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Dark matter constraints from the anisotropies of the gamma-ray background measured by the Fermi-LAT

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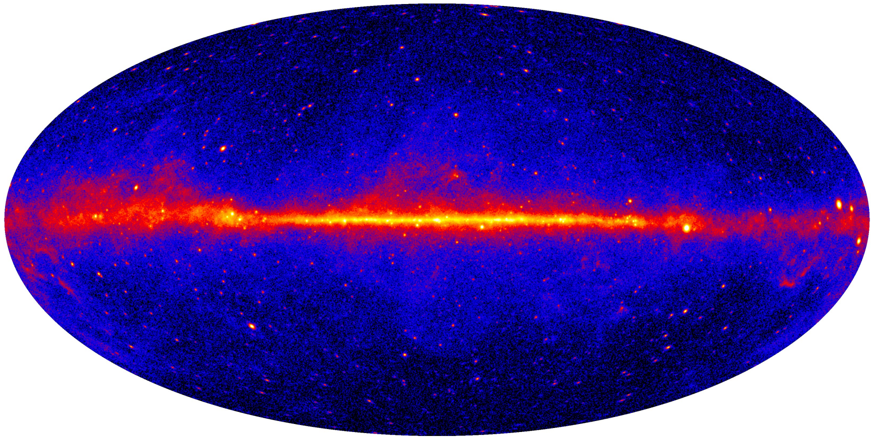
MultiDark
Multimessenger Approach for Dark Matter Detection

Fermi
Gamma-ray Space Telescope

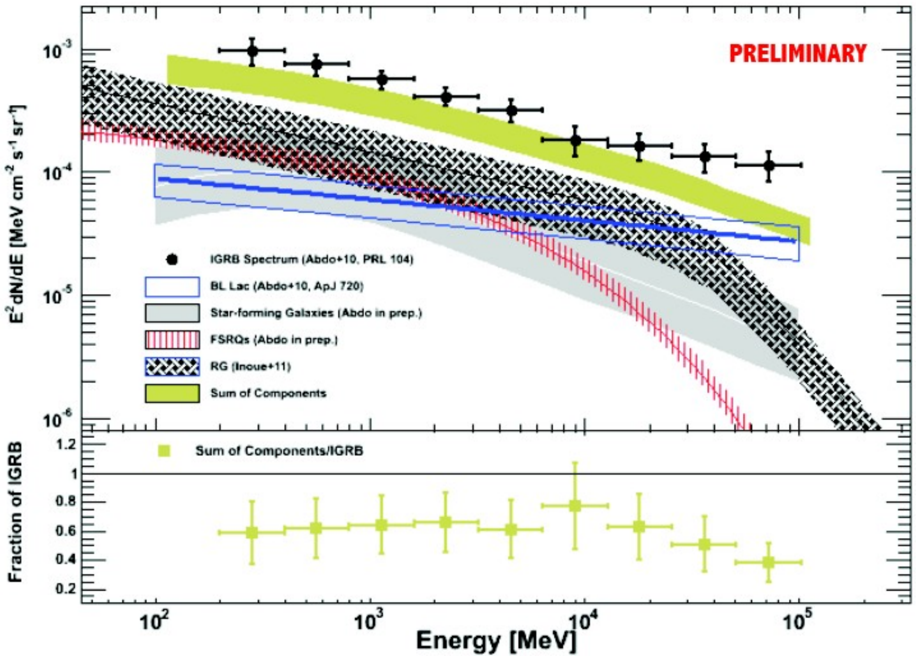
Motivation for anisotropies

- The so-called Isotropic Gamma ray Background (IGRB) is a fainter component of the diffuse emission observed by the LAT. It is considered to have an isotropic or nearly isotropic distribution on the sky.
- It is made of contribution from population sources of various kinds, including blazars, pulsars, and possibly DM structures, not yet detected due to Fermi-LAT angular resolution and photon statistics.
- The angular distribution of photons in the IGRB contains information about the presence and nature of these unresolved source populations.

36-months Fermi-LAT data



Main contributors to EGB



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:

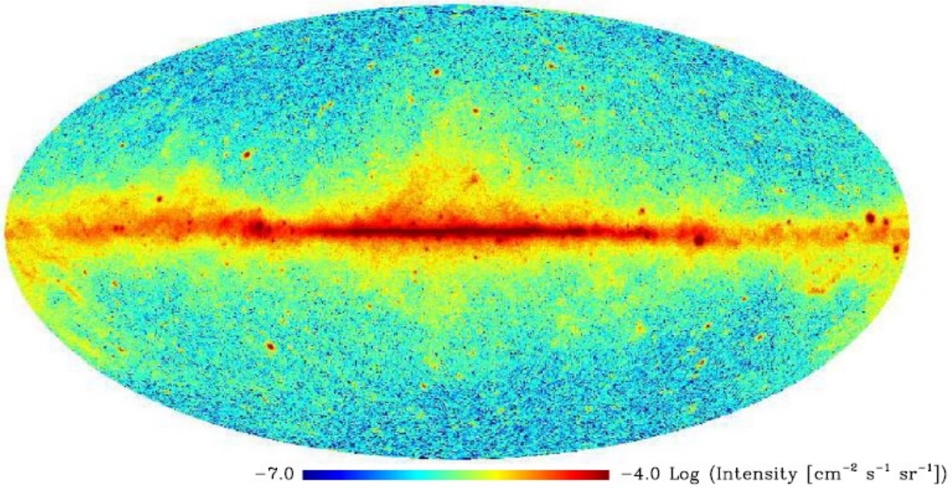
$$I(\Psi)=\sum_{lm} a_{lm} Y_{lm}(\Psi).$$

- The APS is given by the coefficients:

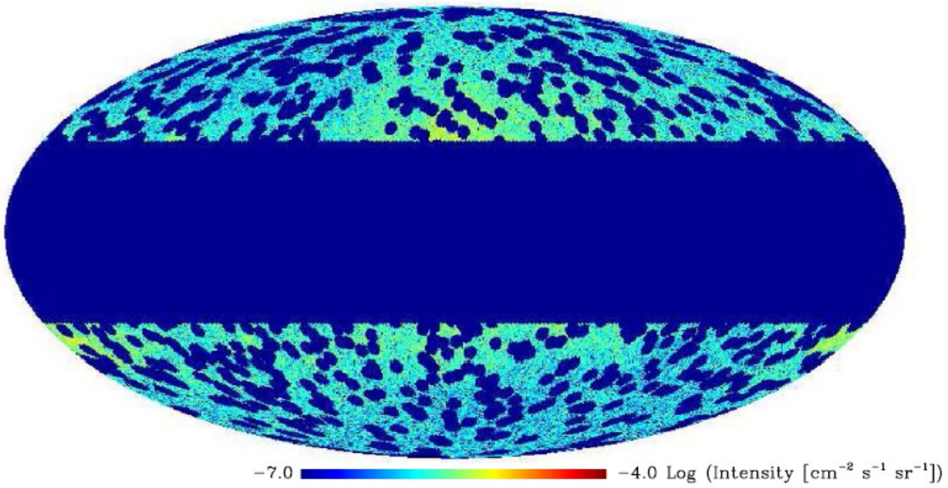
$$C_l=\langle |a_{lm}|^2 \rangle$$

- 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

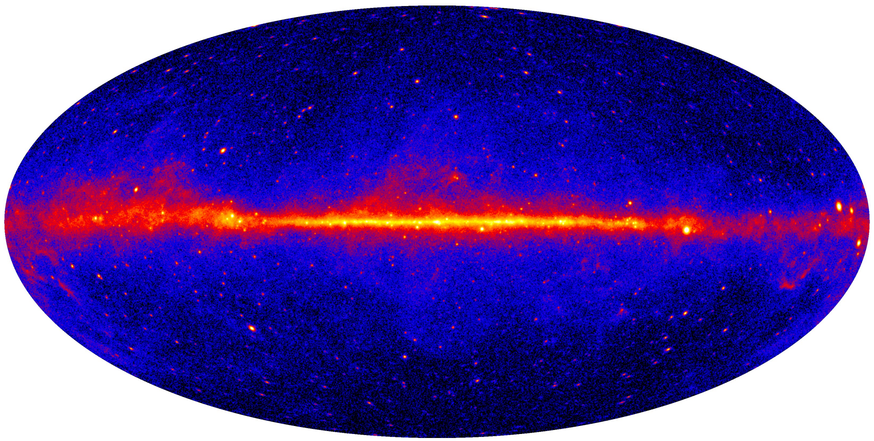


Mask applied to exclude foregrounds contamination.

