
# Diffuse Galactic Emission in the Fermi-LAT Era

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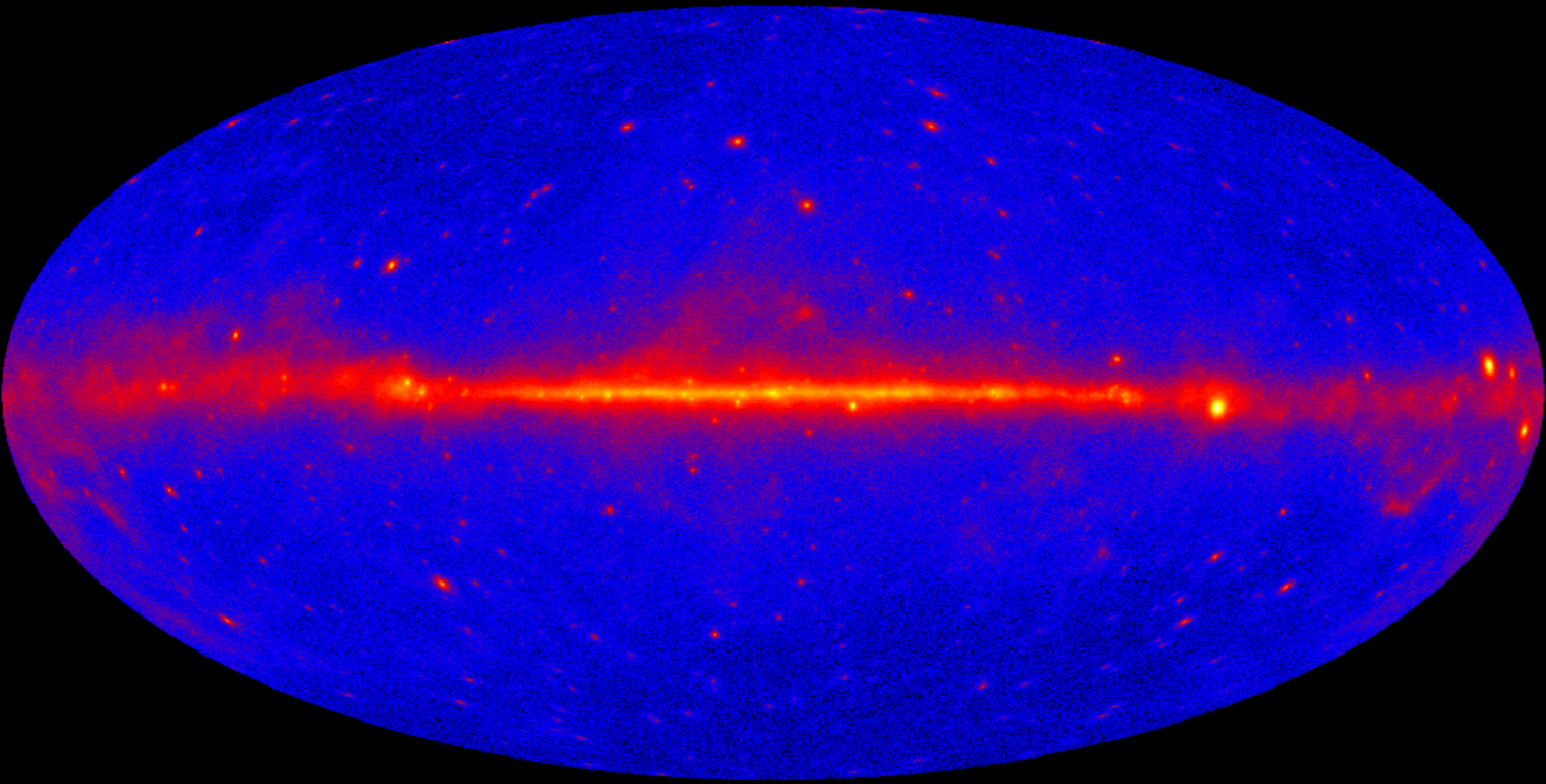
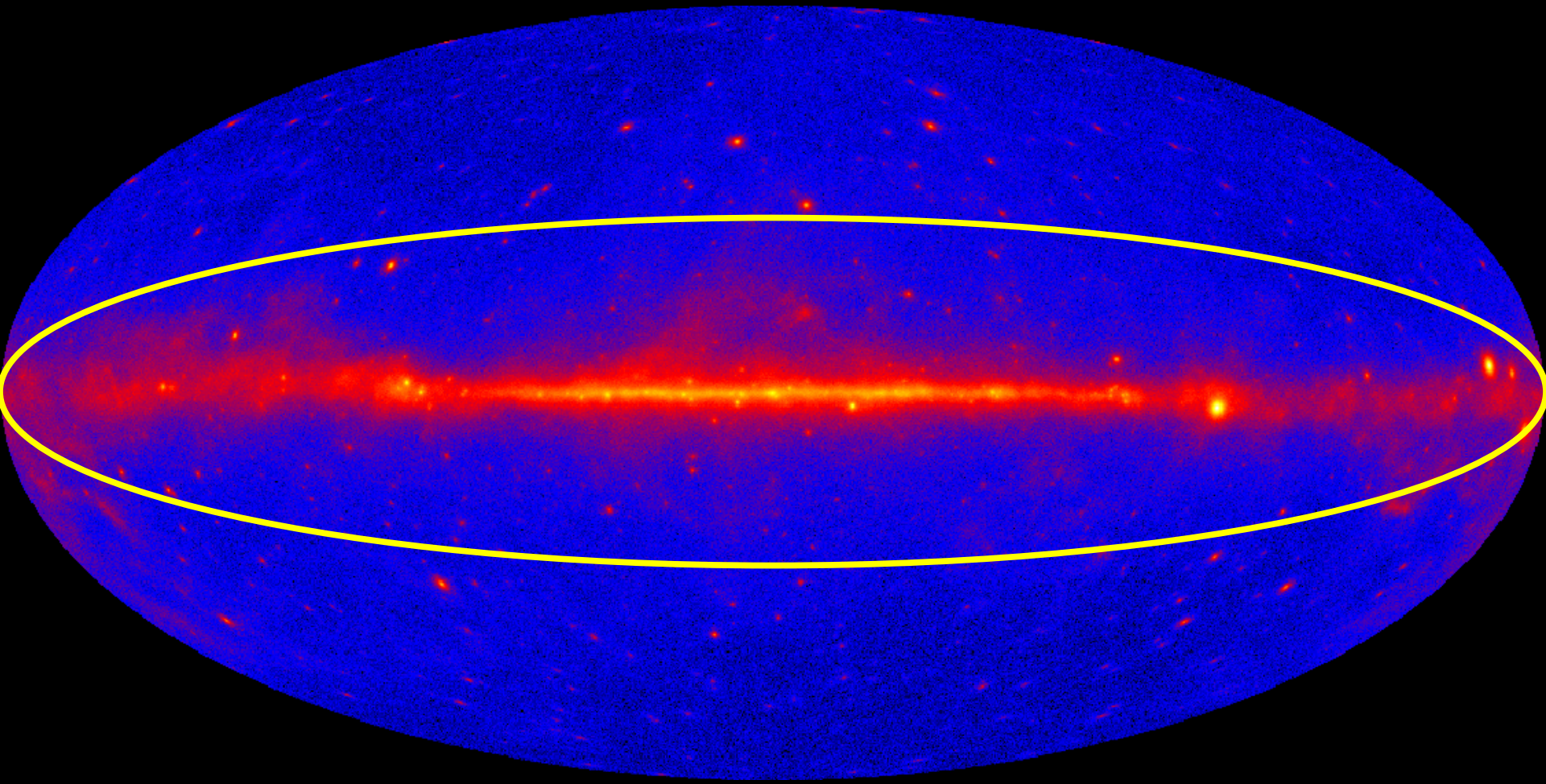
**On behalf of the Fermi Large Area Telescope collaboration**





# Why study the Diffuse Emission?

The Milky Way and its Structure

→ Origin and propagation of cosmic rays
Nature and distribution of sources
The propagation mode itself ↔ relationship to magnetic turbulence in the ISM
Relative proportions of primary species
Production of secondary species
etc.

