Dark Matter implications of Fermi-LAT measurement of anisotropies in the diffuse gamma-ray background

Germán Gómez-Vargas

Universidad Autónoma de Madrid

IFT UAM-CSIC

INFN Roma Tor Vergata

On behalf of the Fermi LAT collaboration, A. Cuoco, M. Fornasa, L. Latronico, T. Linden, A. Morselli, F. Prada, M. SanchezConde, J. SiegalGaskins, F. Zandanel, J. Zavala

MultiDark

Multimessenger Approach for Dark Matter Detection

RICAP, Roma 2013

Fermi

Gamma-ray Space Telescope

4 years Fermi-LAT data

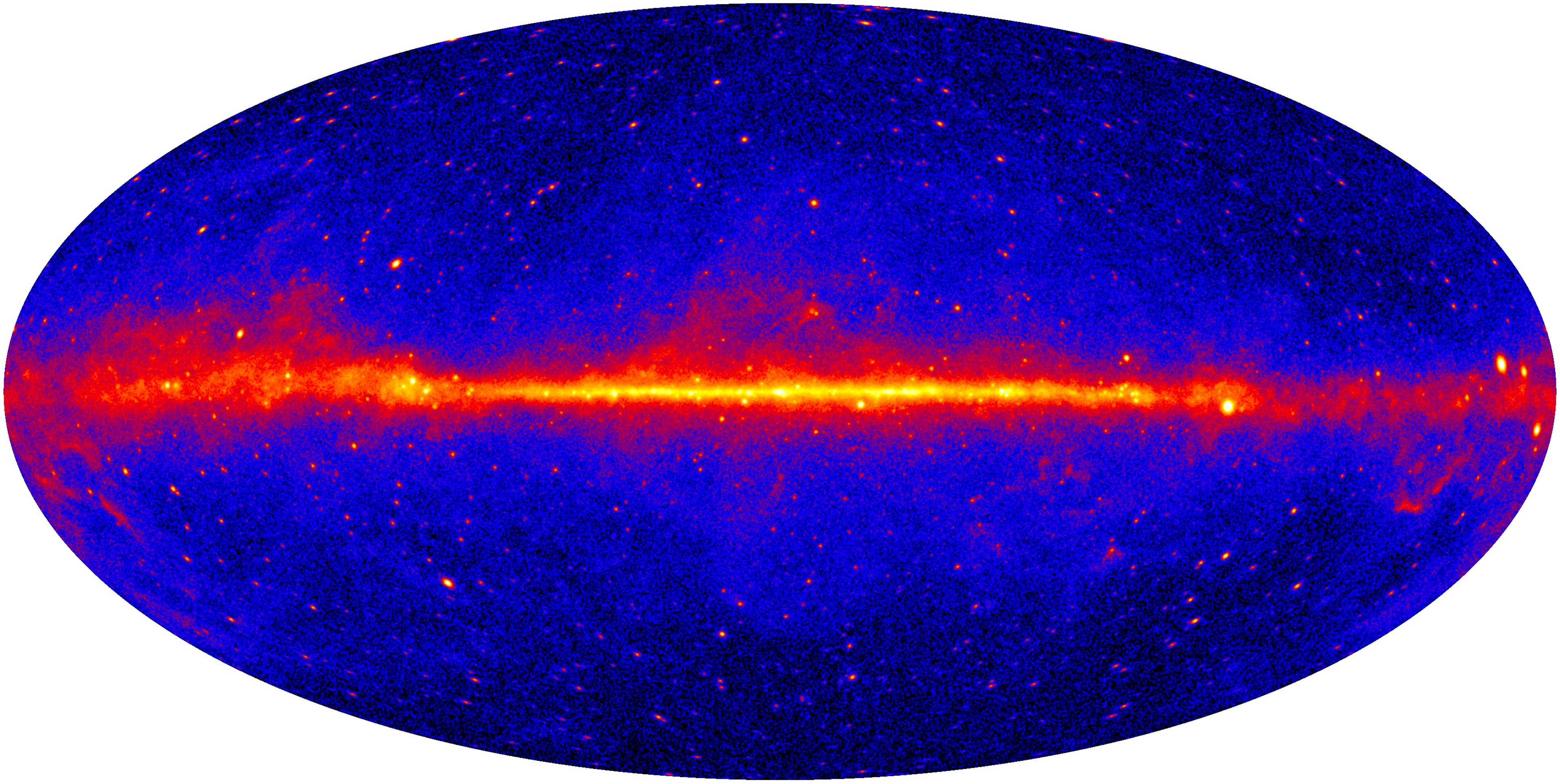
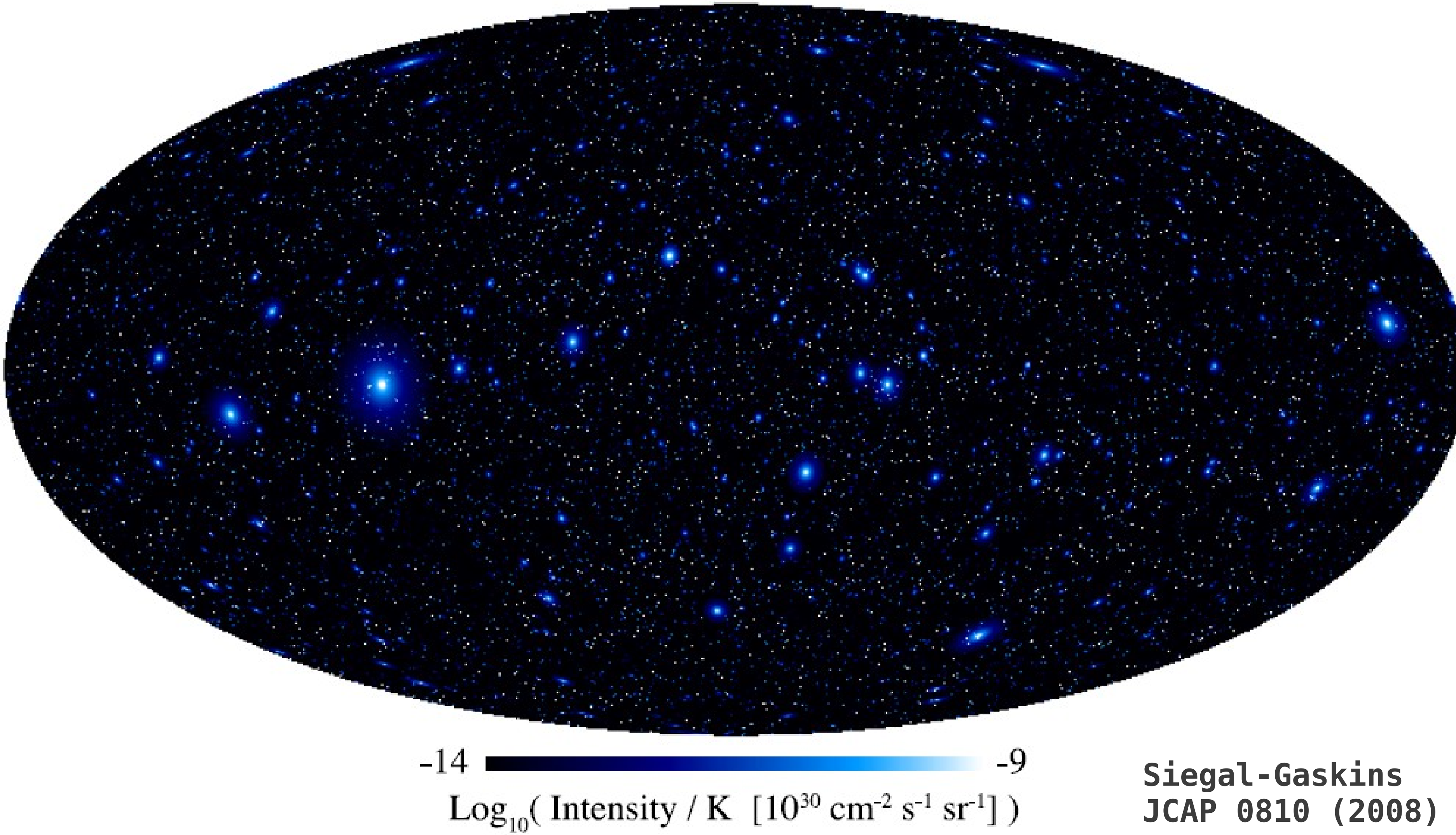


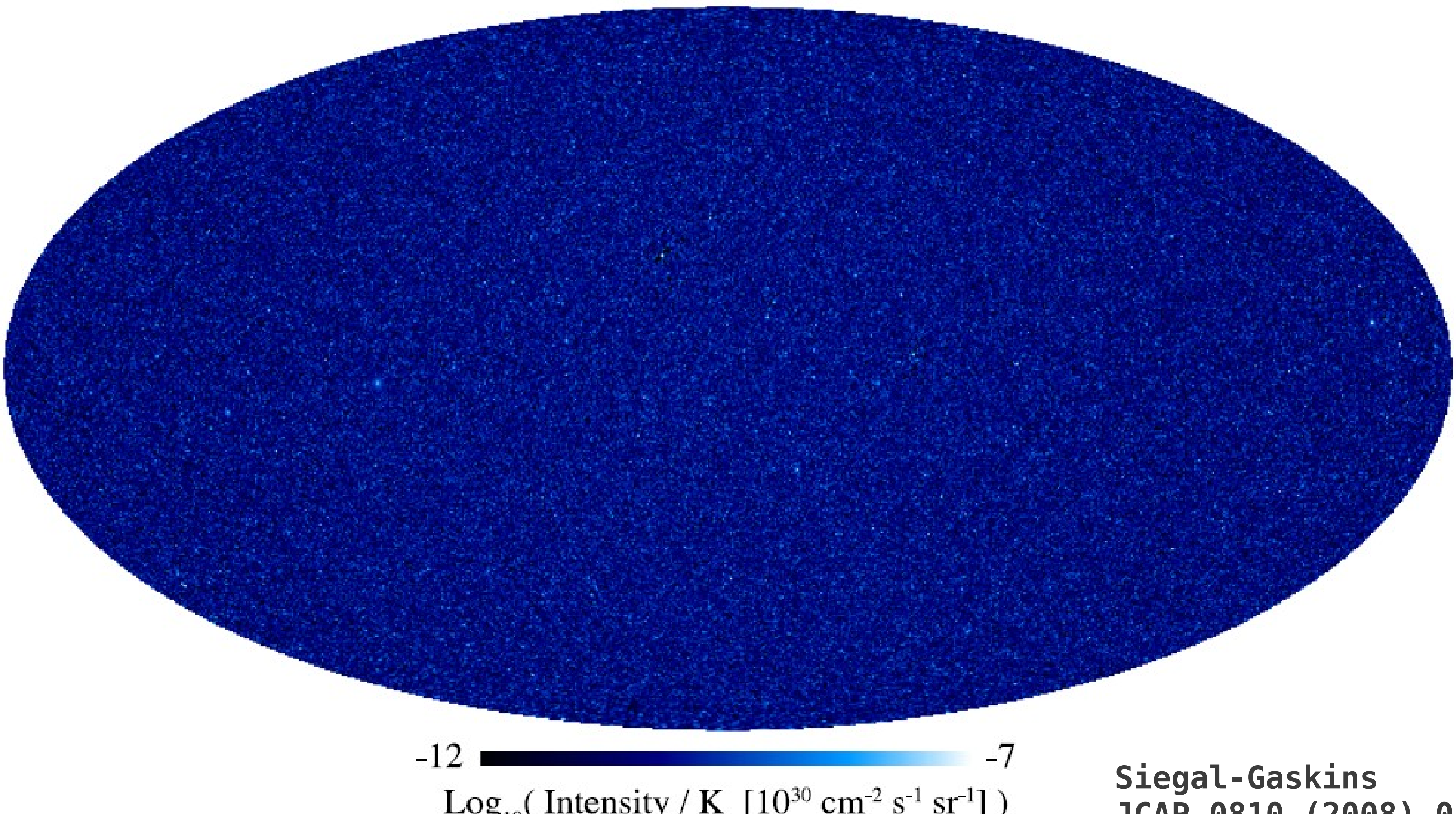
Image Credit: NASA/DOE/International LAT Team

Gamma-ray intensity from dark matter annihilation in galactic substructure



Siegal-Gaskins
JCAP 0810 (2008) 040

The same gamma-ray map, but smoothed with a Gaussian beam of σ=0.1º



Siegal-Gaskins
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How to seek for those signals in the Fermi sky?

