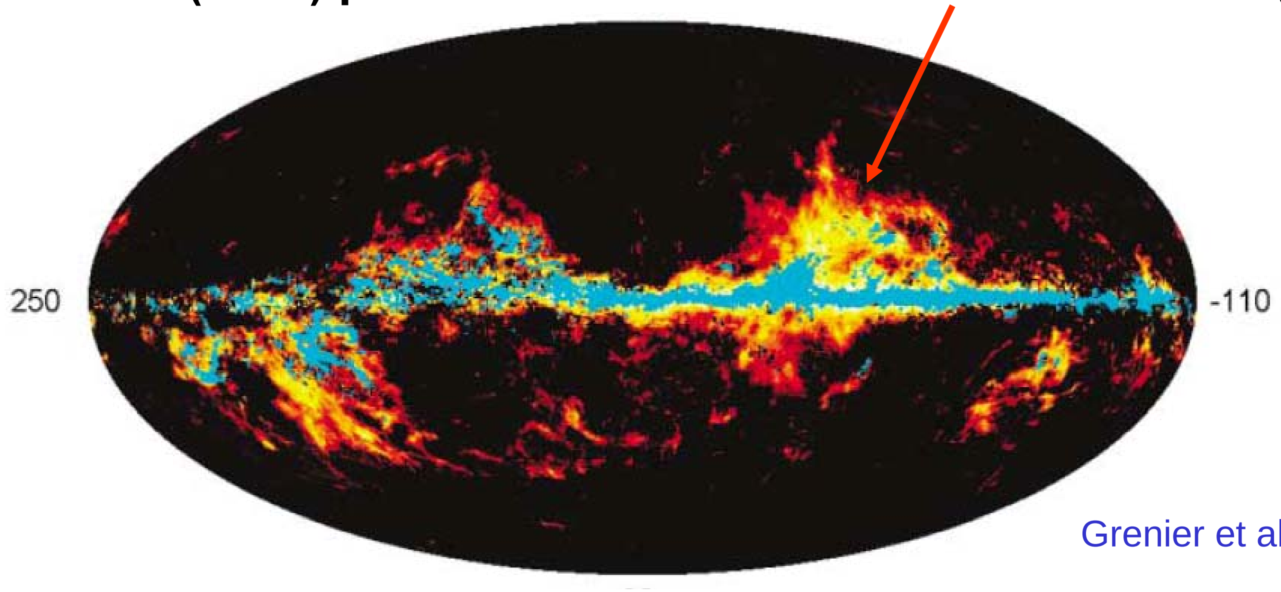


Torres, Dame, & Digel (2005)

- **Extrapolating to the entire |*b*| > 10° sky, Torres et al. estimate ~140 detectable high-latitude clouds with ~30 resolvable**

‘Dark’ interstellar gas

- Grenier et al. (2005) presented evidence for ‘dark’ interstellar gas



N.B. not centered on G. C.

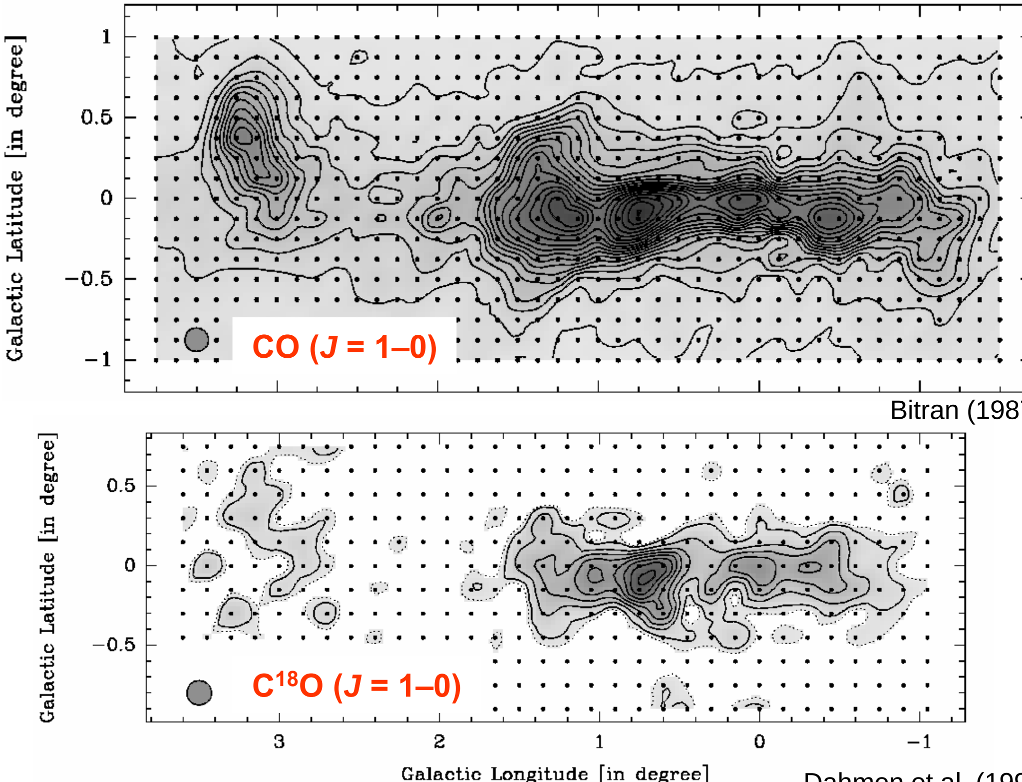
Grenier et al. (2005)

