Constraining Dark Matter annihilation with the Fermi-LAT isotropic gamma-ray background

Fiorenza **Donato** @ Physics Dept., Un. Torino

"The gamma-ray sky" - Minneapolis, October 10, 2013

Plan of my talk

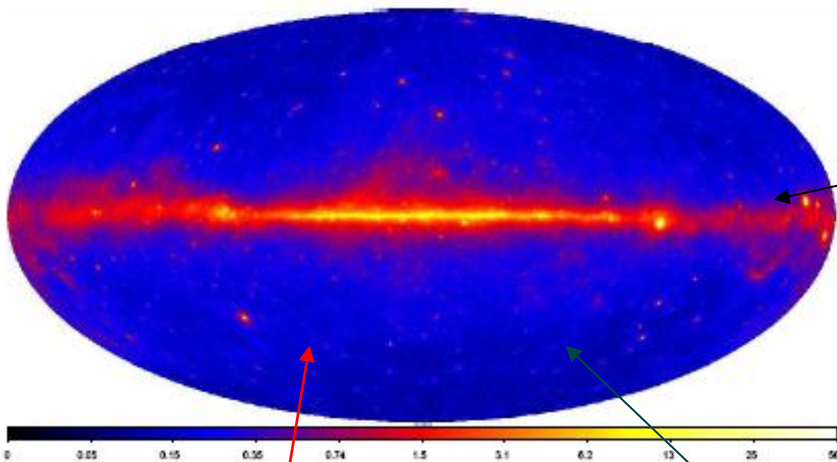
What is the isotropic γ-ray background (IGRB)

New results on (unresolved) mis-aligned AGN diffuse γ-ray emission

New results on unresolved BL Lacs

Bounds on annihilating Dark Matter (DM) particles in the Milky way halo

The extragalactic gamma-ray background



Fermi-LAT 2° catalog

Galactic diffuse emission:
CR interaction with the interstellar medium:
1. π^0 decay
2. Inverse Compton (IC)
3. Bremstrahalung

Resolved point sources

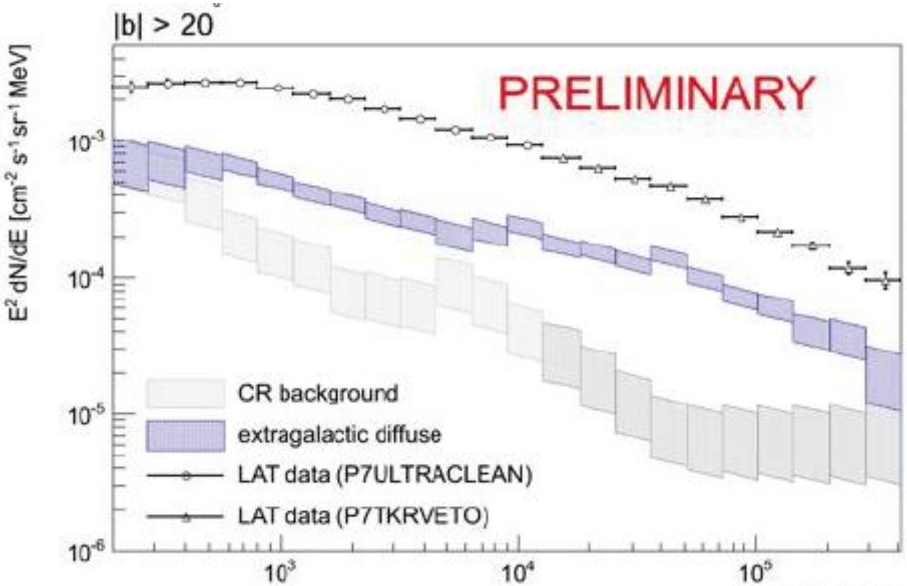
Isotropic extragalactic diffuse emission

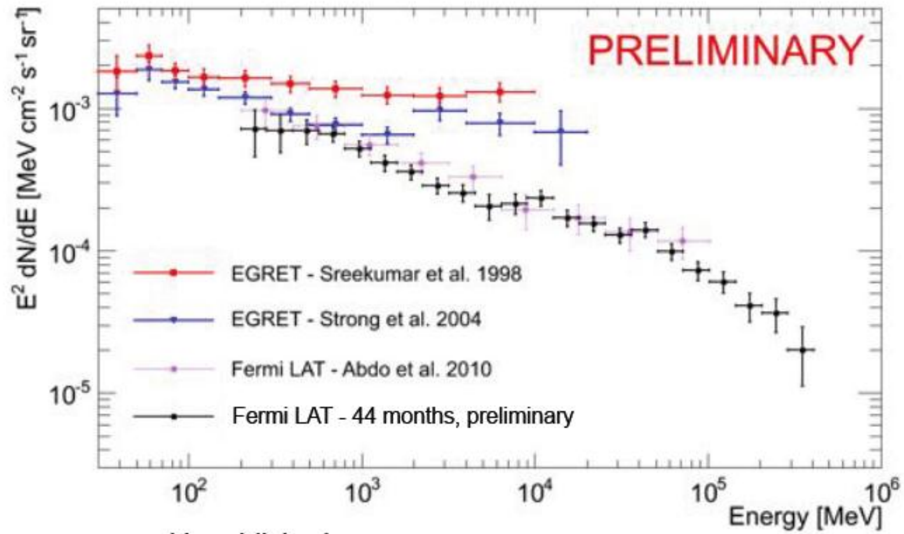
The Fermi-LAT γ-ray sky = galactic diffuse model (!) + point sources +
solar and local emissions + isotropic diffuse emission

(putative) extragalactic diffuse emission + CR background

The Fermi-LAT EGB

From M. Ackermann (Fermi-LAT Coll., Fermi Symp. 2012)





The origin of the EGB (in Fermi-LAT energies)

Undetected sources: AGN (blazars: BL Lacs, FSRQ; mis-aligned AGN)
star forming galaxies,
(galactic) milli-second pulsars (MSP), [...]

Diffuse processes: UHECRs interacting with EBL,
dark matter annihilation,
intergalactic shocks, [...]

Digression on definitions

EGB = extragalactic gamma-ray background

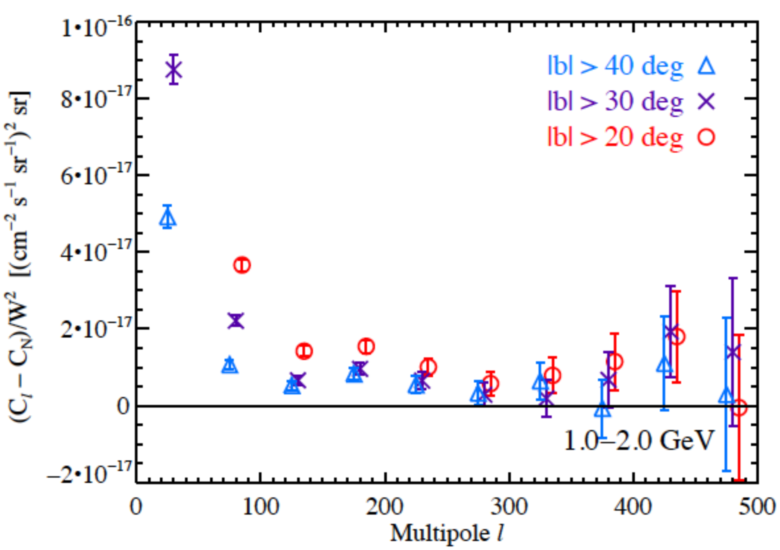
→ it supposes that the residual flux observed at high latitudes comes from extragalactic sources

