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

[1] Abdo et al., arXiv:1108.1435, 2011
[2] Abdo et al., ApJ 707, 1310, 2009

Scientific Goals of Gamma-400 optimized at Low and High Energies (I)

❑ 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[1]

- 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

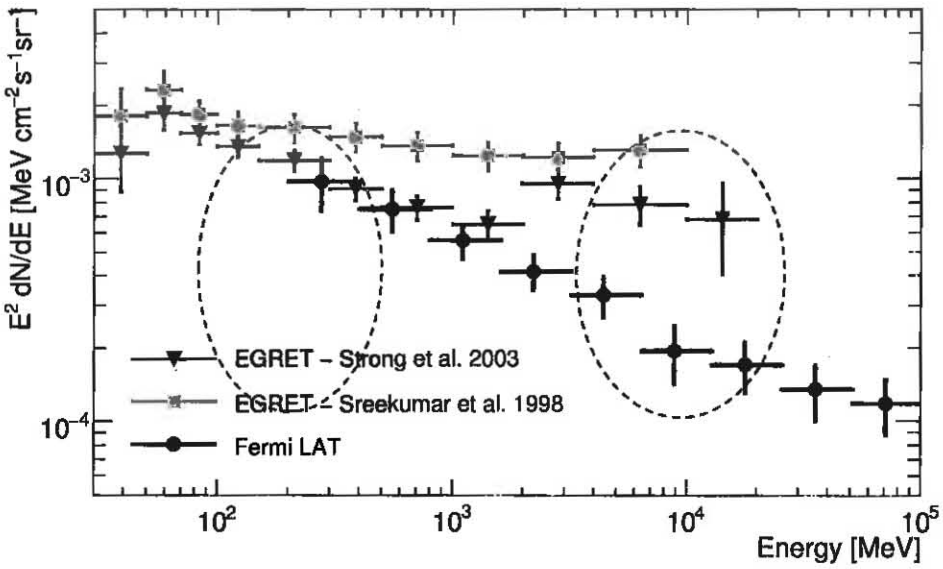
✓ Improved angular and energy resolution (as proposed by the US side) will make Gamma-400 able to better evaluate and remove foreground sources near the Galactic Center, hopefully revealing evidence of DM

[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 ~200 MeV to ~ 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

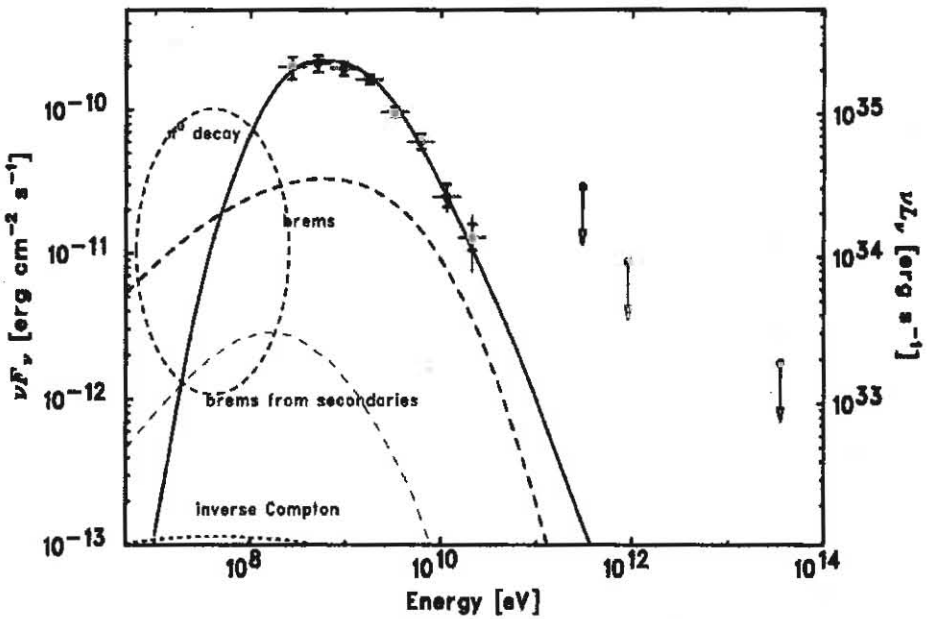
Scientific Goals of Gamma-400 optimized at Low and High Energies (III)

❑ 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



Spectrum of W44 as measured by LAT (red points) [1]

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

Scientific Goals of Gamma-400 optimized at Low and High Energies (IV)

