# Fermi Gamma-ray Haze via Dark Matter and Millisecond Pulsars

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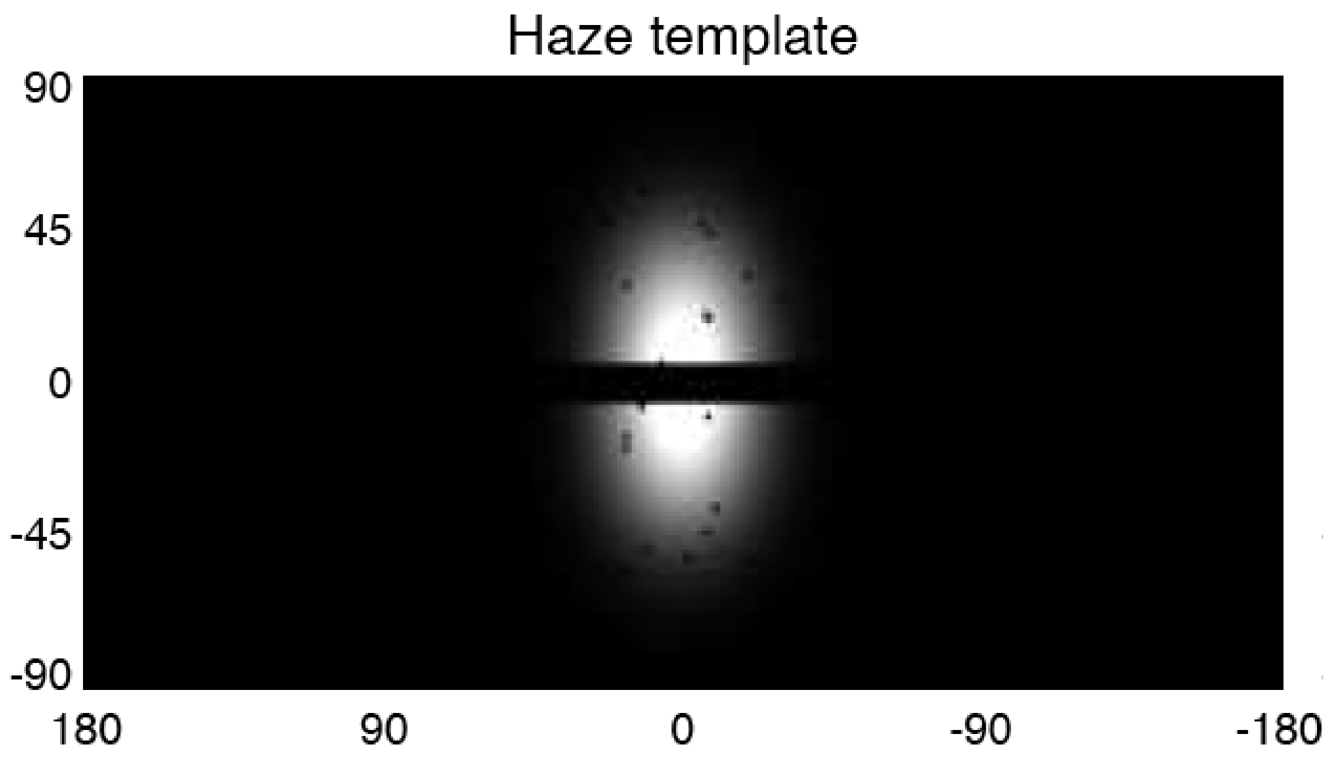
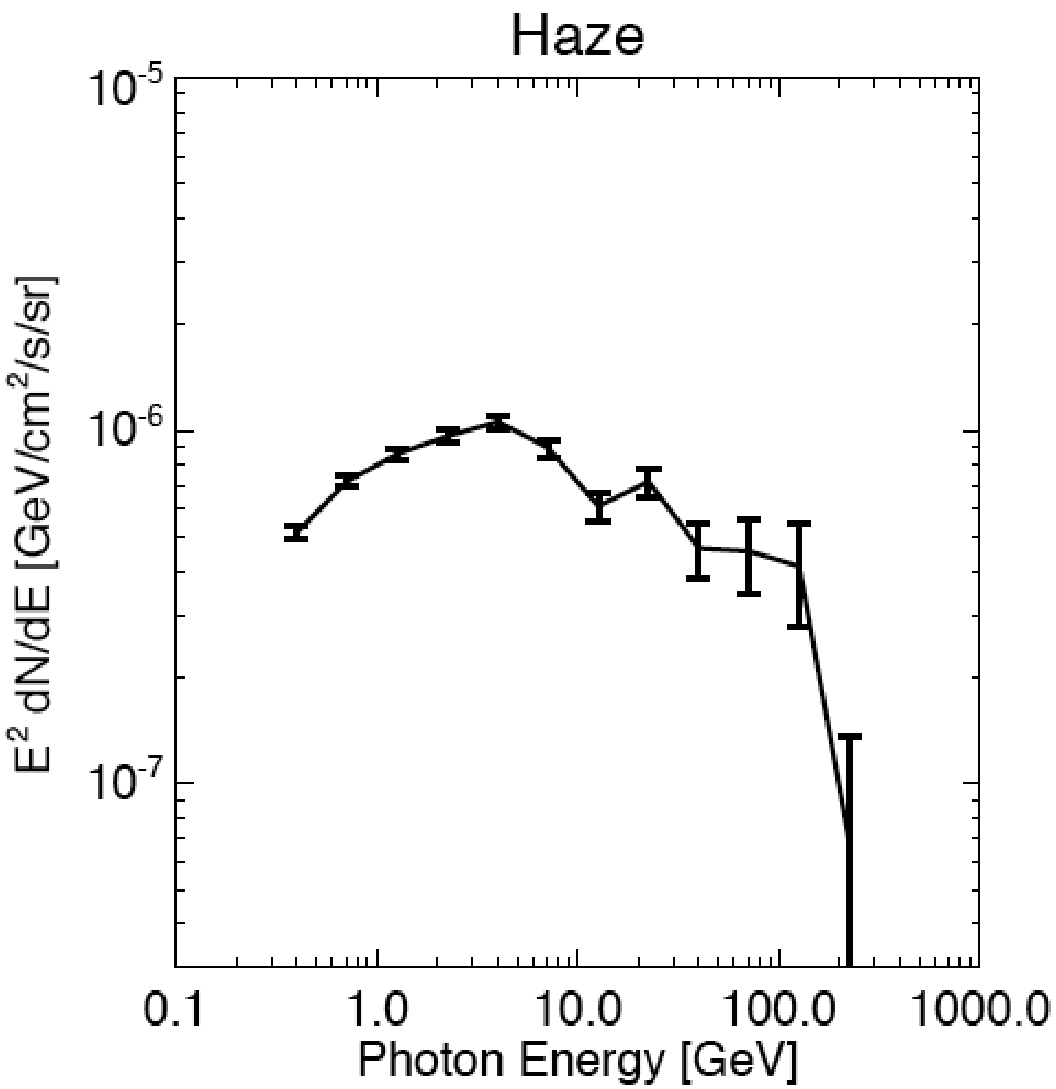
arxiv:1002.0587

