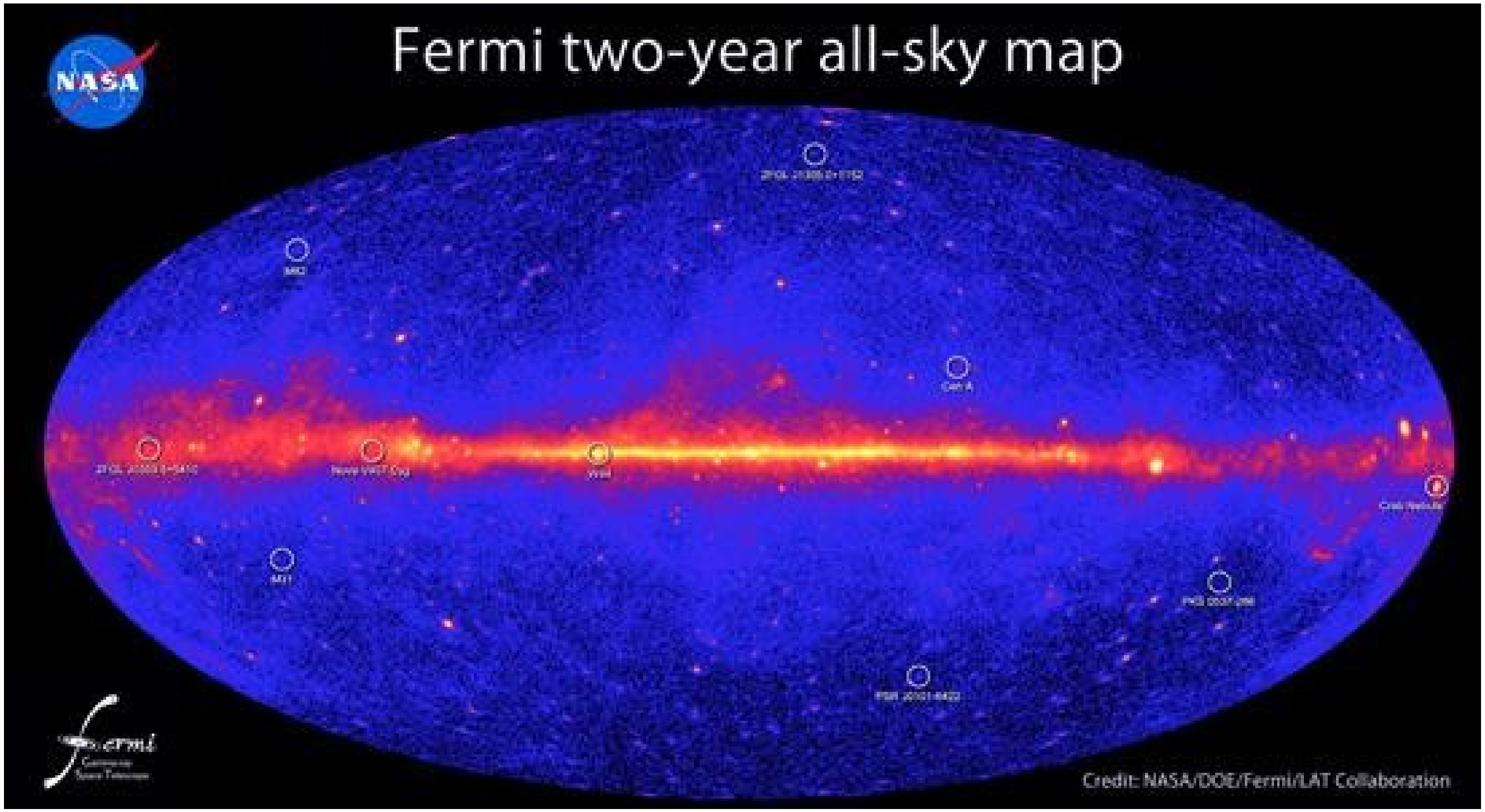
It all started with the galactic plane analyss



Fermi sees two things – point sources
– <u>diffuse emission</u>

$$\pi^0 \longrightarrow \gamma + \gamma$$

If any part of the emission is hadronic...

