Fermilab

Searching for signals of dark matter in the extragalactic gamma-ray background

Work done with Sam McDermott and Dan Hooper

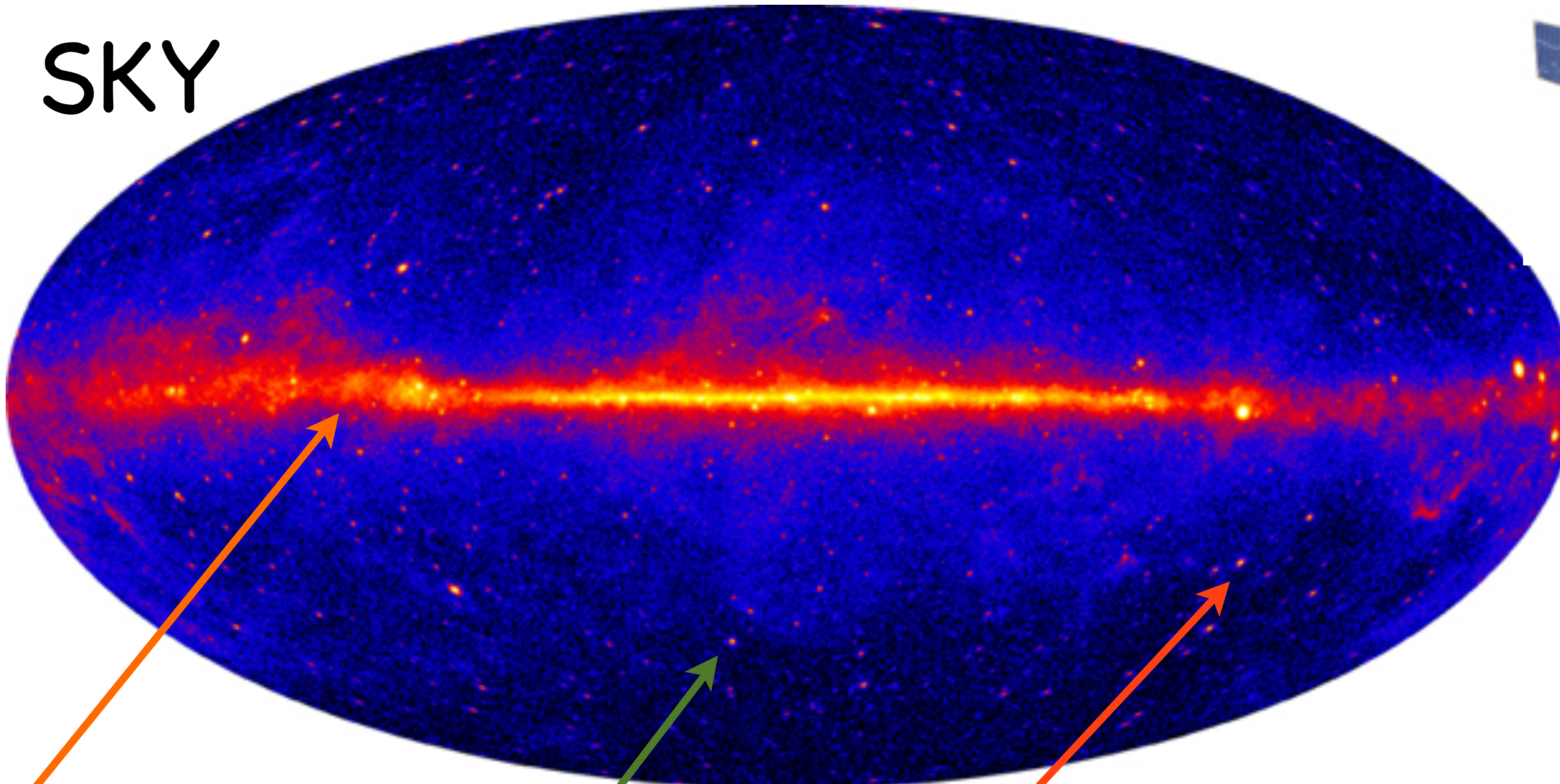
JCAP 1402 (2014) (arXiv:1312:0806) and work in progress Dan Hooper and Andrew Hearin, Christoph Weniger

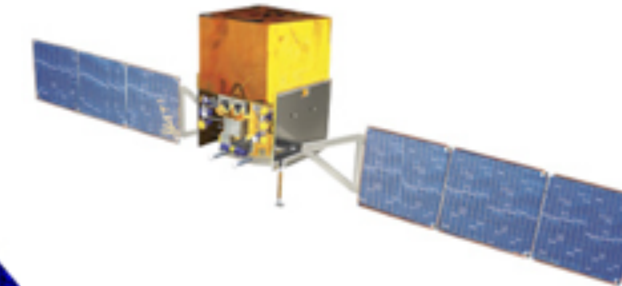
Ilias Cholis (FNAL)

29/8/2014

Gamma-ray Backgrounds

Fermi SKY





Known sources for the observed gamma-rays are:

i)Galactic Diffuse: decay of pi0s (and other mesons) from pp (NN) collisions (CR nuclei inelastic collisions with ISM gas), bremsstrahlung radiation off CR e, Inverse Compton scattering (ICS): up-scattering of CMB and IR, optical photons from CR e

ii)from point sources (galactic or extra galactic) (1873 detected in the first 2 years)

iii)Extragalactic Isotropic

iv)"extended sources"

iv)misidentified CRs (isotropic dew to diffusion of CRs in the Galaxy)

Looking for DM annihilation signals

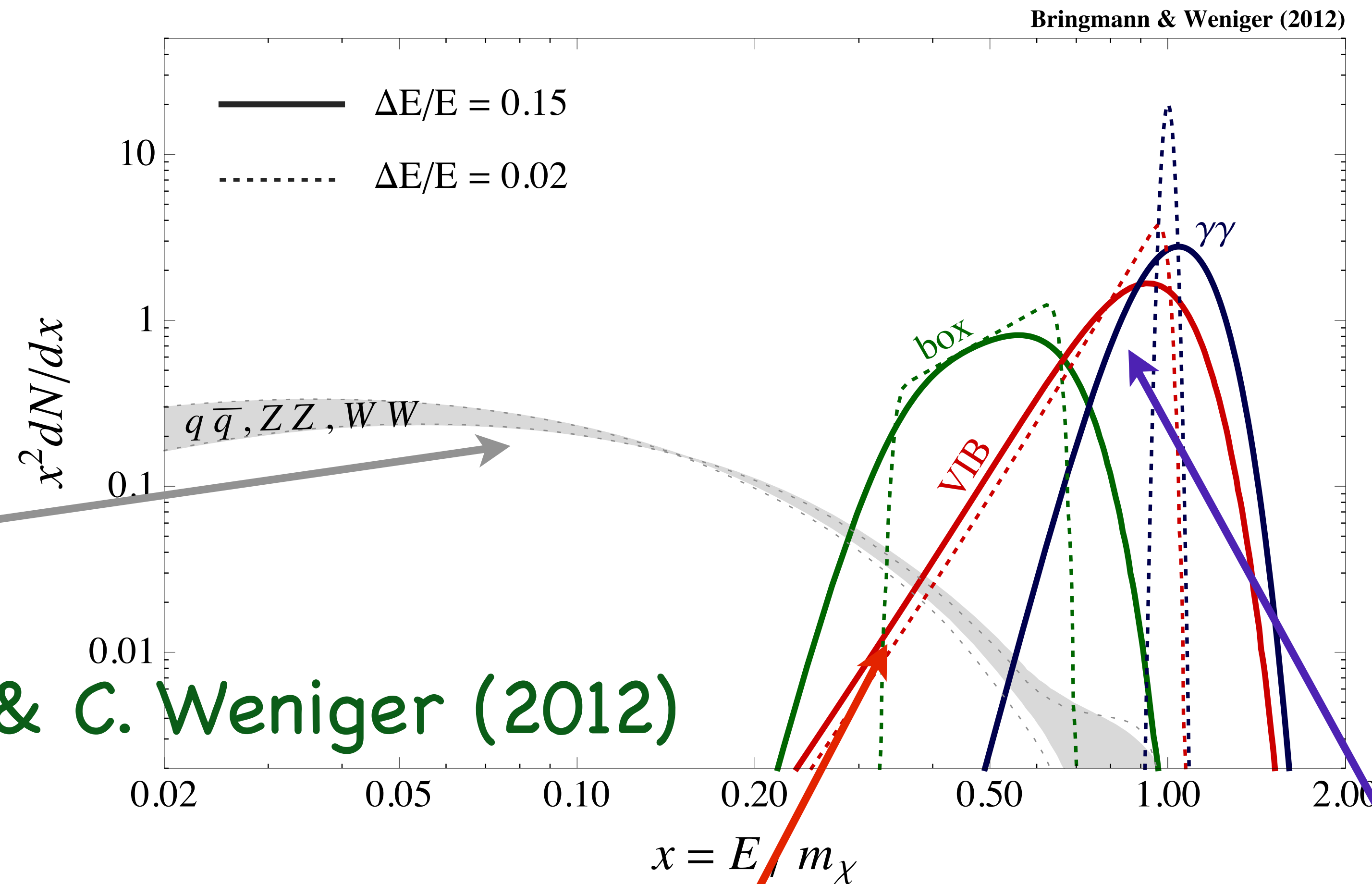
For a DM annihilation signal (within the galaxy)

We want to observe: $$\frac{d\Phi_\gamma}{dE} = \int\int \frac{\langle \sigma v \rangle}{4\pi} \frac{dN_\gamma}{dE}_{DM} \frac{\rho^2_{DM}(l,\Omega)}{2\,m^2_\chi} dl d\Omega$$

- Hardening of a spectrum without a clear cut-off localized in a certain region (Fermi haze->Fermi bubbles)
- Hardening of a spectrum with a clear cut-off: ~40-50 GeV DM claims towards the Galactic Center (GC) inner few degrees
- Line or lines
- One of the most likely targets is the GC (though backgrounds also peak), others are the known substructure (dSphs) or Galaxy clusters AND the extragalactic

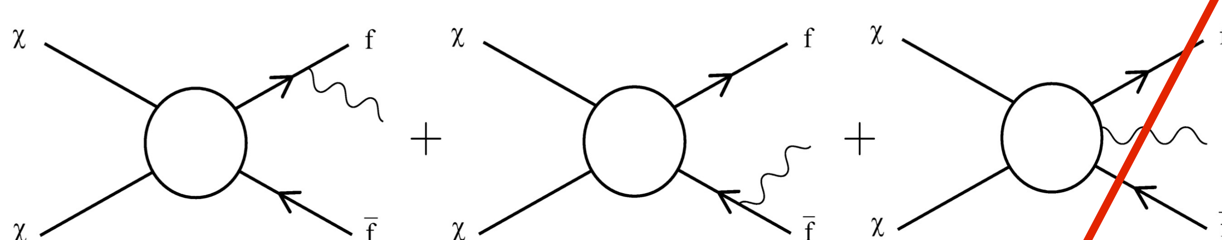
DM annihilation spectra

Continuum emission, tree level, relatively hard spectrum, but featureless



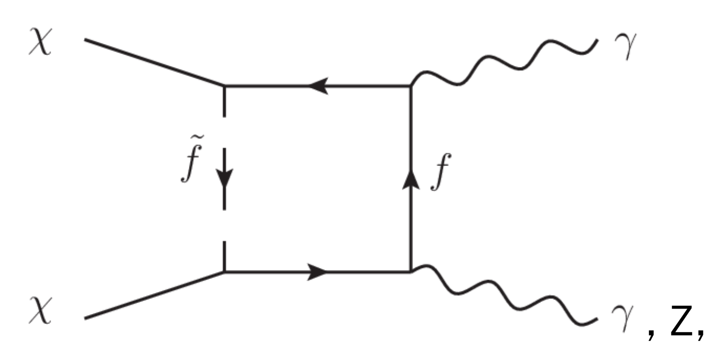
T. Bringmann & C. Weniger (2012)

Two body annihilation to photons. Almost monochromatic Line, but suppressed at O(a^2).



Final state radiation Virtual Internal Bremss.

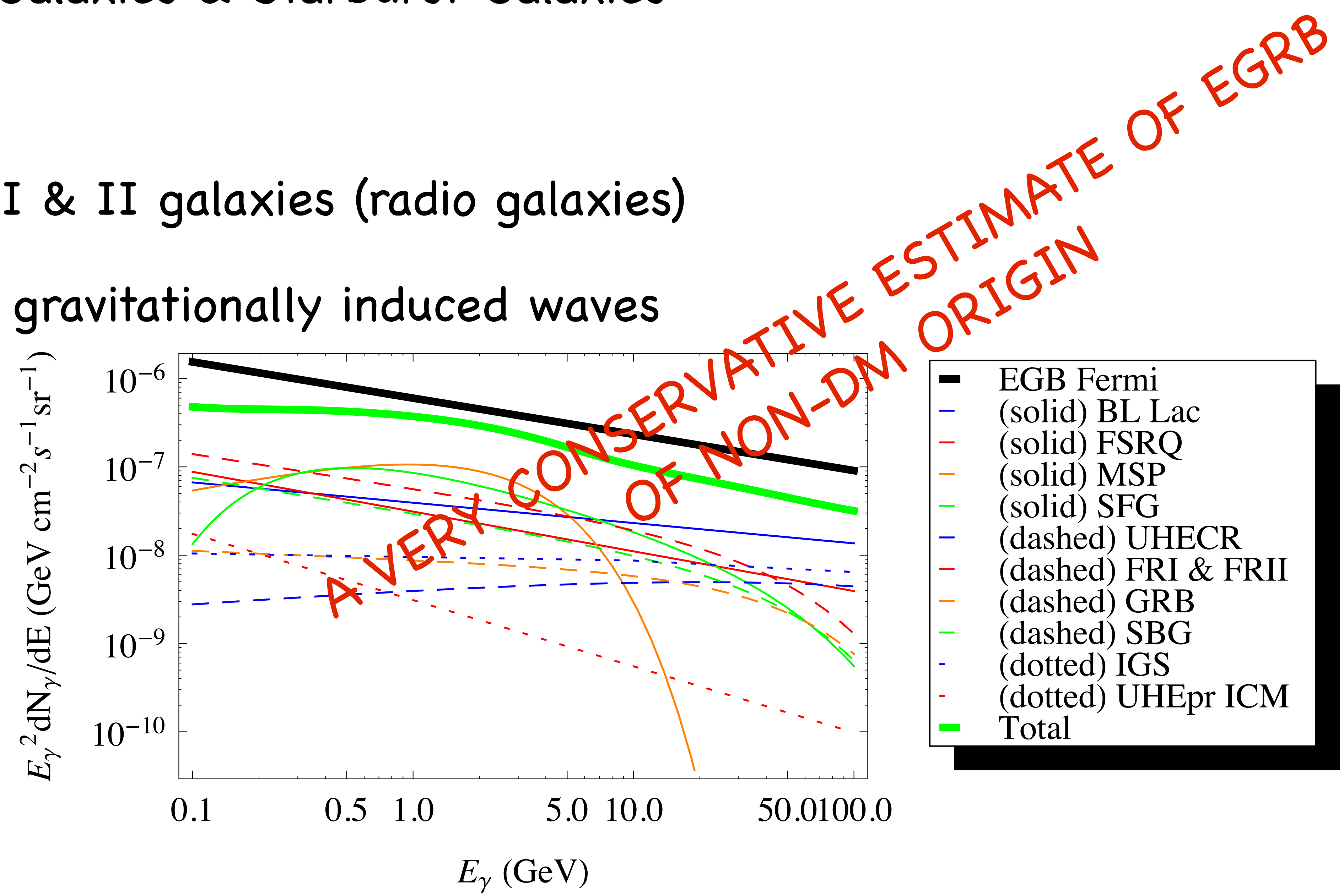
Comes from radiative corrections to processes with charged particles. Suppressed by O(a), but with a much harder spectrum; FSR has an additional suppression factor of (mf/Mchi)^2



