Aldo Morselli
INFN Roma Tor Vergata
on behalf of the
ASTROGAM team

The ASTROGAM mission concept

The New High Energy Sky after a Decade of Discoveries INTEGRAL 2015
Roma 5 – 9 October, 2015
Particle Astrophysics Experiments (future in red)

Creation, acceleration, injection

Modulation

Propagation

Source

Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm²)

Cosmic Rays

40 km

23 Xo

Atmosphere

Balloons ~ 40 km ~3 g/cm² residual atmosphere

High Montain Detectors

Cherencov Detectors

Particle Accelerators

Extensive Air Shower Detectors

Underground, Under-ice, Underwater

ARGO-JBJ Milagro HAWC LHAASO

MAGIC HESS Veritas CTA

KASCADE Grande DECOR AUGER

AGILE Fermi Integral Swift PAMELA AMS Cream

Dampe Gamma-400 HERD AstroGam Pangu

NEMO ANTARES IceCube Km3

Direct detection

Space experiments ~ 400 km

Further acceleration?
coverage of the electromagnetic spectrum

- Compton scattering
- x-rays
- gamma-rays
- UV
- visible
- ultraviolet
- rayons X
- rayons gamma
- haute énergie
- basse énergie
- e⁺e⁻
- 26Al
- pair tracking
- total external reflection
- coded apertures
- grazing incidence
- mirror telescopes
- sub-mm/IR
- air
- water
- Cerenkov

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• 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
• and...
  - Terrestrial Gamma-Ray Flashes
Gamma-light project

Power ~ 400 W
Weight Tracker ~ 110 Kg
Weight Calorimeter ~ 60 Kg
Total weight ~ 600 Kg
GAMMA-LIGHT

• First proposed in 2012 for the ESA Call of Small Scientific Missions.
• Focused on gamma-ray detection with much improved sensitivity in the range 10-100 MeV.
• Very high level of readiness (AGILE, Fermi heritage).
• New astrophysics in the range below 100 MeV for both Galactic and extragalactic sources
GAMMA-LIGHT: the instrument
(total weight: 260 kg)

- Silicon Tracker with analog readout and
  no heavy absorber (10 MeV – 1 GeV)
- CsI Calorimeter (200 keV – 200 MeV)
- Anticoincidence
- Data Handling
Gamma-light Simulation

100 MeV

1 GeV
Gamma-Light Point Spread Function (angular resolution)

68% Containment radius (deg)

Energy (MeV)

Effective area

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

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

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.
ASTROGAM
This proposal is the result of the merging of the ASTROMEV and GAMMA-LIGHT groups that submitted two separate LOLs. The proposal is presented on behalf of the ASTROGAM Collaboration by:

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ASTROGAM a unified proposal from the entire gamma-ray community

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<td>AGILE 2007</td>
<td>FERMI 2008</td>
<td>Gamma-Light</td>
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M4

ASTROGAM

AstroMeV
An instrument that combine two detection techniques

Tracker

Calorimeter

Tracked Compton event

Pair event

AC system
• 70 layers of 6×6 double sided Si strip detectors = 2520 DSSDs

• Each DSSD has a total area of 9.5×9.5 cm², a thickness of 400 μm, a strip width of 100 μm and pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm

• Spacing of the Si layers: 7.5 mm

• The DSSDs are wire bonded strip to strip to form 2-D ladders

⇒ 322 560 electronic channels

• DSSD strips connected to ASICs (32 channels each) through a pitch adapter (DC coupling)

• 144 ASICs (IDeF-X HD) per layer (72 per DSSD side)

⇒ 10 080 ASICs total
ASTROGAM Angular Resolution

Angular resolution (degree)

Gamma-ray energy (MeV)

COMPTEL
Fermi/LAT
ASTROGAM
Compton
Pair

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ASTROGAM

positron annihilation

**total galactic 511 keV flux**
• **ASTRO-H/SGD** – 3σ sensitivity for 100 ks exposure of an isolated point source
• **COMPTEL** and **EGRET** – sensitivities accumulated during the whole duration of the CGRO mission (9 years)
• **Fermi/LAT** – 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
• **ASTROGAM** – 5σ sensitivity for a high Galactic latitude source after 3.5 years in survey mode
A wide-field $\gamma$-ray observatory operating at the same time as facilities like LSST and SKA will give a more coherent picture of the transient sky.