  - From carefully treated IR surveys (Schlegel et al. 1998), the column density of dust can be inferred;
  - If the properties of the dust, and the gas-to-dust ratio, are invariant, then this is a tracer of column density
  - The dark gas is the residual component of inferred column density that does not

Galactic center

- CO fails as a tracer of molecular hydrogen in the Galactic center region
- Molecular clouds there have extremely broad velocity dispersions, and this makes the clouds much brighter in the (optically thick) CO line
- We will investigate other tracers of column density, e.g., $C^{18}O$ (optically thinner)
  - H.E.S.S. (Aharonian et al. 2006) used a CS survey

Galactic Center



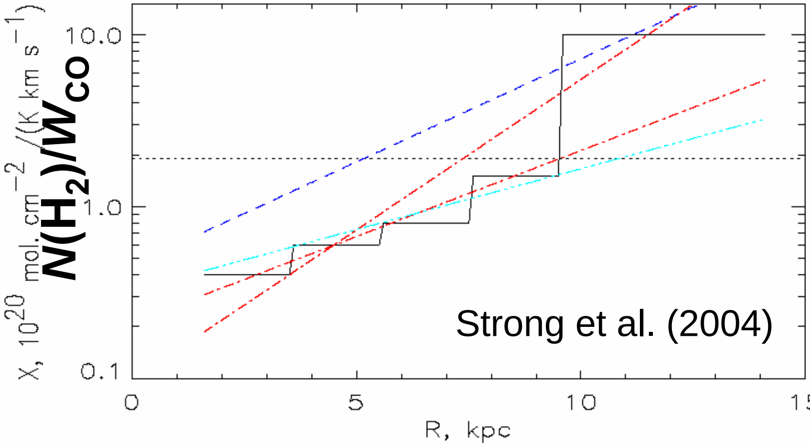
Bitran (1987)

Dahmen et al. (1998)

Metallicity gradient and distribution of CR sources

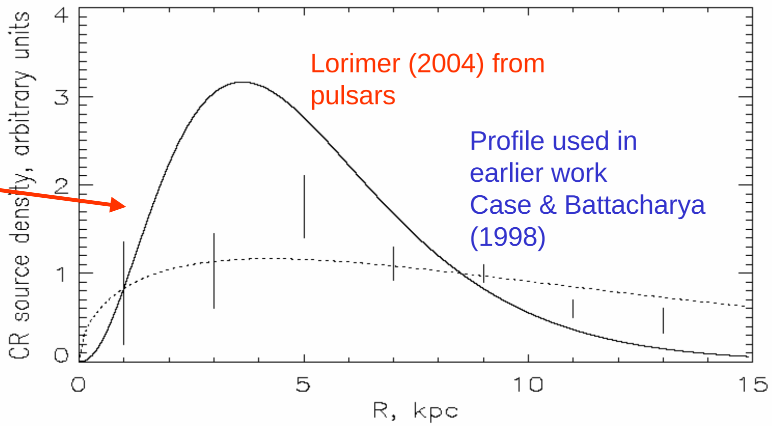
- Metallicity of the interstellar gas depends on processing in successive generations of stars
  - Metallicity gradient may be as steep as 0.04-0.07 kpc^{-1} in log Z
- Z dependence of $N(H_2)/W_{CO}$ may be as steep as Z^{-1} or even $Z^{-2.5}$