→ Interstellar Medium
Distribution of HI, $H_2$, HII gas
Nature of $X_{CO}$ relation in Galaxy
Distribution and intensity of interstellar radiation field ↔ formation of $H_2$
etc.

As a Foreground

→ The diffuse emission is the foreground against which sources are detected
Point sources : limitation on sensitivity
Extended sources : disentanglement

→ Indirect dark matter detection
Predicted gamma-ray/cosmic-ray signals rely on accurate subtraction of standard astrophysical sources

→ Foreground for isotropic diffuse background
Whatever its nature

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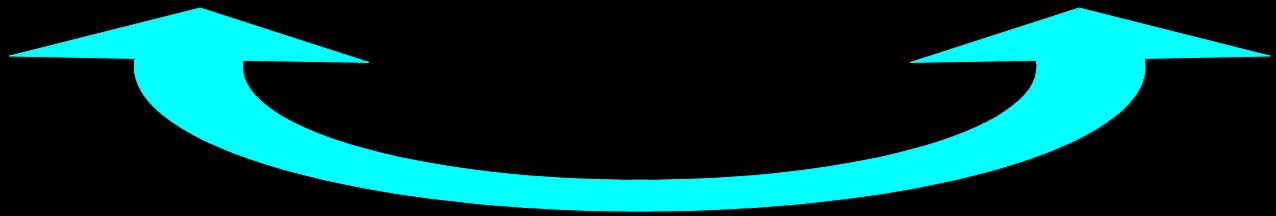
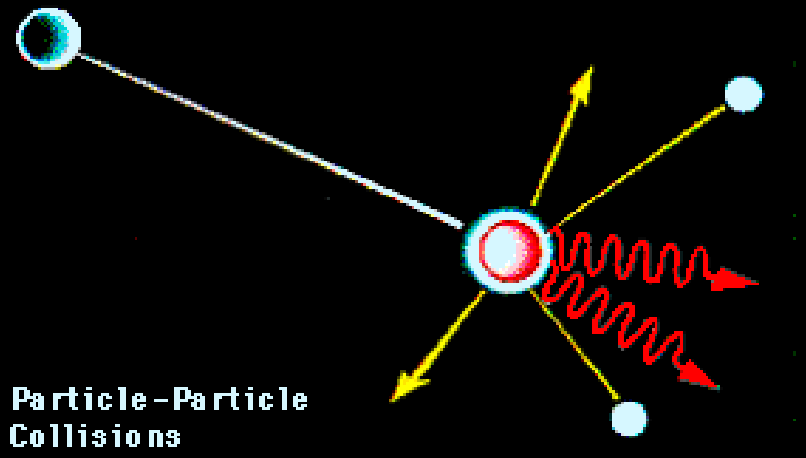
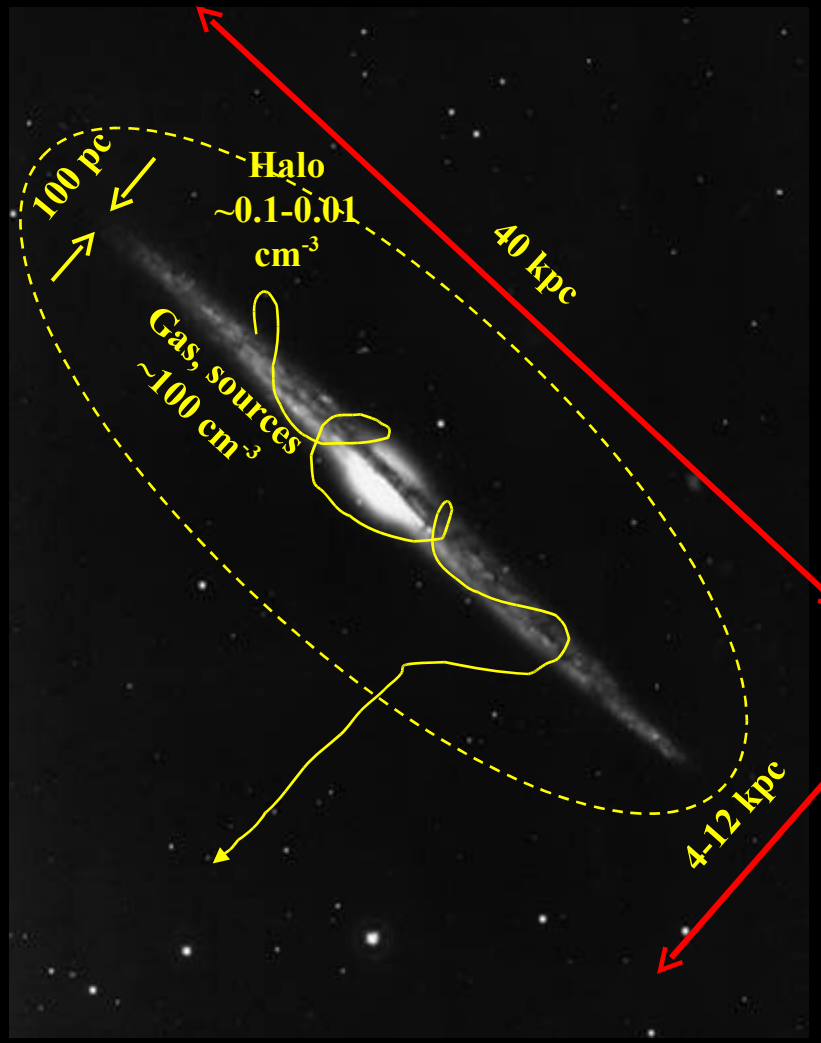


# Cosmic Rays and Diffuse Emission

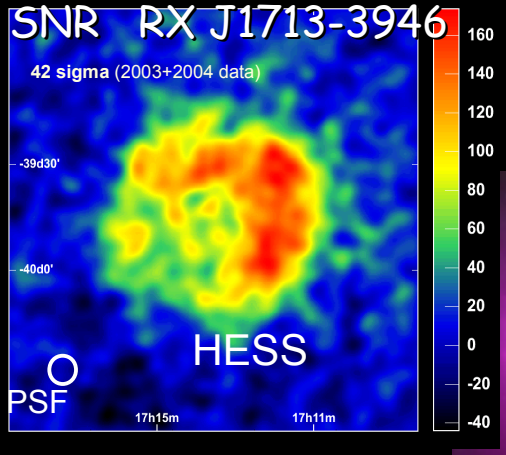
- Cosmic rays injected into ISM propagate for millions of years before escape to intergalactic space
- Particle interactions with interstellar gas and radiation fields produce gamma rays and other secondaries

