COMPOSITION OF THE ISOTROPIC γ RAY BACKGROUND AND DARK MATTER CONSTRAINTS

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FIFTH INTERNATIONAL FERMI SYMPOSIUM
NAGOYA (JAPAN) OCTOBER 20-24, 2014

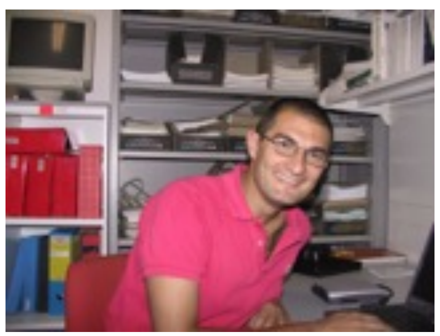
Fermi-LAT all sky maps with 5.4 years of data

TALK BASED ON THE FOLLOWING PAPERS:

Francesca Calore
GRAPPA Institute,
University of Amsterdam

Marco Ajello
Clemson University

1. Diffuse γ-ray emission from galactic Millisecond Pulsars. M. Di Mauro, F. Calore, F. Donato. arXiv:1406.2706. Accepted for publication in APJ.
2. Diffuse γ-ray emission from misaligned active galactic nuclei. M. Di Mauro, F. Calore, F. Donato, M. Ajello, L. Latronico. arXiv:1304.0908. 2014 ApJ 780 161
3. Diffuse γ-ray emission from BL Lac blazars. M. Di Mauro, F. Donato, G. Lamanna, D. A. Sanchez, P. D. Serpico. arXiv:1311.5708. 2014 ApJ 786 129.
4. The composition of the Fermi-LAT IGRB intensity: astrophysical emissions and dark matter annihilations. M. Di Mauro, F. Donato. In preparation.



Luca Latronico
INFN Torino

David Sanchez
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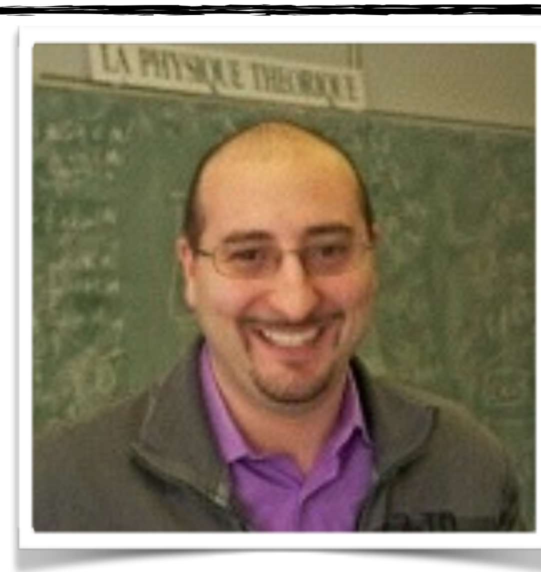
Fiorenza Donato
Universita' di Torino



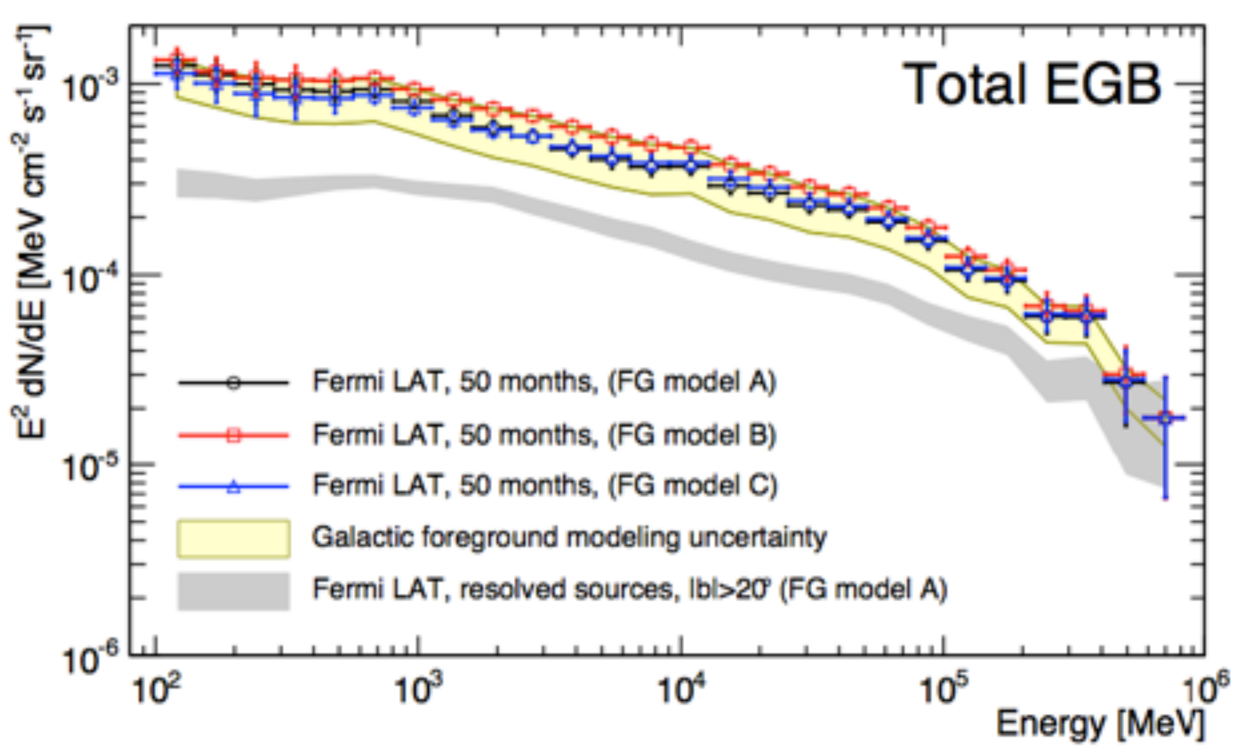
Pasquale Dario Serpico
LAPTh - CNRS

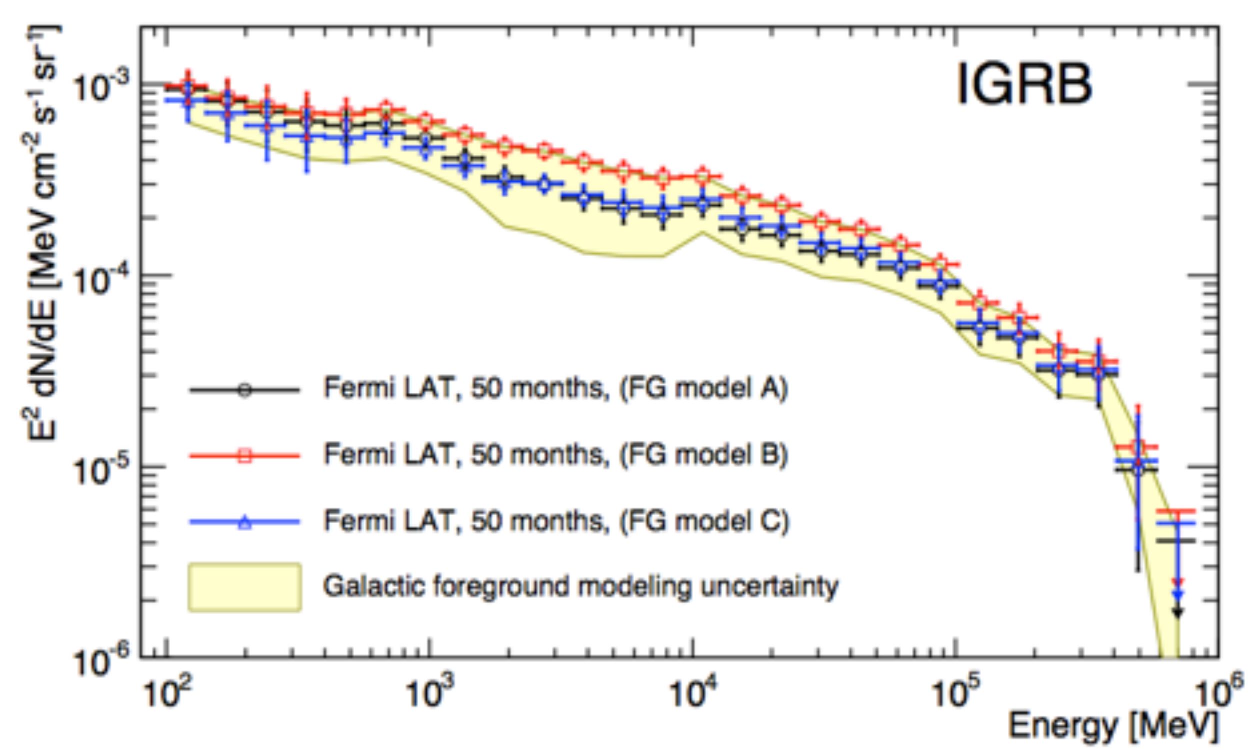
Giovanni Lamanna
LAPP - CNRS

FERMI-LAT IGRB AND EGB

- The Fermi Large Area Telescope provides a view of the entire gamma-ray sky from 10 MeV to 820 GeV.
- Galactic diffuse emission (GDE) produced via:
  -decay of π^0 produced in protons/interstellar gas collisions
  -Bremsstrahlung of relativistic electrons in gas and Inverse-Compton of relativistic electrons with ISRF.
- Solar emission and cosmic ray background
- 2FGL catalog resolved sources.

