Summary of the Development of the Model of Galactic Diffuse Emission for Use with Pass 7 Reprocessed LAT Data

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This document describes the model of interstellar emission recommended for point source analyses of the *Fermi*-LAT Pass 7 reprocessed data (P7REP). **For reasons described below we do not recommend using this model for analyses of spatially extended sources in the region defined in Fig. 1.** A forthcoming publication will detail the method used to develop the model.

At *Fermi*-LAT energies diffuse γ-ray emission of the Milky Way dominates the sky. Above 50 MeV its intensity averaged over the sky is 5 times greater than the intensity produced by resolved sources. The high-energy interstellar γ-ray emission is produced by the interaction of energetic cosmic rays with interstellar nucleons and photons. The decay of secondary particles produced in hadron collisions, the inverse Compton scattering of the interstellar radiation field by electrons and their bremsstrahlung emission in the interstellar medium (ISM) are the main contributors to the Galactic diffuse emission. It is bright and structured, especially at low Galactic latitudes, and is a celestial foreground for detecting and characterizing γ-ray point sources. Standard LAT analyses based on model fitting techniques require an accurate spatial and spectral model for the Galactic diffuse emission.

We have modeled the diffuse γ-ray intensity at some particular energy as a linear combination of gas column-density map templates (I_{tp}), a predicted inverse-Compton (IC) intensity map I_{IC} and a residual intensity map of unmodeled emission (i.e., Galactic diffuse emission not traced by the gas and the IC model) RES_{IC} :

$$\frac{dI}{dE}(E,l,b) = \sum_{i=gas} \frac{dq_i}{dE}(E) I_{tp_i}(l,b) + N_{IC}(E) I_{IC}(E,l,b) + RES_{IC}(E,l,b) \quad (1)$$

where $\frac{dq_i}{dE}$ are the differential gas emissivities, N_{IC} renormalizes the IC intensity, E is energy and l, b are Galactic coordinates.

About 99% of the mass of the ISM is composed of gas and about 70% of this mass comes from atomic (H I) or molecular hydrogen (H_2). Helium and heavier elements are considered to be uniformly mixed with the hydrogen. Gas column-density map templates of eq 1 include H I, H_2 and dark neutral medium (DNM).

We derived the atomic hydrogen column density N(H I) from the 21 cm all-sky Leiden-Argentine-Bonn composite survey of Galactic HI (Kalberla et al. 2005) on the assumption of a uniform spin temperature T_S=140 K. Since the CR flux varies with Galactocentric distances and since eq. 1 is valid only if the CR flux is constant in each template, we partitioned the Galaxy into Galactocentric annuli and assigned to each annulus the corresponding H I column density.

H_2, which does not have a permanent dipole moment, generally can not be observed directly in its dominantly cold phase. We assumed that $N(H_2)$ column densities are proportional to the intensities of the 2.6-mm CO line, $W(CO)$. We obtained the velocity-integrated CO brightness temperature map $W(CO)$ from the Center for Astrophysics composite survey (Dame et al. 2001). We derived Galactocentric annuli from radial CO velocities in the same way as for H I.

Studies of HI absorption against background radio sources have shown that the spin temperature is not uniform in the multi-phase ISM. We also know that CO is not a perfect tracer of H_2. In order to correct for those assumptions, we included in our model a template for the total dust column-density which is an alternative tracer for the atomic and molecular hydrogen in the Milky Way. We derived a DNM template from the residual of the optical depth map of Schlegel et al. (1998) obtained after subtracting the part linearly correlated with the $N(\mathrm{H\,I})$ and $W(CO)$.

While the different gas column-density maps offer a template for photons originating mainly from π^0-decay and Bremsstrahlung emission, there is no simple template for the inverse-Compton emission I_{IC}. Instead it must be calculated. For that we used the prediction from the GALPROP code (Strong et al. 2007) with galdef identification prefix LRYusifovXCO4z6R30_Ts150_mag2. It corresponds to one of the diffusive reacceleration models described in Ackermann et al. (2012).

The assumptions that the CR flux is uniform within each template of eq. 1 or that the distribution of CR sources used to derive the IC intensity is axisymmetric leads to excesses or deficits of a simple template model when compared to the *Fermi*-LAT observations. A large excess of γ rays associated with the Loop I giant radio continuum loop and two hard-spectrum lobe-shaped excesses extending North and South from the direction of the Galactic center (*Fermi* Bubbles) were for example observed in the residuals after subtracting the model. There is no accurate a priori template for the γ-ray emission of those large structures. In a first step we roughly modeled them with the 408 MHz radio continuum emission of Haslam et al. (1981) and ad hoc patches of spatially uniform intensity to derive the gas emissivities and IC renormalization.

We combined the gas template maps, the Loop I region of the 408 MHz radio emission and patches together with an isotropic background, a residual intensity of the Earth limb and counts associated with point and extended sources in a γ-ray LAT model with normalizations or emissivities left free to vary. We fitted this γ-ray LAT model to the LAT data to derive the emissivities and normalization factors. We have used the P7REP Clean class events for the first 4 years of the mission. We binned the LAT counts into 14 equally spaced logarithmic intervals from 50 MeV to 50 GeV.