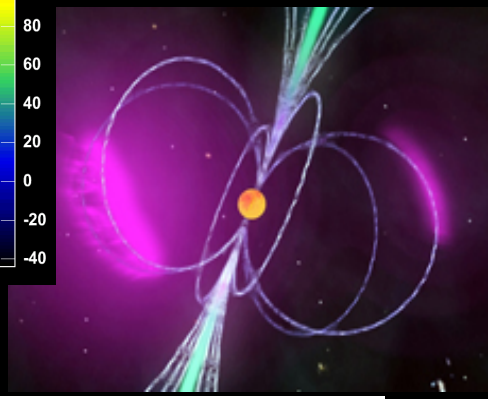


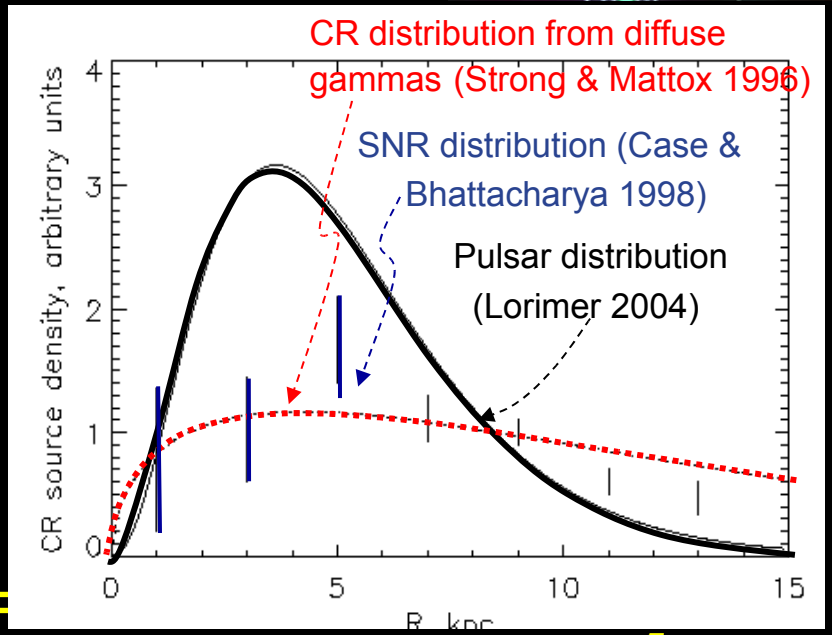



# The Particle Beam: Cosmic Rays

- Primary cosmic rays from SNR, pulsars, …
- Secondary cosmic rays ($e^{\pm}$, pbar, ..) from interactions with ISM
- Propagation from sources via `interactions' with magnetic turbulence in the ISM
- Details of propagation interpreted within context of model → comparison with measured cosmic-ray spectra

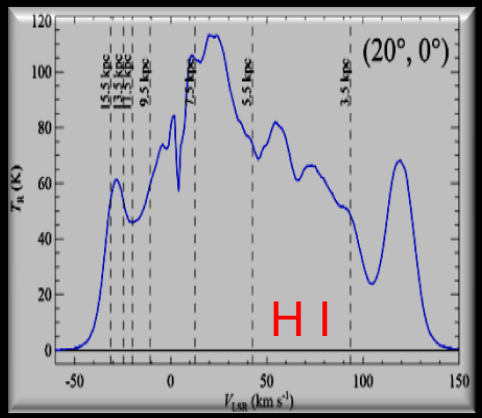


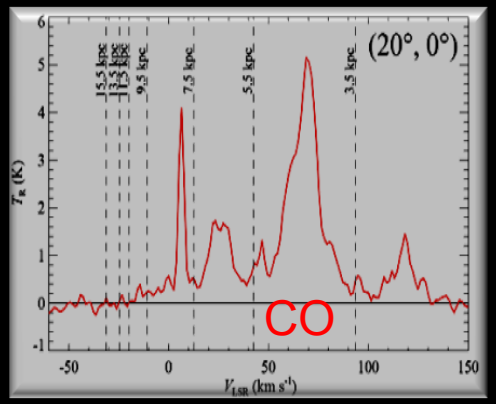



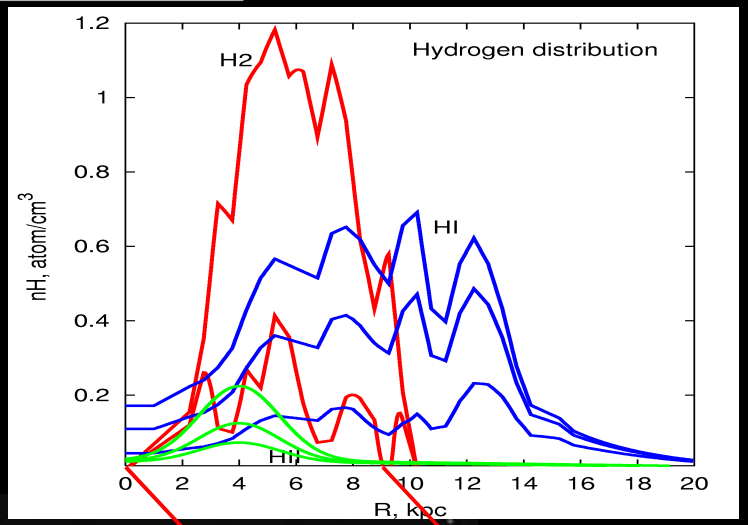


# The Targets #1: Interstellar gas

- Neutral interstellar medium – most of the interstellar gas mass
- Obtain information via 21-cm H I & 2.6-mm CO (second most abundant molecule in ISM - surrogate for $H_2$)
- Transitions excited even for interstellar conditions
- Allow determinations of column densities → Doppler shifts of lines interpreted as distance measure
- HII low density → obtained from modelling pulsar dispersion measurements
- Helium ~10% by number
- `Metals' (i.e., Z > 2) contribute very small fraction compared with H and He