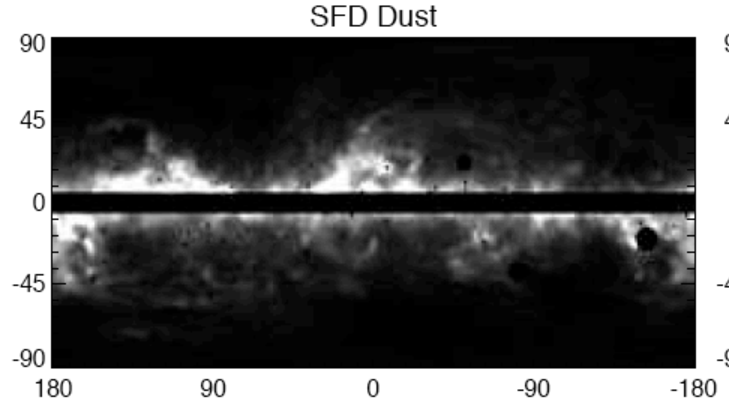
# Gamma-ray haze

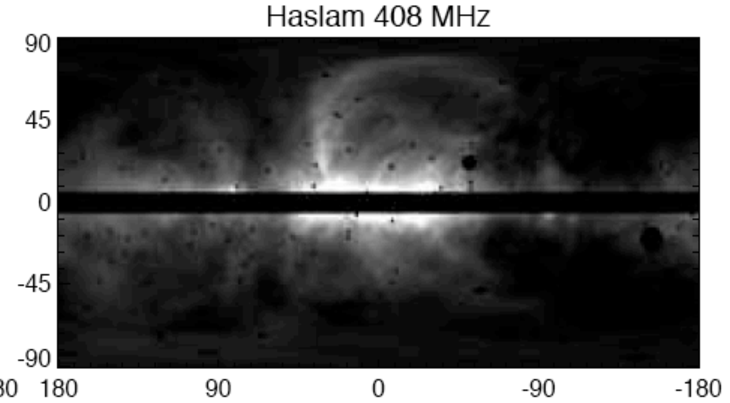



Dobler et al. arxiv:0910.4583

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



# Possibilities to consider:

1. Dark Matter annihilation
2. IA supernovae electrons
3. Millisecond pulsars pulsed gamma-rays and e+e-

# 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

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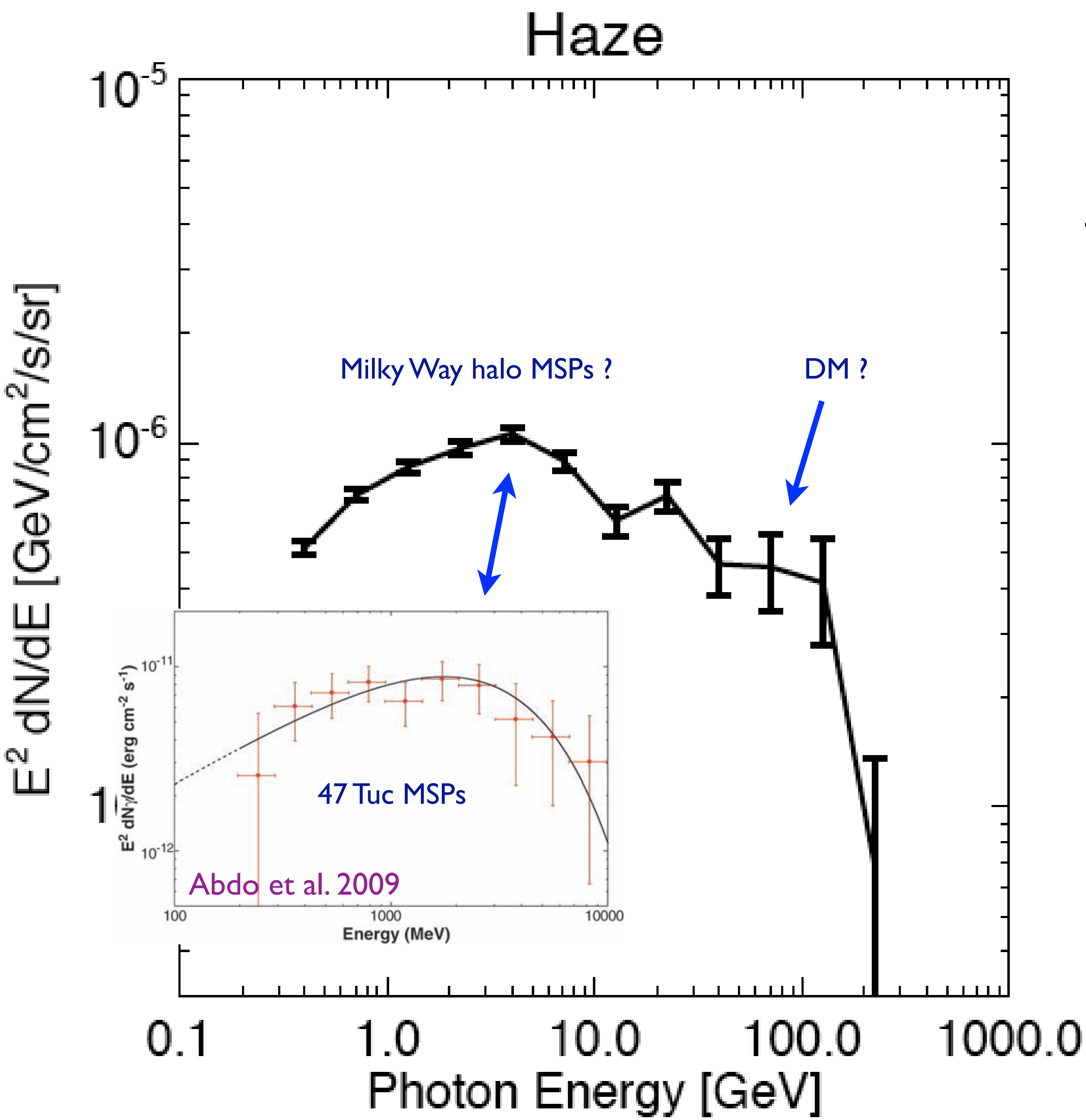
1. Dark Matter: $\sim 2 \times 10^{37} \mathrm{erg/s}$