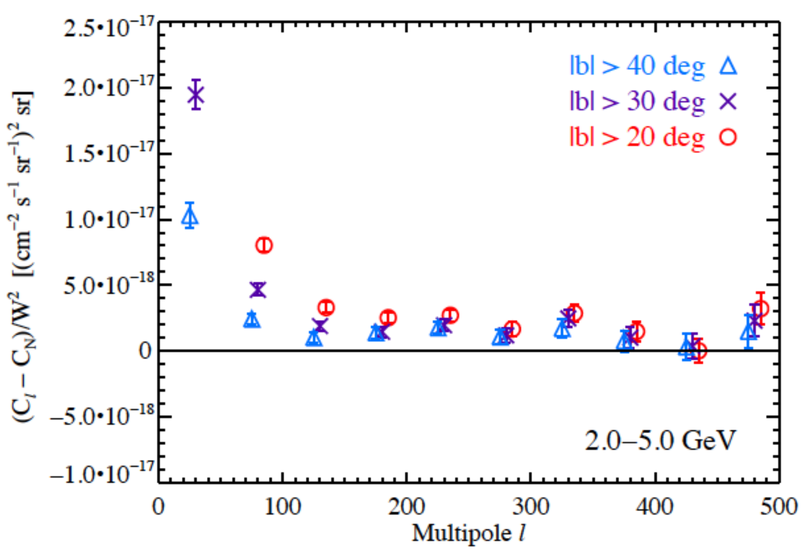
Note: galactic milli-second pulsars (and dark matter) can contribute

IGRB = isotropic gamma-ray background

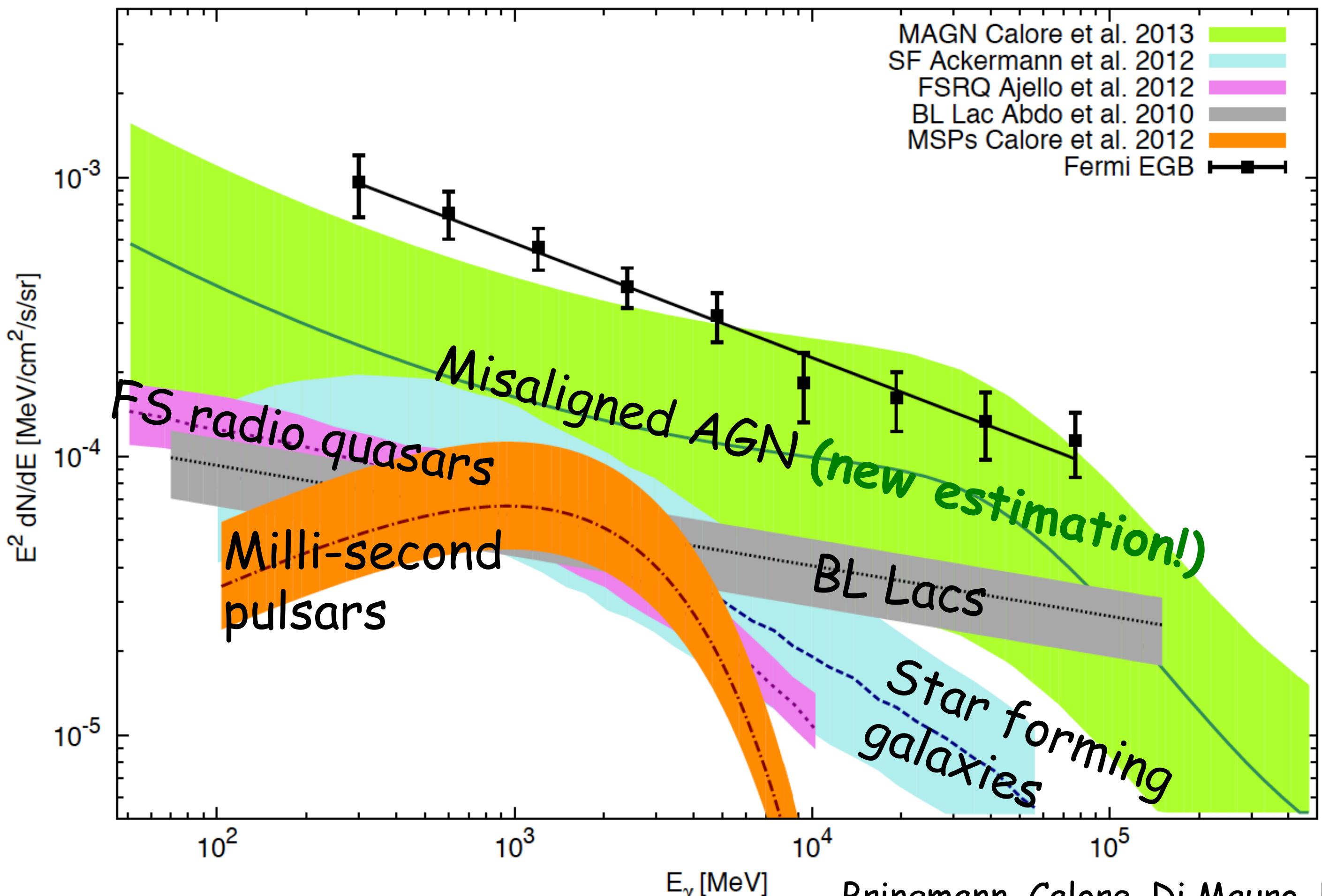
→ it suppose that the residual flux observed at high latitudes is isotropic

Note: Fermi-LAT has detected anisotropies in the diffuse emission , BUT they appear on scales < 2 kpc (l<155) (Fermi-LAT Coll 1202.2856)





Possible contributions to the EGB from unresolved astrophysical sources



Bringmann, Calore, Di Mauro, FD 1303.3284

Diffuse γ-ray emission from Misaligned Active Galactic Nuclei (MAGN)

M. Di Mauro, F. Calore, FD, M. Ajello, L. Latronico ApJ submitted, 2013 1304:0908

MAGN: AGN with jet not aligned along the line-of-sight (l.o.s.)
Doppler boosting negligible
Radio galaxies (RG) and steep-spectrum radio quasars (SSRQs)

RG have been classified by Fanaroff&Riley (1974)

- FRI edge-darkened, less powerful, Bl Lacs parent
- FRII edge-brightened, more powerful, FSRQs parent

Abundant RADIO data:
total (including lobes) and central compact region (core)

Fermi-LAT observed 15 MAGN between 0.1-100 GeV
(Fermi-LAT ApJ 720, 2010)

