Russian Academy of Sciences
P.N.Lebedev Physical Institute
LPI

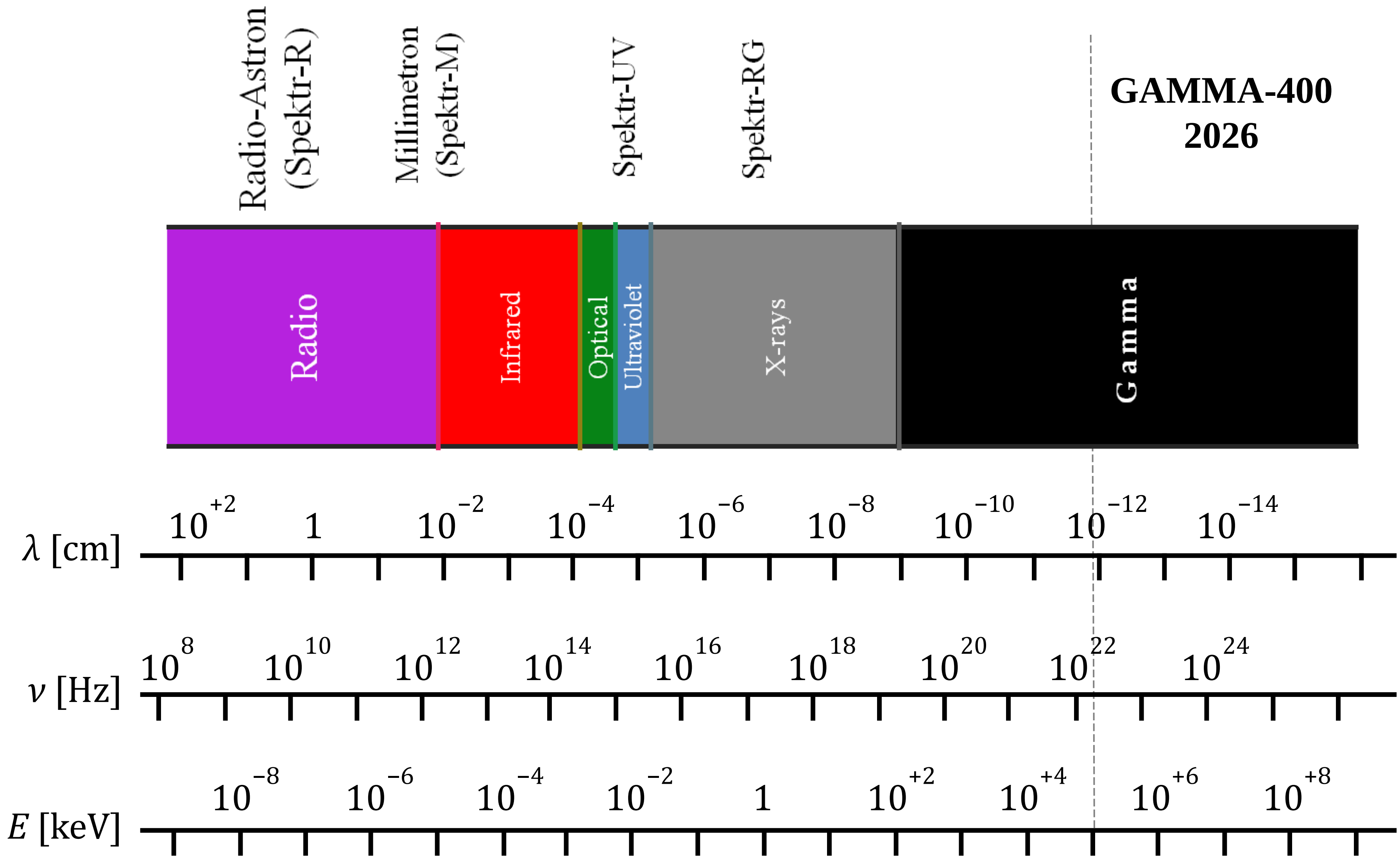
Arkadiy Galper

for the GAMMA-400 Collaboration

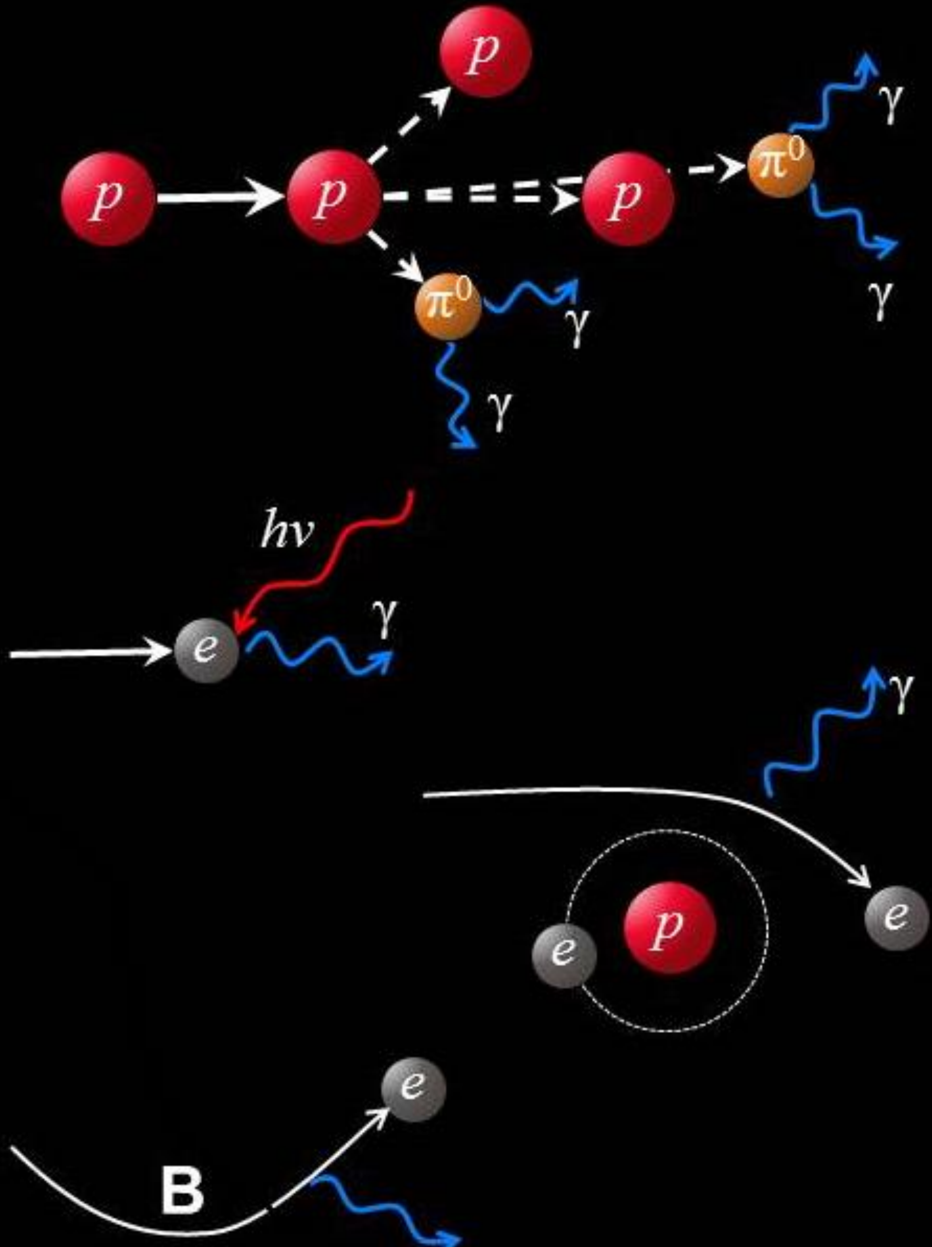
GAMMA-400 Project

April 23-27, 2018, The Third Zeldovich meeting, Minsk, Belarus

Russian space observatories
for research in various electromagnetic-spectrum ranges



