HIGH-LATITUDE MOLECULAR CLOUDS AS GAMMA-RAY SOURCES FOR FERMI

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Abstract

The first large scale Galactic CO survey extending to |b| > 10° was done by Dame, Hartmann, and Thaddeus (2001) with the 1.2 meter millimeter-wave telescope at the Center for Astrophysics. This unbiased survey has been extended to higher Galactic latitudes with a spacing of 0.25° (roughly every other beam-width), where over 200 molecular clouds at |b| > 10° between the Galactic longitudes of 0° and 230° (Dame and Thaddeus, 2004) has been mapped. Here we present results from new CO observations, started in October 2008, which beam-width sample all of the high-latitude clouds uncovered by our unbiased mapping. As of June 2009 approximately 63,277 CO spectra have been obtained toward 205 clouds and mapping of 15 more is ongoing. We expect that all isolated clouds at high-latitudes (|b|>10°) and at δ > -15° will be mapped by the same manner by the end of 2009. It has been shown by Torres, Dame, and Digel (2005) that high-latitude CO clouds should be detected as gamma-ray sources in the first-year all-sky survey of Fermi depending on their angular size and their column densities. Since the number of such high-latitude clouds is predicted to be around 100, they are expected to be the most numerous high-latitude gamma ray sources after AGN. It is therefore crucial for the diffuse gamma ray emission from these clouds to be well understood and characterized. Additionally, the new survey will be used to investigate the nature and extent of the so-called dark gas proposed by Grenier, Casandjian, and Terrier (2005). The data may also contribute to the Fermi search of dark matter in the Galactic halo, providing molecular column densities toward suspected regions of WIMP annihilation (Baltz, Taylor, and Wai 2007).

References

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I. A. Grenier, J. -M. Casandjian, R. Terrier, Science, 307, 1292 (2005)
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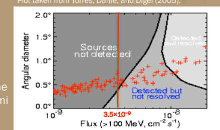
Gamma-ray Emission from Molecular Clouds

Interstellar gas clouds are sources of diffuse hadronically-produced gamma rays. Most of the molecular clouds at |b|> 10 deg lie in a thin layer of 87 pc within 1 kpc of the Sun. Therefore, we assume that the CR spectrum is the same in the clouds as that measured in the neighborhood of the Earth. Figure-1 shows boundaries of fluxes for Fermi to detect and/or resolve molecular clouds (red crosses).

Figure-1: The limiting gamma-ray fluxes of the sources with given angular extend to be detected and/or resolved by Fermi. Plot taken from Torres, Dame, and Digel (2005).



- Gamma-ray flux measured above 100 MeV is given by:

$F(>100\ \mathrm{MeV}) = 2.4\times10^{-9}\,(M / 10\ M_{\odot})\,(D / 100\ \mathrm{pc})^{-2}\,k$

k: Enhancement factor for cosmic rays (=1)
D: Distance to the cloud (pc)
M: Mass of the gas ($M_{\odot}$)

- The mass of molecular hydrogen expressed in terms of the integrated intensity of the CO line, S_{co}, in units of deg^2 K km/s is given as:

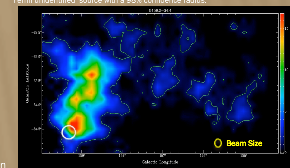
$M\,(M_{\odot}) = 860\,S_{co}\,D^2$ → $F(>100\ \mathrm{MeV}) = 2.06\times10^{-9}\,S_{co}$ *For cutoff $F = 3.5\times10^{-9}$ cm^{-2} s^{-1} $S_{co} = 1.7$ K km/s deg^2*

Factor 860 incorporates the X factor ($X = N(H_2)/W_{co} = 1.8\times10^{20}$ cm^{-2} (K km s^{-1})$^{-1}$).

Observations and Results

As of June 1st 2009, 63,277 spectra have been obtained. We have completed mapping 205 clouds and mapping of 15 more is ongoing. The large plot in the middle of the poster is the northern-sky map of velocity integrated CO intensity from the previous CO surveys of the northern sky as of 2008. The gray areas on the northern-sky plot show areas not yet mapped. Some of the more interesting individual cloud maps are shown with their positions indicated on the northern-sky map. The light-blue contours on each individual cloud map represent the 3-sigma noise level. We have done comparisons of the high-latitude clouds with the Fermi (Abdo et al. 2009) 9-month and 11-month lists of unidentified sources and found spatial associations with some of the Fermi unidentified sources. One example is shown in Figure-2, where the Fermi unidentified source is drawn as a white circle on the CO data. Using the integrated CO intensity over the entire cloud, S_{CO}, the gamma-ray flux above 100 GeV is calculated and found to be 3.06×10^{-8} cm^{-2} s^{-1}, which is comparable to the steady flux from the unidentified Fermi source measured above 100 GeV.

Figure-2: CO data taken with a beam size of 0.12 deg. White circle represents a Fermi unidentified source with a 98% confidence radius.