Fermi-LAT MAGNs:
main radio and gamma properties

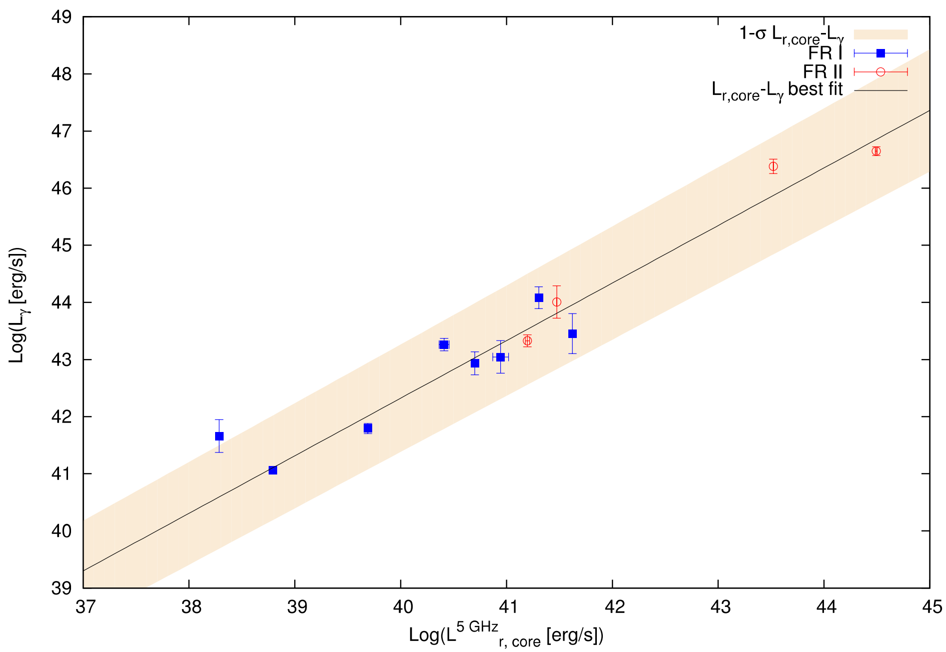
MAGN(FRI,FRII)	z	$b\,[^\circ]$	$\alpha_{core}(\alpha_{tot})$	S_{core}^{5GHz} [Jy] (S_{tot}^{5GHz}) [Jy])	Γ	F_γ $[10^{-9}\mathrm{ph\,cm^{-2}\,s^{-1}}]$	$L_{r,core}^{5GHz}$ $[\mathrm{erg\,s^{-1}}]$	L_γ $[\mathrm{erg\,s^{-1}}]$
3C 78/NGC 1218(I)	0.0287	-44.6	$0\ (0.64^{1})$	$0.964 \pm 0.164^{1}\ (3.40 \pm 0.11^{2})$	1.95 ± 0.14	4.7 ± 1.8	$(8.8 \pm 1.4) \cdot 10^{40}$	$(1.11 \pm 0.54) \cdot 10^{43}$
3C 274/M 87(I)	0.0038	74.5	$0\ (0.79^{8})$	$3.0971 \pm 0.0300^{7}\ (71.566 \pm 0.993^{9})$	2.17 ± 0.07	25.8 ± 3.5	$(4.90 \pm 0.05) \cdot 10^{39}$	$(6.2 \pm 1.1) \cdot 10^{41}$
Cen A(I)	0.0009	19.4	$0.30^{10}\ (0.70^{10})$	$6.984 \pm 0.210^{11}\ (62.837 \pm 0.099^{12})$	2.76 ± 0.05	175 ± 10	$(6.19 \pm 0.19) \cdot 10^{38}$	$(1.14 \pm 0.09) \cdot 10^{41}$
NGC 6251(I)	0.0247	31.2	$0(0.72^{9})$	$0.38 \pm 0.04^{13}\ (0.510 \pm 0.050^{13\ a})$	2.20 ± 0.07	18.2 ± 2.6	$(2.57 \pm 0.27) \cdot 10^{40}$	$(1.82 \pm 0.41) \cdot 10^{43}$
Cen B(I)	0.0129	1.68	$0\ (0.13^{16})$	$2.730^{15}\ (6.58 \pm 1.04^{16})$	2.33 ± 0.12	39.3 ± 11.4	$5.02 \cdot 10^{40}$	$(8.6 \pm 3.2) \cdot 10^{42}$
For A(I)	0.00587	-56.7	$0.50^{17}(0.52^{1})$	$0.051^{17}\ (72^{1})$	2.16 ± 0.15	7.7 ± 2.4	$1.93 \cdot 10^{38}$	$(4.6 \pm 2.2) \cdot 10^{41}$
3C 120(I)	0.0330	-27.4	$0\ (0.44^{18})$	$3.458 \pm 0.588^{1}\ (8.60 \pm 1.46^{1})$	2.71 ± 0.35	29 ± 17	$(4.20 \pm 0.71) \cdot 10^{41}$	$(2.9 \pm 1.6) \cdot 10^{43}$
PKS 0625−35(I)[b]	0.0546	-20.0	$0\ (0.65^{3})$	$0.600 \pm 0.030^{3}\ (2.25 \pm 0.09^{4})$	1.93 ± 0.09	12.9 ± 2.6	$(2.02 \pm 0.10) \cdot 10^{41}$	$(1.21 \pm 0.43) \cdot 10^{44}$
Pictor A(II)	0.0351	-34.6	$0\ (1.07^{1})$	$1.15 \pm 0.05^{19}\ (15.45 \pm 0.47^{4})$	2.93 ± 0.03	21.9 ± 3.6	$(1.58 \pm 0.07) \cdot 10^{41}$	$(2.13 \pm 0.46) \cdot 10^{43}$
3C 111(II)	0.0485	-8.61	$-0.20^{b}\ (0.73^{5})$	$1.14^{20}\ (6.637 \pm 0.996^{18})$	2.54 ± 0.19	40 ± 8	$2.98 \cdot 10^{41}$	$(1.01 \pm 0.38) \cdot 10^{44}$
3C 207(II))[c]	0.681	30.1	$0\ (0.90^{5})$	$0.5391 \pm 0.0030^{6}\ (1.35 \pm 0.04^{4})$	2.36 ± 0.11	17.3 ± 3.3	$(3.32 \pm 0.02) \cdot 10^{43}$	$(2.41 \pm 0.61) \cdot 10^{46}$
3C 380(II))[c]	0.692	23.5	$0\ (0.71^{9})$	$5.073 \pm 0.105^{14}\ (7.45 \pm 0.37^{4})$	2.34 ± 0.07	30.3 ± 3.7	$(3.12 \pm 0.07) \cdot 10^{44}$	$(4.44 \pm 0.73) \cdot 10^{46}$
IC 310(I)	0.0189	-13.7	n.a.(0.75^{23})	n.a. (0.258 ± 0.031^{24})	2.10 ± 0.19	11.1 ± 6.2	-	$(7.9 \pm 4.9) \cdot 10^{42}$
3C 84/NGC 1275(I)	0.0176	-13.2	(0.78^{5})	high variability	2.00 ± 0.02	175 ± 8	-	$(1.22 \pm 0.07) \cdot 10^{44}$
PKS 0943−76(II)	0.270	-17.2	n.a.	upper limits(0.757^{22})	2.44 ± 0.14	19.5 ± 5.1	-	$(2.47 \pm 0.71) \cdot 10^{45}$

- Some of Fermi-LAT sources are variable
- Radio CORE data taken at 5 GHz, and contemporary to Fermi-LAT data
- Up to z~0.7
- 4 FRII and 8 FRI

γ-ray vs radio luminosity function for MAGN

Correlation between luminosity of radio core at 5 GHz
and γ-ray luminosity > 0.1 GeV