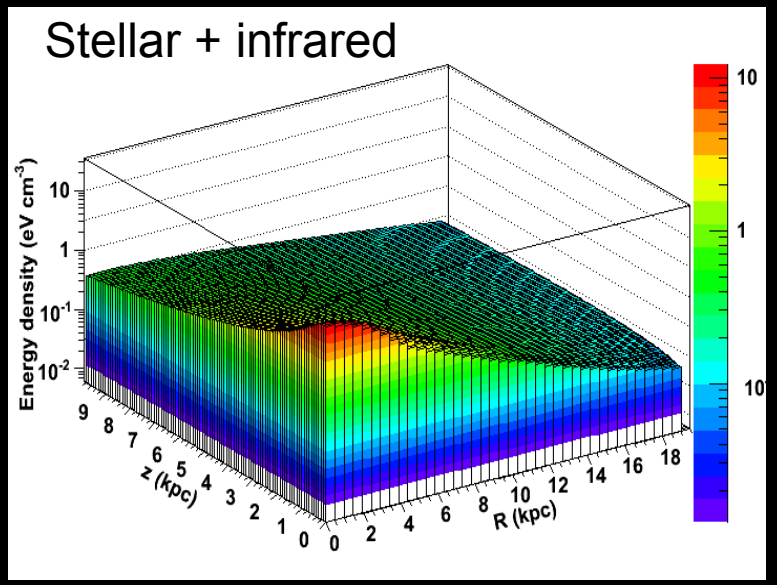


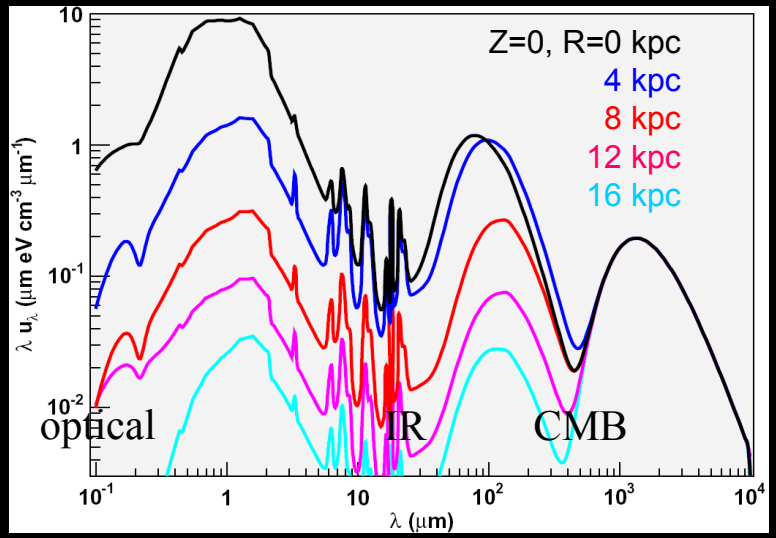



# The Targets #2: Interstellar Radiation Field

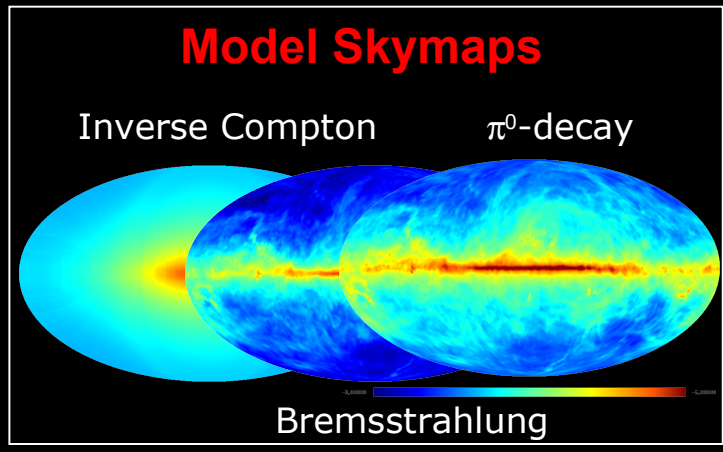
- Interstellar radiation field = low energy photon populations in Galaxy from stellar emission and dust reprocessing of starlight
- Only observed locally so use modelling for spectral energy and angular distributions throughout Galaxy
- Inner Galaxy ISRF energy density > x100 local
- The scale height above the Galactic plane is large (~10 kpc) → pervasive contribution by IC over the sky



# Starting Point

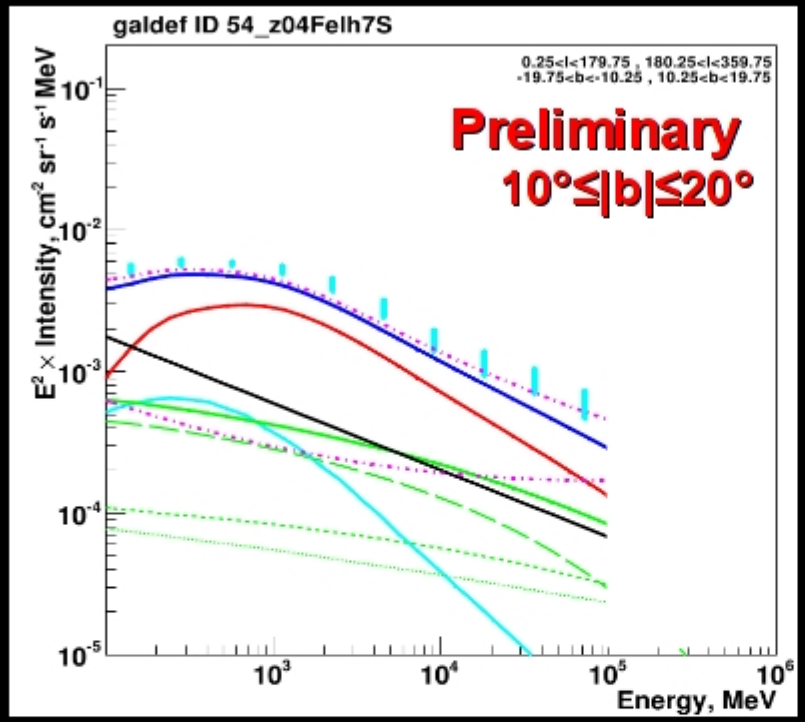
- We use a code called `GALPROP' to study the relation between cosmic-ray production and diffuse emission in the Galaxy
- Starting point for our studies: the cosmic-ray spectra consistent with local observations (cosmic-ray nuclei, Fermi LAT electrons) → reference model
- Model skymaps compared with data using maximum likelihood
- Data we use are same as for the isotropic gamma-ray background analysis → improved background rejection with respect to the standard `diffuse' class events