DATA
–
GDE
–
SUN + CR BACK
=
EGB
–
RESOLVED SOURCES
=
IGRB

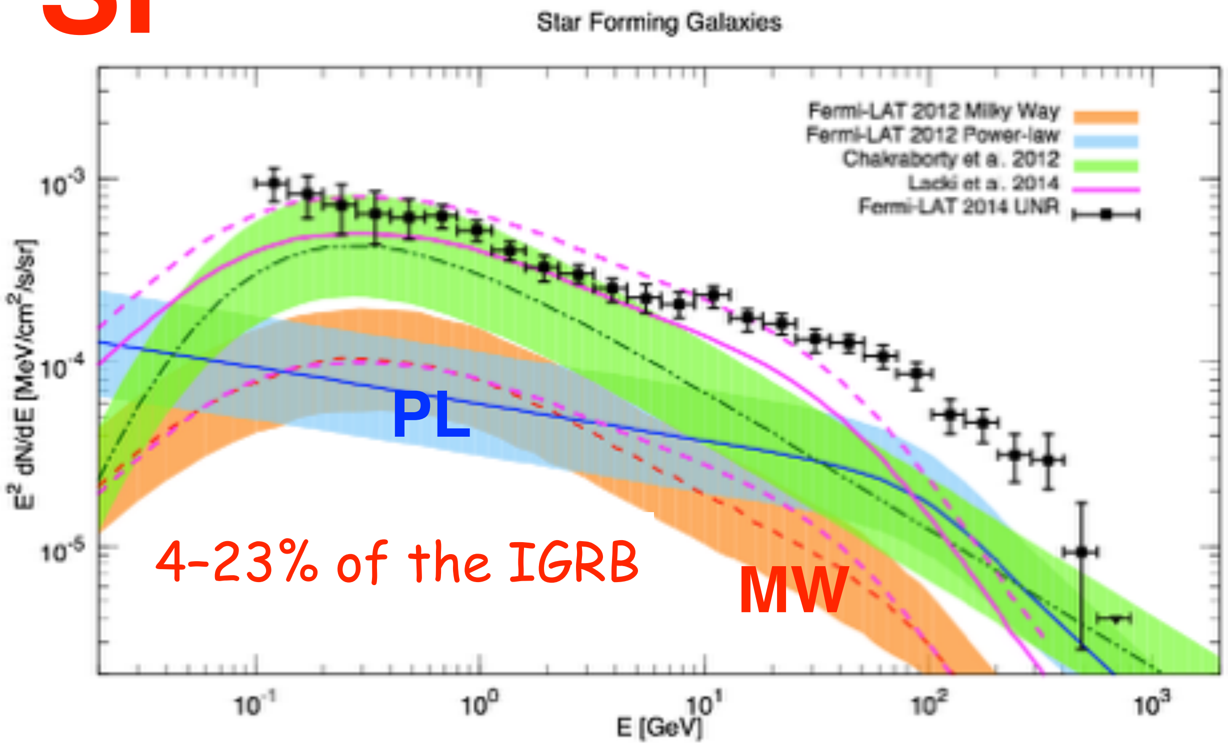




Ackermann et al. Arxiv 1410:3696 ApJ 2014

EXTRAGALACTIC GAMMA-RAY EMITTING POPULATIONS

SF

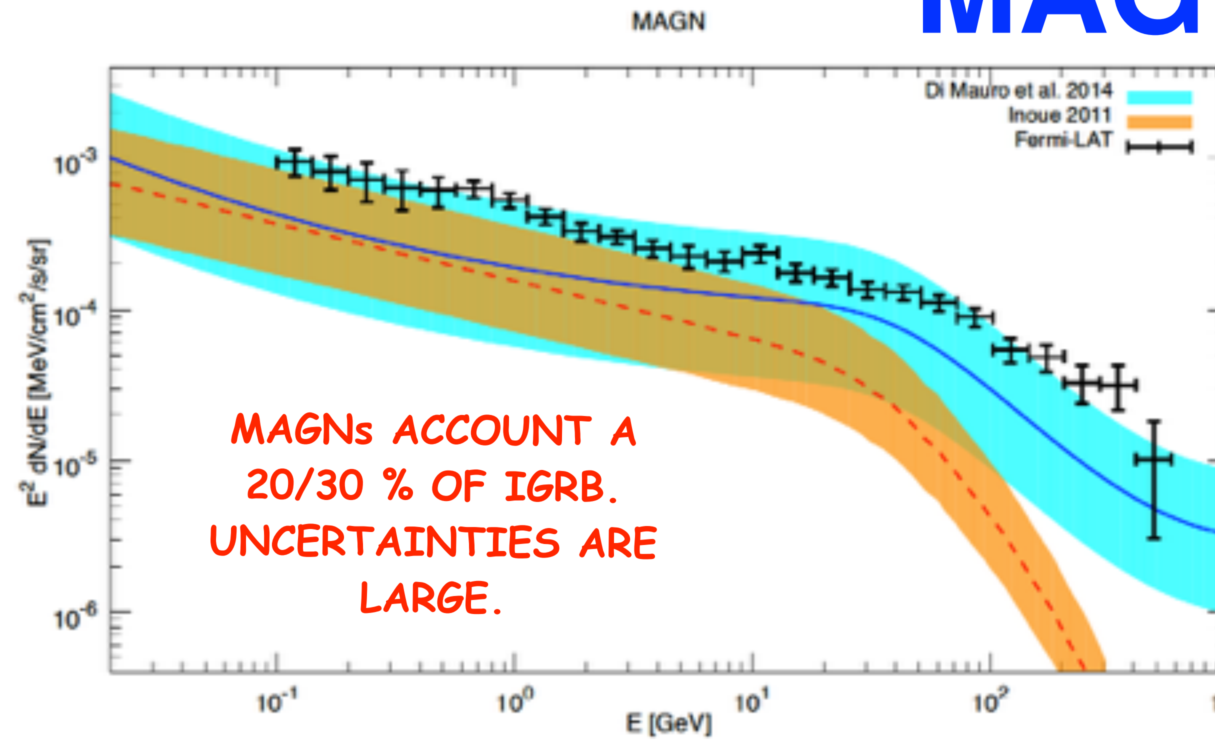


Ackermann et al. 2012 ApJ 755 164A

Hooper et al. 2013, Phys.Rev., D88, 083009

Lacki et al. 2011, ApJ, 734, 107

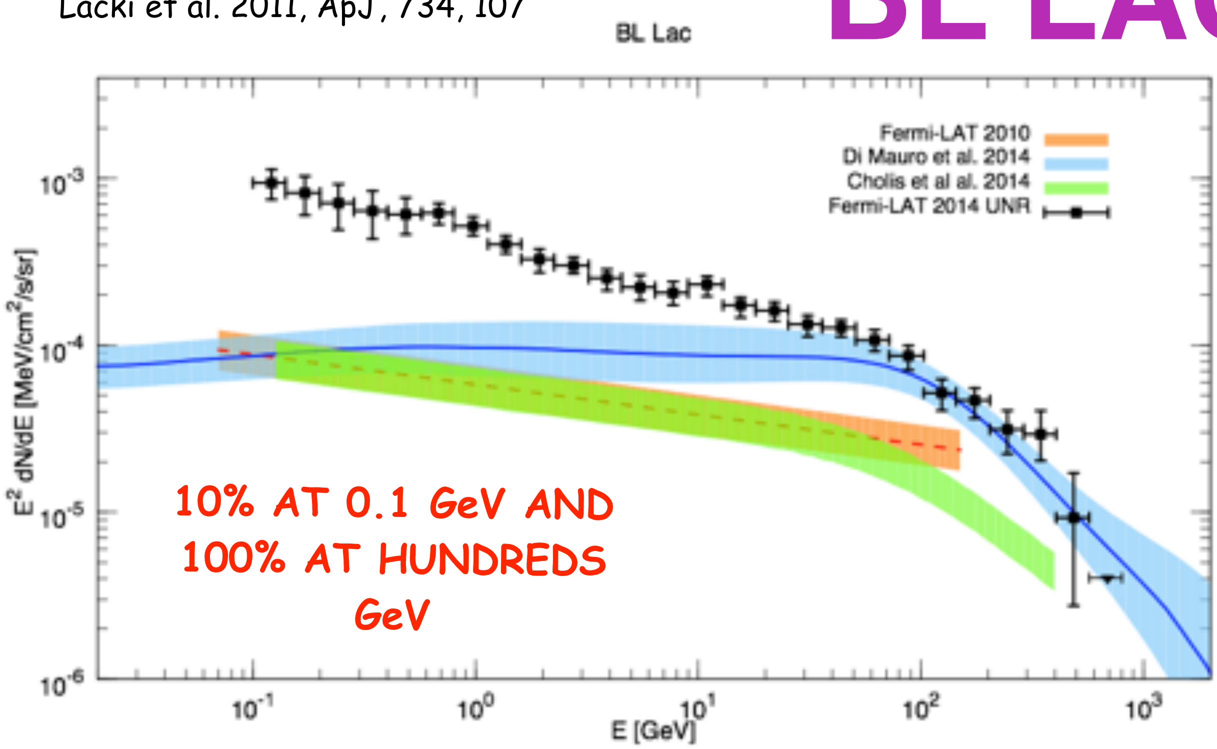
MAGN



M. Di Mauro et al. 2014 ApJ 780 161

Inoue 2011 ApJ 733 66I,

BL LAC



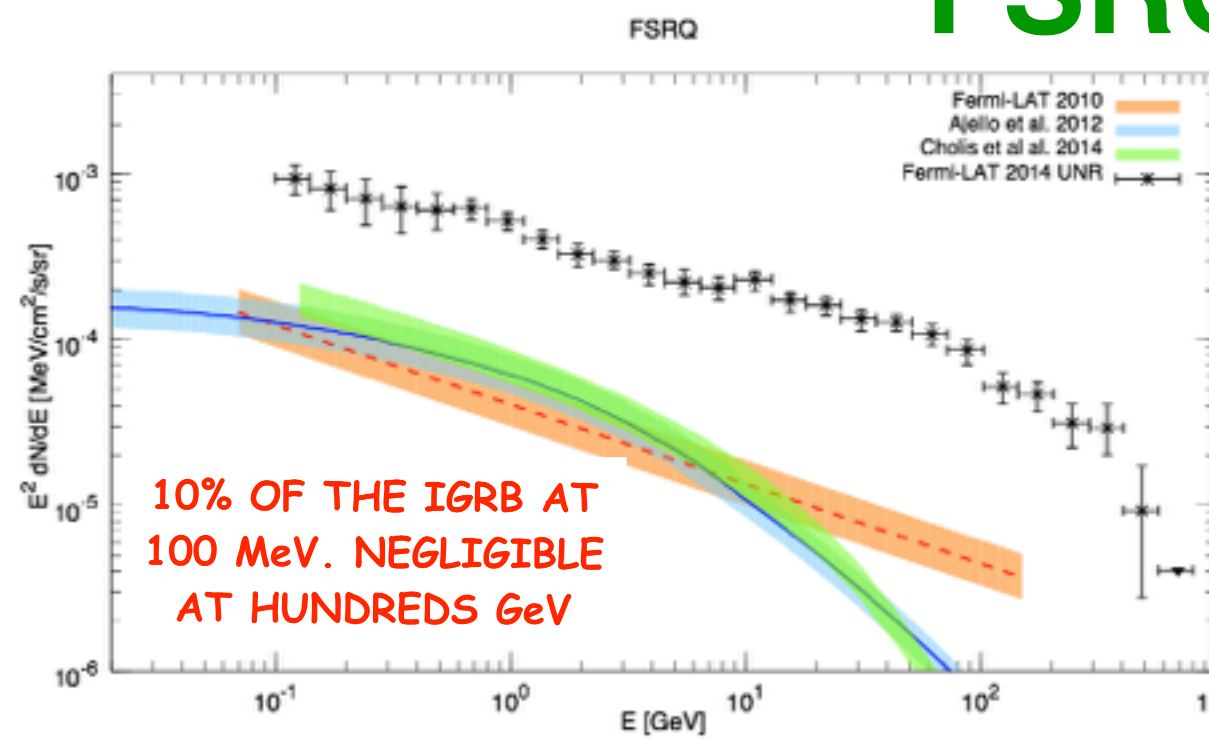
Di Mauro et al. 2014b,ApJ, 786, 129

Ajello et al. 2014 ApJ 780 73.

Hooper et al. 2013, Phys.Rev., D88, 083009

Abdo al. 2010, ApJL, 709, L152

FSRQ

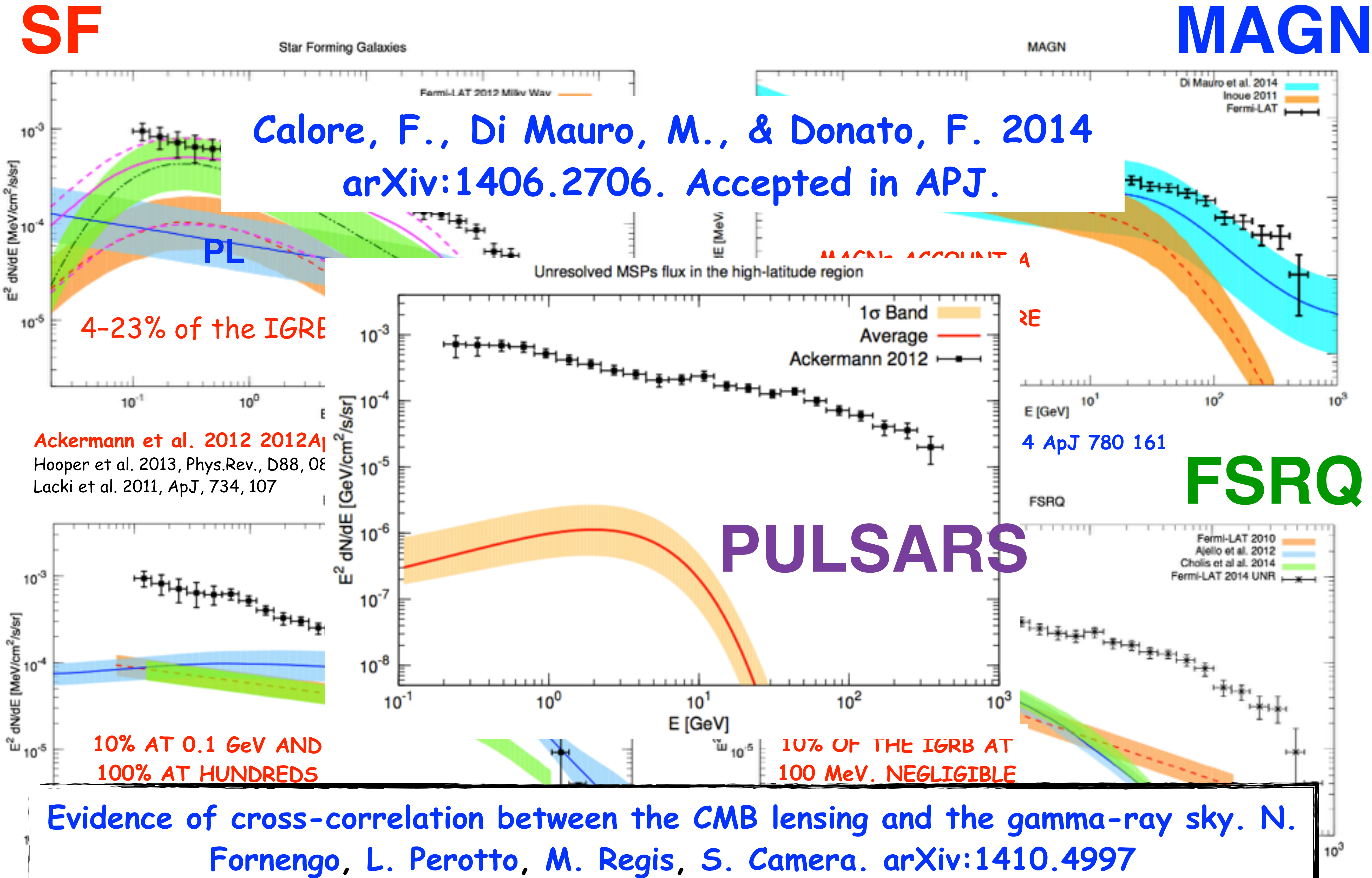


Ajello et al. 2012 ApJ 751,108.

Abdo al. 2010, ApJL, 709, L152

Hooper et al. 2013, Phys.Rev., D88, 083009

EXTRAGALACTIC GAMMA-RAY EMITTING POPULATIONS



Calore, F., Di Mauro, M., & Donato, F. 2014
arXiv:1406.2706. Accepted in APJ.

Evidence of cross-correlation between the CMB lensing and the gamma-ray sky. N. Fornengo, L. Perotto, M. Regis, S. Camera. arXiv:1410.4997

Ackermann et al. 2012 2012Ap
Hooper et al. 2013, Phys.Rev., D88, 08
Lacki et al. 2011, ApJ, 734, 107

4 ApJ 780 161

Ajello et al. 2014 ApJ 780 73.
Hooper et al. 2013, Phys.Rev., D88, 083009 Abdo al. 2010, ApJL, 709, L152

Ajello et al. 2012 ApJ 751,108.
Abdo al. 2010, ApJL, 709, L152
Hooper et al. 2013, Phys.Rev., D88, 083009

COMPOSITION OF THE EGB AND IGRB

Luminosity function

Fermi-LAT EFFICIENCY

$$\Phi(E_\gamma) = \int_{\Gamma_{\min}}^{\Gamma_{\max}} d\Gamma \int_{z_{\min}}^{z_{\max}} dz \int_{L_\gamma^{\min}}^{L_\gamma^{\max}} dL_\gamma \, \Theta_\gamma(z, \Gamma, L_\gamma) \frac{dF_\gamma}{dE} e^{-\tau_{\gamma\gamma}(E,z)} \Omega(F_\gamma)$$