CTA science related to variable sources will need a coverage of the $\gamma$-ray sky at lower energies to trigger Target-of-Opportunity observations.
gamma-ray spectrum of SNRs W44. The red curve shows the expected Astrogam sensitivity for a 1-year effective time integration.
The SEDs of many blazars (FSRQs) and non-blazar AGNs detected in $\gamma$-rays peak in the “MeV range”

**Total energy output $\Rightarrow$ feedback**

Observations below 100 MeV are useful to distinguish leptonic and hadronic models

AstroGam will detect more than 1000 AGNs (mostly FSRQs)

- Evolution (“Blazar sequence”)
- Origin of UHECRs and HE neutrinos
- MeV gamma-ray background
SN 2014J

Type Ia supernova exploded on 2014 Jan 14 in the starburst galaxy M82 at $D \approx 3.5$ Mpc ⇒ nearest SN Ia in more than 40 years

Detection with INTEGRAL of gamma-ray lines from $^{56}$Co decay ($T_{1/2} = 77$ d) ⇒ synthesis of $0.6 \pm 0.1 \, M_{\odot}$ of $^{56}$Ni (Churazov et al. 2014, *Nature*, 28 Aug) and from $^{56}$Ni decay ($T_{1/2} = 6.1$ d) ~20 d after explosion (Diehl et al. 2014, *Science*, 5 Sep); $^{56}$Ni lines are broad and redshifted (!) (Isern et al., in prep.)

INTEGRAL and NuSTAR observations can not be explained by current SN Ia explosion models (Burrows et al., in prep.)
The extragalactic gamma-ray background (EGB)

- Extragalactic X-ray and gamma-ray background now measured over 9 orders of magnitude in energy.
- Largest uncertainties in the 1 MeV - 100 MeV range.
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- Largest uncertainties in the 1 MeV - 100 MeV range.
The Galactic Center with Fermi-LAT

LAT counts = sum of:
- Galactic Center diffuse emission
  - Interaction of Cosmic Rays (density?) with gas
    (distribution?) and interstellar radiation fields (intensity?)
- Foreground/background (all-sky analysis)
  - Interaction of Cosmic Rays with gas and interstellar radiation fields
- Individual sources (~catalog analysis)
- Additional components?

Fermi LAT 1-100 GeV

5.2 years

15x15deg
ASTROGAM view of the Galactic Center Region
100-500 MeV

2 years, Sources from 3 years Fermi catalog, template ring model for diffuse

with Gomez Vargas

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ASTROGAM view of the Galactic Center Region

100-500 MeV

Fermi PSF Pass7 rep v15 source

with Gomez Vargas
Galactic Center Region 0.5-2 GeV

Fermi PSF Pass7 rep v15 source

with Gomez Vargas
Galactic Center Region 0.5-2 GeV
Fermi PSF Pass7 rep v15 source

with Gomez Vargas
Spectrum (E > 400 MeV, 7°x7° region centered on the Galactic Center analyzed with binned likelihood analysis)

The GeV excess 7°x7° 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

the GALACTIC CENTER: any hints of Dark Matter?
the beginning of the history

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope
Lisa Goodenough, Dan Hooper

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

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

i.e. Calore et al, arXiv:1409.0042v1
 Galactic Center and Dark Matter

arXiv:1306.5725

Se non è vero è ben trovato
(If it is not true, it is well conceived)

arXiv:1401.6458
The GeV excess: Other explanations exist

- past activity of the Galactic center
  (e.g. Petrovic et al., arXiv:1405.7928, Carlson & Profumo arXiv:1405.7685)

- Population of millisecond Pulsars around the Galactic Center
  (e.g. Hooper et al. arXiv:1305.0830, Yuan and Zhang arXiv:1404.2318v1
  Lee et al. arXiv:1506.05124)

- Series of Leptonic Cosmic-Ray Outbursts
  Cholis et al. arXiv:1506.05119

- Different diffusion coefficient in the GC region
- ........

How to discriminate between different hypotheses?
The Fermi LAT 2FGL Inner Galactic Region

August 4, 2008, to July 31, 2010

100 MeV to 100 GeV energy range

arXiv:1108.1435

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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
Dwarf spheroidal galaxies (dSph) : promising targets for DM detection
Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

Flux upper limits are combined with the DM density inferred by the stellar data (*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on $\langle \sigma v \rangle$ vs WIMP mass for specific DM models.