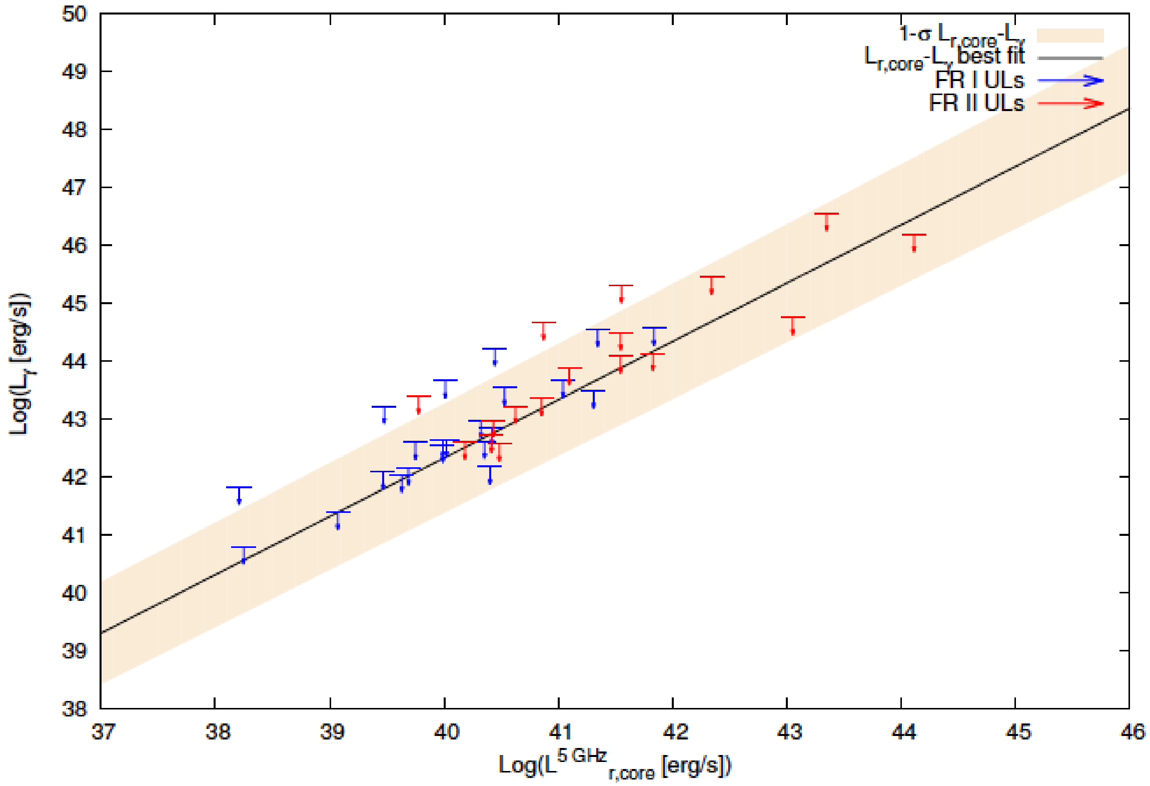
$$\log\left(L_\gamma\right) = 2.00 \pm 0.98 + (1.008 \pm 0.025)\log\left(L_{r,\mathrm{core}}^{5\mathrm{GHz}}\right)$$



The strength of the correlation has been confirmed by the Spearman test and the modified Kendall τ rank correlation test: chance correlation excluded at 95% C.L.

Testing L_γ-L_r correlation: upper limits from undetected FRI&FRII

We derive upper limits for FRI and FRII having strong radio core fluxes



GREAT!!!

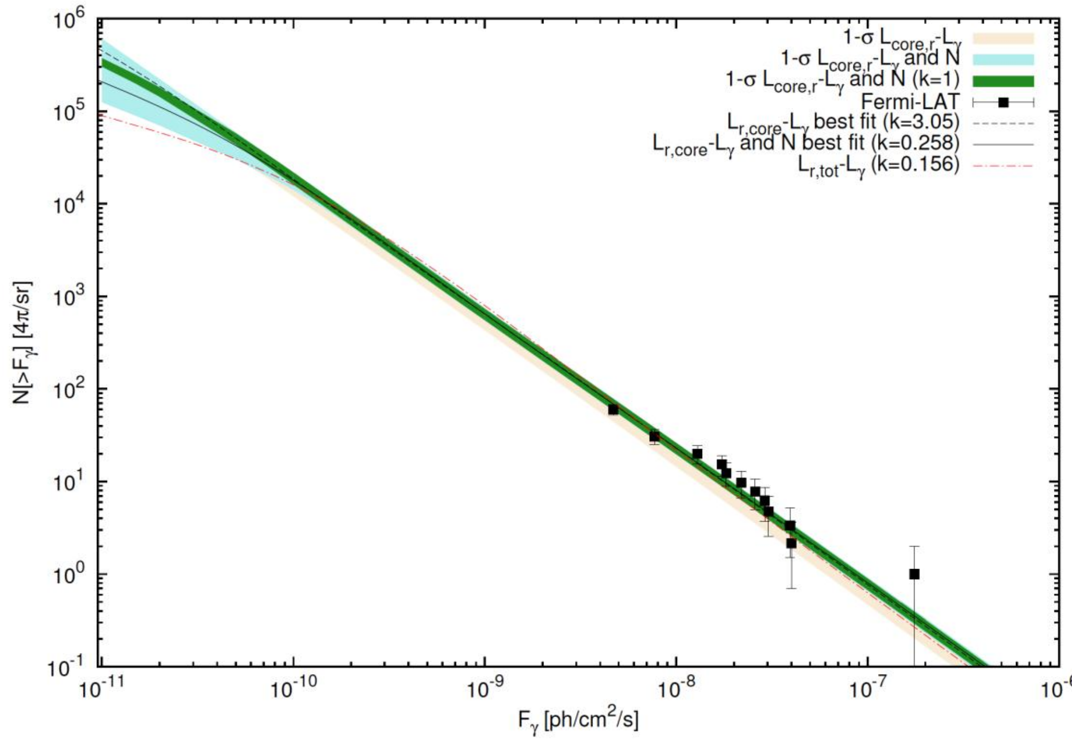
they do not violate the correlation → It looks physical

Constraints from logN-logS

The cumulative source number above a given flux:

$$N_{\rm th}(>F_\gamma) = 4\pi \int_{\Gamma_{max}}^{\Gamma_{min}} \frac{dN}{d\Gamma} d\Gamma \int_0^{z_{max}} \frac{d^2V}{dz d\Omega} \int_{L_\gamma(F_\gamma,z,\Gamma)}^{L_\gamma^{max}} \frac{dL_\gamma}{L_\gamma \ln(10)} \rho_\gamma(L_\gamma, z, \Gamma)$$

$$\rho_\gamma(L_\gamma, z) = k\ \rho_r(L_r, z) \frac{d\log L_r}{d\log L_\gamma} \ **$$



Our assumptions (core radio – γ-ray correlation, link between core and total radio emission, …) are **consistent** with the Fermi-LAT MAGN number count

Consistency also for k=1 (equal number of radio and γ-ray emitters)