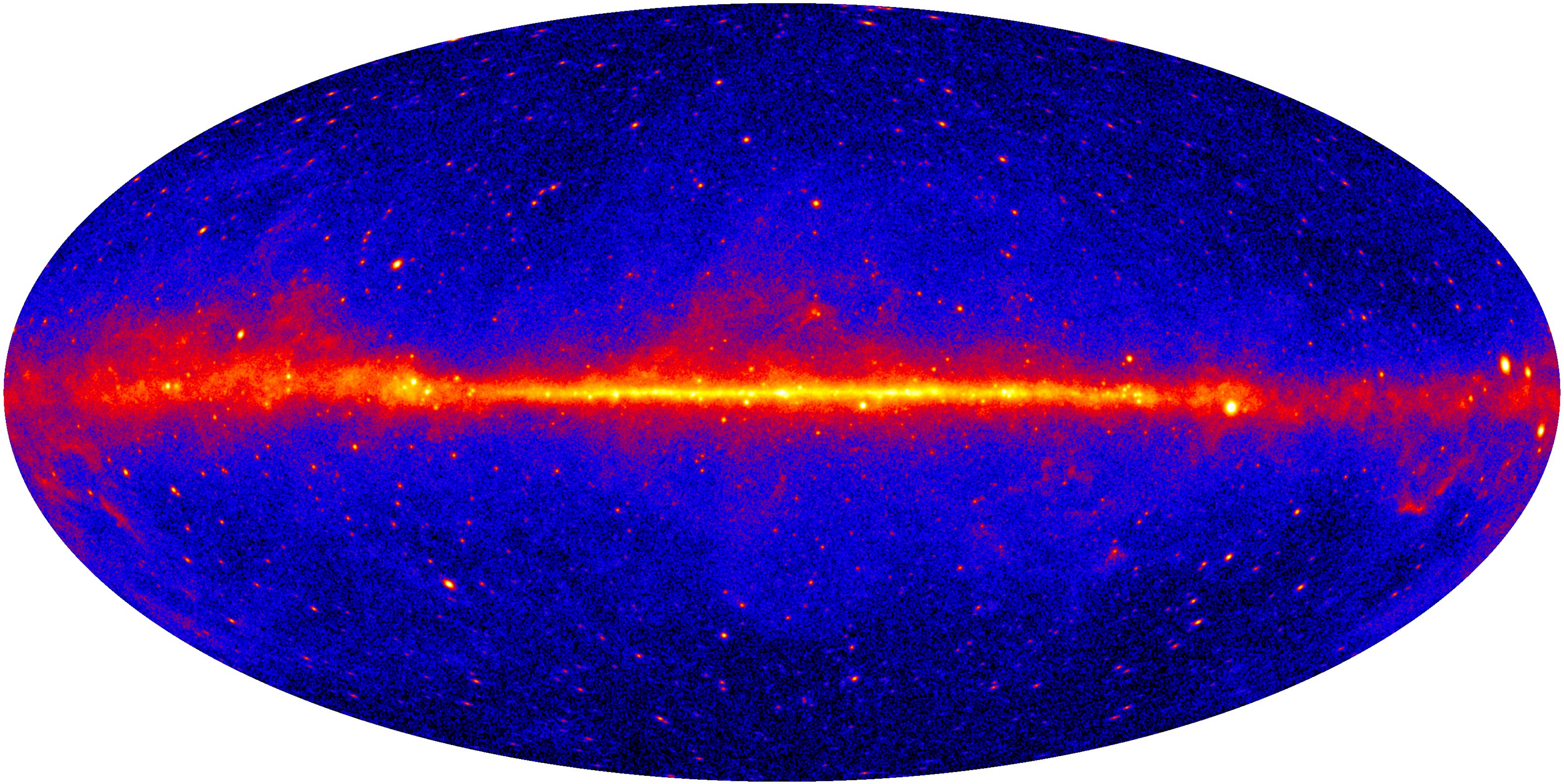


Image Credit: NASA/DOE/International LAT Team

How to seek for those signals in the Fermi sky?

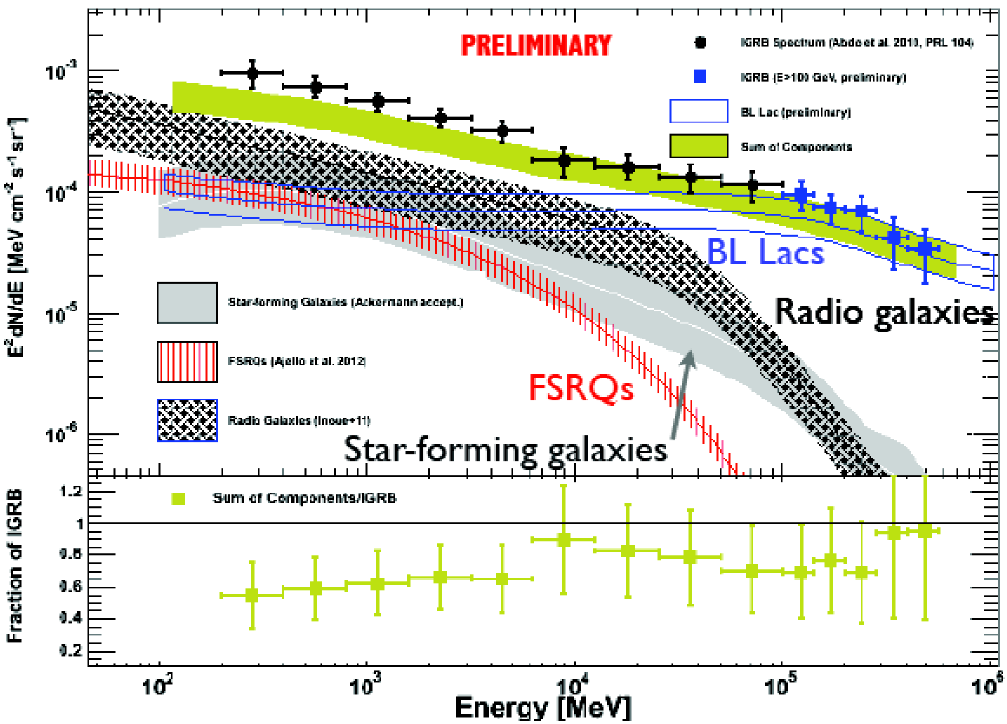
•That kind of DM signal will contribute to the so-called Isotropic Gamma-ray Background (IGRB).

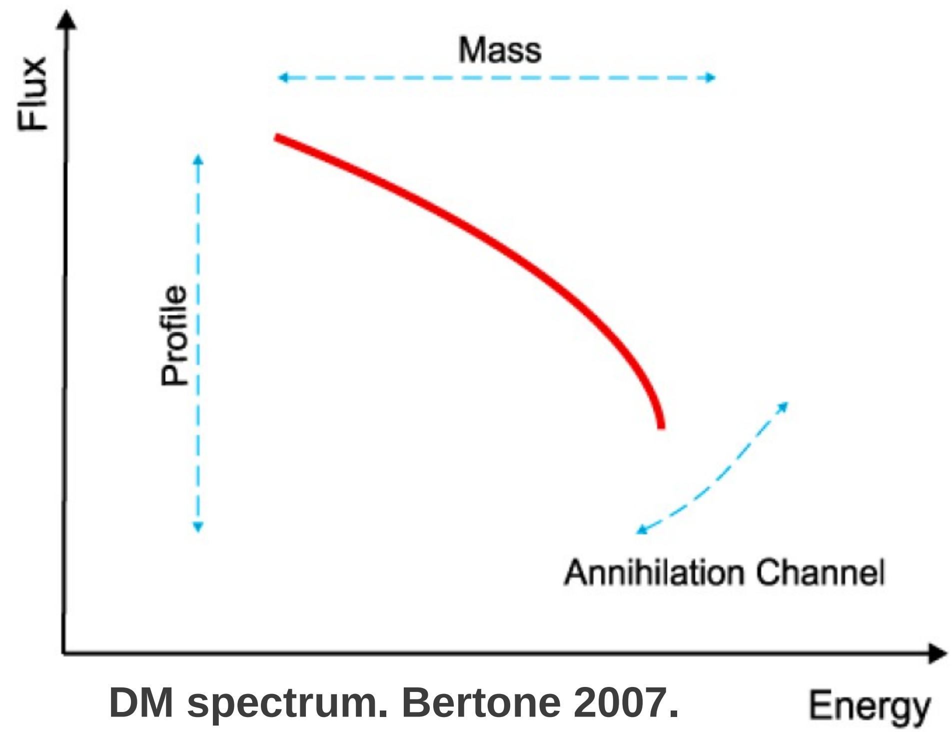
• It is a fainter component of the diffuse emission observed by the LAT.

