Dark Matter search in the low energy gamma-rays domain

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Dark Side of the Universe 2014
Cape Town Nov 2014
The Low Energy frontier
History of the publications on the observations of the GALACTIC CENTER

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope
Vincenzo Vitale, Aldo Morselli, the Fermi/LAT Collaboration

Search for Dark Matter with Fermi Large Area Telescope: the Galactic Center
V.Vitale, A.Morselli, the Fermi/LAT Collaboration

Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope

On The Origin Of The Gamma Rays From The Galactic Center

Detection of a Gamma-Ray Source in the Galactic Center Consistent with Extended Emission from Dark Matter Annihilation and Concentrated Astrophysical Emission

Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations
Published in Phys.Rev. D88 (2013) 083521

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
GC Residuals 7°×7° region centered on the Galactic Center
11 months of data, E >400 MeV, front-converting events
analyzed with binned likelihood analysis

- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV
ARE WE SEEING DARK MATTER WITH THE FERMI-LAT IN A REGION AROUND THE MILKY WAY CENTER?

• Maybe yes, but we can’t be sure as far as we don’t understand the background at the level needed for disentangle a DM-induced γ-ray flux in this interesting region.

It would be really very nice to have a new experiment with better angular resolution at energies below 100 MeV
Constraints from the inner Galaxy

3σ upper limits on the annihilation cross-section for different channels and halo profiles

No assumption on background

very robust result

Gomez-Vargas et al. JCAP 10 (2013) 029
arXiv:1308.3515
Low energy lines limits and implications for gravitino dark matter in the $\mu\nu$SSM


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*See talk of Carlos Munoz*
New Low Energy Line Search

- Modeling effective area
- background emission
- not masking known point sources: because the broad PSF of the LAT at low energies.

This Analysis is Systematics Limited

To improve this search better energy and angular resolutions at energies below 100 MeV are needed

Differential yield for each annihilation channel

- Quite distinctive spectrum (no power-law)
- Solid lines are the total yields, while the dashed lines are components not due to $\pi^0$ decays

Differential yield for $b\bar{b}$ for different neutralino mass.

Low energy range is very important also for high mass neutralino search.

Elements of a pair-conversion telescope

- Photons materialize into matter-antimatter pairs:
  \[ E_\gamma \rightarrow m_e c^2 + m_e c^2 \]

- Electron and positron carry information about the direction, energy and polarization of the \( \gamma \)-ray.

(energy measurement)
Interaction of photons with matter

Fractional energy loss for $e^+$ and $e^-$ in lead

\[ \frac{dE}{dx}_{\text{Brems}} = -\frac{E}{X_0} \Rightarrow E(x) = e^{-\frac{x}{X_0}} \]

Prob. of Int. = $1 - \exp\left(-\frac{7}{9} \frac{x}{X_0}\right)$

<table>
<thead>
<tr>
<th>$x/X_0$</th>
<th>Prob Int.</th>
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<tr>
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<tr>
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<tr>
<td>2</td>
<td>0.79</td>
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<td>7</td>
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\[ \theta_0 = \theta^\text{rms}_{\text{plane}} = \frac{1}{\sqrt{2}} \theta^\text{rms}_{\text{space}} \]

\[ \theta_0 = \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{\frac{x}{X_0}} \left[ 1 + 0.038 \ln \left( \frac{x}{X_0} \right) \right] \]
Elements of a pair-conversion telescope

• photons materialize into matter-antimatter pairs:
  \[ E_\gamma \rightarrow m_e c^2 + m_e c^2 \]

• electron and positron carry information about the direction, energy and polarization of the \( \gamma \)-ray

(energy measurement)
We originally propose **Gamma-light**

40+1 x-y planes
100 µm pitch each
~0.025 $X_0$

Tot~ 1 $X_0$

54.7 cm

height of a plane 1.3 cm

2 $X_0$ Calorimeter

**Compton scattering and pair production telescope**
Gamma-light Simulation

100 MeV

1 GeV
**G-LIGHT Simulation**

Compton interaction of a 10 MeV photon producing a low-energy single-track electron, and depositing energy in the Calorimeter for a 30° incidence.
Gamma-light payload

Power ~ 400 W
Weight Tracker ~ 110 Kg
Weight Calorimeter ~ 60 Kg
Total weight ~ 600 Kg
GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA

- a companion satellite similar to G-LIGHT can be accommodated.
Gamma-Light Point Spread Function (angular resolution)

Mission proposed to ESA


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Effective area

- **Fermi LAT (Front + Back)**
- **Fermi LAT (Front)**
- **GAMMA-LIGHT 30°**
- **AGILE 30°**

Kalman reconstruction, assumed bkg rejection eff. $10^{-4}$

Sensitivity

\[ N_{\gamma_s} = \Phi_s (cm^{-2}) \times A_{eff} \times \Delta T \]

\[ N_{\gamma_B} = \Phi_B (cm^{-2} sr^{-1}) \times \Delta \Omega \times A_{eff} \times \Delta T \]

\[ N_{\gamma_s} \geq 5 (N_{\gamma_B})^{-\frac{1}{2}} \]

\[ \Delta \Omega \sim \pi \theta^2 \sim \pi E^{-2} x \]

\[ \Phi_s \geq \frac{5}{E} \left( \frac{\Phi_B \times x}{A_{eff} \times \Delta T} \right)^{-\frac{1}{2}} \]
good detector

\[
\Phi_s \geq \frac{5}{E} \left( \frac{\Phi_B \ast x}{A_{e f f} \ast \Delta T} \right)^{-\frac{1}{2}}
\]

small converter plane

large effective area
(large geometric area and large total conversion efficiency)

large field of view
Sensitivity of γ-ray detectors

Integral flux (photons cm\(^{-2}\) s\(^{-1}\))