EBL absorption

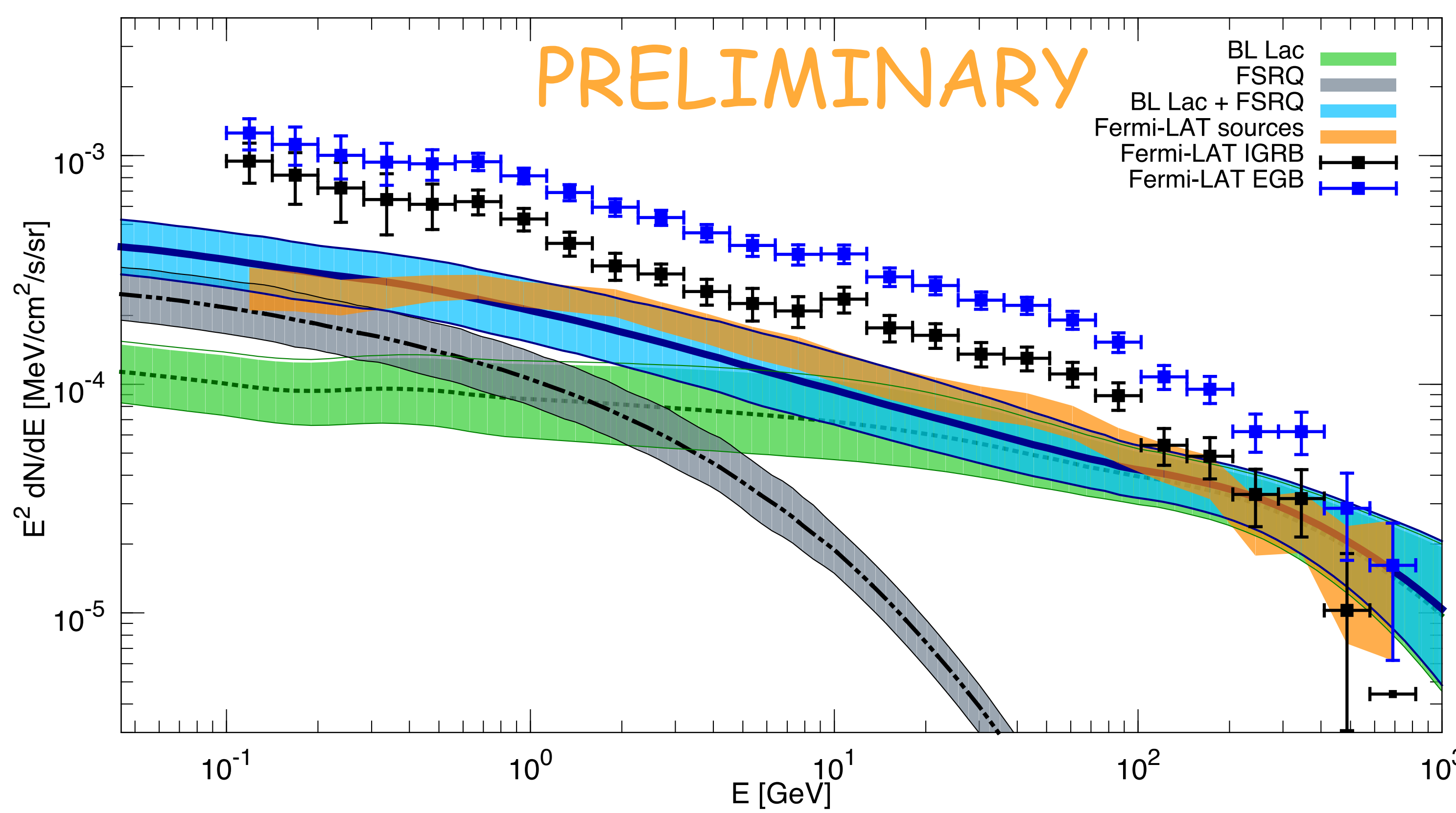
UNRESOLVED

$$\Omega(F_\gamma)_{\rm unr} = [1 - \omega(F_\gamma)]$$

TOTAL

$$\Omega(F_\gamma)_{\rm tot} = 1$$

Comparison of BL Lac and FSRQ resolved emission with Fermi-LAT sources



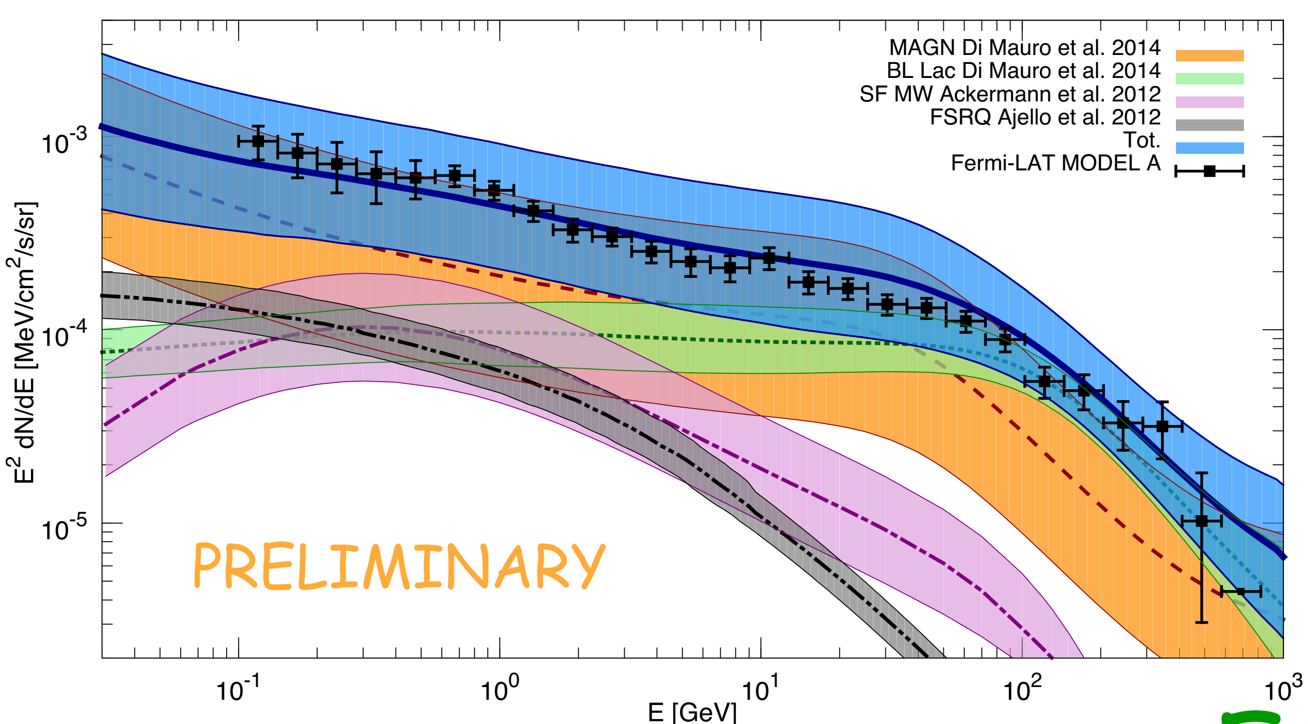
COMPOSITION OF IGRB AND EGB

MW SF

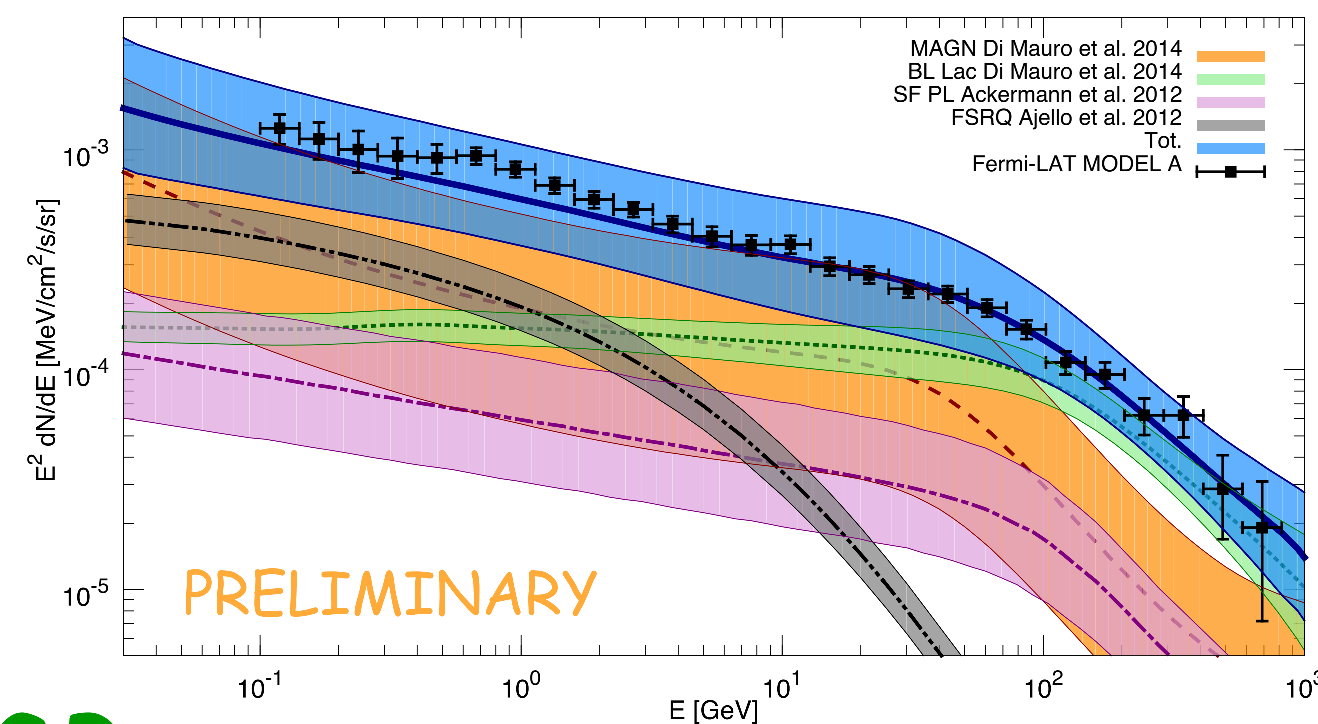
IGRB

PL SF

IGRB composition with MW SF model

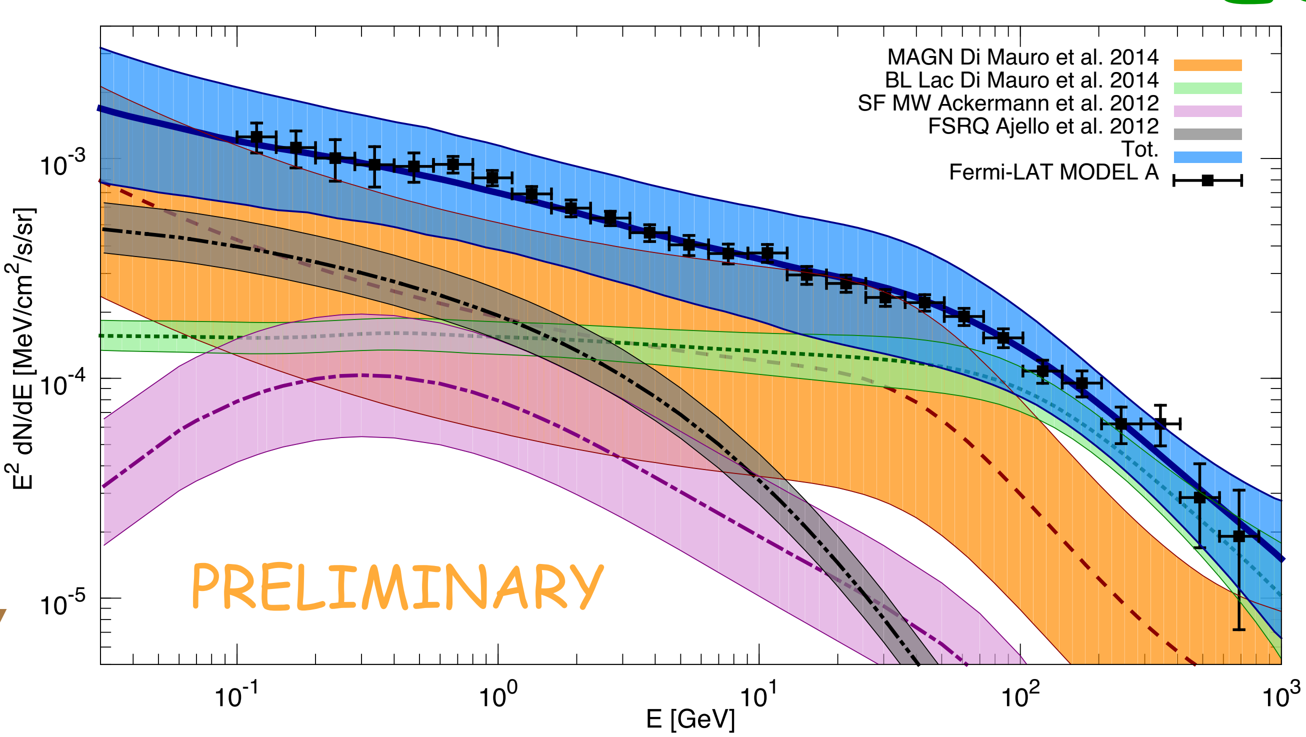


EGB composition with PL SF model

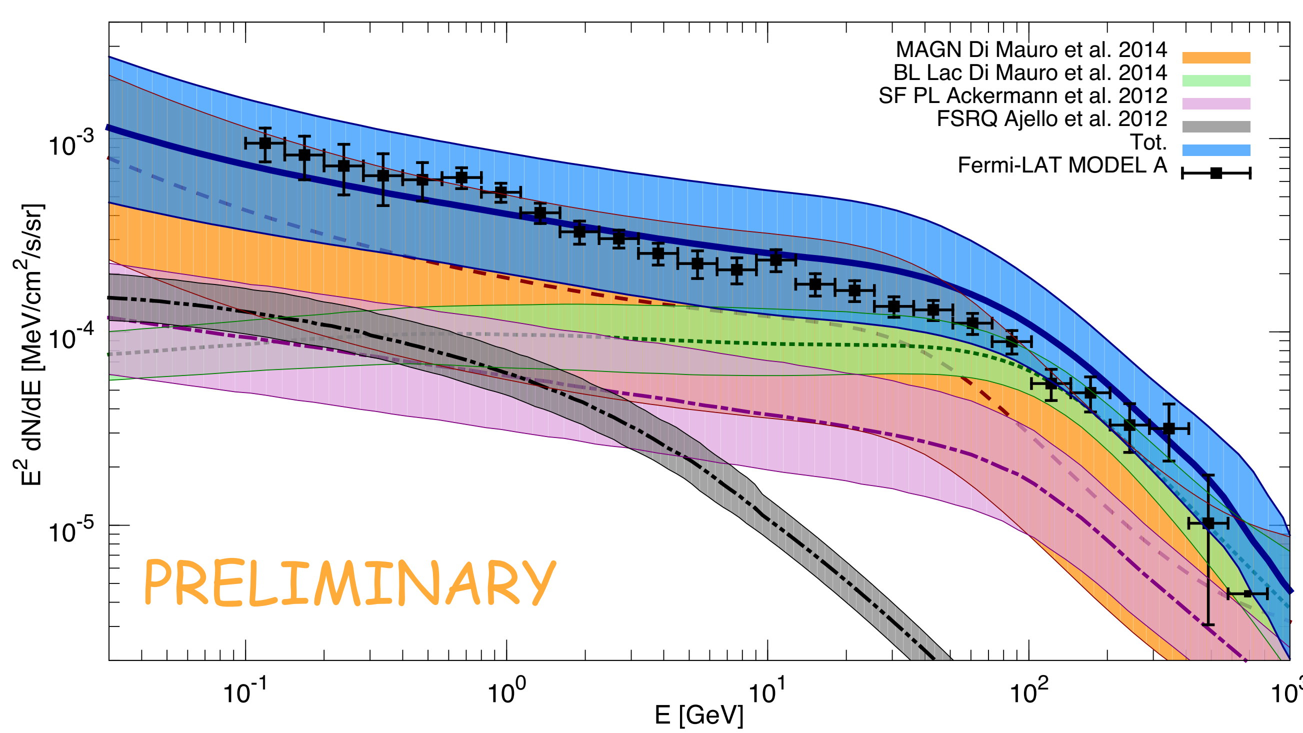


EGB

EGB composition with MW SF model



IGRB composition with PL SF model



FSRQ: Ajello et al. ApJ, 751, 108

SF: Ackermann et al. 2012, ApJ, 755, 164

MAGN: Di Mauro et al APJ, 780, 161

BL LAC: Di Mauro et al. APJ, 786, 129

FIT TO EGB AND IGRB: METHOD

F_j and σ_j are the average value and 1σ total **IGRB** and **EGB** error

Statistical chi-square on IGRB or EGB data (j=[1,.....N])

Chi-square associated to the uncertainties on the emission from AGN and SF.

$$\chi^2(\vec{\alpha}) = \sum_{j=1}^{N} \frac{(\mathcal{F}(\vec{\alpha}, E_j) - F_j)^2}{\sigma_j^2} + \sum_{i=1}^{M} \frac{(\alpha_i - \bar{\alpha}_i)^2}{\delta_i^2}$$

α_i are the index which are used to **model** the emission from AGN and SF:

1

- MAGN: normalization
- BL LAC and FSRQ: normalization
- SF: normalization

$\longrightarrow$

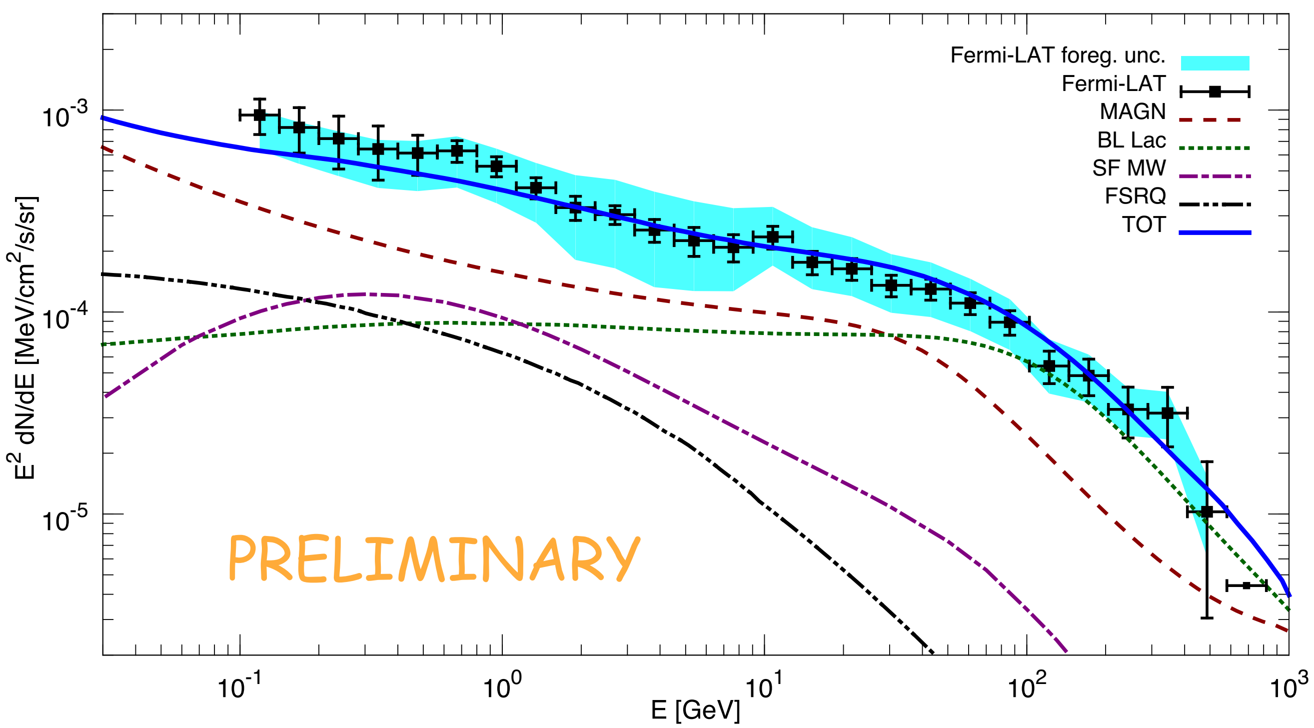
2

- MAGN: normalization and slope
- BL LAC and FSRQ: normalization and slope
- SF: normalization

