Fermi Gamma-ray Haze via Dark Matter and Millisecond Pulsars

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arxiv:1002.0587, submitted to ApJ

TeVPA 2010

Indirect DM searches

Charged particles => diffusion

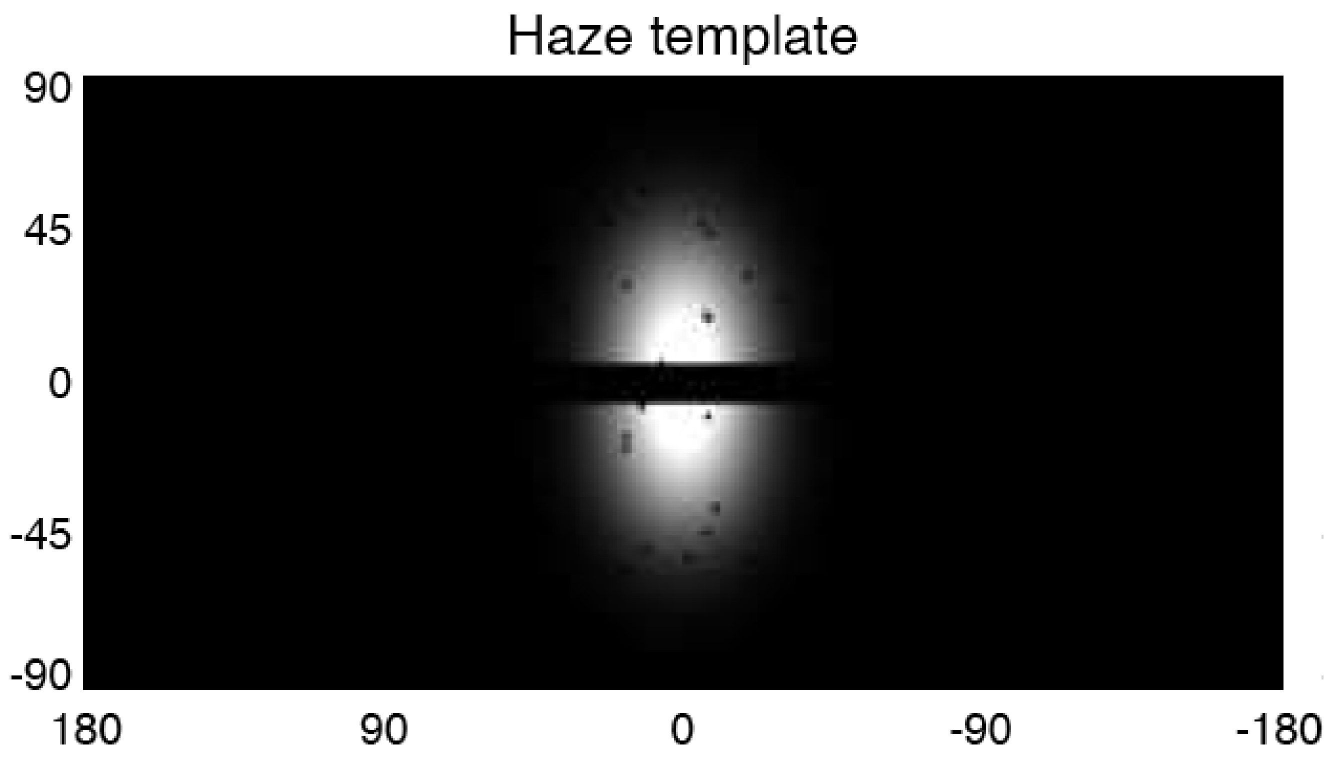
Only local sources
Look for anomalies in the spectrum