Photon Energy (GeV)

5 sigma, 50 hours, > 10 events

5/E from here

generical angular resolution

limited by statistics
Flux Sensitivity

Energy (MeV)

GAMMA-LIGHT

AGILE

Fermi LAT (Front + Back)

Fermi LAT (Front)

5σ Sensitivity E^2 dN/dE (MeV cm^-2 s^-1)

P7REP SOURCE V15 PSF Front 68% cont. at normal incidence

Containment angle (deg) vs Energy (MeV)

- Fermi-PSF
- 0.25xFermi-PSF
Galactic Center Region 1-5 GeV

Sources from two years Fermi catalog, template ring model for diffuse background.


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Sources from two years Fermi catalog, template ring model for diffuse,

Galactic Center Region 50-200 MeV

Fermi PSF Pass7 rep v15 *0.25  Fermi PSF Pass7 rep v15 source

ESA M-4 Call

• quite different from previous Medium-sized Mission Calls (Solar Orbiter, EUCLID, PLATO);
• total ESA budget: 450 Meuro.
• guidelines for an ‘‘ESA-only’’ mission:
  – Payload mass: 300 kg;
  – total spacecraft mass: 800 kg.
ESA M-4 Call

• idea of “marriage’’ with a Compton telescope sensitive in the range 200 keV – 10 MeV.

• possible merging with the Astro-MeV group.

• Science, Instrument, Community.
the ‘‘MeV-GeV’’ concept

- range 200 KeV – 100 MeV: new window.

- sensitivity (continuum and lines) better than INTEGRAL, COMPTEL, AGILE and FERMI by a factor 10-20.

- **Two options under considerations:**
  - One single instrument for Compton and pair
  - Two instruments on board the same spacecraft
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heritage

M1/M2 (2007)

M3 (2011)

S1 (2012)

M4

AstroMeV

& Gamma-Light

CLAIRED

NCT

GRI

DUAL

CAPSITT

GRIPS I

GRIPS II

FERMI / AGILE

Gamma-Light
AstroGam

60 DSSD planes
Each plane 300 µm
~0.003 $X_0$/ per plane
+
~0.0025 $X_0$ for the support
(500 µm of Carbon)

Distance between planes 10 mm

Tot~ 0.32 $X_0$

2.7 $X_0$ Calorimeter

Geometric angular resolution 0.15 deg

Each DSSSD (Si double sided Si strip detectors) has a total area of 10*10 cm$^2$
Sets of 6 DSSSDs are wire bonded strip to strip to form ladders

$\varepsilon_{\text{conv}} = 0.22 \quad \varepsilon_{\text{rec}} = 0.80 \quad \varepsilon_{\text{tot}} = 0.176 \quad A = 4900 \text{ cm}^2 \quad A_{\text{eff}} = 860 \text{ cm}^2$
Point Spread Function (angular resolution) Comparison

AGILE
30°

Gamma-MeV (preliminary)

Fermi LAT (Front + Back)

GAMMA-LIGHT
30°

Fermi LAT front P7v6
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Gamma-MeV (preliminary)

Fermi LAT (Front + Back)

Fermi LAT (Front)

GAMMA-LIGHT 30°

AGILE 30°

Kalman reconstruction, assumed bkg rejection eff. 10^-4

Sensitivity at 511 keV

The graph shows the sensitivity at 511 keV over time from 1970 to 2020. The y-axis represents sensitivity in [ph/cm²/s], and the x-axis represents years. The graph includes data points for balloons, HEAO, SMM, IBIS, OSSE, SPI, and ASTROGAM. The total galactic 511 keV flux is indicated by a dashed line.
**ASTROGAM**

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**Galactic Radioactivities**

$^{26}\text{Al}$, $^{60}\text{Fe}$, $^{44}\text{Ti}$, activation lines

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**e$^-e^+$ Annihilation Radiation**

Sensitive all sky spectro-imaging

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**Compact Sources**

AGN, XRBs, $\mu$-quasars, magnetars …

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**Gamma-ray bursts**

Localization, spectroscopy, **polarisation**!

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**Cosmic gamma background**

Multipole analysis, search/constrain AM

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**Dark Matter Search**

DM signatures, fundamental physics

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*Science summary*
Conclusions

Detection of gamma rays from the annihilation or decay of dark matter particles is a promising method for identifying dark matter, understanding its intrinsic properties, and mapping its distribution in the universe (in synergy with the experiments at the LHC and in the underground laboratories).

In the future it would be extremely important to extend the energy range of experiments at lower energies (compared to the Fermi energies) (AstroGAM) and higher energies (HAWC, Dampe, HERD, Gamma-400, CTA, LHAASO).

Thank you!
.. and if you are interested all of you are invited to the sixth edition of RICAP 2016 that will be hosted by INFN & Roma Tor Vergata University.