Fermi Gamma-ray Haze via Dark Matter and Millisecond Pulsars

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Based on papers:

1. Fermi Gamma-ray Haze via Dark Matter and Millisecond Pulsars

   DM, Ilias Cholis, and Joseph Gelfand
   arxiv:1002.0587, submitted to ApJ

2. Spherical harmonics analysis of Fermi gamma-ray data and the Galactic dark matter halo

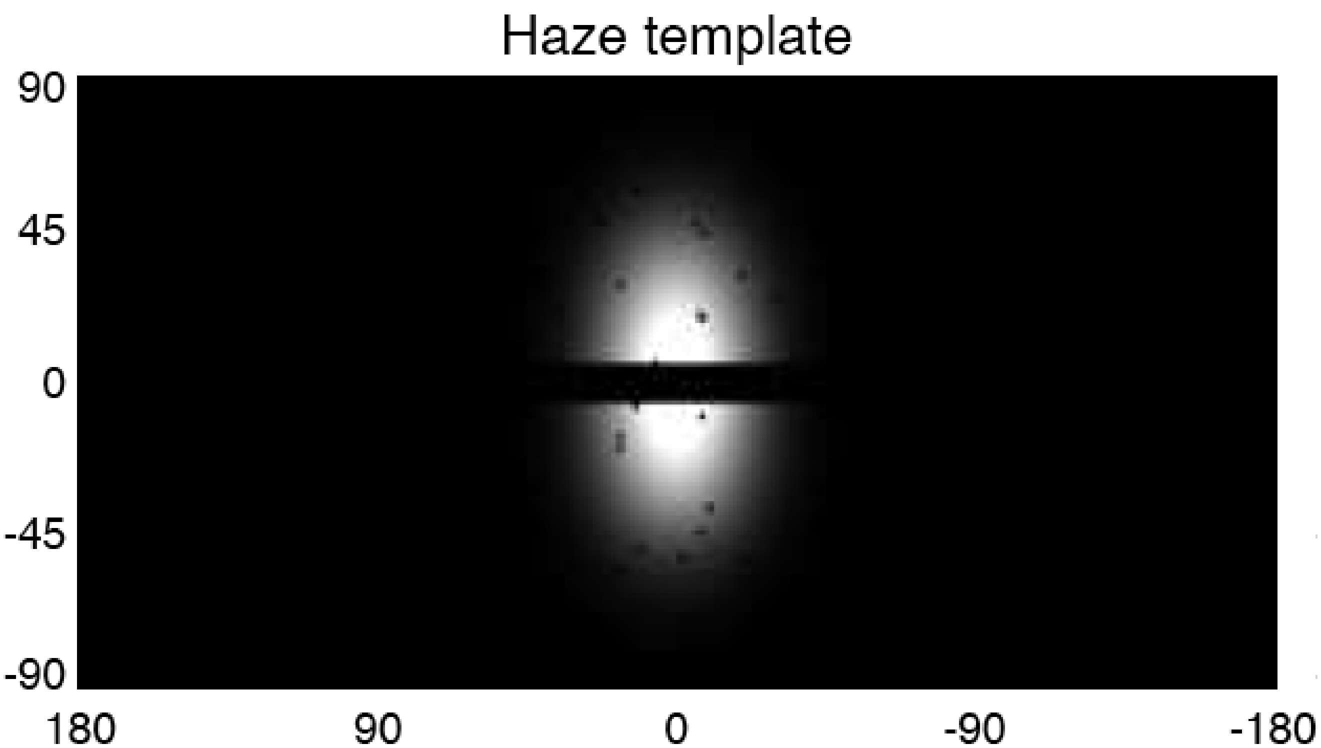
   DM, Jo Bovy, and Ilias Cholis
   arxiv: to appear tomorrow

Outline

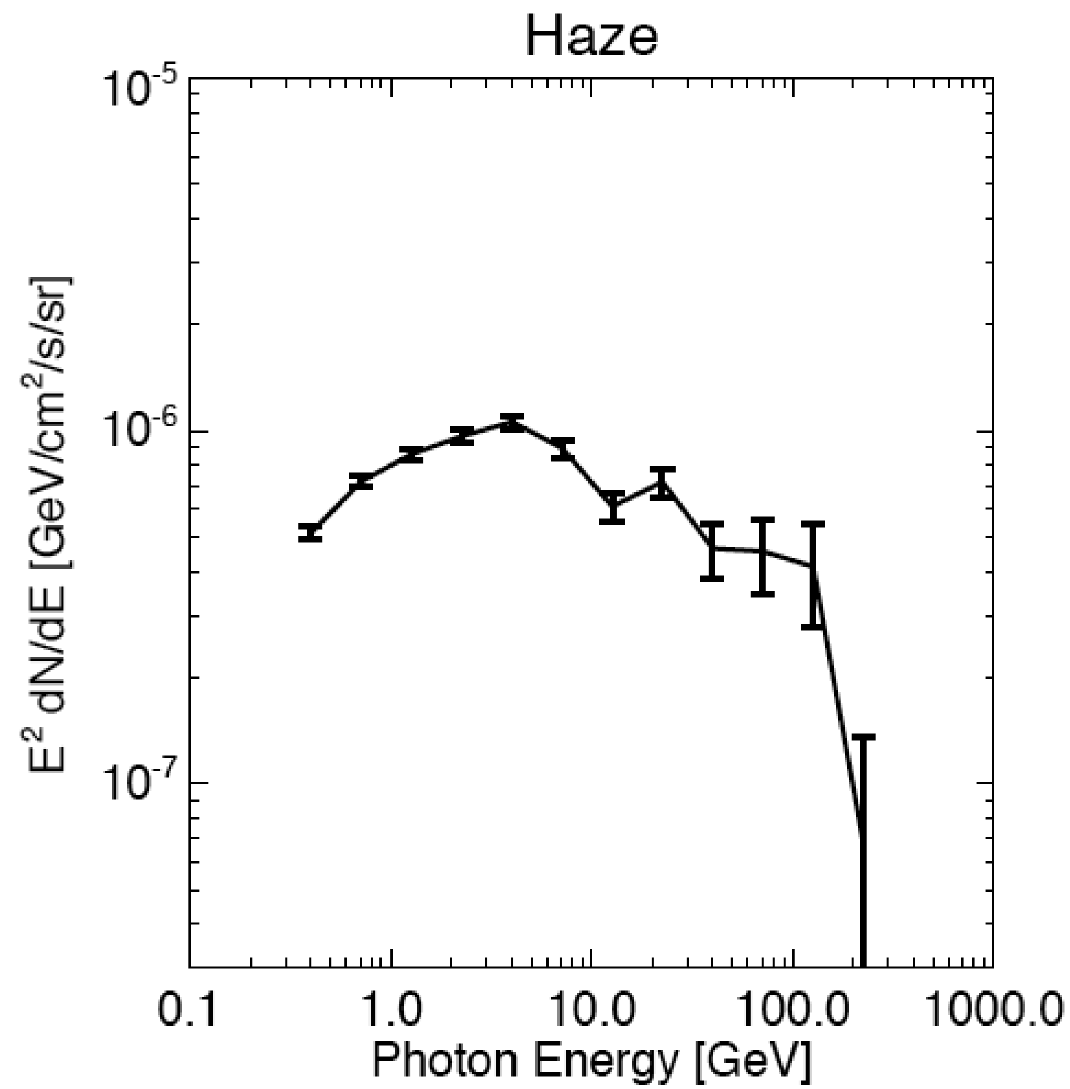
1. Comments on the gamma-ray haze.
   Template fitting in coordinate space and in spherical harmonics space