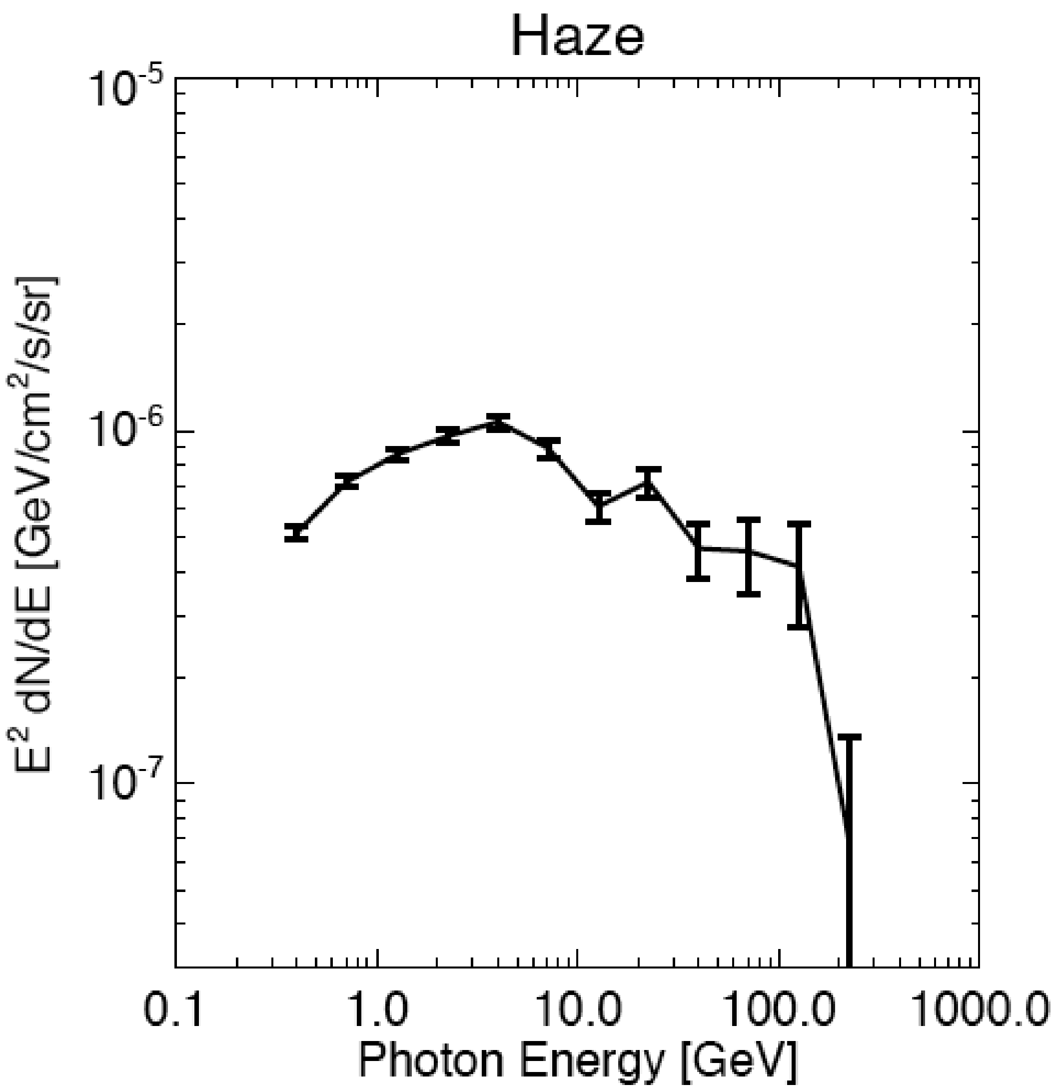
Photons => propagate on straight lines

Morphology of the source
Also possible anomalies in the spectrum

Beware of astrophysics

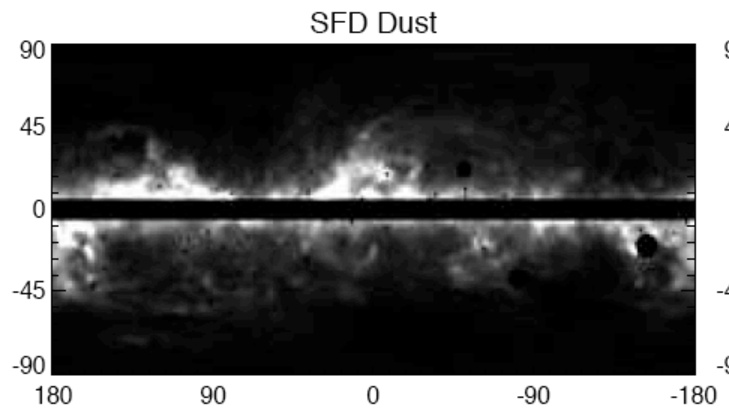
Gamma-ray haze

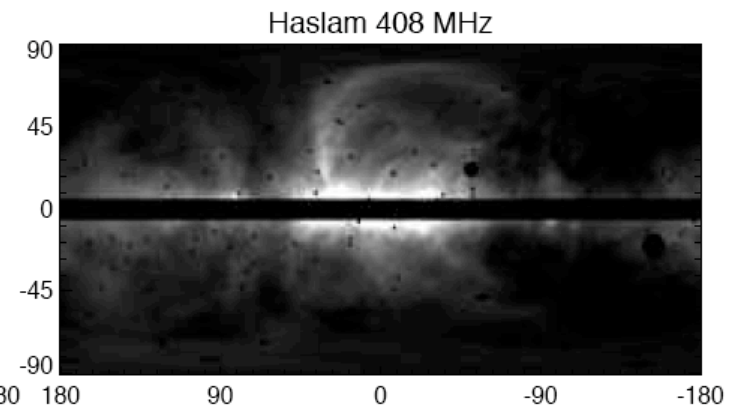


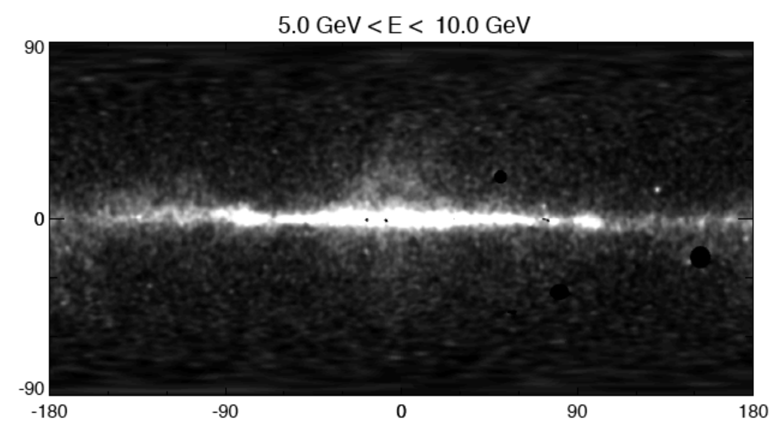


Dobler et al. arxiv:0910.4583

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

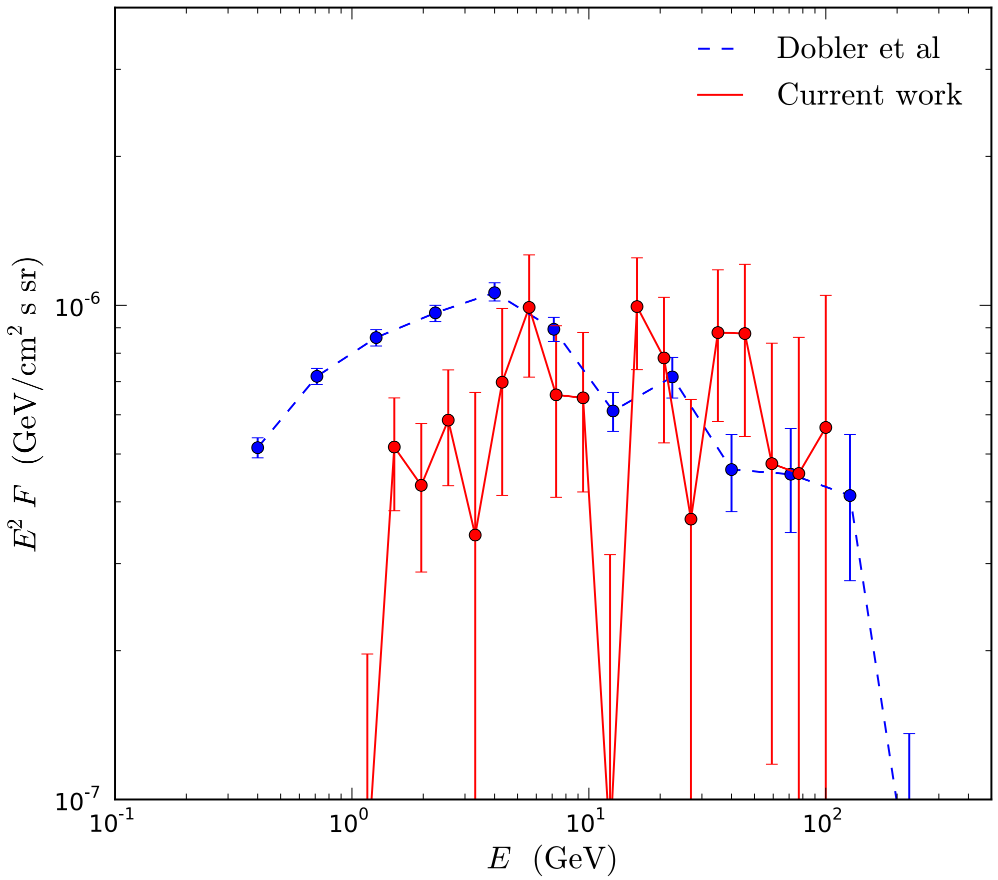






Gamma-ray haze via spherical harmonics decomposition

Work in progress... (DM, J. Bovy, I. Cholis)



- Fitting in a window excluding Galactic plane
- Templates:
  Astrophysics: 100 MeV bin
  Isotropic distribution
  Bivariate gaussian template
- Fit the data by the templates in the space of spherical harmonics

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

Motivation

Is gamma-ray haze real?
Are we missing something?

It is impossible to resolve this at the moment,
may be it will be possible in the future.