Gamma-Rays at High Latitudes (mainly extragalactic)

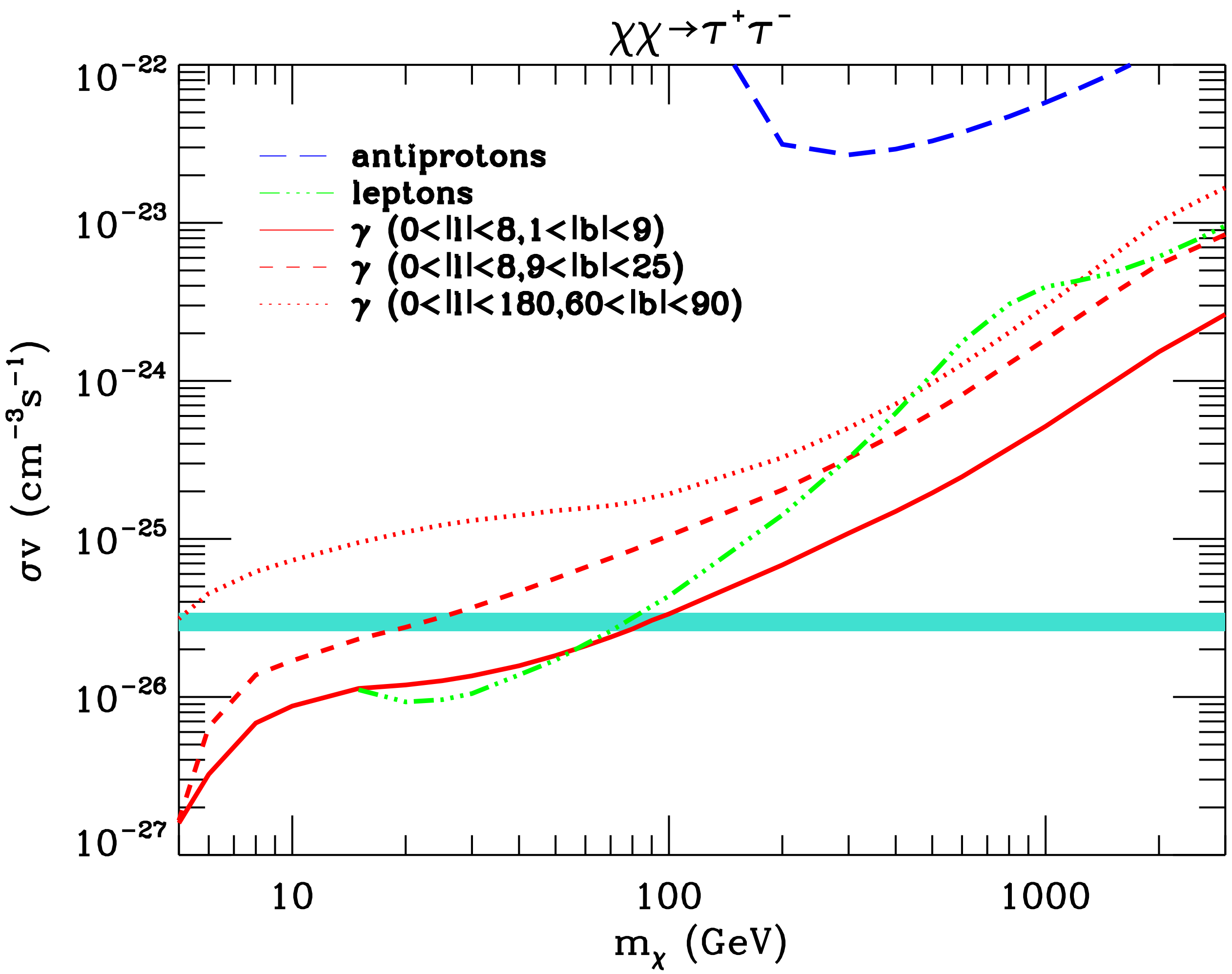
Many possible components. These are astrophysical sources that suffer from relatively large uncertainties.

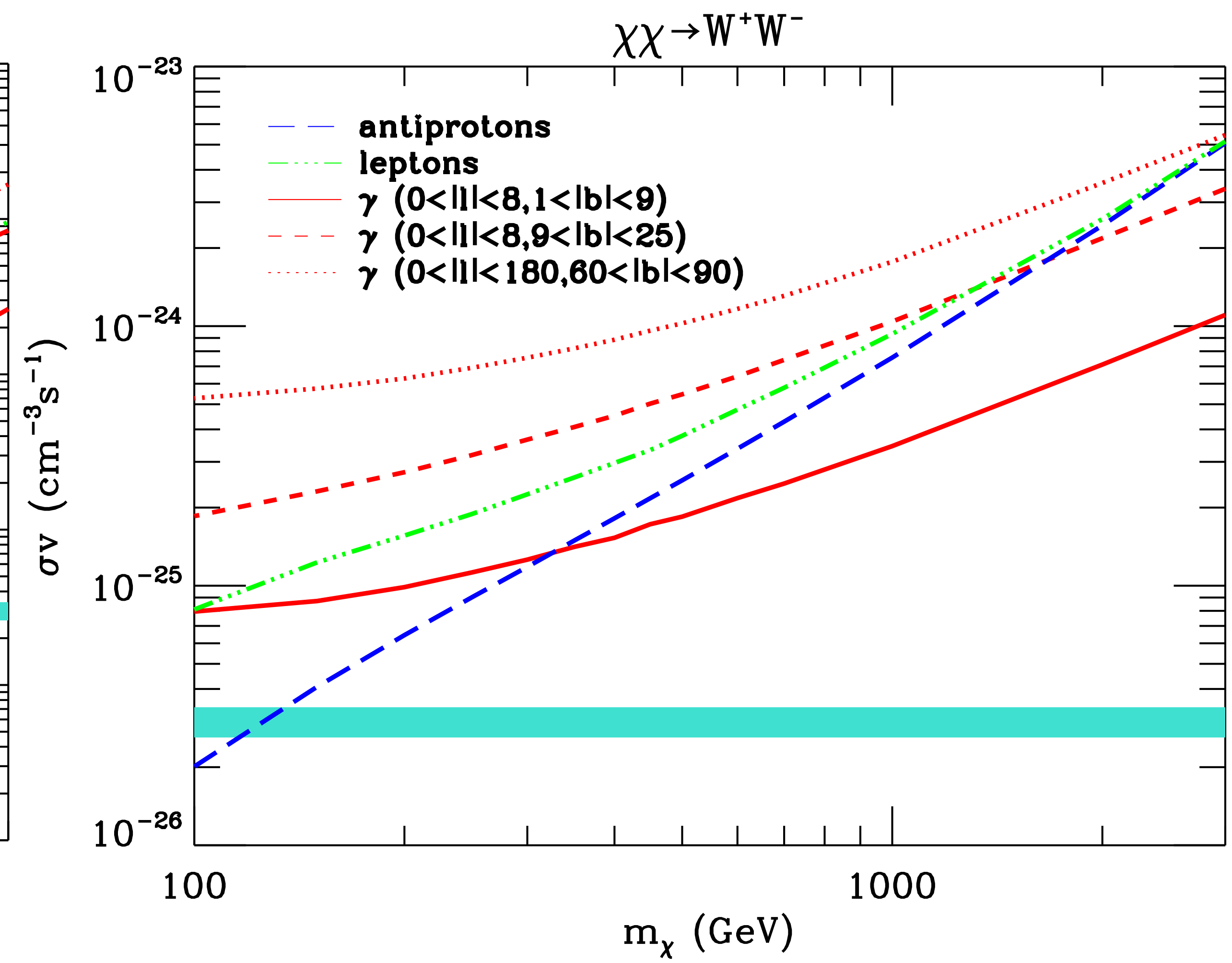
- BL Lacs & Flat Spectrum Radio Quazars
- Star Forming Galaxies & Starburst Galaxies
- UHECRs
- Fanarov Riley I & II galaxies (radio galaxies)
- Gammas from gravitationally induced waves
- GRBs
- MSPs



M. Tavakoli, I.C., C. Evoli, P. Ullio, JCAP 1401 (2014)

Using the very conservative assumptions on the contribution of conventional sources at high latitudes (and very conservative assumptions on the DM contribution):

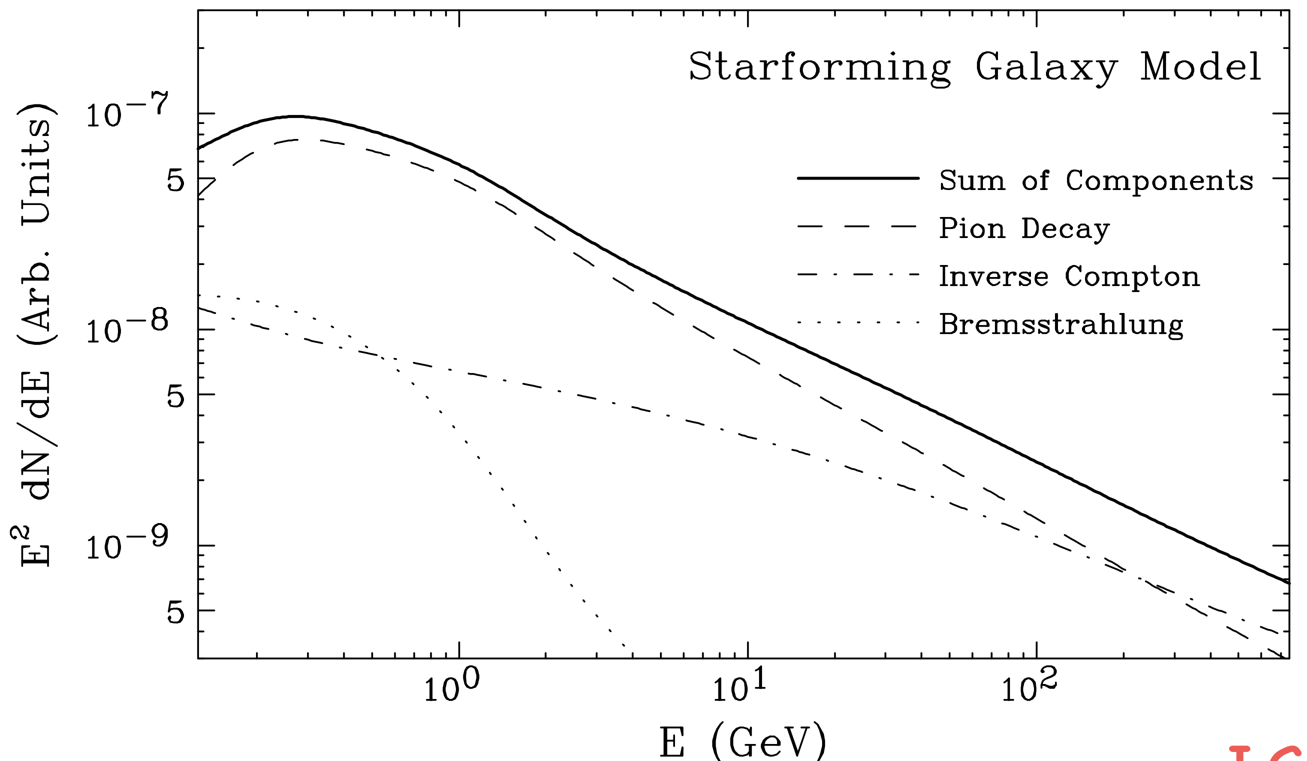


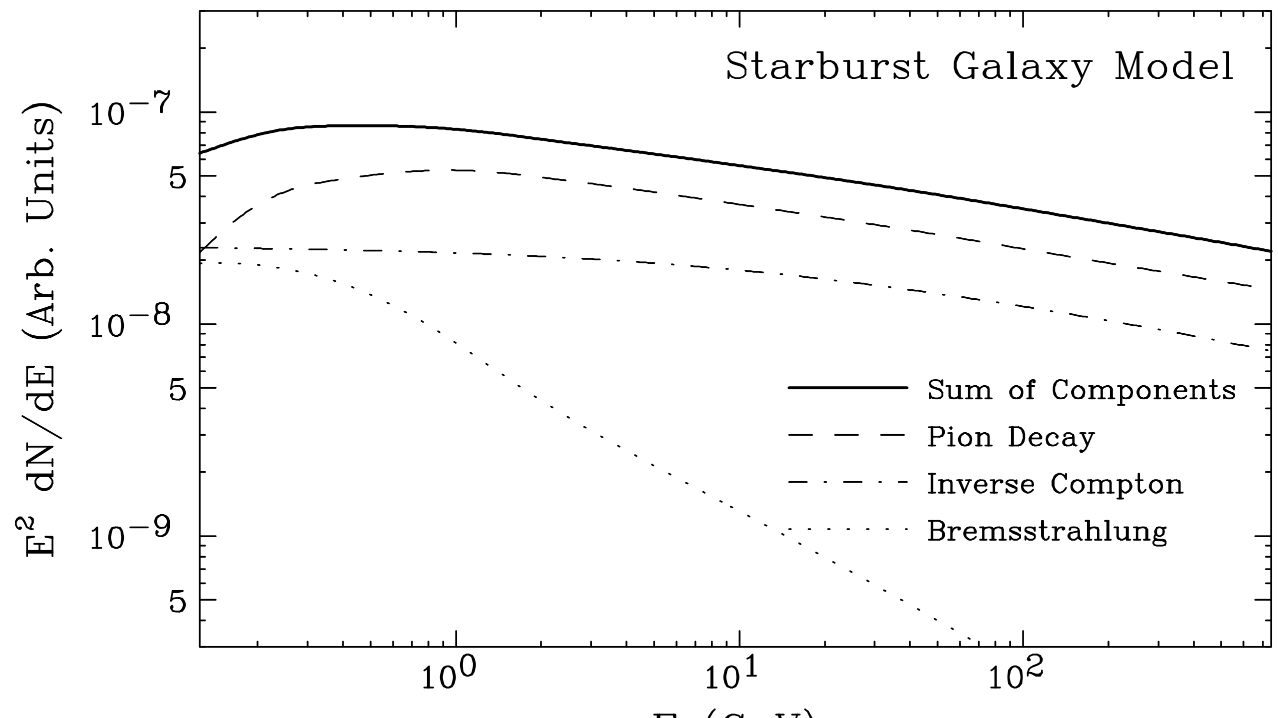


M. Tavakoli, I.C., C. Evoli, P. Ullio, JCAP 1401 (2014)

The gamma-ray observations at high latitudes give the weakest limits compared to other indirect detection probes... but that's not the full story since these limits are truly very conservative.

