Dark Matter Gamma-ray Emission from the Local Universe

CLUES from Fermi

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OVERVIEW

• Dark Matter Gamma Emission
• Constrained Simulation from the CLUES project

• *Fermi*-LAT All-Sky Maps

• The $\mu$νSSM Gravitino Case
• Outlook
In the last years, many evidences for the existence of Dark Matter (DM) have been accumulated (e.g. rotational curves, lensing, Bullet cluster).

We do not know what DM is... BUT we know that the DM particle should:

- be NOT - BARYONIC
- be COLD (non-relativistic when decoupling)
- have NEUTRAL ELECTRIC and COLOR CHARGES
- interact only via GRAVITATIONAL and WEAK forces
- be MASSIVE

WIMPs: Weakly Interacting Massive Particles
Direct products of decay or annihilation of DM particles are model dependent. HOWEVER, the decay and hadronisation of these products result in $\gamma$-rays:

$$\Phi(E > E_0) = J(\Psi) \cdot \Phi^{PP}(E > E_0)$$

**ASTROPHYSICAL FACTOR:**
- DM distribution
- instrument PSF, $\Delta E$, effective area

**PARTICLE PHYSICS FACTOR:**
- DM mass and cross section
- $\gamma$-ray spectrum
Constrained simulations are a particular case of cosmological N-body simulations in which observational data are used to set the initial conditions, reproducing in this way the main features visible on the sky. We use that to obtain realistic all-sky DM maps of the Local Universe.

The observer is placed at the right distance with respect to Virgo (fixed in its real position) and the all-sky map is rotated to minimise the Coma, Perseus and GA distances with respect to their real positions.

- Only particles with distance between 5 and 80 \( h^{-1} \) Mpc from the observer are considered.
- The halos’ central density is typically underestimated and it has been corrected analytically.
- No boost factors are taken into account.

Klypin et al. 2003
Constrained Simulations
THE ALL-SKY DM MAPS

DM decay "luminosity" all-sky map in Cartesian projection and galactic coordinates

\[ L_i = \sum \frac{m_p}{4\pi d_i^2} \]

Cuesta et al. 2011
Constrained Simulations
THE ALL-SKY DM MAPS

DM *annihilation* "luminosity" all-sky map in Cartesian projection and galactic coordinates

\[
L_i = \sum m_p \rho_i / 4\pi d_i^2
\]

Cuesta et al. 2011

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**Fermi All-Sky DM Maps**  
**THE SATELLITE**

- **Fermi** satellite was successfully launched on 11\textsuperscript{th} June 2008
- It constantly surveys the sky between 100 MeV and 300 GeV
- After 1 year of operation, **more than 1400 point-like sources** have been detected by LAT, while the previous $\gamma$-ray satellite, EGRET, discovered 270 sources in almost 10 years of operation!

*Fermi is revolutionising our vision of the $\gamma$-ray Universe*
The DM density and density-squared maps are taken as input for the Fermi observation simulation tool to obtain 5-year observation photon count maps:

- we use the routine `gtobssim` of Fermi Science Tool (v9r15p2)
- we consider the Fermi instrument response function
- we take into account the extragalactic & galactic background as released by the Fermi collaboration

Running the Fermi simulations, we use as input two different DM particle physics models:

- 100 GeV neutralino
  - b-bbar channel
  - SUSY “bino-like” LSP
  - $\langle \sigma v \rangle = 1 \times 10^{-23} \text{ cm}^3 \text{ s}^{-1}$
  - $\tau = 1 \times 10^{26} \text{ s}$

- 1.6 TeV particle
  - $\mu^+\mu^-$ channel
  - fits PAMELA $e^\pm$ data
  - $\langle \sigma v \rangle = 5.8 \times 10^{-23} \text{ cm}^3 \text{ s}^{-1}$
  - $\tau = 3 \times 10^{26} \text{ s}$
By running *Fermi* observation simulation (5-year survey) we properly take into account the REAL backgrounds and instrument response → **S/N maps**

*DM decay (b-bbar channel)*

Cuesta et al. 2011
By running *Fermi* observation simulation (5-year survey) we properly take into account the **REAL** backgrounds and instrument response $\rightarrow$ **S/N maps**

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*DM annihilation (b-bbar channel)*

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*Cuesta et al. 2011*
CONCLUSION SUMMARY