The existence of the haze in two independent derivations is a sufficient motivation to think about possible galactic DM and astro contributions to high latitude gamma-rays.

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: $\sim 10^{38} \mathrm{erg/s}$

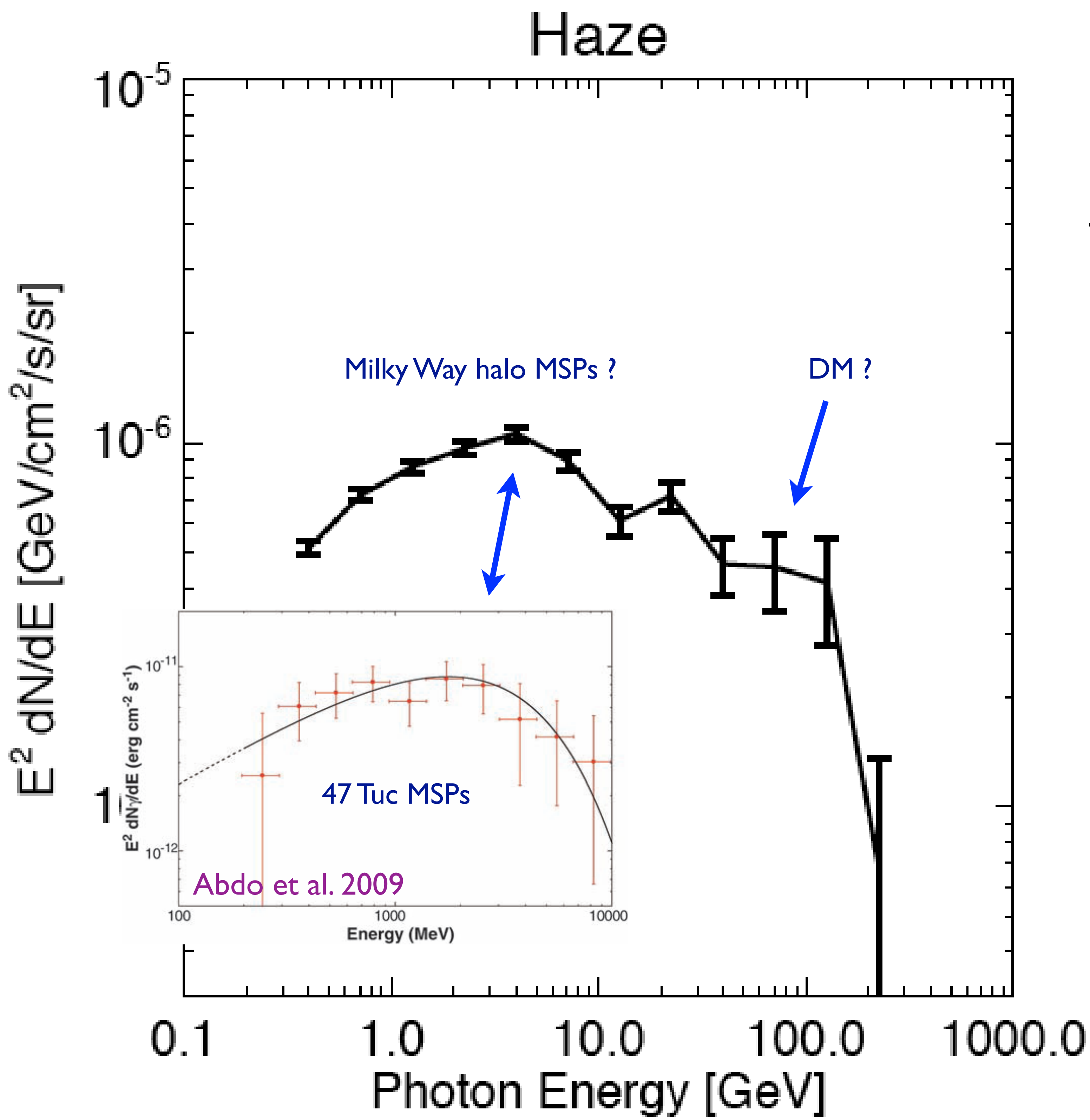
1. Dark Matter: $\sim 2 \times 10^{37} \mathrm{erg/s}$

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)