•The IGRB is considered to have an isotropic or nearly isotropic distribution on the sky

•We can use spectral and/or spatial information to disentangle a possible DM signal in the IGRB from other contributors

Spectral information

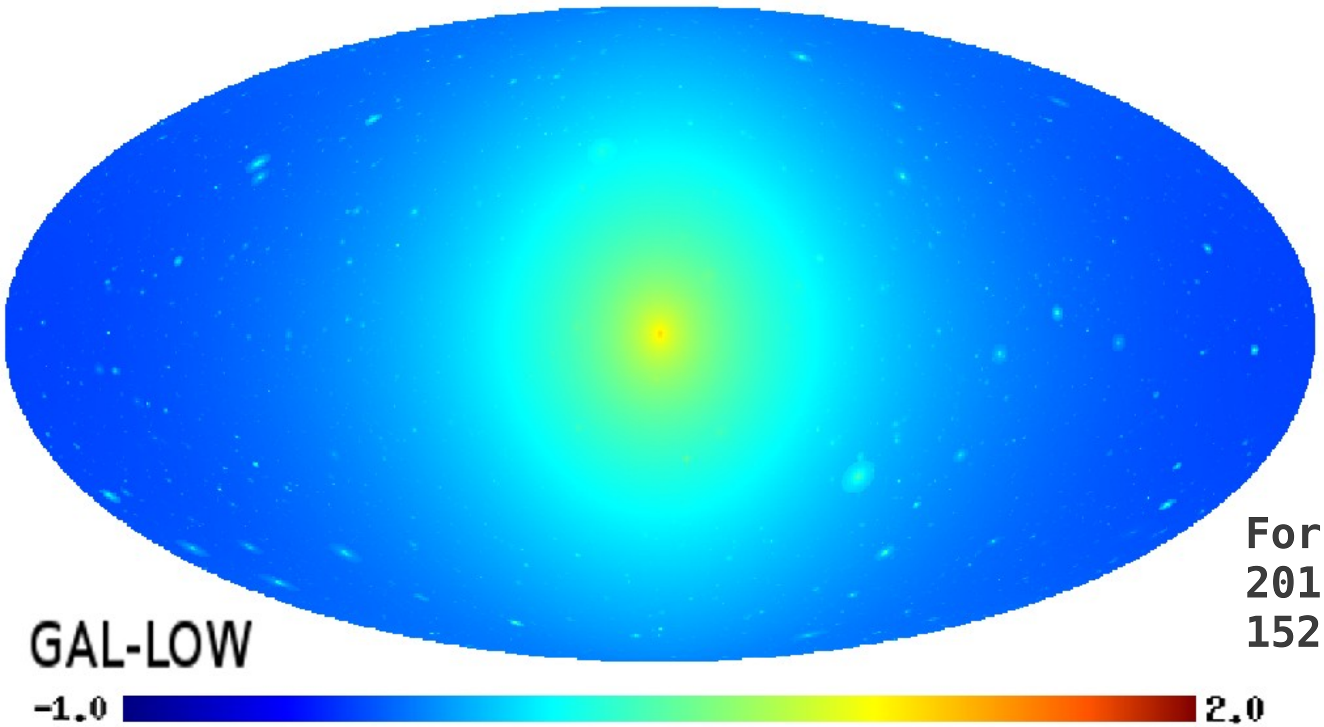




DM spectrum. Bertone 2007.

- The IGRB spectrum is featureless and may have contributions from population sources of various kinds, including blazars, pulsars, and possible DM structures
- DM annihilate to Standard Model particles, the energy spectrum of those process strongly depends on the SM particles products, the density profile, and the DM mass. Since we don't know any of these properties disentangle a DM signal using only spectral information is a difficult task.

Spatial information



Fornasa et al, 2013, mnras, 429, 1529

- diffuse emission that originates from one or more unresolved source populations will contain fluctuations on small angular scales due to variations in the number density of sources in different sky directions.
- the amplitude and energy dependence of the anisotropy can reveal the presence of multiple source populations and constrain their properties

Angular Power Spectrum (APS)

- We consider the APS as a metric for anisotropy.
- We decompose an intensity map I(Ψ), with Ψ the sky direction, in spherical harmonics:

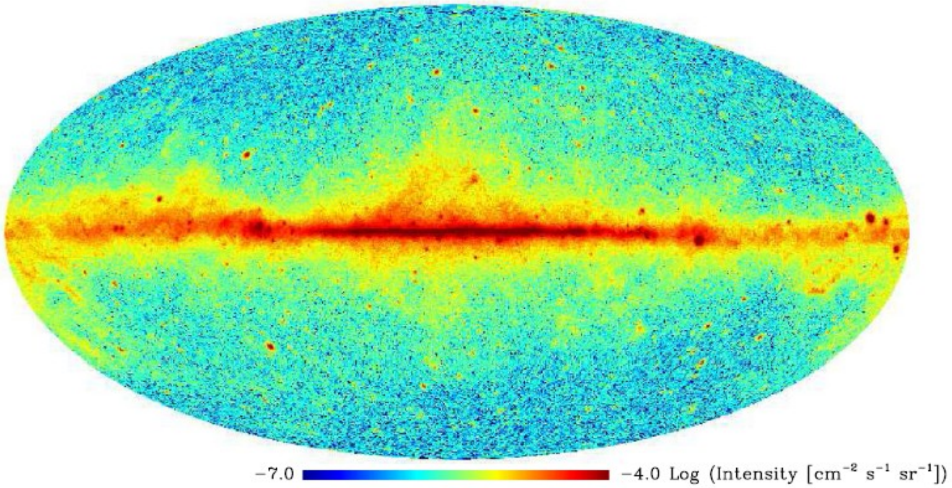
$$I(\Psi) = \sum_{lm} a_{lm} Y_{lm}(\Psi).$$

- The APS is given by the coefficients:

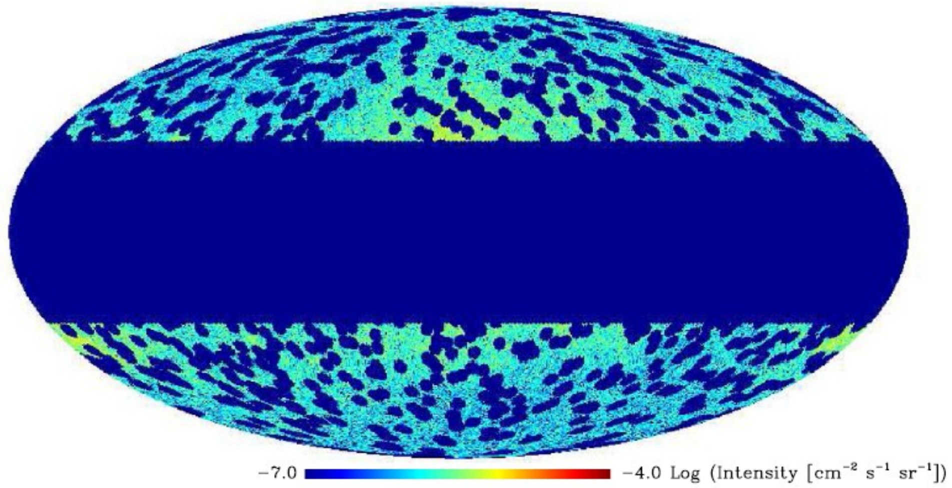
$$C_l = \langle |a_{lm}|^2 \rangle$$

- The intensity APS indicates the dimensionful size of intensity fluctuations and can be compared with predictions for sources classes whose collective intensity is known or assumed

22-months data, 1.0 -2.0 GeV

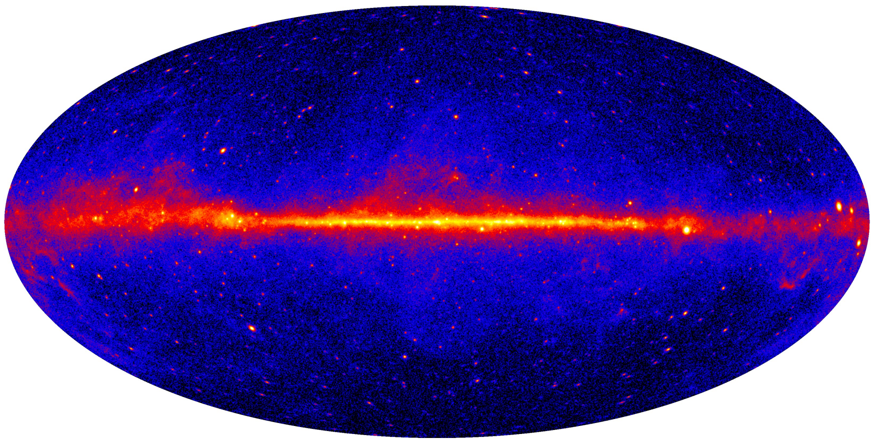


Mask applied to exclude foregrounds contamination.

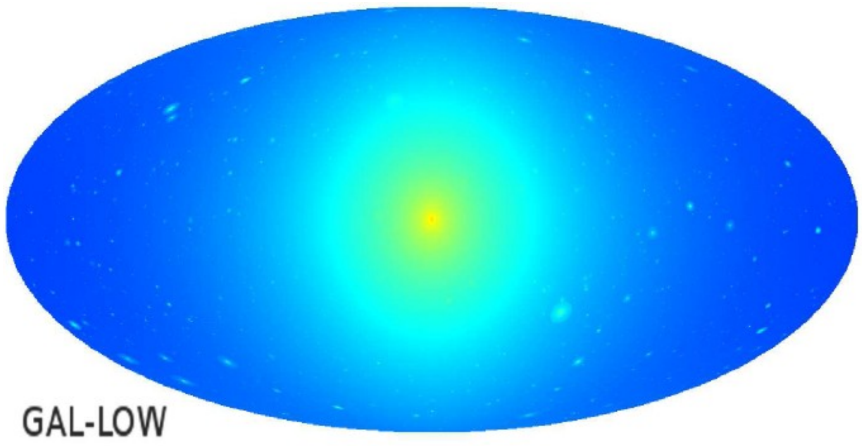


A Joint project between Fermi-LAT and MultiDark

- Utilize high-resolution numerical simulation of the Galactic and extragalactic DM distribution (Aquarius and Millenium II)
- Predict the DM anisotropy signal from annihilation and decay, accurately accounting for redshifting and extragalactic background light attenuation for extragalactic DM, and secondary emission from Galactic DM
- Extend and improve the Fermi LAT anisotropy measurement.
- Compare the predicted Angular Power Spectrum (APS) to the measurement to place constraints on DM nature.



