Characterization of Dark-Matter-induced anisotropies in the diffuse gamma-ray background

Mattia Fornasa
School of Physics and Astronomy – University of Nottingham
Instituto de Astrofísica de Andalucía
MultiDark fellow
Motivation

The study of anisotropies has played a fundamental role in modern physics

- alternative to the study of point sources
- complementarity with the analysis of the intensity energy spectrum
- APS mainly depends on the spatial distribution of sources
- good prospects for DM detection
Isotropic Gamma-Ray Background (IGRB)

- galactic foreground (due to interactions of cosmic rays with the interstellar medium)
- point sources
- residual emission (IGRB)

Unresolved sources contribute to the IGRB. Measured by Fermi-LAT between 300 MeV and 100 GeV and found compatible with a power-law with $\Gamma = -2.4$
Contribution of unresolved sources

Known source classes sum up to (at most) 80% of the total IGRB.

Room for new physics.

From Ajello's talk at the Fermi Symposium 2011
Fermi-LAT measurement of the APS

- data from 22 months of data
- 4 energy bins from 1 GeV to 50 GeV
- point sources and Galactic plane ($b<30$) are masked
- results tested with different foreground models, latitude cuts, etc.
- APS DATA are compared with a source MODEL

Angular power is detected in the multipole range from $\ell=155$ to and 504 with a significance of almost 7$\sigma$. 

From arXiv:1202.2856
Fermi-LAT measurement of the APS

Intensity APS
(dimensionful amplitude of anisotropies)

\[ I(\psi) = \sum_{\ell, m} a_{\ell m} Y_{\ell m}(\psi) \]

\[ C_\ell = \langle |a_{\ell m}|^2 \rangle \]

Fluctuation APS
(dimensionless, independent of intensity normalization)

\[ \frac{C_\ell}{\langle I \rangle^2} \]
Interpretation of results

1) independent on multipoles: unclustered sources

2) independent on energy (fluctuation APS): one single population of sources contributing

3) shape of the energy dependence of the intensity APS gives you information on the emission of the sources contributing

From arXiv:1202.2856
Overview of the project

Build a map of DM distribution around us that is as complete and realistic as possible (arXiv:1207.0502)

- both annihilating DM and decaying DM are considered
- the DM distribution is modeled from the results of the most recent $N$-body simulations (Millennium-II and Aquarius)
- we also account for the contribution of halos and subhalos below $M_{\text{res}}$ down to $M_{\text{min}}$
- “theoretical uncertainties” are discussed (and quantified)

The maps will work as template for DM emission and will be included in the “source model”

- Fermi APS data will be extended to 3 years of data
- DM template maps used to put constraints
- contribution of astrophysical sources will also be considered
“Resolved” (sub)halos

- Millennium-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

From arXiv:0908.2428
Extragalactic DM (sub)halos

“Resolved” (sub)halos
- Millennium-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 $M_{\text{min}}$ is computed analytically
- used to boost up the flux of the smallest objects in MS-II
Extragalactic DM (sub)halos

“Resolved” (sub)halos
- Millennium-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

“Unresolved” subhalos
- probability of having subhalos at different distances from the center of halos
- tune the model to account for different subhalo boosts
Extragalactic DM (sub)halos

Annihilation

Decay

$E = 4 \text{ GeV. } b \text{ channel. } M_{\text{min}} = 10^{-6} \text{ solar masses.}$

Annihilation: $m_{\chi} = 200 \text{ GeV } \sigma v = 3 \times 10^{-26} \text{ cm}^3 \text{s}^{-1}$. Decay: $m_{\chi} = 2 \text{ TeV } \tau = 2 \times 10^{27} \text{s}$
Milky Way smooth halo and its subhalos

Smooth halo

• parametrized as en Einasto profile (taken from Aquarius)
• local density fixed at 0.3 GeV cm\(^{-3}\)

Galactic subhalos (resolved and unresolved)