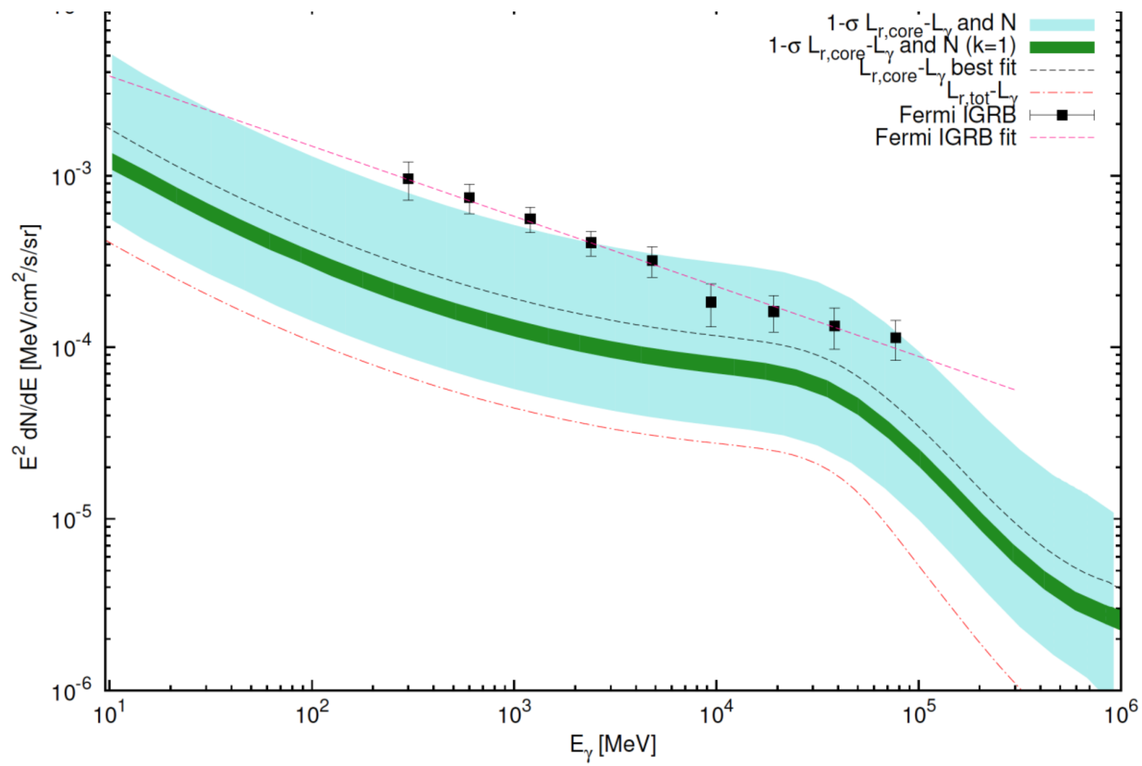
Trend at lowest fluxes → intensity of diffuse flux

**radio luminosity function from Willott+ 2002 (rescaled from total to core by Lara+ 2004)

Diffuse γ-ray emission from unresolved misaligned AGN

Di Mauro,Calore,FD, Ajello, Latronico 2013

$$\frac{d^2F(\epsilon)}{d\epsilon d\Omega} = \int_{\Gamma_{min}}^{\Gamma_{max}} d\Gamma \frac{dN}{d\Gamma} \int_0^{z_{max}} \frac{d^2V}{dz d\Omega} dz \int_{L_{\gamma,min}}^{L_{\gamma,max}} \frac{dF_\gamma}{d\epsilon} \cdot \frac{dL_\gamma}{L_\gamma \ln(10)} \rho_\gamma(L_\gamma, z)(1-\omega(F_\gamma(L_\gamma,z))) \exp\left(-\tau_{\gamma,\gamma}(\epsilon,z)\right)$$



Best fit MAGN diffuse flux: 20-30% Fermi-LAT IGRB, |b|>10°

Estimated uncertainty band: factor 10

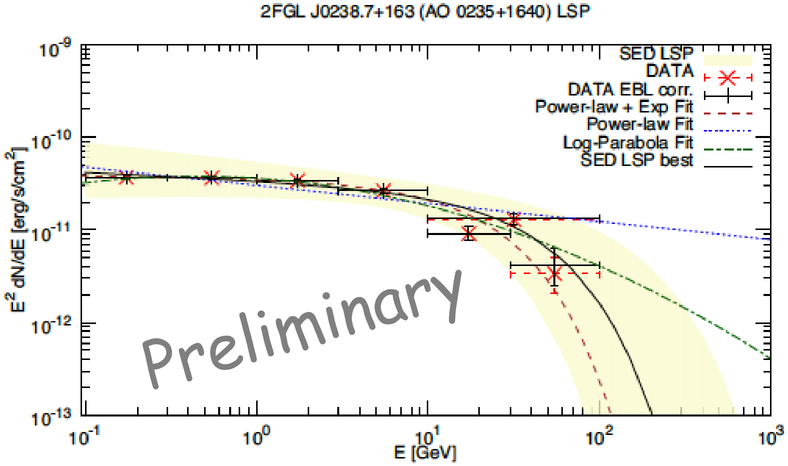
Diffuse γ-ray emission from unresolved BL Lacs

M. Di Mauro, FD, G. Lamanna, D. Sanchez, P.D. Serpico, IN PREPARATION

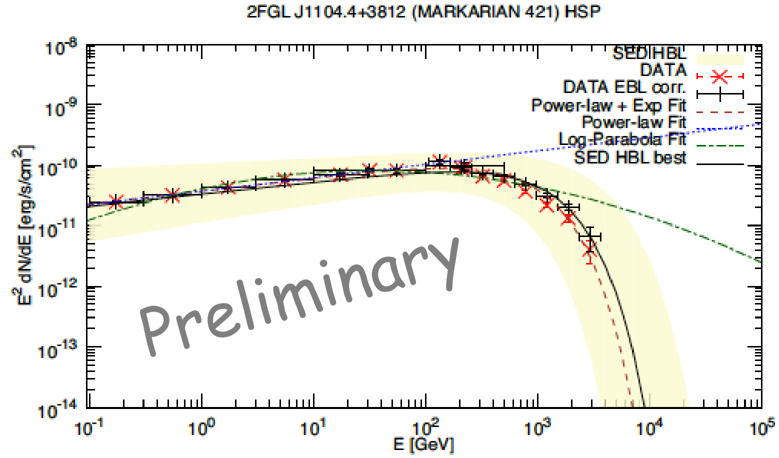
Method and novelties:

- spectral energy distribution (SED) derived from Fermi-LAT data AND TeV catalogs
- Luminosity function derived from Fermi-LAT data
- EBL absorption included (> 100 GeV)
- Blazars studied according to radio and X classification: Low (High) synchrotron peaked (LSP (HSP)) BL Lacs