Inferred Variation of $N(H_2)/W_{CO}$



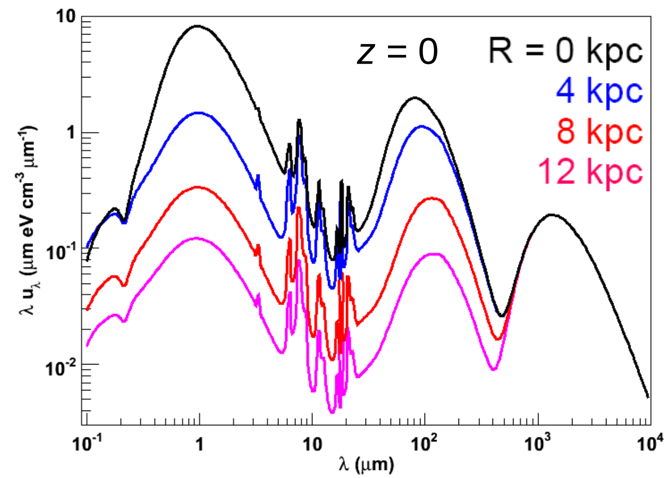
- This gradient could explain the long-standing discrepancy between the cosmic-ray gradient inferred from modeling and that expected from the SN distribution
- Both distributions will be investigated in analysis of LAT data

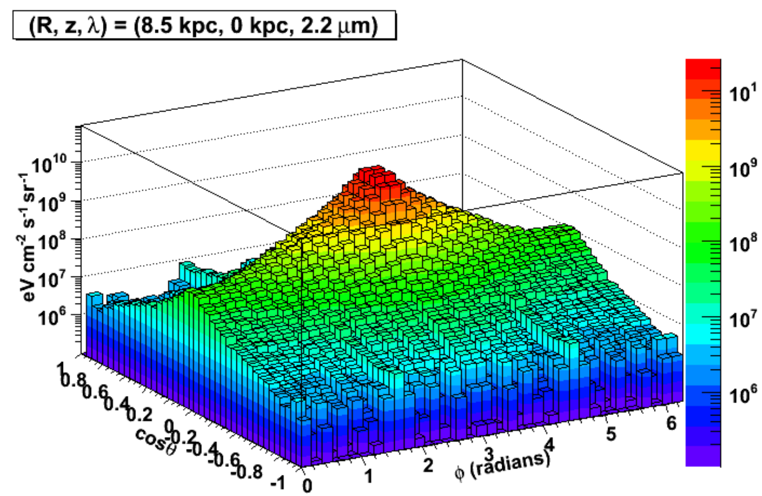
Inferred Distribution of CR Sources



Interstellar radiation field

- Built from detailed stellar population and distribution models, detailed model for dust absorption and scattering, and variation of dust properties across the Milky Way (Porter)
- The recent calculation retains the intrinsic anisotropy – count the dimensions
- AGN analysts please note: The ISRF has other applications – e.g., γ-γ attenuation through the Milky Way at >10 TeV energies (Porter)





Porter, Strong, & Moskalenko (P14.16)

Cosmic rays in the Milky Way

- **We are using GALPROP (e.g., Strong, Moskalenko, & Reimer 2004) as the framework for calculating the gamma-ray emission (and for ultimately learning something from the LAT data*)**
- **GALPROP is a cosmic-ray propagation code (surprise). Other propagation codes exist, e.g., Pohl & Esposito (1998)**
- **Also other approaches have been used for determining CR densities for diffuse γ-rays**
  - **Build in assumption of coupling to gas and derive 3-dim distribution of gas (e.g., Hunter et al. 1997)**
  - **Fit the cosmic-ray density profile (e.g., COS-B papers, Strong & Mattox 1996, and studies of individual clouds)**