$$\pi^+ \longrightarrow \mu^+ + \nu$$

should see counter-part neutrinos

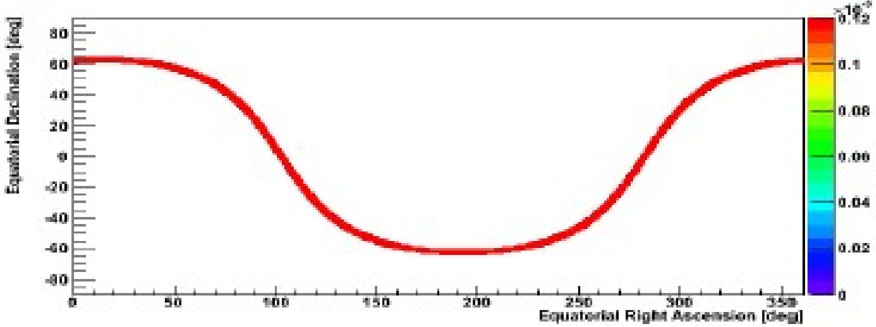
A year ago, I came to ask you what I should use as my input density Map

(the trickiest part of the analysis)

What matters more for neutrino mapping...
Where high-energy cosmic-rays are created?
Or where the targets for these cosmic-rays are?

What matters more? The Sources or the Targets?

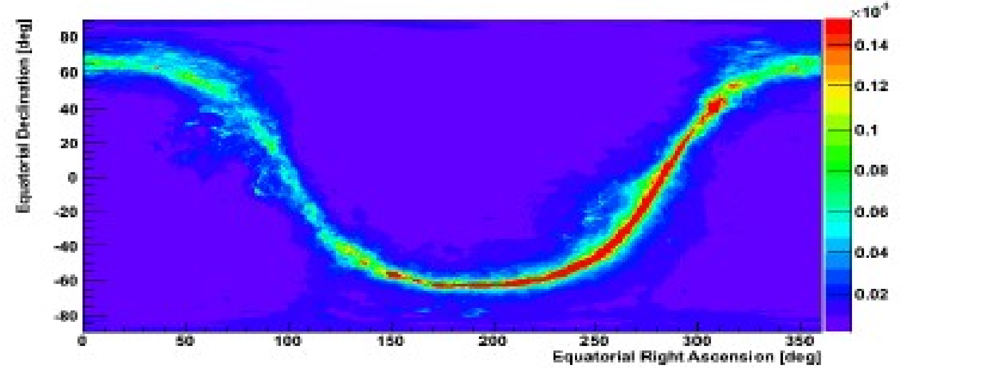
Option 1: Line Source



This is what J. Kelley used with AMANDA-II data.
http://www.icecube.wisc.edu/~jkelley/galactic/unblinding.html
+/-2 degrees for box width