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

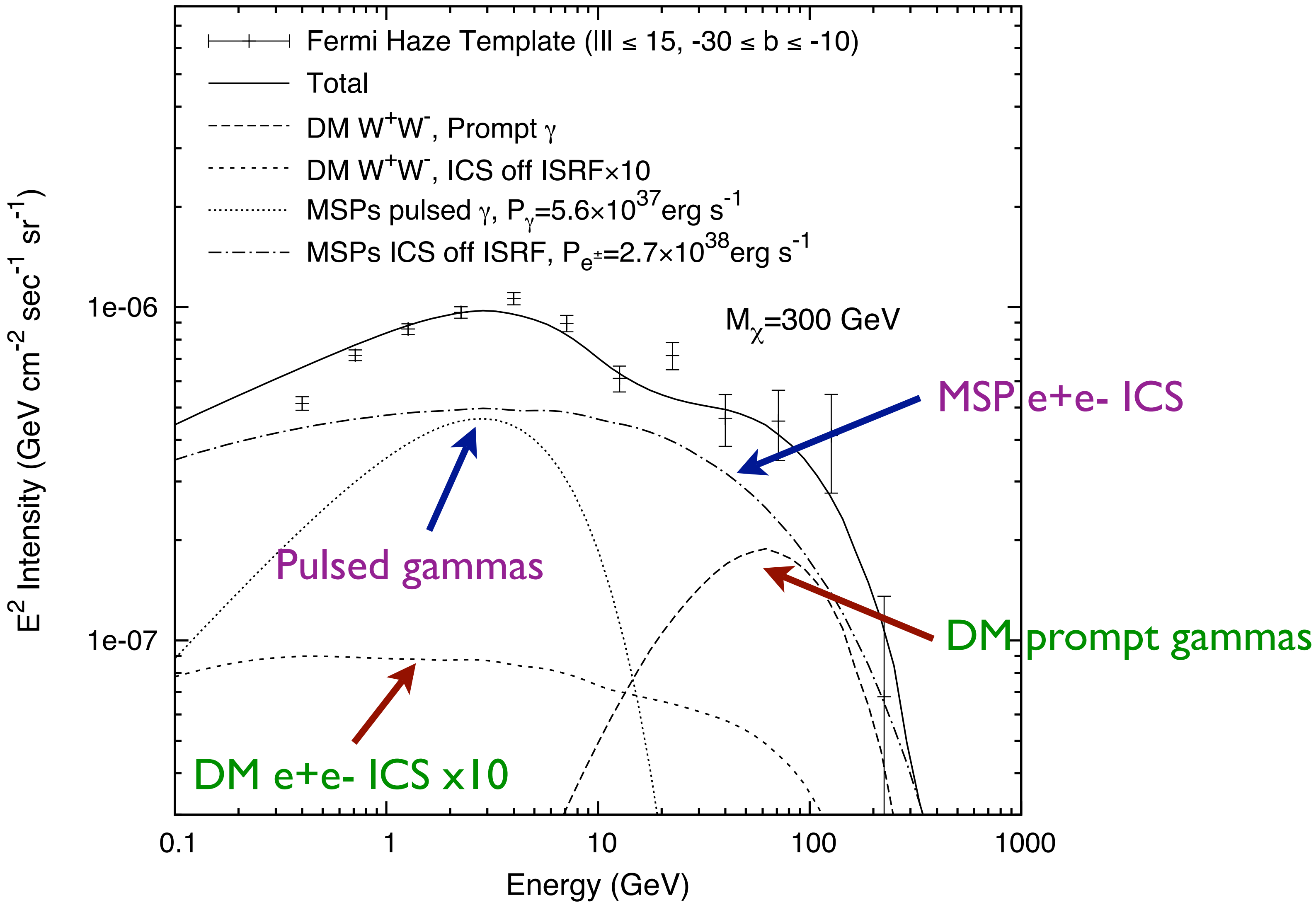


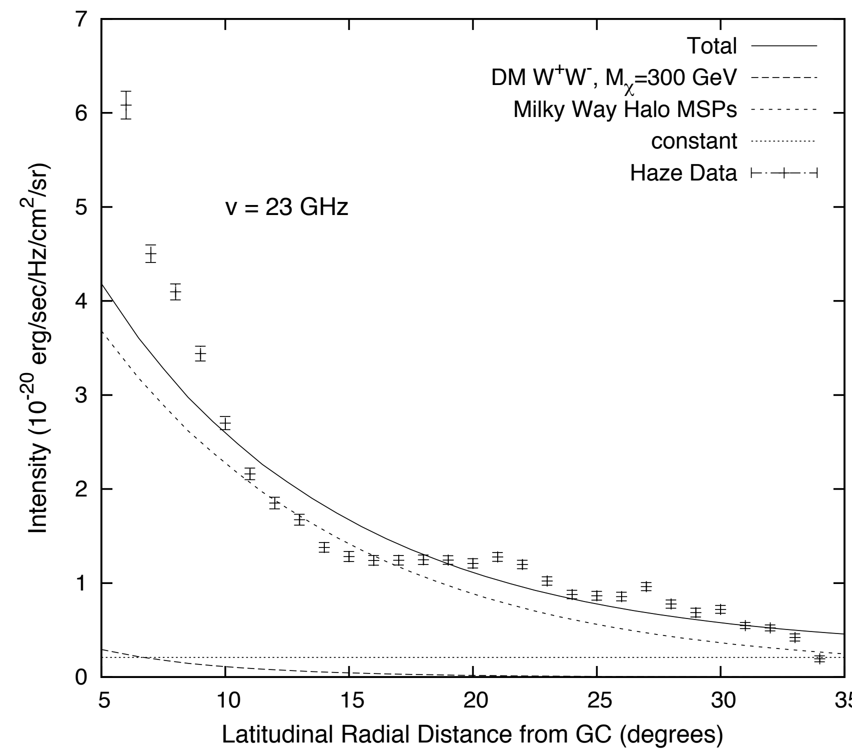
Dobler et al. 2009

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.