2. Dark matter and millisecond pulsars
   as sources of gamma-rays at high latitudes

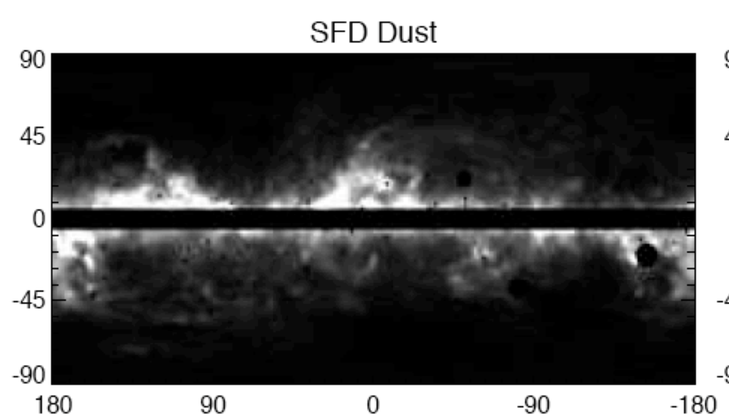
Part 1. Gamma-ray haze

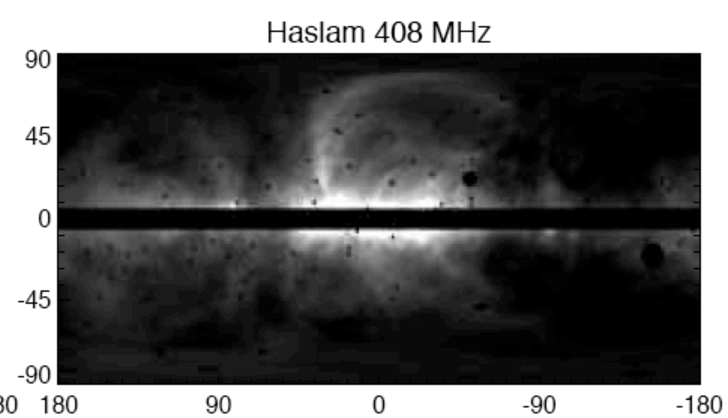


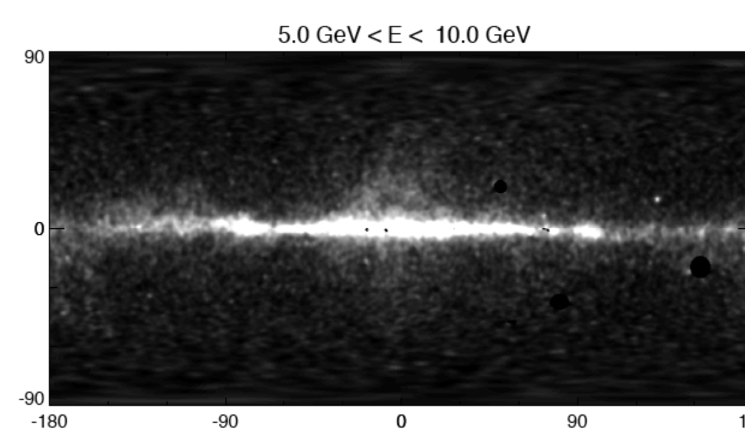
Dobler et al. arxiv:0910.4583



... is a gamma-ray overdensity that remains after subtracting templates from the *Fermi* data







Fitting templates in x-space

Fermi residual map
http://fermi.gsfc.nasa.gov/

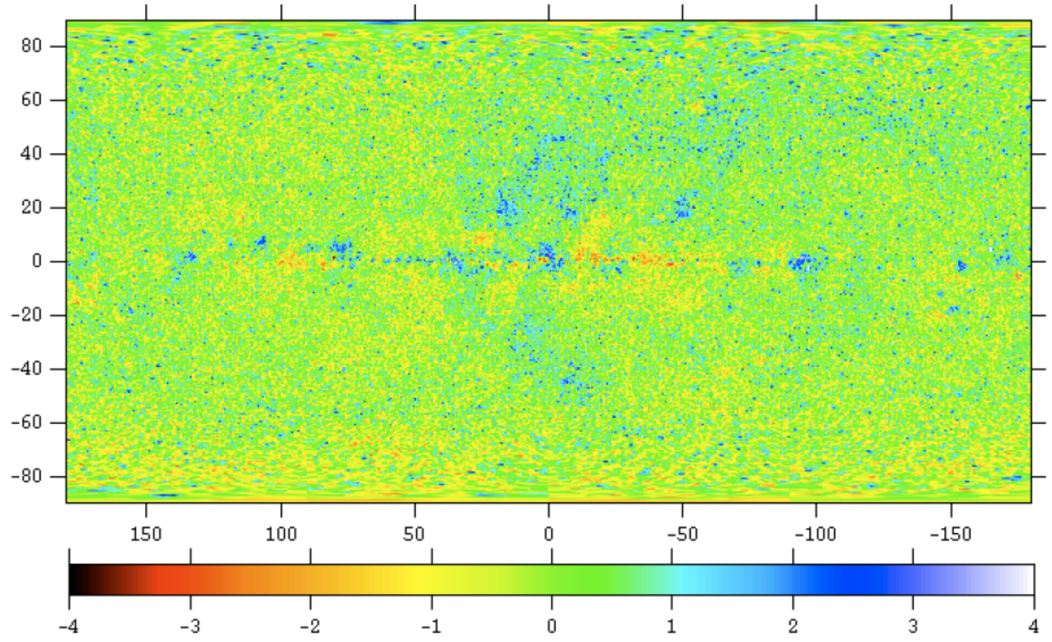
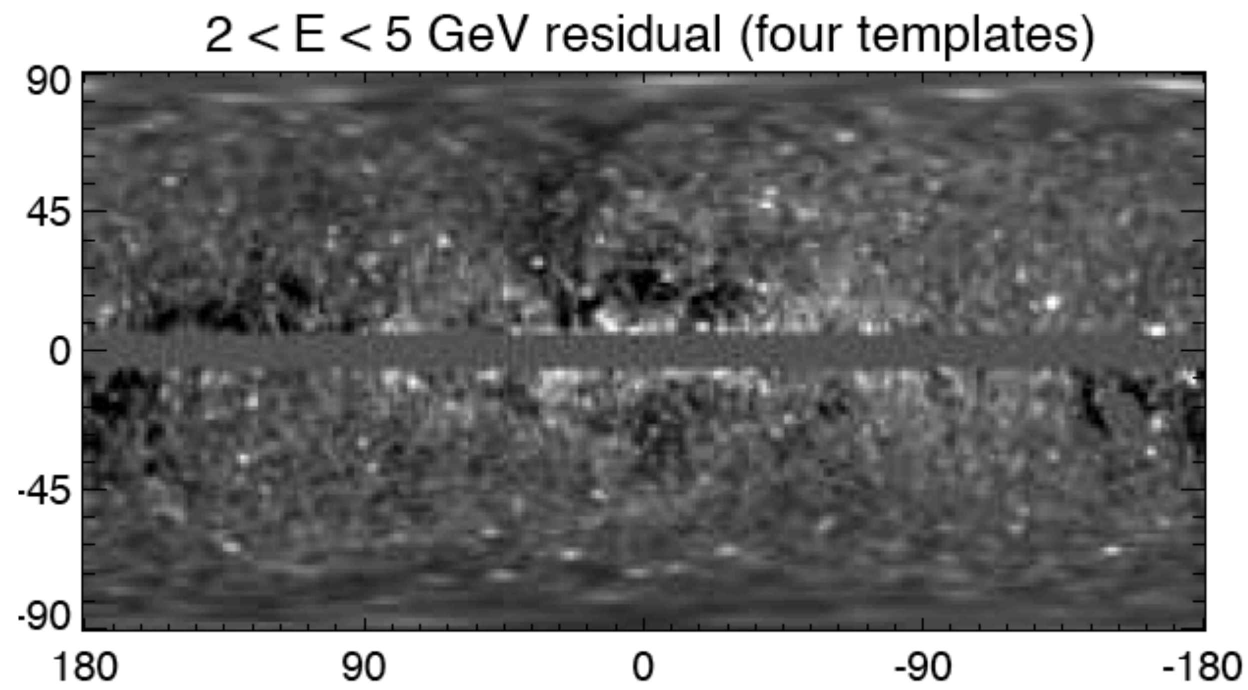


Figure 3: Residual map expressed in sigma values: $(N_{obs} - N_{pred})/\sqrt{N_{pred}}$

A residual map from Dobler et al.
Dobler et al. arxiv:0910.4583



Assumptions and Problems

- Fit all points independently:
  a one sigma positive deviation in the residual for many nearby pixels is OK in x-space fitting, but is it probable for a random noise?
- Assume Poisson distribution in every pixel:
  what about unknown, unobserved and never to be observed point sources?