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)

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

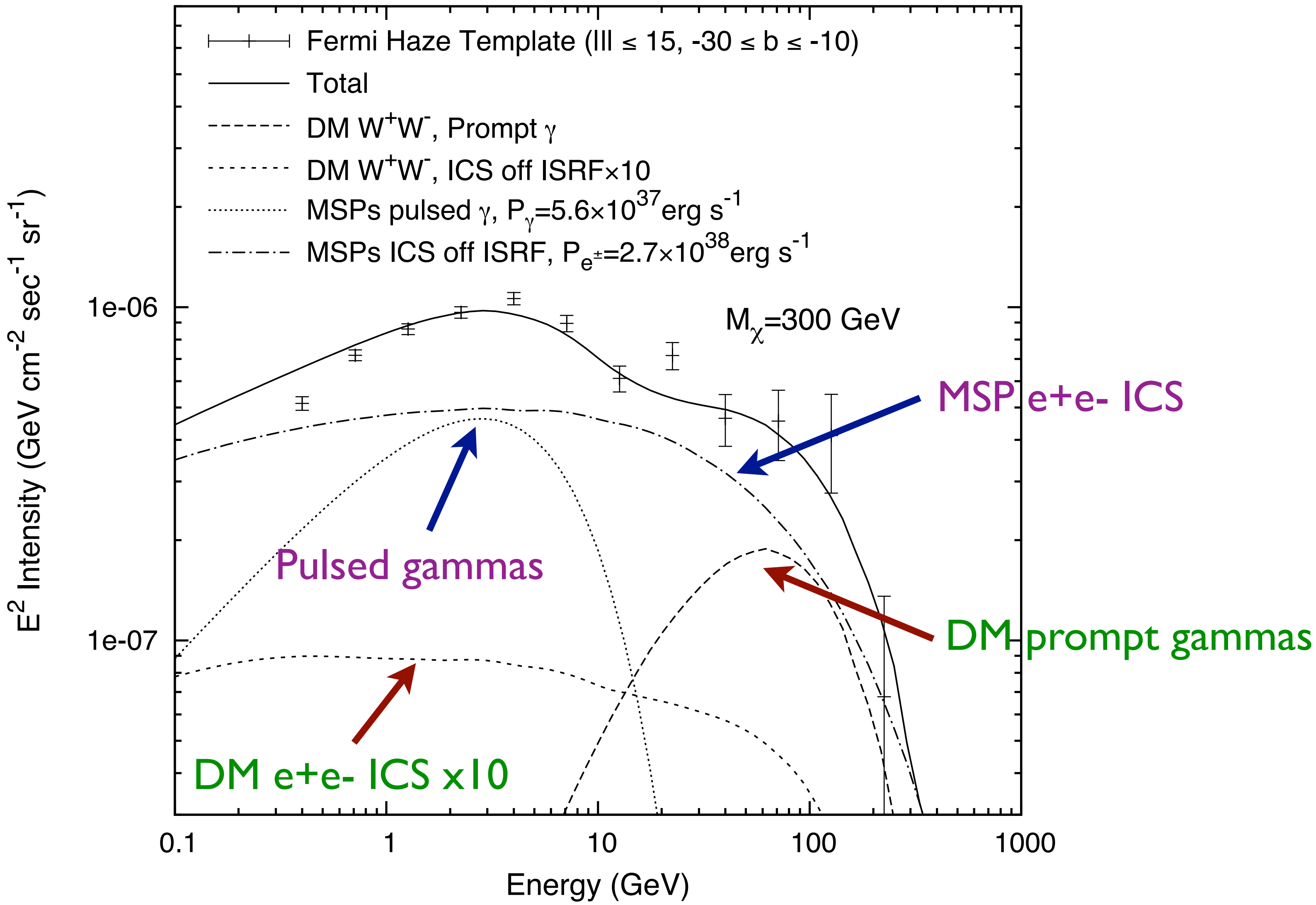


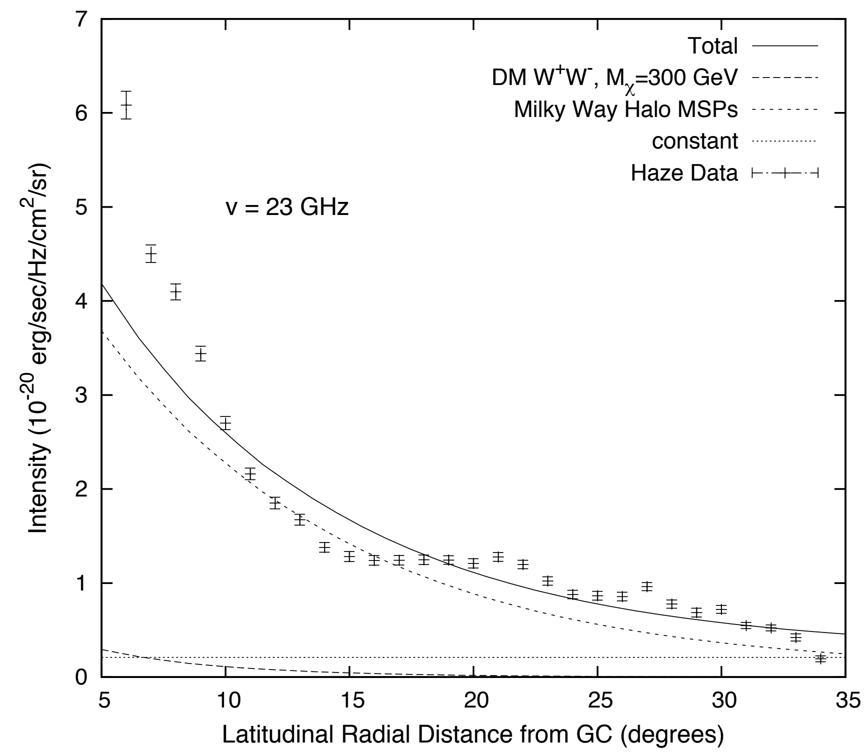

Dobler et al. 2009

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.