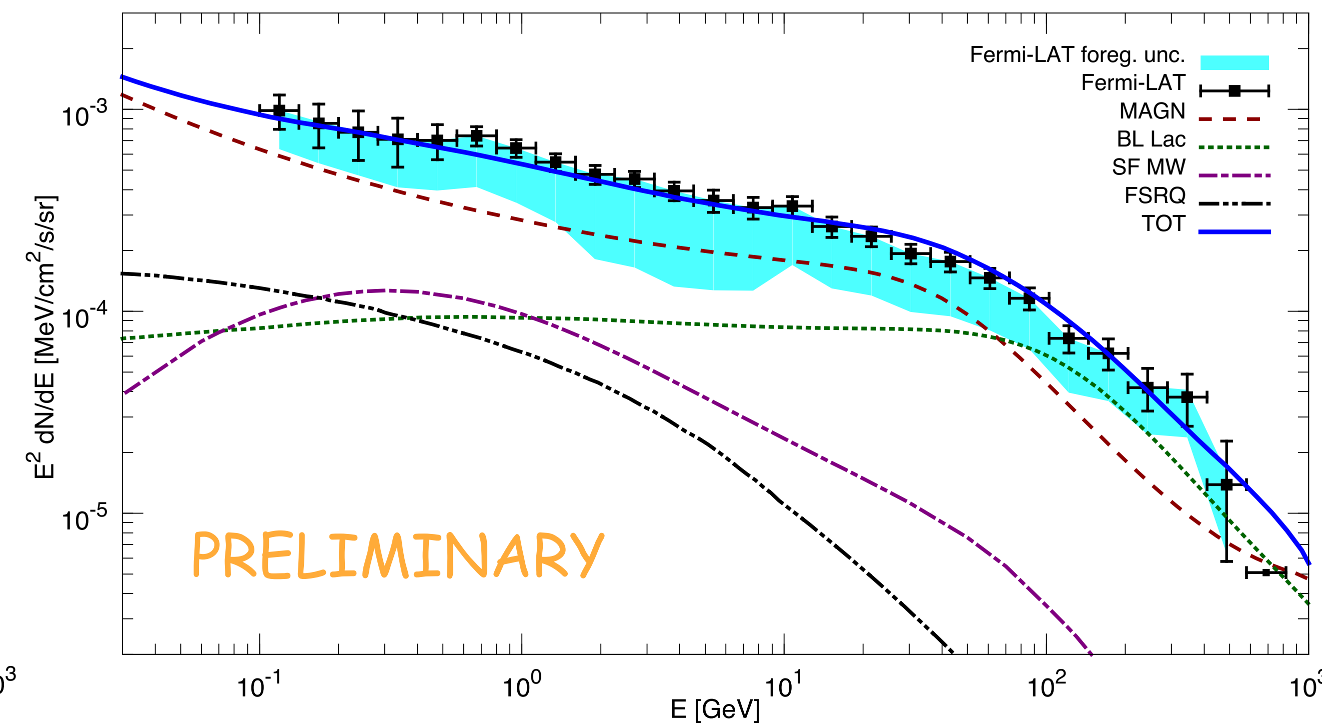
FIT TO IGRB

MW SF MODEL

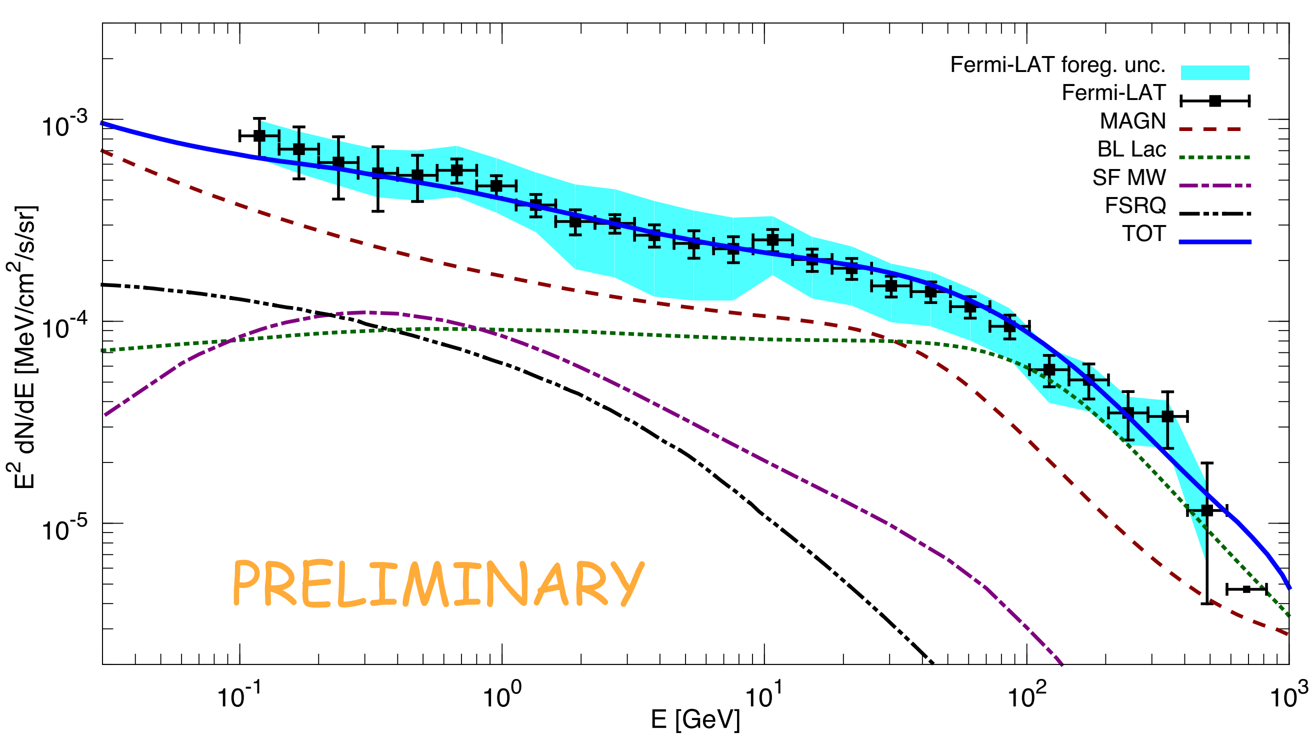
FIT TO FERMI-LAT IGRB MODEL A



FIT TO FERMI-LAT IGRB MODEL B



FIT TO FERMI-LAT IGRB MODEL C



MW model of SF

IGRB	BL LAC	FSRQ	MAGN	SF(MW)	χ^2_{IGRB}
MODEL A	0.90 ± 0.05	1.03 ± 0.06	0.83 ± 0.07	1.18 ± 0.17	34.4
MODEL B	0.96 ± 0.05	1.02 ± 0.06	1.49 ± 0.09	1.22 ± 0.17	26.5
MODEL C	0.94 ± 0.05	1.01 ± 0.06	0.88 ± 0.07	1.07 ± 0.17	16.4
IGRB	BL LAC	FSRQ	MAGN	SF(PL)	χ^2_{IGRB}
MODEL A	0.85 ± 0.05	1.04 ± 0.06	0.79 ± 0.08	0.94 ± 0.09	64.1
MODEL B	0.91 ± 0.05	1.04 ± 0.06	1.44 ± 0.09	0.98 ± 0.09	45.9
MODEL C	0.88 ± 0.05	1.02 ± 0.06	0.83 ± 0.07	0.95 ± 0.09	33.3

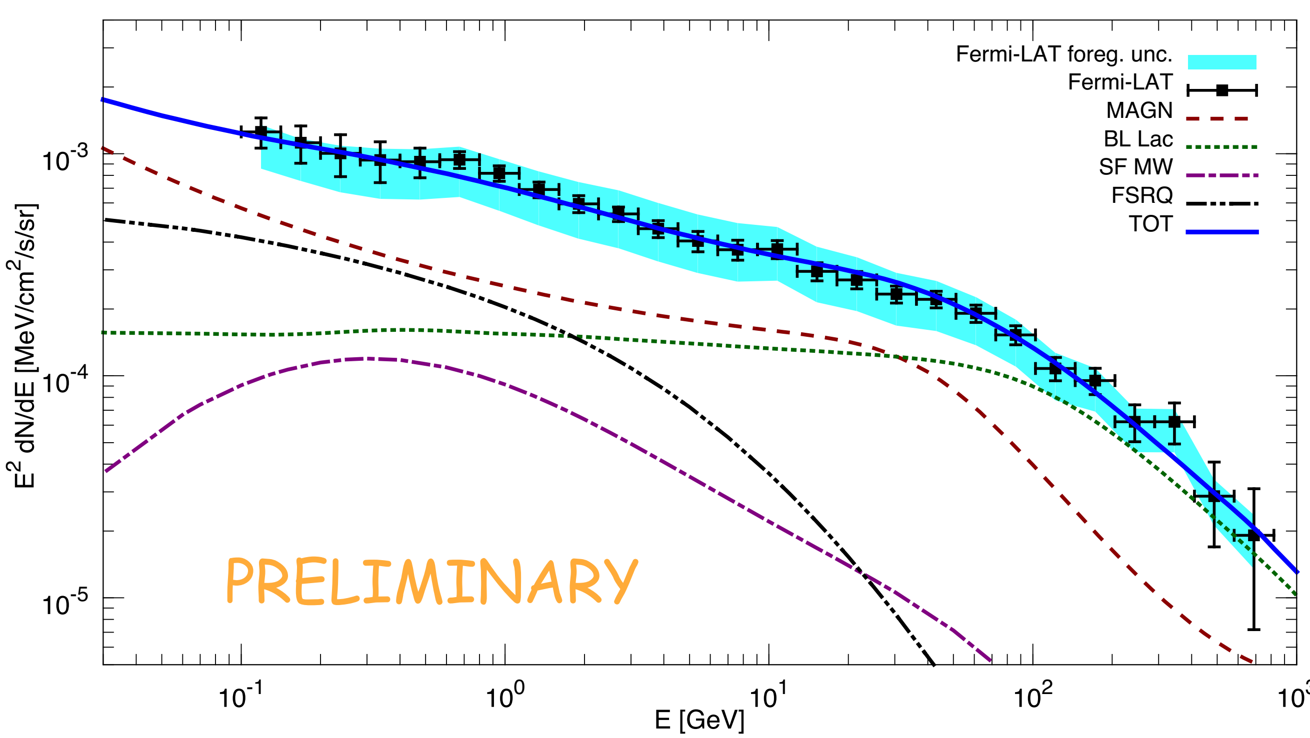
PL model of SF

Renormalization factors

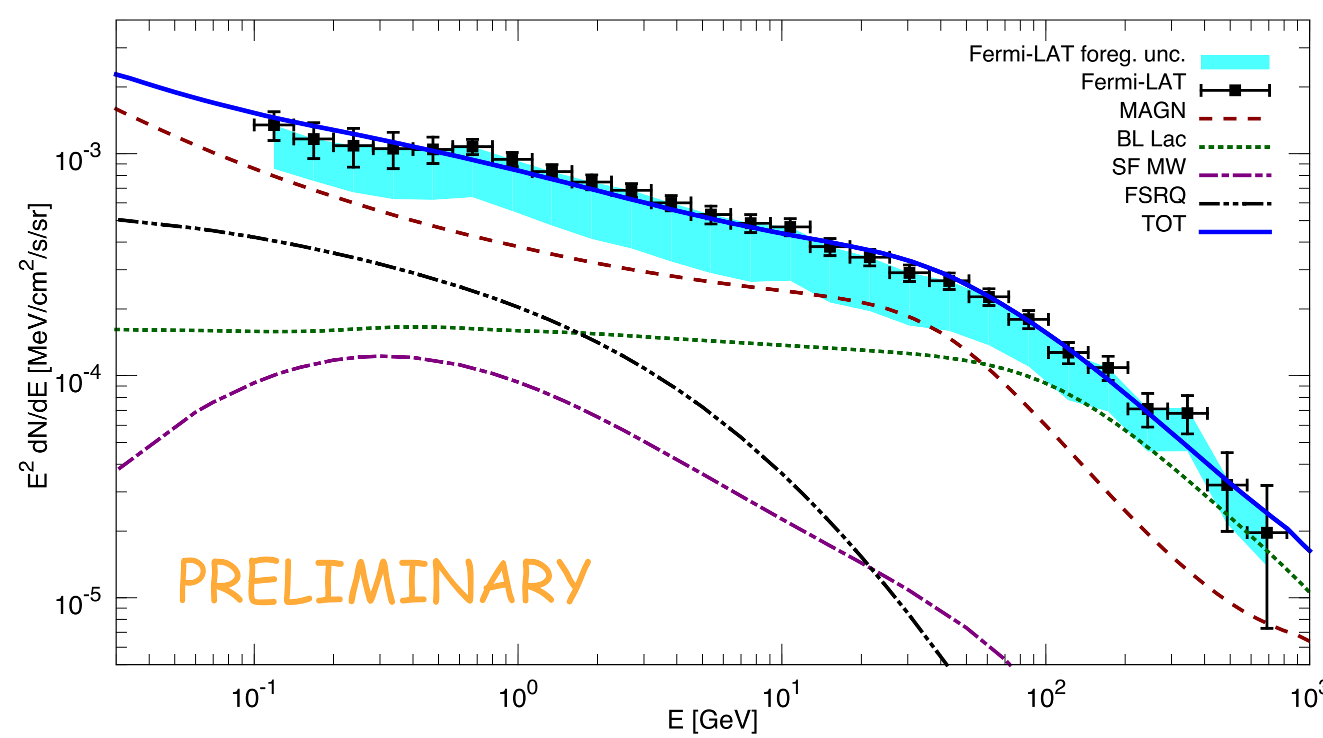
FIT TO EGB

MW SF MODEL

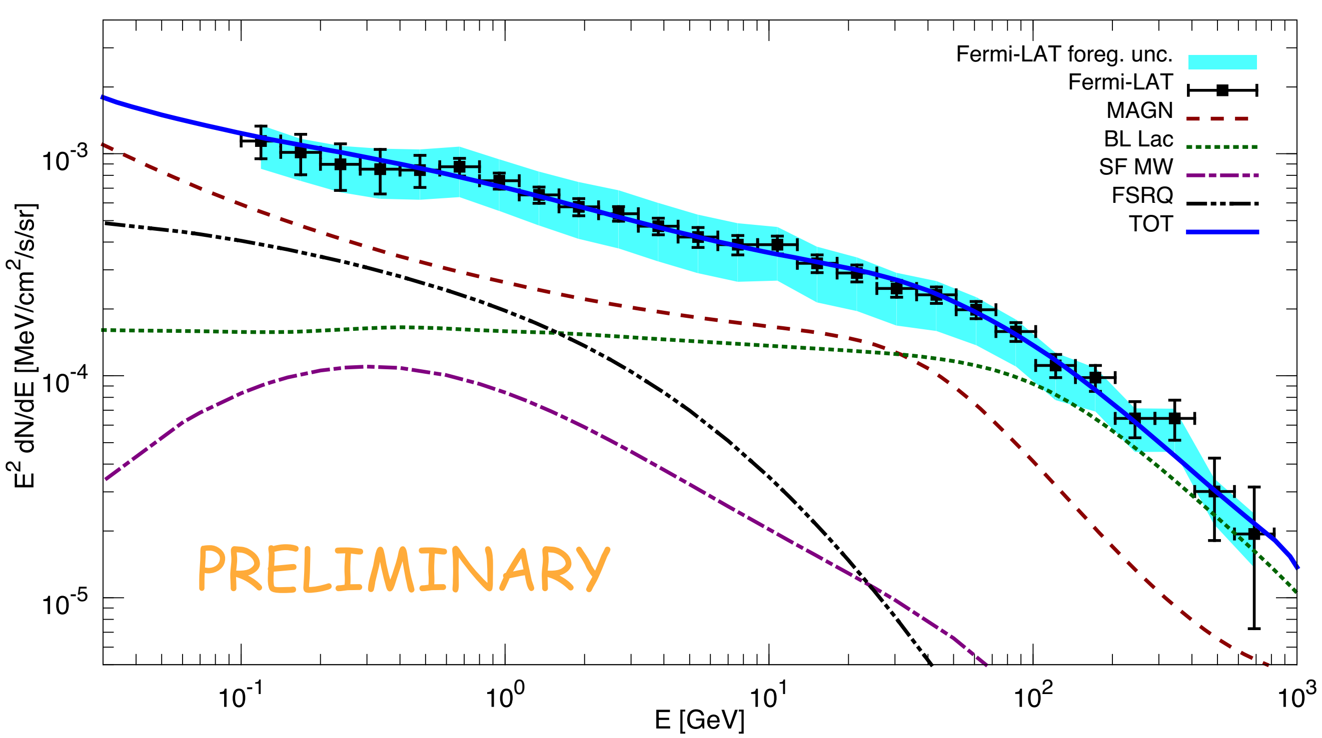
FIT TO FERMI-LAT EGB MODEL A



FIT TO FERMI-LAT EGB MODEL B



FIT TO FERMI-LAT EGB MODEL C



MW model of SF

EGB	BL LAC	FSRQ	MAGN	SF(MW)	χ^2_{IGRB}
MODEL A	1.00 ± 0.05	1.06 ± 0.06	1.33 ± 0.10	1.15 ± 0.17	20.0
MODEL B	1.03 ± 0.05	1.06 ± 0.06	2.00 ± 0.11	1.18 ± 0.17	33.0
MODEL C	1.03 ± 0.05	1.02 ± 0.06	1.38 ± 0.10	1.06 ± 0.17	12.6
EGB	BL LAC	FSRQ	MAGN	SF(PL)	χ^2_{IGRB}
MODEL A	0.97 ± 0.04	1.09 ± 0.06	1.26 ± 0.09	1.00 ± 0.09	29.6
MODEL B	0.99 ± 0.04	1.09 ± 0.06	1.94 ± 0.11	1.07 ± 0.17	38.4
MODEL C	1.03 ± 0.04	1.05 ± 0.06	1.31 ± 0.10	1.01 ± 0.17	16.1

PL model of SF

Renormalization factors near to 1

CONCLUSIONS OF THE IGRB AND EGB COMPOSITION IN TERM OF AGN+SF

EMISSION FROM AGN AND SF **COMPATIBLE** WITH BOTH IGRB AND THE EGB.

