Gamma-400 science objectives built on the current HE gamma-ray and CR results

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The main scientific interest of the Russian Gamma-400 team:
Observe gamma-rays above ~50 GeV with excellent energy and angular resolution with the goals of:
• Studying the fine spectral structure of the isotropic high-energy gamma-radiation,
• Attempting to identify the many still-unidentified Fermi-LAT gamma-ray sources

However, in order to best exploit its promise as a NEXT GENERATION GAMMA-RAY MISSION, it is critical for Gamma-400:
• To be capable of precise measurements in the very important energy range from ~20 MeV to a few hundred MeV, where the LAT energy resolution, angular resolution and background rejection are relatively poor
• For multiwavelength analysis: to have gamma-ray measurements in the tens of MeV to tens of GeV energy range, simultaneous with X-ray and ground-based TeV gamma observations, as well as with neutrino and gravitational radiation detectors such as IceCube, KM3NeT, ALIGO. Currently none are planned after Fermi-LAT observations end
The anticipated focus of the Gamma-400 program:

- Pointed observations of the most interesting sources from Fermi, TeVCat and other catalogs:
  - Unidentified sources (~ 1/3 of all currently known GeV gamma-ray sources\(^1\))
  - Detailed investigation of the Galactic Center
  - Sources at energy more than several tens of GeV with better (than Fermi LAT) angular resolution and background rejection\(^2\)
  - Variable sources

- Diffuse gamma-ray emission at energies above ~ 10 GeV
- High-energy emission from transient sources, including gamma-ray bursts
- Search for features in the spectra of high-energy CR electrons-positrons and nuclei

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\(^1\) Abdo et al., arXiv:1108.1435, 2011
Scientific Goals of Gamma-400 optimized at Low and High Energies (1)

- Search for Dark Matter signatures
  - One major goal of Fermi is to greatly advance the search for the identity of non-baryonic DM
  - Although a clear signature of DM has not yet been detected by LAT (or any other instrument), sensitive cross-section limits for WIMPs, the most probable candidate for DM, have been established via LAT observations of:
    - the Galactic Center and halo,
    - the extragalactic background radiation (EGB),
    - dwarf spheroidal satellite galaxies and local group galaxies,
    - gamma-ray lines
  - The Galactic Center is expected to provide the greatest fluxes of gamma-rays from DM annihilation, but the bright diffuse and discrete-source gamma-ray emission from astrophysical processes give an intense foreground

- Gamma-400 with its superior energy resolution will improve the search for high-energy gamma-ray lines from DM emission
- Improved angular and energy resolution (as proposed by the US side) will make Gamma-400 able to better evaluate and remove foreground sources near the Galactic Center, hopefully revealing evidence of DM

1 Ackermann et al., PRL 107, 241302, 2011 and References therein
Scientific Goals of Gamma-400 optimized at Low and High Energies (II)

Diffuse Radiation

- Galactic and isotropic (extragalactic gamma-ray background EGB) diffuse radiation have been studied with the LAT from $\sim 200$ MeV to $\sim 100$ GeV\(^1,2\)

- To define the spectral structure of this emission and search for gamma-ray lines (which may reveal DM contributions), these measurements need to be
  - extended to LOWER energy with excellent energy resolution
  - studied with improved energy resolution at high energy

Extragalactic background spectrum as measured by the LAT. Ovals show areas of interest for Gamma-400

\(^1\)Abdo et al., PRL 103, 251101, 2009
\(^2\)Abdo et al., PRL 104, 101101, 2010 Alexander Moiseev April 19, 2012
Scientific Goals of Gamma-400 optimized at Low and High Energies (III)

- Gamma Radiation from Supernova Remnants
  - SNRs are generally thought to be the sources of Galactic cosmic rays; both electrons and nuclei are likely accelerated to high-energy in SNR
  - Fermi LAT has measured accurate gamma-ray spectra from many SNR, but has, so far, failed to definitely determine whether the radiation originates from electrons or hadrons

- Extension of the energy range of SNR observations below the LAT limits to ~20 MeV will be critical to make this distinction
- No current or planned instrument EXCEPT Gamma-400 can measure gamma-rays from SNR of a few tens of MeV

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1Abdo et al., Science 327, 1103A, 2010

Alexander Moiseev
April 19, 2012
Discrete Gamma-ray Sources

- There are 1,873 sources in the Second Fermi Catalog (2FGL), with about 1/3 unidentified\(^1\).