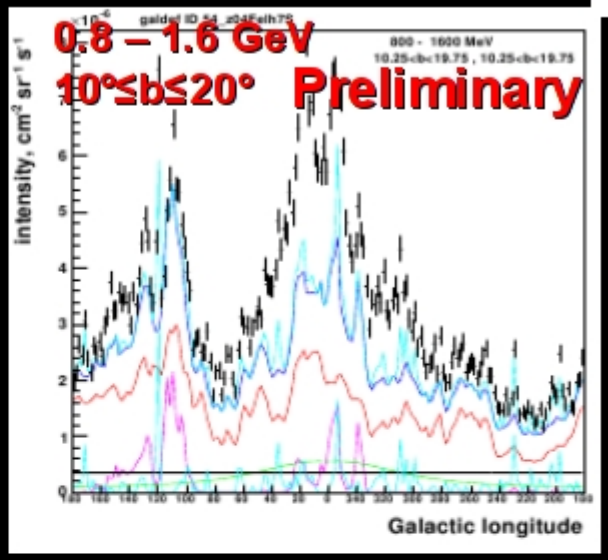


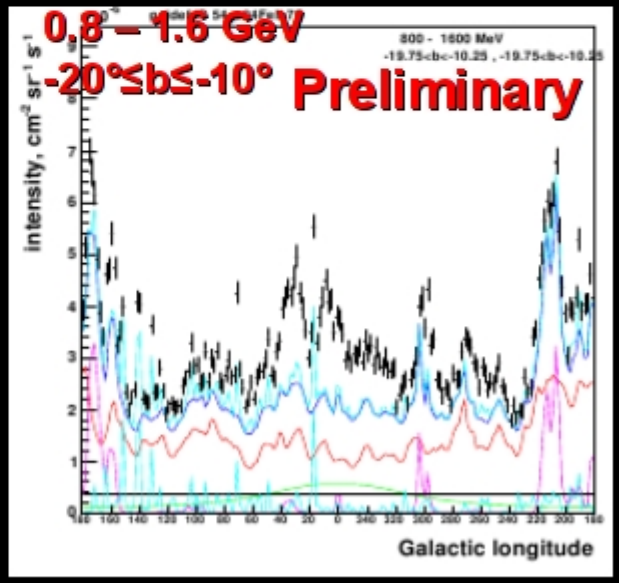

See Poster P4-138

# Reference Model: Intermediate Latitudes

IC:
Total
OPT
IR
CMB
$\pi^0$-decay
Brem
Model total
Catalogue sources



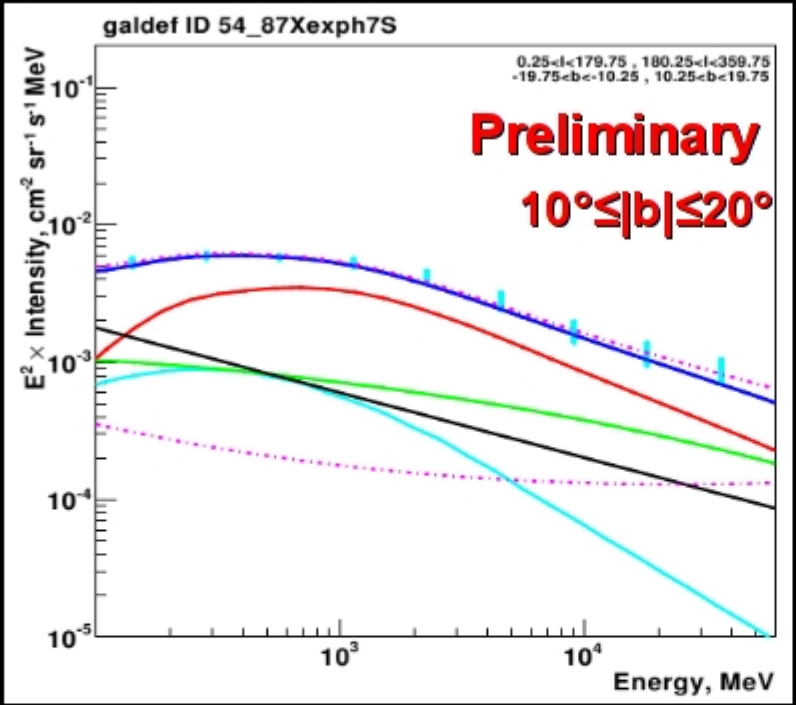

HI
$H_2$
IC
Model
Model + Sources

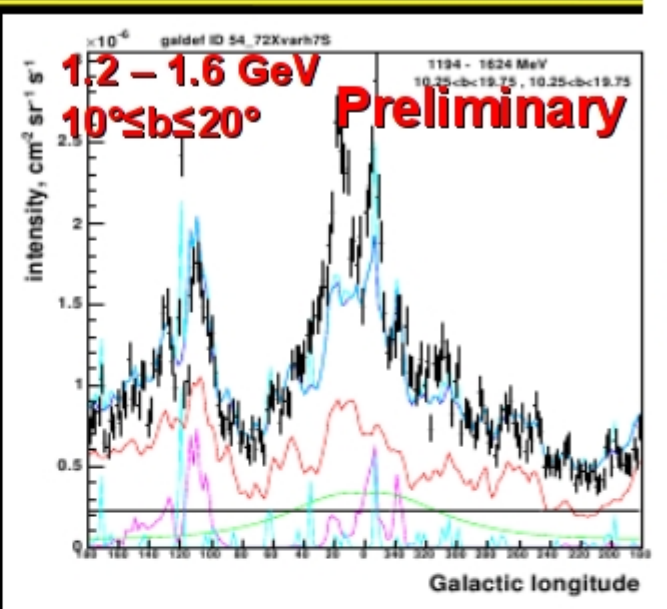
Overall spectral shape is consistent but intensity is too low → increase cosmic-ray intensities or gas not traced by usual methods

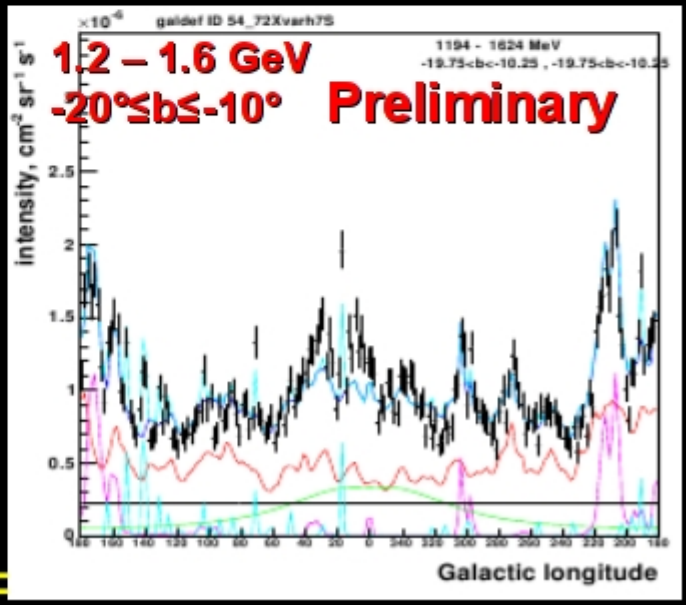
Note: errors systematics dominated

# Modified Model: Intermediate Latitudes

IC:
Total
OPT
IR
CMB
$\pi^0$-decay
Brem
Model total
Catalogue sources




HI
$H_2$
IC
Model
Model + Sources

Spectrum after increasing cosmic-ray intensities is good agreement → residuals in profile plots indicate missing gas, not accounted for with usual tracers

Protons: x1.3

Primary Electrons: x1.7

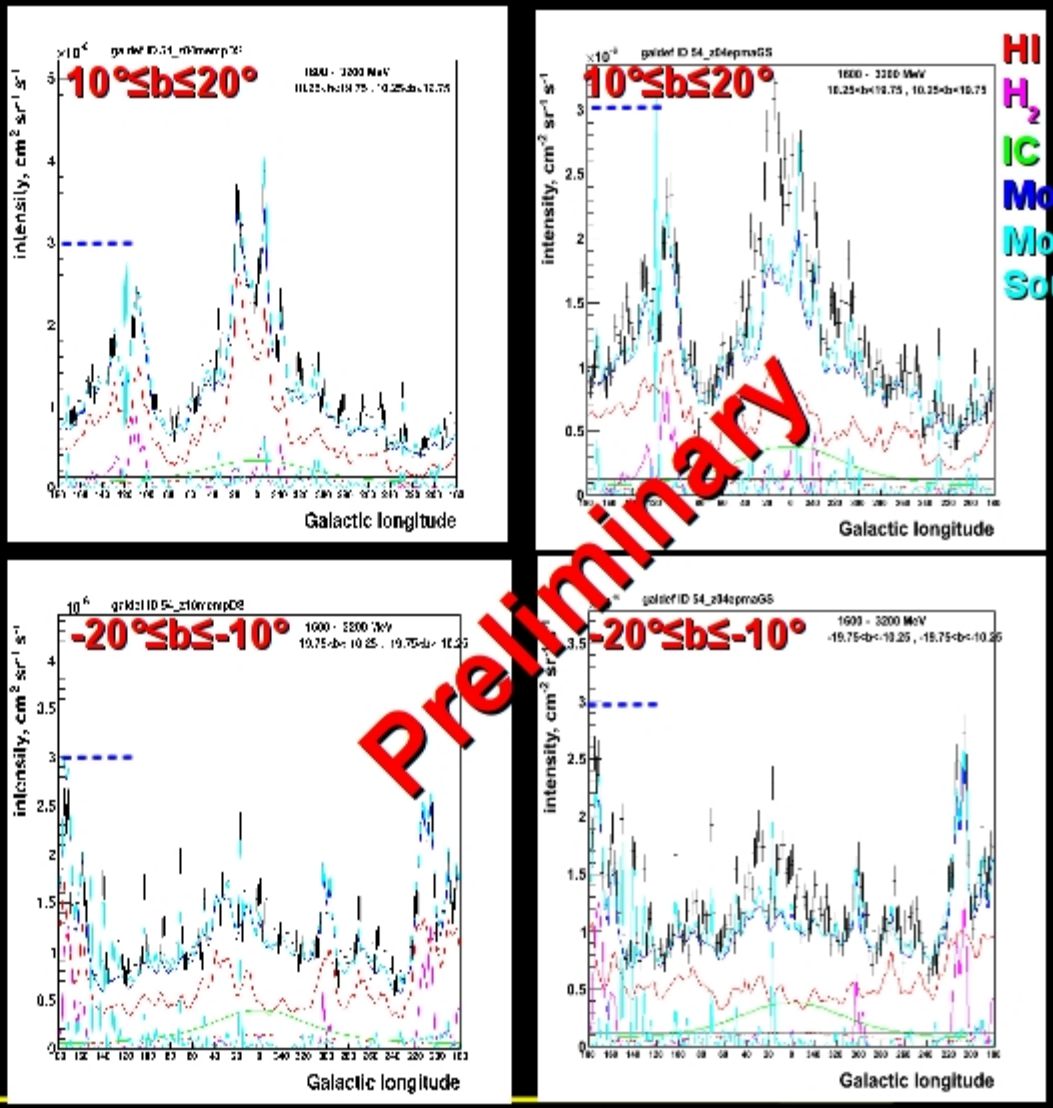
Note: errors systematics dominated

# Modified Model: Including Residual Gas

- Increasing intensity of cosmic-ray spectra improves agreement but profiles show residuals
- Gamma rays → gas not traced by usual methods
- Noted by Grenier & Casandjian (2005)
- A way of incorporating this is into the model is to modify HI with a correction for `local' gas based on dust emission (SFD99)

