Capabilities of GAMMA-400 telescope for observation of electrons and positrons in TeV energy range.

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According to the new approved Russian Federal Space Program 2016-2025 the GAMMA-400 space observatory is scheduled to launch in 2025-2026.
GAMMA-400: Gamma Astronomical Multifunctional Modular Apparatus

GAMMA-400 main scientific goals

- Searching for gamma-ray lines for the energy range of 20 MeV - several TeV in the discrete source, diffuse, and isotropic gamma-ray emission when annihilating or decaying dark matter particles;

- Searching for new and study of known Galactic and extragalactic discrete high-energy gamma-ray sources: supernova remnants, pulsars, accreting objects, microquasars, active galactic nuclei, blazars, quasars;

- Studying the structure of extended sources with high angular resolution and measuring their energy spectra and luminosity with high energy resolution;

- Identifying discrete gamma-ray sources with known sources in other energy ranges;

- High-precision measurements of the high-energy electrons and positrons spectra
GAMMA-400 physical scheme

AC – Anticoincidence System
C - Fiber converter- tracker 1X₀ of W
S₁,S₂ – ToF scintillator counters
S₃,S₄ – Shower scintillator counters

CC₁-CC₂ are two parts of CsI calorimeter
22×22 vertical bars 2X₀+16X₀

The energy range:
from ~ 20 MeV - till almost ~ 10 TeV

Main trigger: \[ M = \overline{AC} \times \text{ToF} \]
\[ \text{ToF} = S_1 \times S_2 \times (time_{s_1} < time_{s_2}) \]

High energy γ and charged particle trigger:
\[ H = S_1 \times S_2 \times S_3 \]
The GAMMA-400 orbit evolution and observation modes

The orbit of the GAMMA-400 space observatory will have the following initial parameters:
- an apogee of 300,000 km;
- a perigee of 500 km;
- an inclination of 51.4°

Under the action of gravitational disturbances of the Sun, Moon, and the Earth after ~6 months the orbit will transform to about circular with a radius of ~200,000 km and will be without the Earth’s occultation and out of radiation belts.

The main observation mode will be continuous long-duration (~100 days) observations of the Galactic Center, extended gamma-ray sources, etc.

Time of operation will be 7-10 years

Downlink rate up to 100 GB per day
Simulation environment: GEANT4 (4.10.01p02)

100 GeV gamma

with secondary gamma visualization

Back scattering photons ~ 1 MeV

no secondary gamma visualization
Modeling gamma-ray detection with energy 50 GeV
Better angular resolutions above ~10 GeV than existing instruments
## Instruments comparison

<table>
<thead>
<tr>
<th></th>
<th>SPACE BASED INSTRUMENTS</th>
<th>GROUND INSTALLATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AGILE</td>
<td>Fermi-LAT</td>
</tr>
<tr>
<td>Particles</td>
<td>$\gamma$</td>
<td>$\gamma$</td>
</tr>
<tr>
<td>Mode of observation</td>
<td>Continuous monitoring of sky</td>
<td>Continuous pointing up to 100 days</td>
</tr>
<tr>
<td>Energy intervals, GeV</td>
<td>0.03-50</td>
<td>0.02-300</td>
</tr>
<tr>
<td>Angular resolution $(E_\gamma = 100 \text{ GeV})$</td>
<td>0.1°</td>
<td>0.1°</td>
</tr>
<tr>
<td>Energy resolution $(E_\gamma = 100 \text{ GeV})$</td>
<td>50% $(E_\gamma \sim 1 \text{ GeV})$</td>
<td>10%</td>
</tr>
<tr>
<td>Effective area, m²</td>
<td>0.36</td>
<td>1.8</td>
</tr>
</tbody>
</table>

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Total electron + positron spectrum