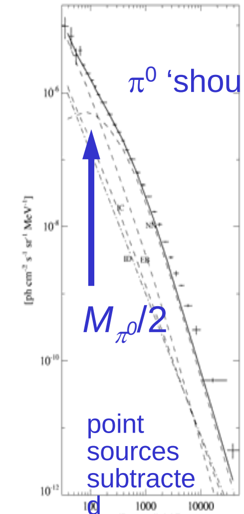
* and PAMELA and Planck

Unresolved point sources in the Milky Way

- A large fraction of the point sources detected by EGRET is within the Milky Way
  - Typical luminosity ~ (1–15) × 10^{35} erg s^{-1} (isotropic) for an EGRET Galactic point source (characteristic distance 1–6 kpc), Mukherjee et al. (1995), Kanbach et al. (1996)
  - Known or plausible source classes include: rotation-powered pulsars, millisecond pulsars, binary pulsars, plerions, microquasars, SNR, OB/WR associations
- The bright pulsars are all quite close by on a Galactic scale
  - Crab (10^{35} erg s^{-1} @ 2 kpc), Geminga (10^{33} erg s^{-1} @ 160 pc), Vela (10^{34} erg s^{-1} @ 300 pc)
- What could be 'under' the diffuse emission as observed by EGRET? For sure more distant, undetected (in γ-rays) pulsars are present

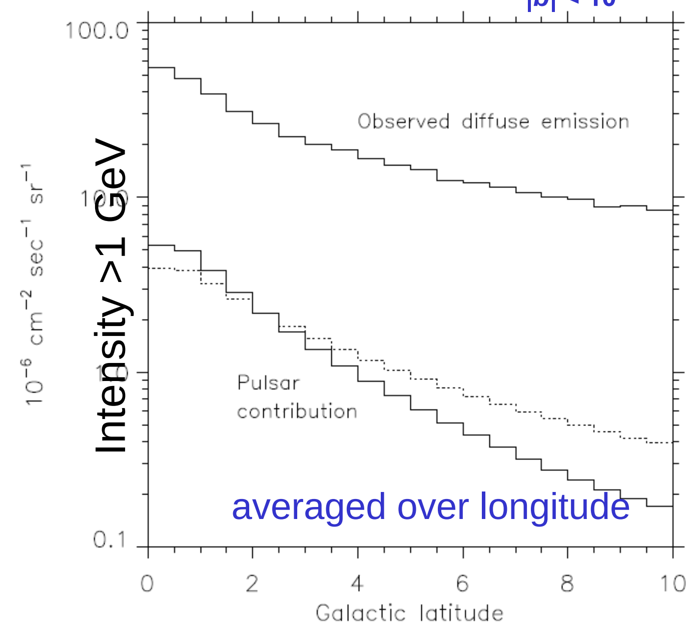
Point sources in MW (2)

- **Hunter et al. (1997) argued that if the unresolved sources are distributed like the molecular gas and typically have photon index -2, then** the fraction of the diffuse emission from cosmic-ray interactions with the H_2 which can be attributed to the unidentified sources must be less than 10%; otherwise the good spectral agreement between the model and the observation (30–1000 MeV) would be reduced.



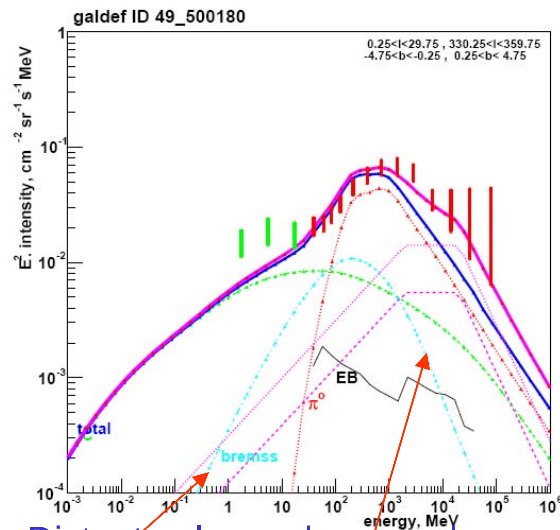
Hunter et al. (1997)

- **Pohl et al. (1997) find that pulsars can contribute significantly (up to ~18%) in the range >1 GeV but the distribution in latitude of the unresolved γ-ray pulsars is narrower than that of the diffuse emission**