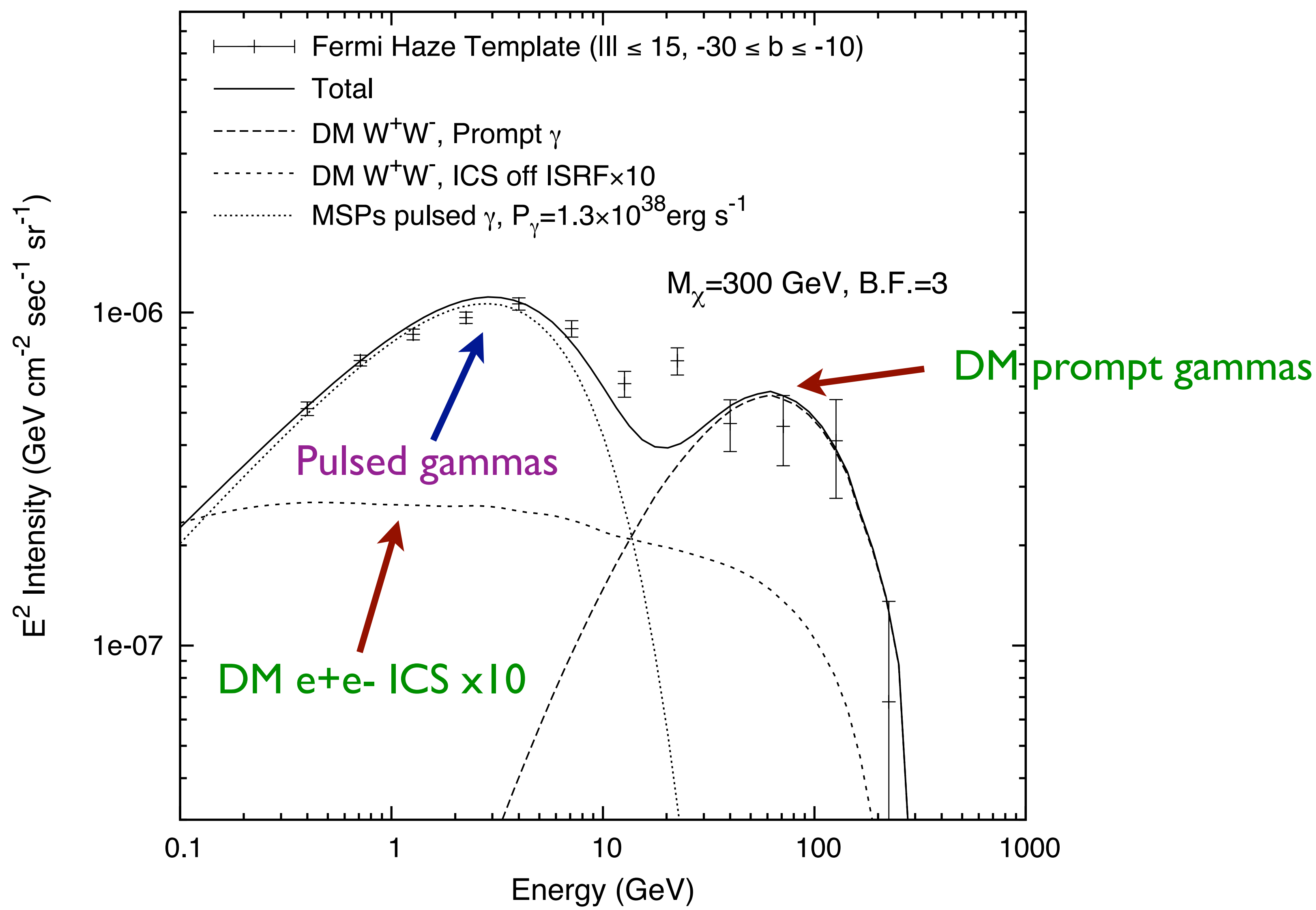


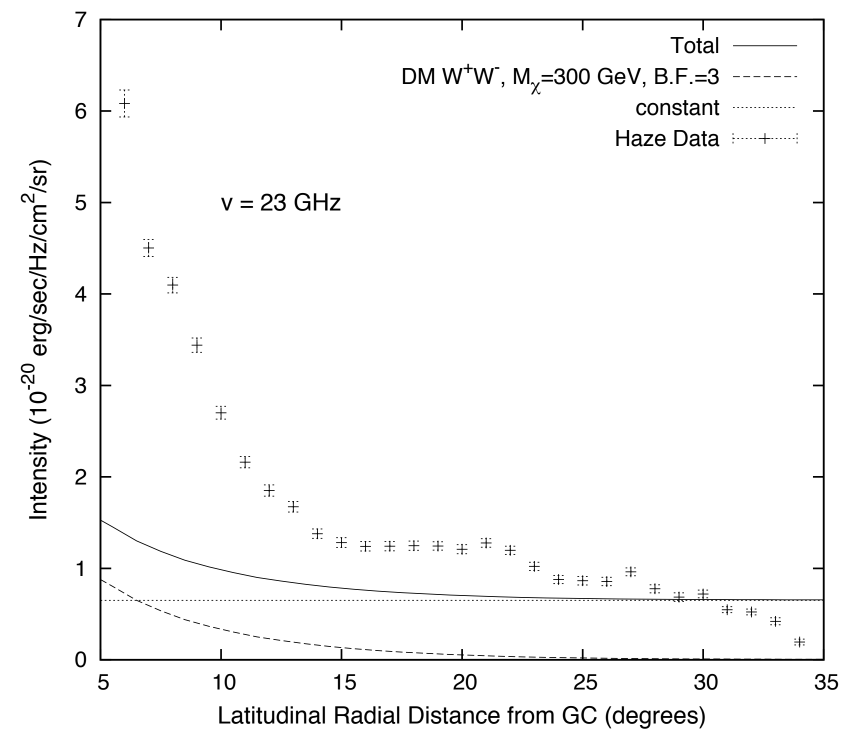
Both gamma-ray haze and WMAP haze are OK

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



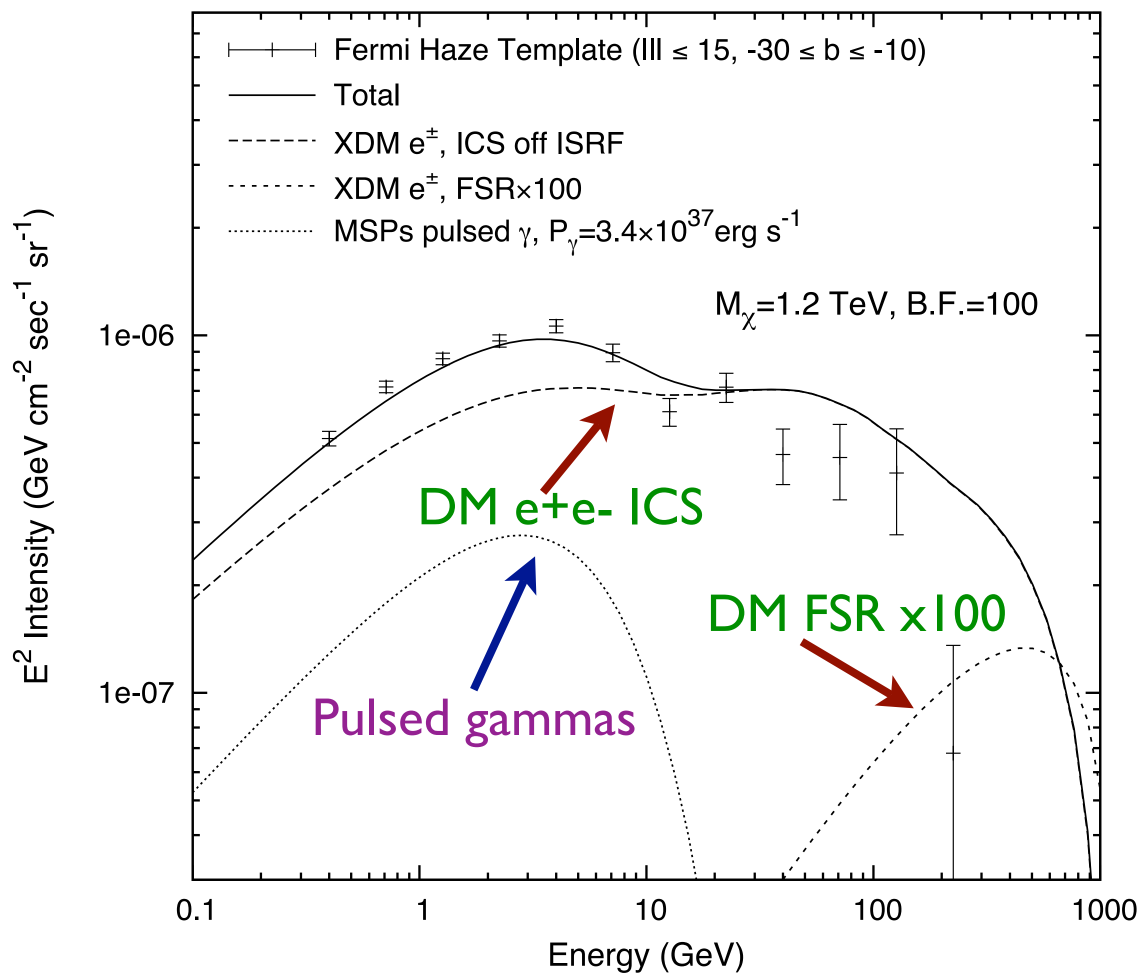


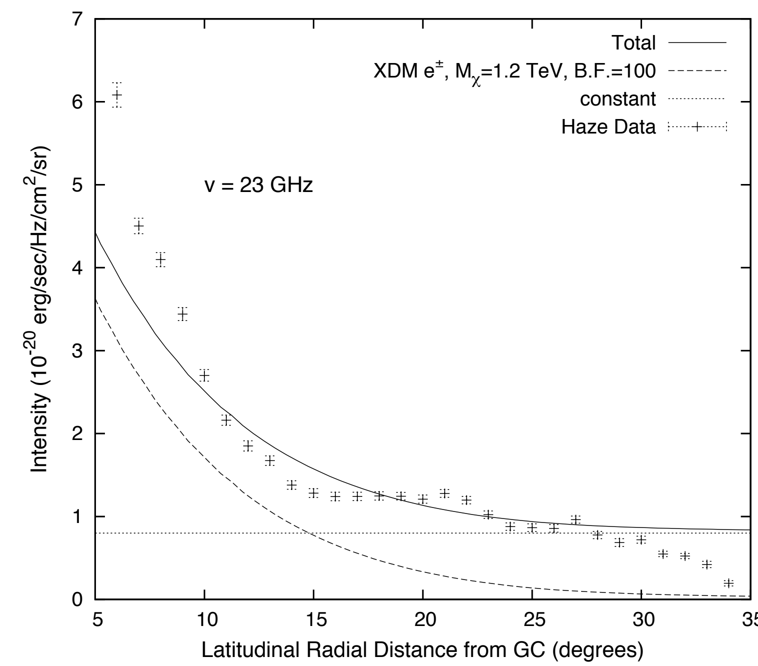
WMAP haze: No

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. WIMP DM annihilating into W+W-, b-bbar etc., is not excluded by gamma-rays. Moreover it can provide a significant contribution.