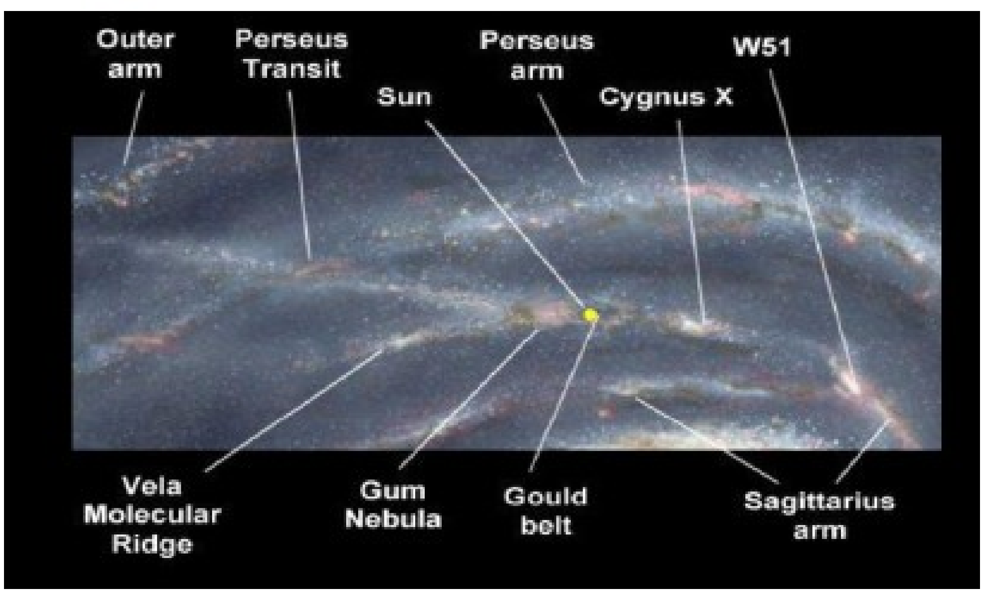
+/-4.4 degrees for Gaussian width

Option 2: Fermi Diffuse Model

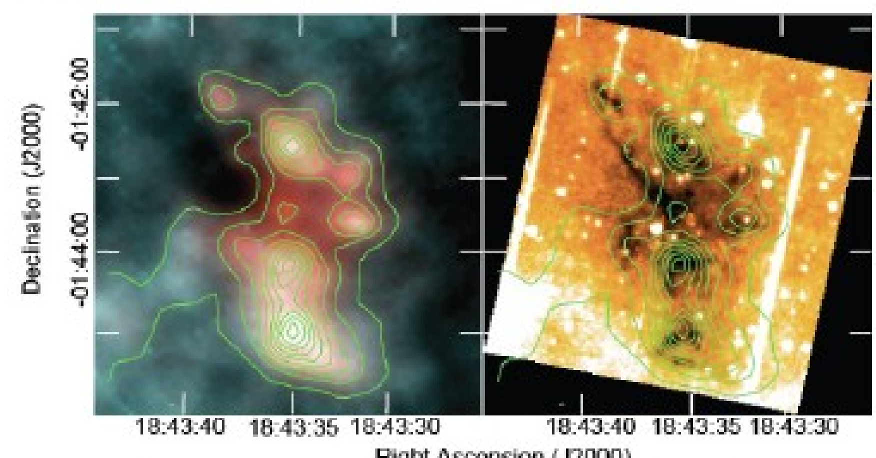


- atomic hydrogen (HI) distribution
- Carbon monoxide (CO) distribution as a tracer to HII
- dust column density correction obtained via infrared emission
- Inverse-compton scattering of electrons in interstellar radiation
- isotropic extragalactic background

Option 3: Local Cosmic Ray Sources



Option 4: Local Dark Clouds



Infrared Dark Cloud map from Herschel Observatory from the Hi-GAL galactic plane survey
http://io.jb.man.ac.uk:8080/SDC

This was the first I've heard of Dark Clouds!

I got myself a very capable undergraduate REU student, **Erin Middlemas** (East Tennessee State), to dig more into the dark clouds

Most of the slides that follow are hers, and her work over summer 2012

Infrared Dark Clouds

Figure: Atlas image mosiac of the filamentary infrared dark cloud G11.11-0.12

- Infrared Dark Clouds are reservoirs of cold, dense molecular gas seen in extinction against the strong background emission of the galactic plane(N. Perretto 2010).
- Defined as connected structures with column density peaks around $NH_2 = 2 \times 10^{22} cm^{-2}$ (N. Perretto 2009).
- Infrared Dark Clouds were discovered in 1996 using the Midcourse Space Experiment (MSX) Galactic plane mid-IR surveys

Main Characteristics

- Size $\sim 4pc$; varies from .3 pc to 30 pc (Simon et al. 2006)
- Mass $\sim 10^3 M_\odot$; varies from $1 M_\odot$ to $67,000 M_\odot$
- Shape varies from filamentary to compact
- Temperature around 10-20 K
- Non-uniform temperature, due to vast differences in dust temperature
- IRDC's - High-mass analogues to bok globules?

Surveys and Catalogs

- GLIMPSE Survey
- MIPSGAL Survey
- Two Micron All Sky Survey
- Digitized Sky Survey I
- ISOGAL Survey
- Hi-GAL Survey

- Simon et al 2006 MSX 8 m
- Peretto and Fuller 2009 Spitzer GLIMPSE and MIPSGAL
- Atlas and Catalog of Dark Clouds (based on Digitized Sky Survey I)
- Atlas and Catalog of Dark Clouds (based on 2MASS)

