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The Diffuse Galactic Gamma-Ray Emission Model for GLAST LAT

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Abstract: Diffuse emission from the Milky Way dominates the γ-ray sky. About 80% of the high-energy luminosity of the Milky Way comes from processes in the interstellar medium. The Galactic diffuse emission traces interactions of energetic particles, primarily protons and electrons, with the interstellar gas and radiation field, thus delivering information about cosmic-ray spectra and interstellar mass in distant locations. Additionally, the Galactic diffuse emission is the celestial foreground for the study of γ-ray point sources and the extragalactic diffuse γ-ray emission. We will report on the latest developments in the modelling of the Galactic diffuse emission, which will be used for the Gamma Ray Large Area Space Telescope (GLAST) investigations.

Introduction

Diffuse Galactic emission (DGE) dominates the γ-ray sky with more than 80% of the total luminosity coming from processes in the interstellar medium (ISM). The DGE is a tracer of energetic interactions of cosmic ray (CR) particles in the ISM, and is produced by inverse Compton scattering (IC), bremsstrahlung, and π^0-decay. It delivers information about spectra and intensities of CR species at distant locations and allows the study of CR acceleration in sources as well as propagation in the ISM. Gamma rays can be used to trace the interstellar gas independently of other astronomical methods, e.g., the relation of the molecular H_2 gas to CO [18] and hydrogen overlooked by other methods [7]. Additionally, the DGE is the bright "background" against which γ-ray point sources are detected and its accurate determination is important for localisation of such sources and their spectra, especially at low Galactic latitudes. Furthermore, the DGE acts as a "foreground" for any extragalactic signal that we seek to recover.

Calculation of the DGE requires a model of CR propagation. Such models are based on the theory of particle transport and interactions in the ISM as well as many kinds of data provided by different experiments in Astrophysics and Particle and Nuclear Physics. Such data include: secondary particle and isotopic production cross sections, total interaction nuclear cross sections and lifetimes of radioactive species, gas mass calibrations and gas distributions in the Galaxy (H I, H_2, H II), interstellar radiation field (ISRF), CR source distribution and particle spectra at the sources, and the Galactic magnetic field. All interactions that particles might undergo during transport, such as energy losses, and γ-ray and synchrotron production mechanisms, are similarly included.

Study of the DGE will advance greatly with the forthcoming GLAST mission. In the following, we describe our ongoing efforts for un-

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derstanding and modelling the DGE that will be incorporated into the model for the GLAST Large Area Telescope (LAT) Science Groups.

Cosmic-Ray Propagation and GALPROP

GALPROP is a code for CR propagation and diffuse γ-ray emission. We give a brief summary of GALPROP; for details we refer to the relevant papers [19, 12, 20, 13, 22] and a dedicated website[1]. The propagation equation is solved numerically on a spatial grid, either in 2D with cylindrical symmetry in the Galaxy or in full 3D. The boundaries of the model in radius and height, and the grid spacing, are user-definable. Parameters for all processes in the propagation equation can be specified. The distribution of CR sources can be freely chosen, typically to represent supernova remnants. Source spectral shape and isotopic composition (relative to protons) are input parameters. Cross-sections are based on extensive compilations and parameterisations [11]. The numerical solution is evolved forward in time until a steady-state is reached; a time-dependent solution is also an option. Starting with the heaviest primary nucleus considered (e.g., ^{64}Ni) the propagation solution is used to compute the source term for its spallation products, which are then propagated in turn, and so on down to protons, secondary electrons and positrons, and antiprotons. In this way secondaries, tertiaries, etc., are included. Primary electrons are treated separately. The local proton, helium, and electron spectra are normalised to data; all other isotopes are determined by the source composition and propagation. Gamma rays and synchrotron emission are computed using interstellar gas data (for pion-decay and bremsstrahlung) and the ISRF model (for IC).

We are continuously improving the GALPROP code to keep up with new theory and information. Recent extensions to GALPROP relevant to the GLAST-LAT diffuse emission model include

- interstellar gas distributions based on current H I and CO surveys (see below)
- H_2 mass calibration (X_{CO}-factors) which can vary with Galactocentric distance
- new detailed calculation of the ISRF (see below)
- proper implementation of the anisotropic IC scattering using the new ISRF (Figure 1 [left])
- new parameterisation of the π^0 production in *pp*-collisions [9] which includes diffractive dissociation
- the extension of the γ-ray calculations from keV to tens of TeV, and the production of full sky maps as a function of energy; the output is in FITS format (Figure 1 [right])

Interstellar Gas

The maps of the neutral interstellar medium (ISM) used in the γ-ray intensity calculations have been updated recently. The neutral gas is traced by observations of the 21-cm line of H I and the 115 GHz line of CO (the standard surrogate for H_2, which is not directly detectable at interstellar conditions). The differential rotation of the Milky Way causes distance-dependent Doppler shifts of the line frequencies. These shifts can be used to derive approximate Galactocentric distances for the emitting regions corresponding to the observed spectral lines. We use the rotation curve of Clemens [3] in deriving Galactocentric distances and divide the Milky Way into equidistant rings of ~2 kpc width. Because for longitude ranges within 10° of the Galactic centre and anticentre so-called kinematic distances cannot be determined, we interpolate the maps across these ranges, using a method that ensures that the integrated column densities in the interpolated regions are consistent with the survey observations.