Modeling the contribution from extragalactic backgrounds



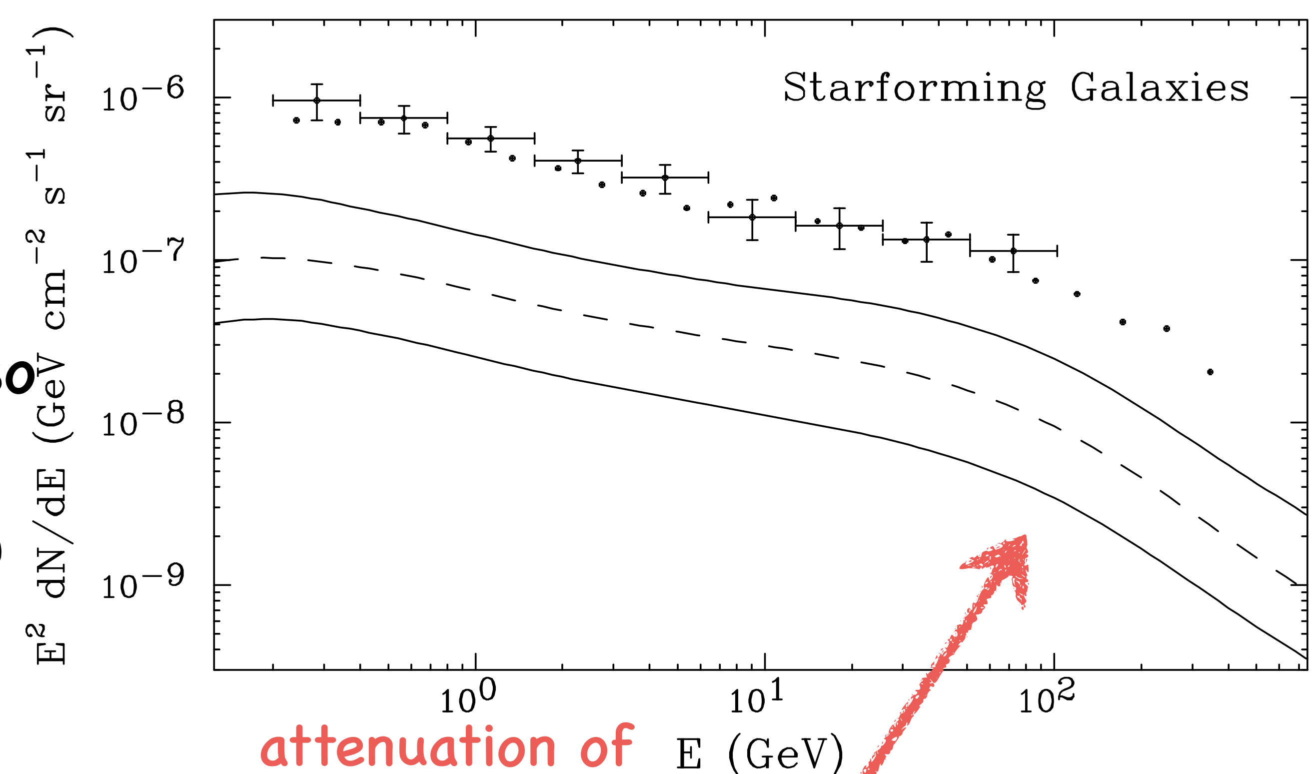


I.C., S. McDermott, D. Hooper, JCAP 1402 (2014)

$$\frac{dN_\gamma}{dE_\gamma} = f \, \frac{dN_\gamma}{dE_\gamma}\bigg|_{\rm star-forming} + (1-f) \, \frac{dN_\gamma}{dE_\gamma}\bigg|_{\rm starburst}$$

Combining the star-forming and the star burst galaxies at equal weights (f=0.5):

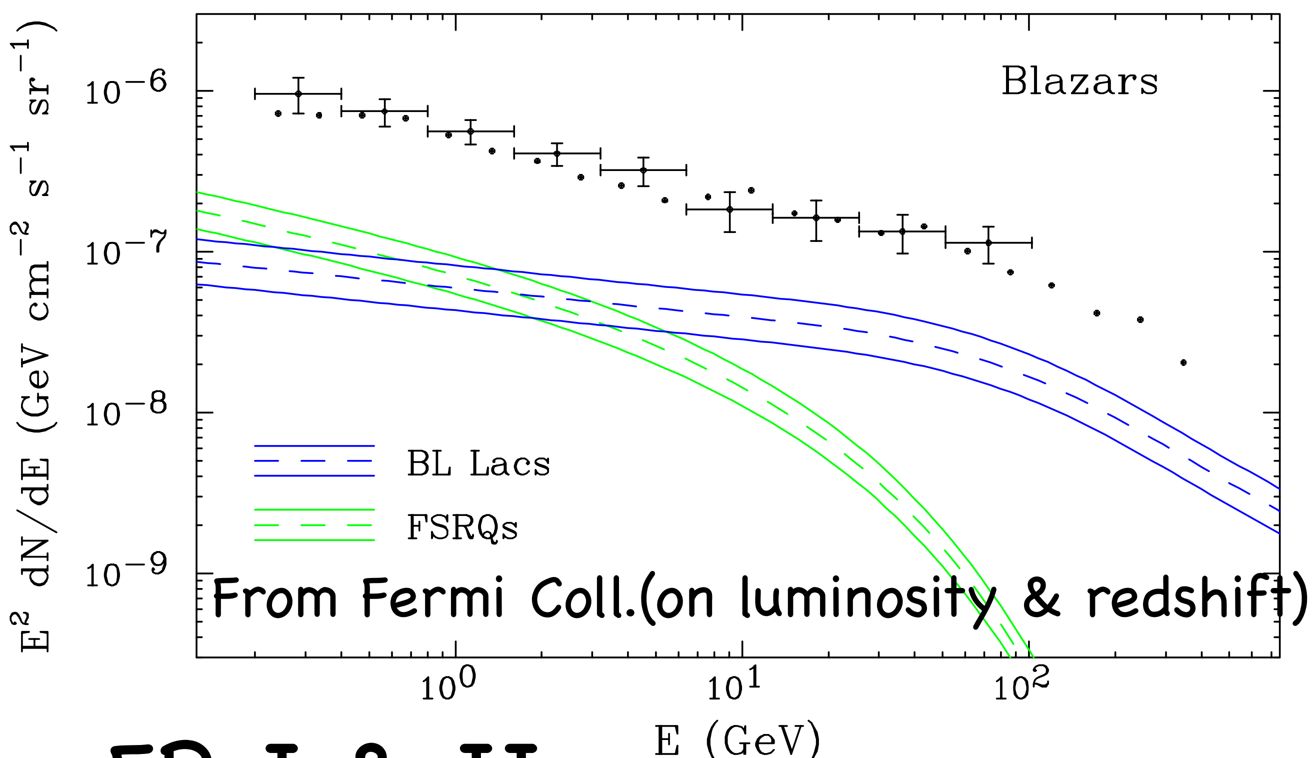
We have detected 9 so-far, but we can also make a connection between the luminosity of SF(B)G in Fermi gamma-rays (E>0.1-100 GeV) and the luminosity in radio-IR.-> SF(B)G contribute about 10-15% of EGRB.



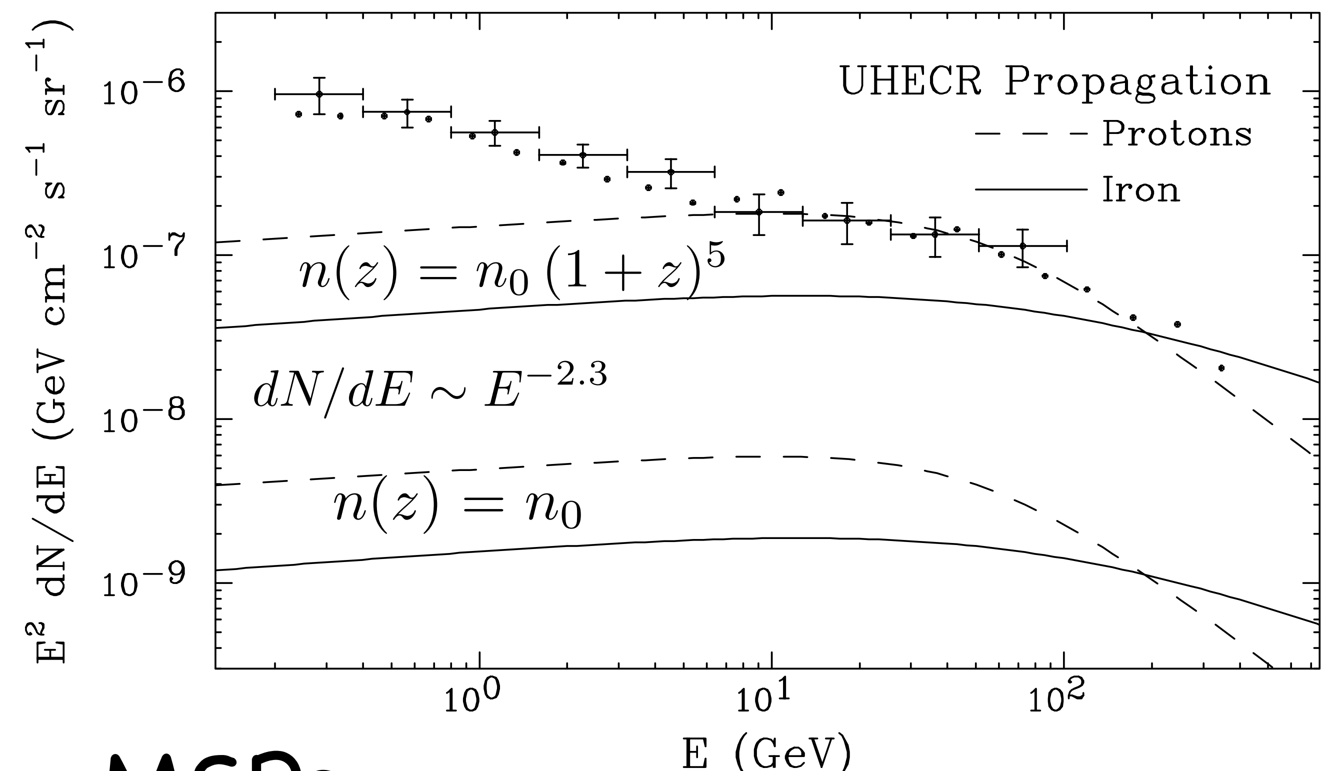
attenuation of gamma-rays due to IR IGB

Modeling the contribution from extragalactic backgrounds(2)

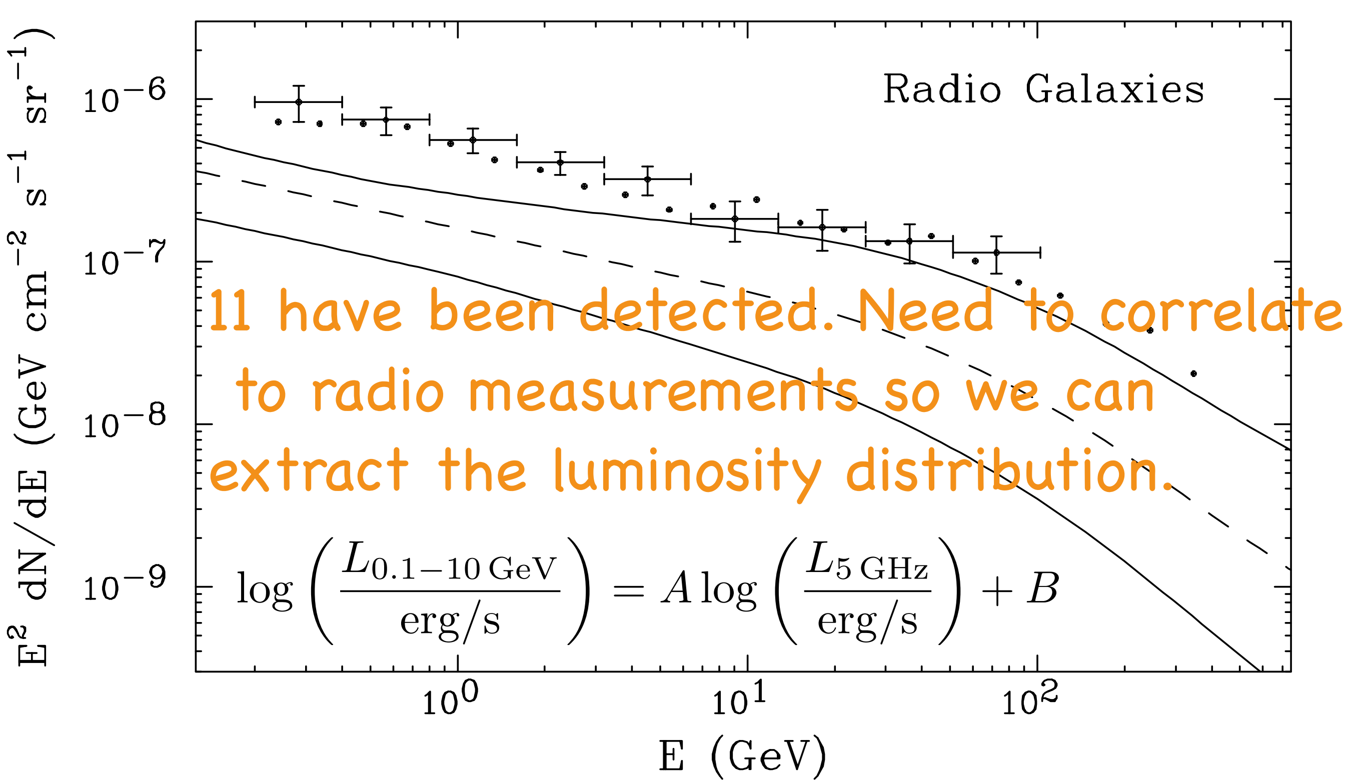
From Blazars:



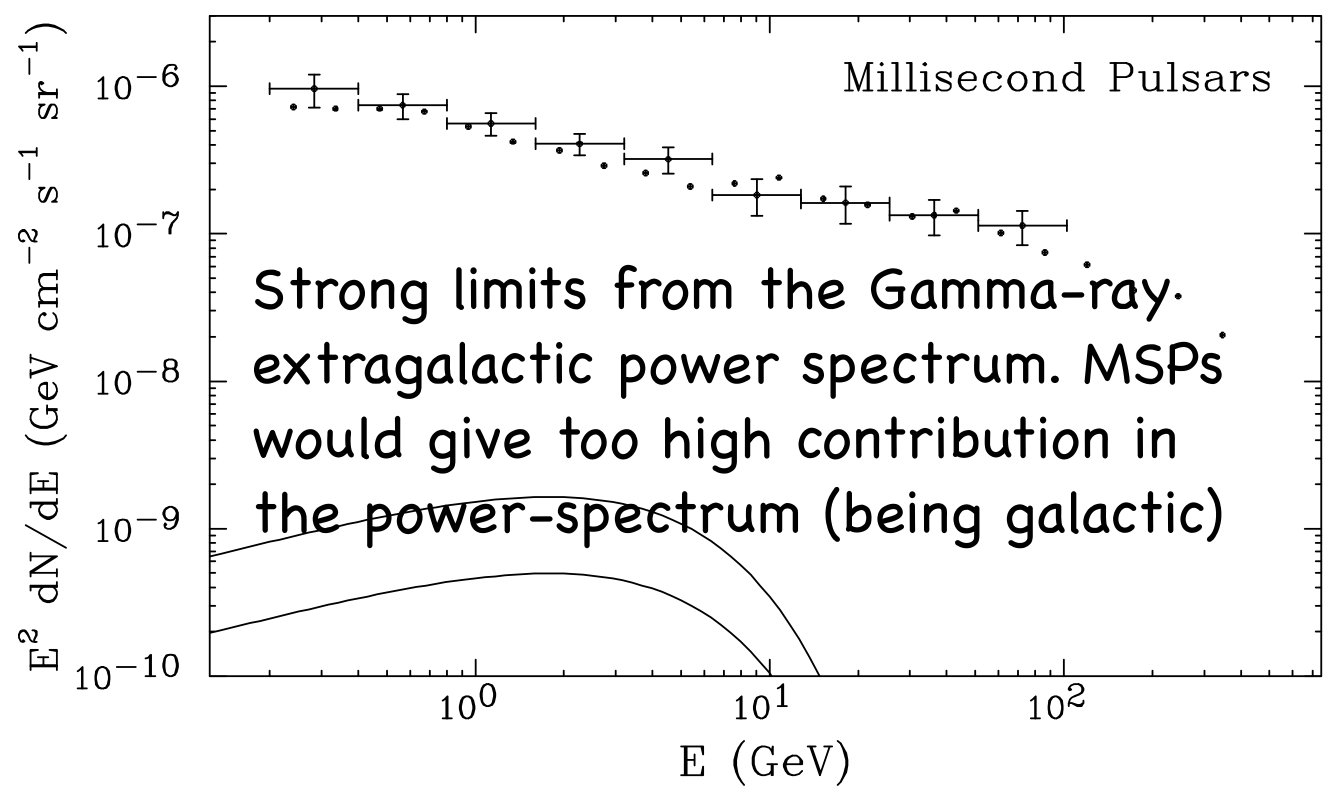
UHECRs:



FR I & II (misaligned BL Lacs and FSRQs):

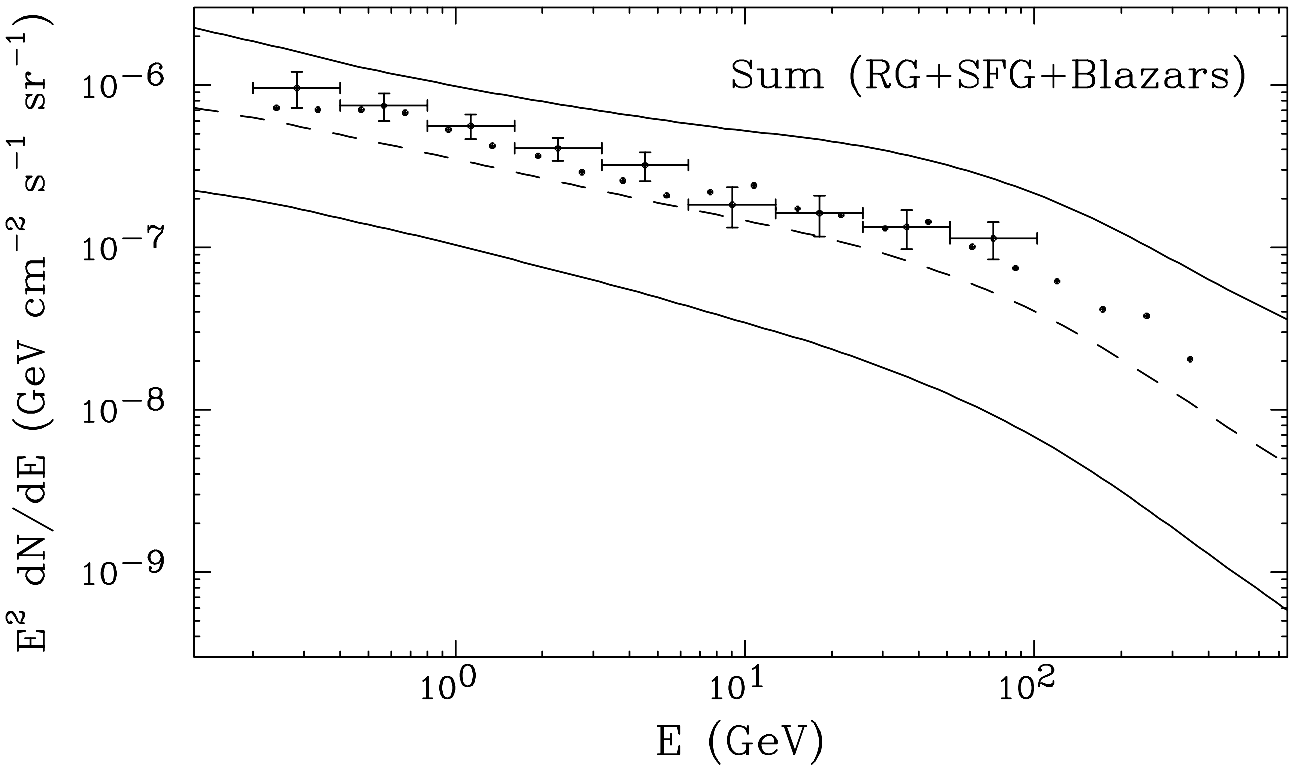


MSPs (recycled pulsars):

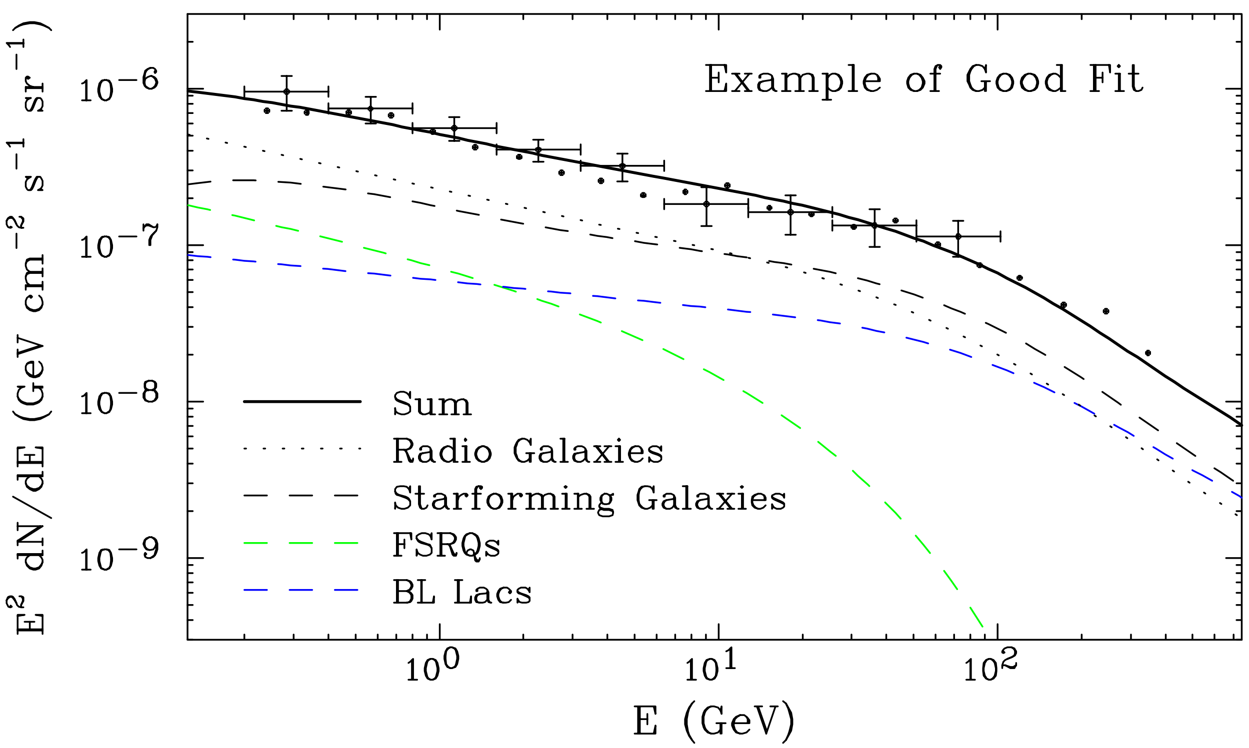


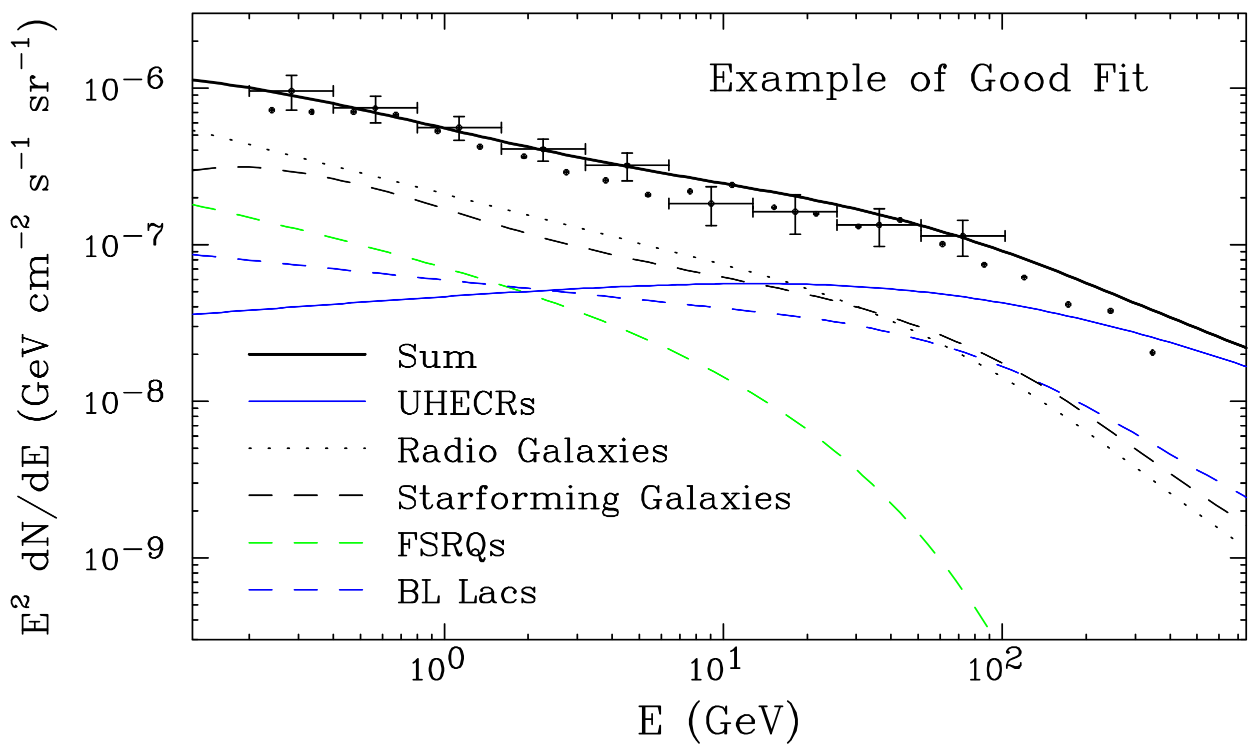
Combining the various contributions:

Build models for the non-DM contribution and derive limits on DM:



We can even see that it could be very likely the case that the known source of gamma-rays can explain just fine the current data:

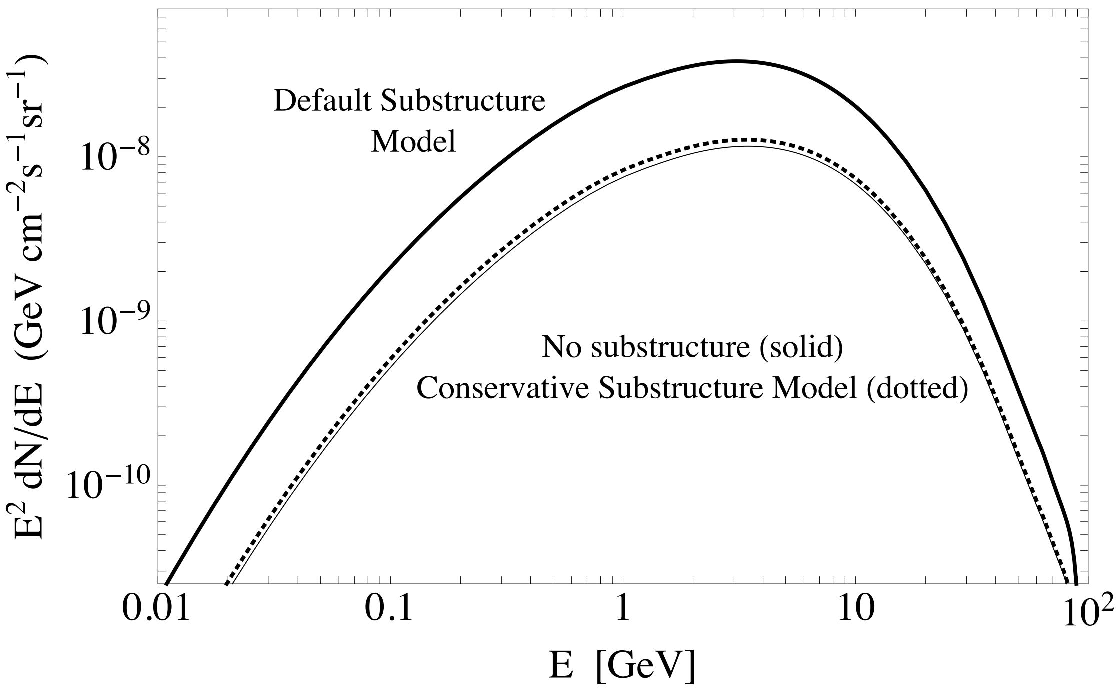




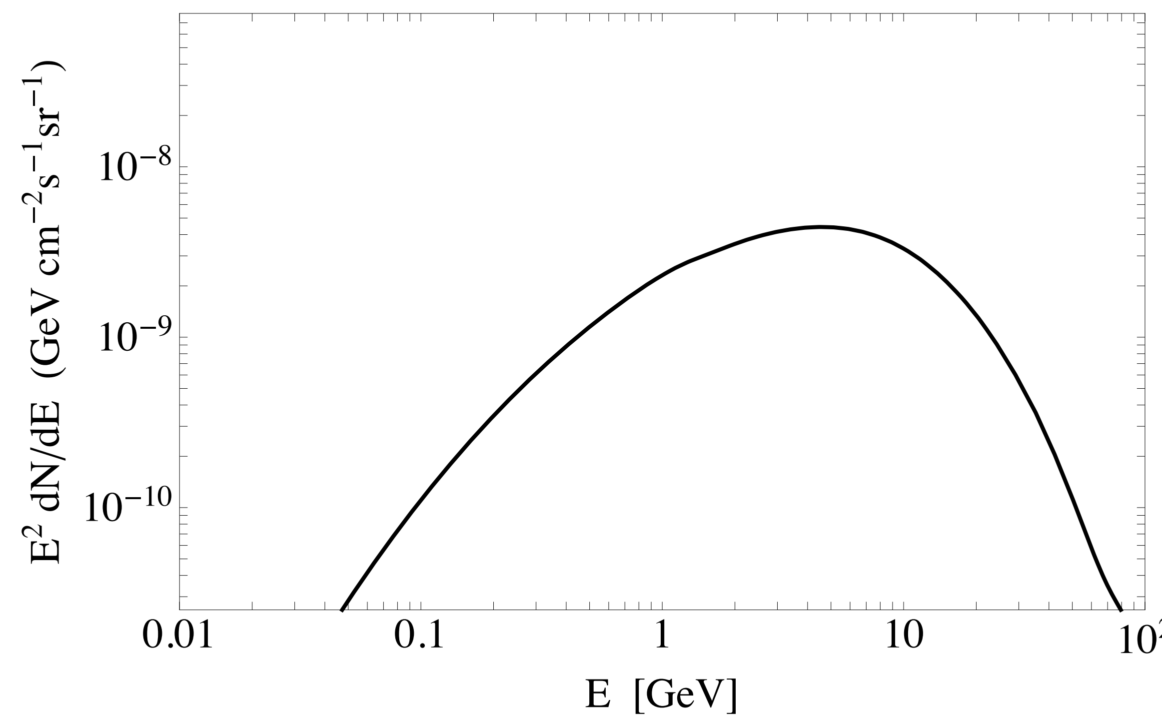
I.C., S. McDermott, D. Hooper, JCAP 1402 (2014)