Spherical harmonics decomposition

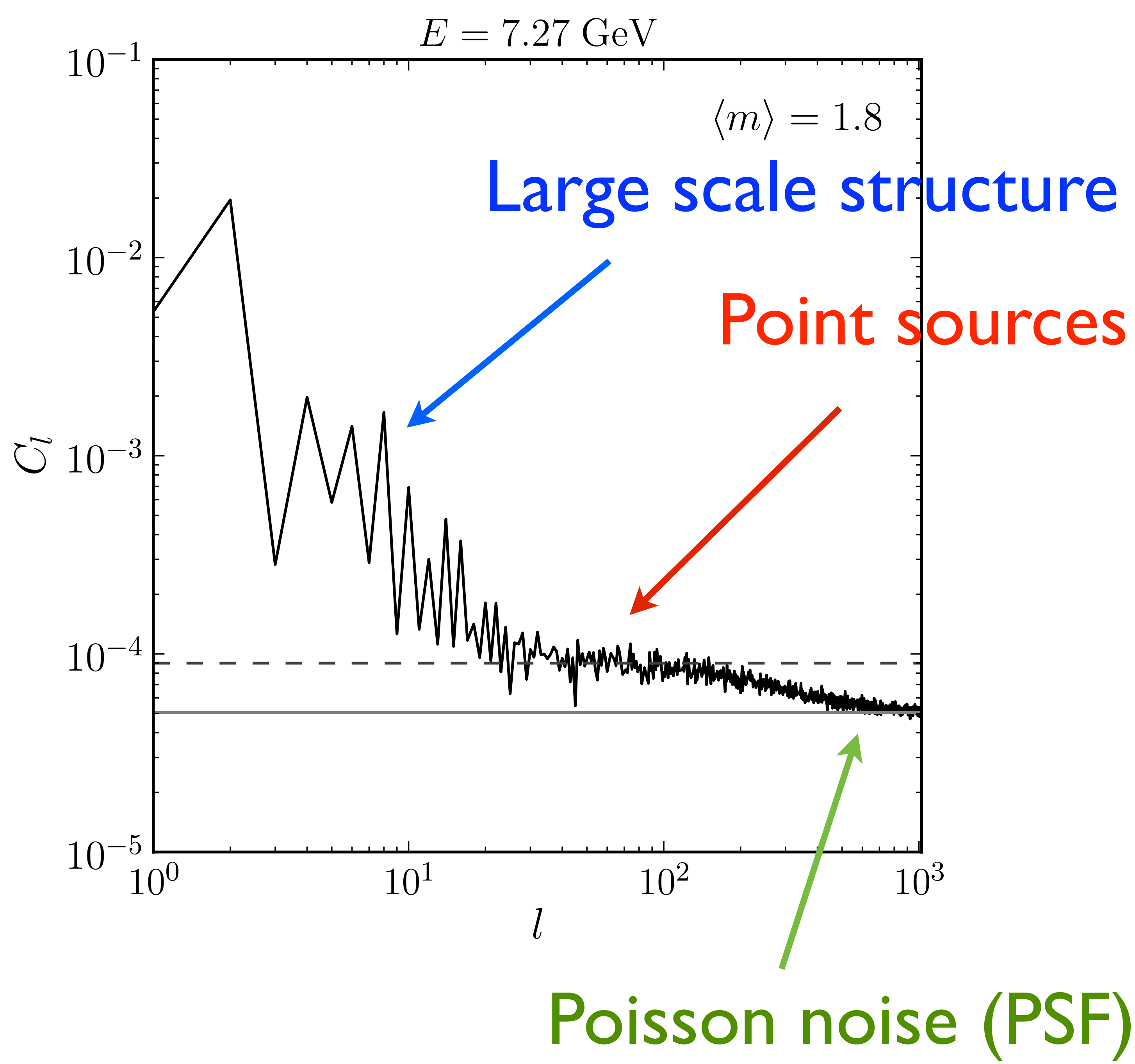
... is a necessary (may be not sufficient) method to asses the likelihood of a template fit

Advantages

- Residuals in large scale structure fitting (low L harmonics) are compared with the Poisson noise expectations for the large scale structure harmonics
- The effect of never-to-be-observed point sources can be estimated (indirectly): they increase the dispersion of spherical harmonics coefficients