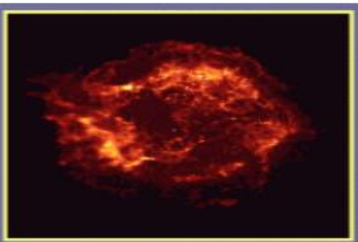
High energy gamma-ray emission processes



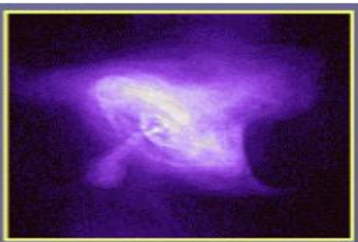
- ✧ $pp \rightarrow \pi^0(2\gamma)+X$ – neutral pion production and decay
- ✧ Inverse Compton scattering
- ✧ Bremsstrahlung
- ✧ Curvature (or synchrotron) radiation

Possible gamma-ray sources in high-energy range (> 10 GeV):

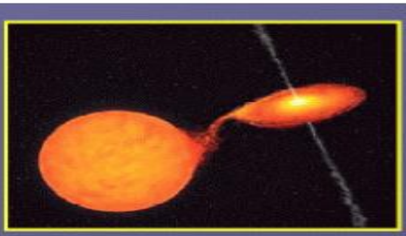
- **Dark-matter decay radiation, etc.**
- **Galactic Center**
- Active galactic nuclei (blasars, Seyfert galaxies, etc.)
- Starburst galaxies
- Galaxy clusters
- Neutron stars
- Radio pulsars
- “Radio invisible” pulsars
- Magnetars
- Other single neutron stars
- Supernova remnants
- Double stars
- Accretive compact objects (microquasars)
- Massive-star wind collision
- Radio pulsar systems
- INTEGRAL high-absorption sources
- Galactic diffusive emission
- Extragalactic diffusive emission
- Gamma-ray bursts
- Restrictions on fundamental theories
- Exotic and unidentified sources (single black holes; EGRET sources not detected by COMPTEL; H.E.S.S. sources lost in 1 Fermi catalog, etc.).