THE FIT TAKES INTO ACCOUNT BOTH THE FERMI-LAT DATA ERRORS AND THE UNCERTAINTIES OF AGN AND SF EMISSION MODELS.

ONLY NORMALIZATIONS

ALSO SLOPES

$\tilde{\chi}^2$	IGRB (MW)	EGB (MW)	IGRB (PL)	EGB (PL)
MODEL A	1.72; 1.56	0.95; 1.02	3.20; 2.54	1.41; 1.36
MODEL B	1.33; 1.32	1.57; 1.72	2.30; 1.96	1.83; 2.06
MODEL C	0.82; 0.84	0.60; 0.60	1.67; 0.95	0.77; 0.84

FOR THE THREE GALACTIC FOREGROUND MODELS AND FOR BOTH THE FIT ON THE IGRB AND EGB THE MW MODEL OF SF GIVES THE BETTER FITS.

FOR BOTH THE SF MODELS AND FOR BOTH THE FIT ON THE IGRB AND EGB THE **MODEL C** GIVES THE BETTER FITS.

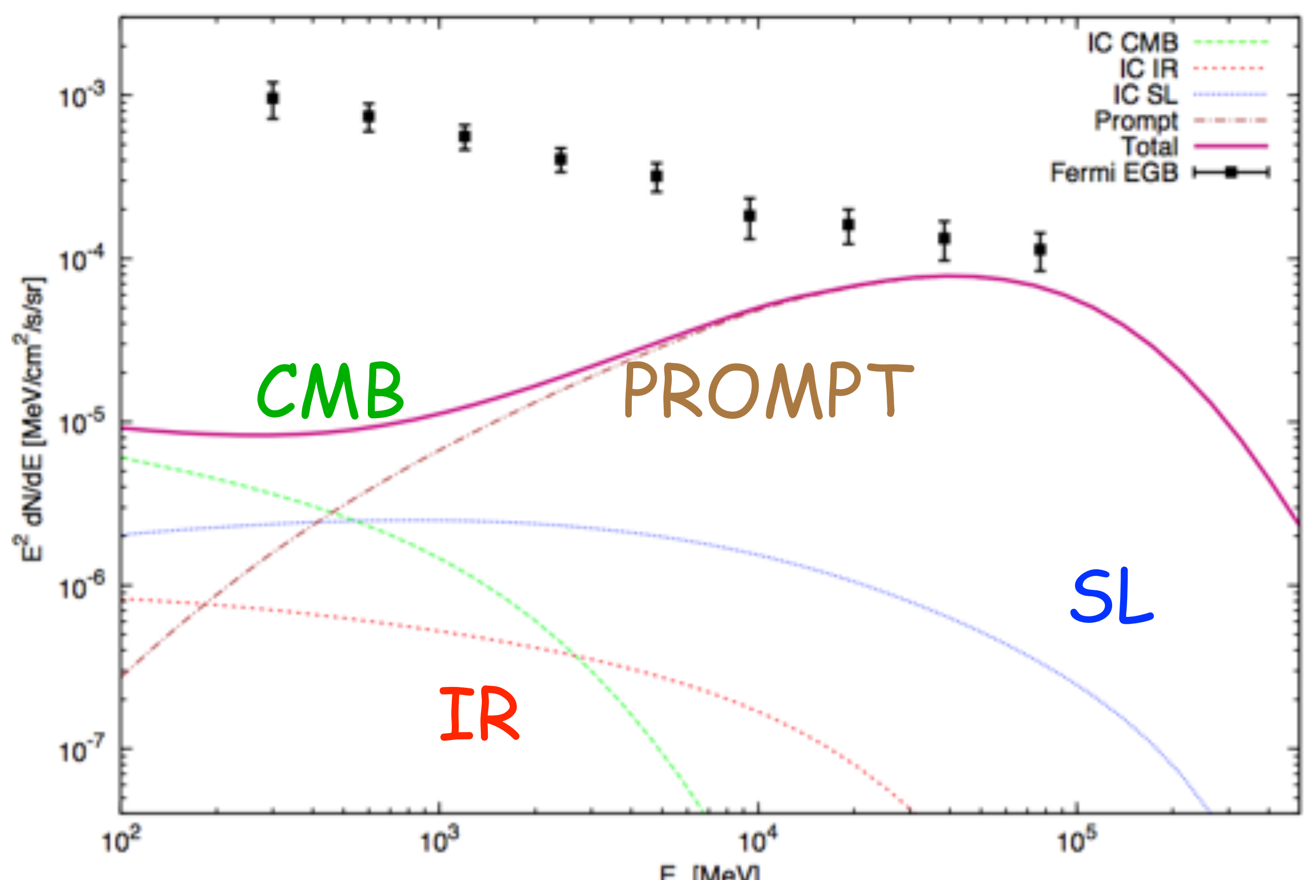
THERE IS A SIGNIFICANT DEPENDENCE OF THE RESULTS WITH RESPECT TO THE GALACTIC FOREGROUND MODEL CONSIDERED IN THE ANALYSIS

γ-RAYS FROM GALACTIC DARK MATTER MAIN GALACTIC HALO

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

- dN/dE_γ: photon spectrum from Prompt and Inverse Compton (IC) emission.
- $I(\psi)$: geometrical factor for Einasto profile. $I(\psi) = \int_{l.o.s.} \rho^2(r(\lambda,\psi))d\lambda$
- $\langle\sigma v\rangle$: annihilation DM cross section.
- M_X: DM mass
- $\rho_\odot$: local DM density: 0.4 GeV/cm^3.
- $r_\odot$ Sun-Earth distance: 8.33 kpc

bb channel $\langle\sigma v\rangle$ = 2 10^{-24} cm^3/s M_X = 1 TeV

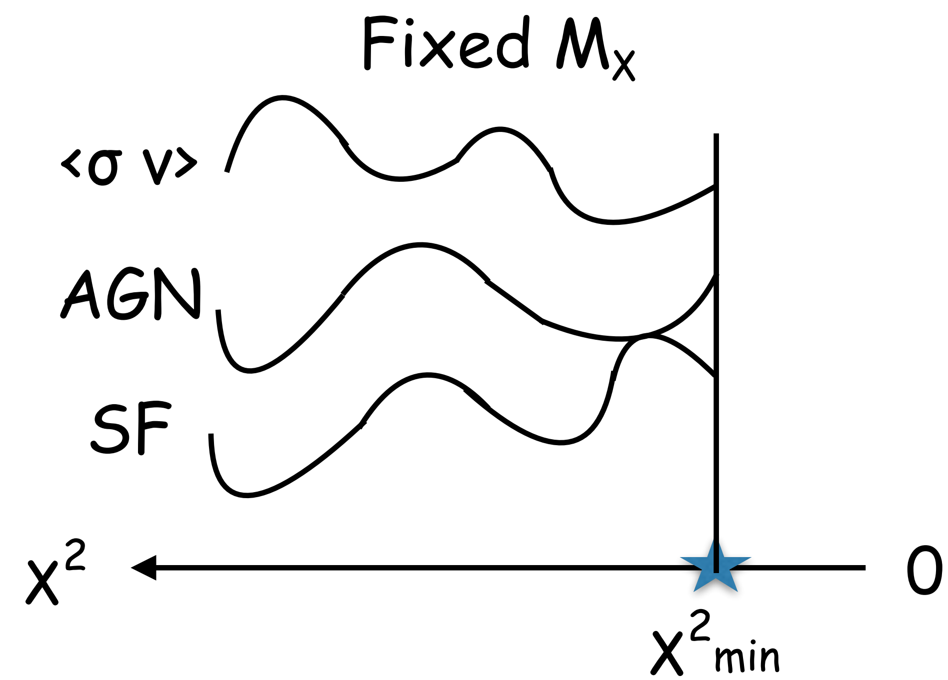


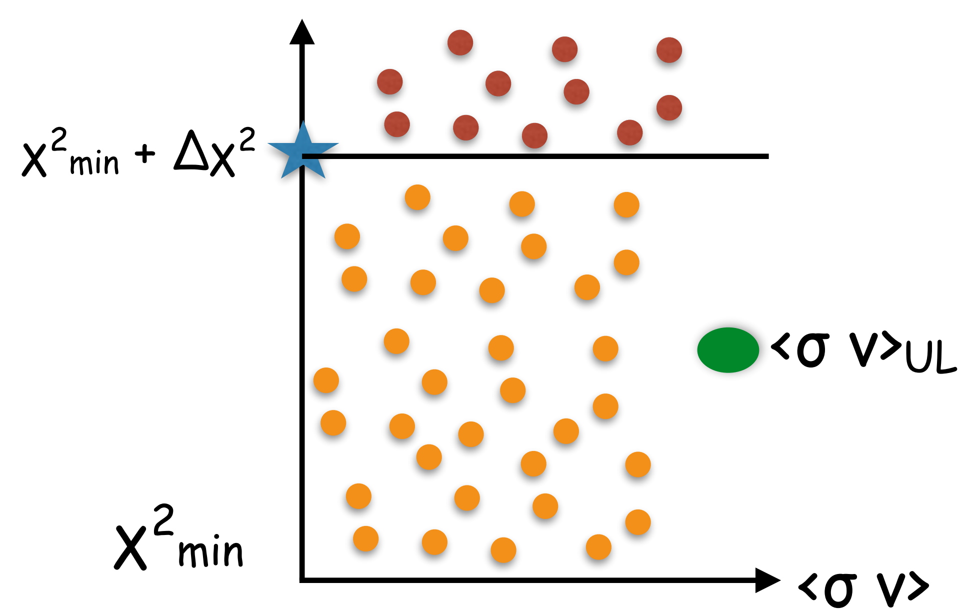
H. Bengtsson, P. Salati, and J. Silk, Nuclear Phys. B 346, 129 (1990).
L. Bergstrom, P. Ullio, and J. H. Buckley, Astropart. Phys. **9**, 137 (1998), 9712318.
A. Bottino, F. Donato, N. Fornengo, and S. Scopel, Phys. Rev. D 70, 015005 (2004), 0401186.
Cirelli et al. 2011 JCAP 1103:051,2011

METHOD TO FIND DM ULS

$$\chi^2(\alpha_{k,i}) = \sum_{k=1}^{4}\sum_{i}\frac{(\alpha_{k,i}-\beta_{k,i})^2}{\sigma_{k,i}^2} + \sum_{j=1}^{N}\frac{(\mathcal{F}(\alpha_{k,j},E_j)-F_j)^2}{\sigma_j^2}$$

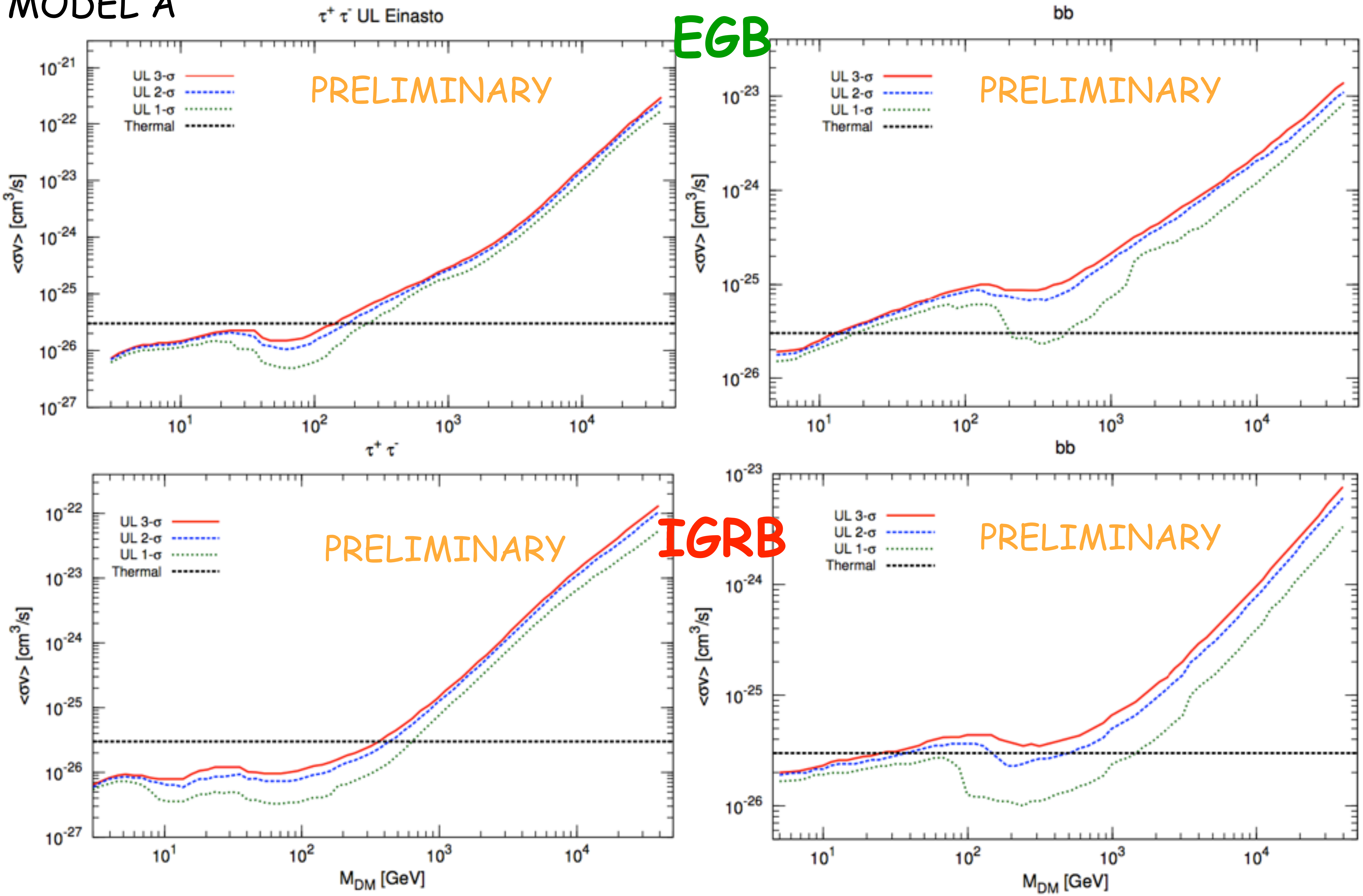
- Using the same chi-square function we vary the parameters of emission from AGN and SF for different values of the DM mass.
- For each mass I derive the best fit configuration associated to a minimum chi-square χ^2_{min}.
- I consider all the configurations with a $\chi^2 \leq \chi^2_{min} + \Delta\chi^2$, where $\Delta\chi^2$ is associated to 1 d.o.f. (the annihilation cross section of DM).
- the UL on <σ v> is the largest value in this sample of configurations.