The most promising clusters for DM studies are the ones at high-galactic latitude (e.g. Virgo, Coma, Perseus)

DM Decay:
• nearby clusters and filamentary regions could be detected by Fermi in a 5-year survey and the satellite can improve significantly the present DM decay constraints (e.g. recent Dugger, Jeltema, Profumo 2010)
• S/N is not very sensitive to the area of the considered region, making possible analysis of few-degrees areas (masking away the point-like sources)
• filamentary structure of the cosmic web constitutes a new interesting target for DM indirect searches: this is the first time that filaments are considered as DM targets

DM Annihilation: we did not found strong evidences in favour of an extra-galactic detection, but we cannot exclude this possibility considering that we are not using any type of boost factor!
The density and density-squared maps are available on-line in fits format:

http://www.clues-project.org/articles/darkmattermaps.html

and you are strongly encouraged to use it!
The gravitino is an excellent DM candidate in the $\mu\nu$SSM theory. $\mu\nu$SSM stays for “$\mu$ from $\nu$” Super-symmetric Standard Model (Lopez-Fogliani & Muñoz 2006) where the MSSM $\mu$-problem is solved by means of the neutrinos’ right-handed super-fields.

→ a Higgs mass term is correctly generated together with the neutrino masses at the correct electro-weak scale without any ad-hoc scale assumption.

→ in $\mu\nu$SSM the R-parity is broken and the LSP is no longer stable since it decays in standard model particles.

→ the gravitino is a DM candidate in theories where the R-parity is broken (Takayama & Yamaguchi 2000) in particular in the $\mu\nu$SSM scenario (Choi, Lopez-Fogliani, Muñoz & Ruiz de Austri 2010).
The gravitino decays through the interaction gravitino-photon-photino due to the photino-neutrino mixing after sneutrinos develop their vacuum expectation values (VEVs) opening the following channel:

\[ \Gamma(\psi_{3/2} \rightarrow \gamma \nu) = \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{3/2}^3}{M_P^2} \]

However it is suppressed (both by the Planck mass and the R-parity breaking), therefore the gravitino lifetime can be longer than the age of the Universe:

\[ \tau_{3/2} \simeq 3.8 \times 10^{27} \text{s} \left( \frac{|U_{\tilde{\gamma}\nu}|^2}{10^{-16}} \right)^{-1} \left( \frac{m_{3/2}}{10 \text{ GeV}} \right)^{-3/2} \]

Since the gravitino decays into a photon and a neutrino, the former produces monochromatic lines at energies equal to \( m_{3/2}/2 \)

\( m_{3/2} \) of the order of few GeV \( \rightarrow \) possible Fermi detection !!!
The Gravitino Case

METHOD

We use the same approach of Cuesta et al. (2011)

Our signal is now the sum of:

- the *smooth Galactic DM halo* (Einasto profile)
- the Local Universe (the Cuesta et al. density all-sky map)
- the *isotropic DM extragalactic emission at z > 0* (Choi et al. 2010)

The *background* are the Galactic foreground emission and the isotropic extragalactic background (*from Fermi*).

We then proceed as before in order to obtain a *Fermi* all-sky map of photon counts for the signal and the background:

- using a $\mu\nu$SSM gravitino with $m_{3/2} = 8$ GeV and $\tau_{3/2} = 5 \times 10^{27}$ s
- simulating events in the energy range $m_{3/2}/2 \pm 2 \Delta E$ where $\Delta E$ is the *Fermi* energy resolution in this range

$\rightarrow$ We obtain a S/N all-sky map for 5-year *Fermi* observations.
We then select a $5 \times 5$ deg region around the Virgo cluster to re-simulate in detail different gravitino scenarios.
The Gravitino Case
PRELIMINARY RESULTS

Choi et al. constraints with mid-latitude Fermi-LAT 5 months data
Choi et al. constraints from SPI/EGRET/COMPTEL data

Gomez-Vargas et al., in prep.
Nearby extragalactic objects (galaxy clusters and groups) as well as the filaments of the cosmic web are very promising targets for DM studies (in particular for decaying DM).

Fermi can constrain important parts of the parameter space of many (decay) DM models.

Constrained simulations (from CLUES) prove to have a strong potential in helping to understand the DM nature.

The realistic DM density and density-squared all-sky maps (available for public use!) that we produced are powerful tools to investigate DM models and detection prospects.

http://www.clues-project.org/articles/darkmattermaps.html
Thanks