Angular power spectrum for Fermi data

in an energy bin with central energy 7.27 GeV

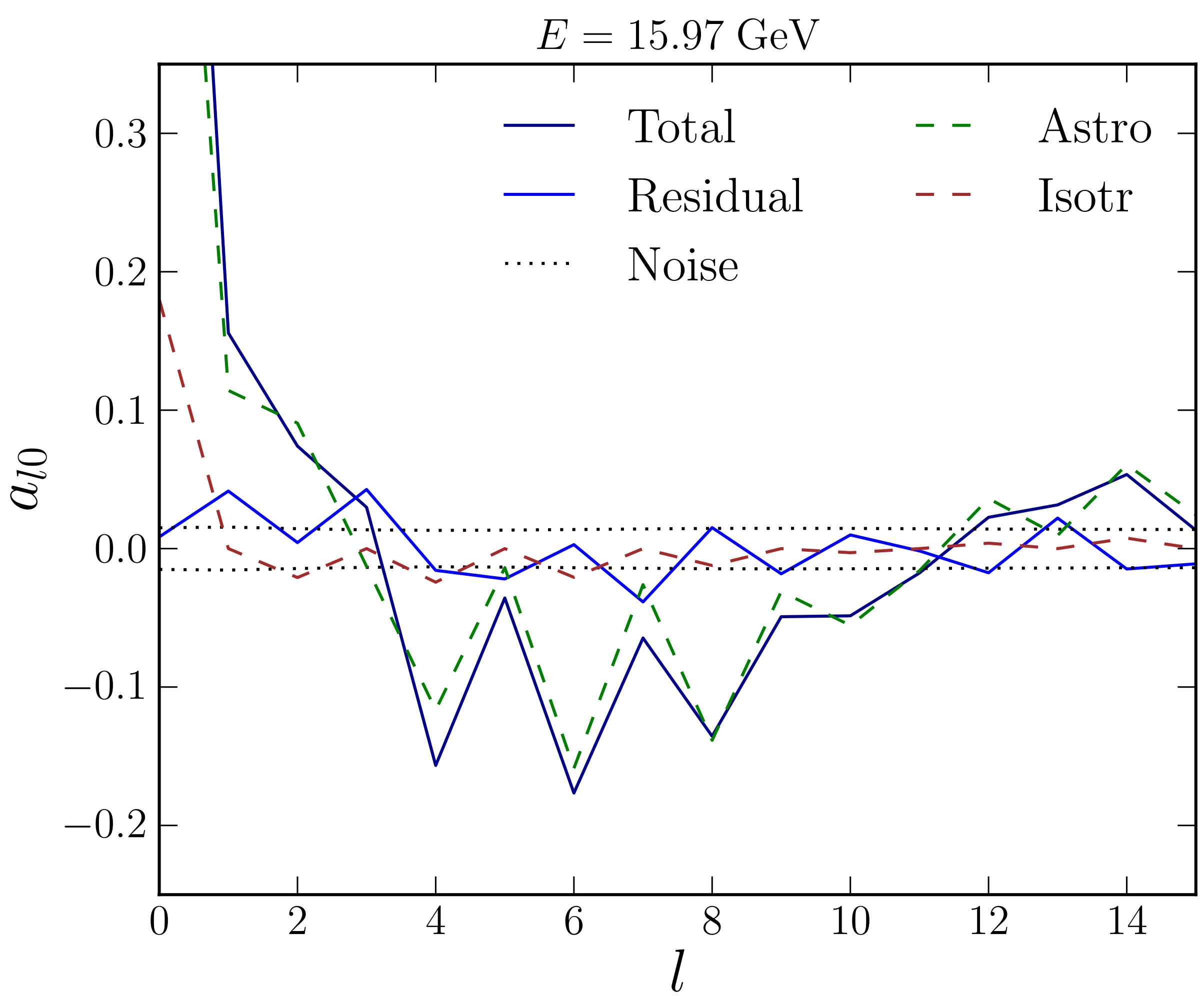


The statistical variance of harmonic decomposition coefficients in the presence of point sources is <m> times larger than the variance in the Poisson statistics case.

<m> is the average number of photons from point sources.
It is equal to the ratio of a plateau in C_l's for medium l's to the Poisson noise level