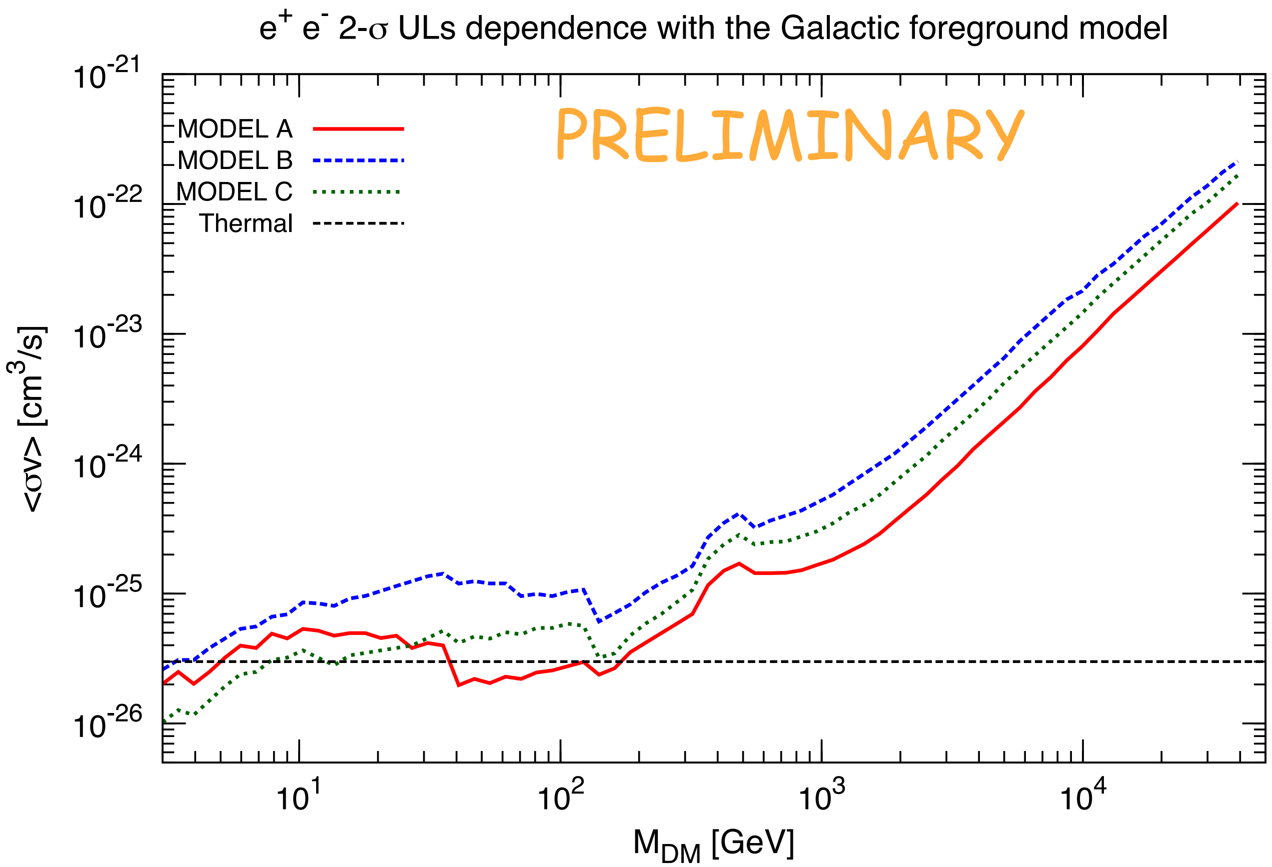


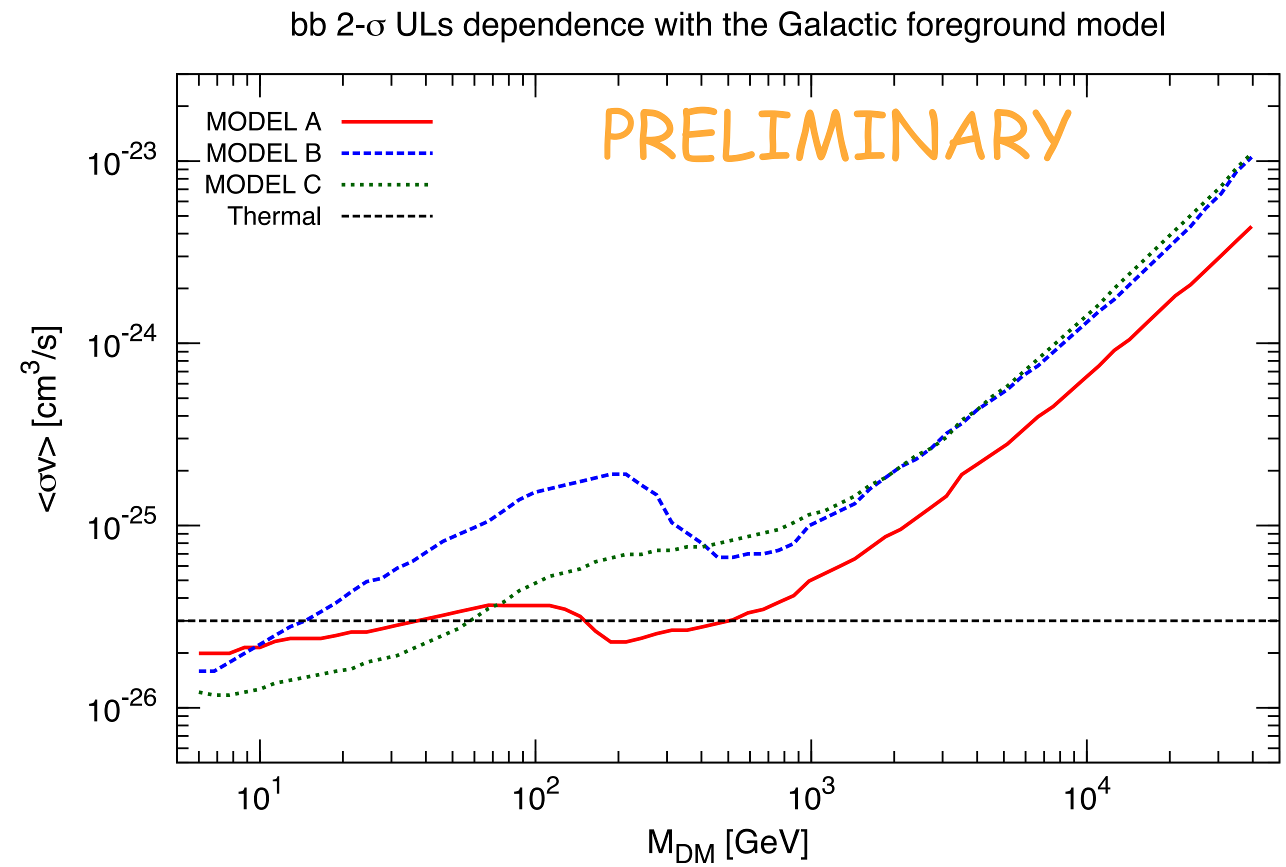
DM UPPER LIMITS USING IGRB AND EGB

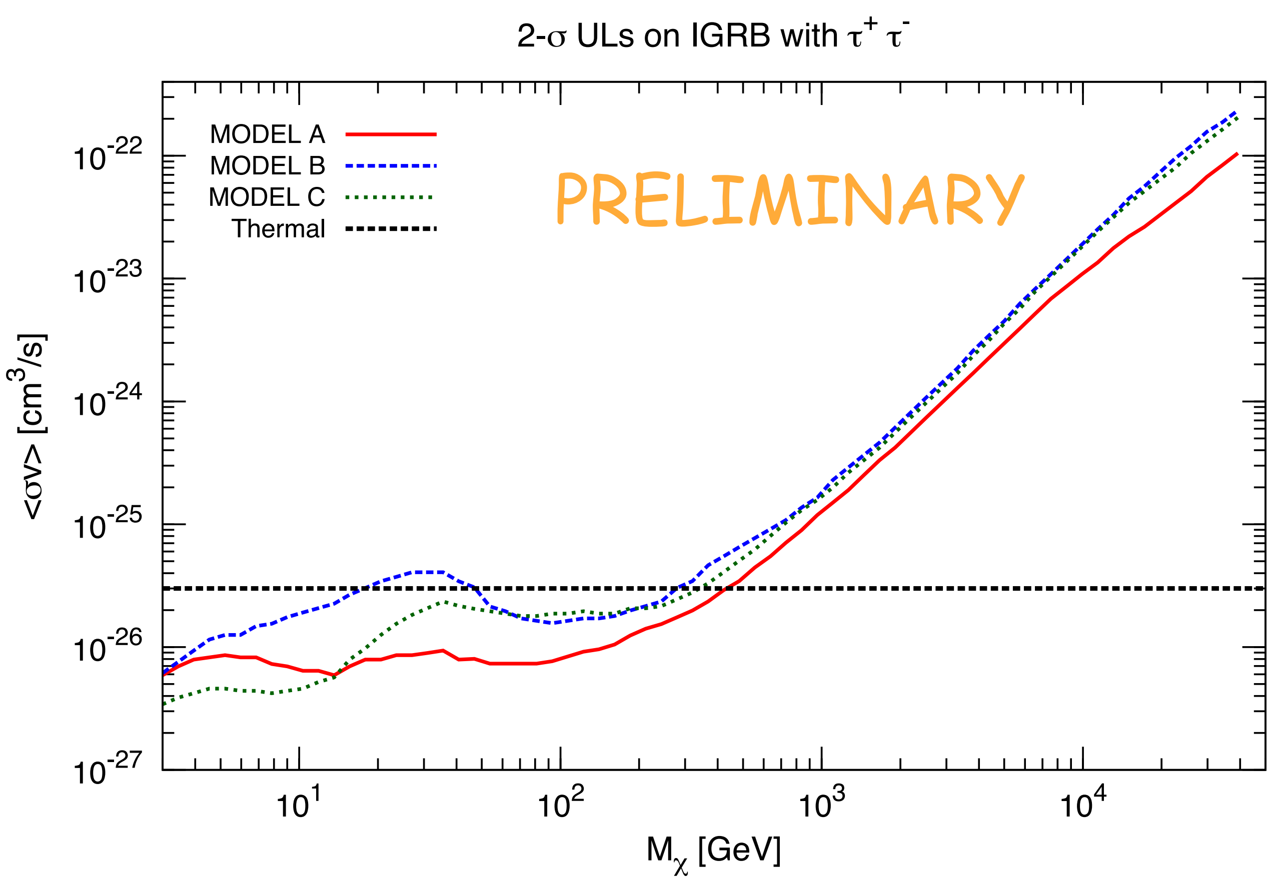
MODEL A



UNCERTAINTIES OF UL RESPECT TO THE GALACTIC FOREGROUND MODEL



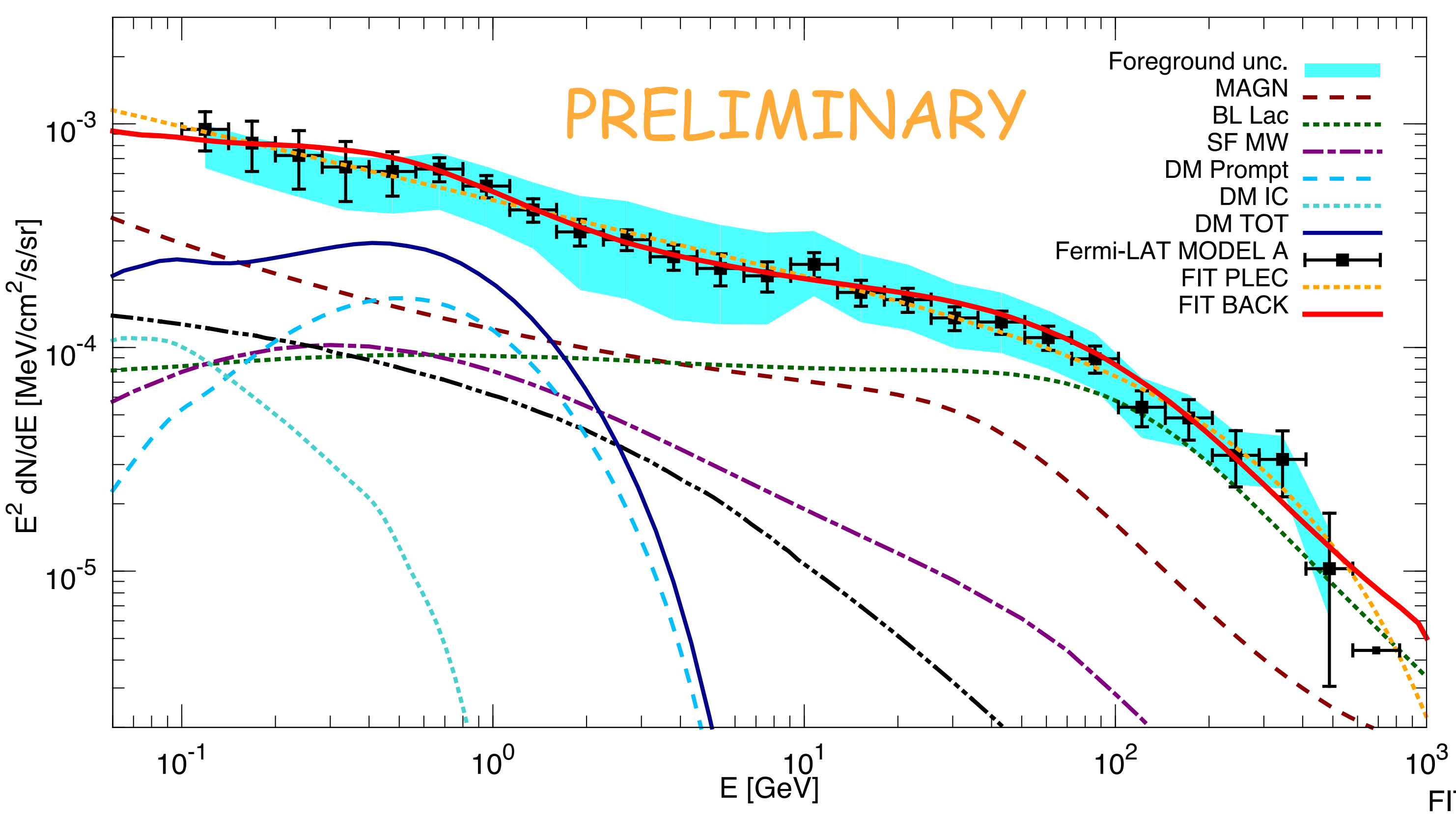




THE ULs NORMALIZATION AND SHAPE CHANGE NOT NEGLIGIBLY CHANGING THE THREE MODELS FOR THE GALACTIC FOREGROUND.