Distribution of IRDCs

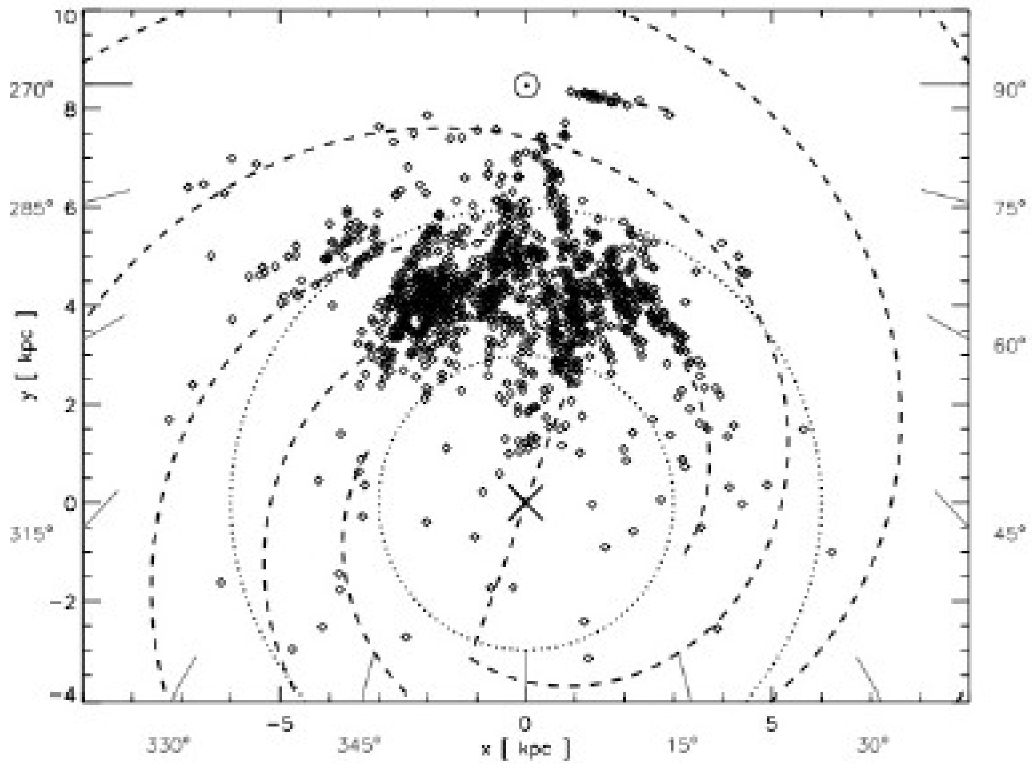


Figure: Distribution of Dark Clouds within the Galaxy

Follows the spiral arms?

Gamma ray connection? Or subtraction problem?