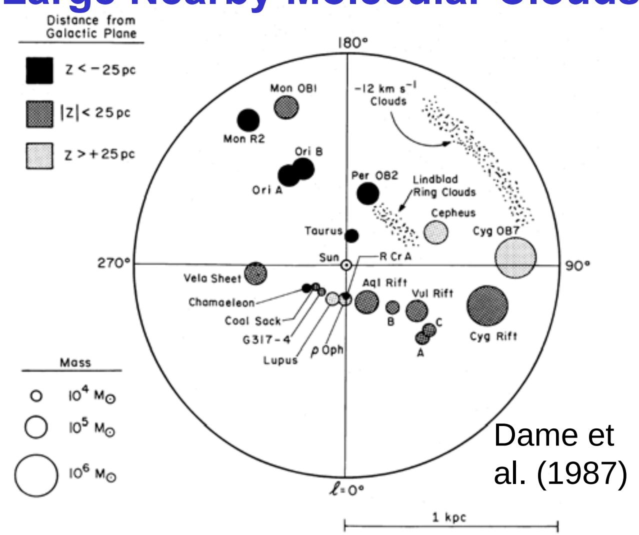
Point sources in MW (3)

- Strong (2006) has shown (more or less as an exercise) that if the GeV excess needed explaining, a simple luminosity function for Geminga-like pulsars can be adjusted to do the job
  - Spatial distribution of pulsars is assumed to be like Lorimer (2004) – and the same question about latitude distribution probably remains
- With the LAT, nearby molecular clouds can be searched for low-luminosity point sources that would not be detected elsewhere



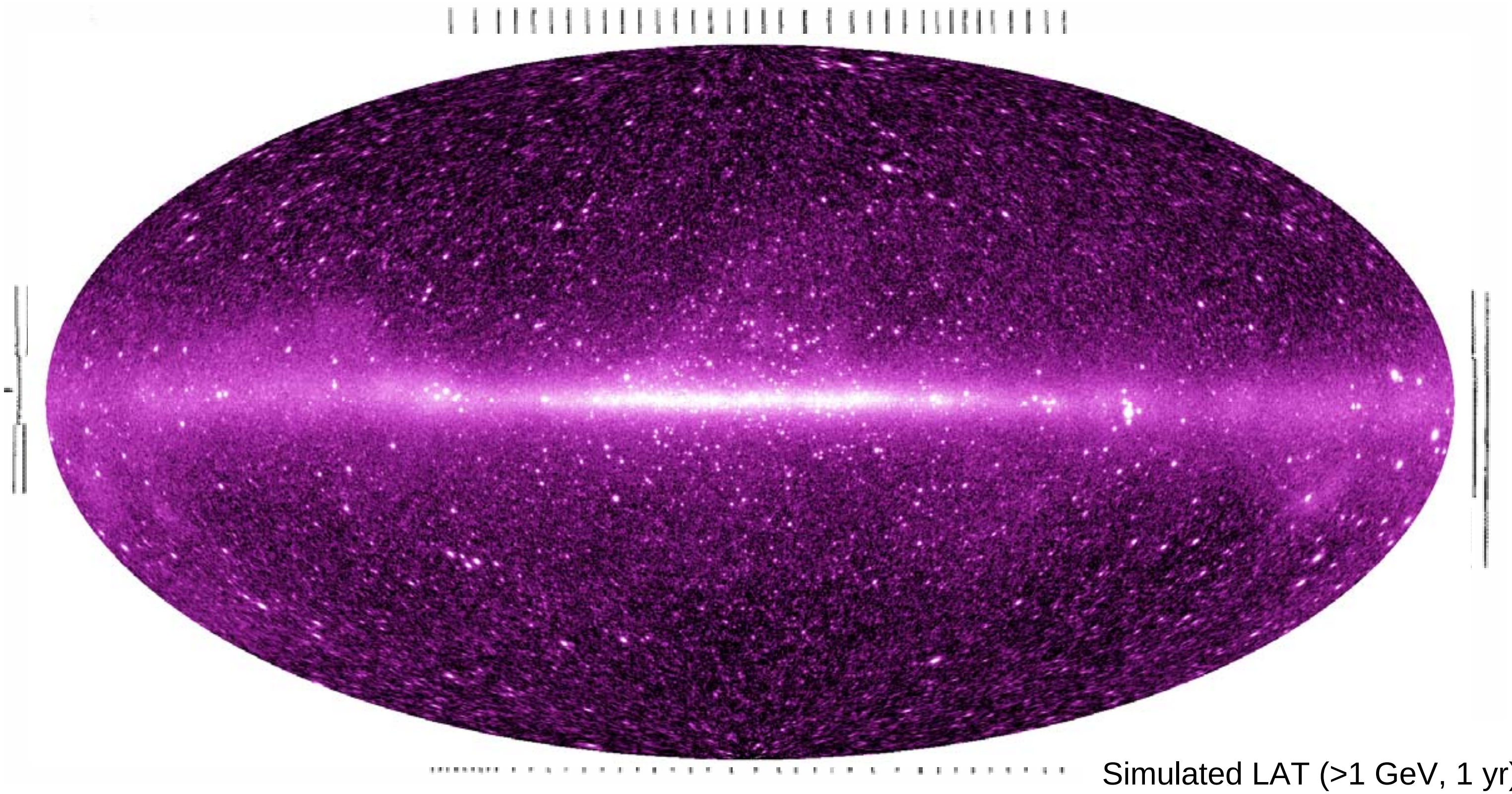
Distant pulsars above and below the EGRET flux limit