BEST FIT WITH BB FROM DM

FIT TO FERMI-LAT IGRB WITH MW SF MODEL, AGN and with DM bb channel



IGRB

$M_X = 8.2 \pm 2.3$ GeV

$\langle \sigma v \rangle = (1.4 \pm 0.3)\ 10^{-26}\ cm^3/s$

$\chi^2 = 15.5$, $\Delta\chi_{BACK\text{-}DM}{}^2 = 18.9$

FIT TO FERMI-LAT EGB WITH MW SF MODEL, AGN and with DM bb channel

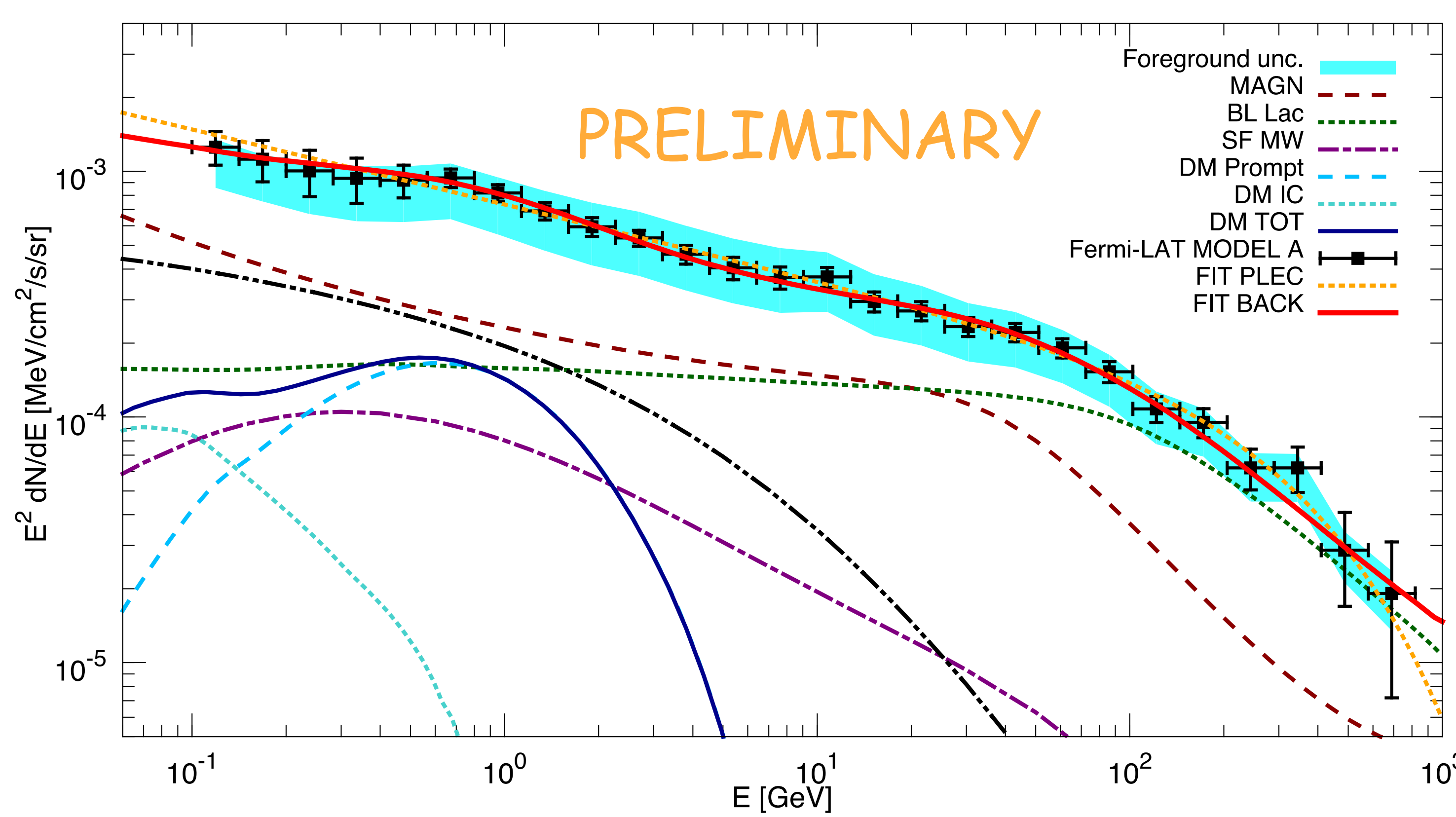
EGB

$M_X = 10.6 \pm 3.1$ GeV

$\langle \sigma v \rangle = (1.6 \pm 0.4)\ 10^{-26}\ cm^3/s$

$\chi^2 = 8.3$, $\Delta\chi_{BACK\text{-}DM}{}^2 = 11.7$

MODEL A



BEST FIT WITH BB FROM DM

FIT TO FERMI-LAT IGRB WITH MW SF MODEL, AGN and with DM bb channel

NOT POSSIBLE TO CONVERT THE $\Delta\chi^2_{BACK-DM}$ IN SIGNIFICANCE OF DARK MATTER

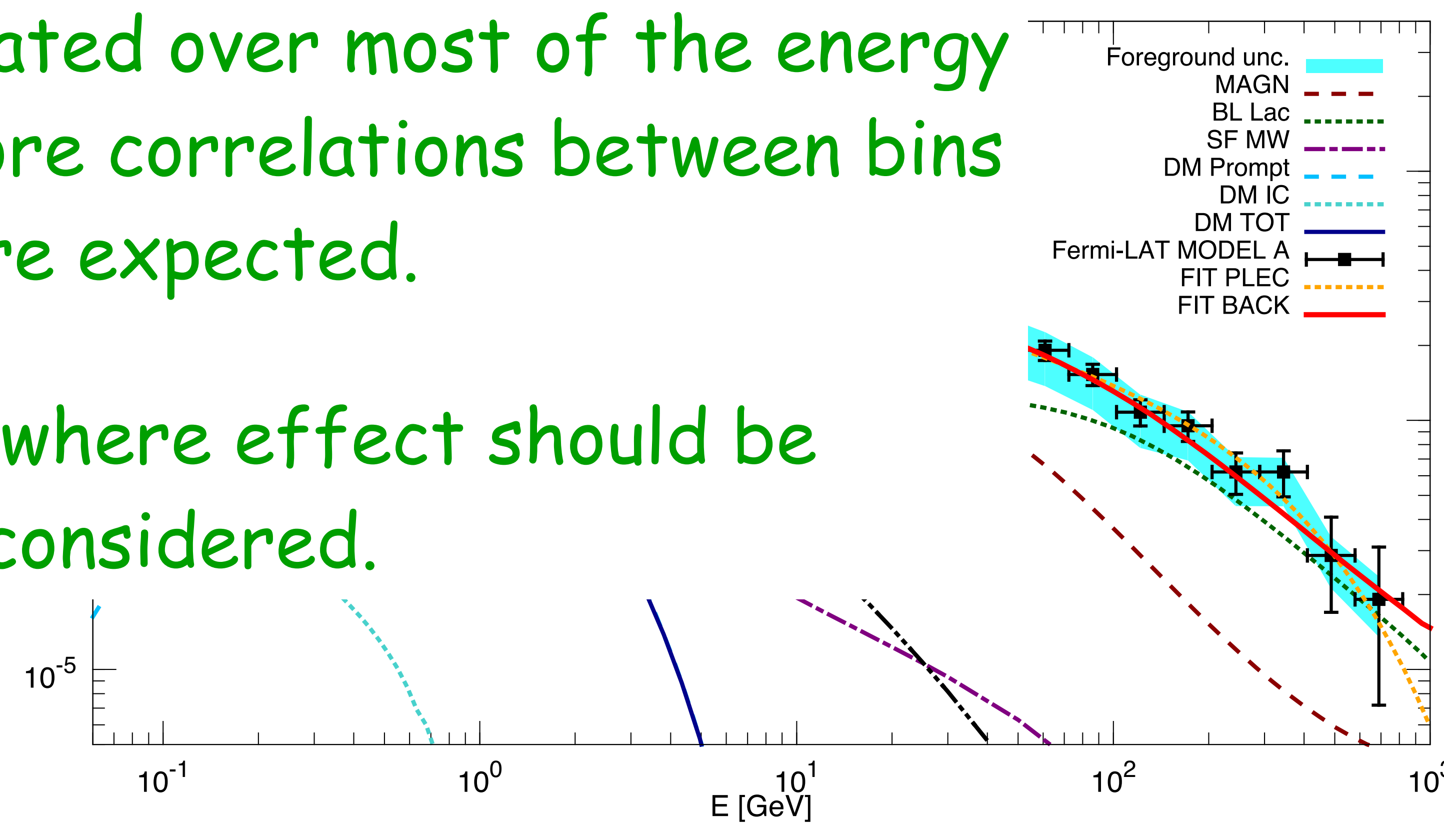
$\langle\sigma v\rangle = (1.4 \pm 0.3)\ 10^{-26}\ cm^3/s$

$\chi^2 = 15.5,\ \Delta\chi_{BACK-DM}{}^2 = 18.9$

1) The error bars of the IGRB spectrum are systematics dominated over most of the energy range, and therefore correlations between bins are expected.

2) The look elsewhere effect should be considered.