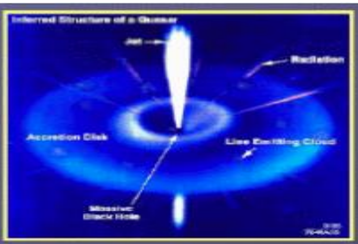
SNRs



Pulsars and PWNe



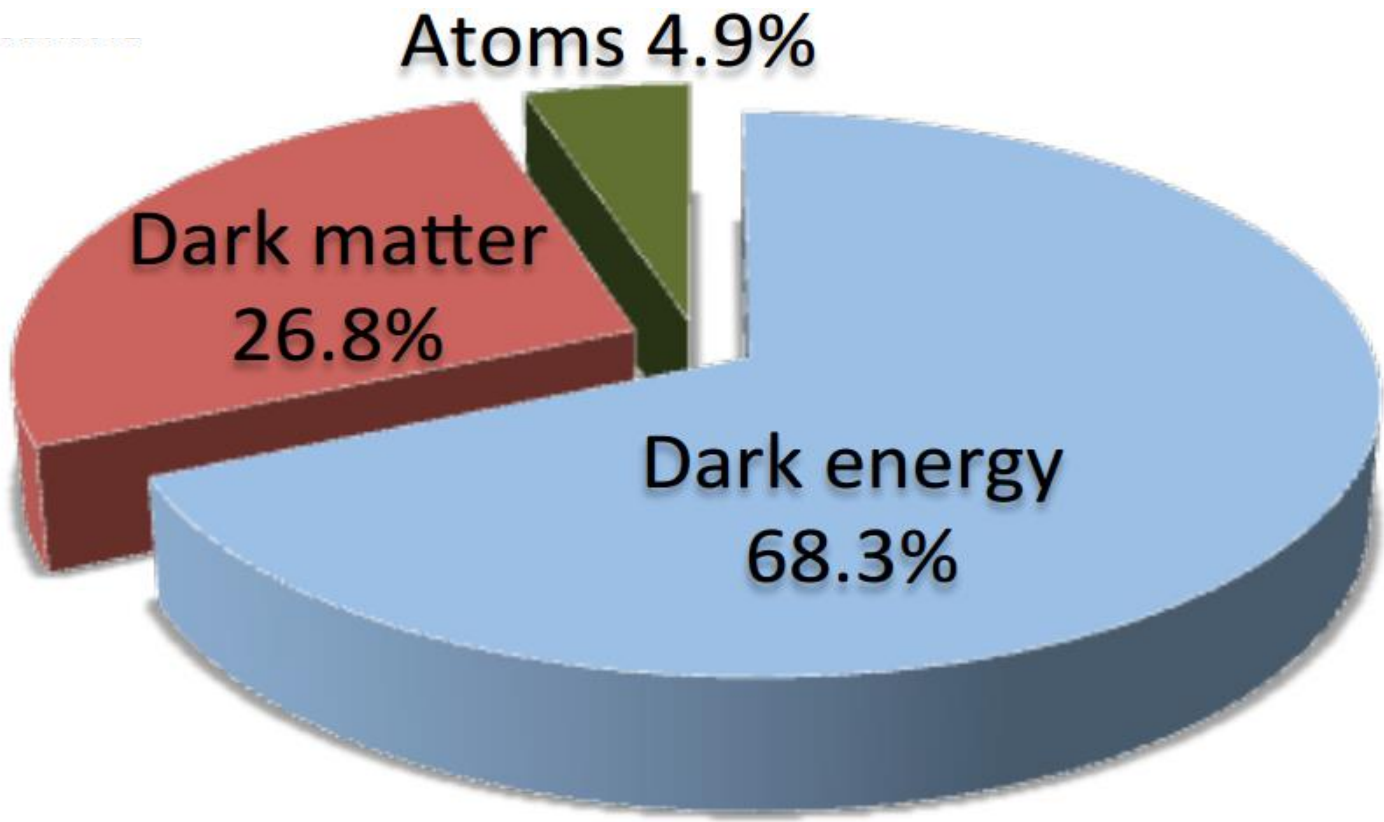
Micro quasars X-ray binaries



AGNs

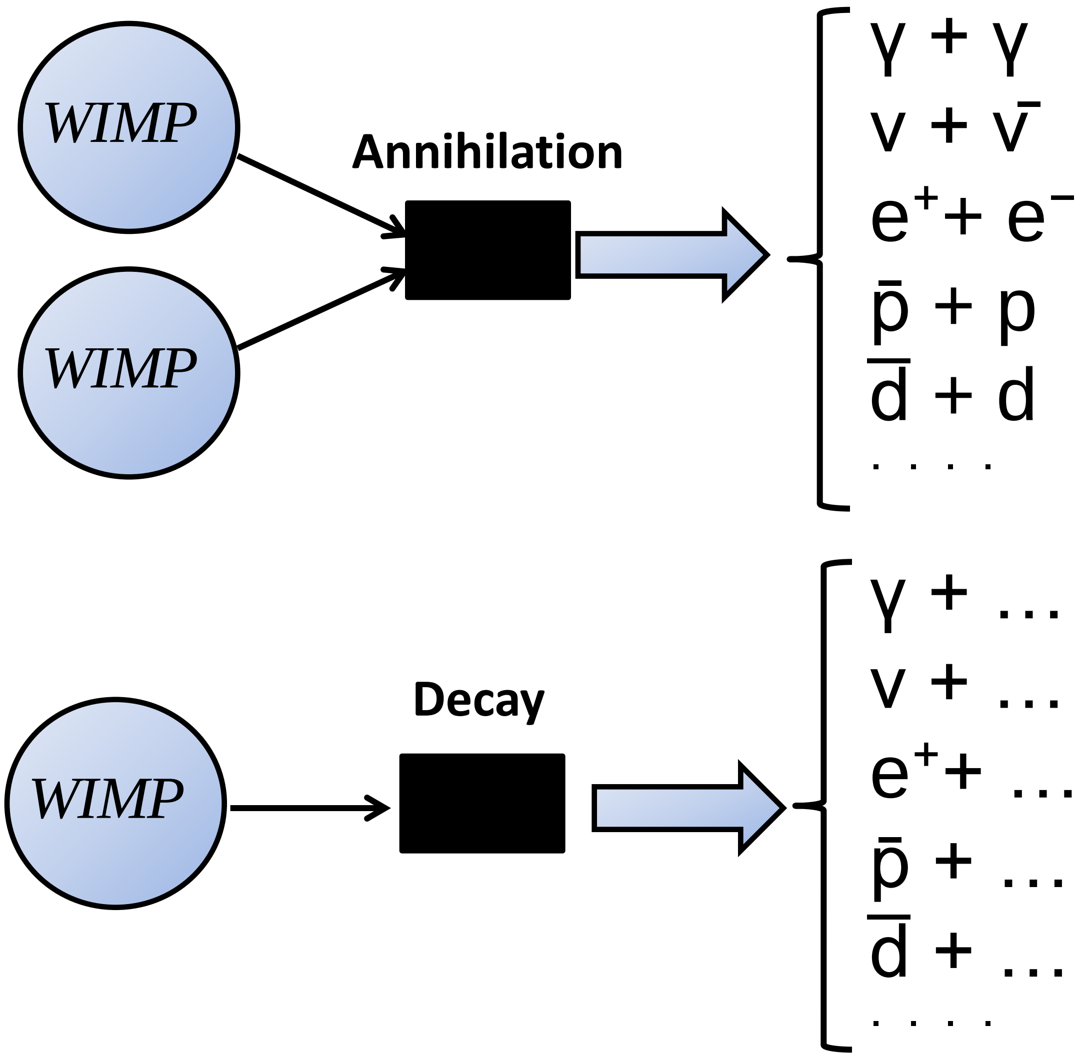
GRBs

The energy budget of the Universe



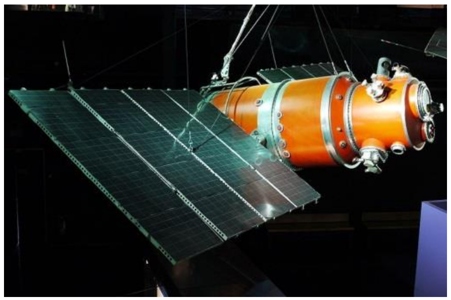
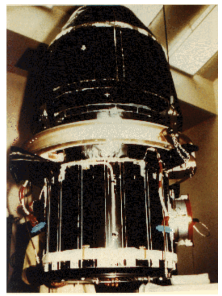
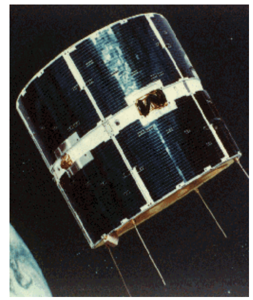
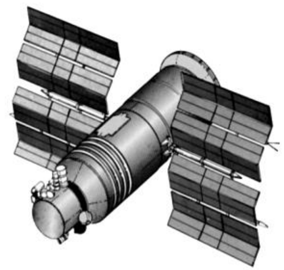
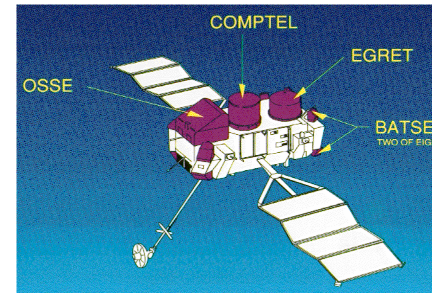
arXiv: 1310.1072

Indirect method for detection of DM particles



Gamma-ray study of discrete sources on spacecraft

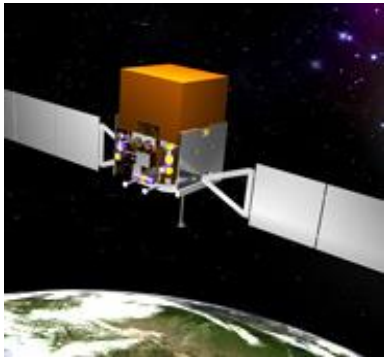
OSO-3 (USA, 1967-1968), Cosmos-208 (USSR, 1968)

ANNA-3	SAS-2	COS-B	GAMMA-1	EGRET
(Cosmos - 251, 264)				(CGRO)
USSR	USA	Europe	USSR	USA
1968, 1969	1972 – 1973	1975 – 1982	1990 – 1992	1991- 1998
200 MeV – 1 GeV	20 MeV – 1 GeV	30 MeV – 5 GeV	30 MeV – 5 GeV	30 MeV - 30 GeV

Gamma-ray study of discrete sources on current spacecraft

AGILE
Italy
2007
100 MeV – 50 GeV

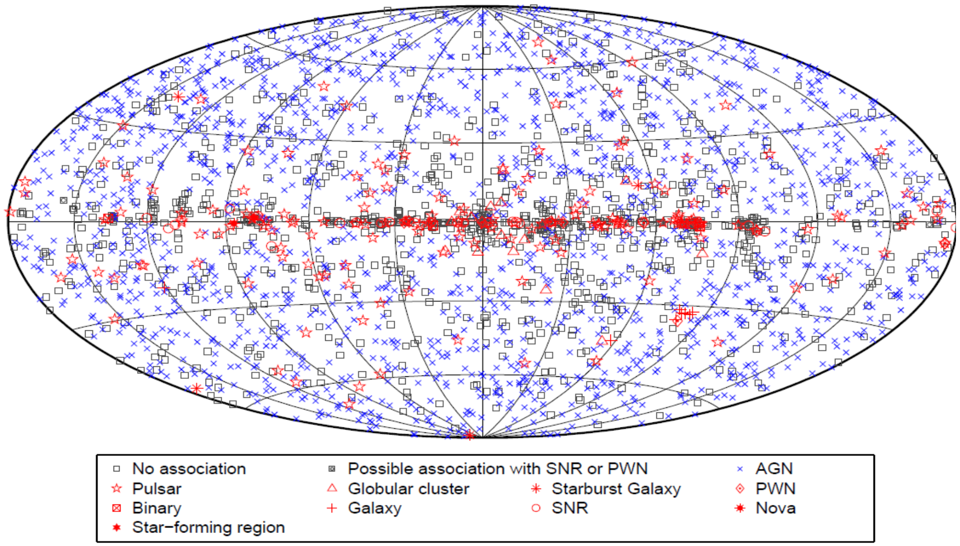


Fermi-LAT
USA
2008
100 MeV – 300 GeV

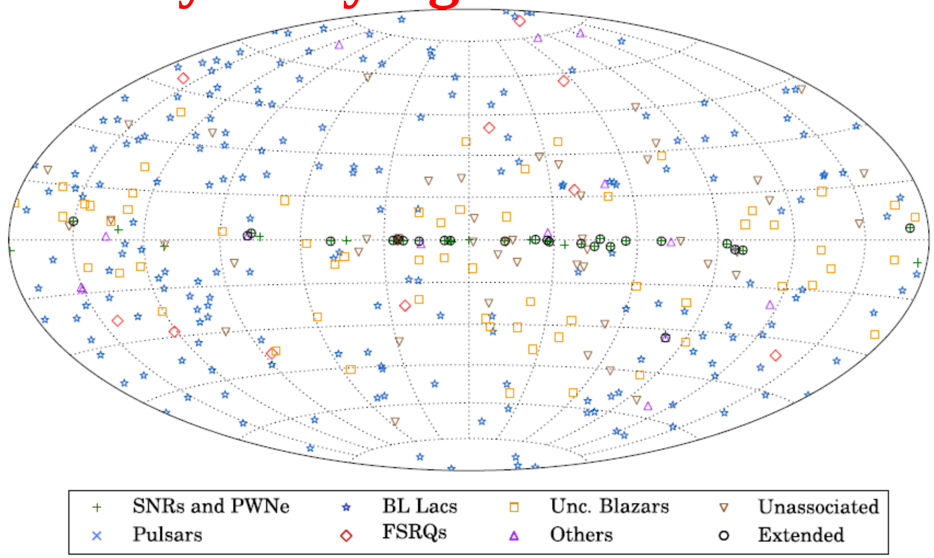
CALET
Japan
2015
1 GeV – 10 TeV

DAMPE
China
2015
5 GeV – 10 TeV

High-energy gamma-ray studying



Distribution of 3033 discrete sources
(**3FGL**, E_γ = 100 MeV – 300 GeV)