Large Nearby Molecular Clouds



Dame et al. (1987)

Looking forward to the LAT

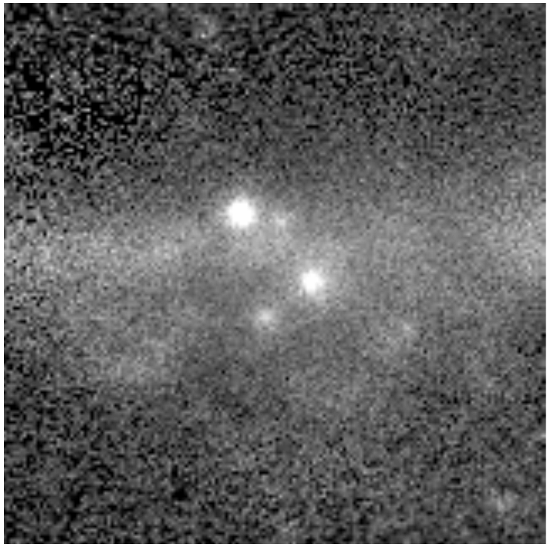


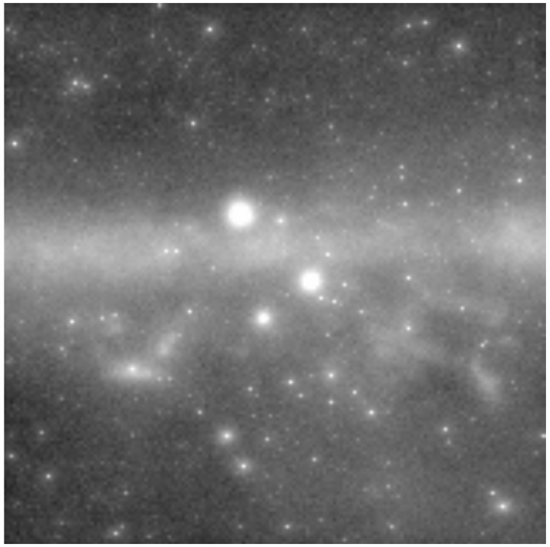
Simulated LAT (>1 GeV, 1 yr)

Summary

- The diffuse emission of the Milky Way is bright and pervasive at LAT energies
- Galactic diffuse emission
  - Relates to the density of cosmic rays and the distribution of interstellar gas and radiation, which are themselves of interest to astronomers
  - Models have been used since COS-B; many refinements are being investigated for the LAT to maximize the scientific return, both for diffuse and point sources