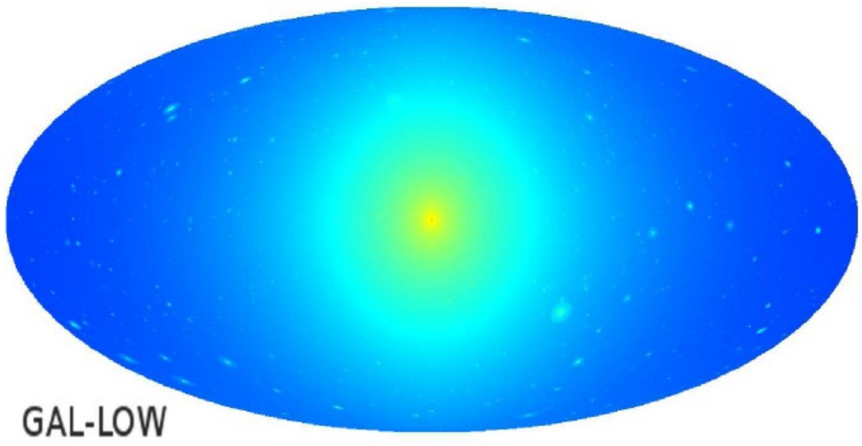


A Joint project between Fermi-LAT and MultiDark

- 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

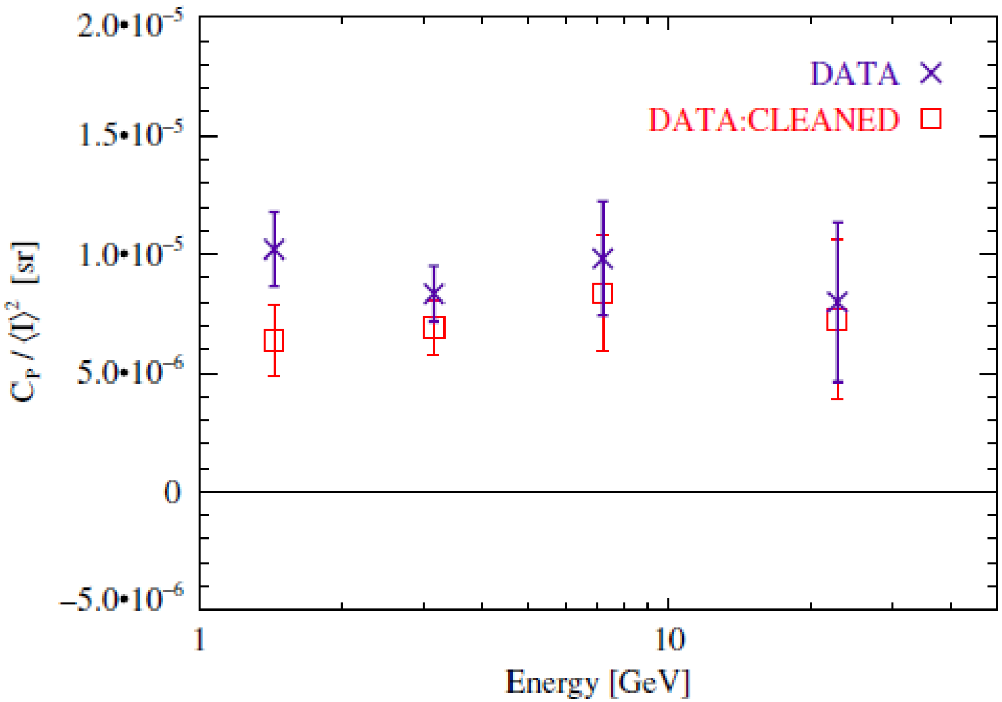


DM MultiDark map
arXiv:1207.0502

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)

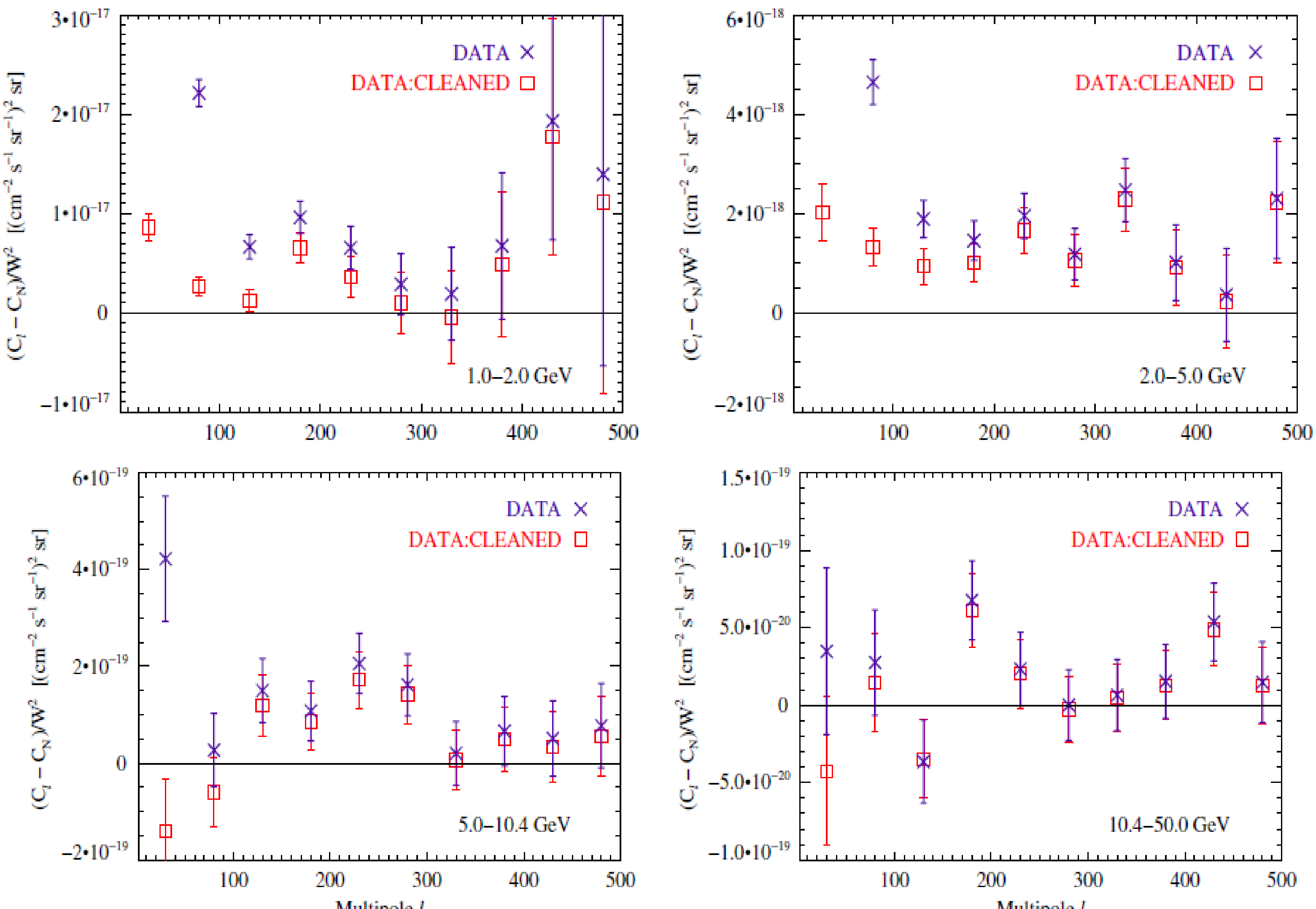
Fermi LAT measurement of APS

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.