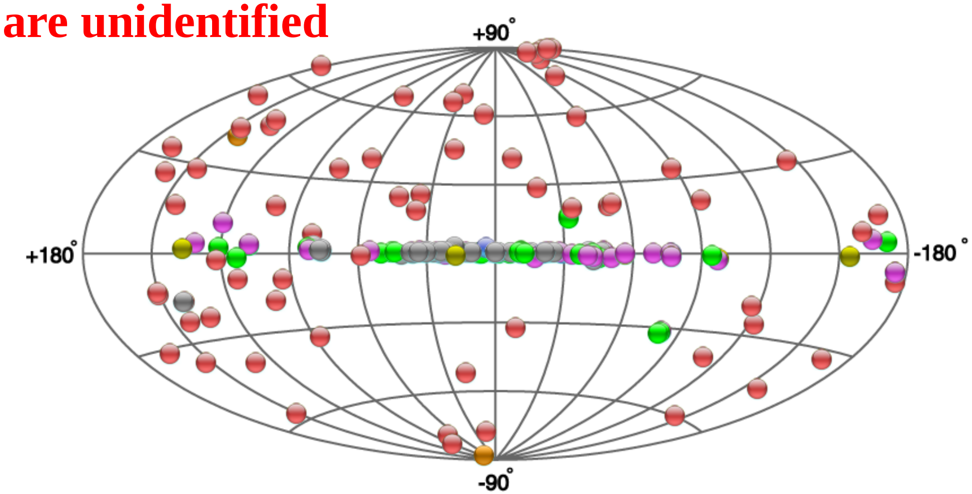


Distribution of 360 discrete sources
(**2FHL**, E_γ = 50 – 200 GeV)

~33% sources are unidentified

Fermi-LAT angular resolution is ~0.1° (E_γ > 10 GeV)

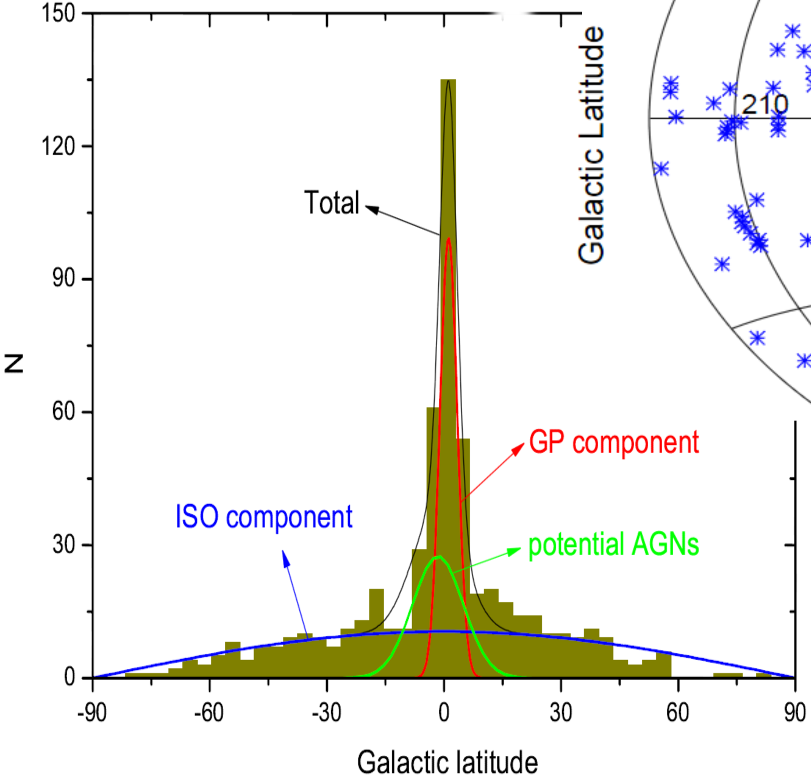
Ground-based telescope angular resolution is ~0.1° (E_γ ~ 100 GeV)

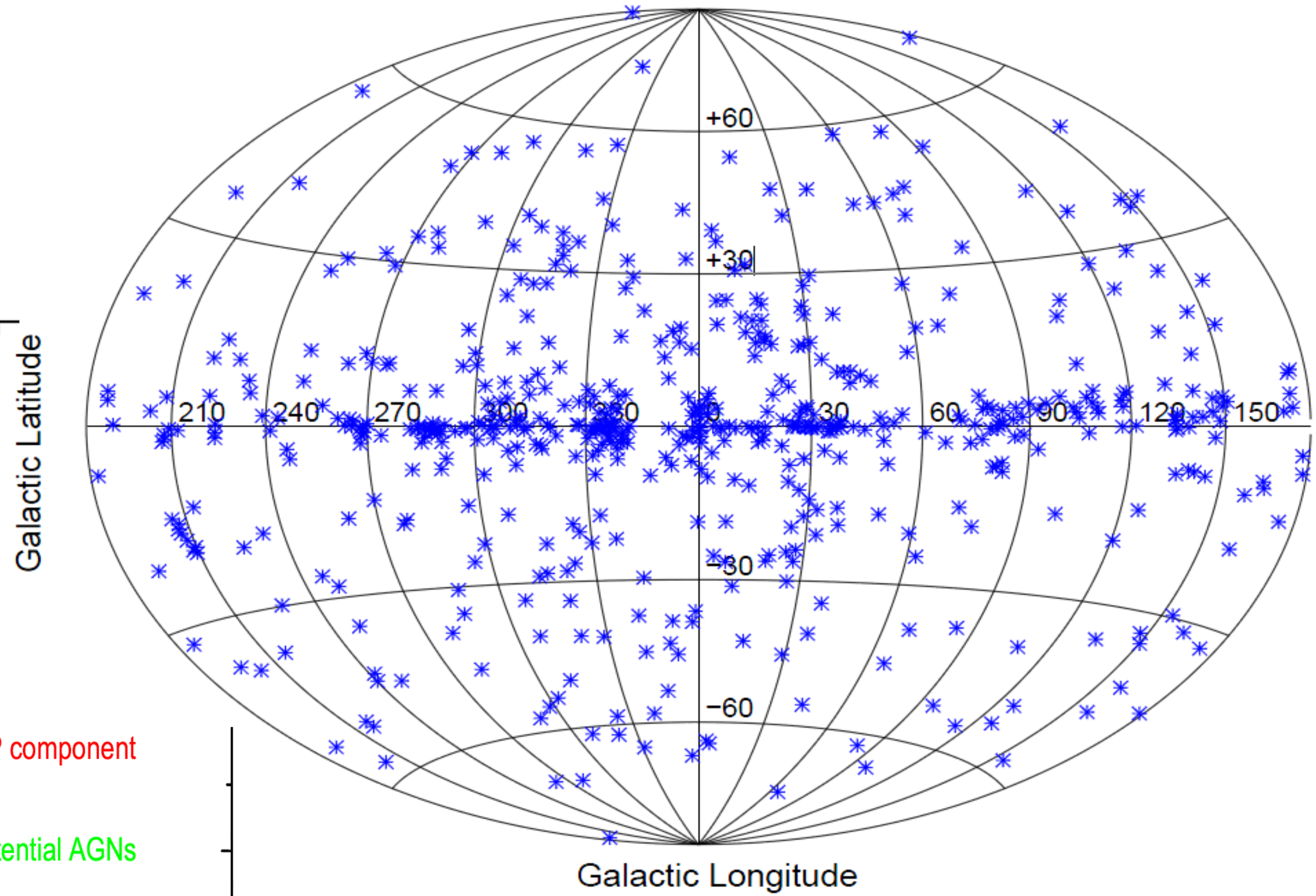


Distribution of 210 discrete sources
(**TeVCat**, E_γ > 100 GeV)

Distribution of 575 unidentified sources (2FGL)

Zhu Mao, Yun-Wei Yu,
arXiv:1304.3989v1





Gamma-ray observatory H.E.S.S.