36-months Fermi-LAT data

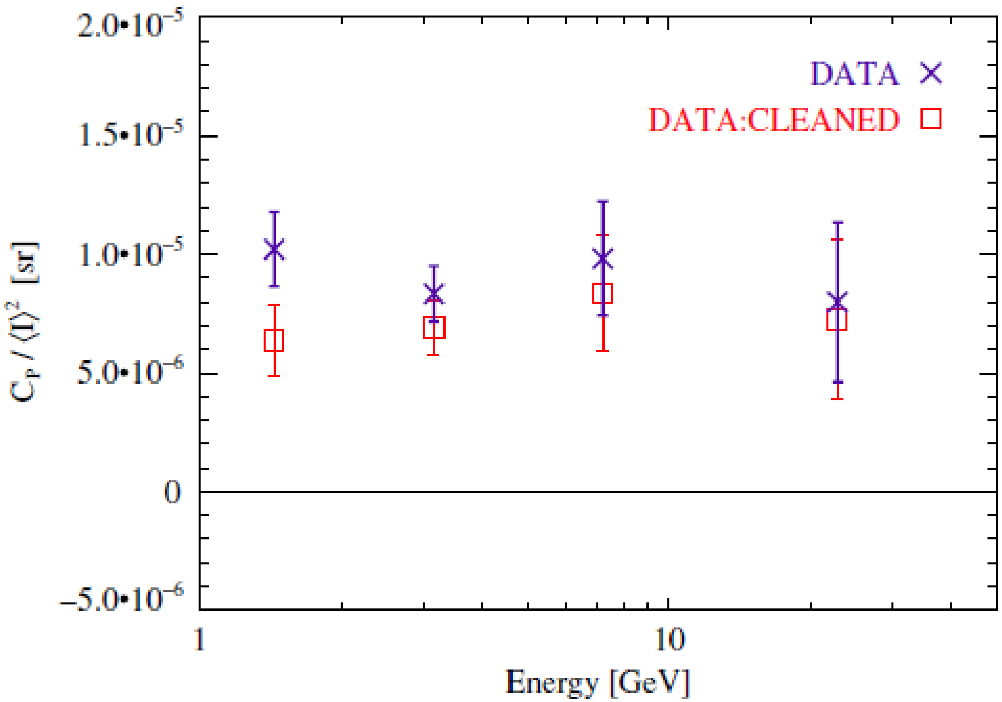


DM MultiDark map
arXiv:1207.0502

Fermi LAT measurement of APS

- Data from the first 22 months.
- 4 energy bins (from 1GeV to 50 GeV).
- Masking is applied covering point sources (1 year Fermi catalog) and the galactic plane (|b|<30 deg).
- Galactic diffuse contribution to the high-latitude emission is minimized by subtracting the Fermi-LAT recommended model of the Galactic foregrounds from the data, and then calculating the APS of the residual map -> DATA:CLEANED.

Angular power is detected with a significance up to 7σ.



Fermi-LAT collaboration, PRD. **85** 083007 (2012)

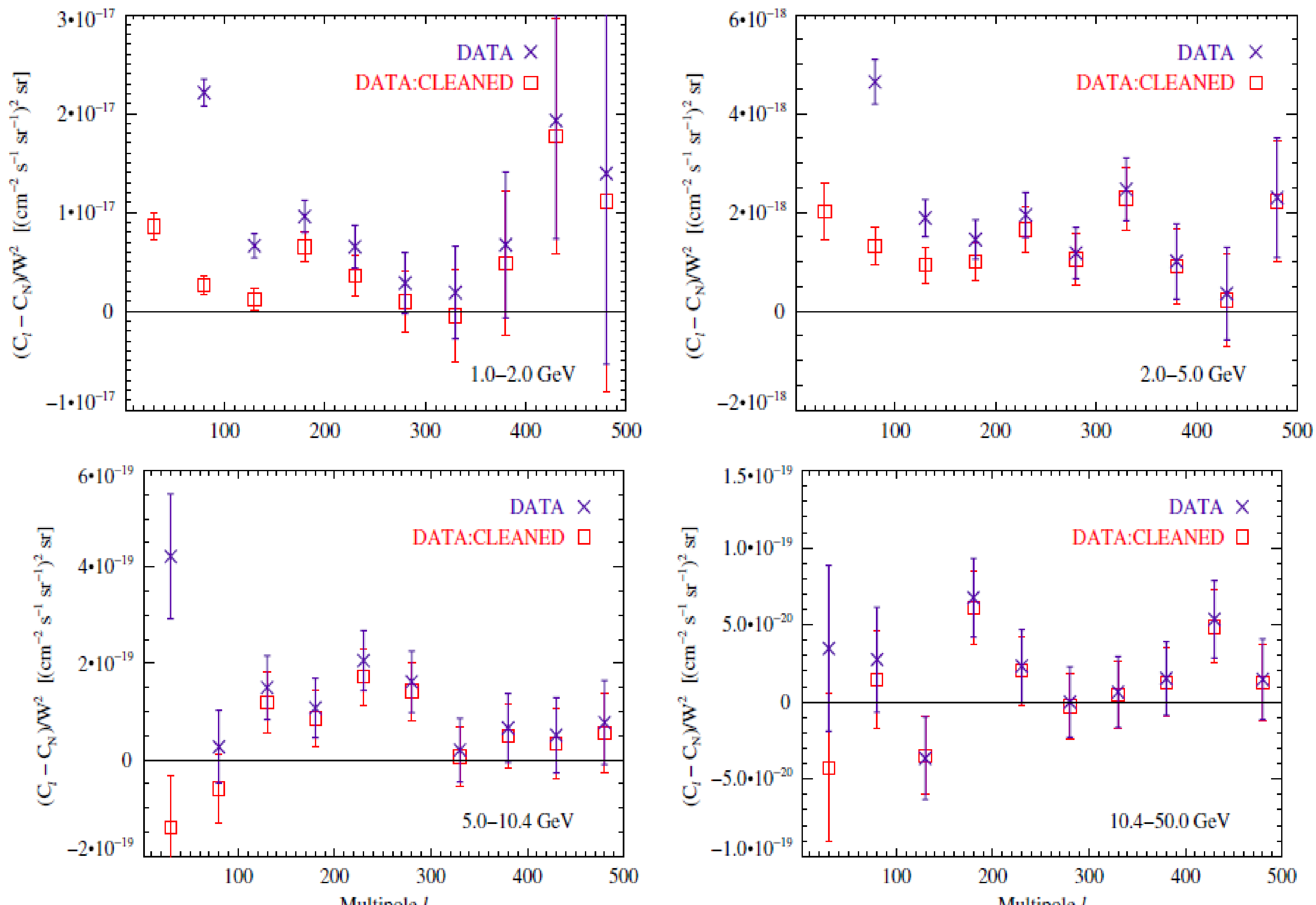
Fermi LAT measurement of APS

$E_{\min}$ [GeV]	$E_{\max}$ [GeV]	C_P [(cm^{-2} s^{-1} sr^{-1})^2 sr]
1.04	1.99	$4.62 \pm 1.11 \times 10^{-18}$
1.99	5.00	$1.30 \pm 0.22 \times 10^{-18}$
5.00	10.4	$8.45 \pm 2.46 \times 10^{-20}$
10.4	50.0	$2.11 \pm 0.86 \times 10^{-20}$

Best-fit to constant values over the multipole range 155<l<504. DATA-CLEANED

At low multipoles and higher energies the Galactic foreground contribution is important, as we expected.

We use *l* larger than 155 and data-cleaned measurement to avoid it.



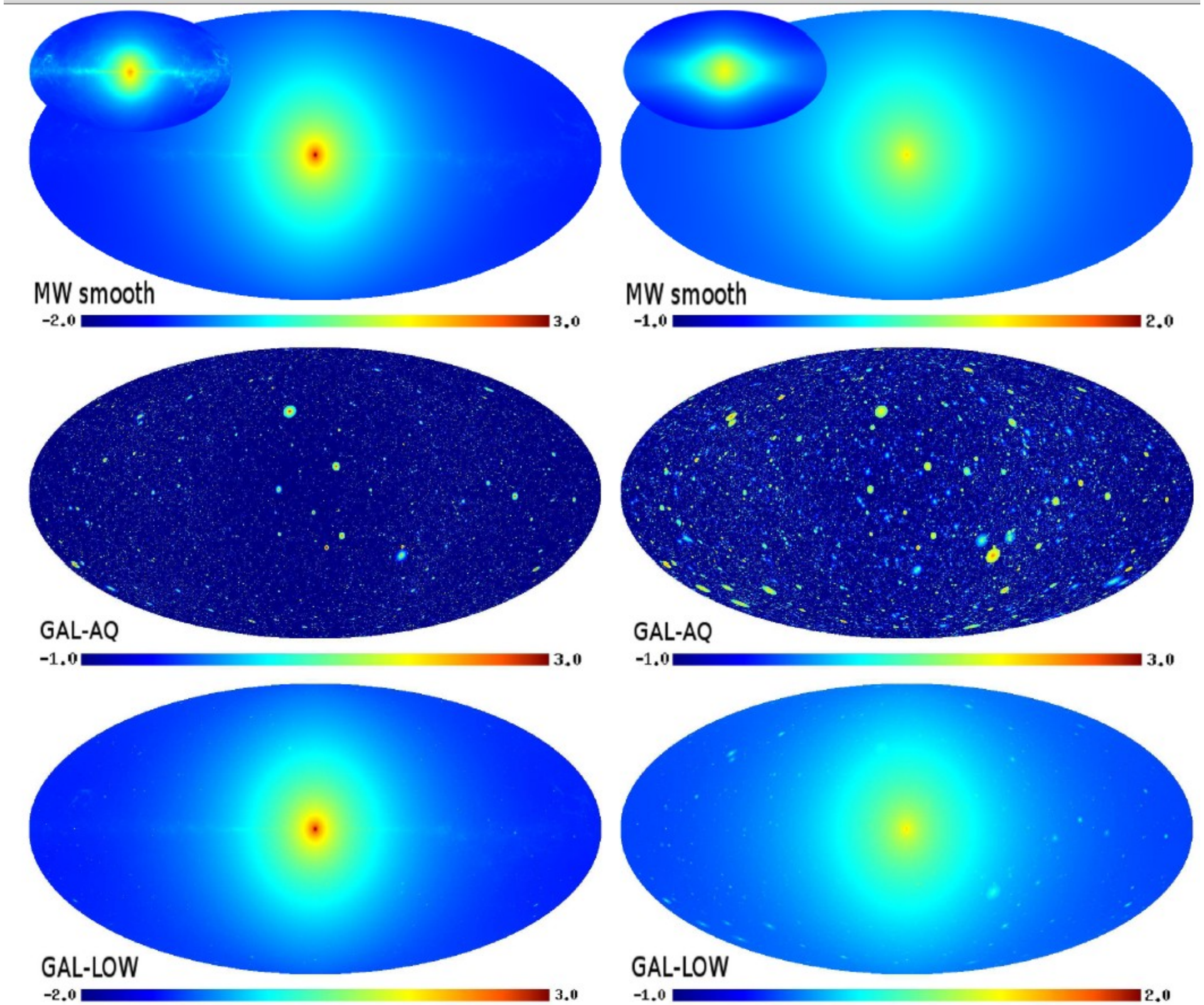
Fermi-LAT collaboration, PRD. **85** 083007 (2012)

DM Milky Way Model

All-sky DM maps of the galactic gamma-ray emission at 4 GeV for DM annihilation (left) and decay (right).

First row: smooth halo is modeled as an Einasto profile based on Aquarius results (Springel et al. 2008; Navarro et al. 2008), renormalized to the local DM density.

Contribution from 3 mechanisms of emission: Prompt, ICS on both, CMB and ISRF, and hadronic.