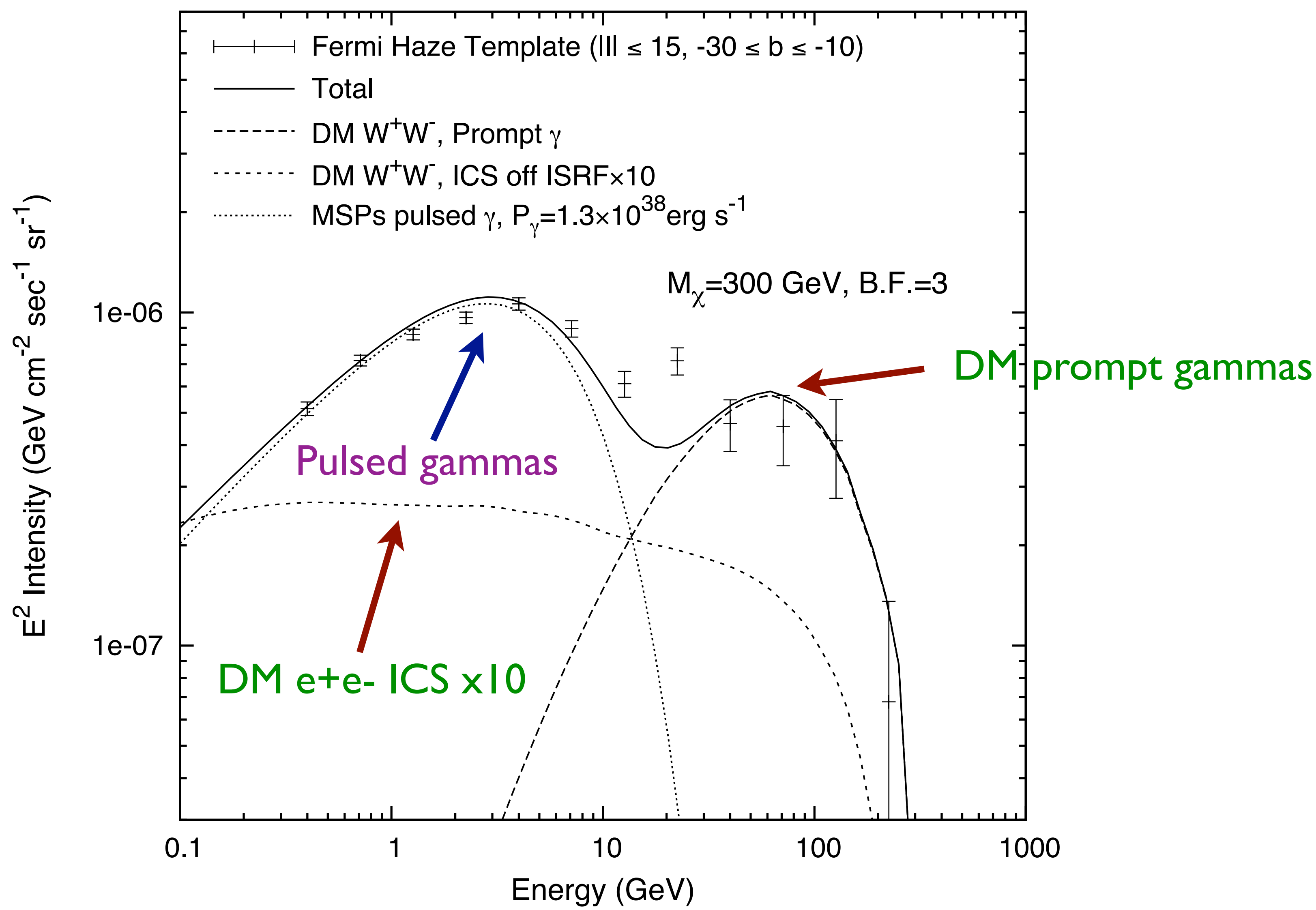



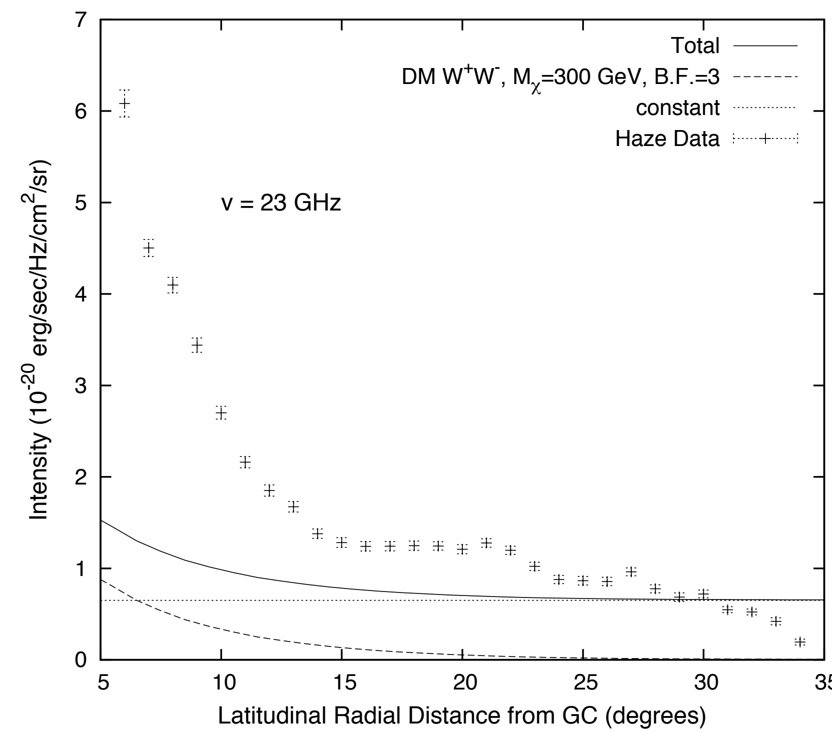

Both gamma-ray haze and WMAP haze are OK

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



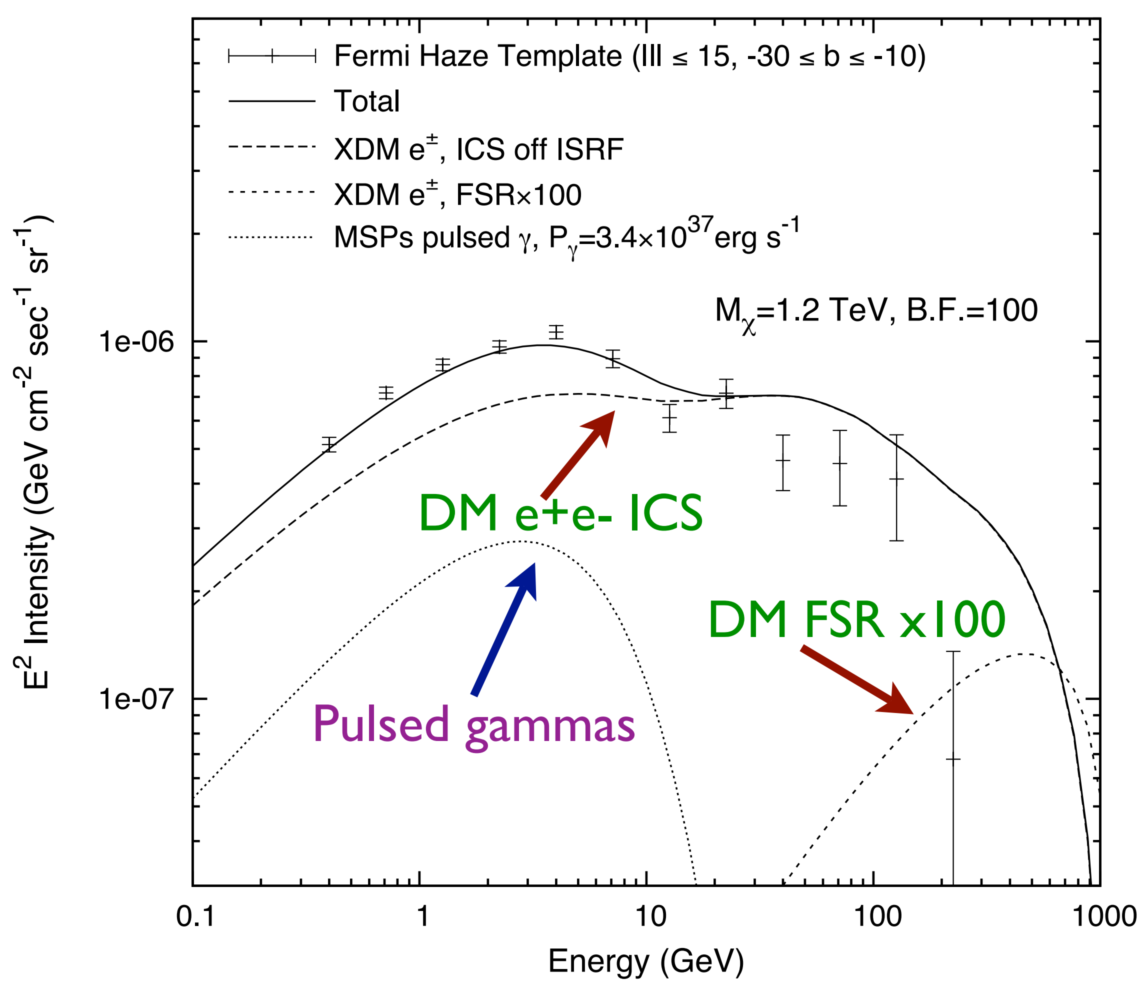



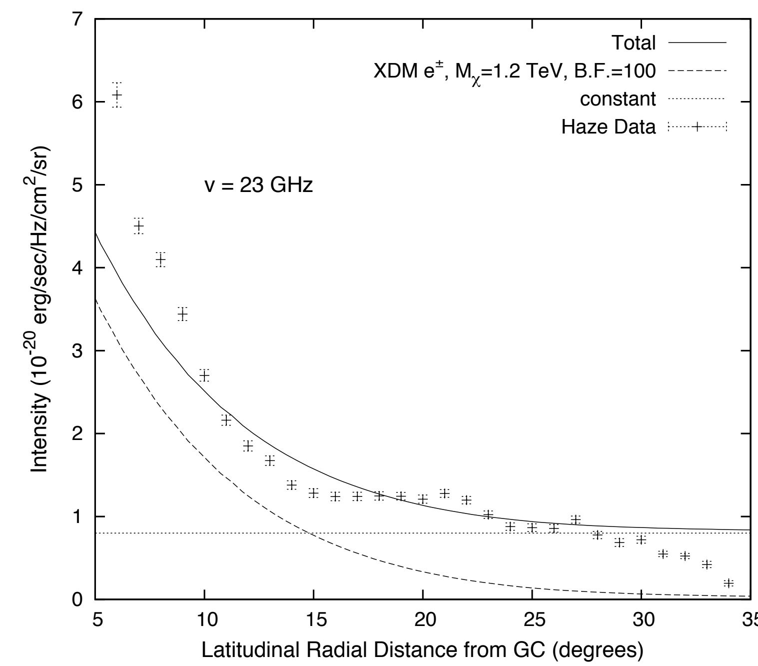

WMAP haze: No

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. In DM models with one type of DM particles we need an astrophysical source of gamma-rays in the Milky Way halo