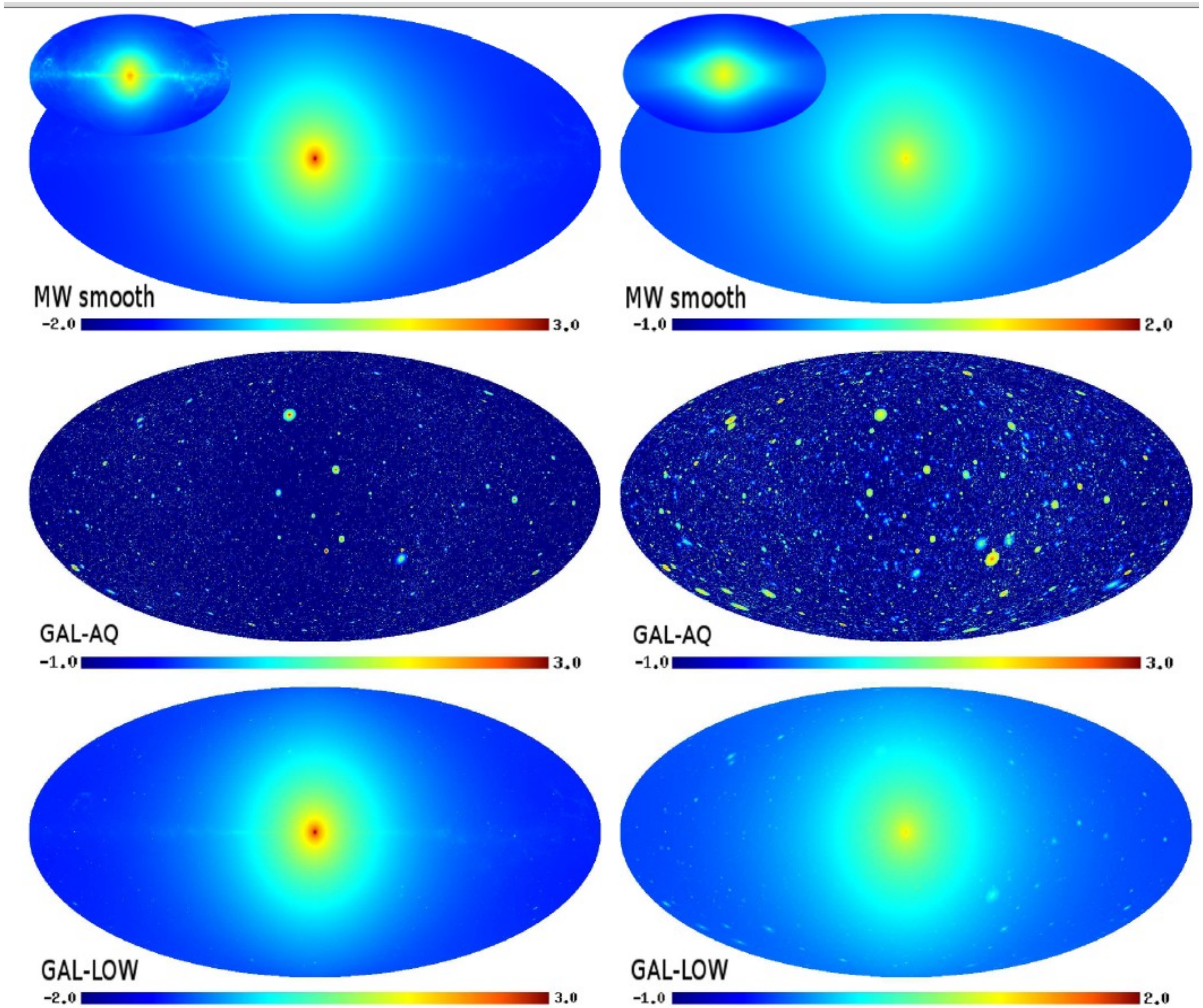
Fermi-LAT collaboration, PRD. **85** 083007 (2012)

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.

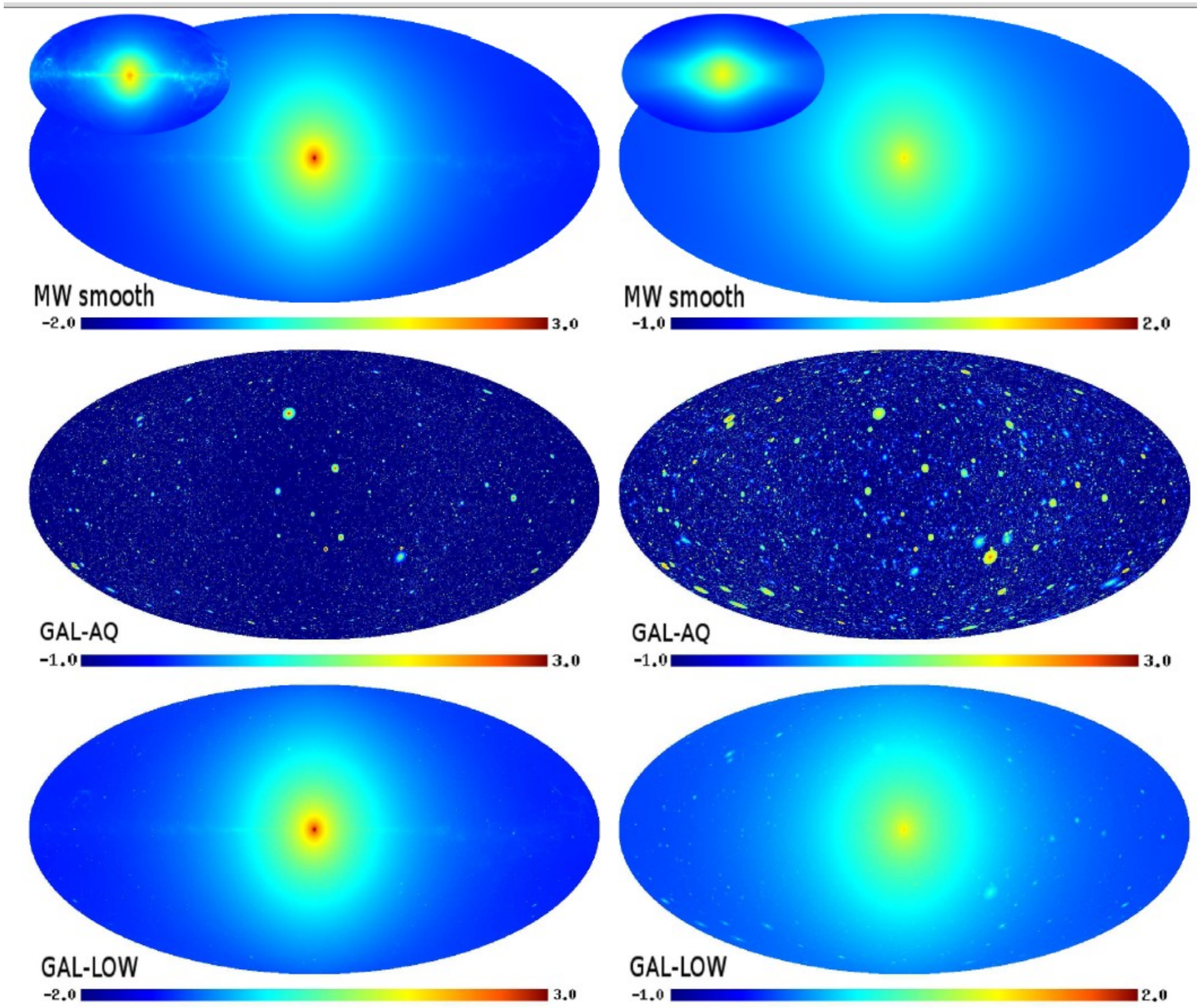


For more details on the model see Fornasa et.al. 2012 (1207.0502).

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.