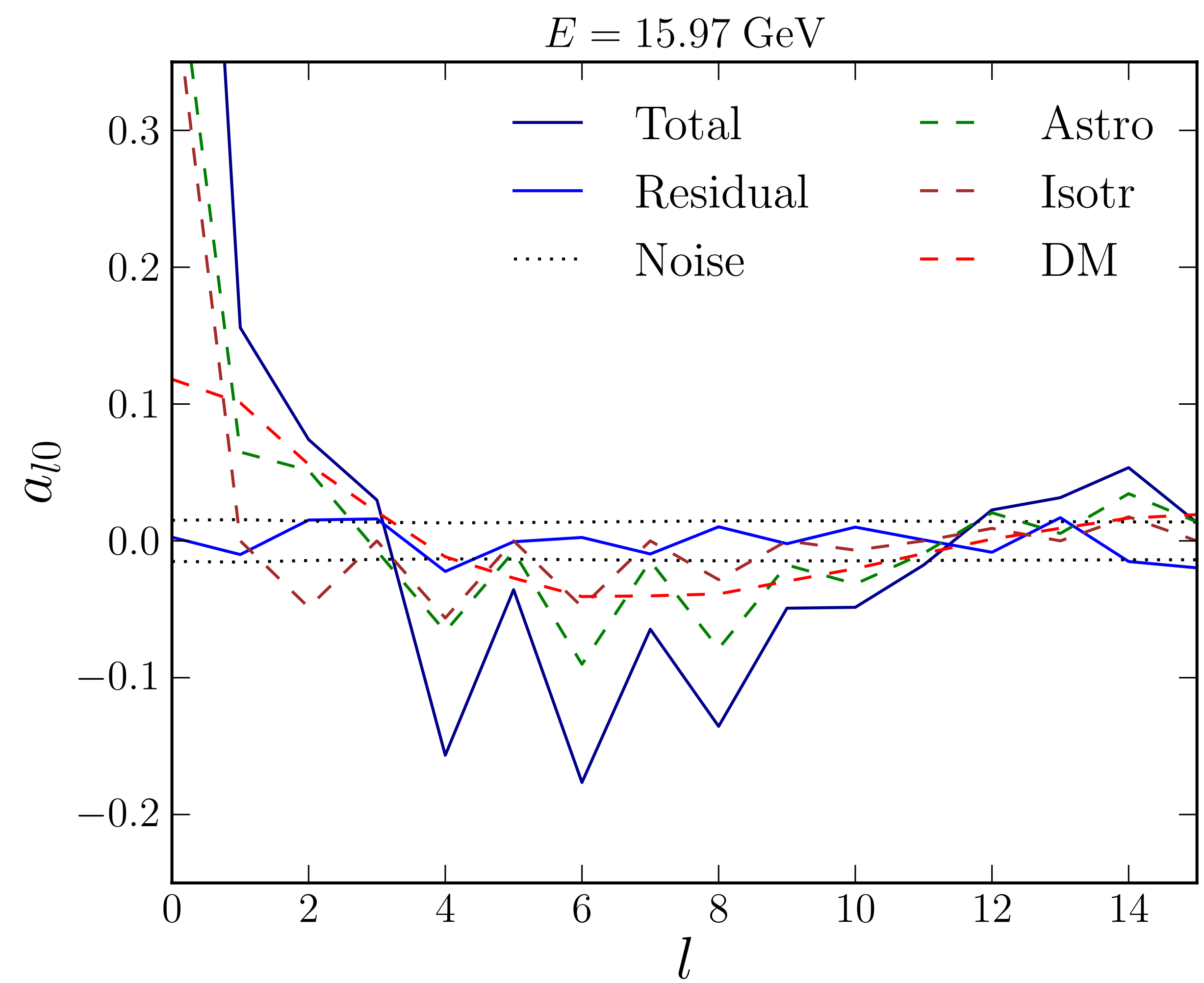
Fitting the a_lm's in one energy bin

Two templates model



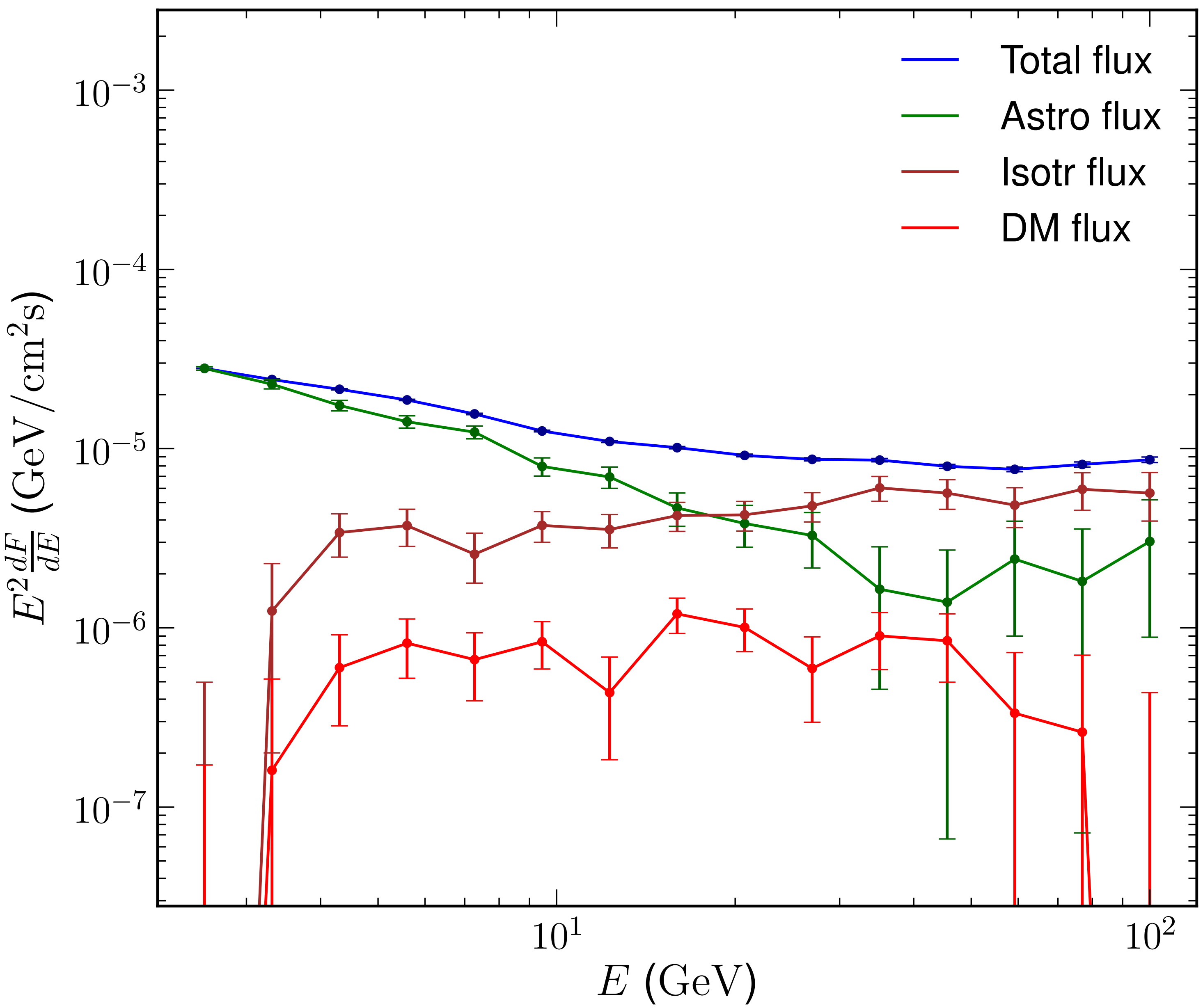
$$\chi^2/\text{dof} = 32.8/14$$

Three templates model



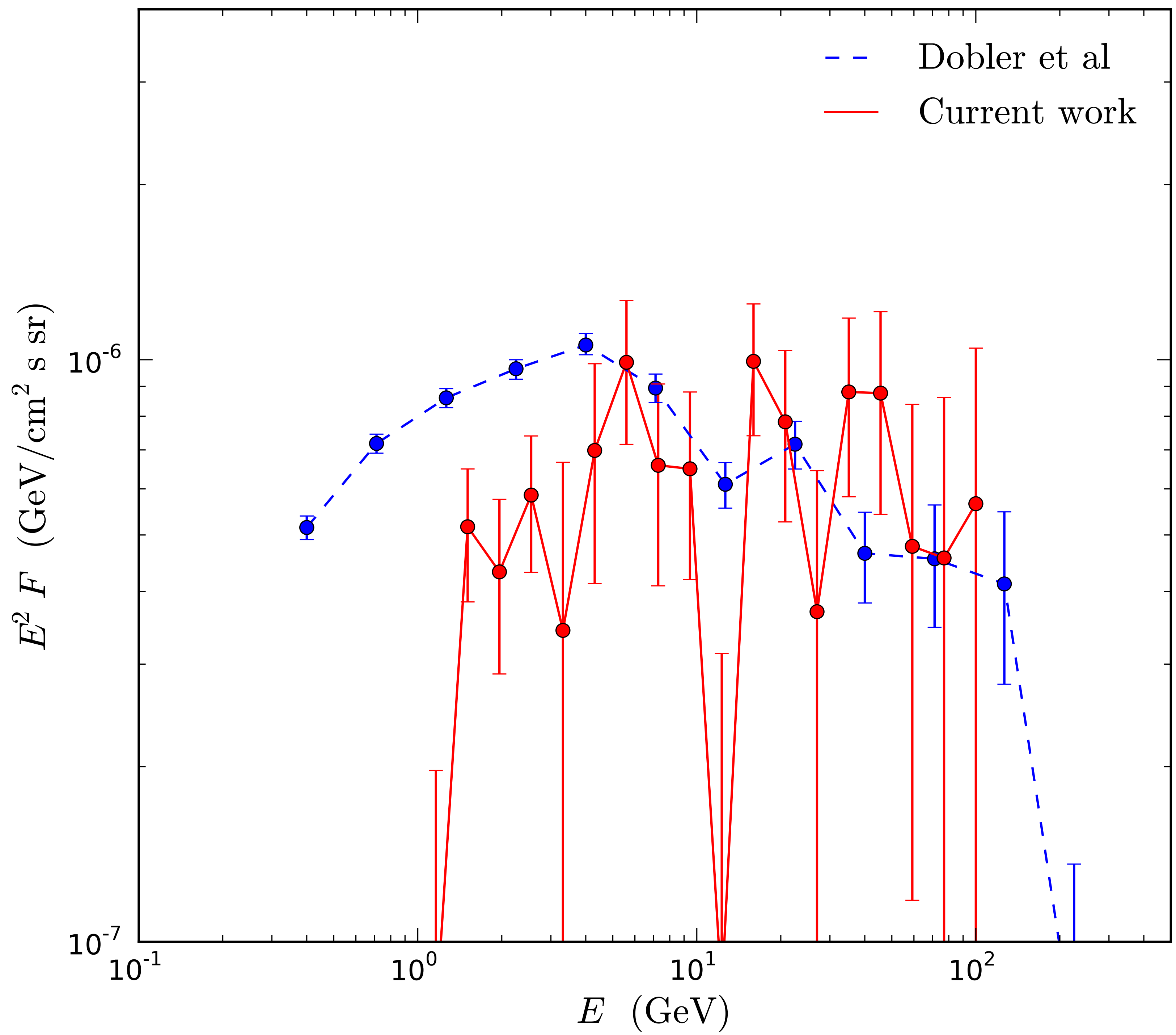
$$\chi^2/\text{dof} = 12.7/13$$

Three-template fitting



In some of the bins the significance of a spherical template is above three sigma

Gamma-ray haze via spherical harmonics decomposition



Part 2. Sources of gamma-rays at high latitude

Dark Matter: 'natural'

There exists a stellar halo, but...

- the mass of the stellar halo is at least 10 times smaller than the mass of the Galactic disk
- the stellar population of the halo is old and usually inactive.

However there are at least two exceptions:

- Type IA supernovae
- Millisecond pulsars

Compare the luminosities in the Milky Way halo

Gamma-ray haze: $\sim 10^{38} \mathrm{erg/s}$

1. Dark Matter

2. IA supernovae

3. Millisecond pulsars

Compare the luminosities in the Milky Way halo

Gamma-ray haze: $\sim 10^{38} \mathrm{erg/s}$

1. Dark Matter: $\sim 2 \times 10^{37} \mathrm{erg/s}$

freeze out cross section $\langle \sigma v \rangle_0 = 3.0 \times 10^{-26} \mathrm{cm^3 s^{-1}}$
mass 300 GeV
NFW or Einasto profile
local DM density $\rho_{\mathrm{DM}} = 0.4\, \mathrm{GeV cm^{-3}}$