Dust emission tracer + standard gas

`Standard' HI gas 1.6-3.2 GeV



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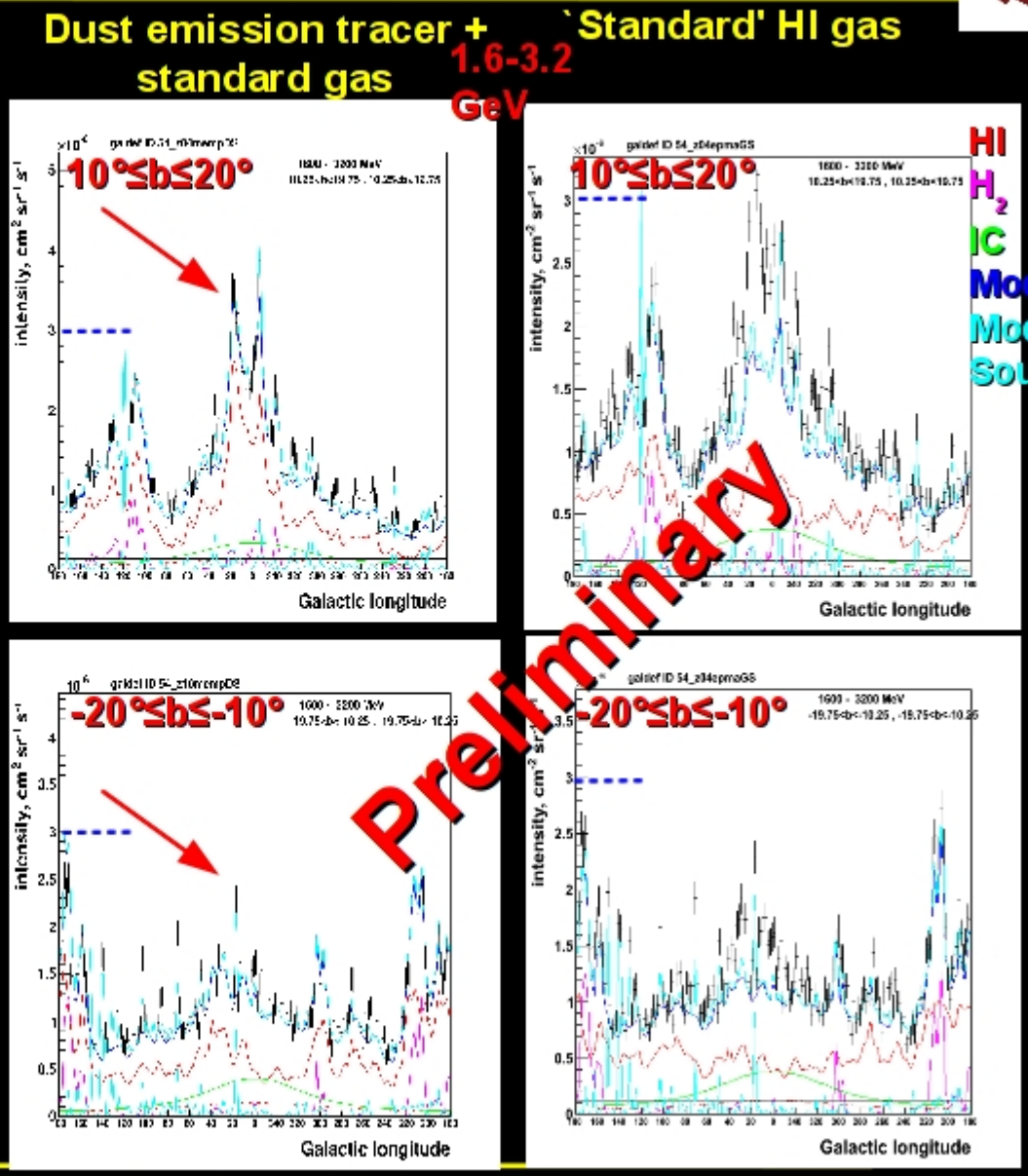
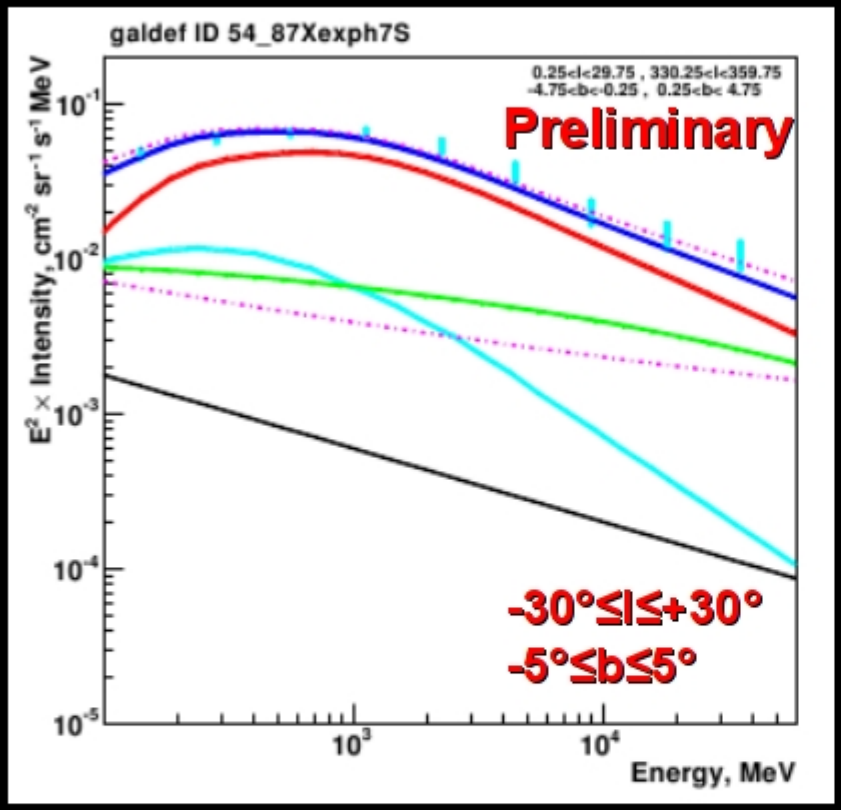
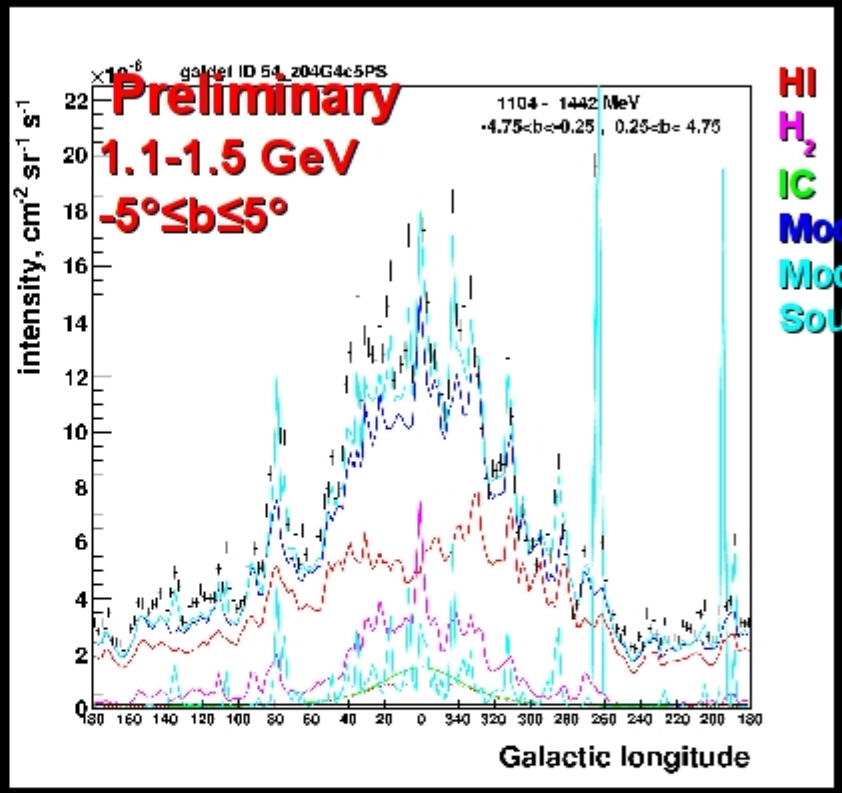