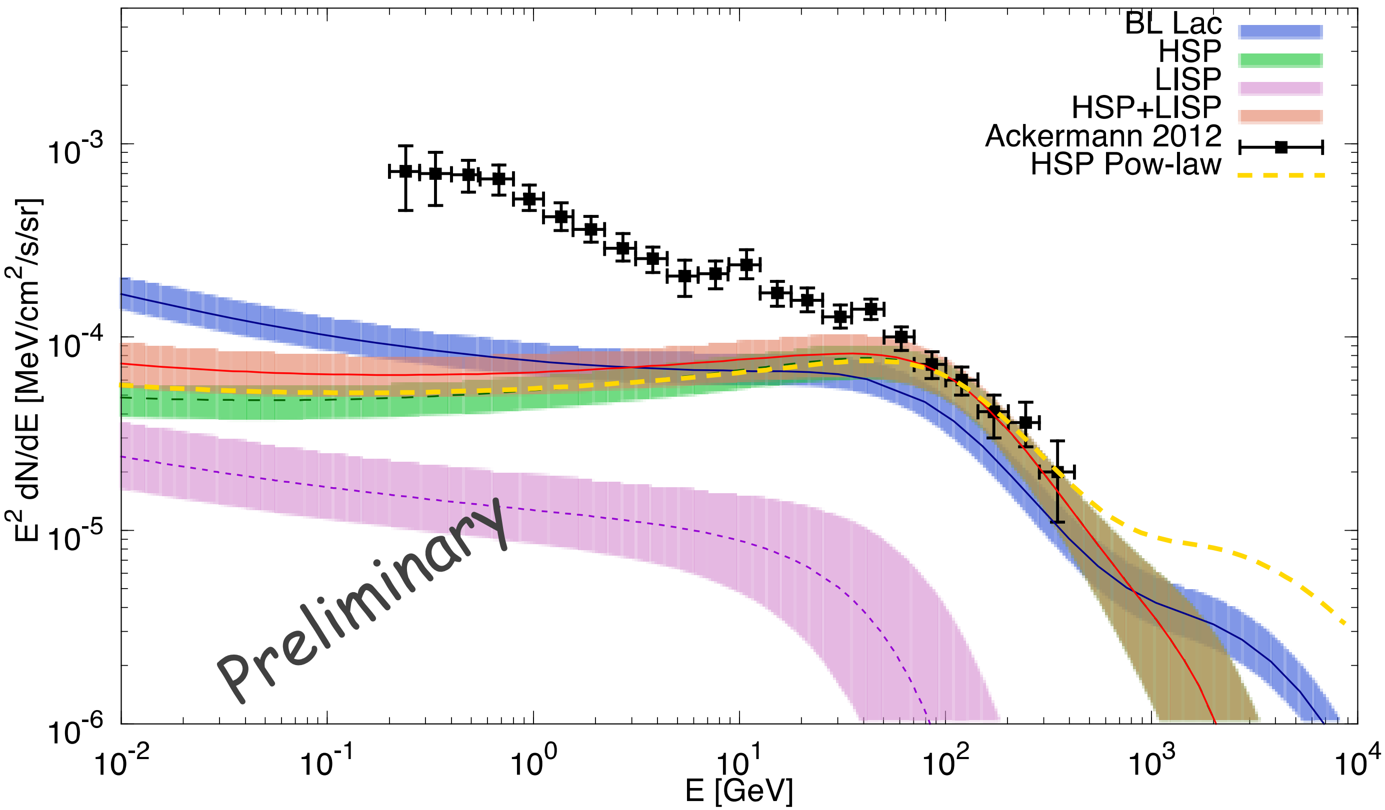
LSP BL Lac SED



HSP BL Lac SED



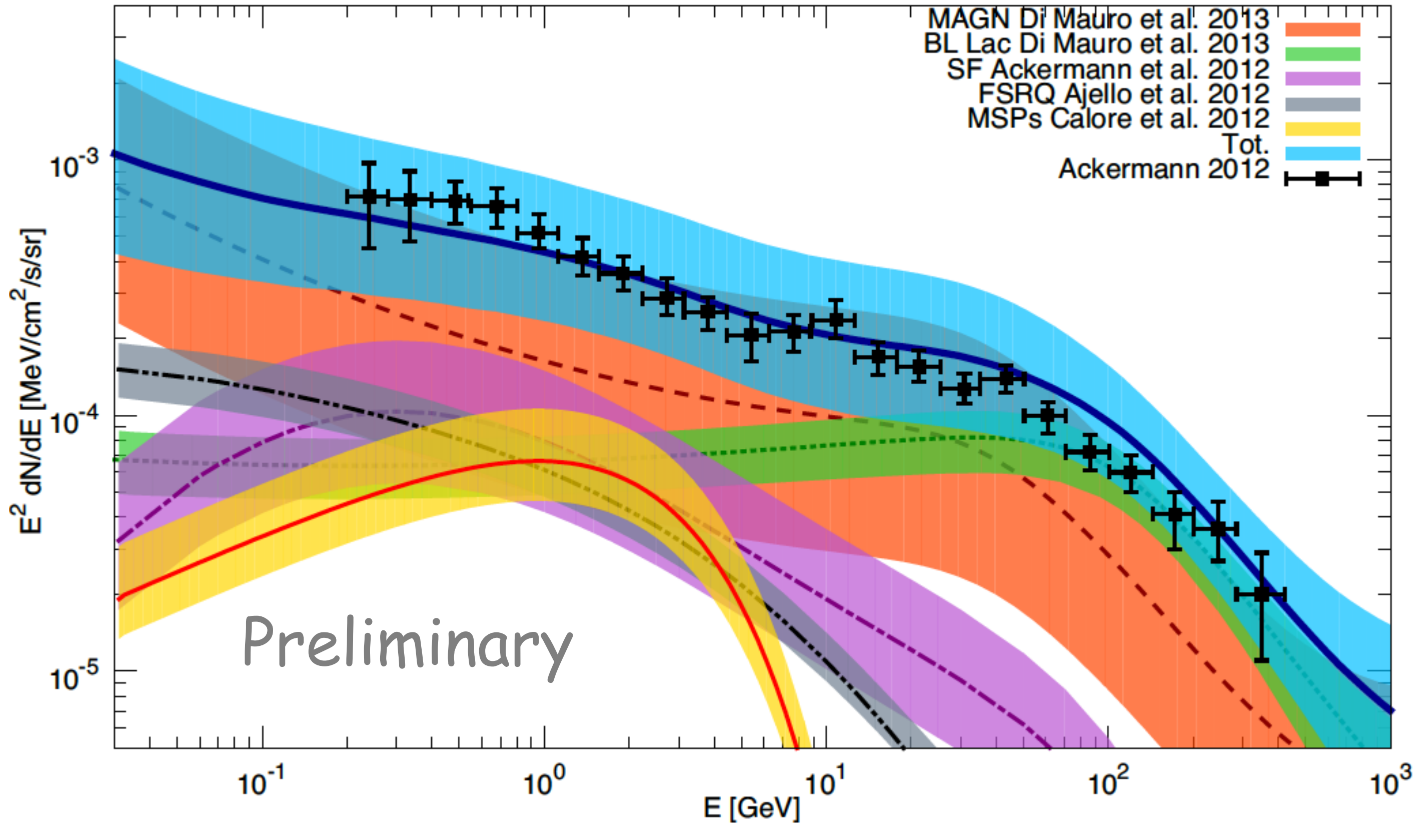
Diffuse γ-ray emission from unresolved BL Lacs Di Mauro et al., in preparation



- Softening at > 100 GeV due to EBL absorption: data are nicely reproduced!
- Treating LSP and HSP separately gives non negligible differences

EGB: sum of astrophysical contributions

Di Mauro et al., in preparation



The sum of all the contributions to fits Fermi-LAT (preliminary) EGB data

Q: Which room is left to Dark Matter annihilation into gamma-rays in the halo of the Milky Way?

Based on Bringmann, Calore, FD, Di Mauro, 1303.3284, PRD subm.

Bounds on WIMP annihilation cross section

Bringmann, Calore, FD, Di Mauro, 1303.3284

$$\Phi_\gamma(E_\gamma, \psi) = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{m_\chi^2} \frac{dN_\gamma}{dE_\gamma} \frac{1}{2} I(\psi)$$