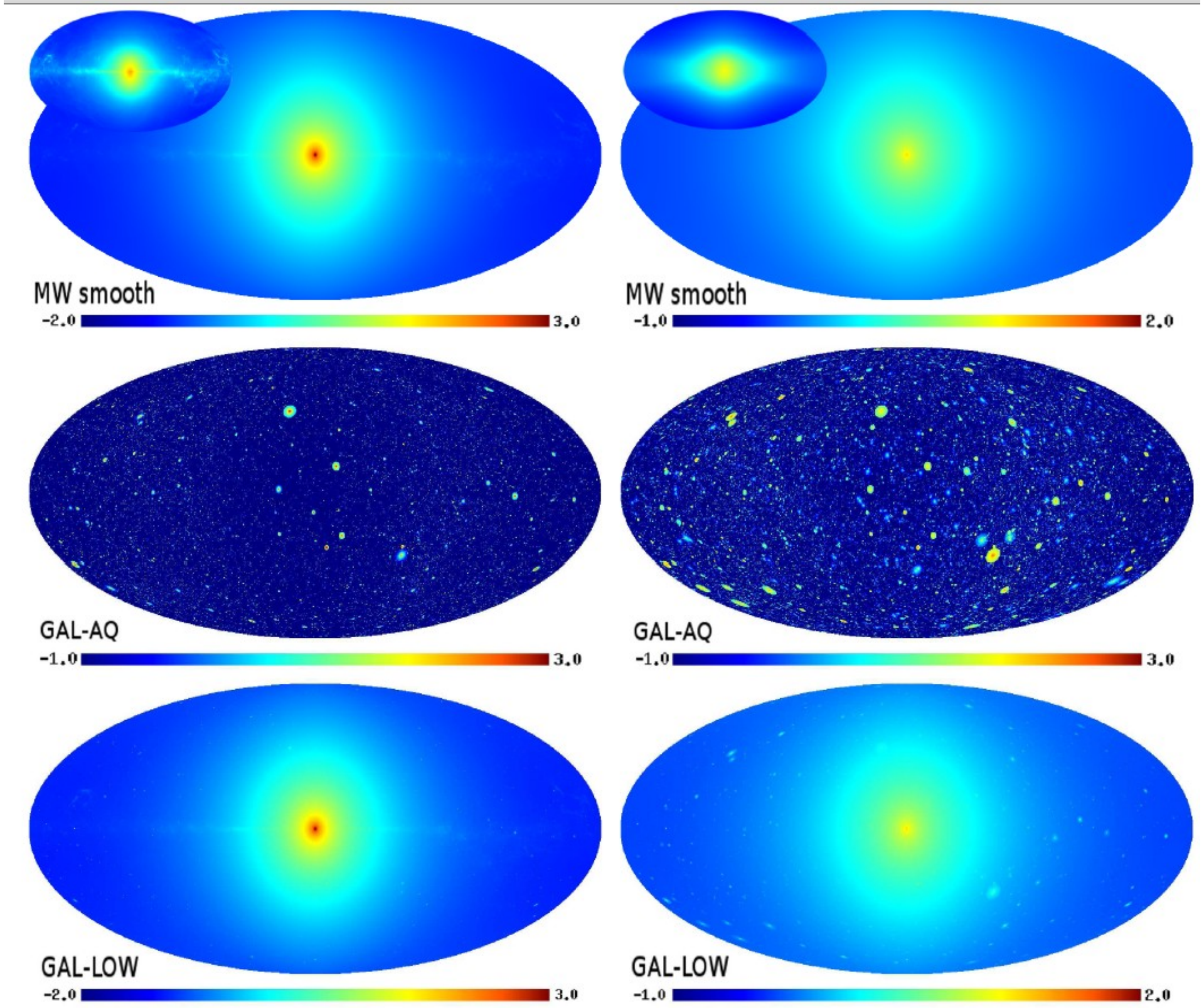


For more details on the model see Fornasa et.al. 2012 (1207.0502).

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}

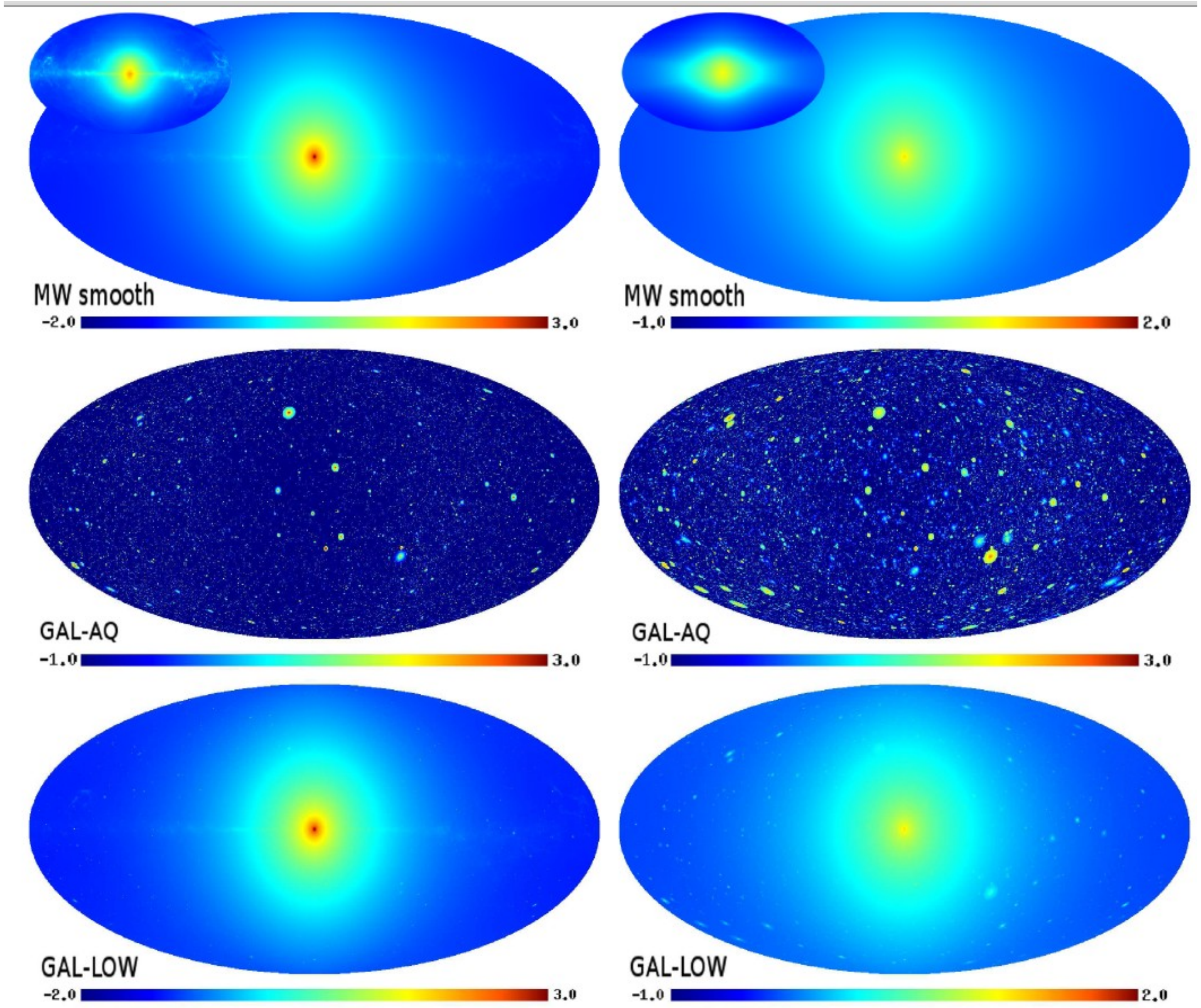


For more details on the model see Fornasa et.al. 2012 (1207.0502).