# Modified Model: Inner Galaxy




IC:
Total
OPT
IR
CMB

Brem
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Catalogue sources
Model total

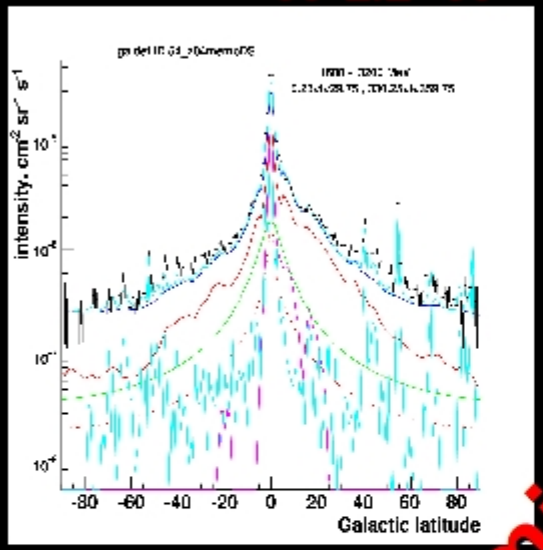
Modified model = increased cosmic-ray intensities and corrections for residual gas → agreement with inner Galaxy is very good in spectrum and profile

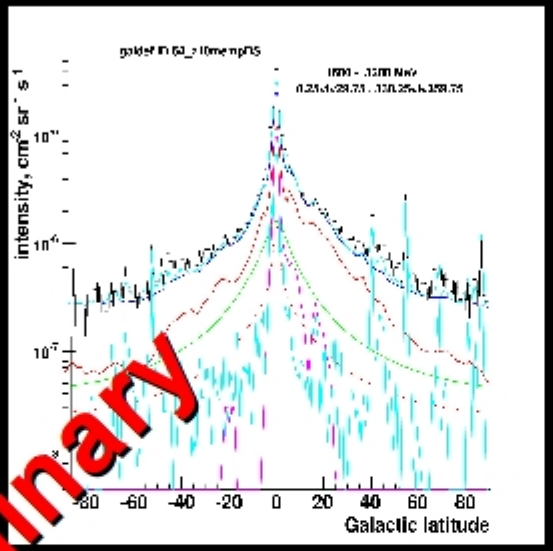
# Extended Cosmic-Ray Halo

## Halo = 4 kpc

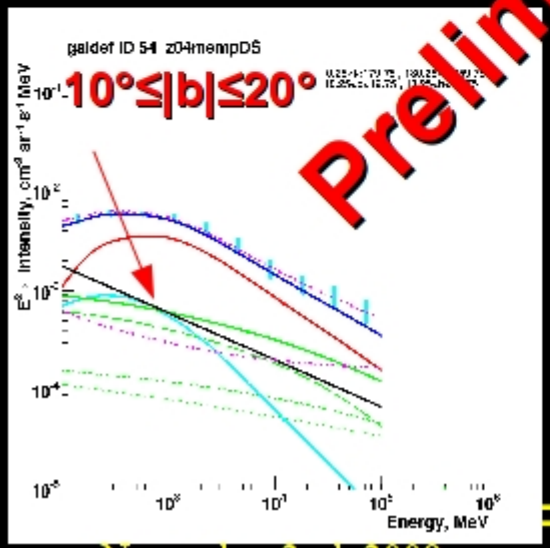
## Halo = 10 kpc

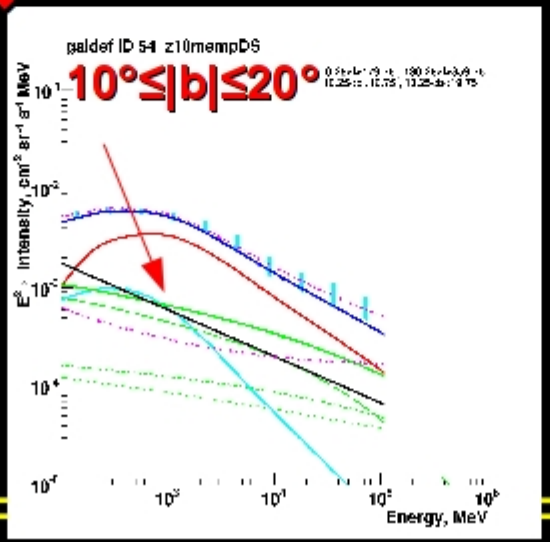
-30°≤l≤+30° 1.6-3.2 GeV



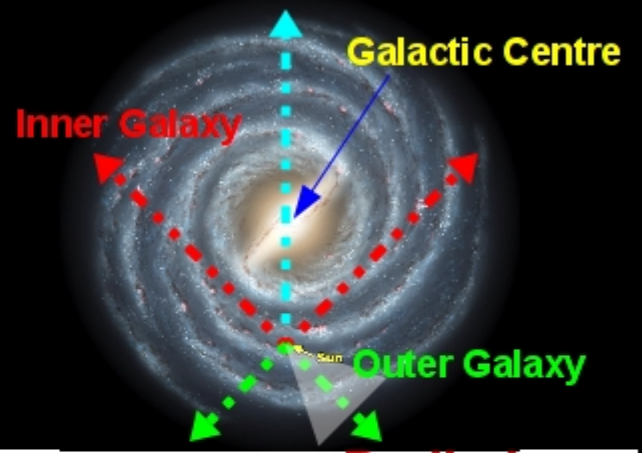




Preliminary




## Study of 3rd Quadrant

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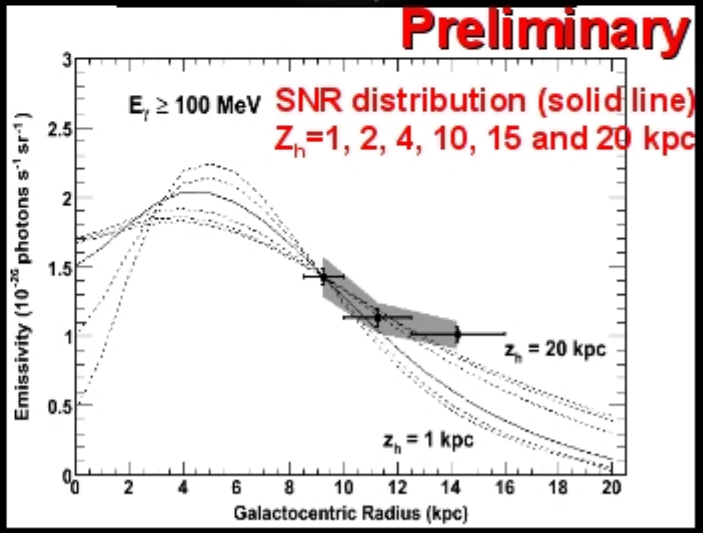