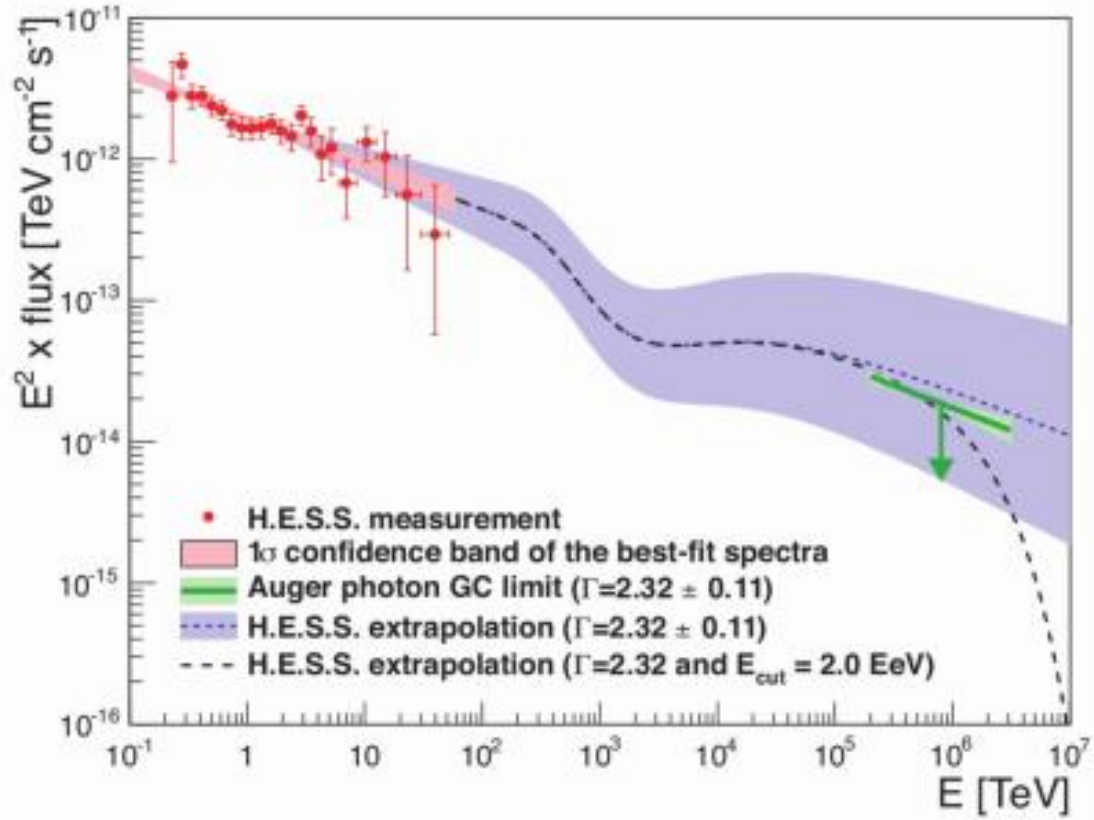
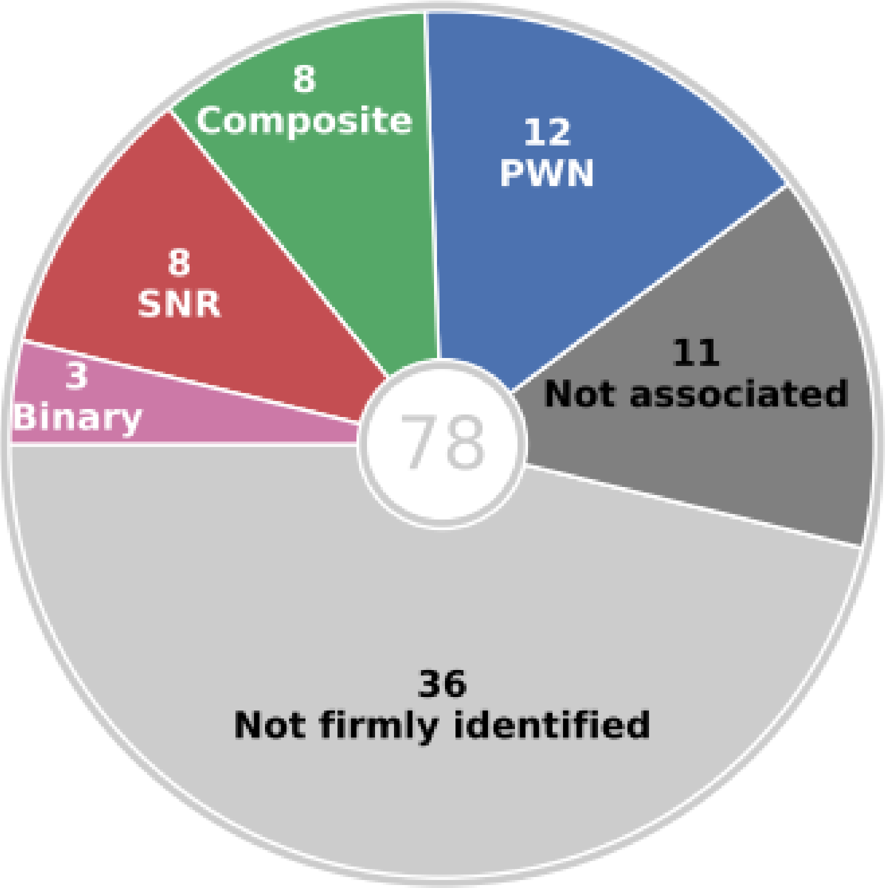


Fig. 5: Photon flux as a function of energy from the Galactic center region. Measured data by H.E.S.S. are indicated, as well as the extrapolated photon flux at Earth in the EeV range, given the quoted spectral indices ([1]; conservatively the extrapolation does not take into account the increase of the *p*-*p* cross section toward higher energies). The Auger limit is indicated by a green line. A variation of the assumed spectral index by ± 0.11 according to systematics of the H.E.S.S. measurement is denoted by the light green and blue band. A spectral index with cutoff energy E_{cut}=2.0×10^{6} TeV is indicated as well. [16]

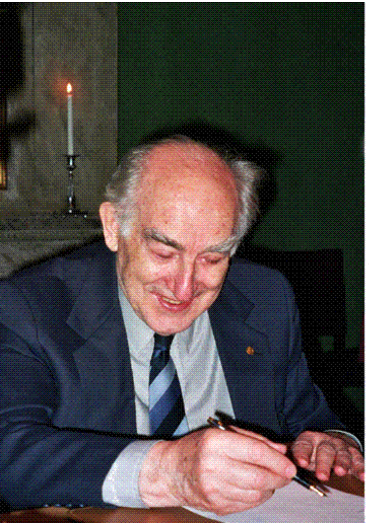
arXiv: 1804.05613



The H.E.S.S. Galactic plane survey

arXiv:1804.02432

Future gamma-ray telescopes should have the significantly improved angular and energy resolutions



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Учреждения Российской академии наук
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им. П.Н. Лебедева РАН
академик
Месяц Г.А.
2 июня 2009 г.