2. Millisecond pulsars may also be a plausible source of gamma-rays at high latitudes

3. One can expect about 20 000 - 60 000 MSPs in the Milky Way stellar halo. This is not a ‘standard’ astrophysics: the gamma-ray contribution from MSPs in the stellar halo is usually neglected.

Extra slides:
various constraints on DM annihilation from gamma-ray data

Fermi model of diffuse gamma-rays

(http://fermi.gsfc.nasa.gov/)

Fermi all-sky map and the model:

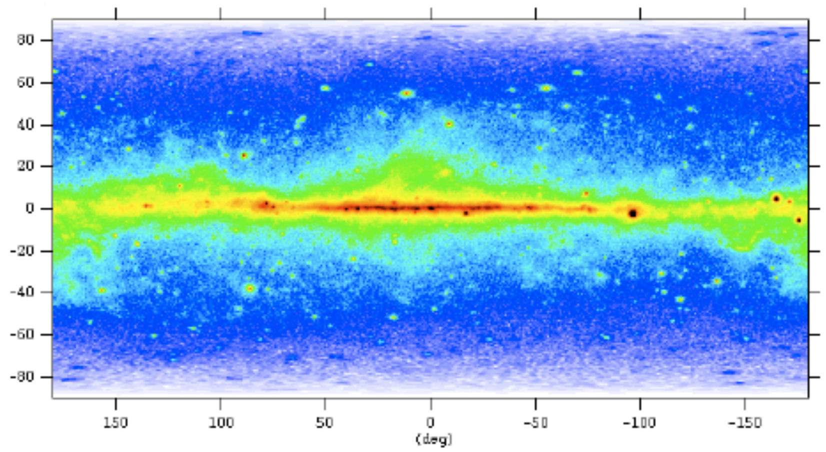


Figure 1: LAT all-sky γ-ray count map, $N_{obs}(l, b)$, in the 0.3–20 GeV energy band, in log-scale.

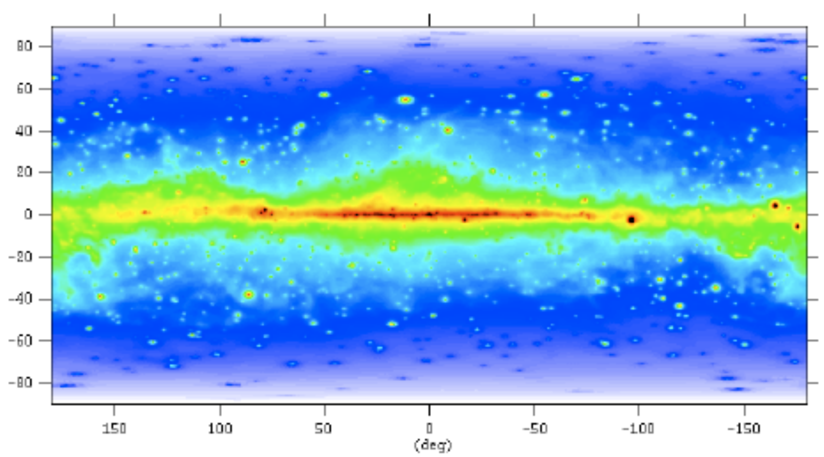


Figure 2: Diffuse model prediction *together with modeled point sources*, $N_{pred}(l, b)$, in the 0.3–20 GeV energy band. The photon counts are displayed with the same log-scale as in Fig. 1.

Fermi residual map

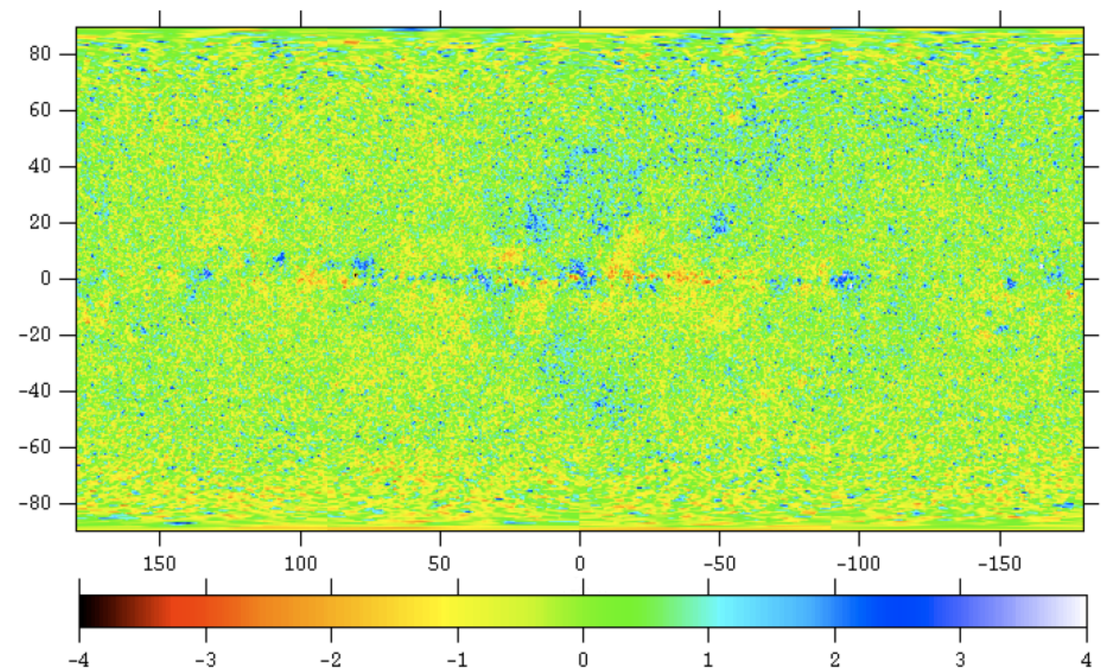
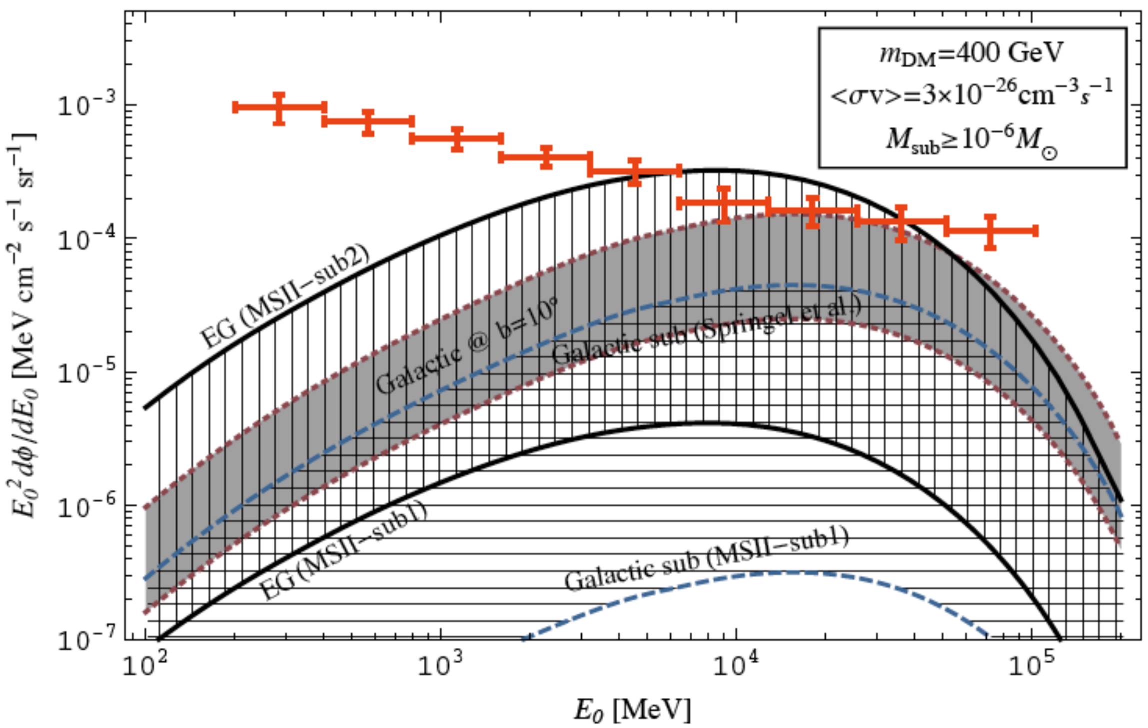


