A First Look at the GeV Excess with Fermi LAT

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Introduction to Galactic Diffuse Emission

- Cosmic-rays propagating through the galaxy interact with gas and radiation to create $\gamma$-rays:
  - $\pi^0$-decay
  - Inverse Compton
  - Bremsstrahlung

The fine structure of the Galactic diffuse emission is determined by the gas distribution

GALPROP output
http://galprop.stanford.edu
Three Month Sky Survey

- Diffuse is \(~80\%~\) of all Galactic emission at LAT energies !!!
Galactic Diffuse Emission is ...

Fermi skymap in Galactic coordinates using 3 months of data.

- 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 sources in the plane are affected.
- Foreground to extragalactic background.
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

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Physical Input Needed

- They need targets to create $\gamma$-rays.
  - Gas distribution determined from radio and mm surveys, $I (v, l, b)$.
    - Velocity $\Rightarrow$ 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.

![Rotation Curve](RotationCurve.png)

Strong et al. (2004)

Clemens (1985)
Physical Input Needed

- They 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)
    - Cosmic Microwave Background (~ > 300 μm)

- There are systematic uncertainties in the physical input!

Moskalenko, Porter & Strong, 2006
Help From Fermi LAT

- Using Fermi LAT and diffuse modeling can guide us in determining both cosmic-ray origin and gas distribution.
- Full-sky analysis used for modeling the diffuse emission
  - Binned maximum likelihood
  - Choose HEALPix grid for fast convolution on the sphere.
- Use template skymaps (from e.g., GALPROP) for individual emission processes and scale them linearly.
  - Can split further (ISM component, galactocentric annuli).
- Additional components
  - Sources (resolved and unresolved)
  - EGB (isotropic)
  - Instrumental (isotropic)
  - Solar system (sun, moon, asteroids)
  - ...
Fermi LAT Diffuse Analysis

• Energy dependent instrument response.
  • Rapidly varying effective area and point spread function.
• Contamination by point sources.
  • Need to model over 100 of the brightest point sources in a global scheme
• Residuals used to iteratively improve the diffuse emission model
• Need to be consistent with other observations
  • Direct cosmic-ray observations
  • Synchrotron radiation
  • ...
Local Galactic Diffuse emission

- Outside of the Galactic plane, most of the gas is *local*.
- Galactic diffuse emission dominated by $\pi^0$-decay emission around 1 GeV.
- Extra galactic background dominates at high latitudes.
- =>$\Rightarrow$ 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.
EGRET GeV Excess

- EGRET showed **excess** emission > 1 GeV when compared with gamma-ray intensities predicted by models based on local observations of cosmic-ray nuclei and electron spectra.
- Seen in all regions of the sky.


factor of ~2 discrepancy > 1 GeV

Hunter et al. (1997)
EGRET GeV Excess

- Variety of possible explanations
  - Variations in cosmic rays over Galaxy, “optimized model”
    - Local cosmic-ray spectrum does not fit but in accordance with expected fluctuations in the Galaxy
  - Unresolved sources (Pulsars, SNRs, ...)
    - Difficult to explain excess at high latitudes
  - Dark matter annihilation
    - Unknown physics
  - Instrumental
    - Excess increased due to change in $A_{eff} > 1$ GeV coming from detailed MC simulation of EGRET + GRO (Baughman, PhD thesis)
    - Calibration issues (Stecker et al. 2008)
The Fermi LAT View

- Search for confirmation of the EGRET GeV excess in the region $10^\circ < |b| < 20^\circ$.
  - Maximize S/N ratio of local Galactic emission to both isotropic component and Galactic emission from further away.
- Resolved sources not included in model but are a minor component $\sim 5\%$.
- EGB + instrumental is assumed to be isotropic and determined from fitting the data at $|b| > 10^\circ$. 
• Spectra shown for mid-latitude range -> GeV excess in this region is not confirmed.

• LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% - this is preliminary.

• EGRET data is prepared as in Strong, et al. 2004 with a 15% systematic error assumed to dominate (Esposito, et al. 1996).
Conclusions

• 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 part of the sky with the LAT.

• The Vela spectrum (see Razzano's talk) shows similar discrepancies, suggesting that the GeV excess is instrumental.

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