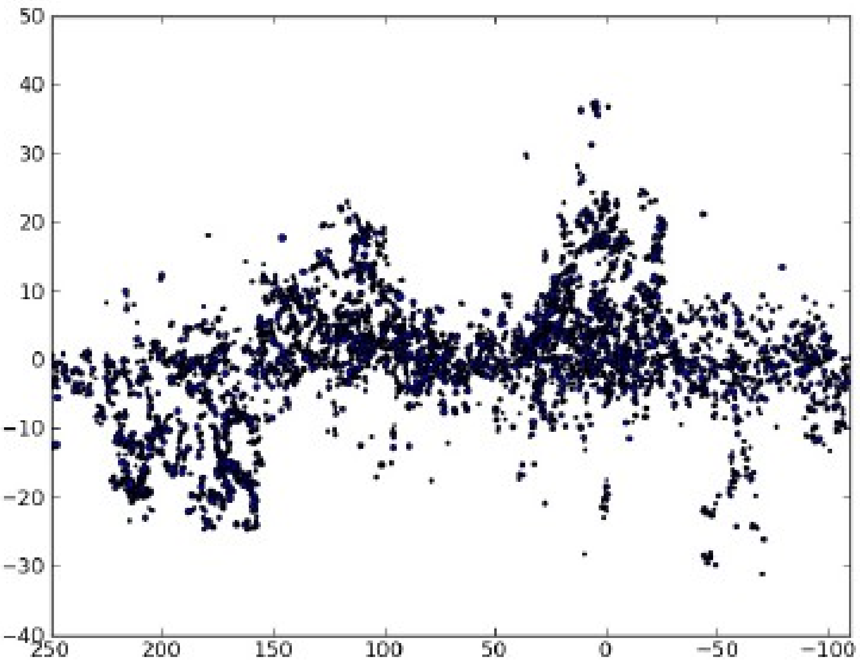


Figure: The Distribution of dark clouds within the galaxy

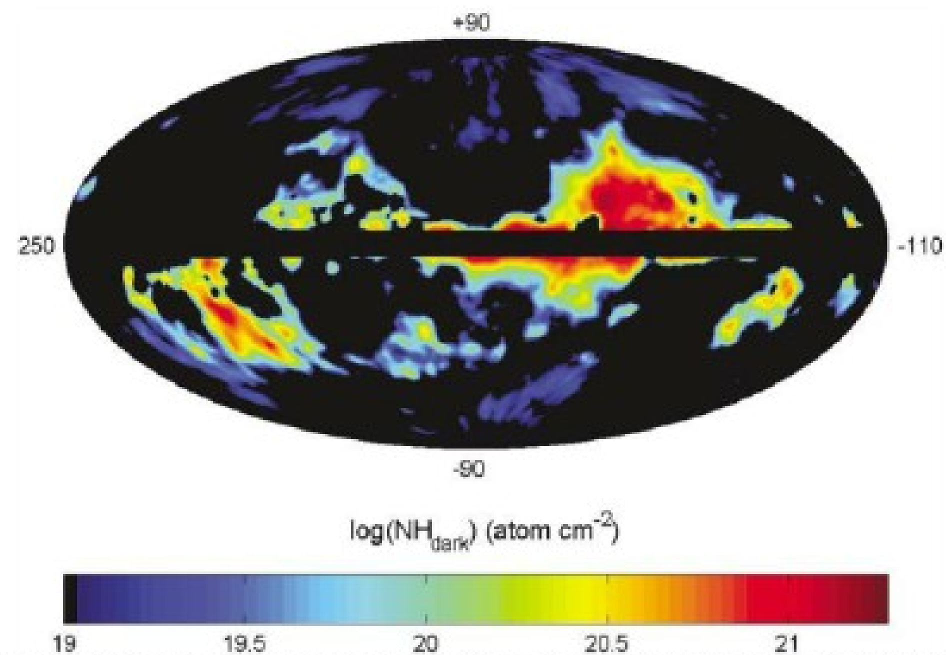


Fig. 4. Map, in Galactic coordinates centered on $l = 70°$, of the column densities of dark gas found in the dust halos, as measured from their γ-ray intensity with the reddening map. This gas complements that visible in HI and CO. The two dust tracers [E(B-V) and 94-GHz emission] yield consistent values within 30% over most regions.

- Grenier, I.A., Casandjian, J., Terrier, R. 2005, Science, 307, 1292

Neutrino Production in Dark Clouds

- Using the column densities of dark clouds from the "Atlas and Catalog of Dark Clouds", based on the Digitized Sky Survey I, we can calculate the amount of neutrinos to expect from these dark clouds.