We need either large boost factors
or prompt gamma-ray emission

Compare the luminosities in the Milky Way halo

Gamma-ray haze: $\sim 10^{38} \mathrm{erg/s}$

1. Dark Matter: $\sim 2 \times 10^{37} \mathrm{erg/s}$

2. IA supernovae: $< 10^{37} \mathrm{erg/s}$

Based on 1A SNe rate in the halo (Sullivan et al. 2006)

$$5 \times 10^{-14}\, \mathrm{yr}^{-1}\, M_{\odot}^{-1}$$

and average SNe output in electrons necessary to account for high energy cosmic rays (Kobayashi et al. 2004)

$$10^{48} \mathrm{erg}$$

Compare the luminosities in the Milky Way halo

Gamma-ray haze: $\sim 10^{38} \mathrm{erg/s}$

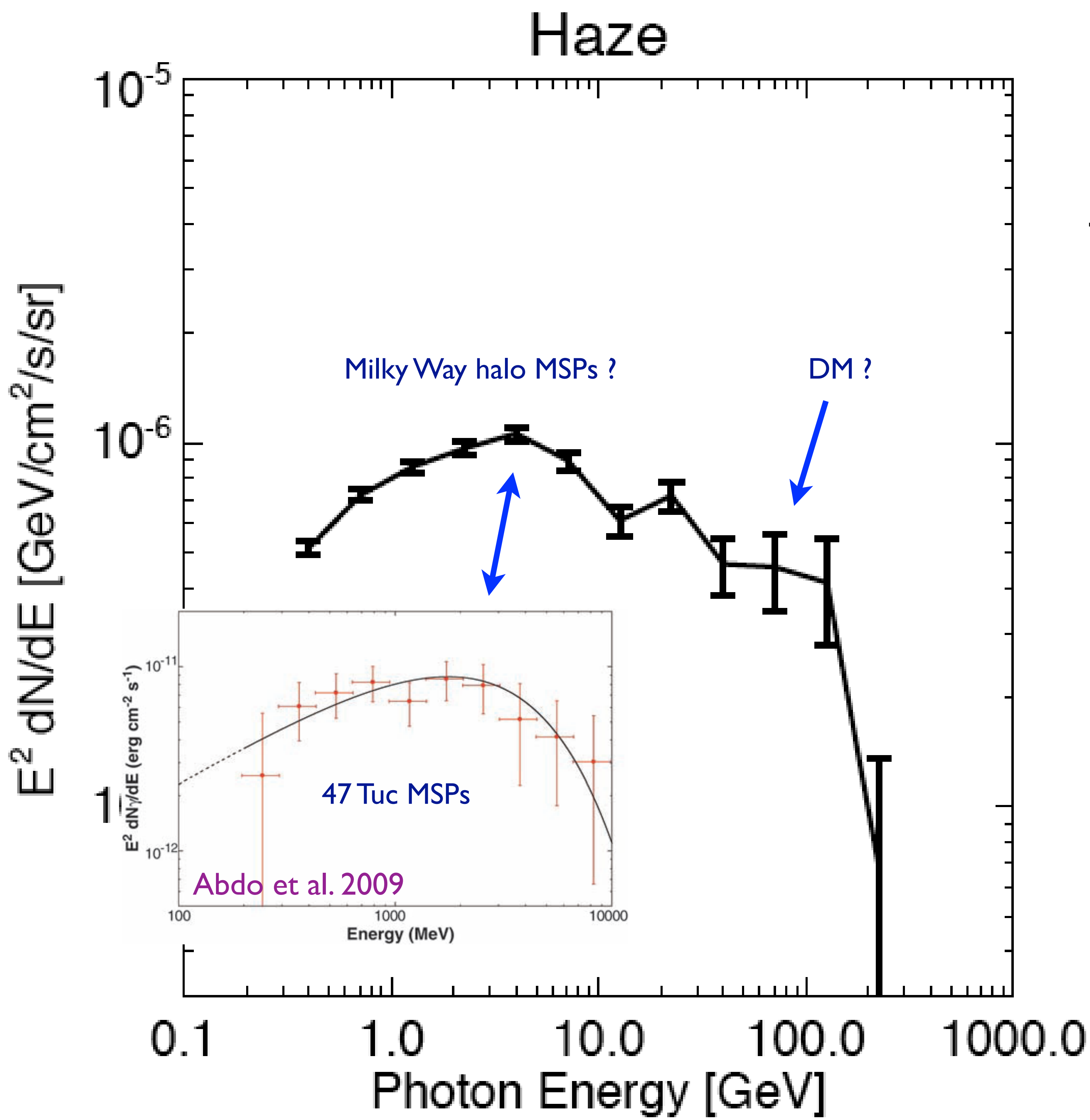
1. Dark Matter: $\sim 2 \times 10^{37} \mathrm{erg/s}$

2. IA supernovae: $< 10^{37} \mathrm{erg/s}$

3. Millisecond pulsars: $< 10^{39} \mathrm{erg/s}$

For a population of 50 000 pulsars in the Milky Way halo
with average spin-down luminosity for 8 MSPs observed by *Fermi*
(Abdo et al. 2009)