ПРОЕКТ ГАММА-400

ИССЛЕДОВАНИЕ КОСМИЧЕСКОГО ГАММА-ИЗЛУЧЕНИЯ И ПОТОКОВ ЭЛЕКТРОНОВ И ПОЗИТРОНОВ В ДИАПАЗОНЕ ЭНЕРГИЙ 1-3000 ГэВ

От ФИАН

Руководитель научного направления
академик
Гинзбург В.Л.
29/V 2009 г.

Научный руководитель проекта
ГАММА-400
профессор, г.н.с.
Гальпер А.М.
21 мая 2009 г.

Москва, 2009 г.

APPROVE
Director of
Lebedev Physical Institute
Academician G.A. Mesyats
June 2, 2009

GAMMA-400 Project
Study of cosmic gamma rays and electron/positron fluxes
in the energy range of 1-3000 GeV

Academician V.L. Ginzburg

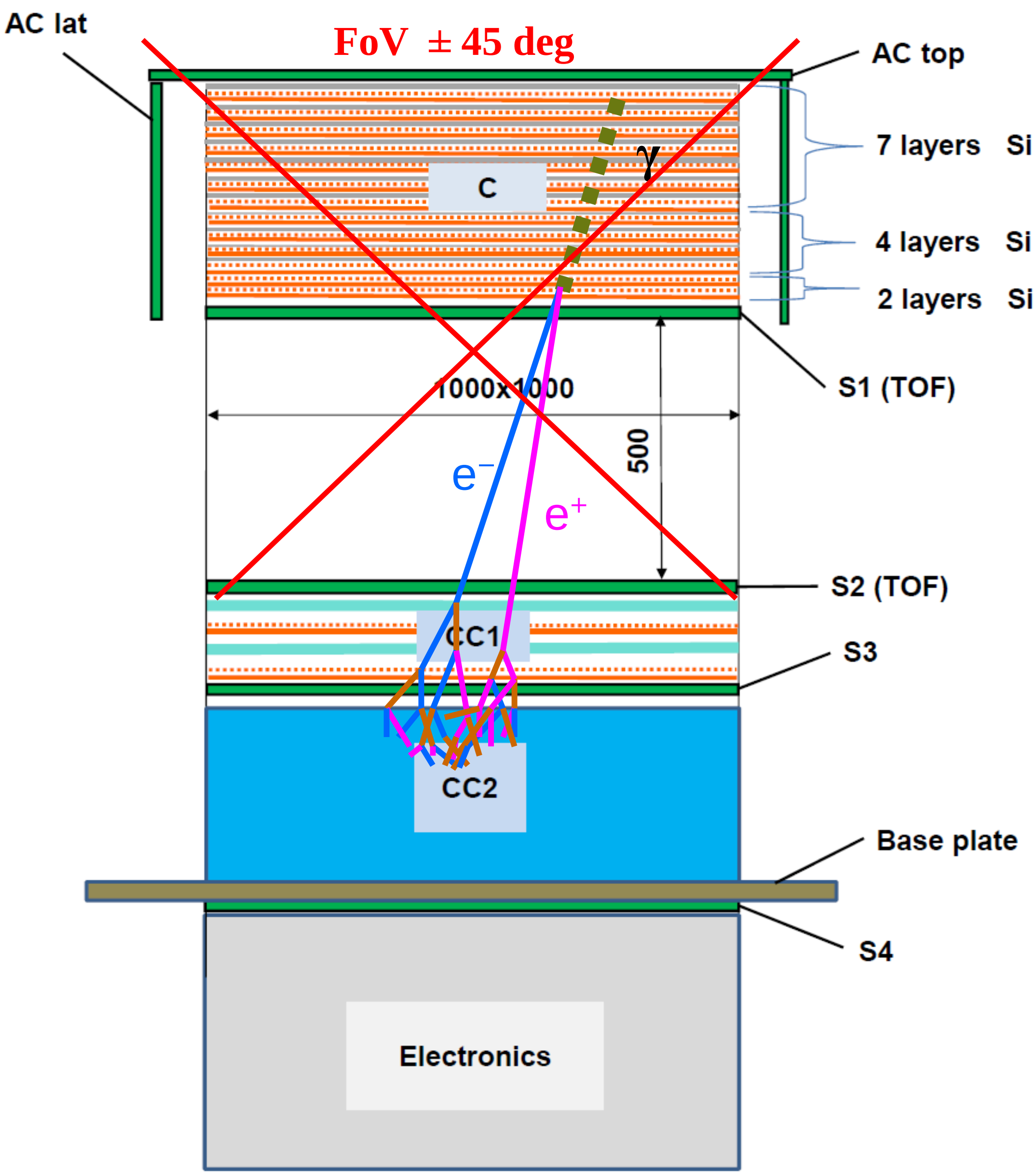
PI GAMMA-400 Project A.M. Galper

Moscow, 2009

GAMMA-400
MAIN SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise and detailed observations of Galactic plane, especially, Galactic Center, Fermi Bubbles, Crab, Vela, Cygnus, Geminga, Sun, and other regions, extended and point gamma-ray sources, diffuse gamma rays with unprecedented angular **(~0.01° at E_γ > 100 GeV)** and energy resolutions **(~1% at E_γ > 100 GeV)**.