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

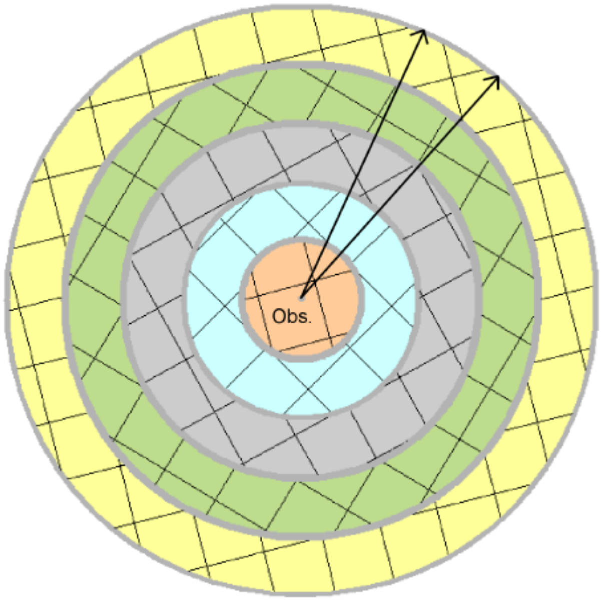
Resolved (sub)halos:
Millenium-II (MS-II) catalogs of halos and subhalos above the mass resolution of the simulations.

32 snapshots at different redshifts

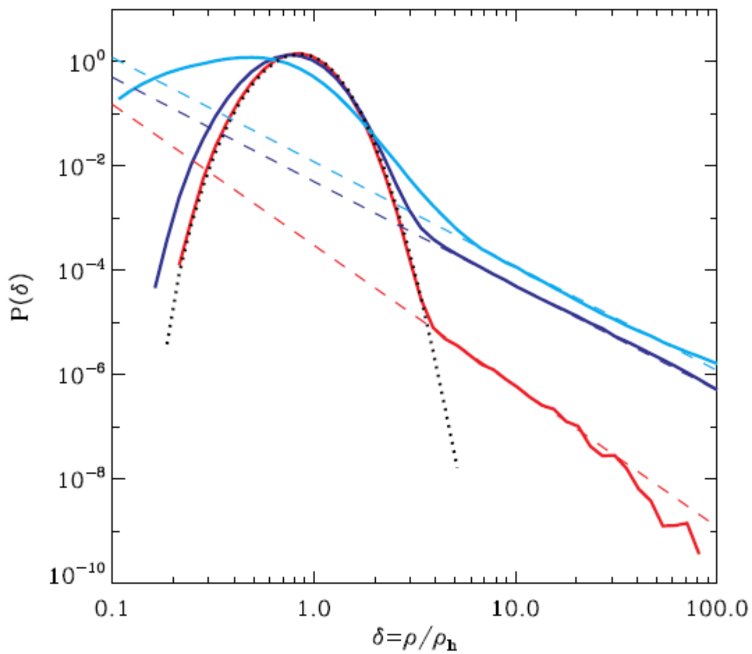
Each halo is considered with its own profile.

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



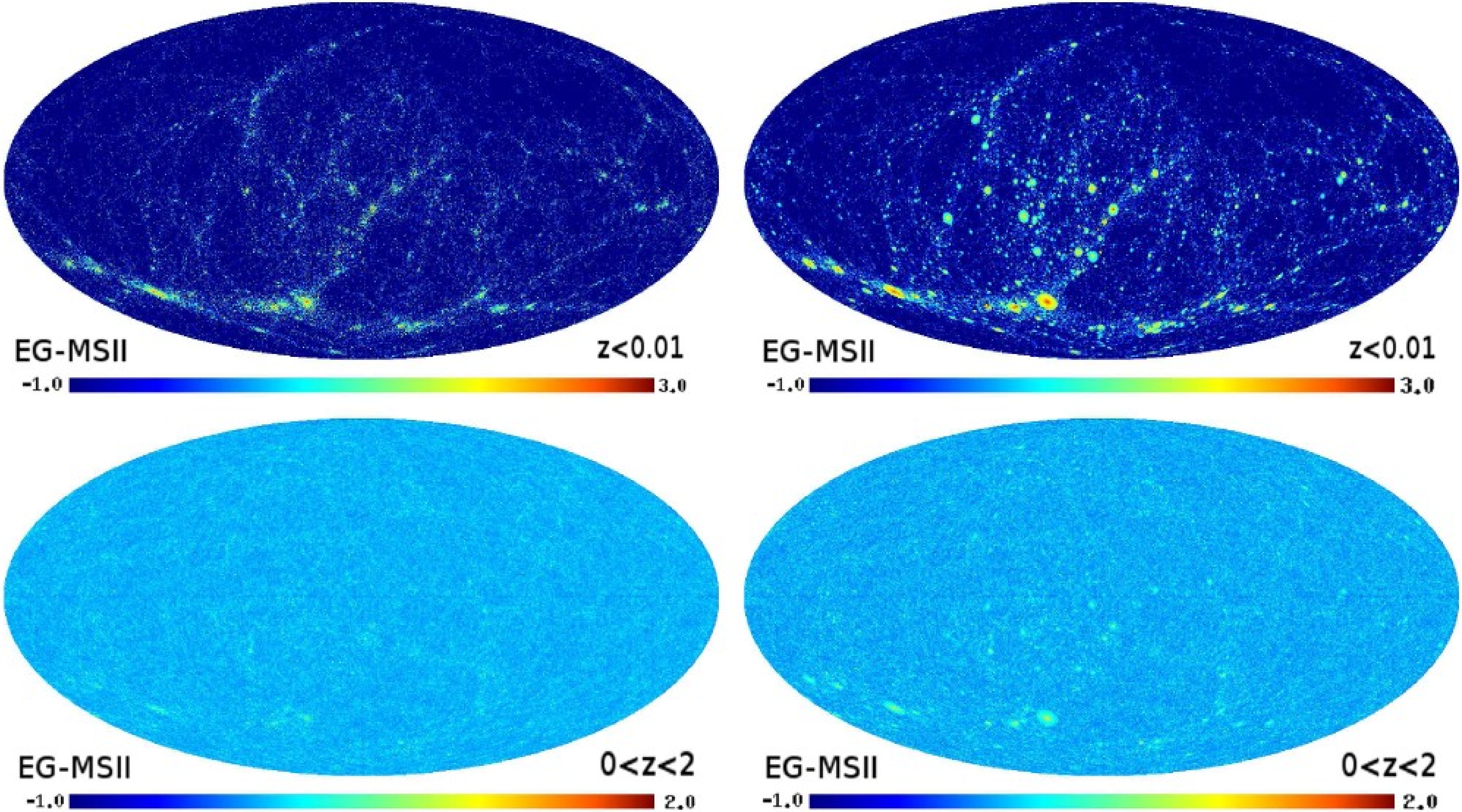
Zavala et.al, MNRAS. **405** 593 (2010)



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.