DM Contribution (at high latitudes):

Extragalactic Contribution



Galactic Halo Contribution



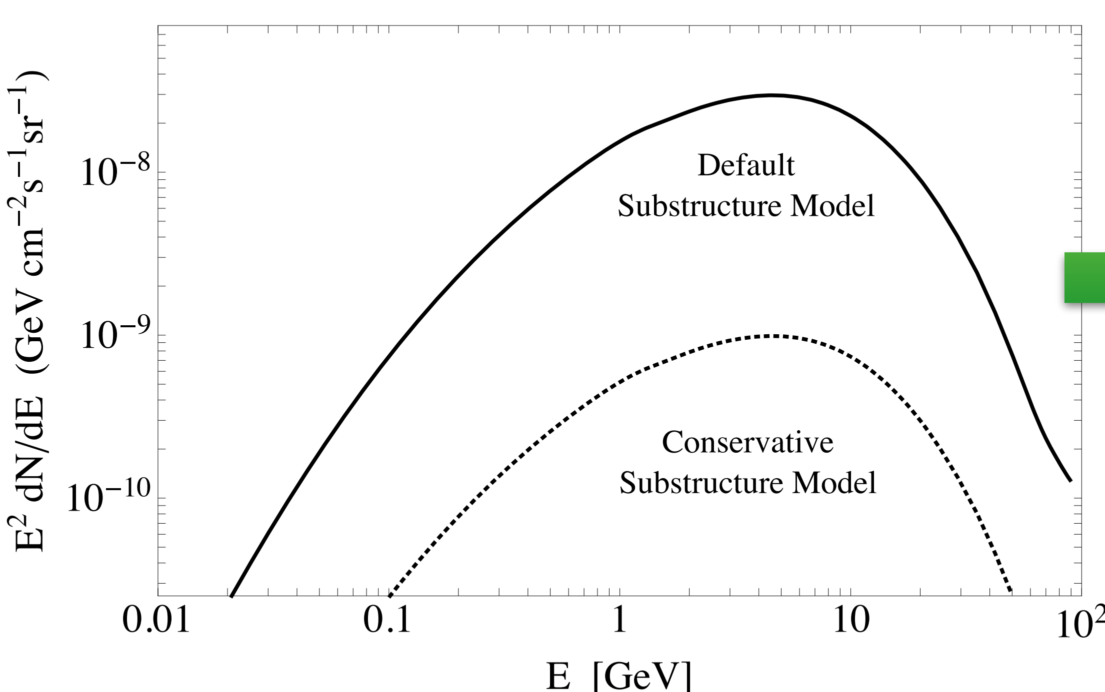
$$\frac{d^2 I_{\rm eg}(E_\gamma)}{dE_\gamma d\Omega} = \int \frac{dz}{H(z)} \frac{\langle\sigma v\rangle}{8\pi m_{\rm DM}^2} (1+z)^3 \frac{dN_\gamma}{dE_\gamma} e^{-\tau[E_\gamma(1+z),z]}$$

$$\times \int dM \frac{dn(M,z)}{dM} \left[1 + b_{\rm sh}(M,z)\right] \int dV \rho_{\rm host}^2(r,M,z),$$

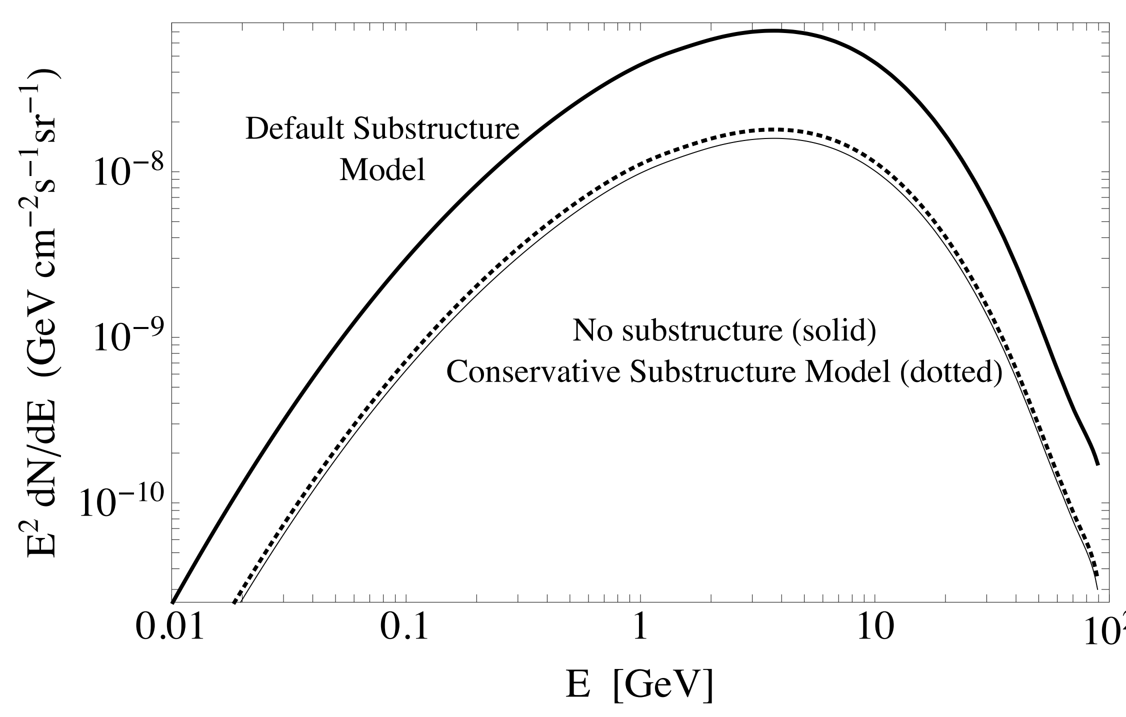
Default sub. model assumpt. :