- The neutrino production rate is descibed by the function :

$$\frac{DN_\nu}{DE_\nu} = NH_2 \int_{E_\nu}^{\infty} \sigma_{inel}(E_p) J_p(E_p) F_{\nu_\mu}(x, E_p) \frac{dE_p}{E_P} \tag{0.1}$$

NH_2 - column density of dark cloud
$\sigma_{inel}(E_p)$ - cross-section of inelastic p-p interactions
$J_p(E_p)$ - proton energy spectrum $\approx \alpha E^{-2.7}$
$\frac{F_{\nu_\mu}(x,E_p)}{E_p}$- number of muonic neutrinos produced per one p-p interaction in the energy interval $(E_p,\ E_p + dE_p)$

Upper Limits

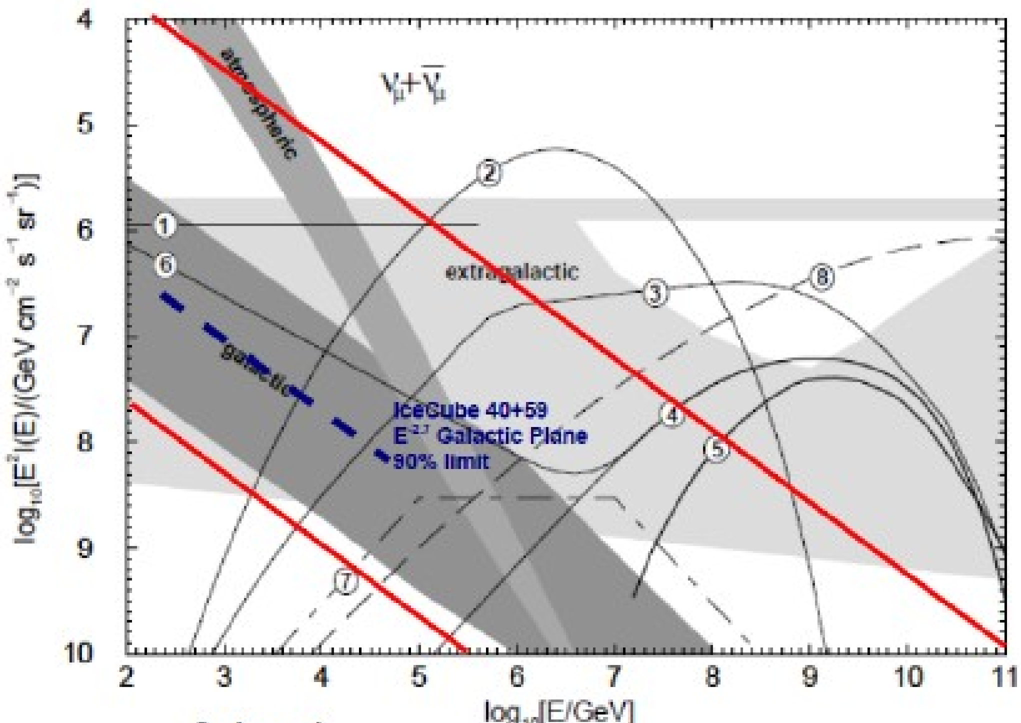
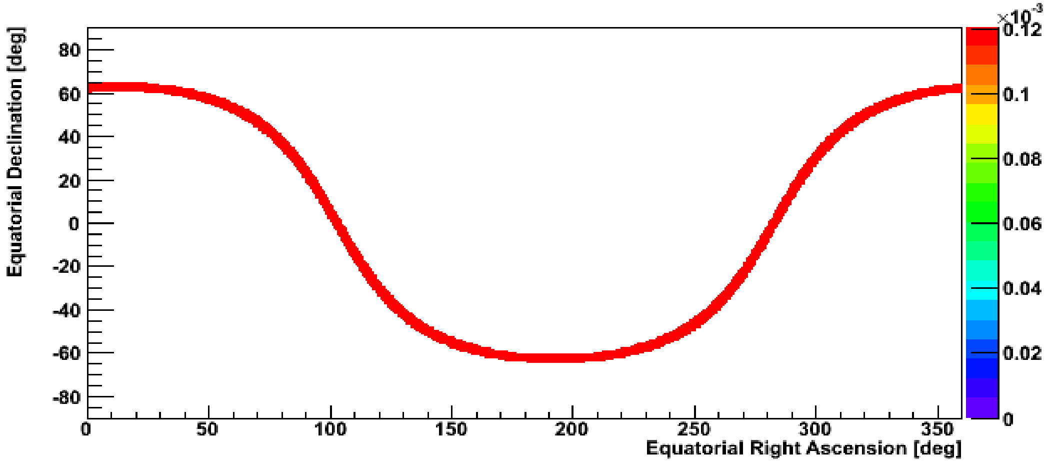