• Aquarius subhalo catalogs are used
• unresolved objects modeled as in the extragalactic case (LOW and HIGH).
  The contribution of unresolved subhalos to the APS has been proved to be negligible (analytic model based on Ando 2009)

\(E=4 \text{ GeV. Annihilation: } \chi m = 200 \text{ GeV } \sigma v = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1}. \) \(\text{Decay: } \chi m = 2 \text{ TeV } \tau = 2 \times 10^{27} \text{s. } M_{\text{min}} = 10^{-6} \text{ sol, mass} \)
Intensity of the DM-induced emission

- Extragalactic (sub)halos in MS-II catalogs
- Total extragalactic emission (LOW subhalo boost)
- Total extragalactic emission (HIGH subhalo boost)
- Dashed: galactic subhalos in the Aquarius catalogs
- Dashed: MW smooth halo
- Dashed: total galactic emission (LOW sub. boost)
- Dashed: total galactic emission (HIGH sub. boost)

Annihilation: $m = 200$ GeV
$\sigma v = 3 \times 10^{-26}$ cm$^3$s$^{-1}$

Decay: $m = 2$ TeV $\tau = 2 \times 10^{27}$ s.
$b$ channel. $M_{\text{min}} = 10^{-6}$ solar masses
Intensity of the DM-induced emission

Annihilation: $m_\chi = 200$ GeV
$\sigma v = 3 \times 10^{-26} \text{ cm}^3\text{s}^{-1}$

Decay: $m_\chi = 2$ TeV $\tau = 2 \times 10^{27}$ s.

$b$ channel.
APS of the DM-induced emission

Extragalactic (sub)halos in MS-II catalogs
Extr. (sub)halos in MS-II + extragalactic main halos
Total extragalactic emission (LOW subhalo boost)
Total extragalactic emission (HIGH subhalo boost)

Dashed: galactic subhalos in the Aquarius catalogs
Dashed: MW smooth halo
Dashed: total galactic emission (LOW sub. boost)
Dashed: total galactic emission (HIGH sub. boost)
APS of the DM-induced emission

Fluctuation APS

Intensity APS

\[ C_\ell^{\text{fluct}} \equiv \left( \frac{d\Phi}{dE} \right)^{-2} C_\ell = \sum_i \frac{\langle d\Phi^i/dE \rangle^2}{\langle d\Phi/dE \rangle^2} C_{\ell,i}^{\text{fluct}} = \sum_i f_i^2 C_{\ell,i}^{\text{fluct}} \]

- Extragalactic (sub)halos in MS-II catalogs
- Extr. (sub)halos in MS-II + extragalactic main halos
- Total extragalactic emission (LOW subhalo boost)
- Total extragalactic emission (HIGH subhalo boost)

- Dashed: galactic subhalos in the Aquarius catalogs
- Dashed: MW smooth halo
- Dashed: total galactic emission (LOW sub. boost)
- Dashed: total galactic emission (HIGH sub. boost)
Annihilation: $m_{\chi} = 200$ GeV $\sigma v = 3 \times 10^{-26}$ cm$^3$s$^{-1}$. Decay: $m_{\chi} = 2$ TeV $\tau = 2 \times 10^{27}$ s. b channel.
Conclusions

- Nature of IGRB is still unknown and predictions from known source classes cannot reproduce the whole emission
  - Information can be obtained from the study of the IGRB anisotropies
  - Fermi-LAT detection of angular power above $\ell=155$ from 1 to 50 GeV
- Possibility of extracting constraints on the DM particle from the comparison of template maps of DM emission with the Fermi-LAT data
  - Keep a look to the arXiv for our publications!
Energy dependence of the APS

\[
\frac{C_{P,\text{tot}}}{\langle I_{\text{tot}} \rangle^2} = f_1^2 \frac{C_{P,1}}{\langle I_1 \rangle^2} + f_2^2 \frac{C_{P,2}}{\langle I_2 \rangle^2} + \ldots
\]