EGRET
Phases 1-5



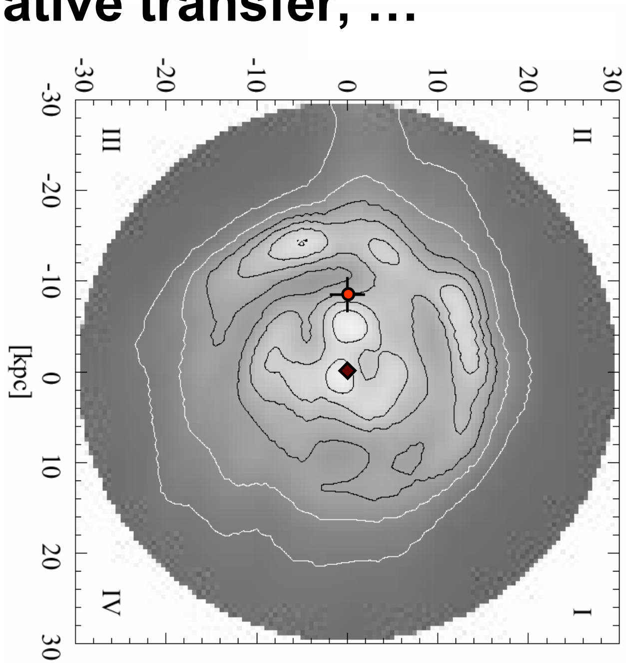


LAT
Sim. 1-yr

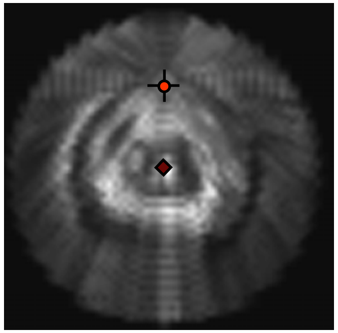
Backup slides follow

Overall distribution of interstellar gas

- **No unique answer – owing to distance ambiguity, choice of rotation curve, streaming motions, radiative transfer, …**



Hunter et al. (1997)



Pohl & Esposito (1998)

Two studies that started with essentially the same data disagree in many details

Sun

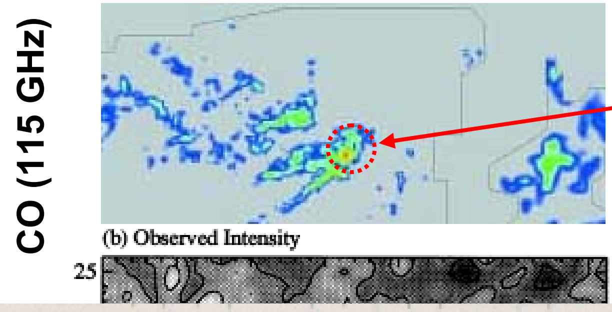
Galactic Center

Also poster P17.12 by M. Pohl

Confusion with point sources

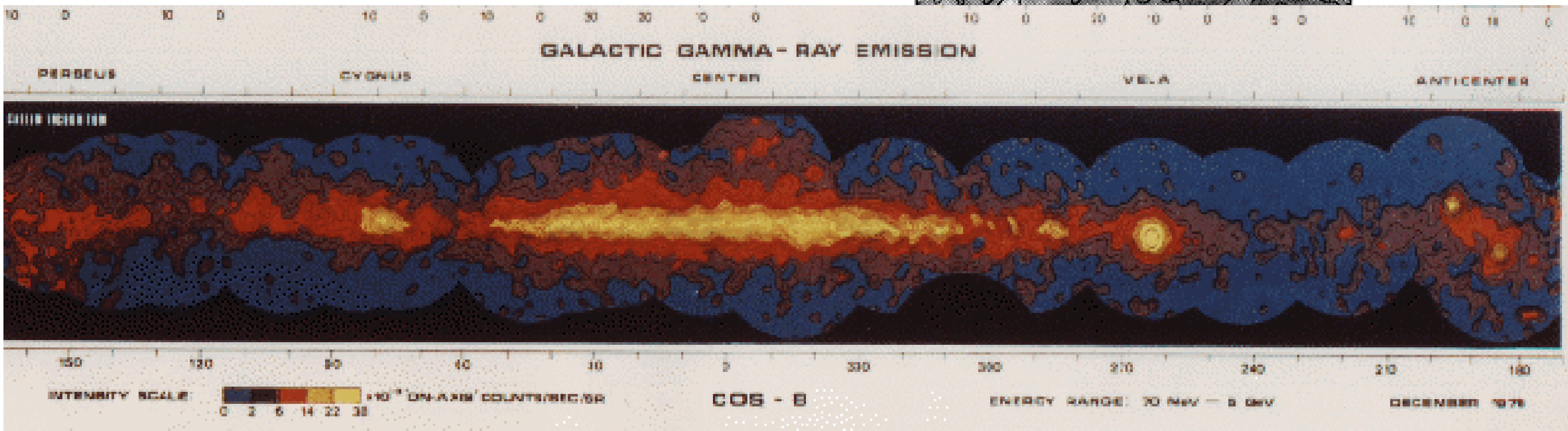
- At low latitudes especially, an inaccurate model will cause spurious detections or at least errors in positions of sources
- Historical example in Ophiuchus