vith DM bb channel



M

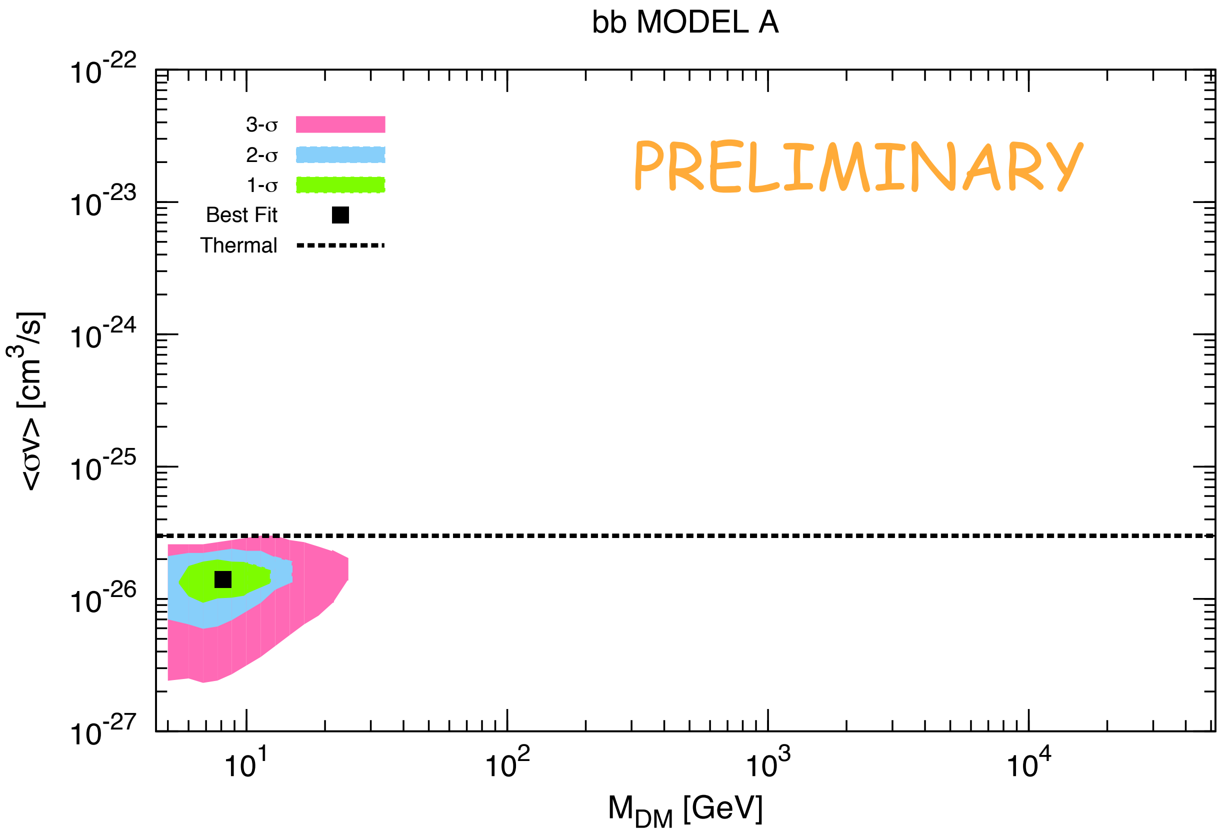
$\langle\sigma v\rangle$ =

χ^2 =

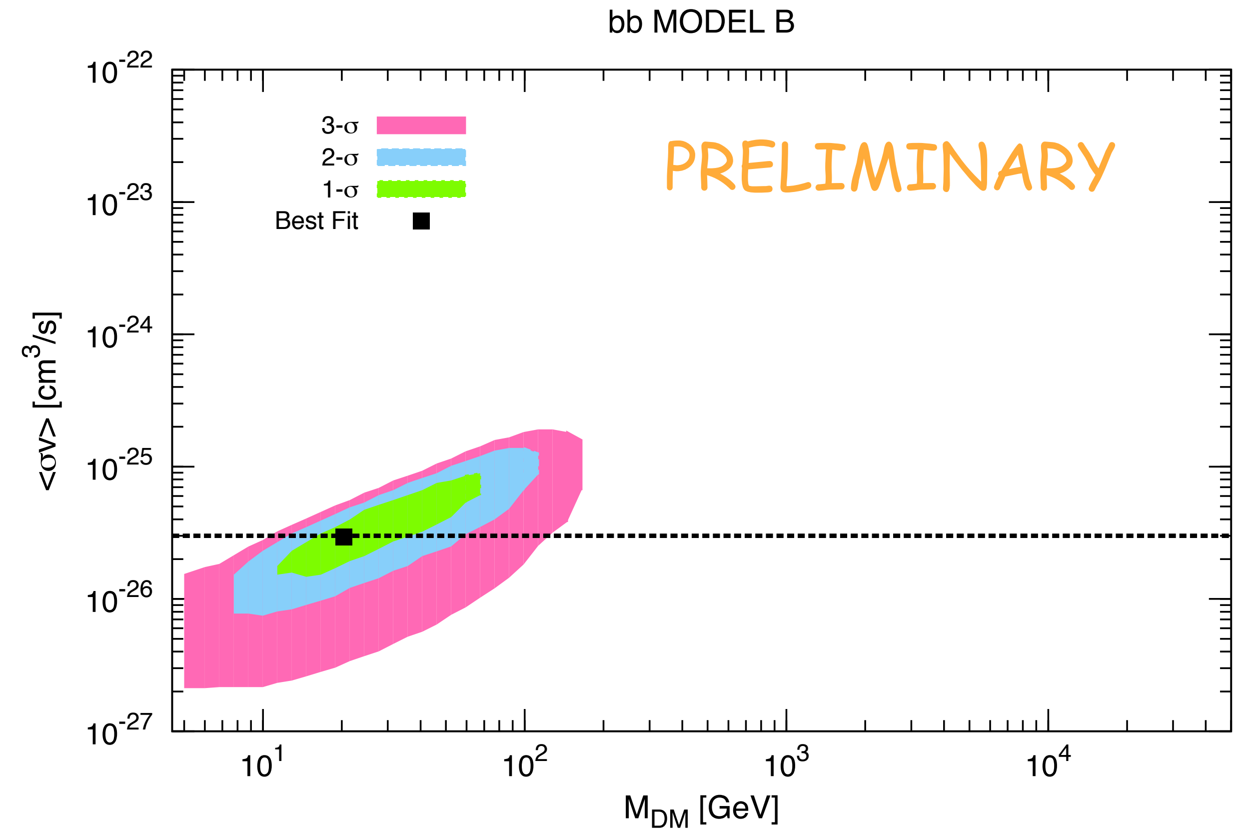
MODEL A

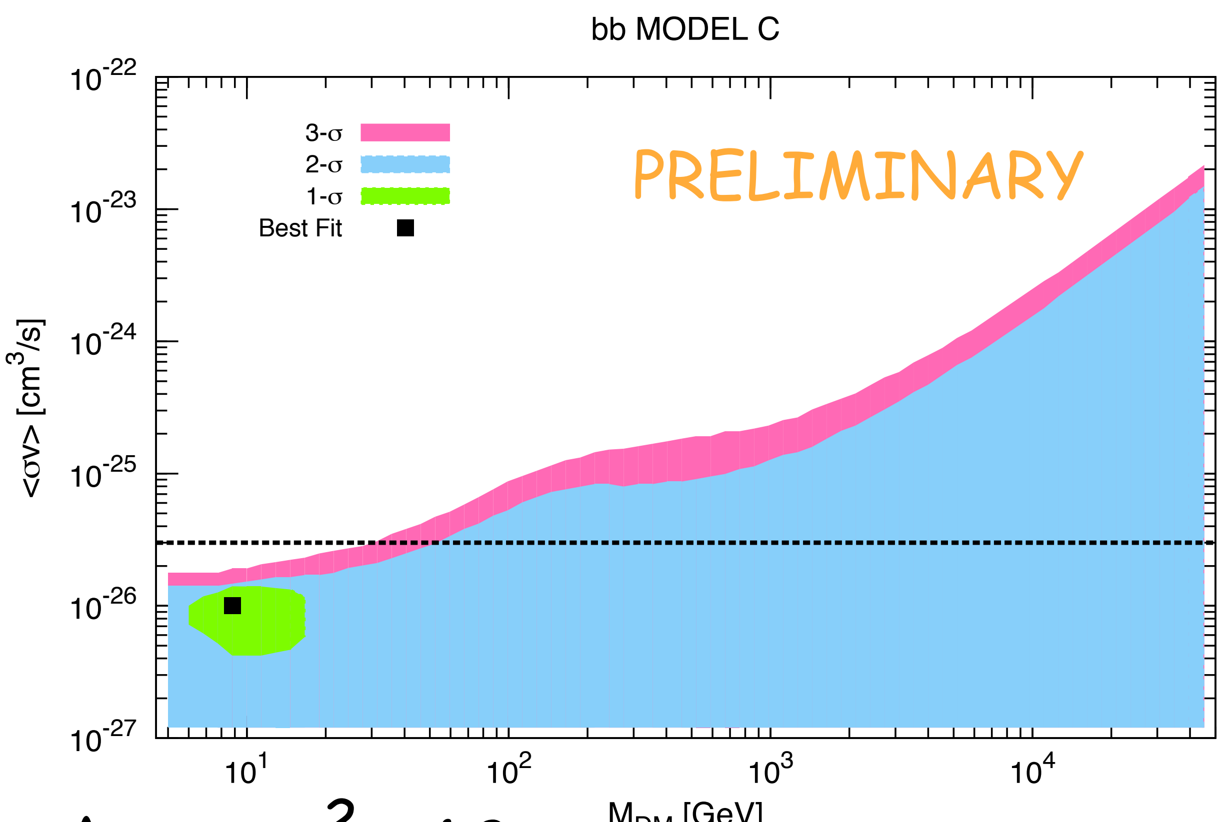
BEST FIT MODEL DEPENDENCE WITH FOREGROUND GALACTIC MODELS

$\Delta\chi_{BACK\text{-}DM}^2 = 18.9$



$\Delta\chi_{BACK\text{-}DM}^2 = 15.7$





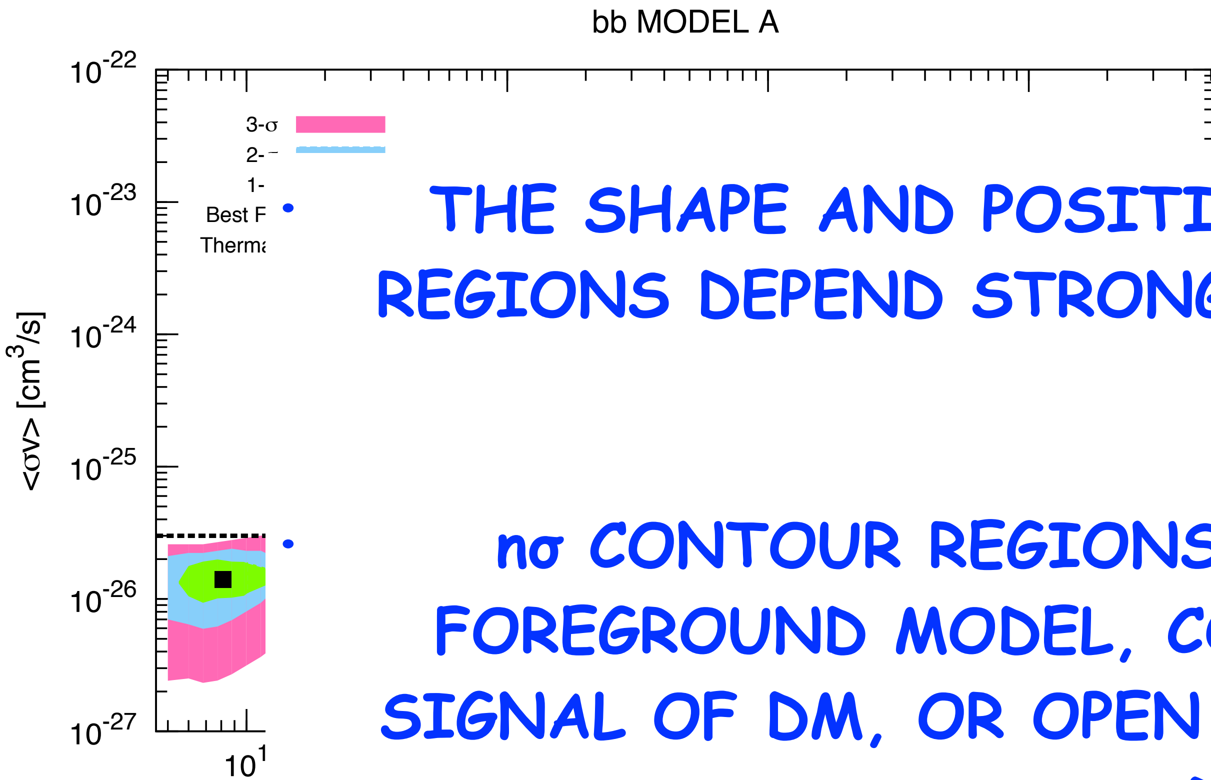
$\Delta\chi_{BACK\text{-}DM}^2 = 4.9$

THE BEST FIT CONFIGURATION IS BETWEEN: 5-40 GeV with a cross section in the range 0.5-4 10^{-26} cm^3/s

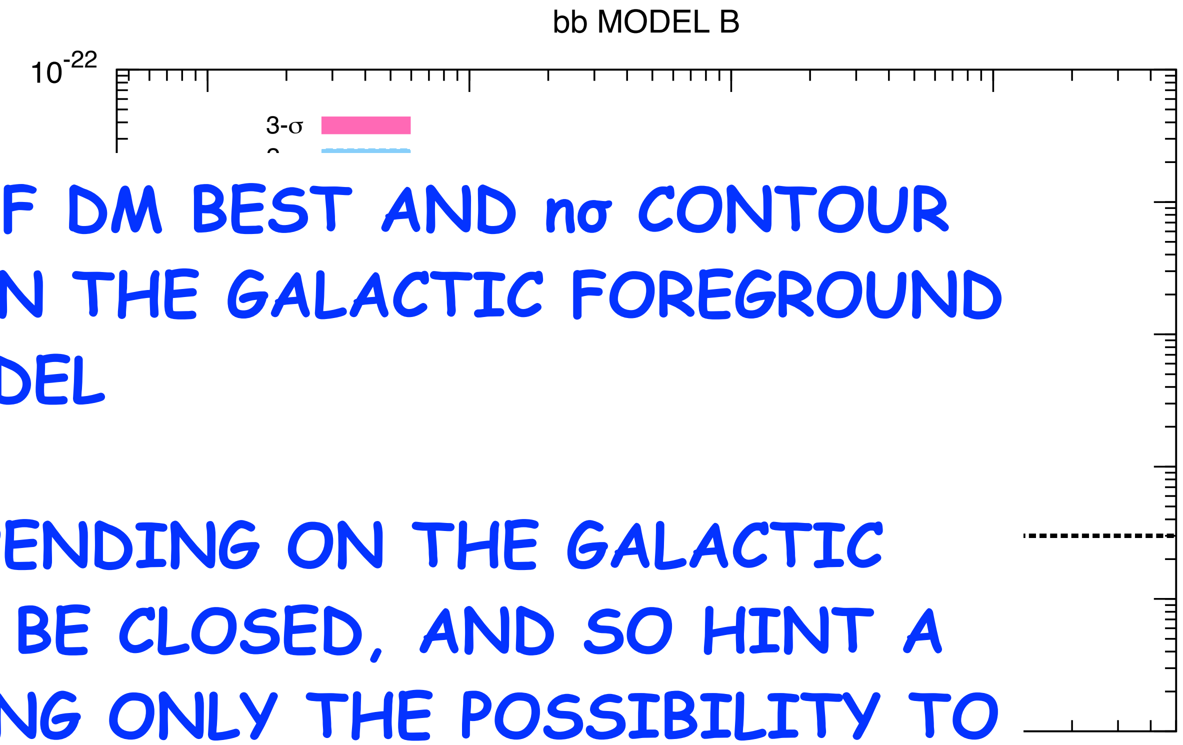
bb Channel

BEST FIT MODEL DEPENDENCE WITH FOREGROUND GALACTIC MODELS

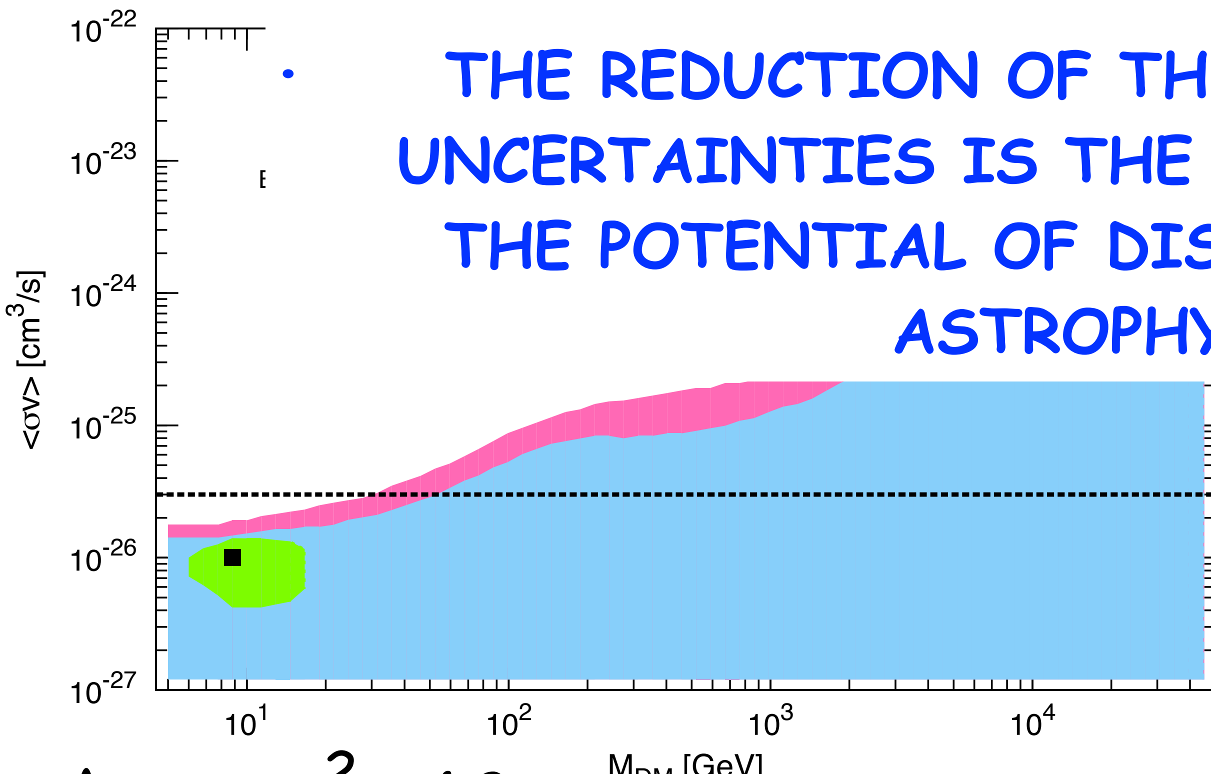
$\Delta\chi_{BACK\text{-}DM}^2 = 18.9$



$\Delta\chi_{BACK\text{-}DM}^2 = 15.7$



- THE SHAPE AND POSITION OF DM BEST AND nσ CONTOUR REGIONS DEPEND STRONGLY ON THE GALACTIC FOREGROUND MODEL
- nσ CONTOUR REGIONS, DEPENDING ON THE GALACTIC FOREGROUND MODEL, COULD BE CLOSED, AND SO HINT A SIGNAL OF DM, OR OPEN GIVING ONLY THE POSSIBILITY TO DERIVE ULs.
- THE REDUCTION OF THE GALACTIC FOREGROUND MODEL UNCERTAINTIES IS THE KEY POINT FOR THE IGRB TO HAVE THE POTENTIAL OF DISENTANGLE THE DM SIGNAL FROM ASTROPHYSICAL BACKGROUND



$\Delta\chi_{BACK\text{-}DM}^2 = 4.9$

4

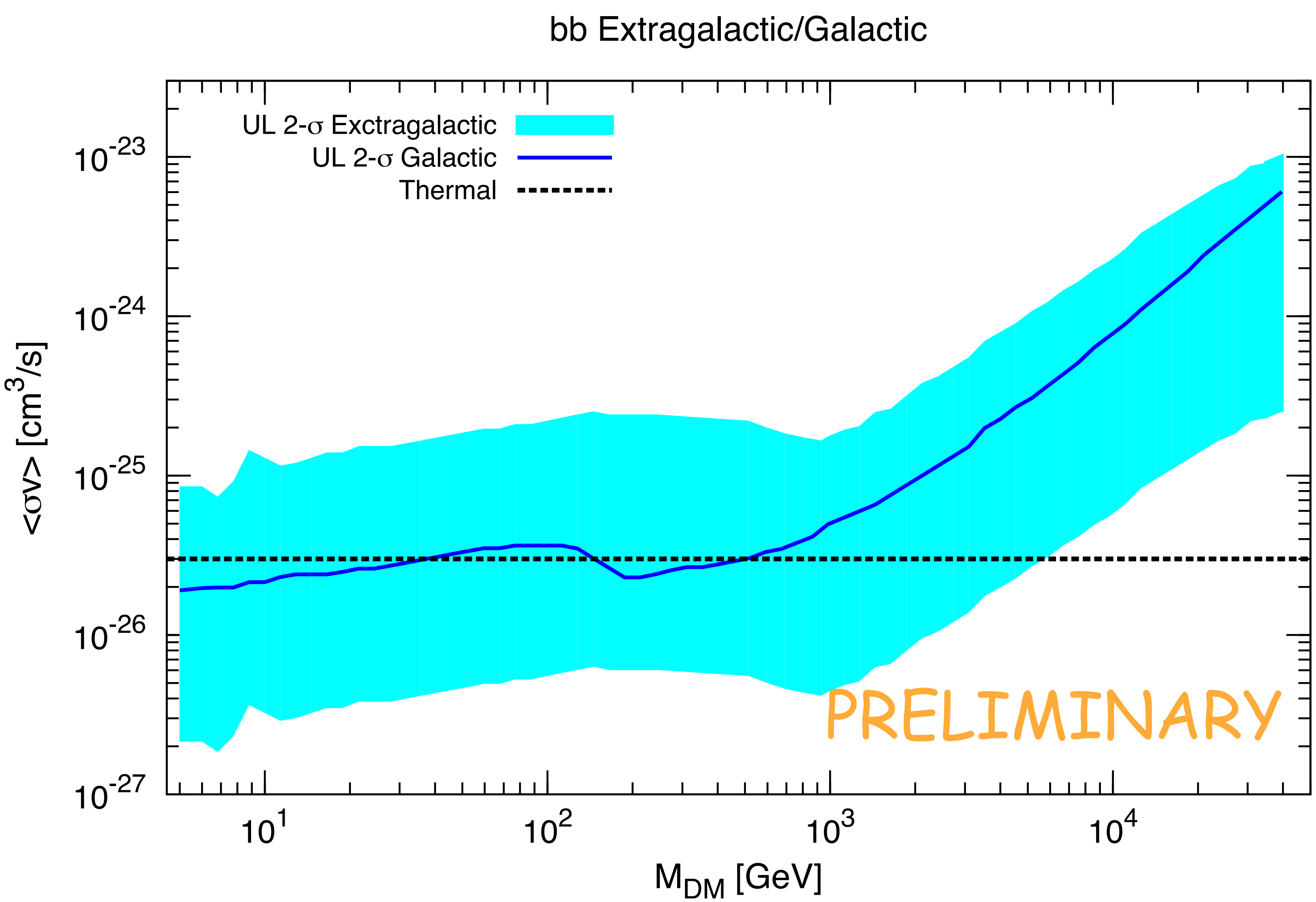
10^{-26} cm^3/s

bb Channel

EXTRAGALACTIC DM

A large uncertainty (at least one order of magnitude) is associated to extragalactic dark matter:

- Mass concentration parameter c(M,z)
- Value of the minimum halo mass
- IC process
- EBL absorption -> uncertainty on the UV density



- AN **UNCERTAINTY OF A FACTOR OF ABOUT 40** IS PRESENT IN THE EXTRAGALACTIC DM UPPER LIMITS
- THE BAND EMBED THE GALACTIC ULs

Maccio et aL MNRAS 391 (2008) 1940-1954
Neto et al., arXiv:0706.2919.
Martinez et al. JCAP 0906 (2009) 014
Bringmann, New J. Phys. 11 (2009) 105027.
Cirelli et al. 2011 JCAP 1103:051,2011

CONCLUSIONS

- EMISSION FROM AGN AND SF IS **COMPATIBLE** WITH BOTH FERMI-LAT IGRB AND THE EGB.

- THE MW MODEL FOR SF GALAXIES PROVIDES A BETTER FIT WITH RESPECT OF PL MODEL.

- THE C MODEL FOR THE GALACTIC FOREGROUND MODEL PROVIDES THE BEST FIT.

- USING A FITTING PROCEDURE WHICH TAKES INTO ACCOUNT BOTH THE ERRORS RESPECT FERMI-LAT DATA AND UNCERTAINTIES ON THE AGN AND SF GAMMA RAY EMISSION SEVERE CONTRAINTS ARE DERIVED FOR GALACTIC DM.

- THE DM UPPER LIMITS DEPEND ON THE GALACTIC FOREGROUND MODEL.

- THE IGRB COULD HAVE THE POTENTIAL TO DISENTANGLE A SIGNAL OF DM ONCE THE UNCERTAINTY ON THE GALACTIC FOREGROUND MODELS AND ON THE EMISSION FROM SOURCE POPULATIONS AND THE SPATIAL DISTRIBUTION OF DM ARE REDUCED.

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THANK YOU!!!

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