2. Millisecond pulsars is the most plausible such source

3. We need about 20 000 - 60 000 MSPs in the Milky Way stellar halo.

4. To fit the WMAP haze we need either
   - leptonically annihilating DM with BF ~ 100 or
   - significant e+e- emission from MSPs (about 50% of spin-down)

# 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:

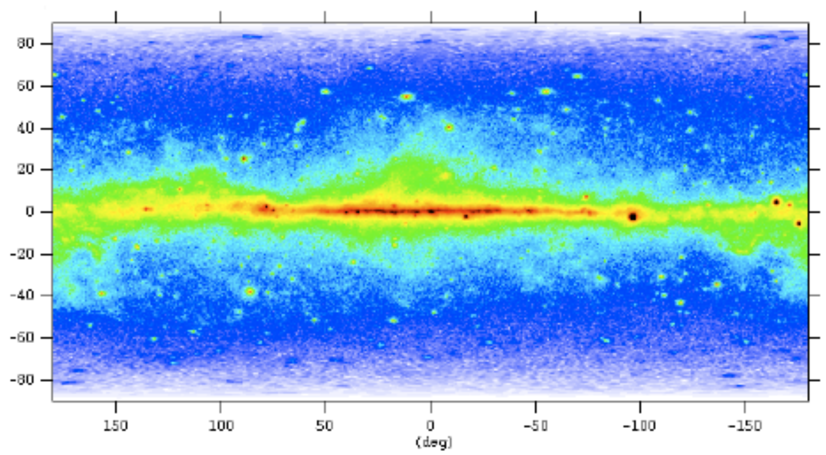


Figure 1: LAT all-sky $\gamma$-ray count map, $N_{obs}(l, b)$, in the 0.3–20 GeV energy band, in log-scale.