Diffuse Emission in Ophiuchus



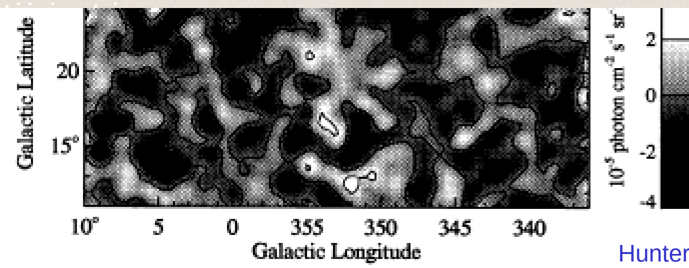
Swanenburg et al. (1981)

Dame et al. (2001)



3!

Oph and found most of the flux to be from a blazar, with accurate position [& variability]

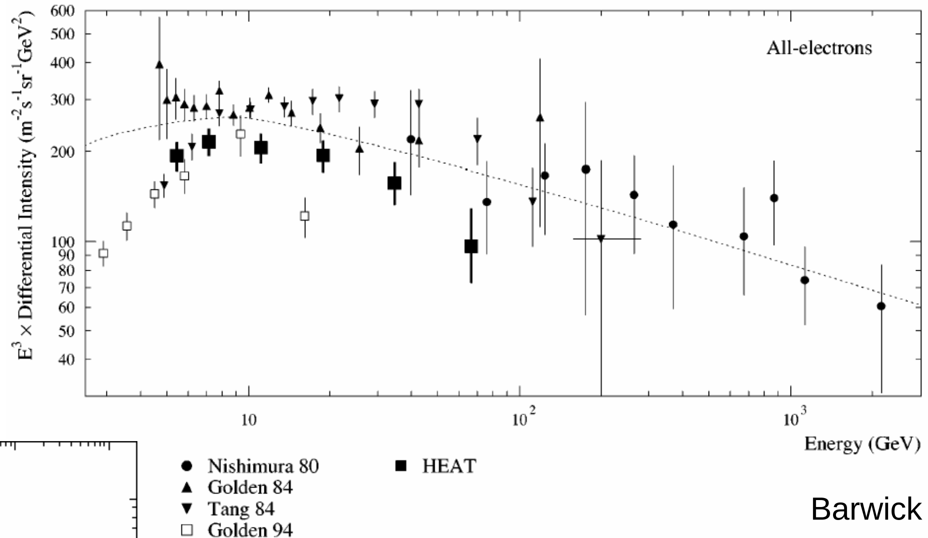


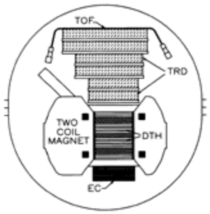
Hunter et al. (1994)

Cosmic rays

- **Measured locally**
- **Corrected for solar modulation**

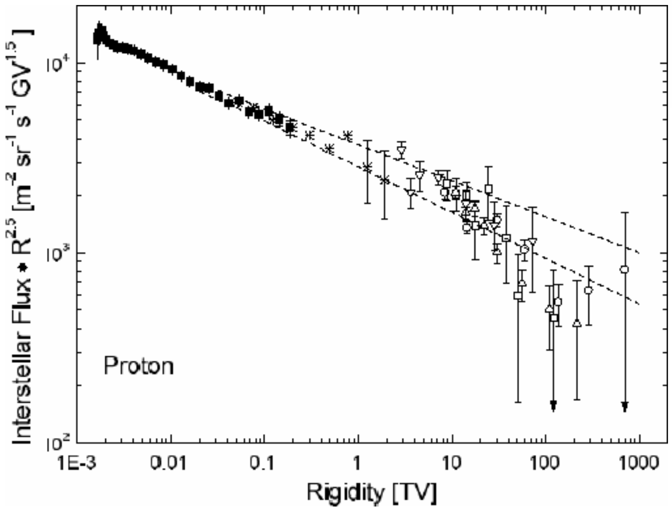
Electrons

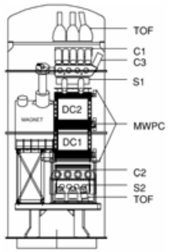




Barwick et al. (1998)

Protons





Menn et al. (2000)