The GAMMA-400 physical scheme

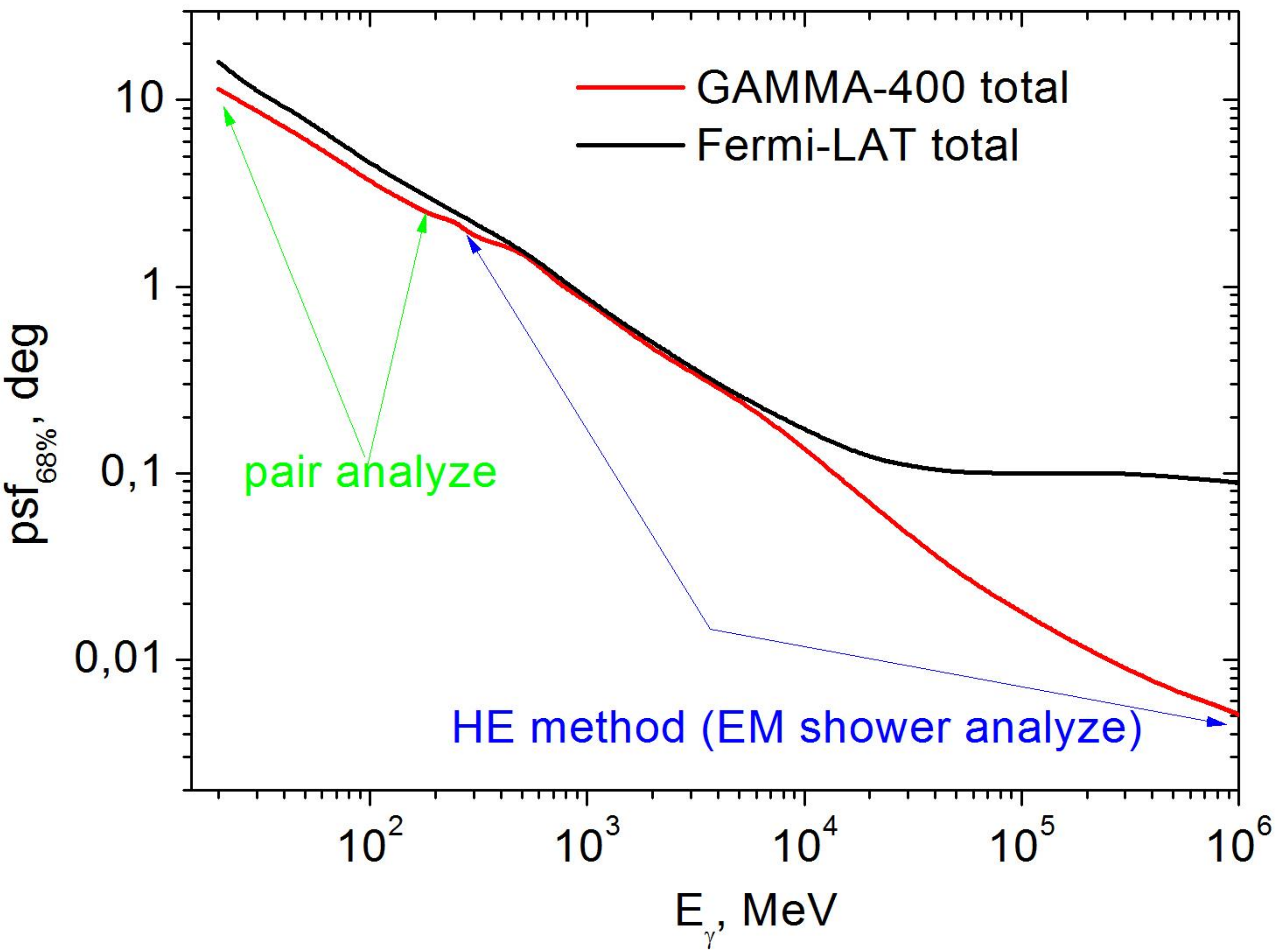


AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter ~22 X_0
S3,S4 – scintillator detectors

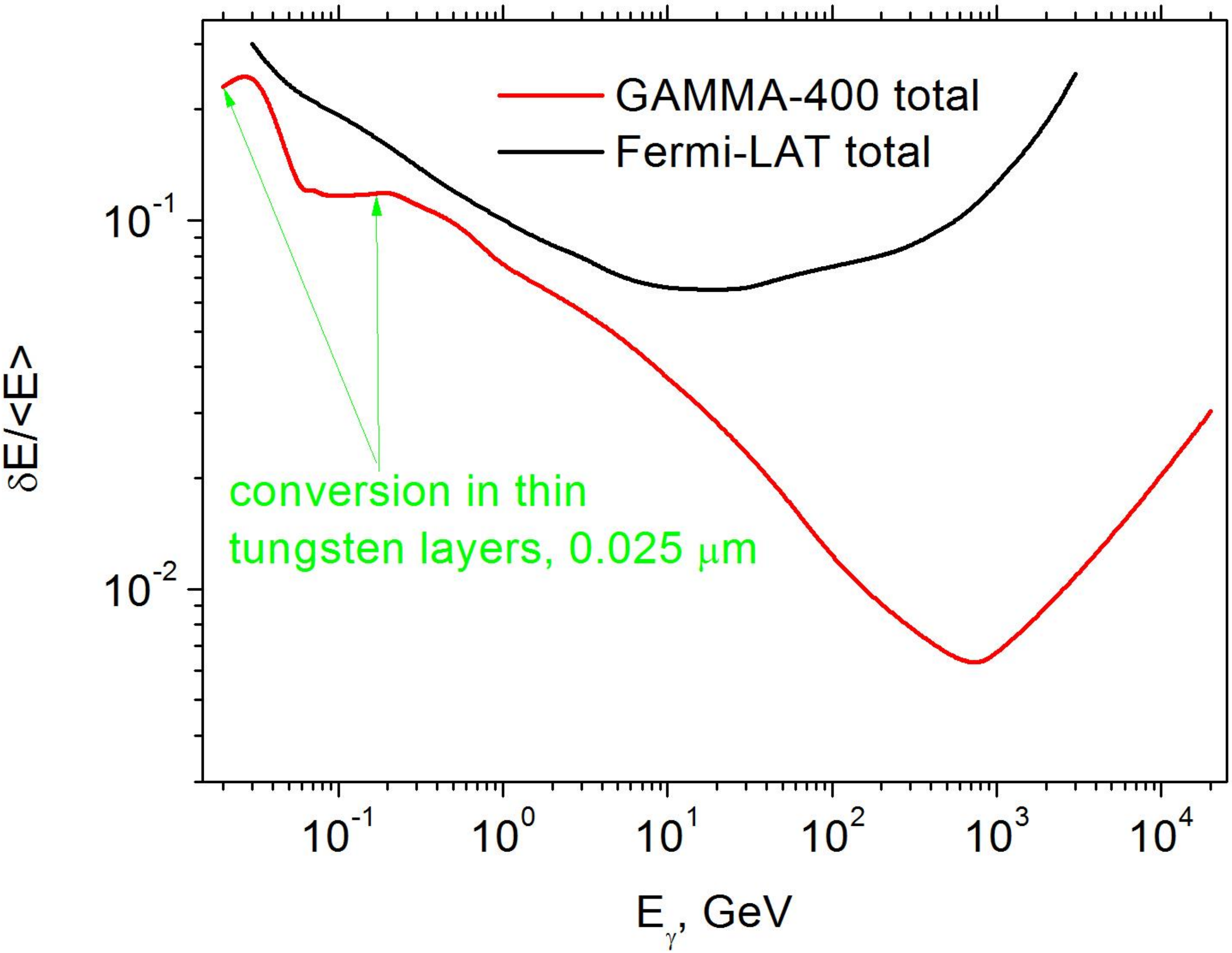
$$\overline{AC} \times S1 \times S2$$

ΔE = ~20 MeV – ~1 TeV
$\Delta\theta$ = ~2° (E_γ = 100 MeV)
$\Delta\theta$ = ~0.01° (E_γ > 100 GeV)
$\Delta E/E$ = ~10% (E_γ = 100 MeV)
$\Delta E/E$ = ~1% (E_γ > 100 GeV)