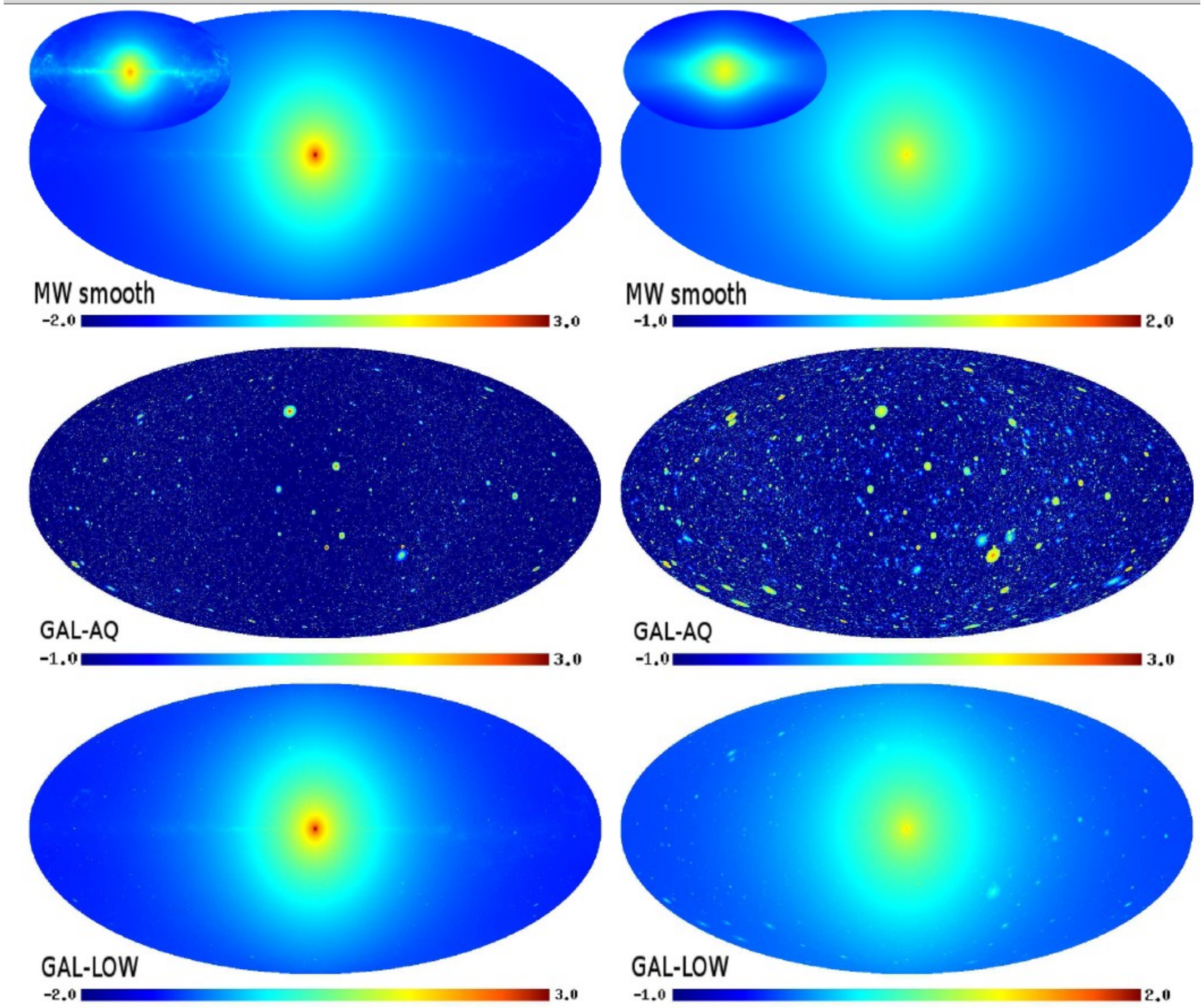


For more details on the model see Fornasa et.al. 2012 (1207.0502).

DM Milky Way Model

All-sky DM maps of the galactic gamma-ray emission at 4 GeV for DM annihilation (left) and decay (right).

The non-prompt emission alone is shown in the smaller panels overlapping with the maps of the first row.

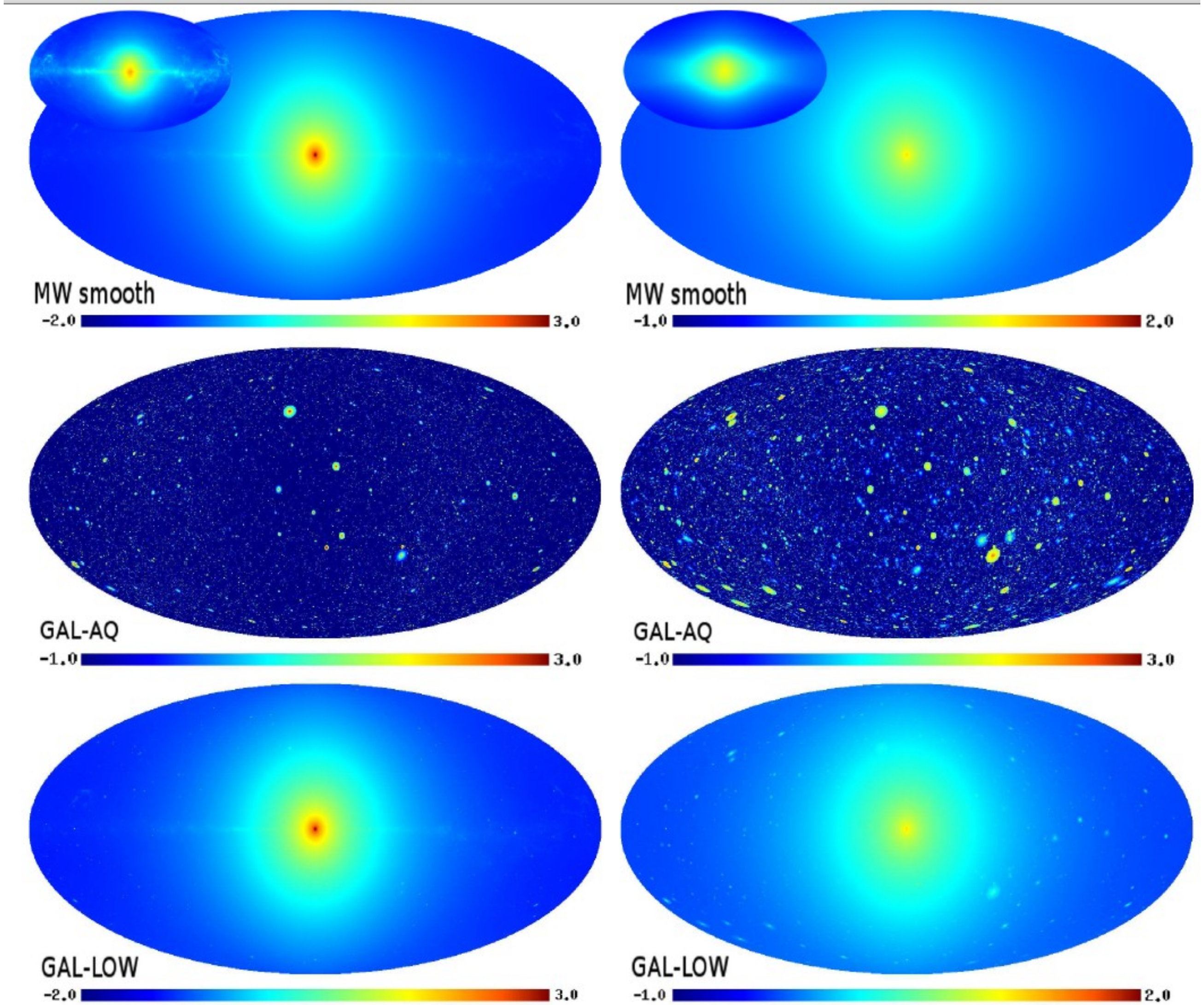


For more details on the model see Fornasa et.al. 2012 (1207.0502).

DM Milky Way Model

All-sky DM maps of the galactic gamma-ray emission at 4 GeV for DM annihilation (left) and decay (right).

Second row: DM subhalos in the Aquarius catalogs with more than 100 particles, i.e. with a mass larger than Mmin=1.71×10^5 M_{sun}

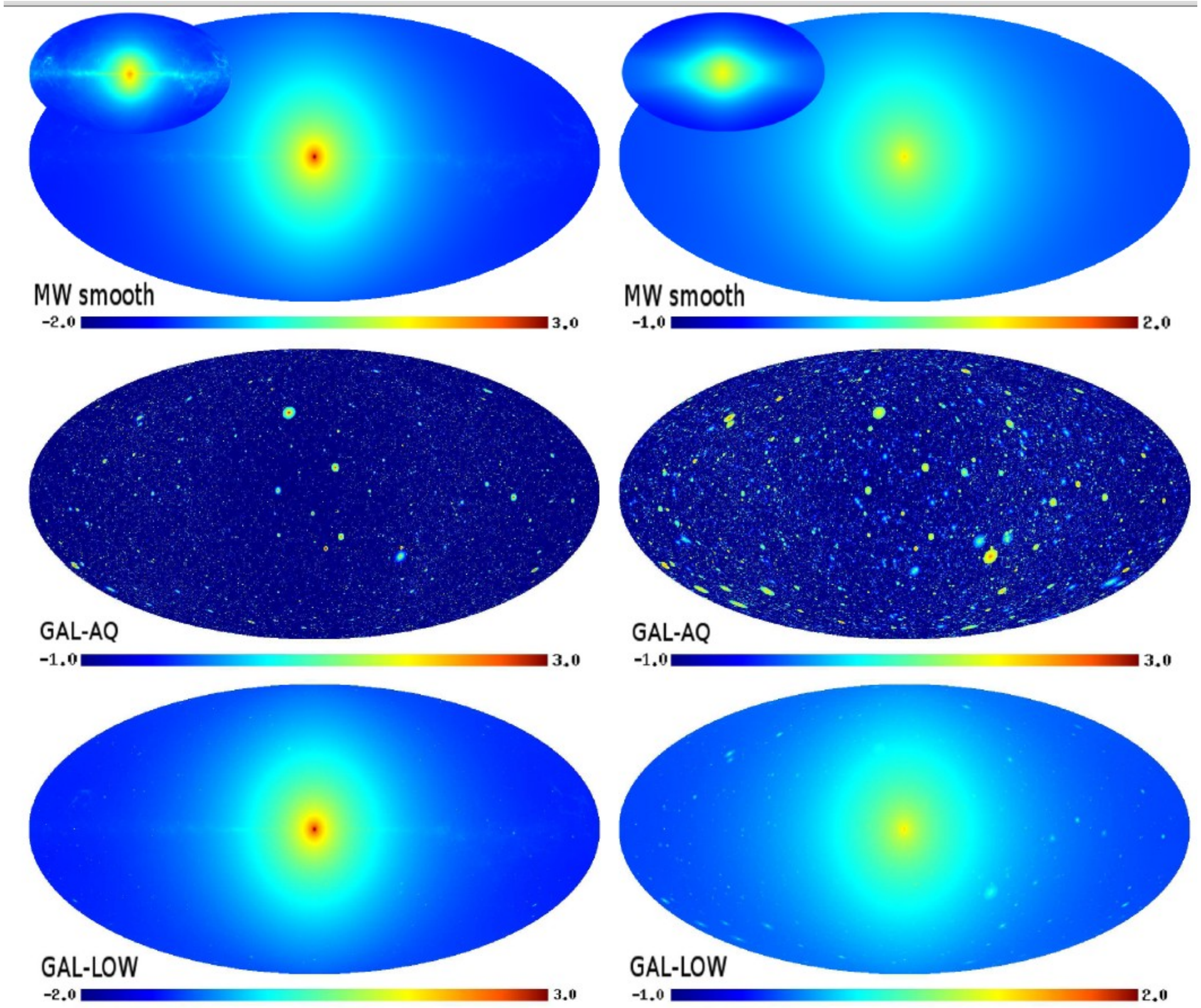


For more details on the model see Fornasa et.al. 2012 (1207.0502).