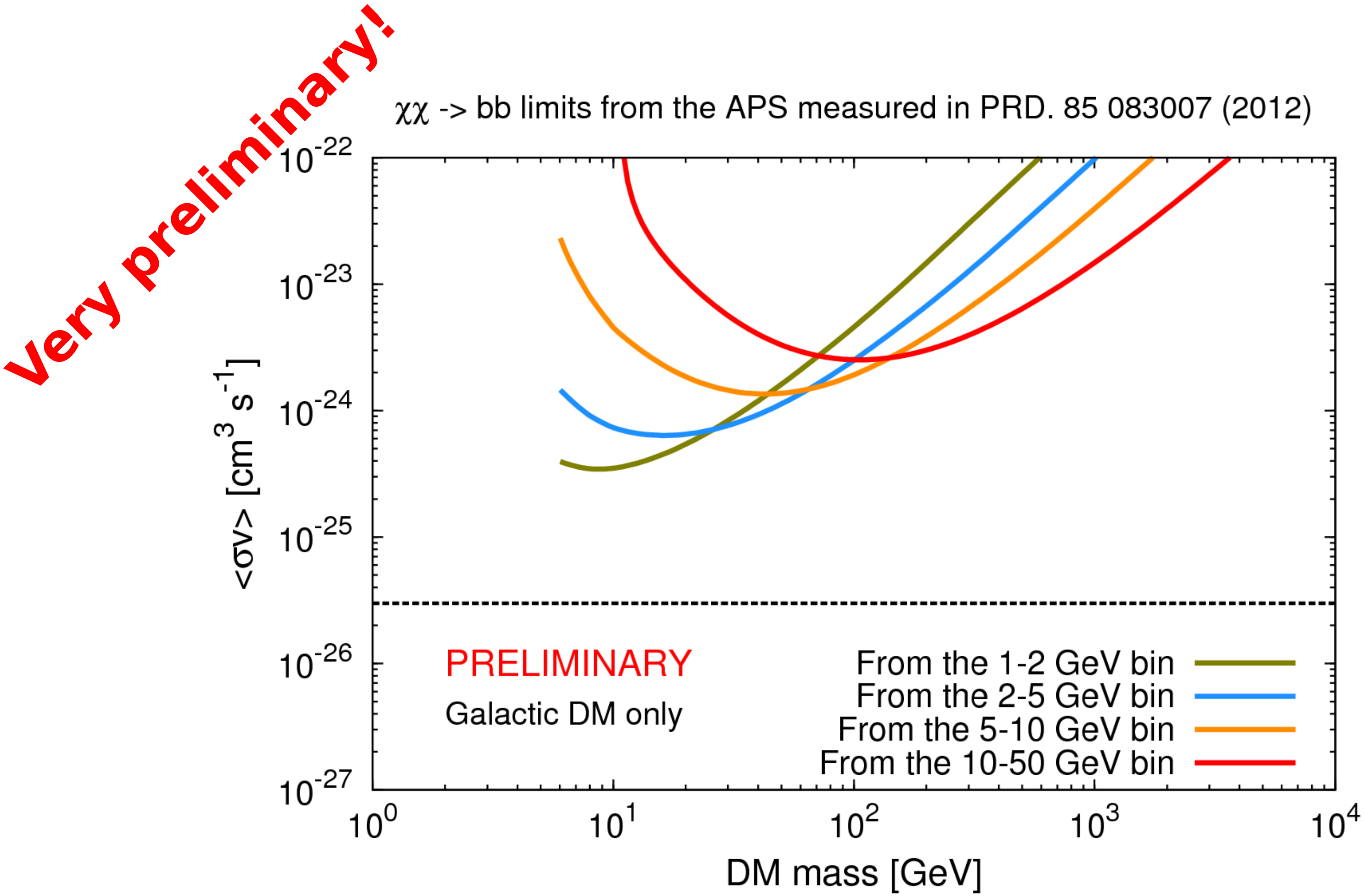
Annihilation: m=200GeV <δv>=3×10^{-26} $cm^3 s^{-1}$. Decay: m=2TeV tau=2×10^{27} s

Setting constraints

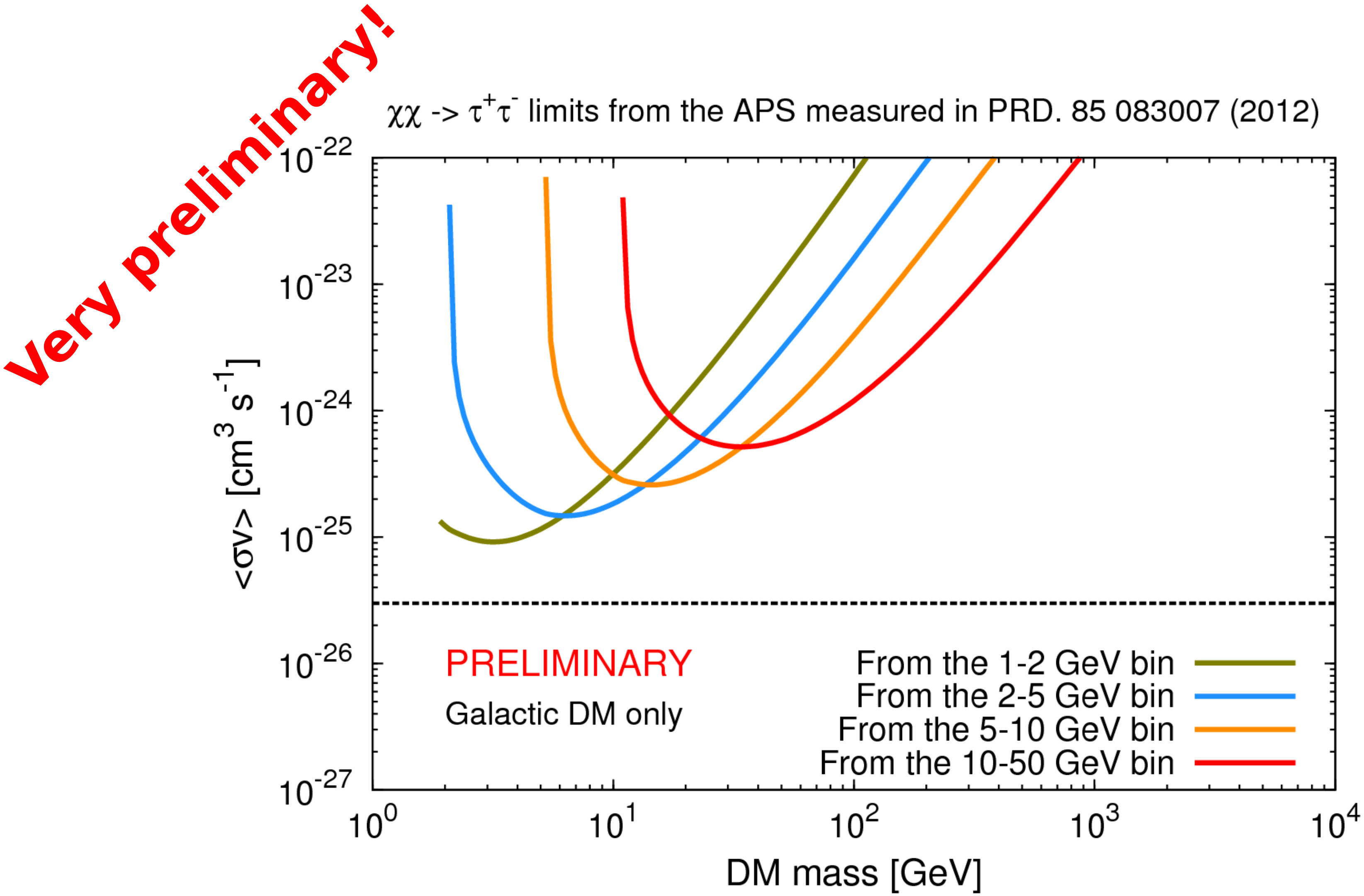
- To set constraints we use the best-fit to Cp constant values for multipoles $155<l<504$ presented in Fermi-LAT collaboration, PRD. **85** 083007 (2012). We use the 22 months DATA-CLEANED measurement.
- We require that DM-induced anisotropy averaged in $155<L<504$ does not overshoot the measured Cp in the same multipole range at 95% CL.
- For this preliminary results we are using only DM prompt emission from the Milky Way DM halo.
- We are using the already published APS measurement.
- We know that the IGRB anisotropy has multiple contributors, therefore these constraints are very conservative.
- Other contributors to IGRB anisotropy are not well known, we are working to set multi-component constraints taking into account uncertainties