Figure 3: Residual map expressed in sigma values: $(N_{obs} - N_{pred})/\sqrt{N_{pred}}$

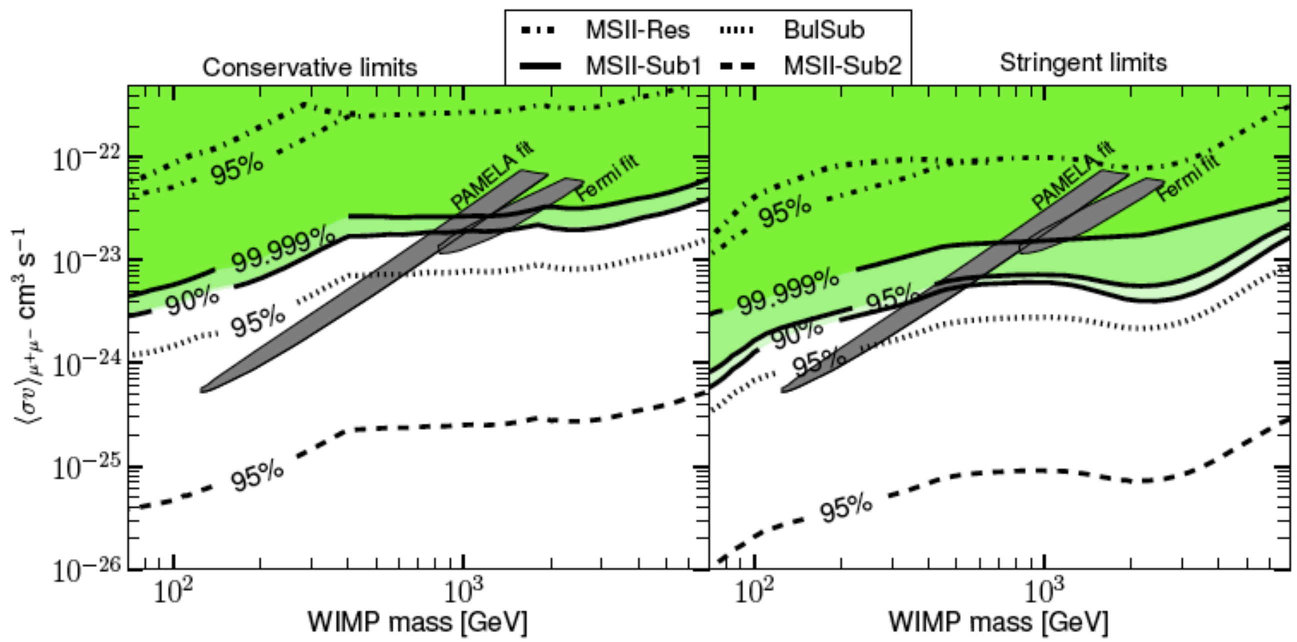
Fermi constraints on DM from gamma-ray spectrum

A. Abdo et al, arXiv:1002.4415, JCAP 1004:014,2010

Fluxes of (extra)galactic gamma-rays from DM annihilation in the main halo and sub-halos



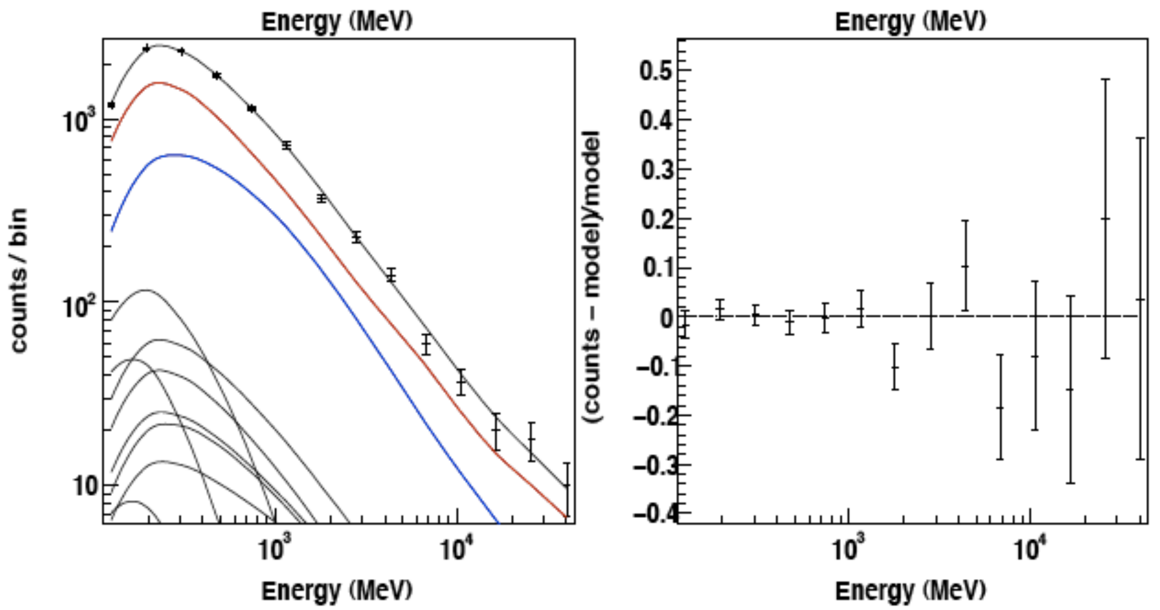
Constraints on DM annihilation in $\mu^+\mu^-$ channel



