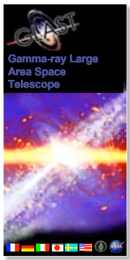
Modeling the Interstellar Diffuse Gamma-Ray Emission for GLAST



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Abstract

Interactions of cosmic rays with interstellar gas and photons make the Milky Way a bright, diffuse source of high-energy gamma rays. An accurate model of the diffuse emission is important for studies of point- and small extended sources of gamma rays as well as the extragalactic diffuse emission. It is also diagnostic of the distributions of gas and cosmic rays in the Milky Way. We present the model under development by the GLAST Large Area Telescope (LAT) team and demonstrate the sensitivity with which the model can be tuned using simulated flight data, to resolve ambiguities in the distribution of interstellar gas or refine the distribution of cosmic-ray sources. The model is implemented in the framework of the GALPROP code for cosmic-ray propagation and incorporates up-to-date surveys of the interstellar medium, as well as current models for the interstellar radiation field and updated production functions and inverse Compton scattering calculations.

Introduction

The Milky Way is a bright, diffuse source of high-energy γ-ray. As a large Sbc spiral galaxy, it has a large mass of interstellar gas and sustains formation of massive stars, which (as SNRs) are sources of cosmic rays (CRs) that diffuse through the Galaxy. The diffuse high-energy γ-ray emission originates in interactions of CRs with interstellar gas and with the interstellar radiation field in the Milky Way.

The interstellar diffuse emission (IDE) from the Milky Way is brightest in a band across the Galactic equator but extends over the whole sky. The emission is quite structured, owing principally to structure in the distribution of interstellar gas, and pervasive; approximately 60% of the γ-ray detected by the Energetic Gamma-Ray Experiment Telescope (EGRET) on *CGRO* were from diffuse emission processes in the Milky Way (Fig. 1). In just its first weeks of science observations after launch in Fall 2007, the LAT should detect as many celestial γ-rays as EGRET did during its entire mission; the design life of GLAST is 5 years.

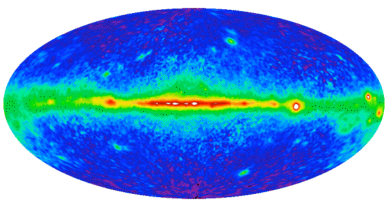

Fig. 1 Gamma-ray intensity >100 MeV observed by EGRET. Most of the emission originates in diffuse processes in the Milky Way

Why model the diffuse emission?

- **Accurate models of the IDE are needed for obtaining accurate positions of point and small extended sources of γ-ray, particularly at low Galactic latitude. Also, owing to the limited angular resolution and sensitivity of γ-ray telescopes, models are important to avoid misidentifying small-scale features in the diffuse emission as point sources.**
- **Accurate, absolute models are also important for measurement of the extragalactic diffuse background and other diffuse components. (Poster 18.01 describes diffuse emission from inverse Compton scattering on solar radiation).**

In this poster we describe the issues that confront modeling the IDE and the approach that is being taken by the Diffuse and Molecular Clouds Science Working Group of the GLAST Large Area Telescope (LAT) collaboration. The model is being developed both for use as a detailed estimate of the celestial foregrounds and also as a tool for investigating cosmic-ray production and propagation and the interstellar medium when the LAT data become available.

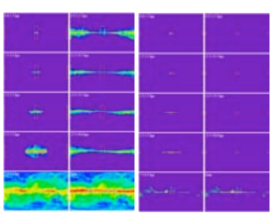

Fig. 2 Annuli of *N*(HI) (left) and W_{CO} right used in the current model. The H I data are from the LAB survey (Kalberla et al. 2005) and the CO data are from the composite CfA survey (Dame, Hartmann, & Thaddeus 2001). For the H I rings, *N*(H I) is derived on the assumption of a uniform spin temperature; directions with absorption against strong continuum sources have been interpolated and the emission from other galaxies in the Local Group has been excised. The boxes indicate the regions that required special interpolation owing to limited kinematic discrimination

Model components & GALPROP

Although the radiative transfer is simple – the Milky Way is transparent to γ-rays at these energies – good models for the absolute intensity and structure of the diffuse emission are not easy. The main components, Interstellar gas, Interstellar radiation field, and cosmic rays are described below.

The calculations of γ-ray intensities from the model components are being made with the GALPROP* code for cosmic-ray production and propagation (Moskalenko et al. 2002), which includes γ-ray production processes – Bremsstrahlung, Inverse Compton (IC) scattering, and π^0 decay.

*Also: **http://galprop.stanford.edu/na_home.html**

Fig. 4 All sky false-color image of the current version of the model for interstellar diffuse emission. The scaling is logarithmic; color variations indicate spectral differences between red (80 MeV), green (2.5 GeV), and blue (40 GeV) energies.

Interstellar gas

The distribution of interstellar gas is inferred from surveys of the 2.6-mm line of CO and of the 21-cm line of H I. In the usual way, the column density of molecular gas (H_2) is assumed to be proportional to W_{CO}.