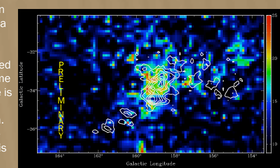
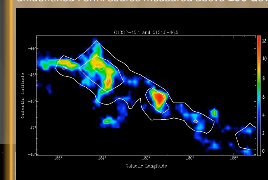
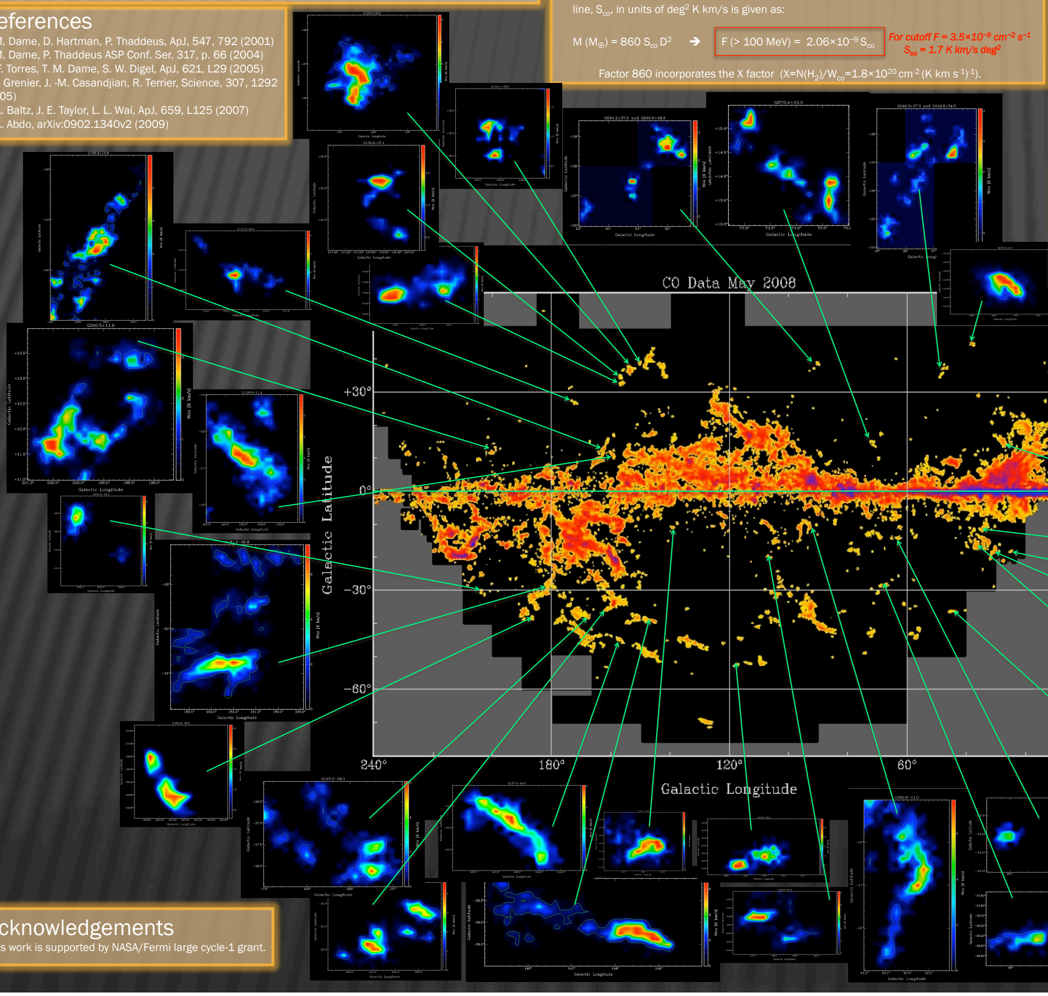


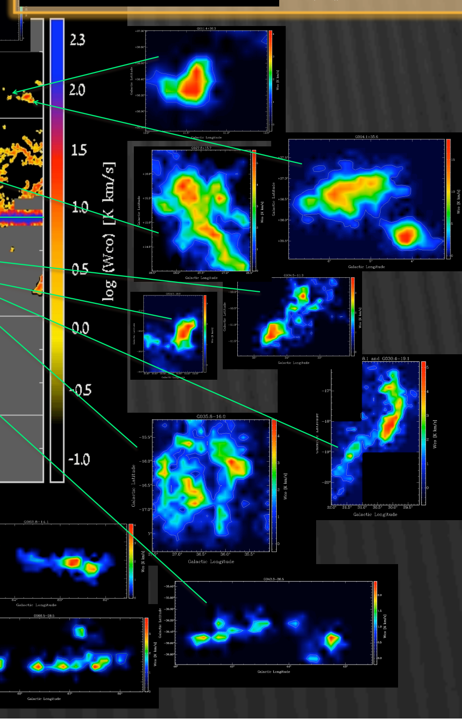
Figure-3: Gamma-ray counts map with a bin size of 0.12 deg. White contours are for the beam-width sampled CO data, where the lowest contour level represents 3-sigma noise level. Step size of contours is 5-sigma.



We also have compared our CO data with the so-called dark gas (Grenier, Casandjian, and Terrier (2005)). Figure-4 is an example where the white intensity contours of the dark-gas are overlaid on the CO intensity map. The comparisons show that the deeper observations of molecular clouds at high latitudes reveal CO emission, which is spatially coincident with dark gas features. This study is ongoing.

Figure-4: CO data taken with a beam size of 0.12 deg. White contours represent the intensity of the so-called dark gas (Grenier, Casandjian, and Terrier (2005)).





Acknowledgements

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