Using best-fit values over the multipole range 155<l<504

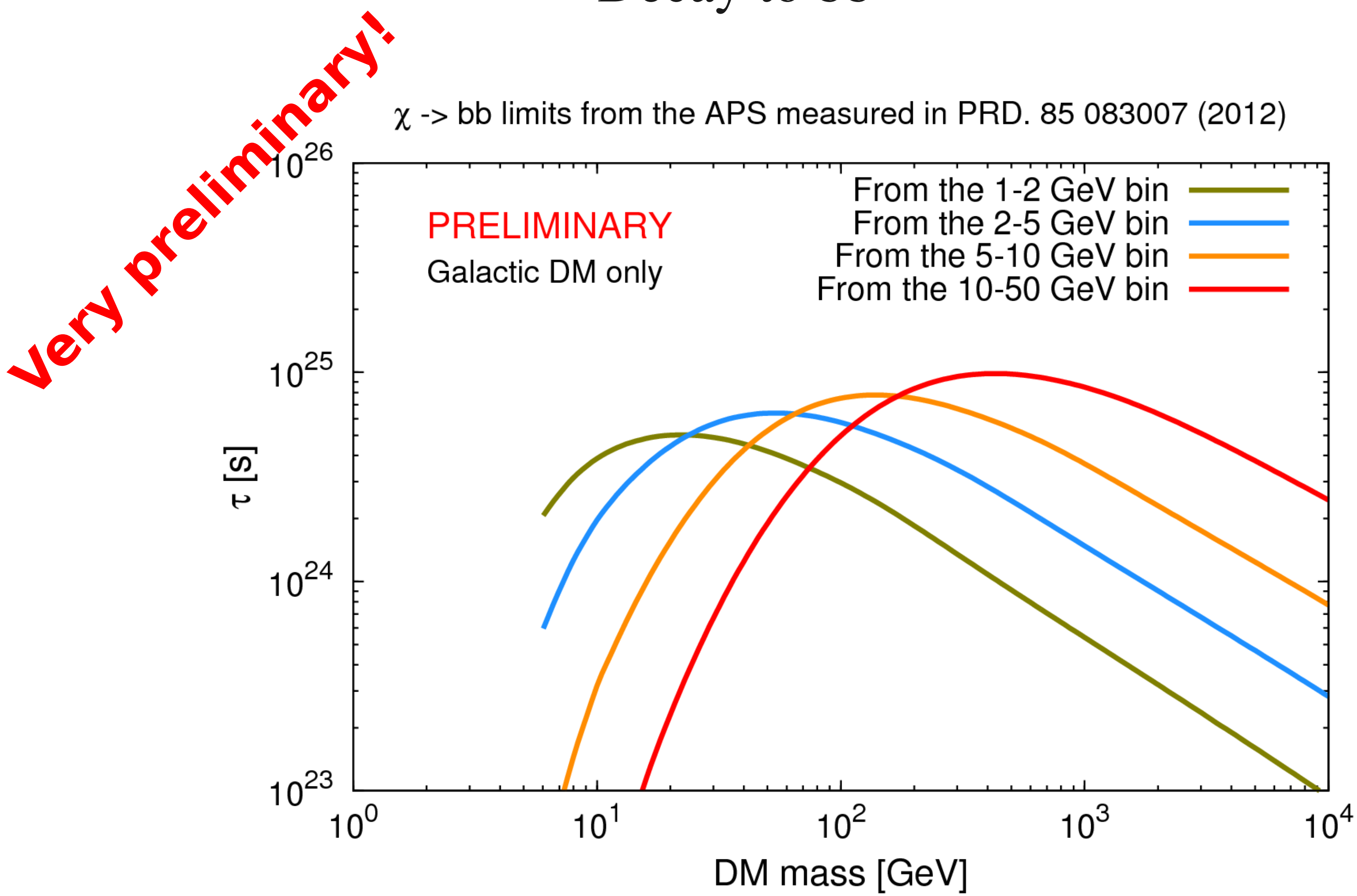
Annihilation to bb



Using best-fit values over the multipole range 155<l<504
Annihilation to $\tau^+\tau^-$