- Break
- Line ?!
- Cut-off
Instrument comparison for $e^+e^-$ measurements

<table>
<thead>
<tr>
<th>Instrument</th>
<th>GAMMA-400</th>
<th>CALET</th>
<th>DAMPE</th>
<th>AMS-02</th>
<th>Fermi-LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gettering power, m$^2$ sr</td>
<td>0.98 (E&gt;10 GeV)</td>
<td>0.1040 (E&gt;10 GeV)</td>
<td>0.3 (E&gt;30 GeV)</td>
<td>0.05 (E&gt;10 GeV)</td>
<td>2.8* (E~50 GeV)</td>
</tr>
</tbody>
</table>

* - there is additional selection for high energy particles
Trigger efficiency for charged particles

High energy trigger $H = S_1 \times S_2 \times S_3(E>E_{th})$

**Electrons**

- Electron efficiency vs. energy (GeV)
- Thresholds: $s_3 > 32$ MeV, $s_3 > 0$ MeV, $s_3 > 100$ MeV, $s_3 > 300$ MeV

**Protons**

- Proton efficiency vs. energy (GeV)
- Thresholds: $s_3 > 32$ MeV, $s_3 > 0$ MeV, $s_3 > 100$ MeV, $s_3 > 300$ MeV

Expected rate of protons is $\sim 50$ Hz at $S_3$ threshold $E_{th}=100$ MeV

To keep high gamma-ray efficiency and low rate of background protons,

Optimal $S_3$ threshold is about 60-100 MeV
Electrons interact in C and CC1, they release almost all energy in 1-3 bars of CC2.
Proton E=50 GeV
Examples of selection criteria

RMS of showers in calorimeter CC2:

Electrons $E = 50$ GeV

Protons $E > 50$ GeV

Electron efficiency $\varepsilon = 0.9$, proton rejection factor $f \sim 50$
Intrinsic weight of rejection criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Electron efficiency</th>
<th>Proton rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude C1</td>
<td>0.93</td>
<td>2.46</td>
</tr>
<tr>
<td>Amplitude S3</td>
<td>0.97</td>
<td>4.22</td>
</tr>
<tr>
<td>Amplitude C4</td>
<td>0.91</td>
<td>2.37</td>
</tr>
<tr>
<td>EC4/ECC2</td>
<td>0.95</td>
<td>20.05</td>
</tr>
<tr>
<td>Total energy</td>
<td>0.97</td>
<td>12.69</td>
</tr>
<tr>
<td>Емакс/ECC2</td>
<td>0.99</td>
<td>1.83</td>
</tr>
<tr>
<td>RMS in CC2</td>
<td>0.98</td>
<td>12.54</td>
</tr>
<tr>
<td>Energy, GeV</td>
<td>Proton rejection</td>
<td>Electron efficiency, %</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>10</td>
<td>$(1.11 \pm 0.42) \cdot 10^4$</td>
<td>72</td>
</tr>
<tr>
<td>30</td>
<td>$(1.3 \pm 0.5) \cdot 10^4$</td>
<td>77</td>
</tr>
<tr>
<td>50</td>
<td>$(1.0 \pm 0.3) \cdot 10^4$</td>
<td>78</td>
</tr>
<tr>
<td>100</td>
<td>$(1.0 \pm 0.3) \cdot 10^4$</td>
<td>81</td>
</tr>
<tr>
<td>500</td>
<td>$(9 \pm 3) \cdot 10^3$</td>
<td>84</td>
</tr>
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</table>

The graph shows the rejection factor as a function of energy in GeV.
Possible fit (red solid line) to the total observed electron spectrum due to distant sources (black line) and one local continuous fading source (orange dotted line) with $t/\tau=0.08$.

**Conclusion:**

Expected count rate of HE electrons is 1Hz

After 5 years of observations Gamma-400 will be able

1) to measure anisotropy of possible local sources of electrons

2) To find time variations of local source with $\tau < 10^3$ years

Data for electrons can be used for calibration of gamma-ray channel.

**arXiv:1811.07551**
Models of gamma telescope detector systems
General view of the C-25P synchrotron accelerator (FIAN, Pakhra)
Positron beam
Tracker: from silicon strips to fibers
Thank you