See Poster P4-120

# Summary #1

- The `a-priori' model works fairly well already
  - Gamma rays are showing missing details
    - Gas → cosmic rays `see' all phases of ISM and usual tracers do not give everything → gamma rays probe of the ISM
    - Providing evidence for an extended cosmic-ray halo → `isotropic' background
- Minor modifications improve the agreement
- LAT measurements of the DGE allow an increased sophistication
  - The targets (gas, ISRF) are obtained using observations at other wavelengths and modelling
  - Cosmic ray sources and transport → improve understanding with knowledge of diffuse emission
- Exploring this within the context of a physical model is crucial for understanding what is missing

# Summary #2

- Understanding what is missing is key
  - Unresolved source populations
    - EGRET had them, so will the LAT
    - This modelling is next to be included into our diffuse emission studies (see poster P4-139)
  - Targets → ongoing studies (see poster P4-137)
  - Information from specific regions for gammas and cosmic rays (see DGE-related poster summary)
- There will be many claims of `excesses'
  - Caution: need to demonstrate understanding of the beam (CRs), targets (gas, ISRF), and unresolved source populations
  - This is best done using a physical model

# Summary of DGE-related Posters

- GALPROP modelling of the Galaxy (P4-138)
- Contributions of source populations to the Galactic diffuse emission (P4-139)
- HI spin temperature with Fermi-LAT (P4-137)
- High Energy Gamma-ray Emission Around the North Polar Spur
- Diffuse Gamma-ray Observations of the Orion Molecular Clouds
- Fermi-LAT study of the cosmic-ray gradient in the outer Galaxy: Fermi-LAT view of the 3rd quadrant (P4-120)
- Fermi measurements of the diffuse gamma-ray emission beyond the solar circle: Cassiopeia, Cepheus and the Perseus arm (P4-136)
- Particle Background Effects on Efficiency and Residual Background Contamination of the LAT Diffuse Class Photon Sample
- Extending the Galactic cosmic-ray positron + electron spectrum measured by the Fermi-LAT
- Searches for Cosmic-ray Electron Anisotropies in the Fermi-LAT Data
- The High Energy Cosmic Ray Electron Spectrum measured with the Fermi Space Telescope: some possible interpretations

# Diffuse Galactic Emission: Spectrum, Longitude, and Latitude Profile

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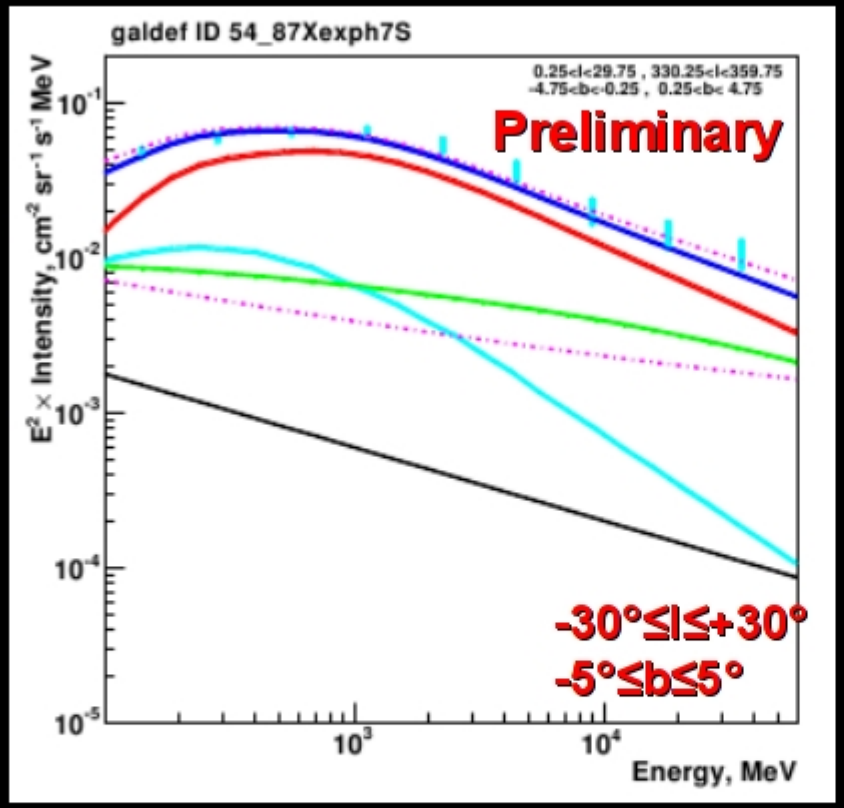
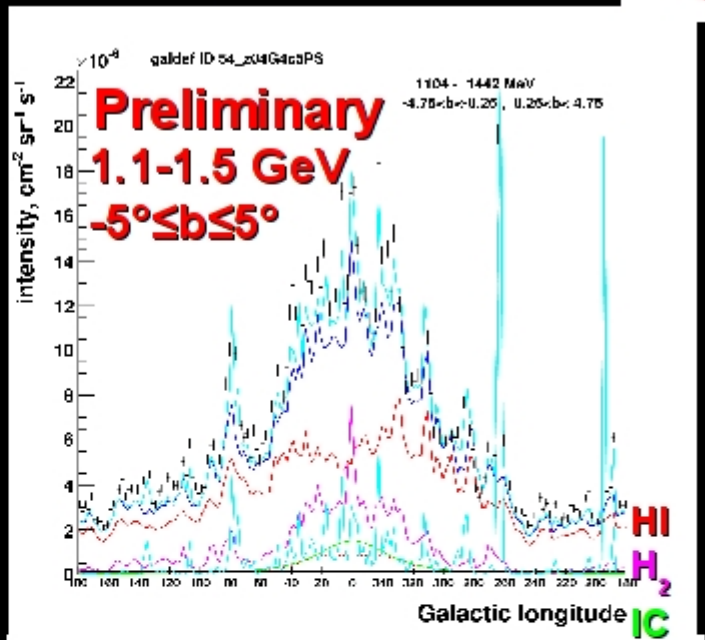
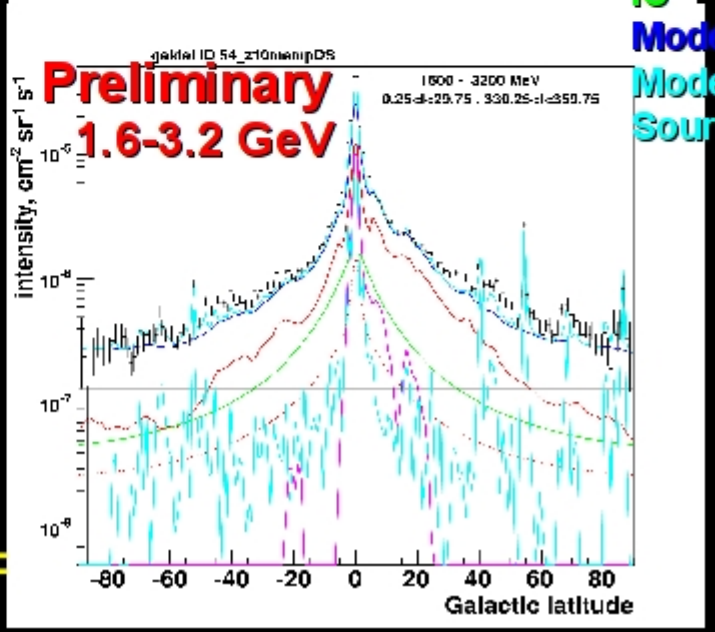
Model total




**Model describes large-scale diffuse emission over whole sky within 10%**