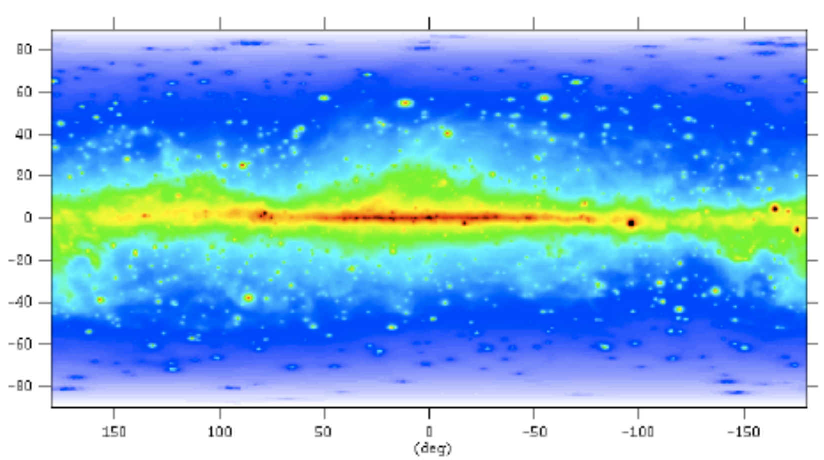


Figure 2: Diffuse model prediction *together with modeled point sources*, $N_{pred}(l, b)$, in the 0.3–20 GeV energy band. The photon counts are displayed with the same log-scale as in Fig. 1.

## Fermi residual map

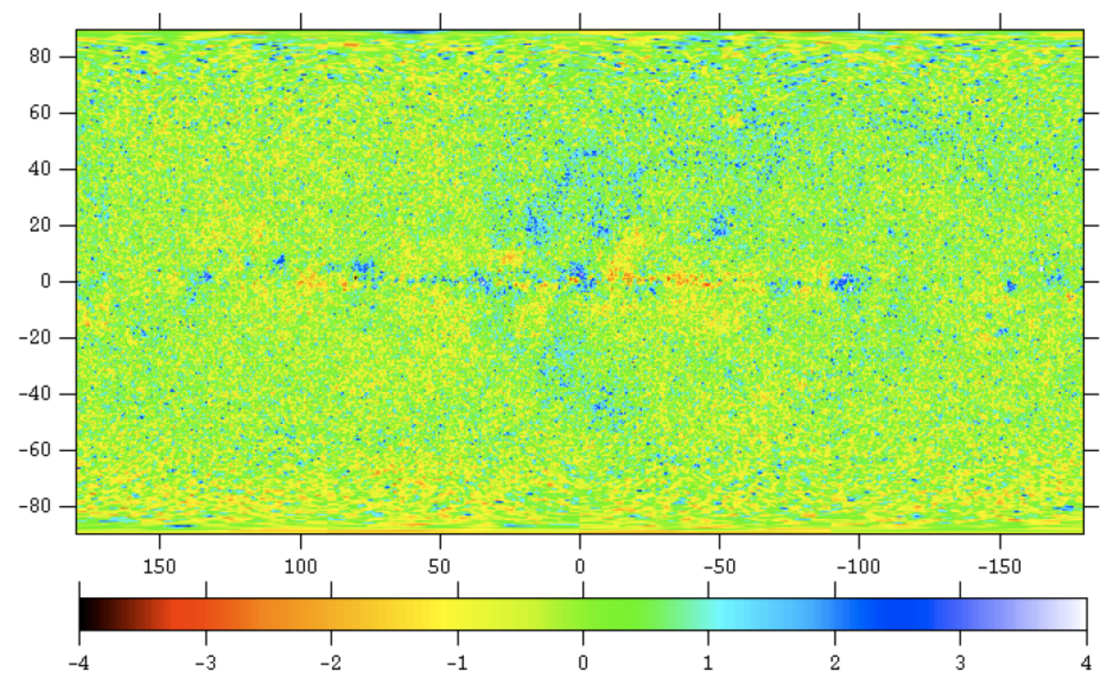
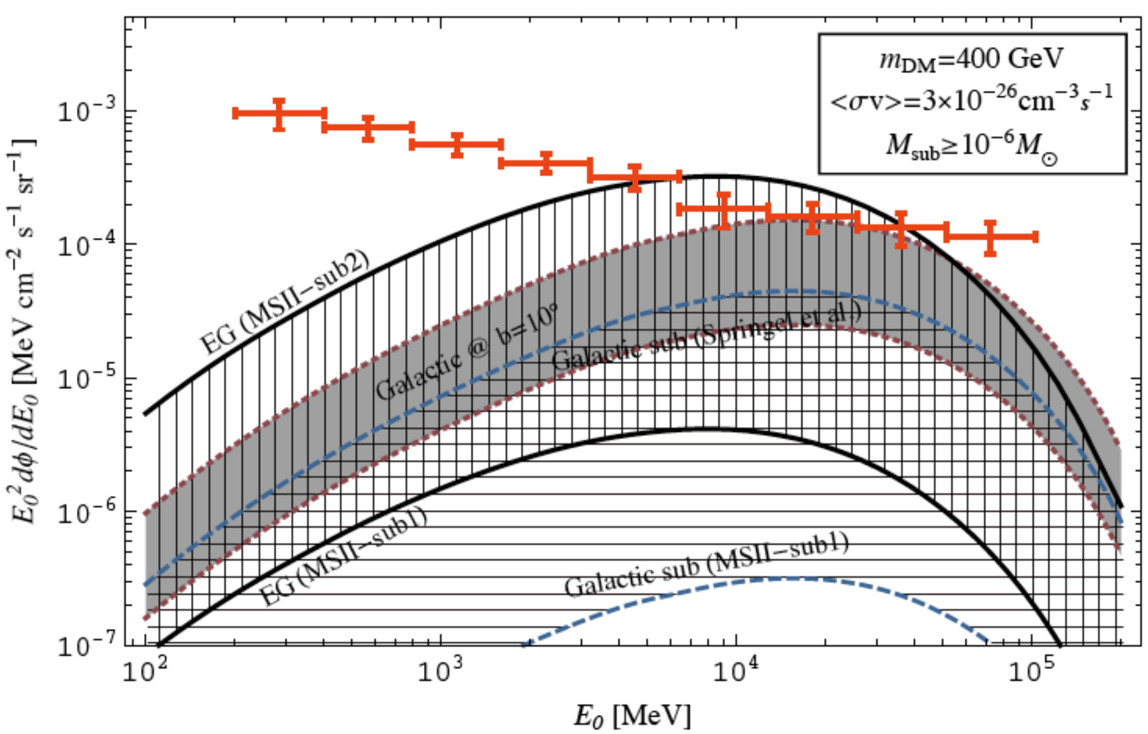