The fine angular resolution of Gamma-400 will allow identification of additional classes of sources

- Fermi LAT has observed \(~500\) sources with photons above 10 GeV
  - some of the sources emit gamma rays
    - only at high energy and are unseen at lower energies
  - a recent example is NGC 1275, which is bright at energies of few GeV, but above 50-100 GeV a nearby source, IC 310, starts to shine brightly, while NGC 1275 diminishes\(^2\)

Gamma-400 will carry out a sensitive search for high energy emitters

\(^1\) Abdo et al., arXiv:1108.1435, 2011
\(^2\) Fermi NASA Press-release 2011
**Scientific Goals of Gamma-400 optimized at Low and High Energies (V. a)**

- **Transient phenomena: totally unexpected flare of Crab**
  - The Crab Nebula has long been used as a reference source for instrument calibration
  - Several very bright flares, discovered by Fermi LAT$^1$ and AGILE and thought to occur in the nebula, have changed our understanding

Other Crab flares, as well as flares of other pulsars, may be detected by continuous Gamma-400 observations. The nature of these flares is still unknown.

![Graph showing spectra of the quiescent and flaring Crab; upper points are during outburst (Fermi LAT)](https://example.com/graph)

\[\text{Alexander Moiseev, April 15, 2011}\]

\[\text{Abdo et al. Science 331, 739A, 2011}\]
Scientific Goals of Gamma-400 optimized at Low and High Energies (V.b)

- Transient phenomena: flares of AGN
  - These are expected but not predictable for individual sources
  - More than half the Fermi LAT sources are AGN of different types; many of them flare, representing some of the most energetic phenomena in Universe\(^1\)

Multiwavelength study requires regular observations in gamma-rays simultaneous with space-based X-ray and ground-based optical, radio, and TeV observations.

Opportunity for Gamma-400 to take over when Fermi LAT finishes its operation

\(^1\)Abdo et al., ApJ 707, 1310, 2009

Alexander Moiseev
April 19, 2012
Scientific Goals of Gamma-400 optimized at Low and High Energies (V.c)

- **Transient phenomena: Nova outburst**
  - Fermi LAT detected a remarkable, unexpected gamma-ray outburst from nova V407 Cygni

  Similar unexpected discoveries can be made during continuous observations of large fractions of the sky.

- **Transient phenomena: Solar Flares**
  - To study gamma-radiation from solar flares high sensitivity at low energy (< 1 GeV) and regular monitoring are critical. Very promising science objective for Gamma-400 with extended capability at low energy.

Image of V407 Cygni as seen by Fermi LAT. Left – before flare, right (in white circle) – during a flare

1Abdo et al., Science 329, 817A, 2010
Transient phenomena: Gamma-ray bursts

- Detailed study of temporal and spectral behavior by Fermi LAT discovered a delay of >100 MeV photons compared to the keV-MeV photons, and other temporal and spectral features addressing quantum gravity issues\(^1\)
- Observation (or absence) of GRB from coalescing binary systems (e.g. neutron star mergers), in synergy with the gravitational wave experiment ALIGO will provide critical information about such process
- Each GRB is different, and observation of a larger GRB sample is critical to understand their nature and mechanism, and fundamental physical phenomena. This is very promising science objective for Gamma-400 and KONUS

\(^{1}\)Abdo et al., Science 323, 1688, 2009 and references therein
Intergalactic magnetic fields

- TeV photons from AGN interact with the Extragalactic Background Light and create lower energy gamma radiation via electromagnetic cascades. Electrons of these cascades are deflected by intergalactic magnetic fields (strength not known yet), so the angular size of given AGN in gamma-rays increases compared to the instrument point spread function (PSF).
- The difference (if observed) can be used to estimate the magnitude of the magnetic field. Current Fermi LAT results do not show significant differences\(^1\)

The excellent PSF of Gamma-400 at high energy is crucial in this approach to the study of intergalactic fields

\(^1\)Abdo et al., in preparation

Alexander Moiseev  April 19, 2012
High-energy electrons

- Fermi LAT has accurately measured the electron+positron spectrum from 7 GeV to 1 TeV\(^1\).
- The spectrum is harder than expected from the superposition of distant sources, and exhibits some broad spectral features above \(\sim 200\) GeV, but does not show the feature reported by ATIC and PPB-BETS.
- The measurements are energy-resolution limited due to the relatively thin Fermi LAT calorimeter.

Its much deeper calorimeter allows Gamma-400 to study spectral structure of the high-energy electron spectrum with much better energy resolution. Spectral structure, if found, would indicate presence of nearby (< 1 kpc) source(s) of electrons, of either astrophysical (e.g. pulsars) or exotic (DM) nature.

\(^1\) Ackermann et al., PRD 82, 092004, 2010  Alexander Moiseev  April 19, 2012
SUMMARY

Gamma-400 will likely be the only space-based gamma-ray observatory operating at the end of the decade. In our proposed Gamma-400-LE version, it will substantially improve upon the capabilities of Fermi LAT and AGILE in both LE and HE energy range.

Measuring gamma-rays from ~20 MeV to ~1 TeV for at least 7 years, Gamma-400-LE will address the topics of dark matter, cosmic ray origin and propagation, neutron stars, flaring pulsars, black holes, AGNs, GRBs, and actively participate in multiwavelength campaigns.