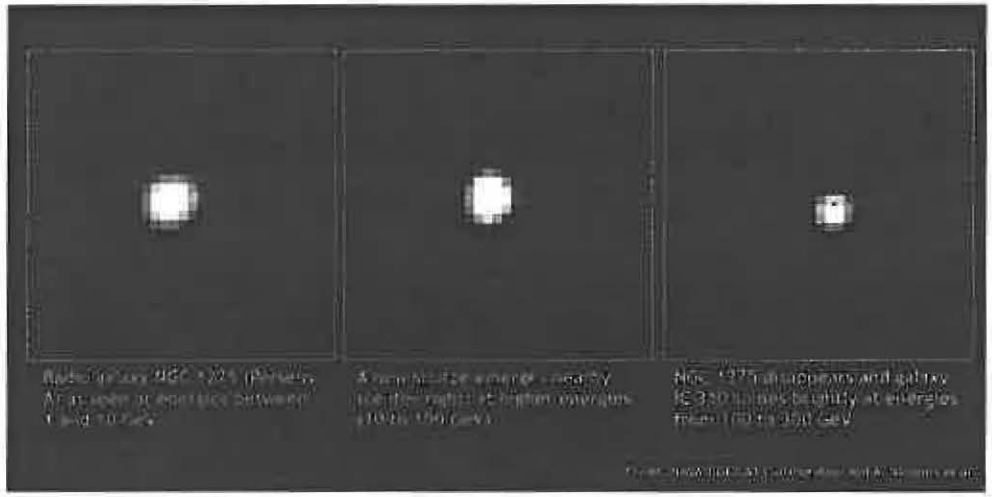
❑ Discrete Gamma-ray Sources

- 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

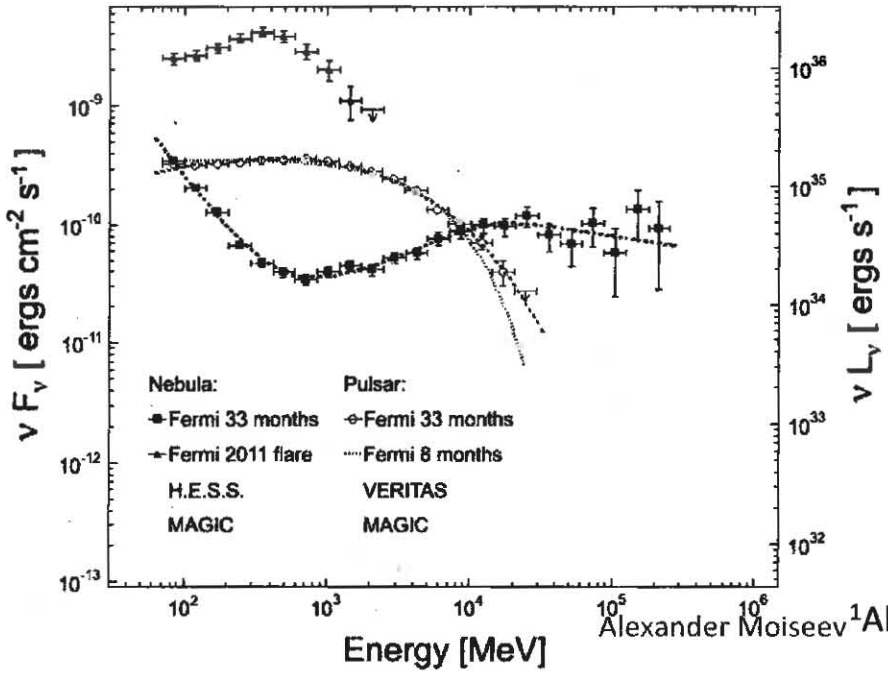
[1]Abdo et al., arXiv:1108.1435, 2011
[2]Fermi NASA Press-release 2011

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.



Spectra of the quiescent and flaring Crab; upper points are during outburst (Fermi LAT)

[1] 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

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[1]

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

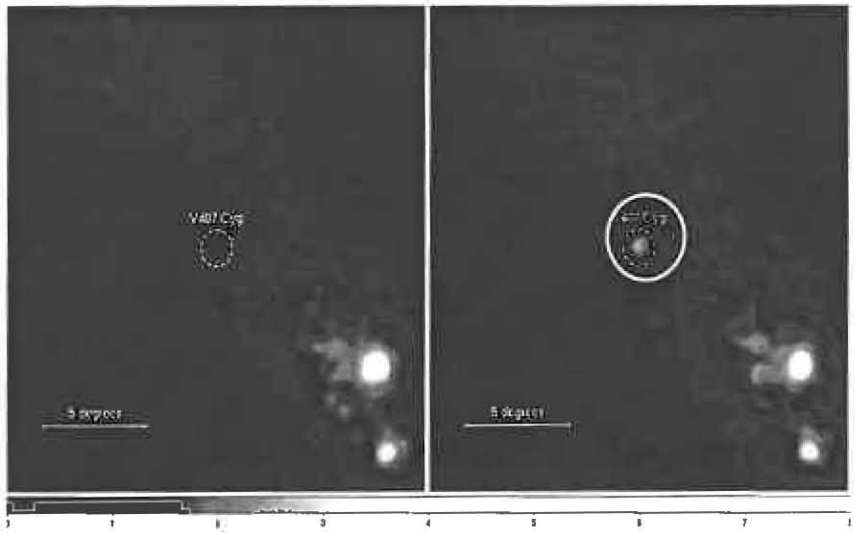


Image of V407 Cygni as seen by Fermi LAT. Left – before flare, right (in whire circle) – during a flare

[1]Abdo et al., Science 329, 817A, 2010

Scientific Goals of Gamma-400 optimized at Low and High Energies (V.d)

❑ **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

Scientific Goals of Gamma-400 optimized at Low and High Energies (VI)

❑ 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

Scientific Goals of Gamma-400 optimized at Low and High Energies (VII)

❑ **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 ~ 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

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