$$b_{\rm sh}(M,z) = 110 \left(M_{200}(M,z)/10^{12} M_\odot\right)^{0.39}$$

Galactic Subhalo Contribution

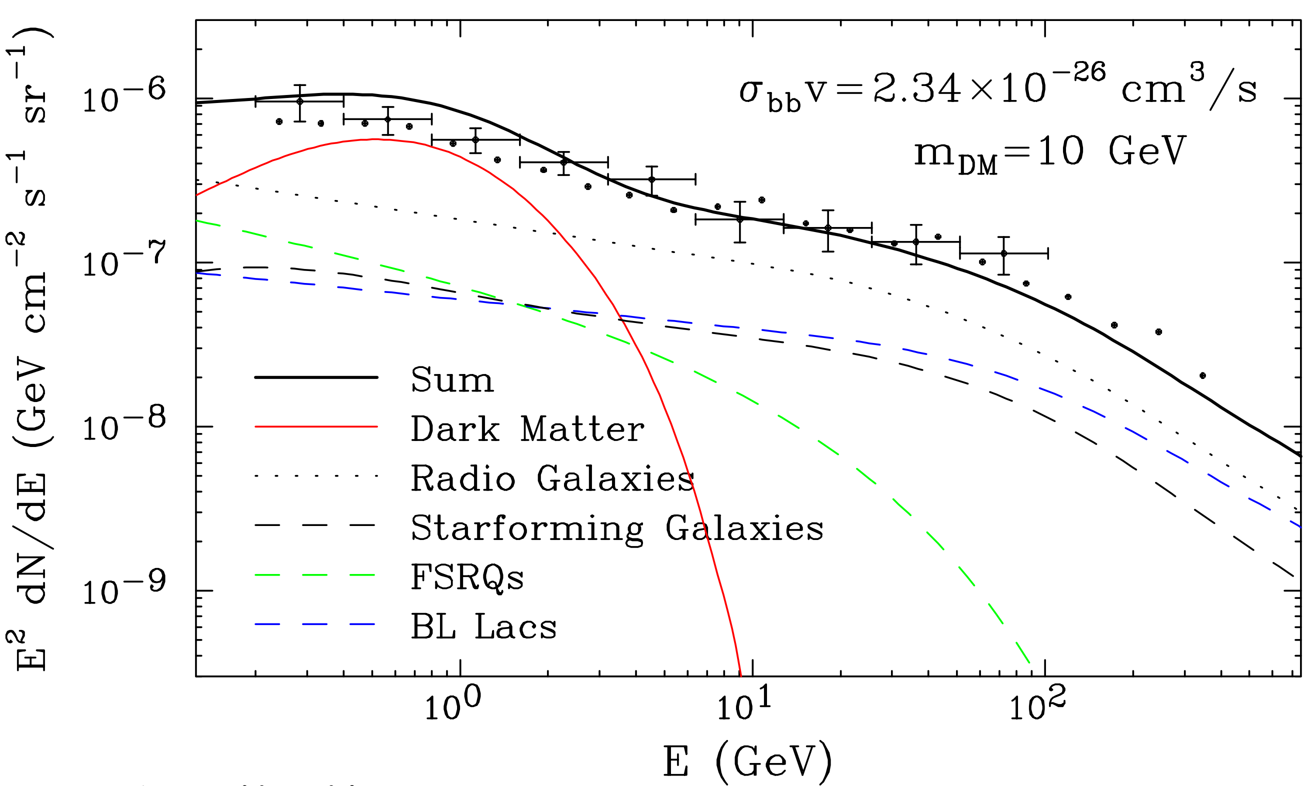


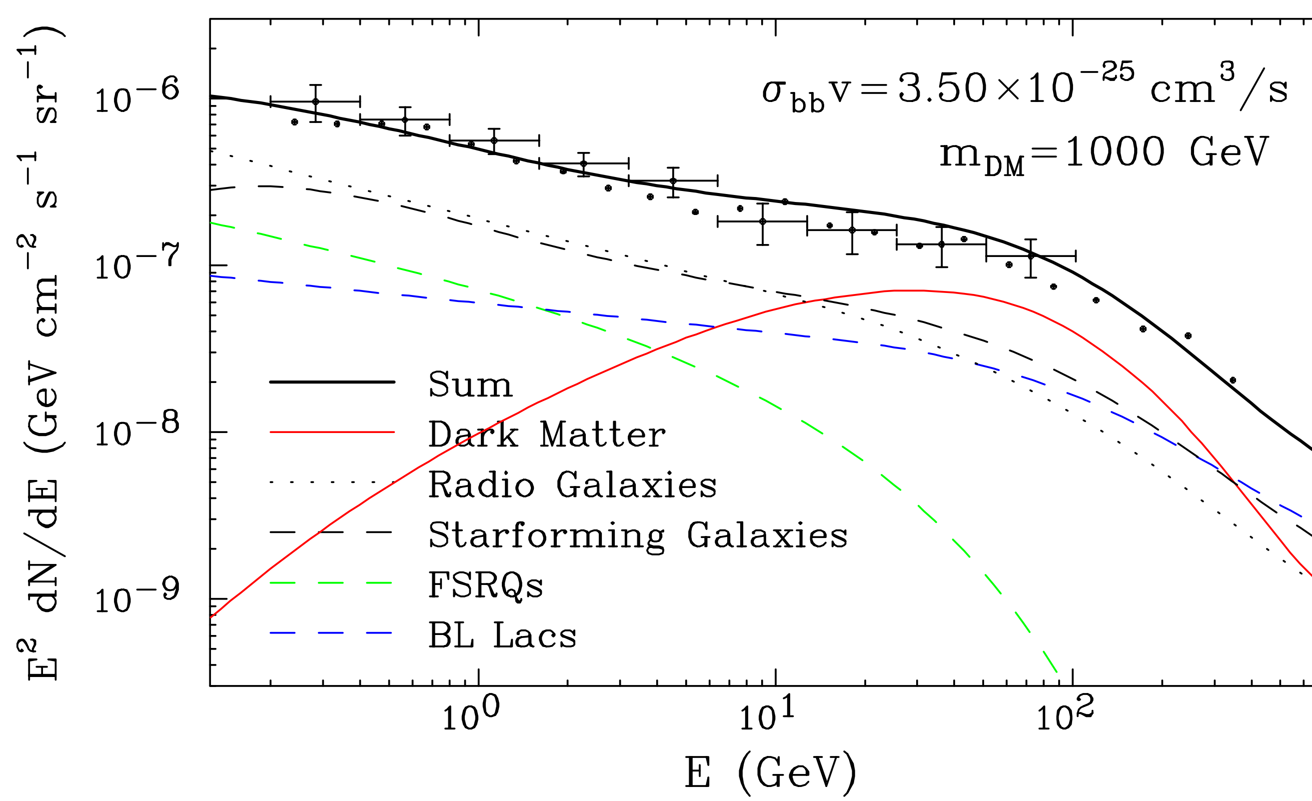
Total Dark Matter Contribution



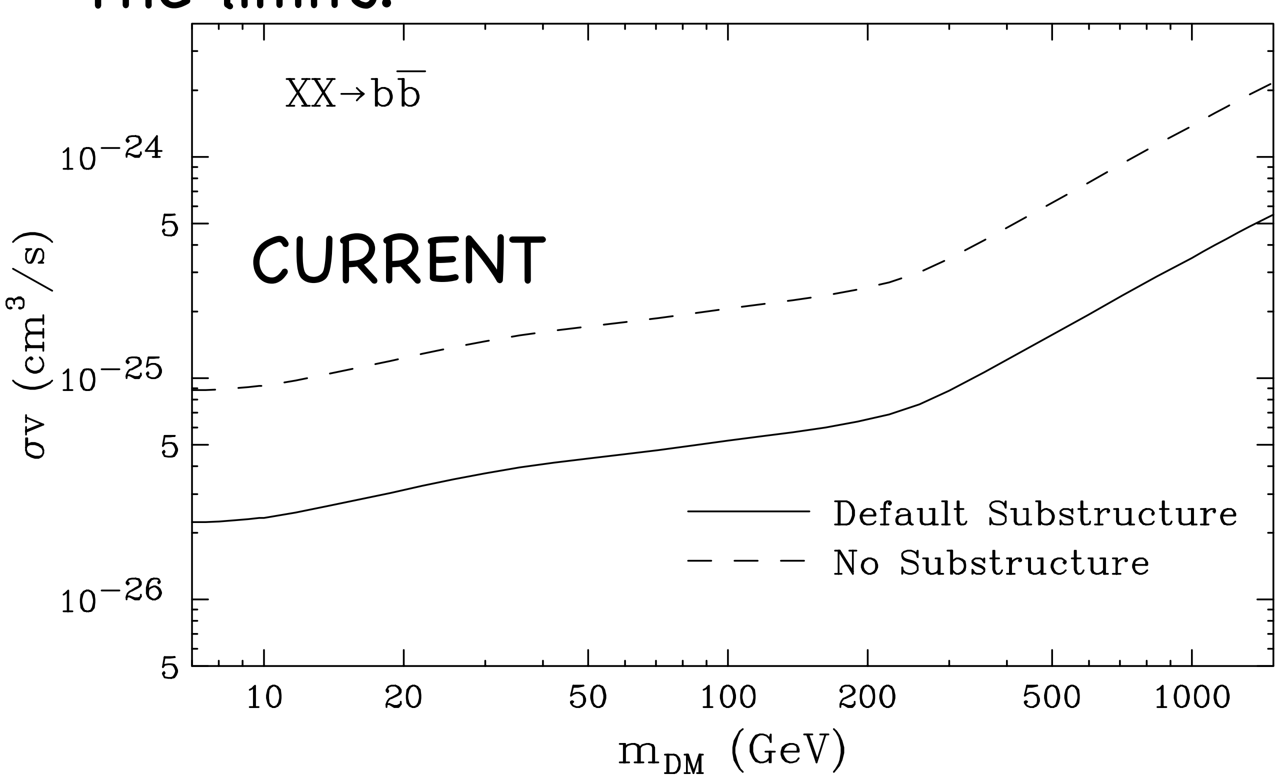
DM Limits

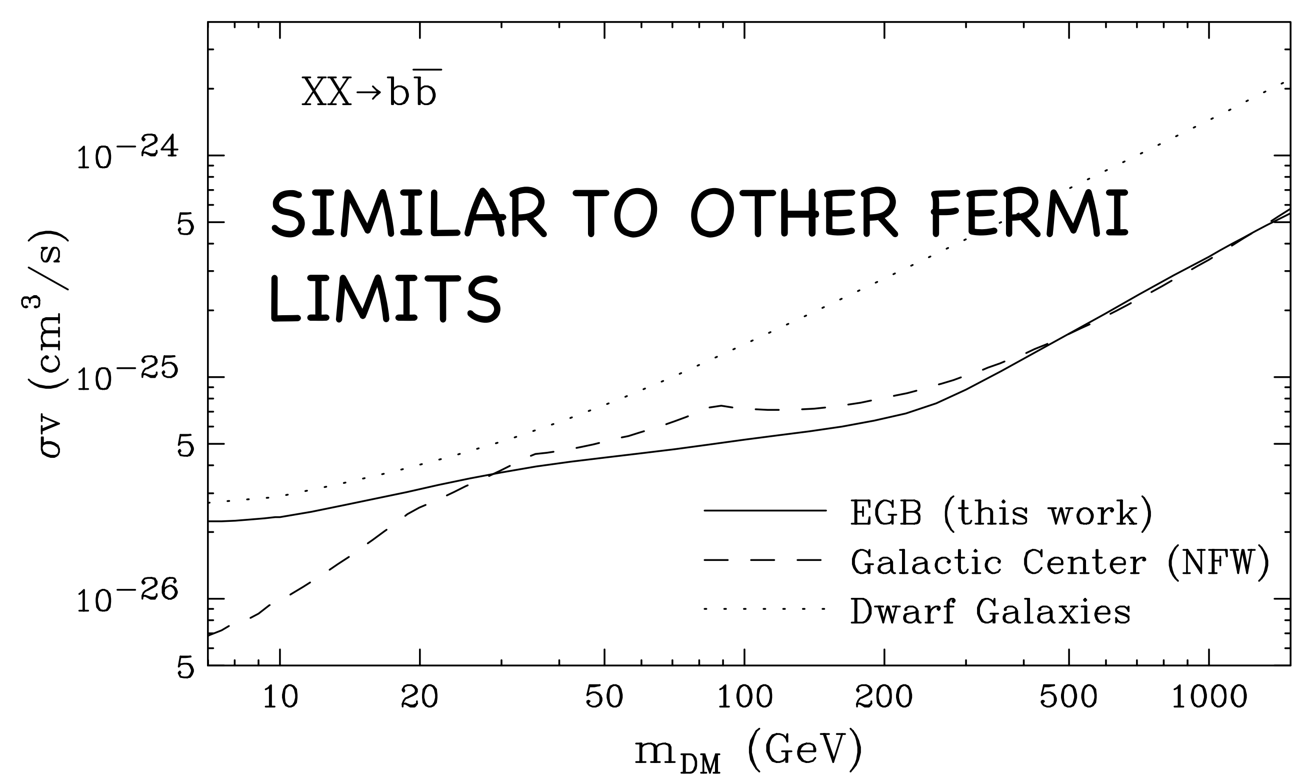
We marginalize of the uncertainties in the non-DM contribution. 2 examples:





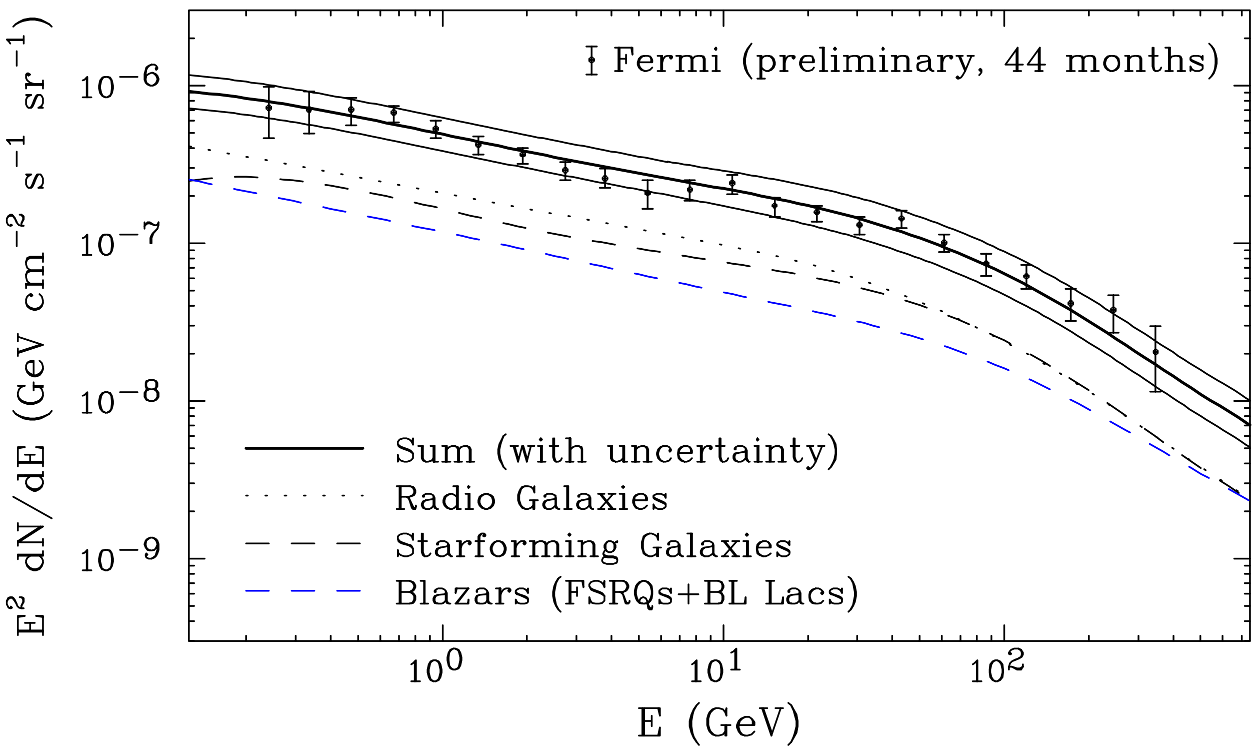
The limits:

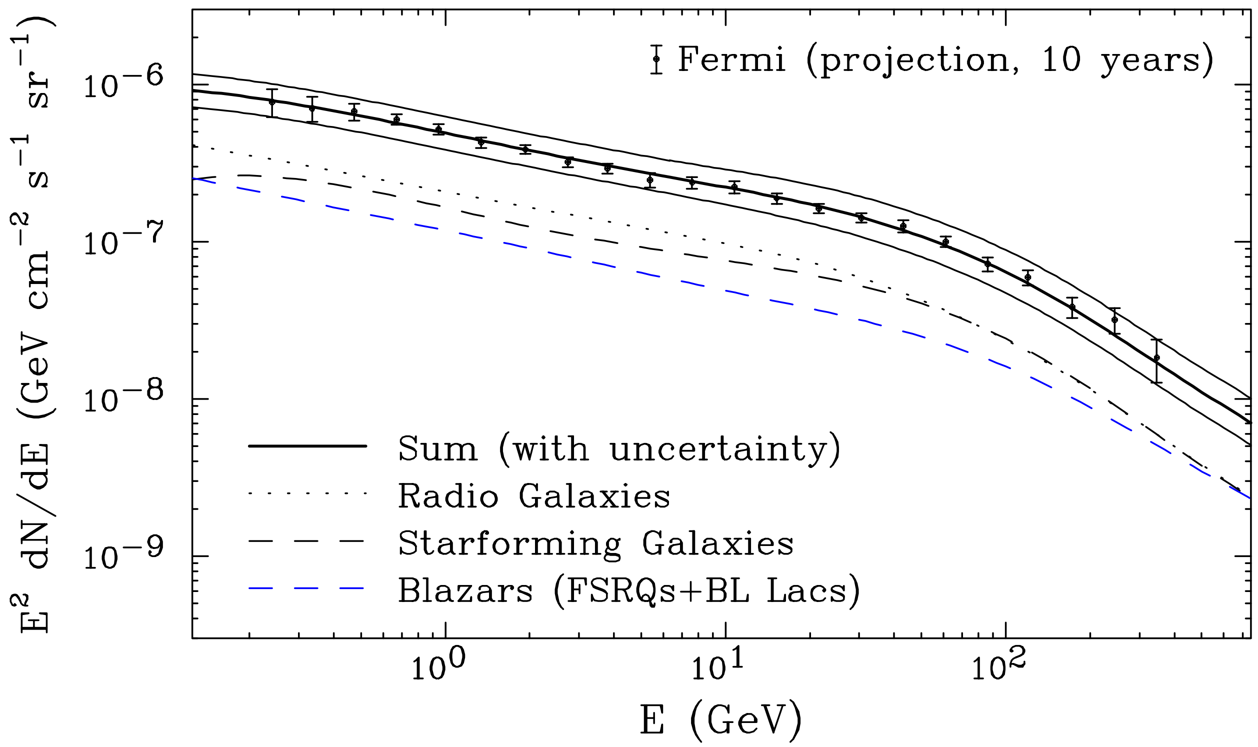


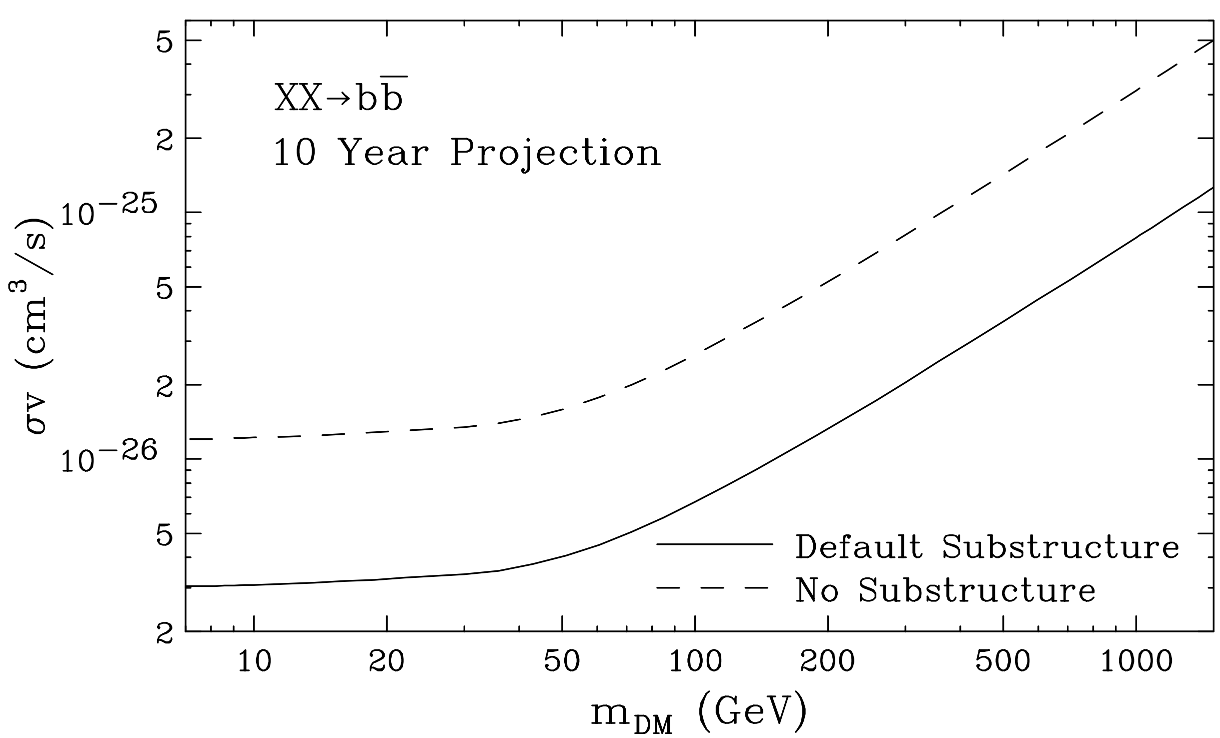


Projections for future:

More data, not just in gamma-rays but also in other wavelengths will let us constrain the backgrounds:



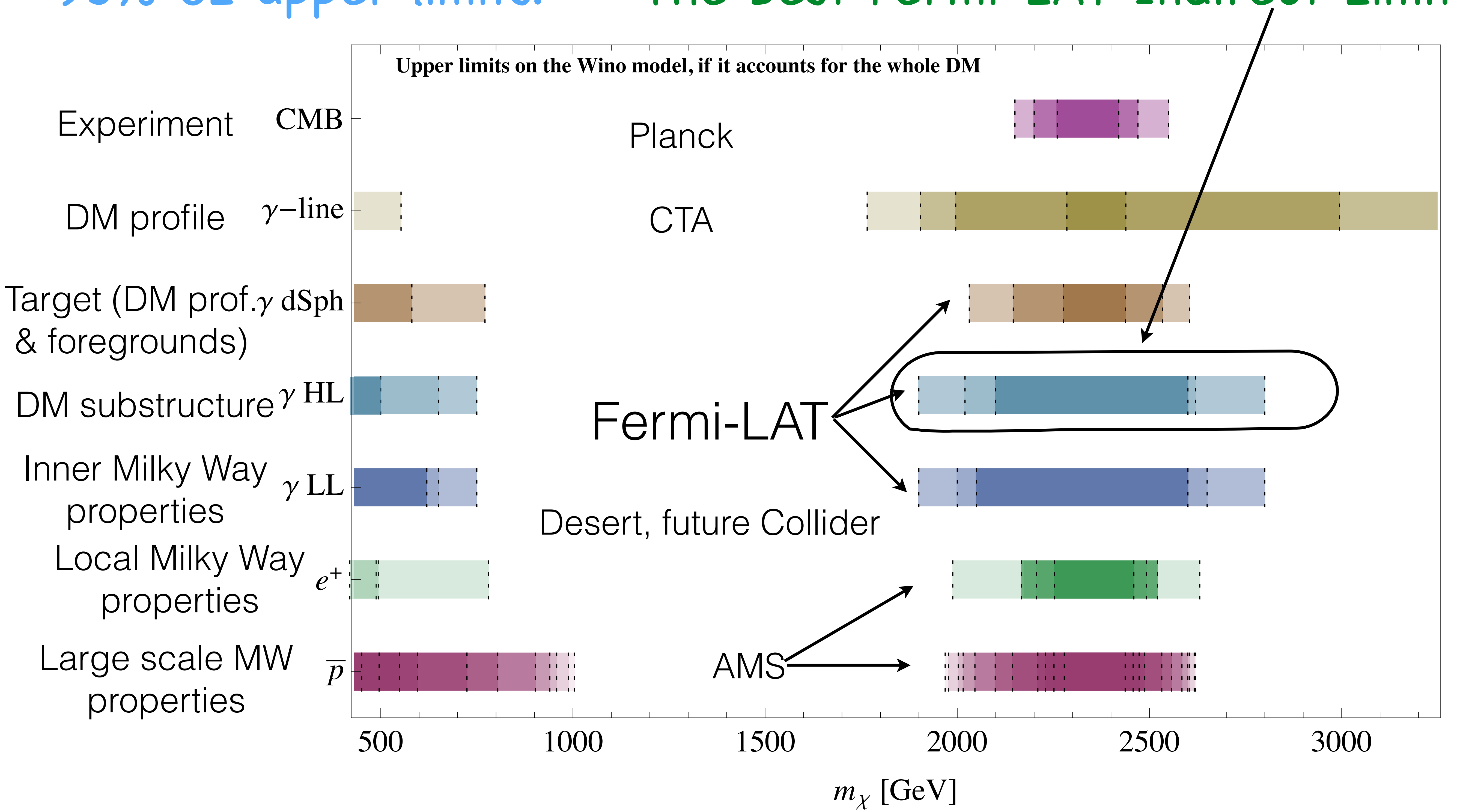




Maybe the most tight-limits by the end of the Fermi-LAT mission.

An example of indirect detection limits: Wino DM

95% CL upper limits: The Best Fermi-LAT Indirect Limit



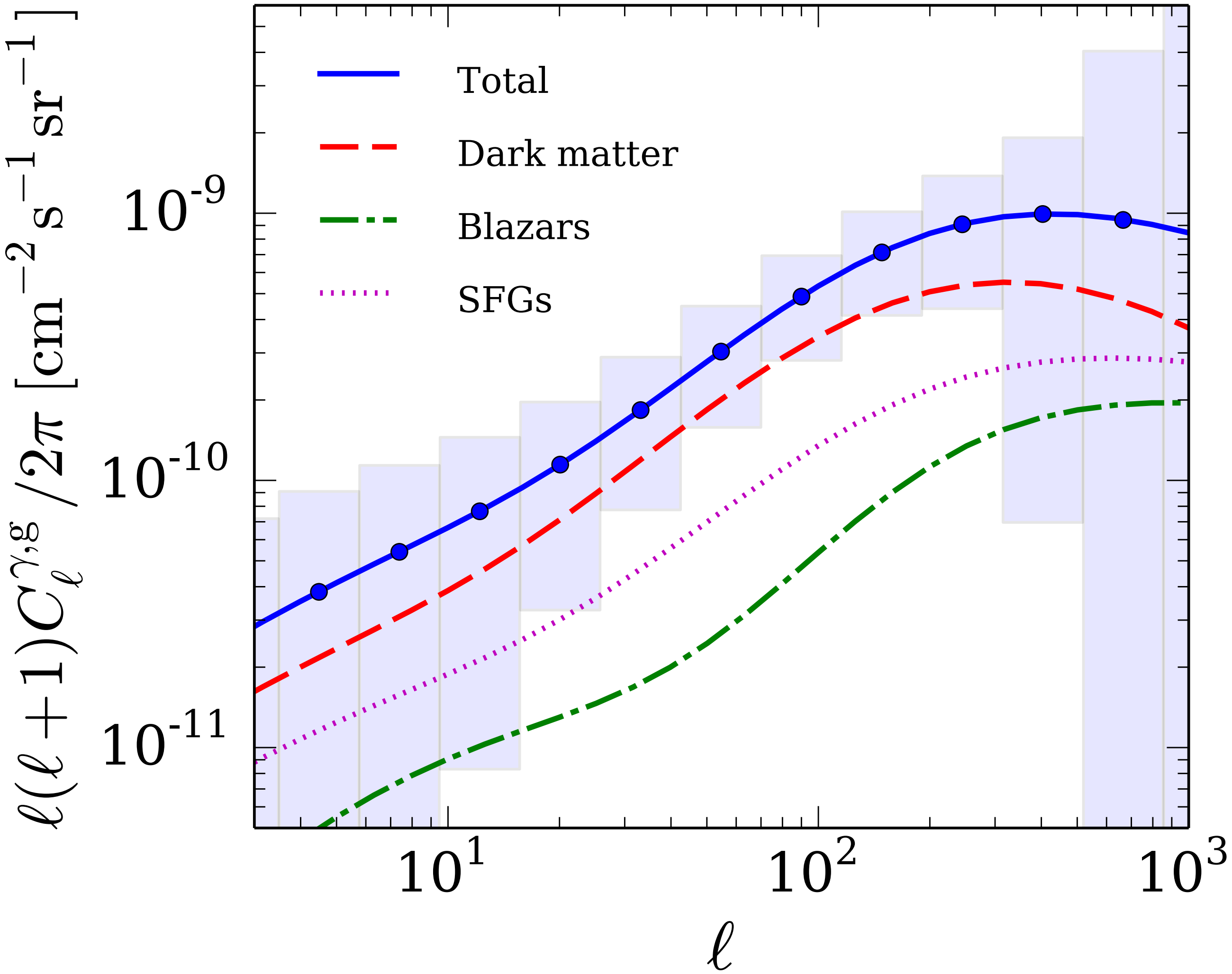
Andrzej Hryczuk, IC, Roberto Iengo, Maryam Tavakoli, Piero Ullio. 1401.6212

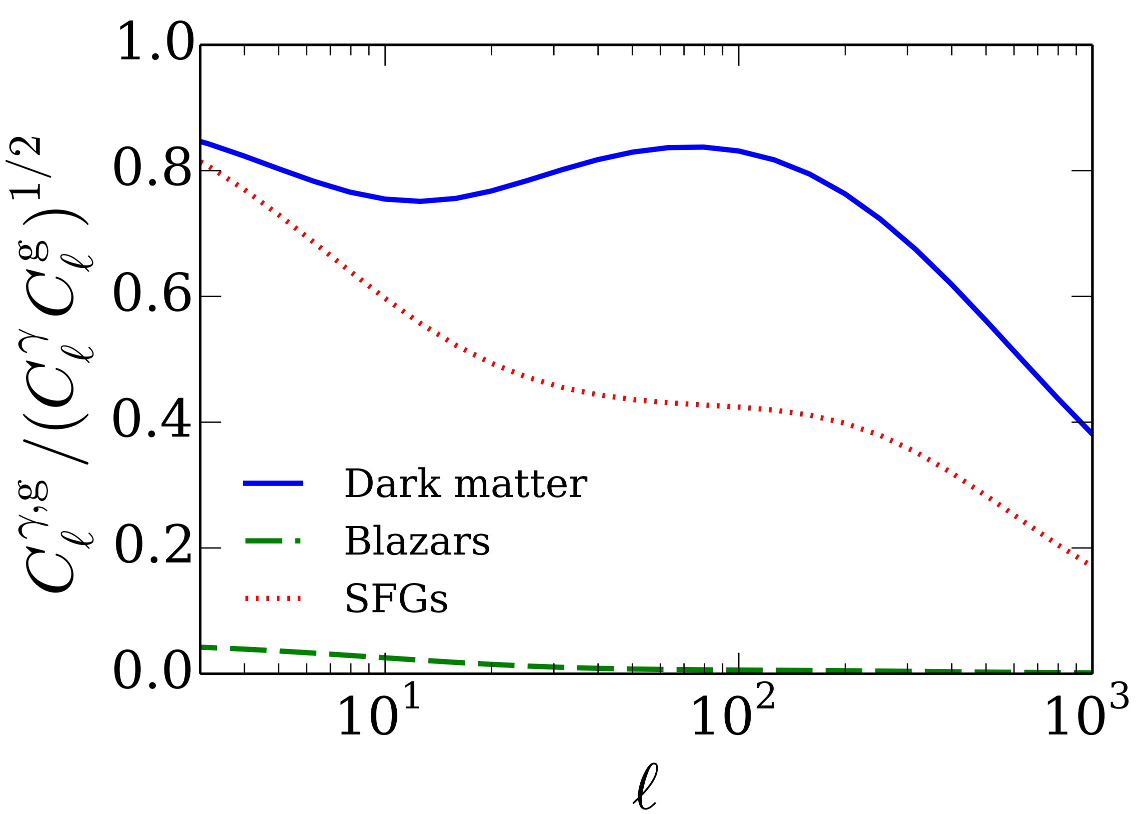
A look into the future

Cross-correlating the gamma-ray map with known galaxies.

Motivations:
New field of DM search
The main contribution in the DM induced anisotropy on the gamma-ray map is expected to come from low redshifts (z~0.1), where the contribution from other sources is actually low, nicely shown in:

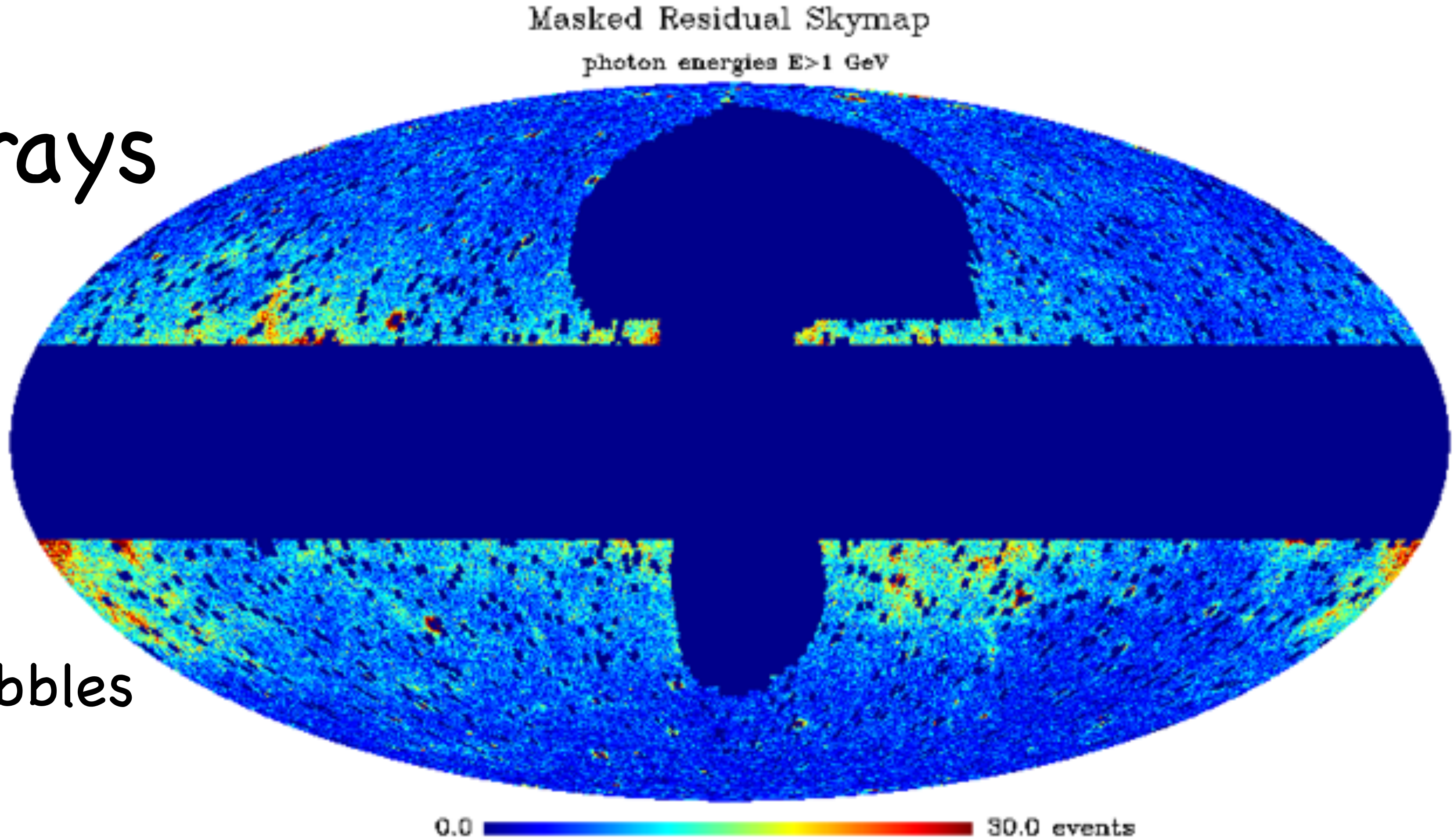
Cross-correlating with 2MASS:



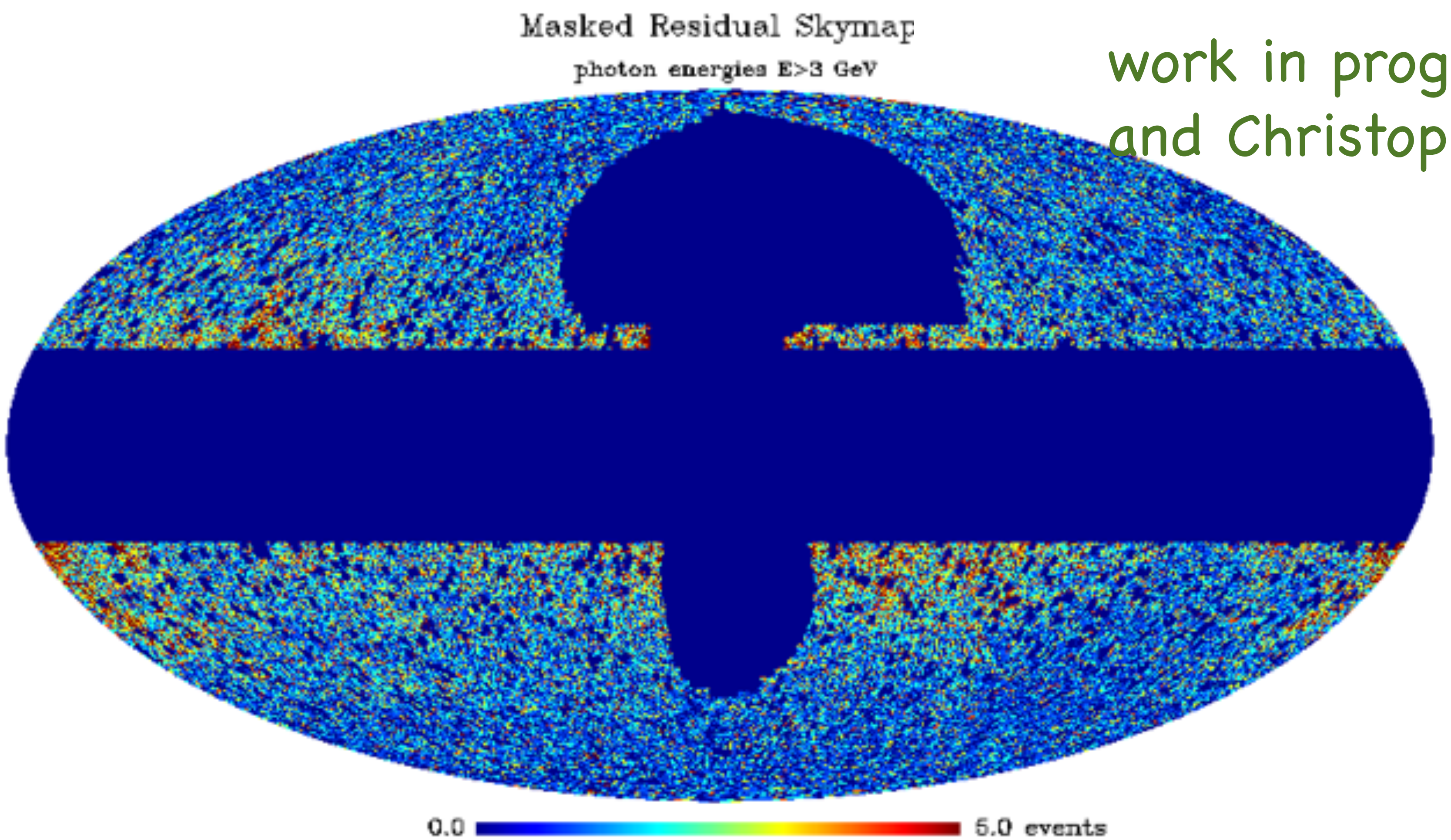


S. Ando, A. Benoit-Levy, E. Komatsu, arXiv:1312.4403

Looking at gamma-rays (5.5yr)



Masking the disk, the Fermi-Bubbles Loop I & known point-sources:



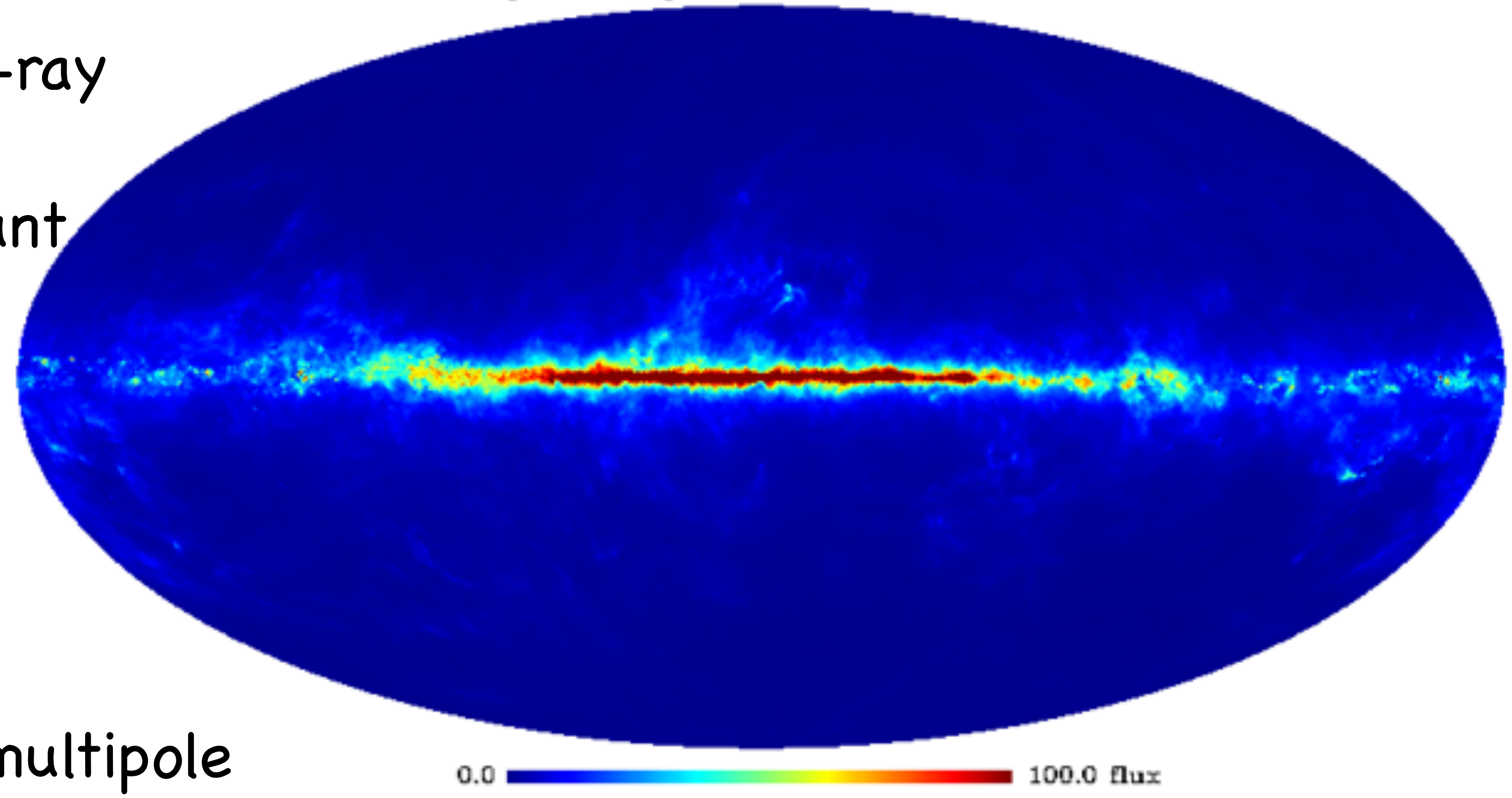
work in progress Dan Hooper, Andrew Hearin and Christoph Weniger

Subtracting the diffuse gamma-ray emission (try MANY different galactic diffuse models to account for uncertainties.

2 example maps (pi0 and bremsstrahlung)

pi0 Emission Event Skymap

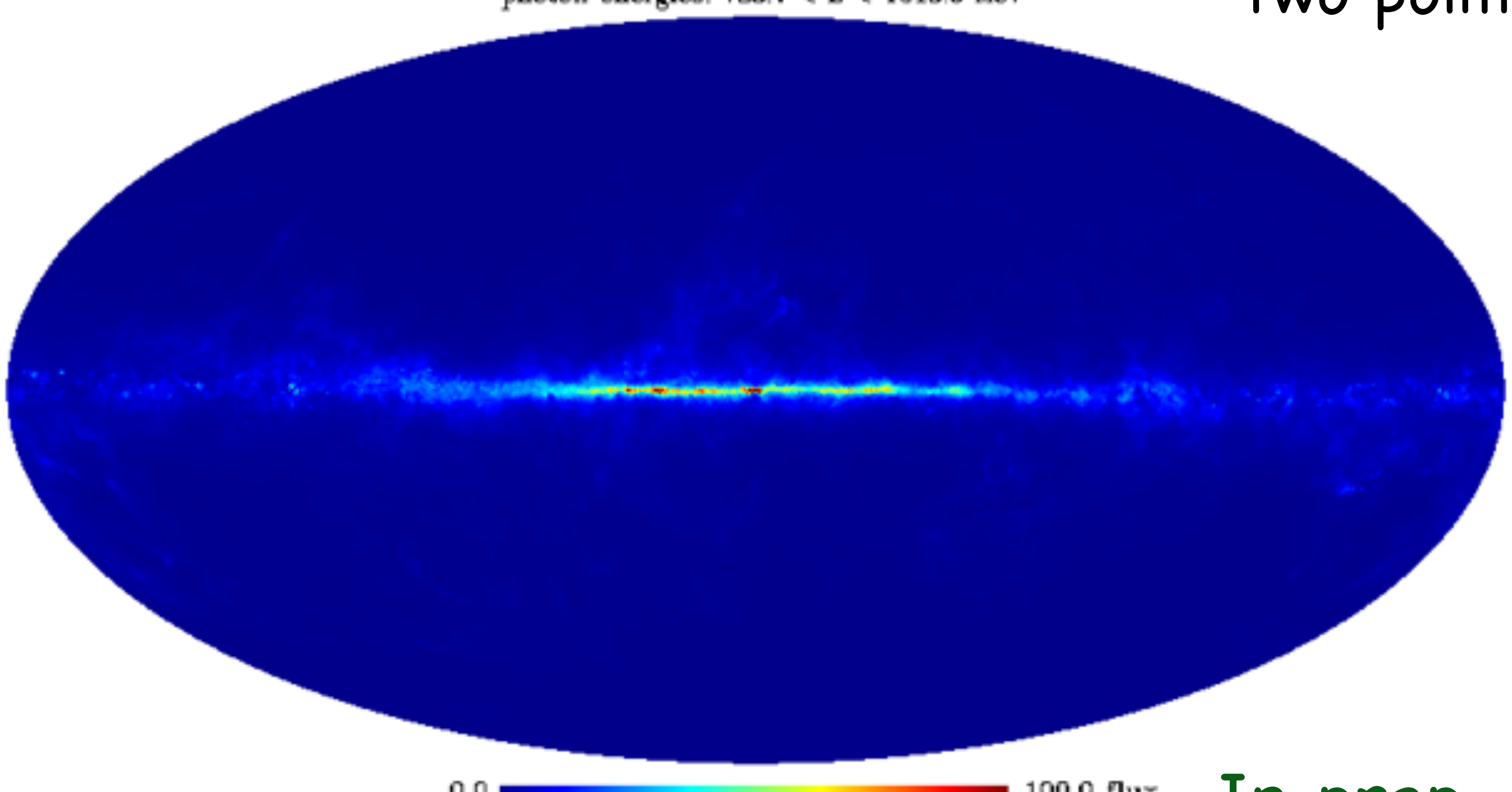
photon energies: 783.7 < E < 1015.6 MeV



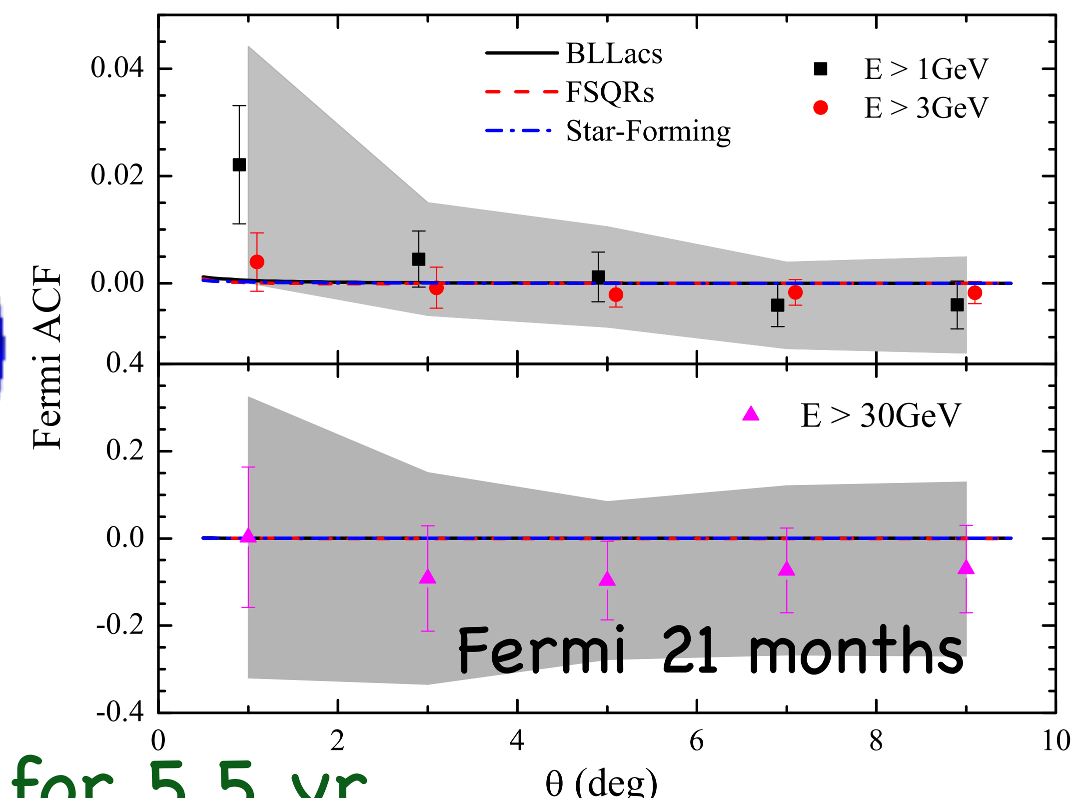
Also need to take out the low multipole residuals.

Bremsstrahlung Emission Event Skymap

photon energies: 783.7 < E < 1015.6 MeV



two point ACF: $\langle \delta I(\mathbf{n_1}) \delta J(\mathbf{n_2}) \rangle = \sum_l \frac{2l+1}{4\pi} C_l^{I,J} P_l[cos(\theta)]$



In prep. for 5.5 yr...

Conclusions

- There is a garden variety of possible indirect signals from DM annihilation or decay even just in the gamma-rays(not including other indirect detection probes or direct or collider)

- Including possible hints of DM-like excesses (see discussion on Thursday on the GC)

- At high latitudes we need to model the extragalactic background. Make connections with other wavelengths (radio, IR)

- Our understanding of the extragalactic background contributions is going to get much better as we continue getting data from both gamma-rays and other wavelengths

- Just from the intensity by the end of the Fermi-LAT mission we can have some of the tightest indirect gamma limits. Already as competitive as the other gamma limits from dwarf spheroidals and towards the GC.

- Also including the gamma-ray power spectrum and cross-correlating with galaxy catalogues can result in future tight limits.

Thank you