Figure 3: Residual map expressed in sigma values: $(N_{obs} - N_{pred})/\sqrt{N_{pred}}$

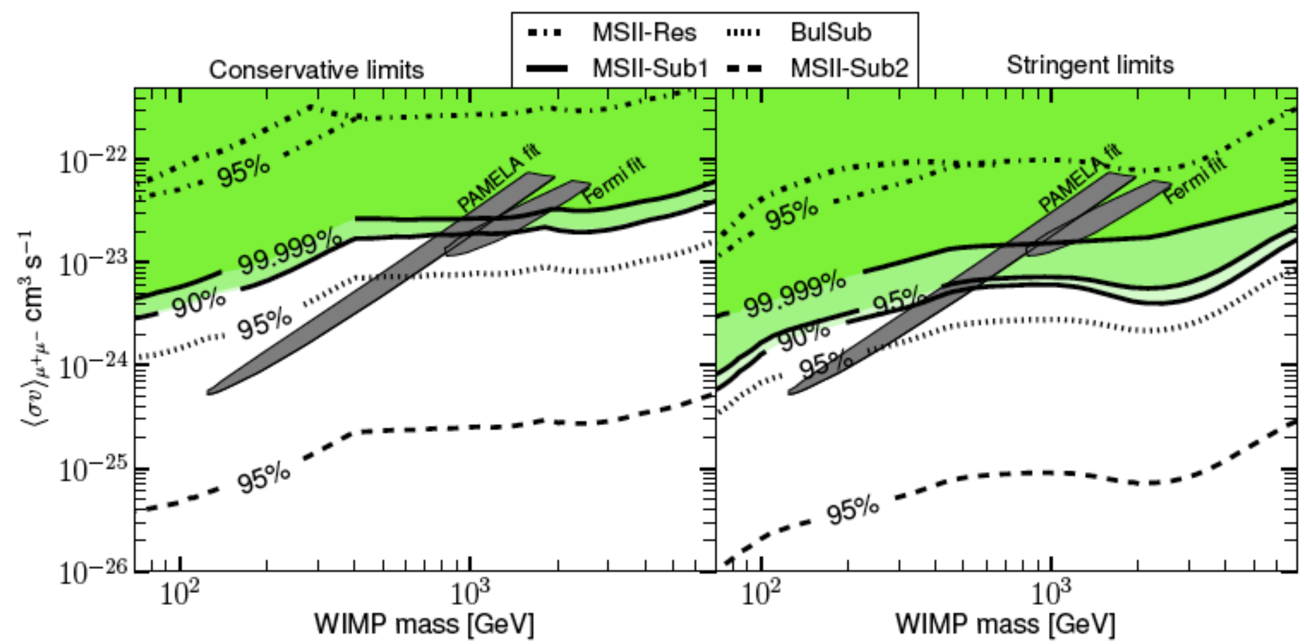
# Fermi constraints on DM from gamma-ray spectrum