We obtained the experimental emissivity from this fit and modeled them with a proton flux functional folded to a π^0 cross-section to derive $\frac{dq_i}{dE}$ of eq. 1. The LAT data fit also provided the IC renormalization coefficient N_{IC} for each band.

We then removed from this model the component related to the 408 MHz radio emission and patches, which do not provide an accurate enough description of the interstellar emission to be added to the final diffuse emission model, and subtracted it from the LAT data in each of the 14 energy bins. We modeled the positive residuals by assuming they all originate from populations of

CR electrons through IC emission and we filtered out with wavelet decomposition the structures with extension less than 2°. RES_{IC} in eq. 1 represents this filtered intensity that we reintroduced into the model in a region shown in Fig. 1.

Note that inside the region of Fig. 1 LAT γ-ray sources with extension more than 2° are included in the model for Galactic diffuse emission. **Therefore we do not recommend to use this model to study extended γ-ray emitters** .

We derived from eq. 1 a MapCube of the interstellar emission model available at the *Fermi* Science Support Center (FSSC) website[1] as a FITS file named *gll_iem_v05.fit*. We resampled all the maps to a resolution of 0.125° that corresponds to the highest angular resolution of the CfA CO survey. The MapCube comprises 30 logarithmically-spaced energies between 50 MeV and 600 GeV. It gives the Galactic differential intensity in photons sr^{-1} s^{-1} cm^{-2} MeV^{-1}. We extrapolated the model from the fitted range with the proton spectrum functionals derived from the emissivity fit for the gas templates and by fixing I_{IC} to GALPROP predictions. The residual emission extrapolation was based on the electron spectrum obtained when supposing it originated from IC scattering.

This model was tuned to LAT data not corrected for the LAT energy dispersion. It can be used directly with LAT data but for this reason it overestimates the true interstellar emission by approximately 10% at 100 MeV and 50% at 50 MeV. It is intended for use with IRF versions P7REP_SOURCE_V15, P7REP_CLEAN_V15, and P7REP_ULTRACLEAN_V15. A FITS file corresponding to Fig. 1 is also provided under the name *gll_iem_v05_region.fit*. The isotropic component is not included in the MapCube.

REFERENCES

Ackermann, M., Ajello, M., Atwood, W. B., et al. 2012, ApJ, 750, 3

Dame, T. M., Hartmann, D., & Thaddeus, P. 2001, ApJ, 547, 792

Haslam, C. G. T., Klein, U., Salter, C. J., et al. 1981, A&A, 100, 209

Kalberla, P. M. W., Burton, W. B., Hartmann, D., et al. 2005, A&A, 440, 775

Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525

Strong, A. W., Moskalenko, I. V., & Ptuskin, V. S. 2007, Annu. Rev. Nucl. Part. Sci., 57, 285

[1] http://fermi.gsfc.nasa.gov/

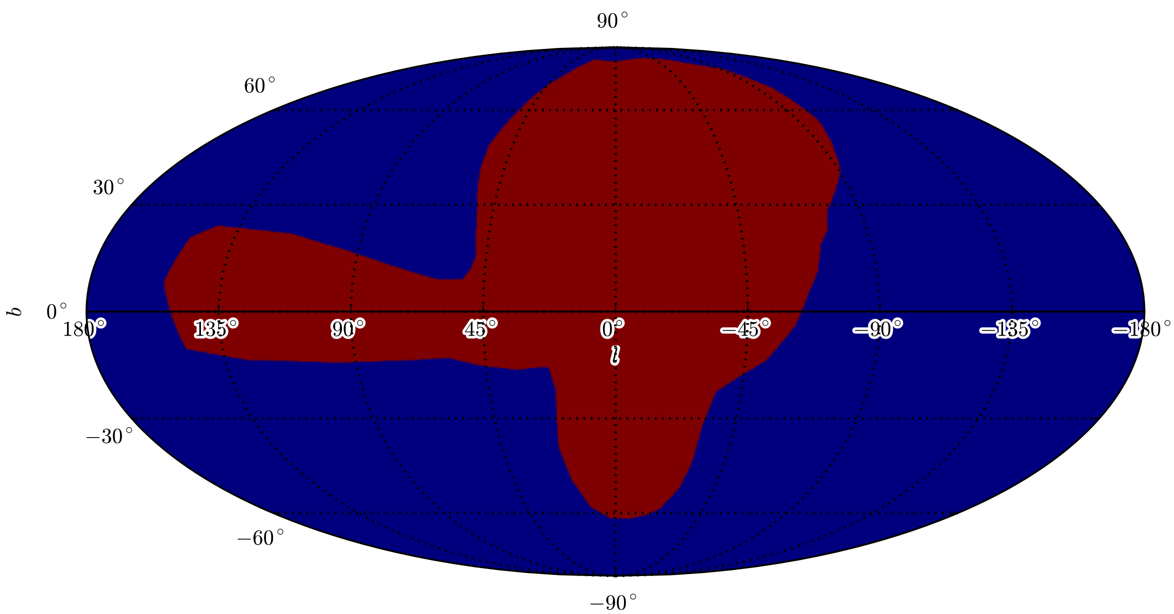

Fig. 1.— This map shows the region, in red, where the RES_{IC} component described in the text contributes to the interstellar emission model.