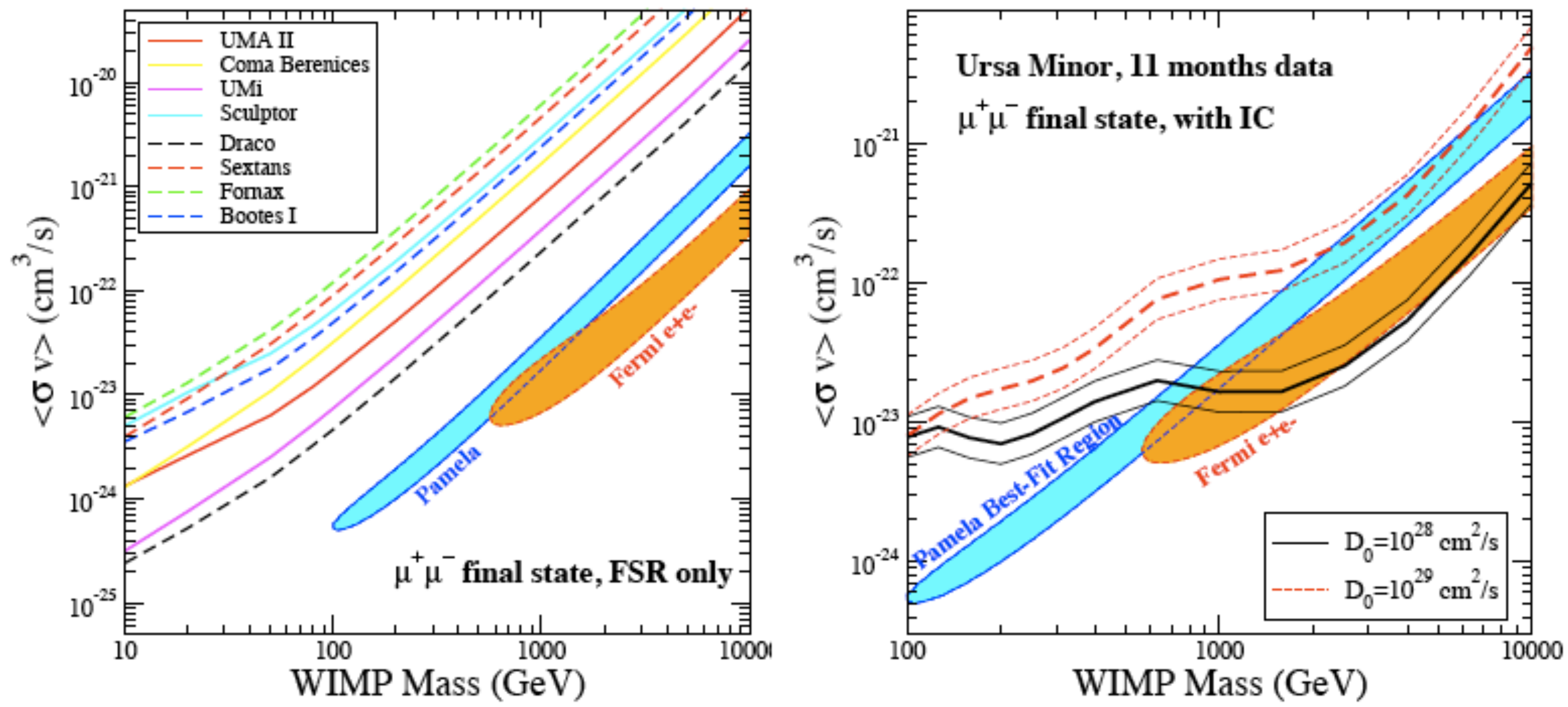
Fermi constraints on DM annihilation from dwarf galaxies

A. Abdo et al, arXiv:1001.4531 Astrophys.J.712:147-158, 2010

Counts and residuals for Draco dwarf galaxy



Constraints on DM annihilation

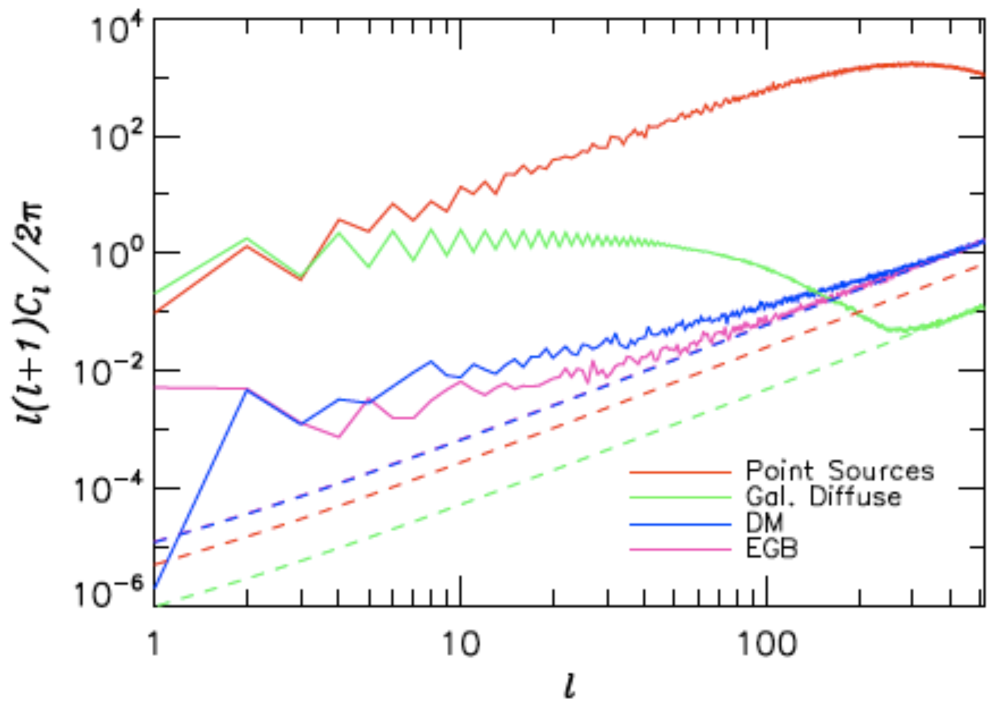


Constraints from DM (sub)structure angular power spectrum

A. Cuoco et al, arXiv:1005.0843

Power spectrum of angular distribution of gamma-rays from DM annihilation and astrophysics

Look for a feature in the intermediate L due to DM sub-halos



Constraints on DM annihilation in $\mu^+\mu^-$ channel