DM Milky Way Model

All-sky DM maps of the galactic gamma-ray emission at 4 GeV for DM annihilation (left) and decay (right).

Third row: total galactic emission accounting for the MW smooth halo and its (resolved and unresolved) subhalos.



For more details on the model see Fornasa et.al. 2012 (1207.0502).

Extragalactic DM (sub)halos

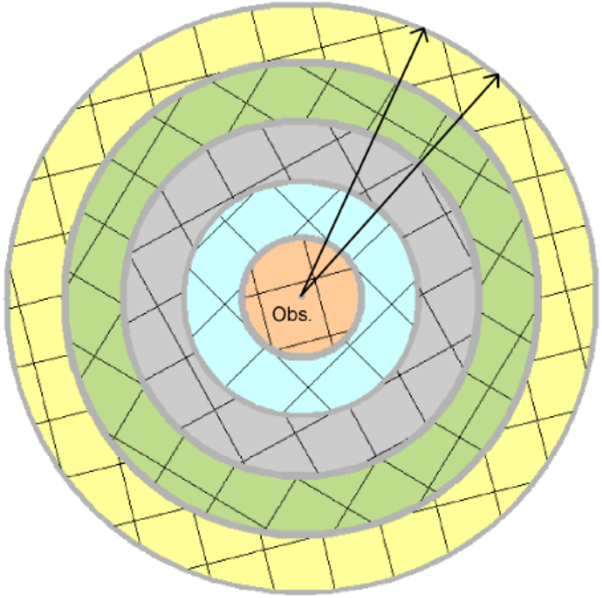
Resolved (sub)halos:
Millenium-II (MS-II) catalogs of halos and subhalos above the mass resolution of the simulations.

32 snapshots at different redshifts

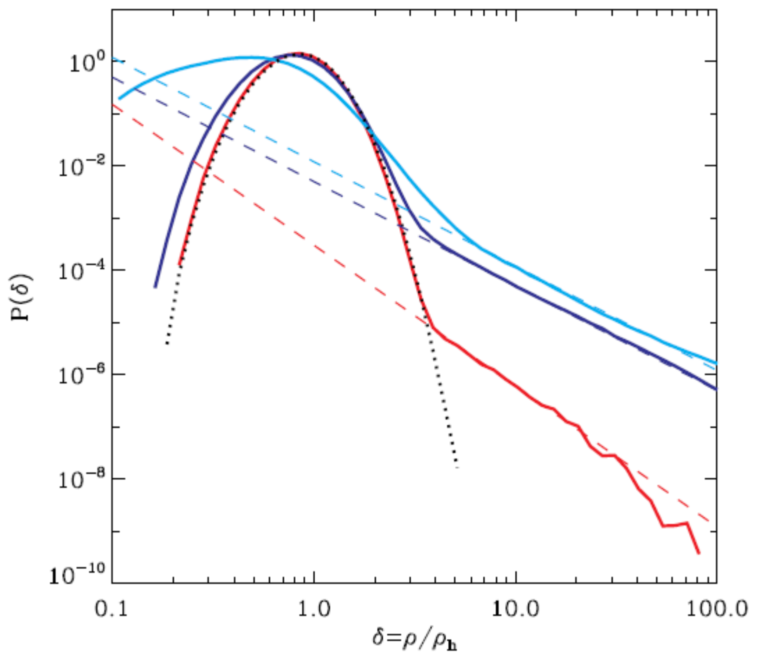
Each halo is considered with its own profile.

Unresolved main halos
Emission produced in main halos below the mass resolution of MS-II down to Mmin is computed analytically

Used to boost up the flux of the smallest objects in MS-II



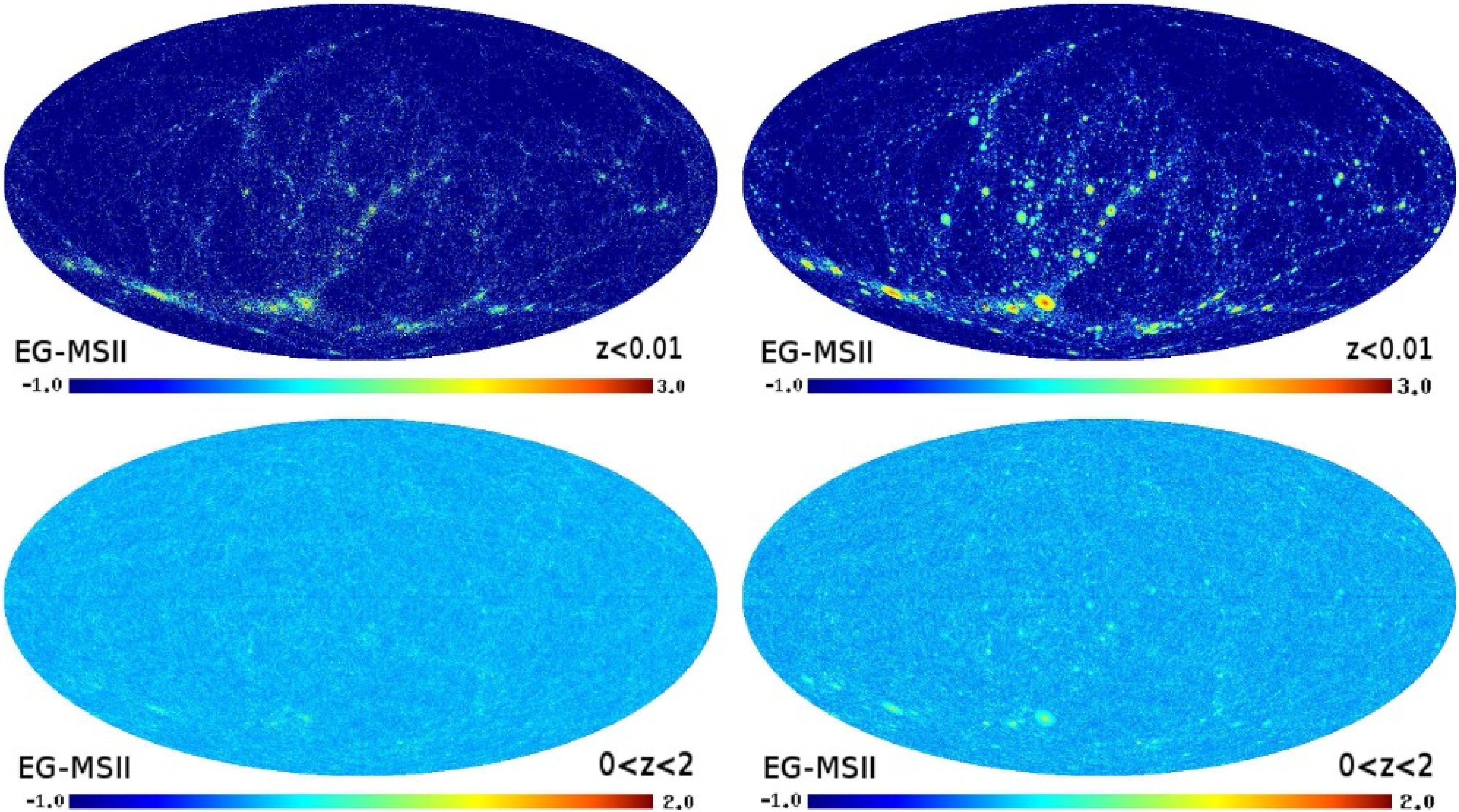
Zavala et.al, MNRAS. **405** 593 (2010)



Kamionkowski et.al, PRD. **81** 043532 (2010)

Extragalactic DM (sub)halos

Fornasa et.al. 2012 (1207.0502).



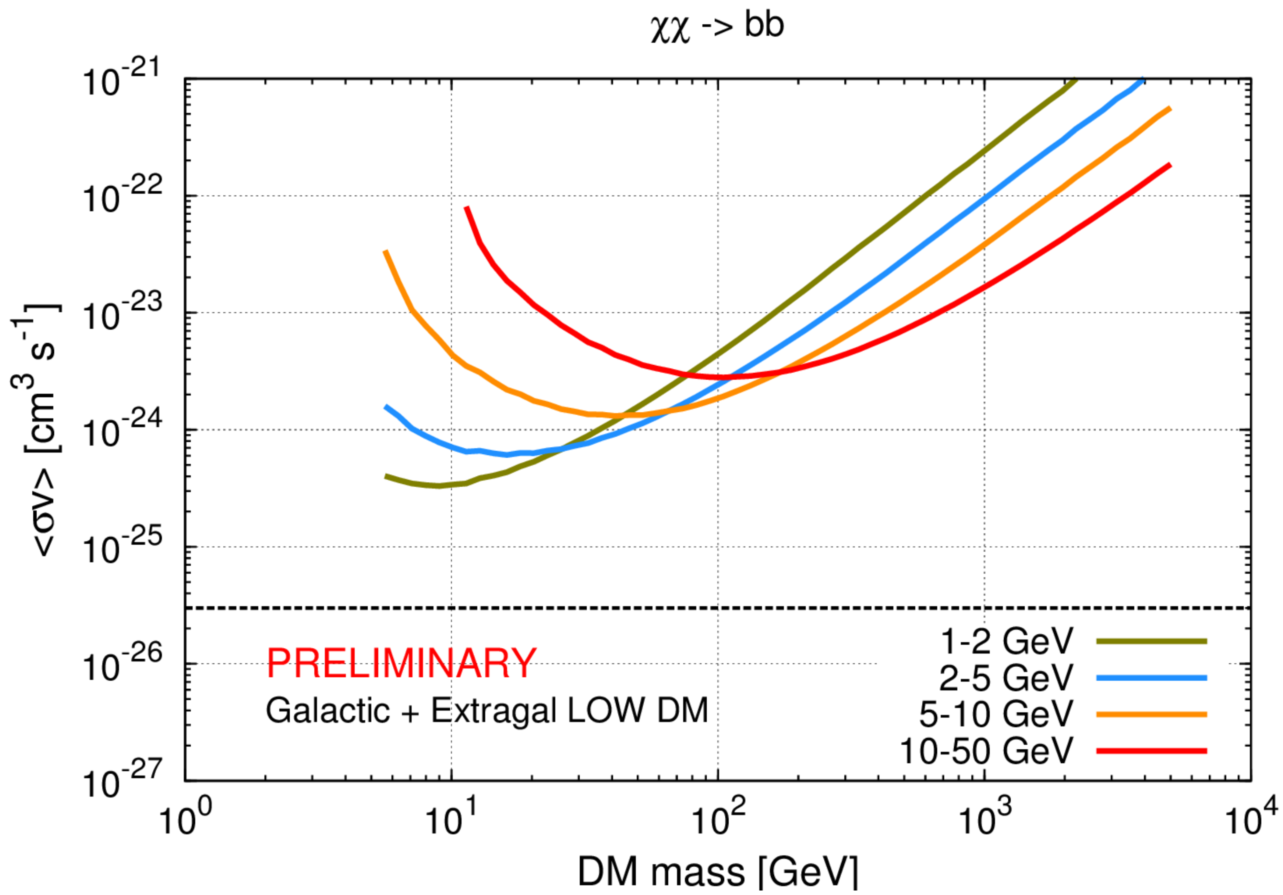
E=4GeV. bb channel. Mmin=10^{-6} solar masses.