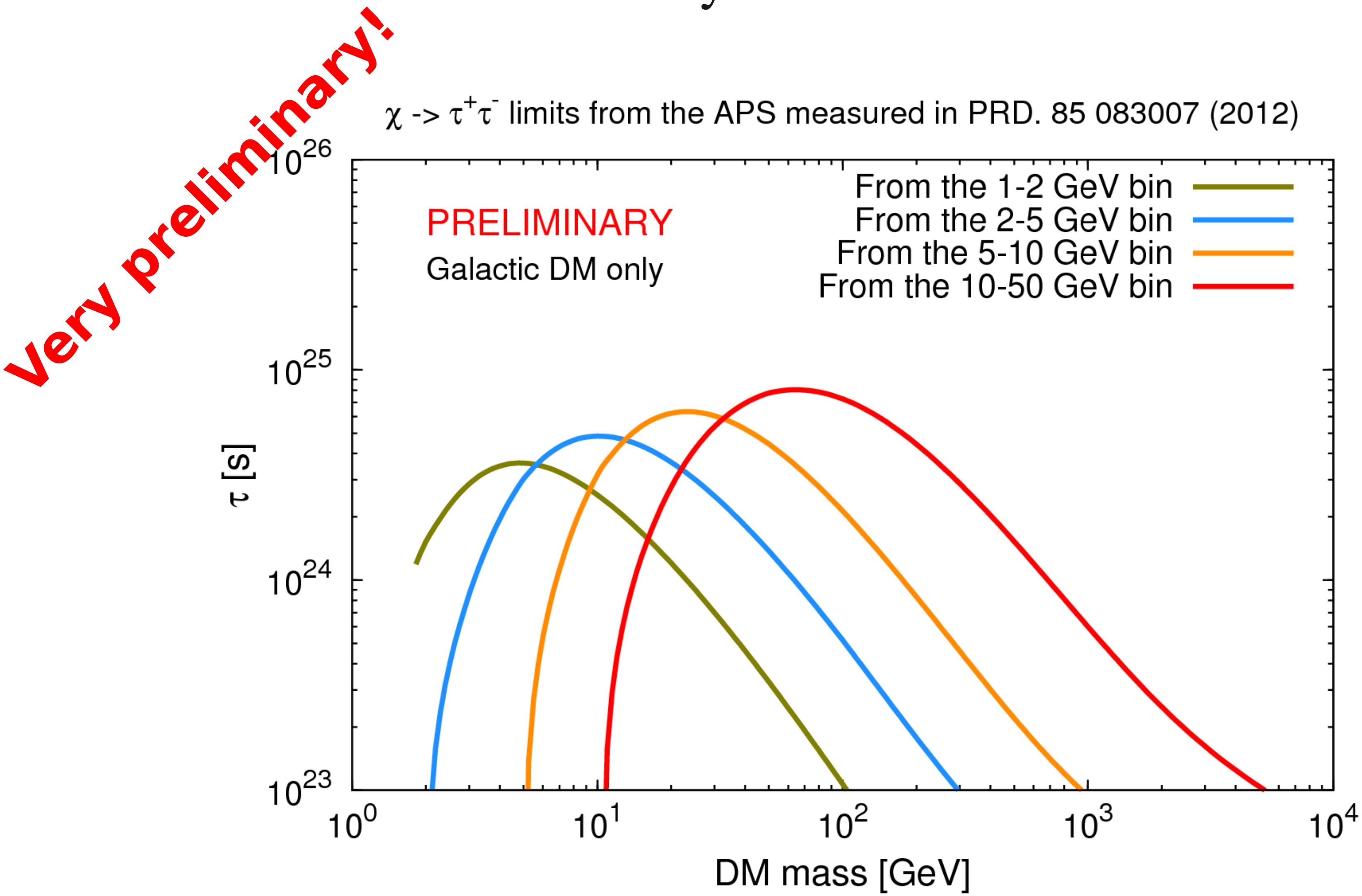


Using best-fit values over the multipole range 155<l<504
Decay to bb



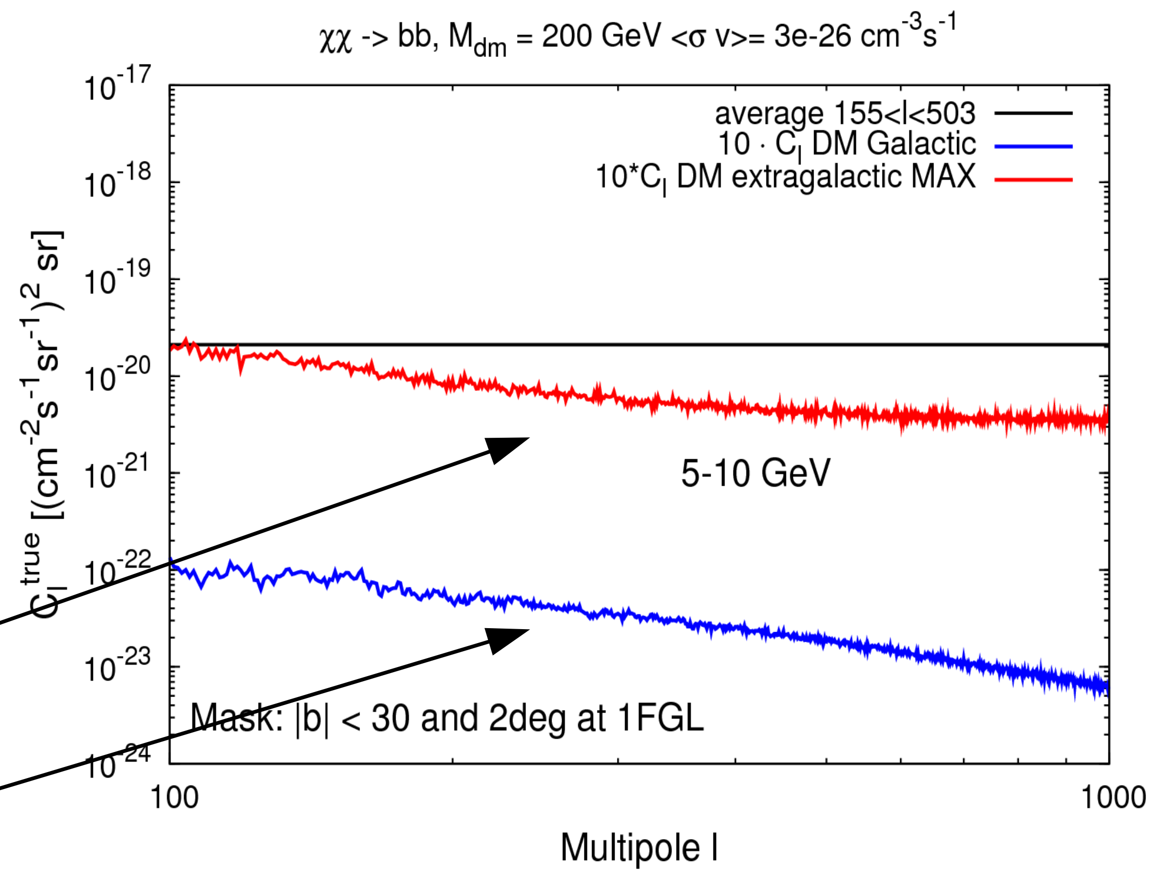
Using best-fit values over the multipole range 155<l<504

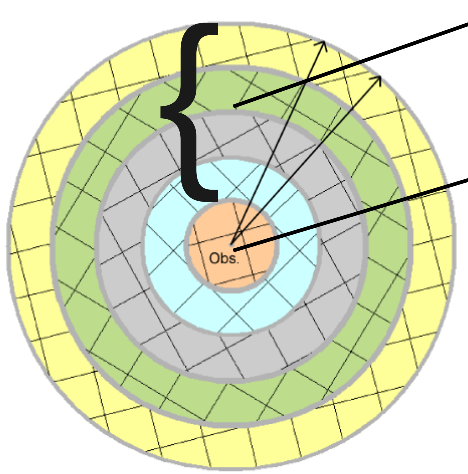
Decay to $\tau^+\tau^-$



Improving the constraints with extragalactic DM contribution

We are using only galactic prompt emission (blue line) to set constraints, but including extragalactic emission (red line) the APS can increases up to 2 orders of magnitude depending of the amount of unresolved main halos we introduce in the model.



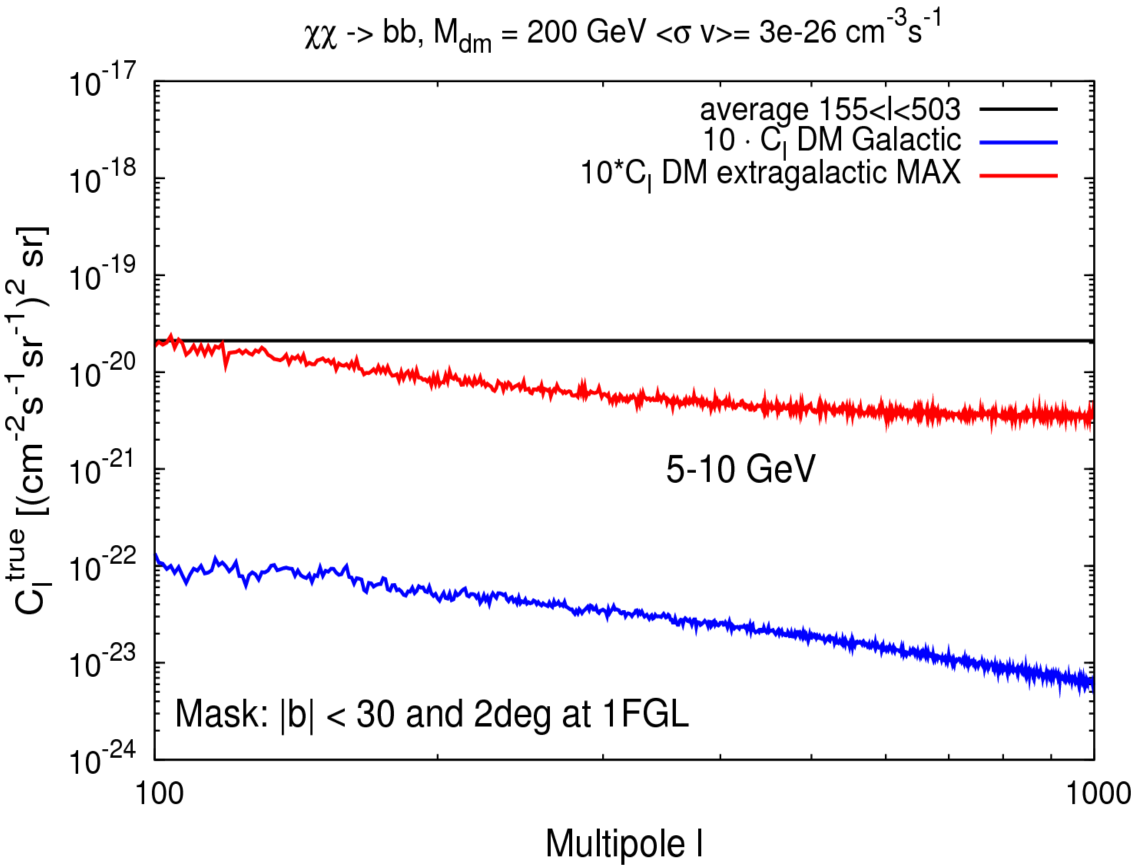


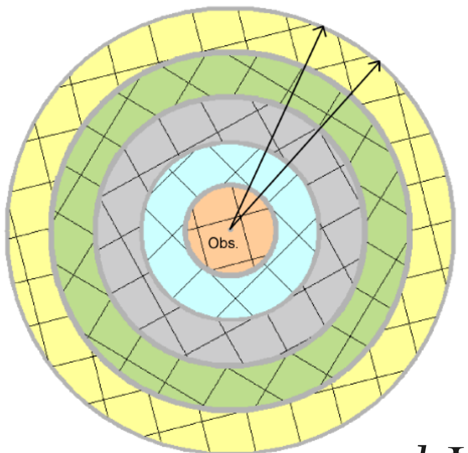
Summary and outlook

- We are presenting an implementation of a novel technique to extract information about DM nature from Fermi-LAT data which is based on general spatial features of DM distribution around us.
- We are presenting the most conservative and robust constraints we can get with the APS measured by the Fermi-LAT.
- Including extragalactic DM component and secondary emission will improve the constraints significantly.
- We are working on constraints using modeling the astrophysical backgrounds
- We intend to publish soon a thorough update of the measurement; it will feature:
  - More data: at least 38 months (vs 22 months): improve the statistics=smaller measurement uncertainties
  - Updated instrument response (P7_V6)
  - Updated even classification (ULTRACLEAN): significantly reduced charged particle contamination at high energies

Backup slides

We are using only galactic prompt emission (blue line) to set constraints, but including extragalactic emission (red line) the APS can increases up to 2 orders of magnitude depending of the amount of unresolved main halos we introduce in the model.





$$\frac{d\Phi}{dE}(E_\gamma,\Psi)=\frac{1}{4\pi m_\chi \tau}\int_{l.o.s} d\lambda \sum_i B_i \boxed{\frac{dN^i_\gamma(E_\gamma(1+z))}{dE}} \rho(\lambda(z),\Psi)\, e^{-\tau_{EBL}(z,E_\gamma)}$$