$$2 \times 10^{34} \mathrm{erg/s}$$

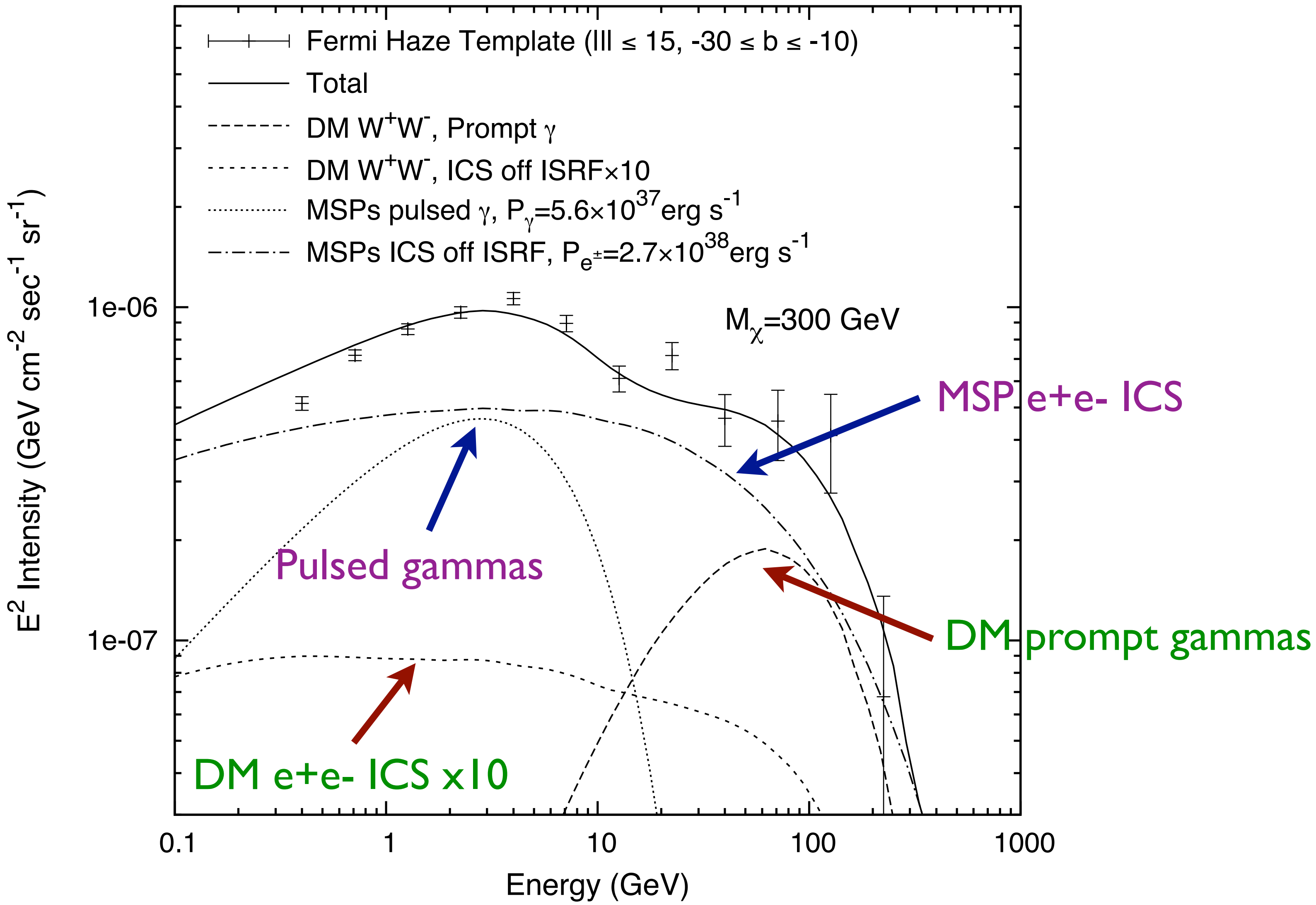


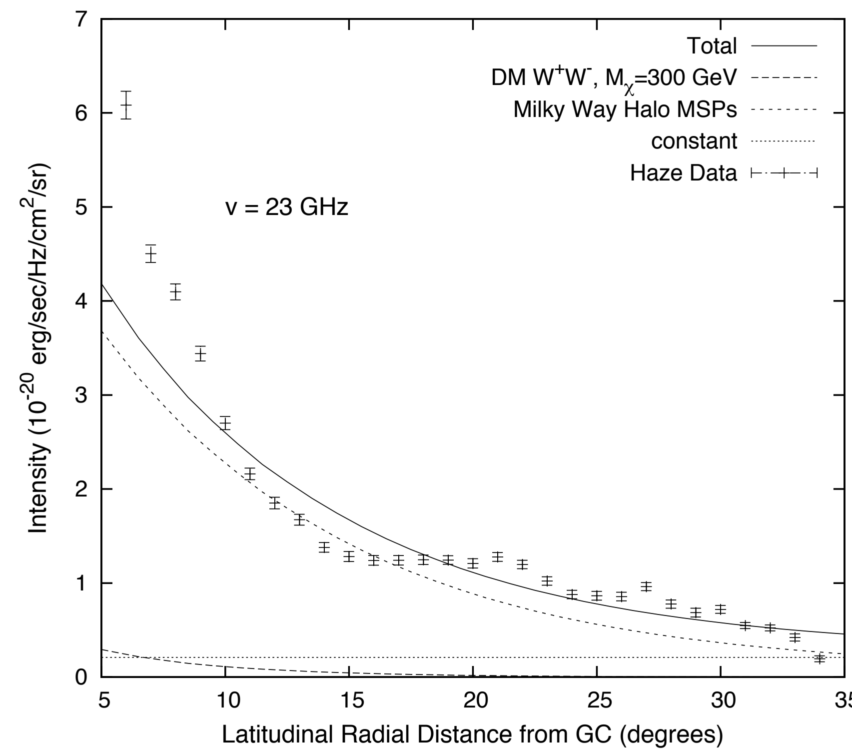
Dobler et al. 2009

Pulsed gamma-rays from 47 Tuc MSPs are similar to low energy part in the gamma-ray haze spectrum.

Thus we can expect that the low energy part can be explained by a population of MSPs in the Milky Way halo.

The high energy part of the gamma-haze spectrum is more difficult to explain.