The new LAB survey of H I [8] is now used for calculating the ‘rings’ of H I. This survey has uniform coverage of the entire sky and has been carefully corrected for the effects of stray radiation. The CfA composite CO survey [4] is now used for calculating the CO rings. The data for the ring that contains the solar circle are augmented using a new intermediate and

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[1] http://galprop.stanford.edu

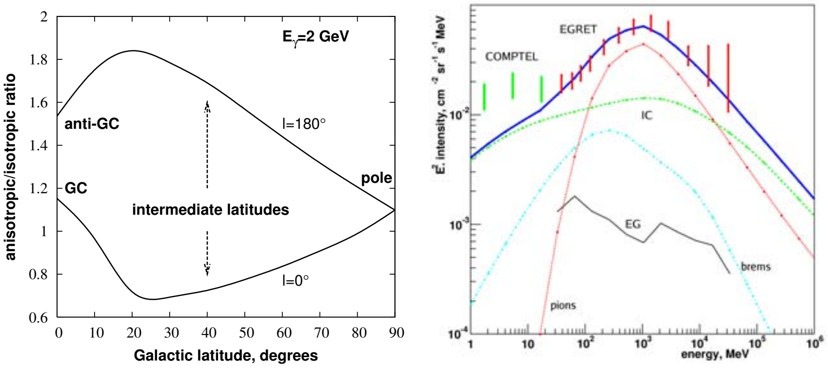

Figure 1: *Left:* The ratio of anisotropic IC to isotropic IC for Galactic longitudes $l = 0°$ and $180°$ vs. Galactic latitude [15]. *Right:* γ-ray spectrum of inner Galaxy ($330° < l < 30°, |b| < 5°$) for the optimised model. Vertical bars: COMPTEL and EGRET data, heavy solid line: total calculated flux. This is an update of the spectrum shown in [22].

high-latitude survey; the initial results of this survey have been published [5], but additional observations have been made [6].

Interstellar Radiation Field

The large-scale ISRF of the Galaxy is the result of stellar emission and dust reprocessing of the star light in the ISM. There is also a contribution by the cosmic microwave background (CMB). A model has been constructed for the Milky Way ISRF [16, 14, 17] incorporating details of stellar population distributions based on recent data from surveys such as 2MASS and SDSS, and a radiative transfer treatment of dust scattering, absorption, and re-emission the star light in the infrared. The dust distribution in the model follows the gas distribution; to ensure the ISRF is consistent with the GALPROP code we use the gas distributions described above.

The ISRF model allows the calculation of the spectral energy density (SED) and angular distribution as a function of position and wavelength throughout the Galaxy. As an example of the model output, we show in Figure 2 the local SED (left) and the local intensity distribution at 2.2 μm (right). The SED is important for the CR electron energy losses during propagation. The intensity distribution of the ISRF, which was previously not available in the literature, allows the calculation of the IC emission using the anisotropic IC cross section [10]. This has been shown to produce significant differences over the sky when compared to the assumption of an isotropic ISRF (Figure 1 [left]); the latter approximation is true only for the CMB.

Summary

From the EGRET era we have learned a great deal about the DGE in the MeV-GeV range while the GeV-TeV range remains largely unexplored. Recent VHE observations [2, 1] indicate the Galaxy is full of surprises. The DGE is also present at multi-TeV energies, but large variations are to be expected because of the inhomogeneity of the sources, and hence CR distribution; this contrasts with the case in the MeV-GeV range where the DGE has a significantly smoother distribution.

We have given a brief summary of work that is being done on the GLAST-LAT DGE model prior to launch; naturally, adjustments will be required after launch. The GLAST-LAT will study the DGE in the GeV-TeV range, providing a clearer picture and connection between the EGRET regime, and that of VHE instruments. This will provide much new

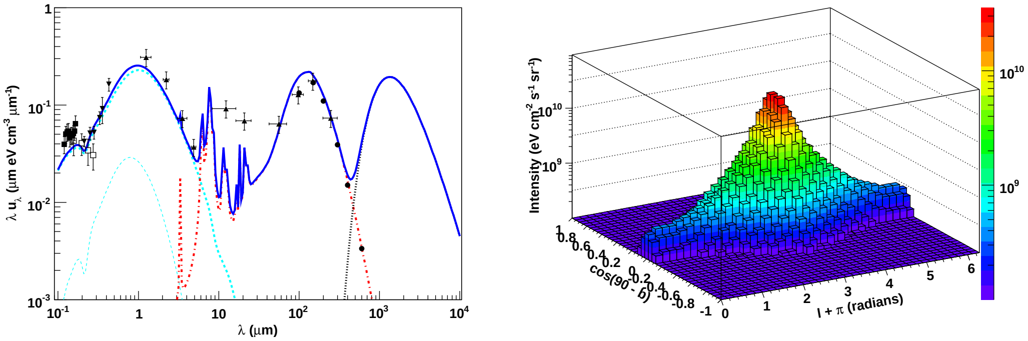

Figure 2: *Left:* Local ISRF spectral energy density. Line-styles: solid, total; thick dashed, stellar; thin dashed, scattered; chain, dust; dotted, CMB. Data points are summarised in [17]. *Right:* Model local ISRF intensity at 2.2 μm as a function of Galactic longitude l and latitude b.

information on CR propagation and sources, and the ISM.

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