Figure: Upper limits on an astrophysical ν_μ flux. Bottom red line: $10^{21} cm^{-2}$ column density. Top red line: $10^{25} cm^{-2}$ column density.

Main Points & Lingering Questions

- In regions thought to be very dense, neutrinos can set better upper limits compared to the conventional technique of IR extinction
- Why hasn't gamma-ray done this already? Too much foreground/background?
- Do gamma-rays get produced in dark clouds? Or absorbed? Or both? or....?
- For astronomers, what is the most interesting question IceCube can answer about dark clouds?
- Anyone interested in taking on this task with me?

Option 1: Line Source



This is what J. Kelly used with AMANDA-II data. He found

+/-2 degrees for box width
+/-4.4 degrees for Gaussian width

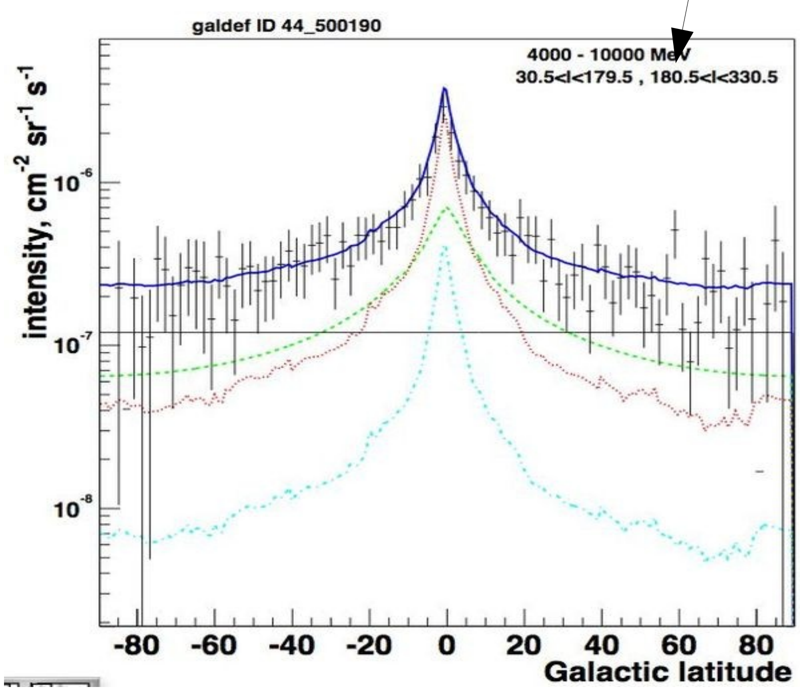
optimal for his analysis

Pros and Cons

• Does not take advantage of locally dense CR-source/CR-target information

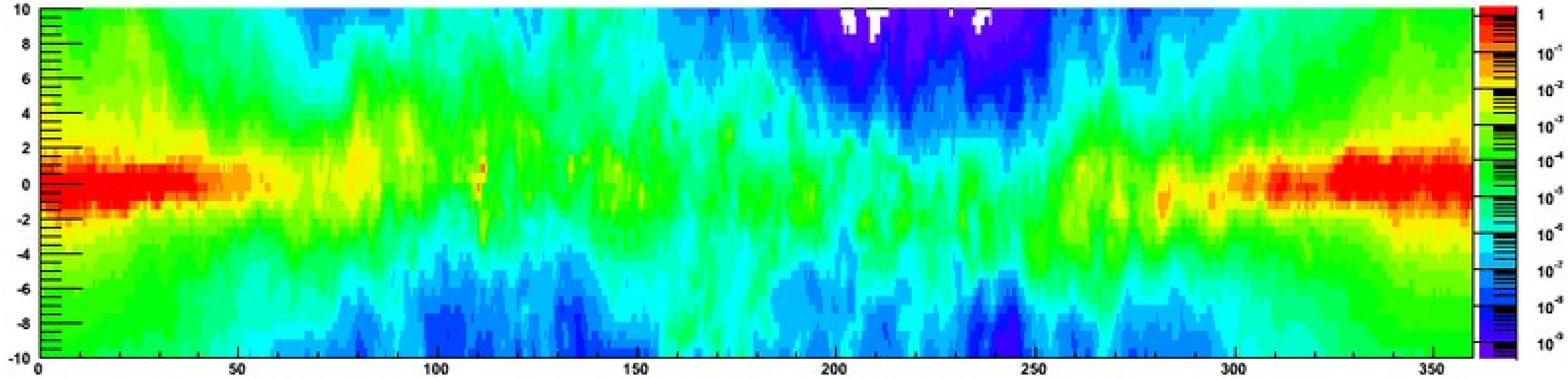
• Latitude width is a somewhat arbitrary pick or you have to make it a fit variable

•Nearby non-uniformities will look like they are "off-plane"... and this might be the best place to look!



taken from J. Kelly's page. A Gaussian profile in latitude

Option 2: Fermi Diffuse Model



This is J. Dumm's Idea. Use the diffuse gamma-ray Fermi model as a template.

This model simultaneously fits,
- atomic hydrogen (HI) distribution
- Carbon monoxide (CO) distribution as a tracer to HII
- dust column density correction obtained via infrared emission
- Inverse-compton scattering of electrons in interstellar radiation
- isotropic extragalactic background

Pros and Cons

• Has inverse-compton contamination that is unknown and energy dependent

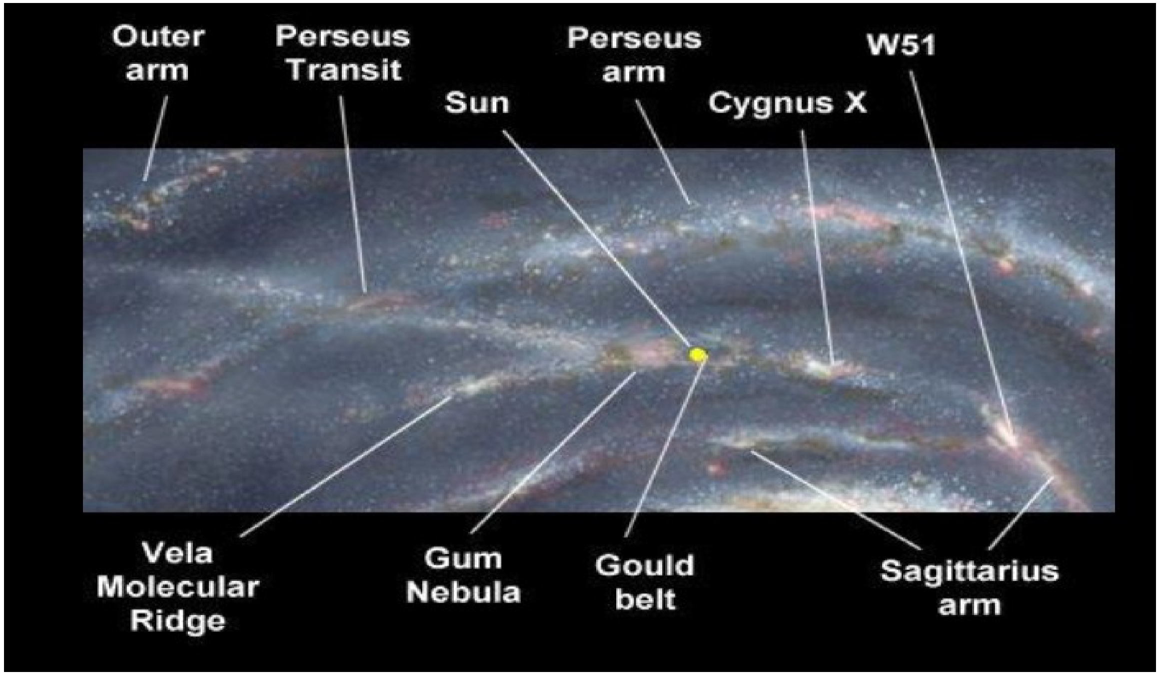
•Does not pick out "dark cloud" locations, where it is opaque to gamma-rays but a great place for neutrino production