Annihilation: m=200GeV <σv>=3×10^{-26} $cm^3 s^{-1}$. Decay: m=2TeV tau=2×10^{27} s

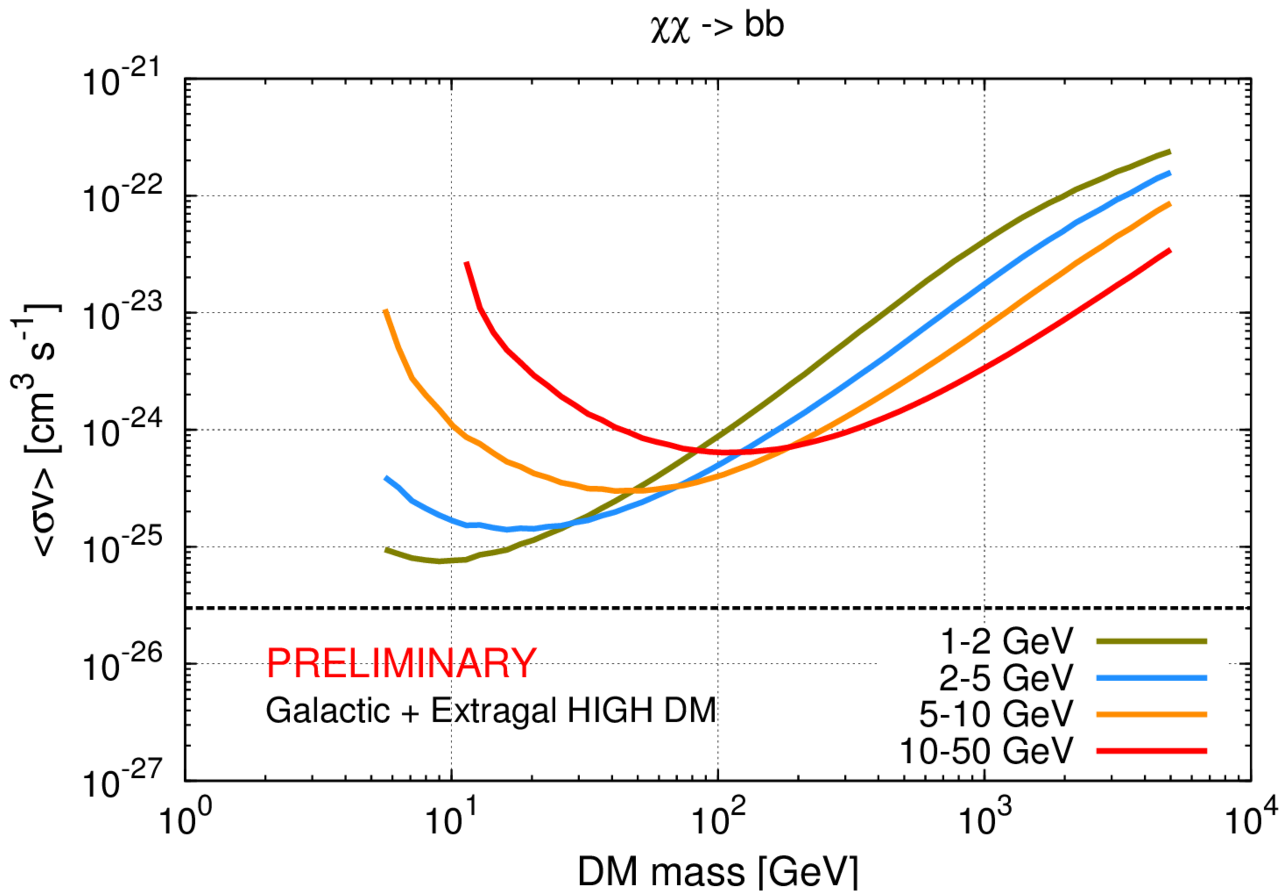
Setting constraint

- To set constraints we use the foreground-cleaned Cp shown in table II of [Ackermann et al. 2012].
- There are four Cp values measured corresponding to four energy bins, 1-2 GeV, 2-5 GeV, 5-10 GeV, and 10-50 GeV. We use them independently to set limits.
- Requiring that the DM-induced intensity APS averaged in $155 < l < 204$ does not overshoot the measured Cp in the $155 < l < 504$ multipole range plus 1.64 x error leads to 95% CL limits on $\langle\sigma v\rangle$.
- We know that the IGRB anisotropy has multiple contributors, therefore these constraints are conservative.
- Other contributors to IGRB anisotropy are not well known, but we already have constraints on the contribution of blazars [Cuoco et al. 2012]. We subtract this contribution from the measured Cp and require that the DM-induced APS does not overshoot this new limit.

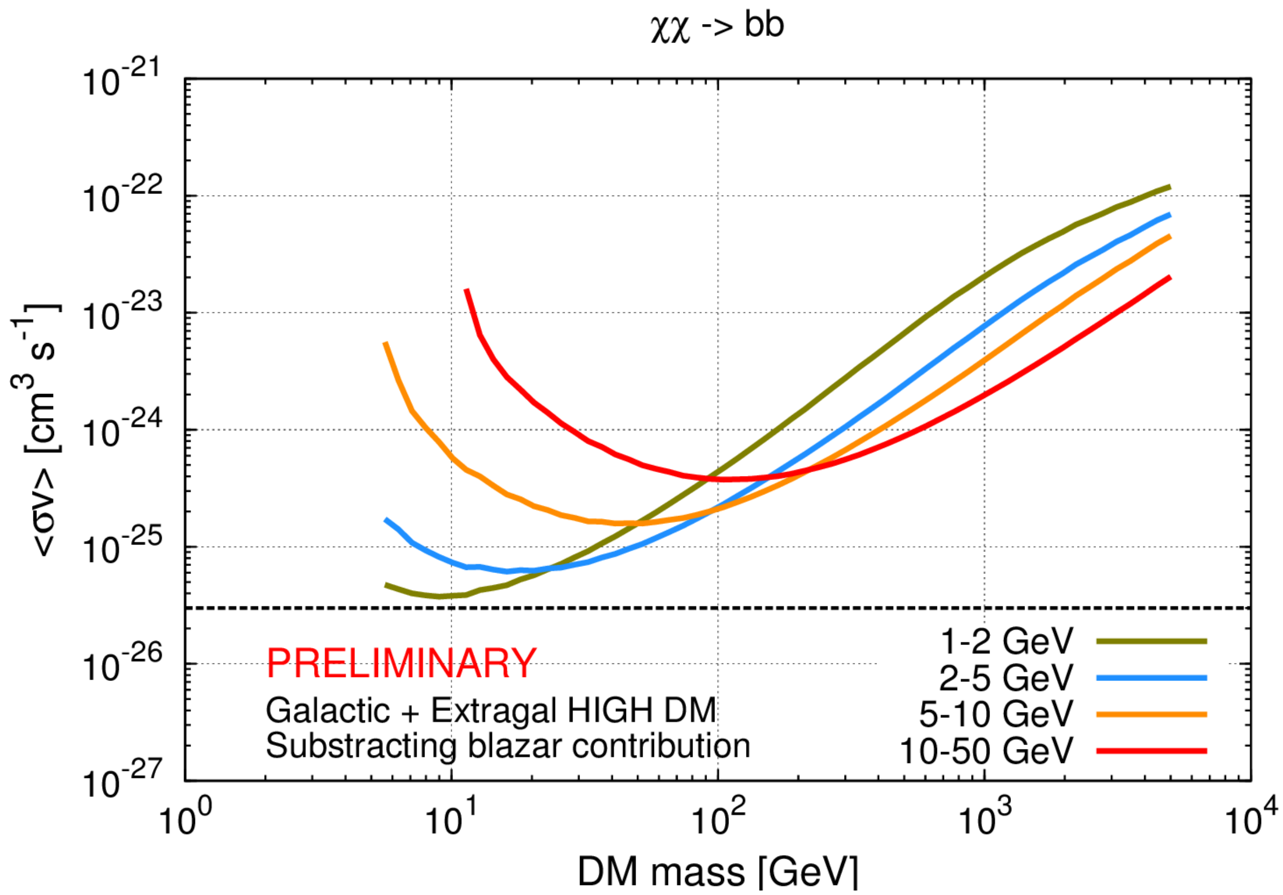
Annihilation into b quarks. Galactic structure and extragalactic halos are relatively poor in subhalos