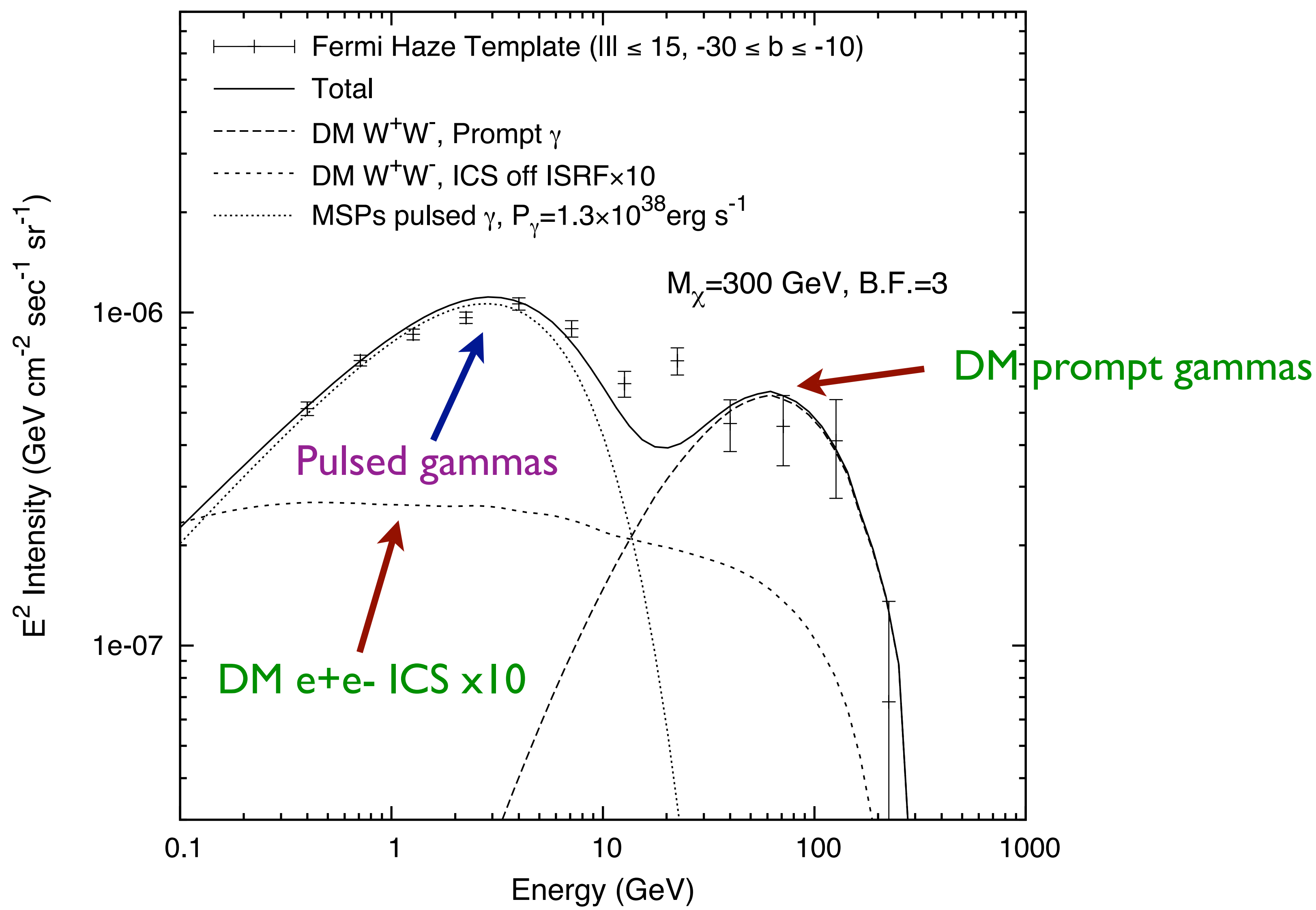


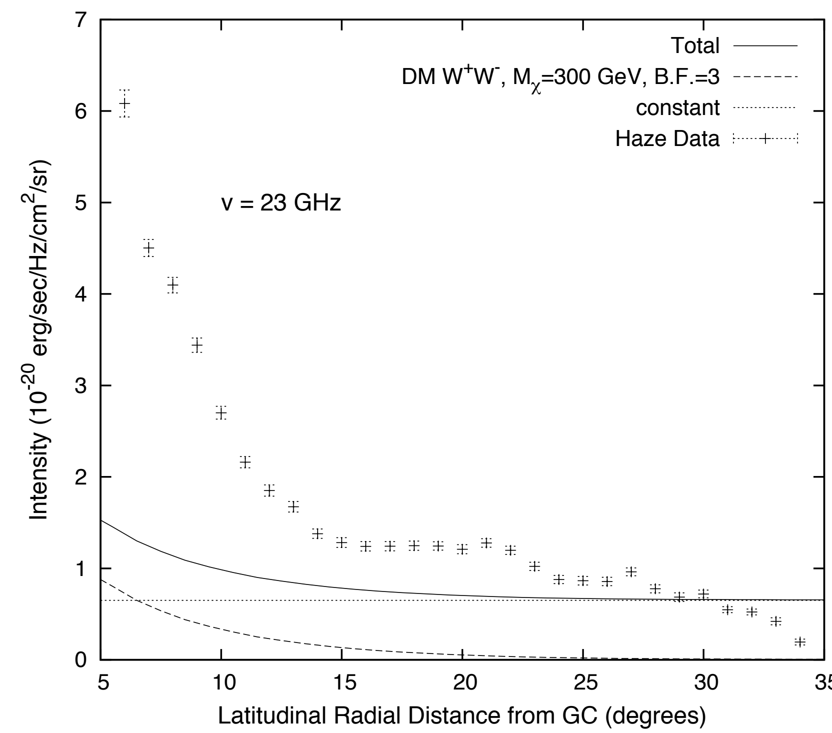
Both gamma-ray haze and WMAP haze are OK

In this model we need 30 000 MSPs in Milky Way halo with average spin-down energy conversion efficiencies

$$\eta_\gamma = 0.1$$
$$\eta_{e^\pm} = 0.5$$

MSPs pulsed gammas and DM to W+W- prompt gammas



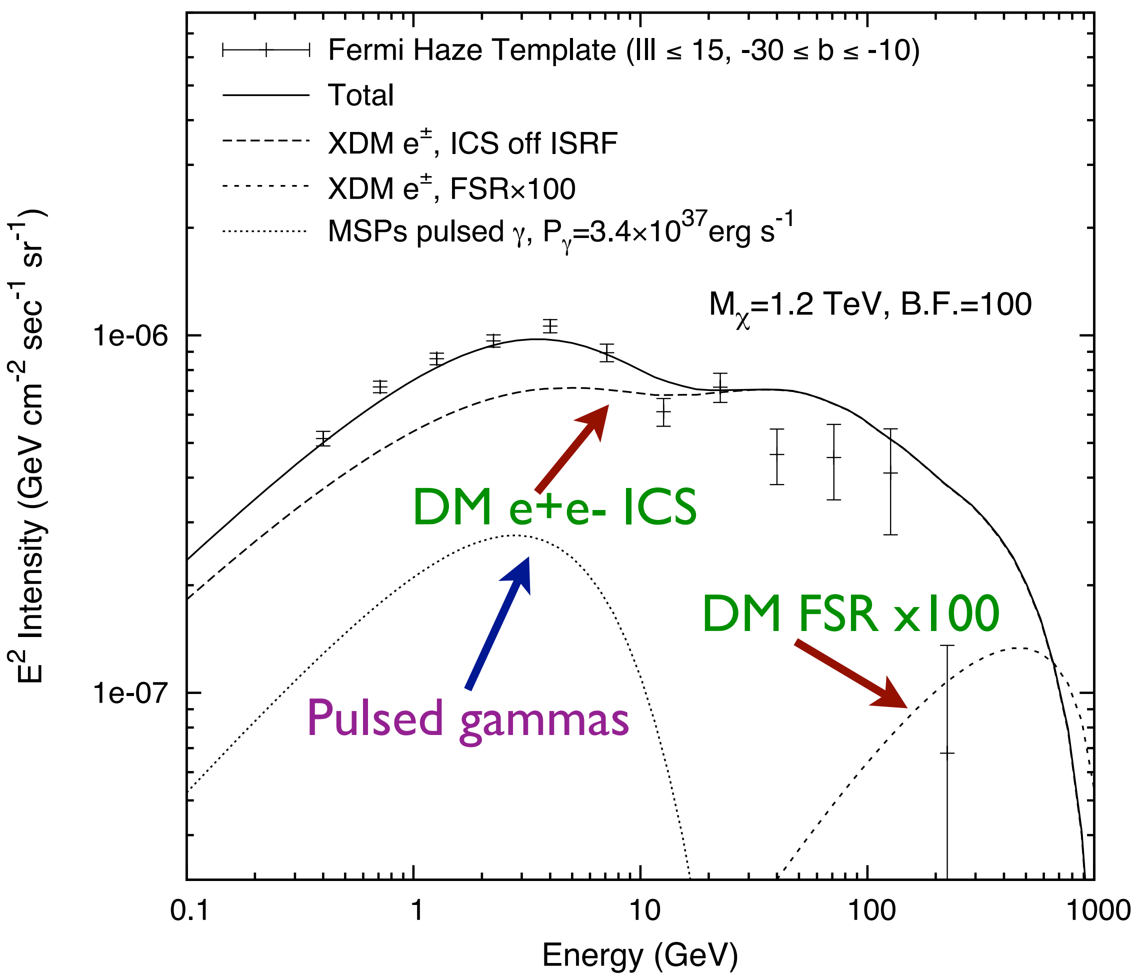


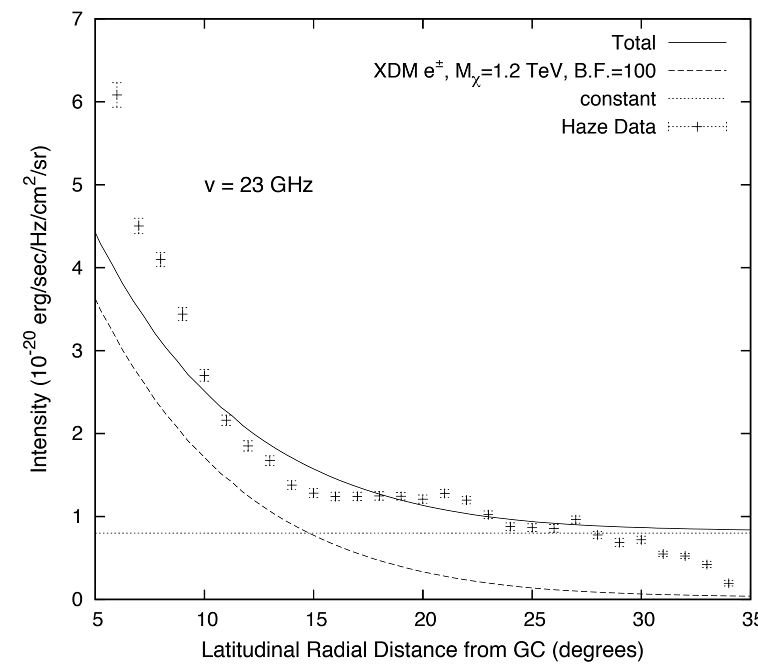
WMAP haze: No

Gamma-ray haze: OK with DM BF = 3

Here we need 60 000 MSPs in Milky Way halo with $\eta_\gamma = 0.1$

MSPs pulsed gammas and DM e+e- annihilation





WMAP haze: OK

Gamma-ray haze: OK with DM BF = 100

In this case we need 20 000 MSPs in Milky Way halo with $\eta_{\gamma} = 0.1$

Conclusions

1. Spherical harmonics method is a natural choice for fitting the large scale structures in gamma-rays, complementary to coordinate-space fitting

2. Standard WIMP dark matter annihilating in W+W-, b-bbar etc. can provide a significant fraction of gamma-rays at high latitudes

3. Millisecond pulsars may also be a plausible source of gamma-rays An existence of a large number of MSPs in the Milky Way stellar halo can provide interesting hints about the history of our Galaxy