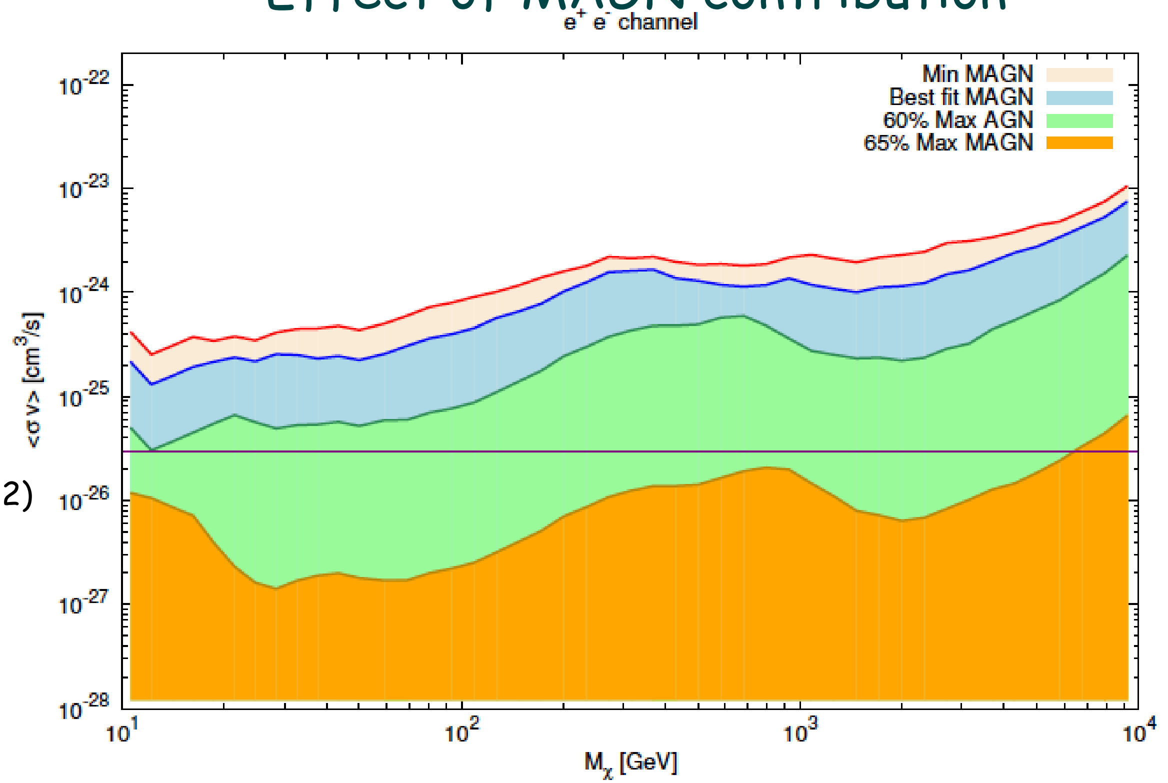
- Standard halo assumptions
- Prompt and IC photons
- BR=1 at fixe annih. channel

- Bkgd= MAGN + Σ_{BMS}

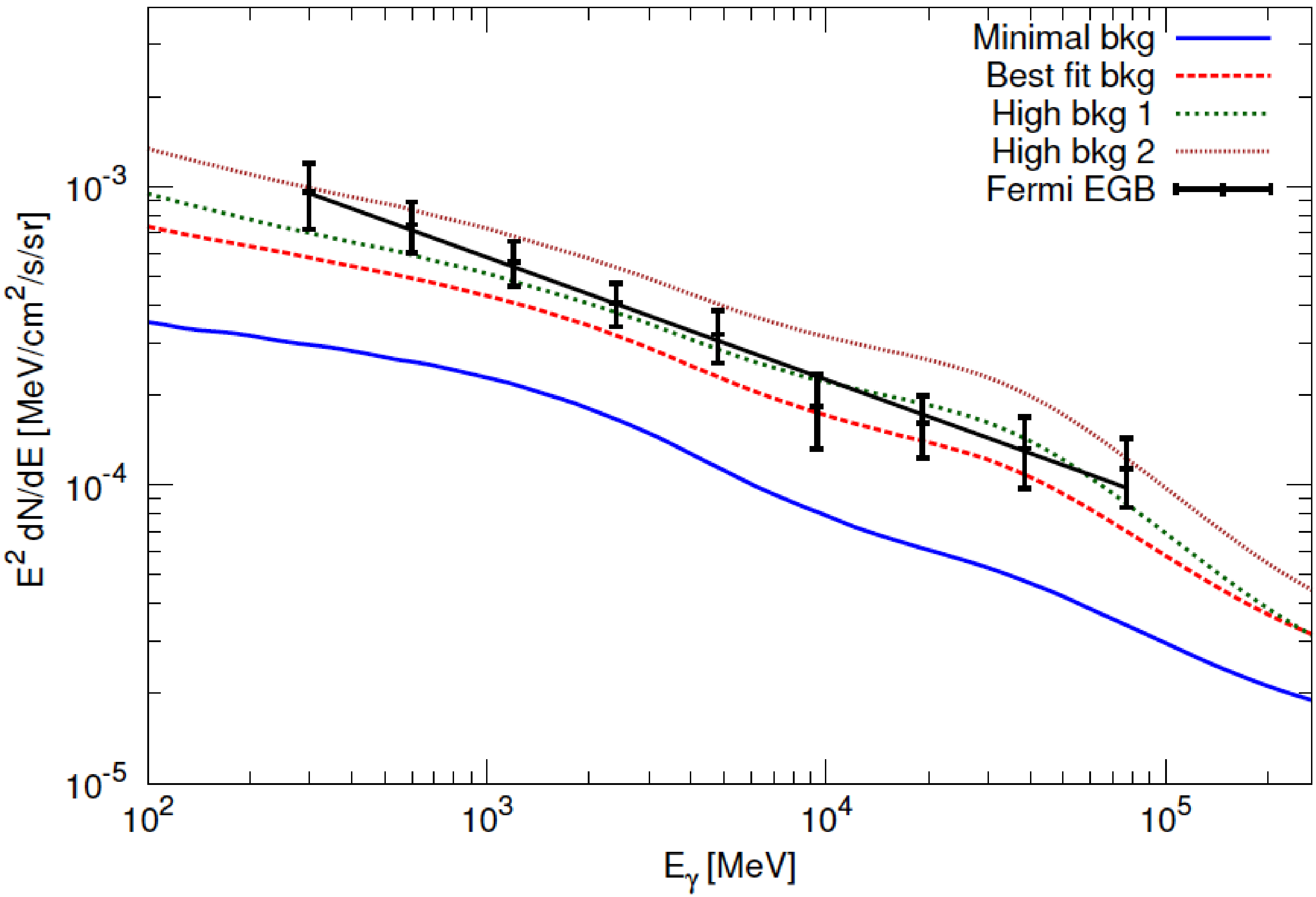
- Σ_{BMS} = MSPs (Calore+2012)+
  BL Lac (Abdo+2010) +
  FSRQs (Ajello+2012) +
  SF galaxies (Ackermann+2012)

- DM + bkgd must not exceed any data point (at 2σ)