(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

robust constraints including J-factor uncertainties from the stellar data statistical analysis

NFW. For cored dark matter profile, the J-factors for most of the dSphs would either increase or not change much

Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]
Dwarf Spheroidal Galaxies upper-limits

Dwarf Spheroidal Galaxies upper-limits (6 years)

M.Ackermann et al., [Fermi Coll.] PRL Accepted [arXiv:1503.02641]
Dwarf Spheroidal Galaxies upper-limits (6 years)

- Pass 8 Combined dSphs
- Fermi-LAT MW Halo
- MAGIC Segue 1
- Abazajian et al. 2014 (1σ)
- Daylan et al. 2014 (2σ)
- Calore et al. 2014 (2σ)

Astrogam range
Upper limits from AMS antiprotons and Fermi LAT for different halo profiles

\[ \sigma_{\nu}[\text{cm}^3\text{s}^{-1}] \]

\[ 10^{-24} \quad 10^{-25} \quad 10^{-26} \quad 10^{-27} \]

\[ m_{\chi} [\text{GeV}] \]

- Isothermal
- NFW
- Einasto
- Moore
- Fermi-LAT

Jin et al., arXiv:1504.04604
Fermi data from M. Ackermann et al., [Fermi Coll.] PRL accepted [arXiv:1503.02641]
Upper limits from Fermi LAT, Antares, IceCube, Magic


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ATLAS-Fermi Results

Annihilation rate $\langle \sigma v \rangle$ for $\chi\chi \rightarrow qq$ [cm$^3$/s]

- $2 \times$ (Fermi-LAT dSphs $(\chi\chi)_{\text{Majorana}} \rightarrow b\bar{b}$)
- D5: $q\bar{q} \rightarrow (\chi\chi)_{\text{Dirac}}$
- D8: $q\bar{q} \rightarrow (\chi\chi)_{\text{Dirac}}$
- $-1\sigma_{\text{theory}}$

$\sqrt{s} = 7 \text{ TeV}, 4.7 \text{ fb}^{-1}, 95\% \text{CL}$

WIMP mass $m_\chi$ [GeV]

Complementarity and Searches for Dark Matter in the pMSSM

Cahill-Rowley et al. arXiv: 1305.6921
## New DES Dwarf Spheroidal Galaxy Candidates

<table>
<thead>
<tr>
<th>Name</th>
<th>$(\ell, b)^a$</th>
<th>Distance$^b$</th>
<th>$\log_{10}(\text{Est. J})^c$</th>
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<tbody>
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<td>DES J0222.7−5217</td>
<td>(275.0, −59.6)</td>
<td>95</td>
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<td>DES J0255.4−5406</td>
<td>(271.4, −54.7)</td>
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<td>DES J0335.6−5403</td>
<td>(266.3, −49.7)</td>
<td>32 (Reticulum II)</td>
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<td>DES J0344.3−4331</td>
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<td>18.8</td>
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<td>DES J2339.9−5424</td>
<td>(323.7, −59.7)</td>
<td>95</td>
<td>18.4</td>
</tr>
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New DES Dwarf Spheroidal Galaxy Candidates


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New DES Dwarf Spheroidal Galaxy Candidates

Dwarf Spheroidal Galaxies upper-limits (6 years)

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- Daylan et al. 2014 (2σ)
- Calore et al. 2014 (2σ)

Astrogam range

M.Ackermann et al., [Fermi Coll.] PRL Accepted [arXiv:1503.02641]
DM limit improvement estimate in 15 years with the composite likelihood approach (2008-2023)

Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section.
The next gamma-ray MeV-GeV mission: the e-Astrogam project

MeV - GeV astrophysics
MeV - GeV community

Proposed for the ESA M4 call; currently under study for enhancement and reconfiguration for the ESA M5 call. ASTROGAM is focused on gamma-ray astrophysics in the range 0.3-100 MeV with excellent capability also at GeV energies.
e-ASTROGAM

- 4 towers
- 50 layers of 5*5 double sides Si strip detectors
- Read-out pitch 240 $\mu$m
- Spacing of Si layers 7.5 mm
- Si thickness 400 $\mu$m

e-ASTROGAM core science

1. The Galactic Center and inner galaxy the central black hole, compact stars, the beginning of Fermi bubbles, DM search
2. Nucleosynthesis throughout the Galaxy and beyond
3. The extragalactic and cosmic gamma-ray background
An instrument to complete the coverage of the electromagnetic spectrum

- Compton scattering
- x-rays
- gamma-ray
- total external reflection
- Cerenkov
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