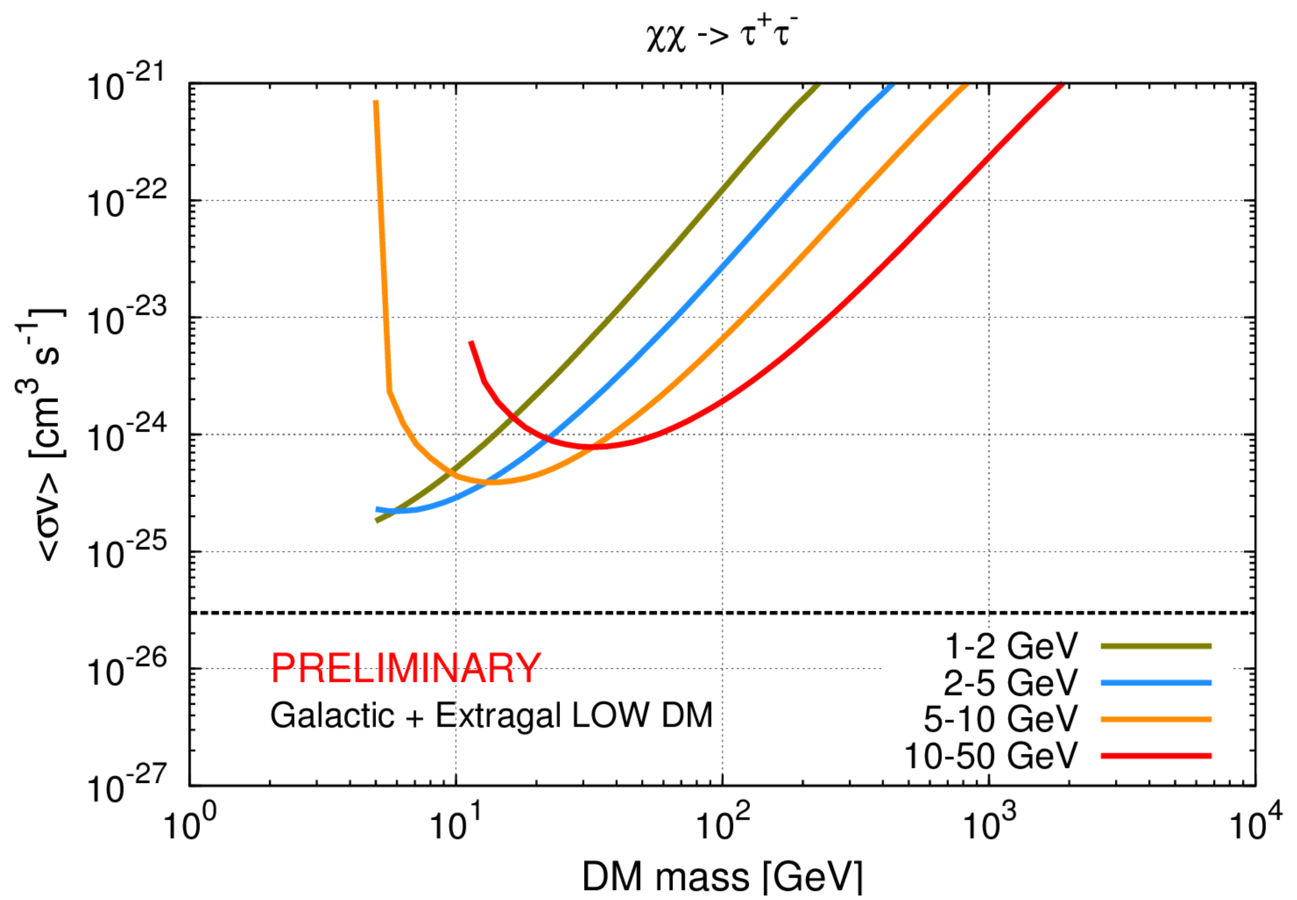
Annihilation into b quarks. Galactic structure and extragalactic halos which subhalo boost



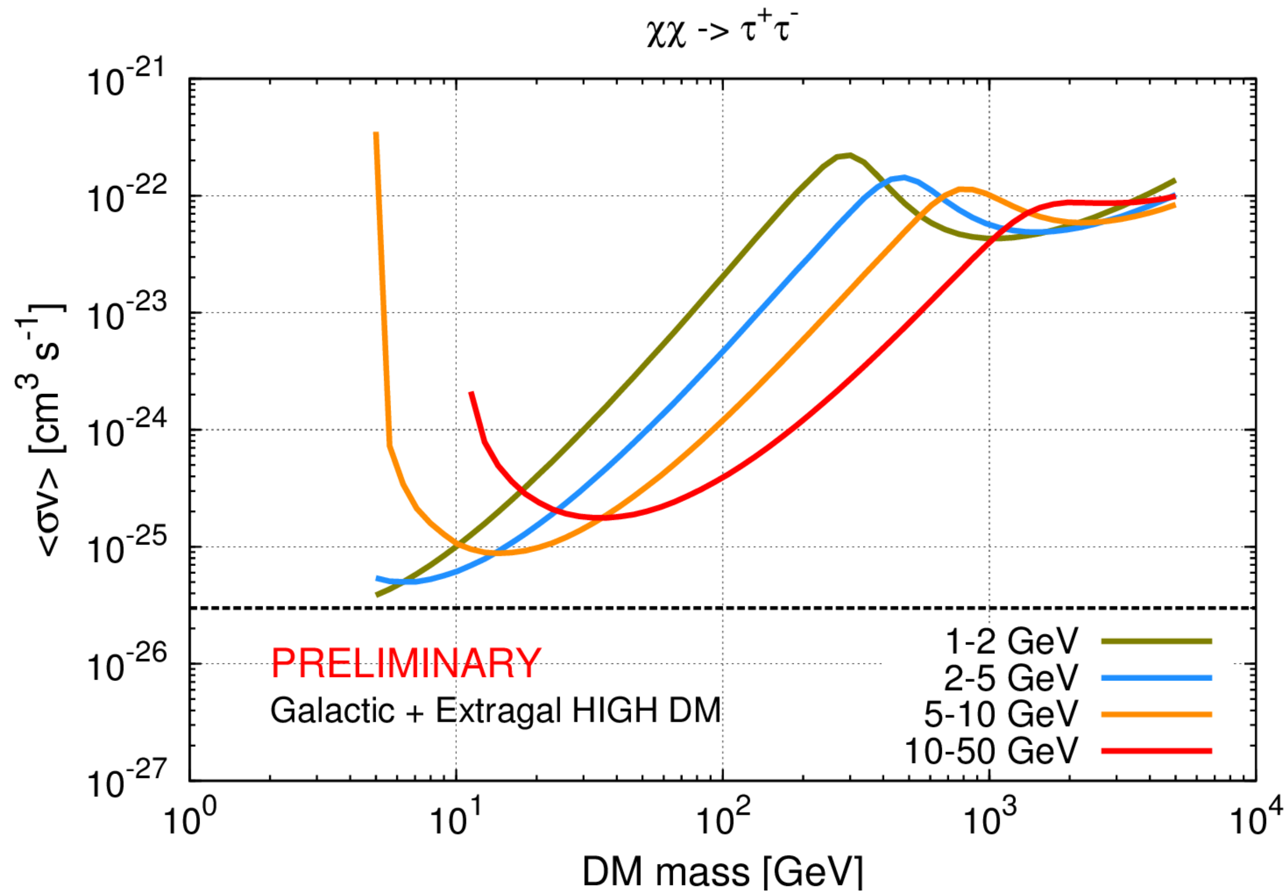
Annihilation into b quarks. Galactic structure and extragalactic halos which subhalo boost, and subtracting blazar contribution



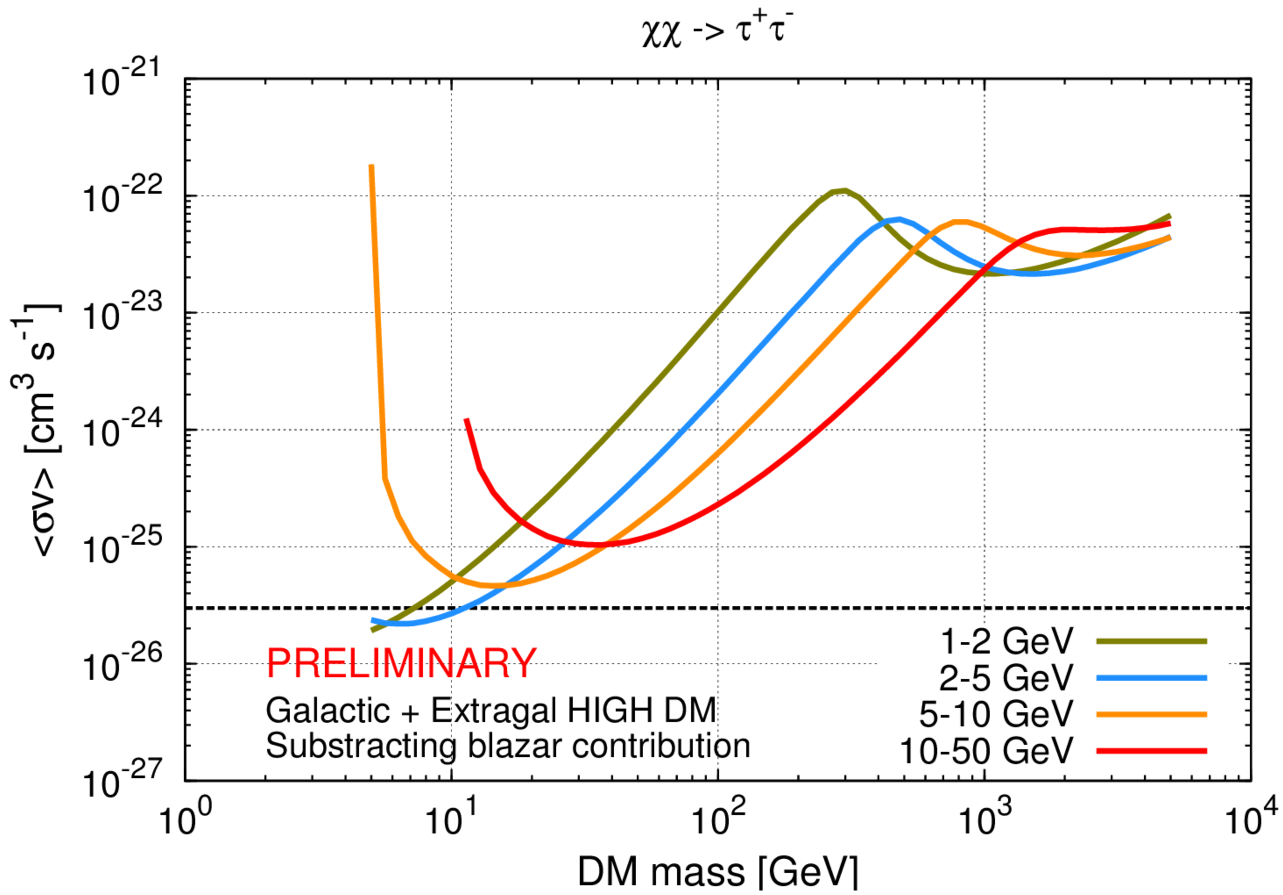
Annihilation into τ leptons. Galactic structure and extragalactic halos are relatively poor in subhalos



Annihilation into τ leptons. Galactic structure and extragalactic halos which subhalo boost



Annihilation into τ leptons. Galactic structure and extragalactic halos which subhalo boost, and subtracting blazar contribution



Summary and outlook

- 95% CL limits on the annihilation cross section for three different annihilation channels are derived using a measurement of anisotropies in the IGRB.
- The main uncertainty in the predictions obtained in [Fornasa et al. 2013] lies in the properties of low-mass subhalos, below the mass resolution of the simulations.
- Different values of the "subhalo boost" strongly aect the prediction for the DM-induced gamma-ray intensity and its anisotropies.
- The most stringent constraints on $<\sigma v>$ are obtained when predictions for the DM-induced APS (with a HIGH subhalo boost) are compared with the APS measured by Fermi-LAT once the contribution from blazars is subtracted.
- We are currently updating the Fermi-LAT APS measurement using 45 months of data, we expect to improve the constraints presented.