In the current version of the IDE model, W_{CO} and *N*(H I) are partitioned into ranges of Galactocentric distance on the assumption that the gas obeys a rotation curve (Clemens 1985); some rules are needed for assigning gas at forbidden velocities and beyond the terminal velocity (Fig. 2). Regions at low latitude within about 10° longitude of the Galactic center and anticenter also require special treatment owing to the loss of kinematic discrimination in these directions. The 'rings' preserve the spatial structure of the diffuse emission but allow only for axisymmetric distributions of cosmic rays.

In progress

High-latitude survey of CO

The filling factor of molecular gas at high latitudes is small, but a recent unbiased survey (Dame & Thaddeus 2004) revealed many small (<1°) molecular clouds that would be detected by the LAT as unresolved point sources (Torres, Dame, & Digel 2005). This survey has since been extended by an additional 7000 deg^2 in collaboration with the LAT team (Dame 2006) and we hope to obtain supplemental data in the southern hemisphere.

3-dimensional distributions of gas

Before launch we expect to investigate models based on 3-dimensional distributions of gas as well. No unique deconvolution exists, although the large-scale spiral structure of the interstellar medium is fairly well characterized. With such a model discrete sources of cosmic rays may also be included.

Interstellar radiation field

For evaluation of the intensity of inverse Compton (IC) emission, we use the new model of Porter & Strong (2006; see Poster 18.63), which is based on current models for stellar populations, includes detailed calculations of absorption and scattering by interstellar dust. The anisotropy of the radiation field is evaluated in the model of Porter & Strong. In our calculation of IC emission the anisotropy of the IC scattering cross section is included (e.g., Moskalenko & Strong 2000). The effect strongly enhances the IC intensity at intermediate latitudes in the outer Galaxy (Fig. 3).

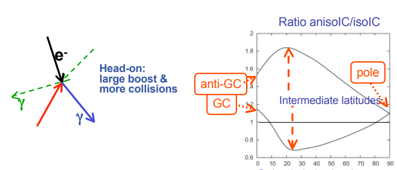

Fig. 3 (*left*) Illustration of shallow-angle and head-on scatterings. The cross section is greater for the latter, and the geometry is typical of scatterings at intermediate latitudes that produce γ-rays that reach Earth. (*right*) Relative intensities of anisotropic and isotropic IC scattering. Two profiles are shown from plane to pole: ***l* = 0°** (GC) and ***l* = 180°** (anti-GC).

Cosmic rays & GALPROP

GALPROP calculates steady-state distributions of cosmic-rays from the assumed distributions of gas and cosmic-ray sources. All relevant processes in propagation of cosmic rays are calculated, including nuclear reaction networks, and local measurements of cosmic rays are used as constraints. Our current model is based on the assumption that cosmic-ray sources are distributed like the distribution of pulsars derived by Lorimer (2004).

In progress

Neutral pion production

The recent re-evaluation by Kamae et al. (2006) of the γ-ray production function is being incorporated in the GALPROP for calculation of γ-ray intensities. The new production functions, which include the logarithmically rising inelastic cross section, diffraction dissociation, and Feynman scaling violation, predict slightly harder γ-ray spectra.

Application of the Model

The current version of the diffuse emission model (Fig. 4) uses the cosmic-ray distribution of Strong, Moskalenko, & Remier (2004), which results in predicted γ-ray intensities consistent with the EGRET observations, including the GeV excess.

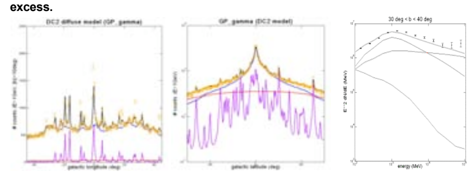

Fig. 5 Illustration of the sensitivity that will be achieved in fitting IDE (*blue*), extragalactic diffuse (*red*) and point sources (*purple*) to LAT data. The analysis is based on a **simulation** of 55 days of LAT observations, and the point sources were derived from analysis of the observations. (*left*) Longitude profile for |*b*| < 10°; (*center*) latitude profile for all longitudes; (*right*) spectral distributions for the region |*l*| < 45°, *b* = 30-40°, with the same color scheme.

The precision with which the IDE model can be compared with LAT data will be quite high (Fig. 5), and several investigations of the model itself are planned, including: nature of the GeV excess, distributions and injection spectra of cosmic-ray sources, mass calibration for molecular gas across the Galaxy and at high latitudes, and contributions from unresolved sources.

Conclusions

A good model for the interstellar diffuse γ-ray emission is needed to support the promise of the GLAST LAT for accurately characterizing point sources as well as other diffuse components, such as the extragalactic diffuse emission or IC scattering on the solar radiation field.

The model that we are implementing is state-of-the-art in terms of the radio and millimeter-wave surveys, determination of the distribution of gas, the interstellar radiation field, self consistently calculation of the distribution of cosmic rays, and incorporation of current production functions. In the GALPROP framework, the model is quite modular, and we expect to take advantage of this for tuning the model and studying the diffuse emission itself when flight data become available.

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