Assessing 2FGL Sources Toward Local Interstellar Clouds

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Summary: We examine the relation between 2FGL point sources and interstellar clouds to assess potential problems with modeling the diffuse gamma-ray emission

Modeling the spatial and intensity distributions of the interstellar diffuse gamma-ray emission with sufficient accuracy for the statistics and angular resolution provided by the Fermi LAT has proven to be challenging. In the 1FGL catalog, a number of sources have been flagged as suspect owing to clear or suspected association with inaccuracies in the diffuse emission model. Part of the challenge has been accurately accounting for column densities of interstellar gas, quantifying the contributions from 'dark gas' and the effects of self-absorption and optical depth variations in interstellar atomic hydrogen. For the 2FGL analysis a number of improvements were made to the model; here we illustrate the changes and assess the performance toward nearby interstellar clouds with an eye toward future refinements of the model.

Introduction

Interactions of cosmic rays with interstellar gas and radiation make the Milky Way a bright and structured source of gamma rays in the GeV energy range. Owing to the limited angular resolution and statistics of the even the Fermi LAT data, characterizing and studying point sources (or small extended sources) in directions where the Milky Way is bright requires an accurate understanding of the diffuse Galactic gamma-ray emission.

In modeling the Galactic gamma-ray emission the radiative transfer is simple – the Milky Way is essentially transparent at GeV energies, and especially for cosmic-ray protons of relevant energies to a good approximation their distributions are uniform on the tens of pc scales of even large interstellar clouds.

Perhaps the greatest challenge in accurately modeling the structure of the diffuse gamma ray emission is accurately mapping the column density of the interstellar medium. Most of the mass of the inter-stellar medium is in neutral gas, cold atomic hydrogen and helium, and molecular hydrogen. Atomic hydrogen can be directly observed at interstellar conditions via the well-known 21-cm spin flip transition. Molecular hydrogen cannot be directly detected but for ~30 years the intensity of J = 1–0 line of CO has been used as a tracer of interstellar H_2.

In fact gamma-ray observations have long been considered a useful for calibrating the relationship between the intensity of the CO line intensity $N(H_2)$. It has been typically modeled as a proportionality, which has turned out to be at least a moderately good approximation.

That it is not perfect was demonstrated in [1]; in an analysis of EGRET data Grenier, Casandjian & Terrier showed that interstellar dust traces some interstellar gas that the CO and H I lines do not. Interstellar dust is small grains of heavier elements, intermixed with interstellar gas, and is perhaps about 1% by mass. The dust tracer, which was derived from infrared sky surveys is denoted as E(B–V) because of the relation between interstellar dust and reddening of the spectra of obscured stars.

Unfortunately E(B–V) is not by itself a completely faithful tracer of interstellar gas, and starting with [1] one approach has been to define the 'residual' $E(B–V)_{res}$ component $E(B–V)_{res}$, which is the interstellar gas traced by E(B–V) but not by the CO or H I lines. It can compensate somewhat for errors in H I optical depth correction, but also could trace H_2 in the peripheries of clouds if the CO is dissociated there or in the densest cores where the CO lines may be saturated.

A version of $E(B–V)_{res}$ has been used as a component of the Galactic diffuse emission models already for the 1FGL catalog analysis (gll_iem_v02.fit, available from the FSSC).

Derivation of $E(B–V)_{res}$ does face potential problems. The results could be unreliable if the gas-to-dust ratio or $N(H_2)/W$(CO) ratio vary strongly across a region under study. Perhaps more importantly for studies of gamma-ray point sources infrared color correction can fail toward star-forming regions and embedded bright stars.

Example: Orion

We illustrate tracers of the interstellar gas, and some of the challenges for modeling the diffuse gamma-ray emission, with the interstellar clouds in Orion. The clouds in Orion are the nearest giant molecular clouds and host abundant massive star formation, most famously in the Orion Nebula, and so represent a particular challenge.

The images to the right show a 23×18° region toward the massive interstellar clouds in Orion in **CO** [2], ***E*(B–V)** [3], and **H I** [4]. The ***E*(B–V)** image has been filtered to suppress small-scale features around bright IRAS sources, and $\boldsymbol{E(B–V)_{res}}$ derived by the LAT team from these maps.

Also shown are the intensity maps from the **diffuse emission models** used for the 1FGL catalog [5] and the updated model that is being used for the 2FGL catalog. Most of the contrast in the intensity of the models is due to variations of column density in the interstellar medium.

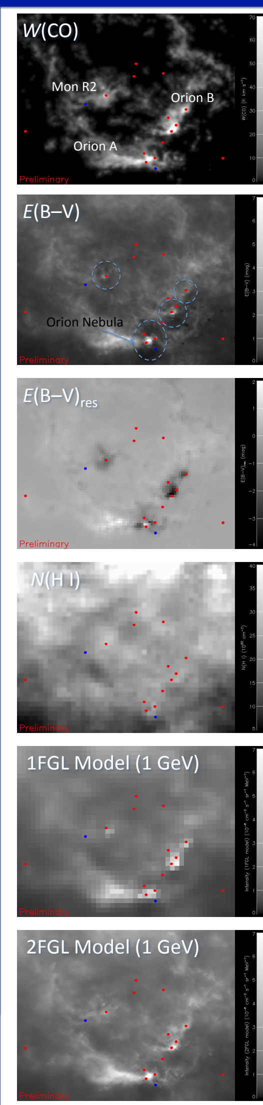
The images also show the positions of the 2FGL point sources in the field. The symbol sizes are much larger than the source location uncertainties, which typically are 10–15' in diameter. Sources in **blue** have high-confidence associations with background blazars; **red** sources have no obvious counterparts at other wavelengths. Each source has a formal significance of at least 4.1 σ.

The 2FGL sources clearly cluster in the Orion A & B molecular clouds and possibly also in the Mon R2 cloud. Localized underestimation of the diffuse gamma-ray intensity can result in such clustering.

The likely cause of these underestimations is artifacts in the original E(B–V) map. Schlegel, Finkbeiner, & Davis [4] note 45 IR-bright regions where at some stage of their analysis the matching of DIRBE and IRAS data did not work well. 4 of these are in Orion. The affected regions are indicated by the **dashed circles in the *E*(B–V) plot** and clearly have artifacts at the scale of the DIRBE beam (42') or larger. These artifacts, coupled with the filtering we applied to the E(B–V) map depressed the dark gas column densities in the model for the Galactic diffuse emission

The model for diffuse gamma-ray intensity used for the 2FGL analysis has many improvements relative to 1FGL – most evidently here improved angular resolution – but further refinement will be necessary to adequately (and objectively) evaluate interstellar reddening in the vicinity of bright star-forming regions, and $E(B–V)_{res}$ probably needs to be evaluated from fits on smaller angular scales to allow for corresponding small-scale variations of molecular mass calibrations or properties of interstellar dust.

The Orion region is not representative of most of the sky, not even most of the intermediate-latitude sky, where massive star-forming regions are uncommon. Also most intermediate-latitude clouds are considerably closer, and hence span a smaller linear scale over which cloud properties should be expected to vary less dramatically.



Conclusions

2FGL sources in some regions of the sky will continue to need to be flagged for caution even in regions where the density of sources is not particularly high and source confusion is not a concern; at least some of these in Orion can be traced to artifacts in E(B–V) that had not been taken into account in the LAT analysis.
Please note that a dedicated study of the diffuse emission in Orion is in preparation for publication

References

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