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



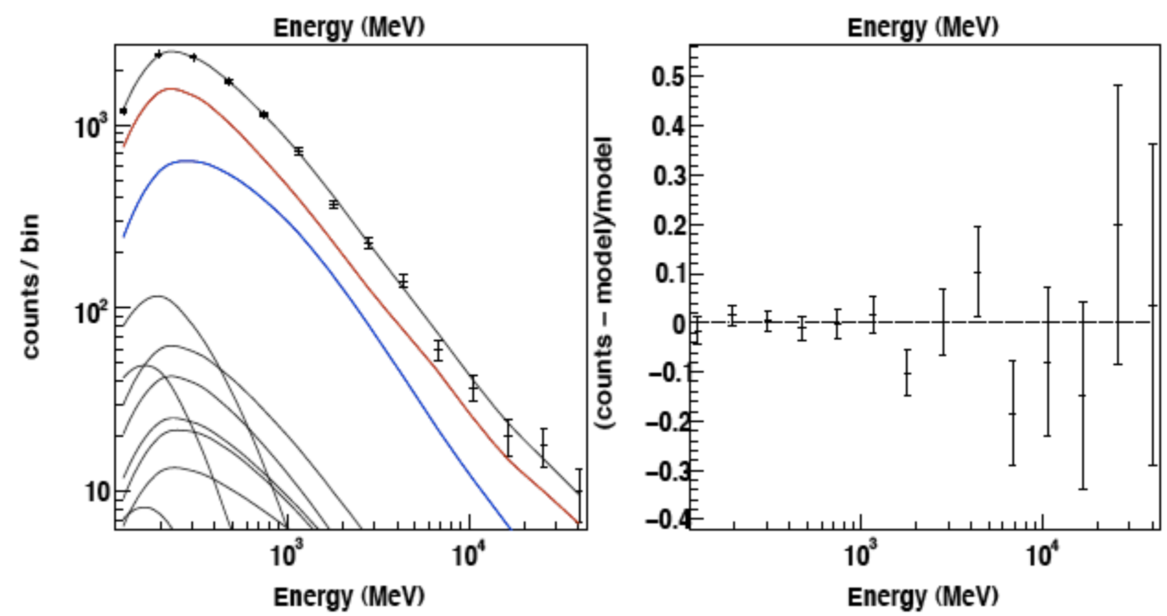

Constraints on DM annihilation in $\mu^+\mu^-$ channel



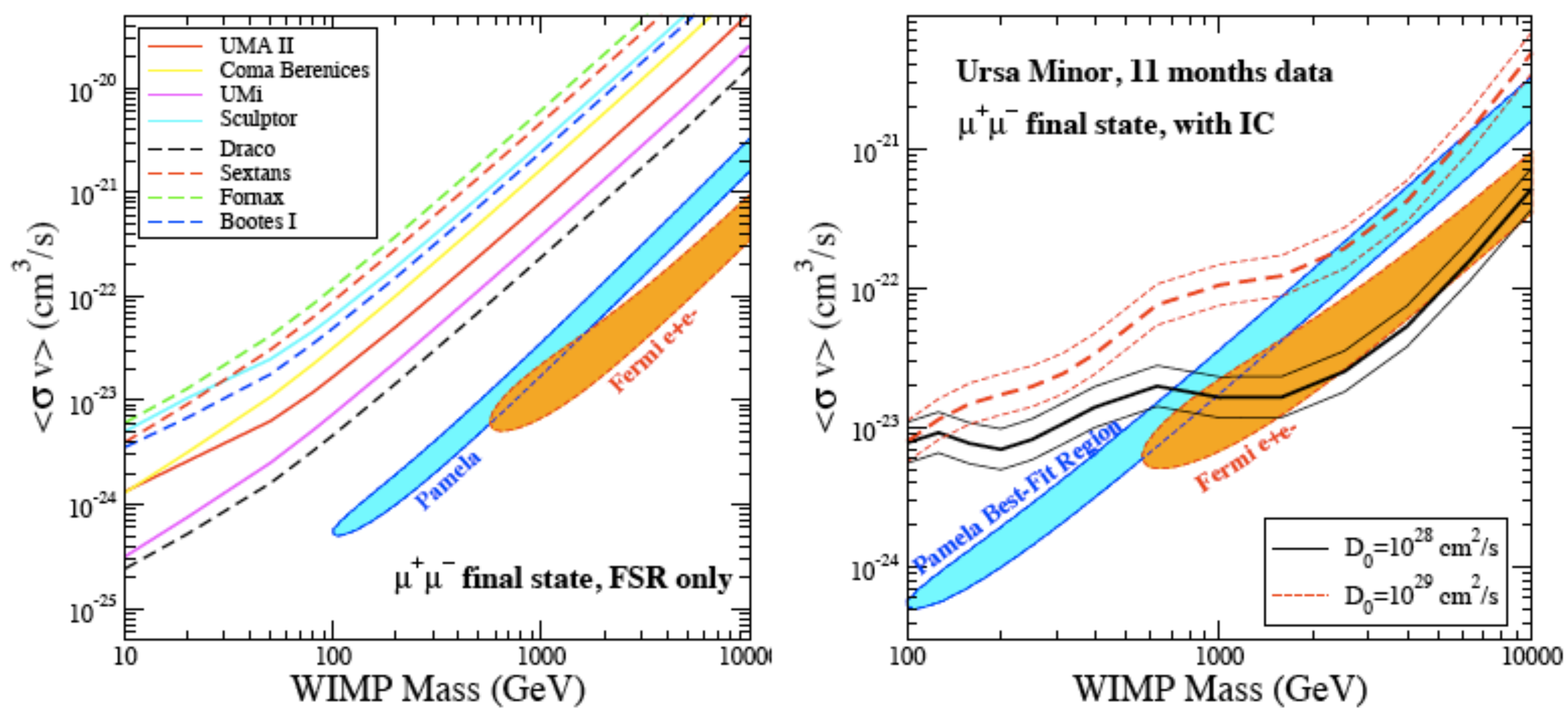
# Fermi constraints on DM annihilation from dwarf galaxies

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

Counts and residuals for Draco dwarf galaxy



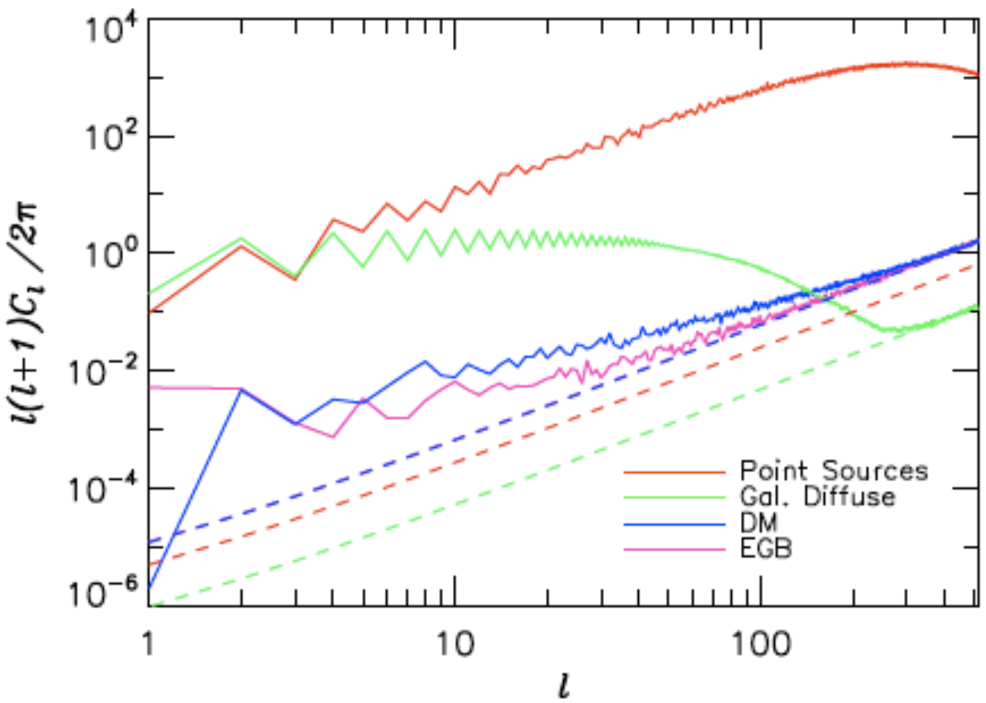

Constraints on DM annihilation



# 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