Effect of MAGN contribution

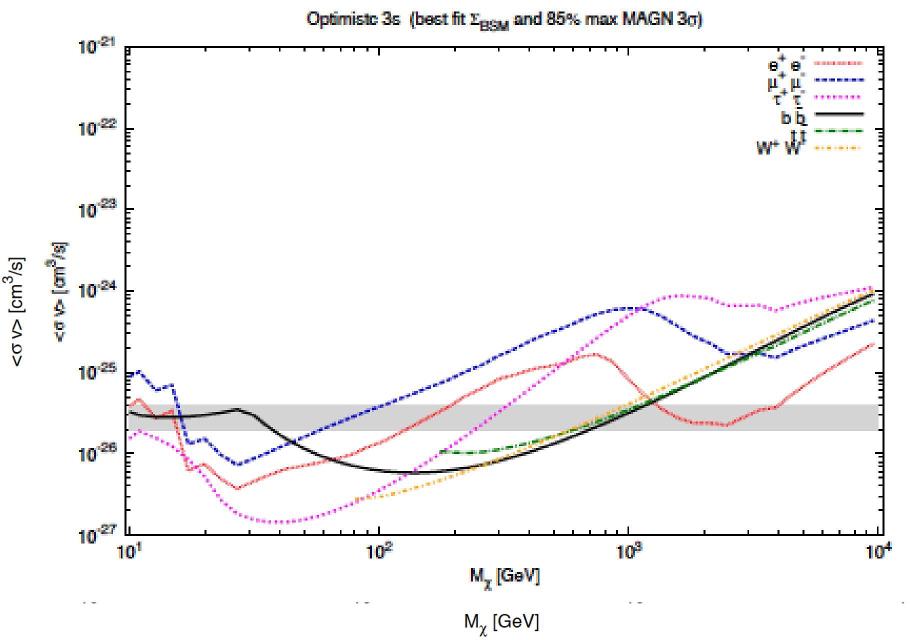


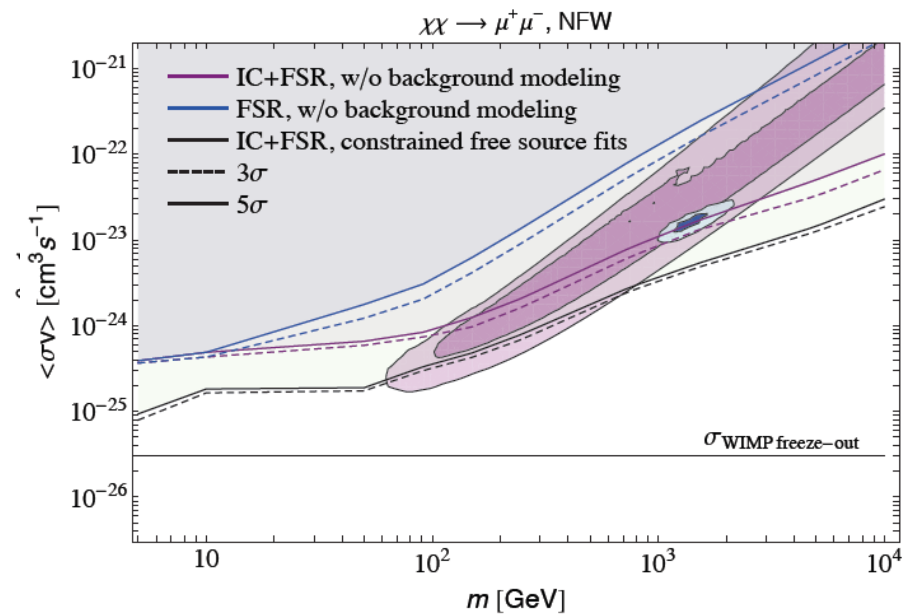
Diffuse γ-ray emission from unresolved sources: benchmarks



Bringmann, Calore, FD, Di Mauro, 1303.3284

Constraints to DM from diffuse γ-ray emission





High latitude data: |b|>10:

Bringmann, Calore, Di Mauro, FD 2013

-Negligible the choice for ρ(r)
-crucial the backgrounds from extra-galactic unresolved sources

Halo 5<|b|<15,|l|<80:

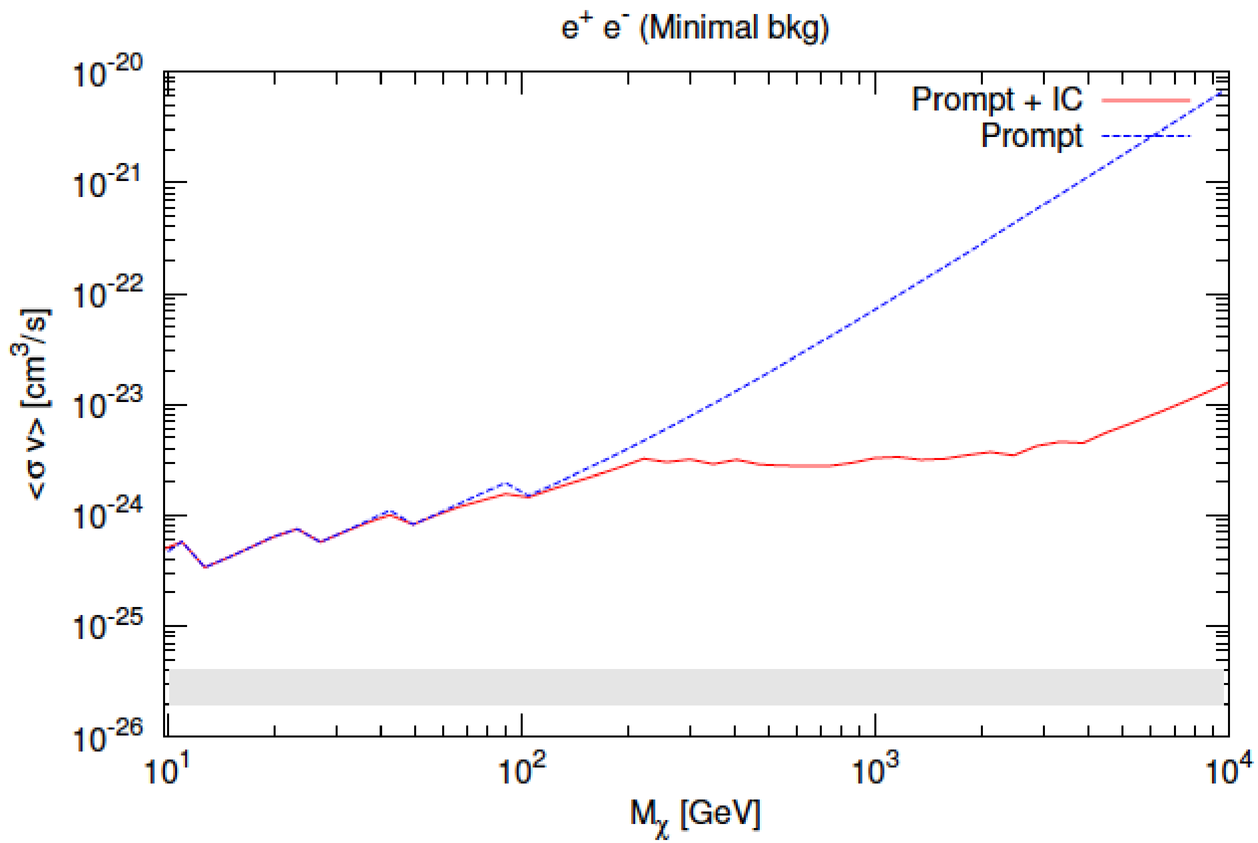
Fermi-LAT Coll. 1204.6474

-Models for the diffuse galactic emission improve the limits
- Important the choice for ρ(r)

Conclusions

- The EGB (or IGRB) is studied for $|b|>10^o$: faint, diffuse, isotropic flux
- Unresolved population of known astrophysical sources may contribute significantly to explain the intensity of the EGB: Blazars, misaligned AGN, milli-second pulsars, star forming galaxies.
- We present a new estimation of the diffuse emission from MAGN, based on a strong **correlation** between radio core emission at 5 GHz and γ-ray data for Fermi-LAT detected MAGN
- The diffuse emission from MAGN is 20-30% Fermi-LAT of measured EGB, up 100%, with **uncertainties** spanning a factor of 10
- Preliminary results for unresolved BL Lacs, studied as LSP and HSP objects
- We show how much the MAGN background reduces the room left to **Dark Matter** annihilation

Effect of Inverse Compton contribution from e^+e^- DM annihilation



The inclusion of the IC scattering (on CMB, infrared radiation, stellar light) is non-negligible for Wimp Dark Matter masses >~ 100 GeV. At m_{DM}=1 (10) TeV the constraints on $\langle\sigma v\rangle$ increase by a factor 10 (50)!