•Very model dependent (gas, magnetic field and GALPROP). Assumes uniform CR source!

• Normalized to fit Fermi LAT data (good thing? bad thing?).

Option 3: Cosmic-Ray Source Map

Assumes that neutrinos trace high-energy CR source sites. This is Yolanda's analysis.



Neutrino production needs to happen close to the CR source sites to trace these maps

↓

Needs interaction target close to source

Pros and Cons

• Needs to have a target at the source (HE-CR source stars have blown away their clouds?)

• Needs interaction length < propagation/diffusion length to use CR map as neutrino tracer. Tricky to validate, magnetic field affects, etc

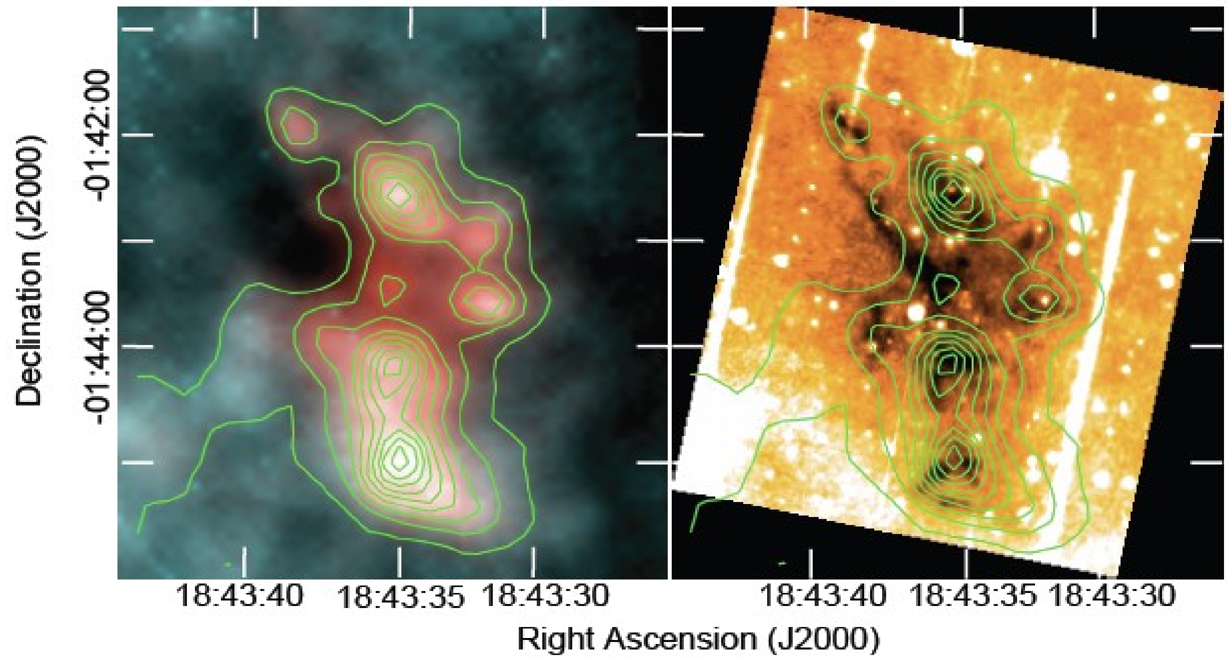
• Which catalog? Star-forming regions? Massive O stars? Only magnetically connected source/targets (= spiral arms)?

•What spectral index is appropriate? No time for diffusion -> gamma = 2?

Option 4: Nearby CR-Target Map

Compile map of nearby targets for cosmic-rays to interact

Infrared Dark Cloud map from Herschel Observatory from the Hi-GAL galactic plane survey http://io.jb.man.ac.uk:8080/SDC



Pros and Cons

•Assumes HE cosmic-rays penetrate uniformly

• Which Survey? (hot vs dark clouds, CO as tracer, IR dark cloud map, etc). Survey might not be complete?