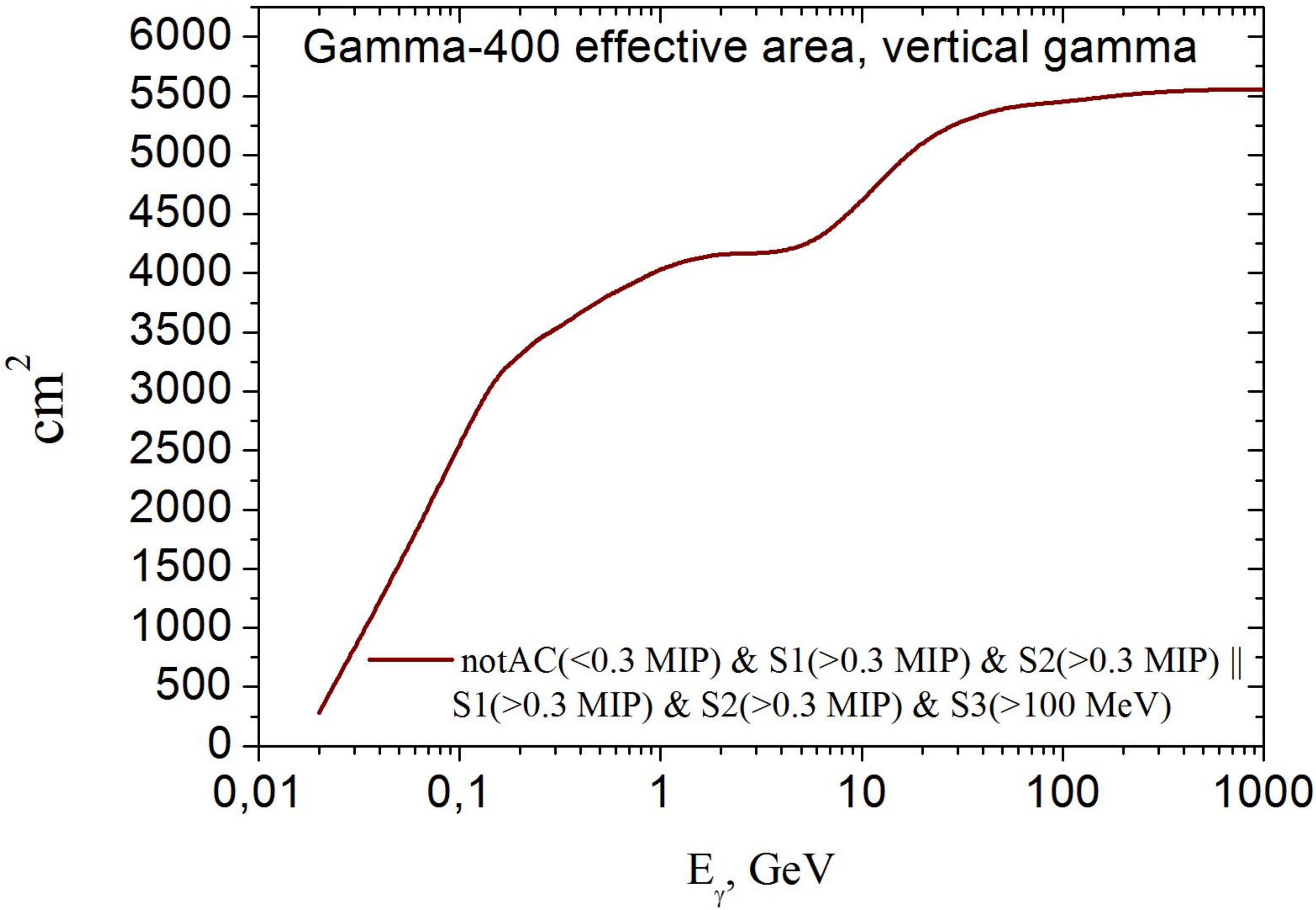
Angular resolution



Energy resolution

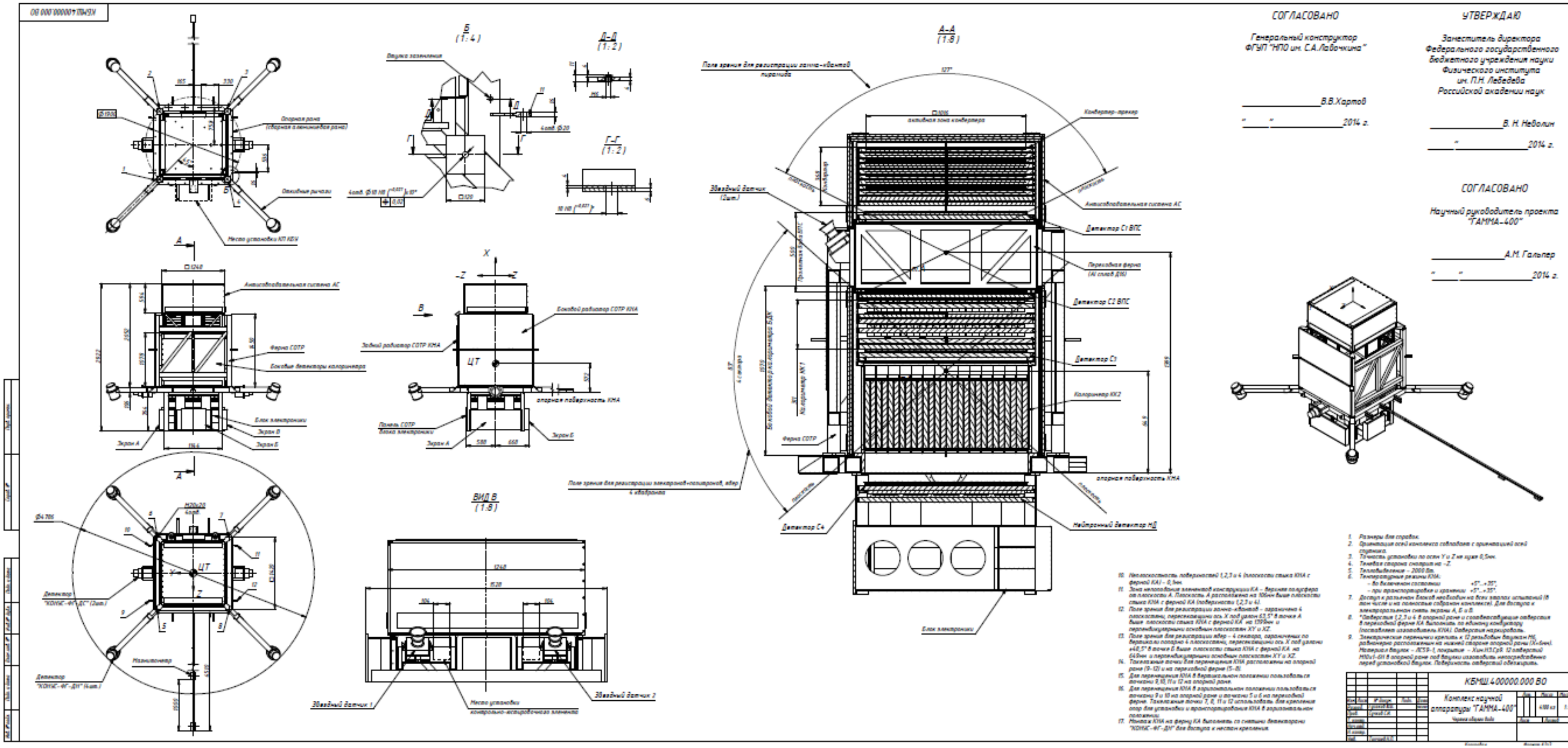


Effective area



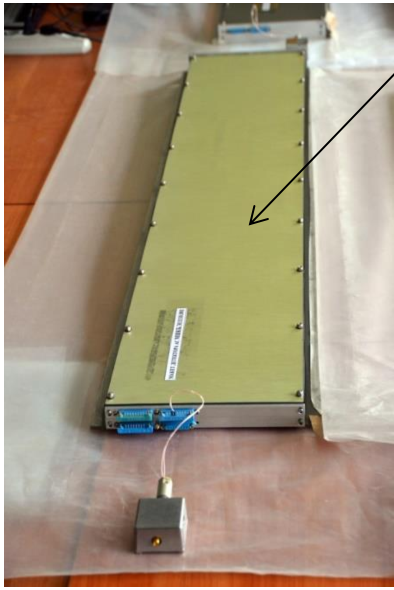
Comparison of the main parameters for GAMMA-400 and Fermi-LAT

	Fermi-LAT	**GAMMA-400**
Orbit	circular, 565 km	Highly elliptical, 500-300000 km **(without the Earth's occultation)**
Operation mode	Sky-survey (3 hours)	**Point observation (up to 100 days)**
Source exposition	1/8	**1**
Energy range	~100 MeV - ~300 GeV	**~20 MeV – ~1000 GeV**
Effective area ($E_\gamma > 1$ GeV)	~5000 cm^2 (front)	~4000 cm^2
Coordinate detectors - readout	Si strips (pitch 0.23 mm) digital	Si strips (**pitch 0.08 mm**) **analog**
Angular resolution	~3° (E_γ = 100 MeV) ~0.2° (E_γ = 10 GeV) ~0.1° (E_γ > 100 GeV)	**~2° (E_γ = 100 MeV)** **~0.1° (E_γ = 10 GeV)** **~0.01° (E_γ > 100 GeV)**
Calorimeter - thickness	CsI(Tl) ~8.5X_0	CsI(Tl)+Si **~22X_0**
Energy resolution	~18% (E_γ = 100 MeV) ~10% (E_γ = 10 GeV) ~10% (E_γ > 100 GeV)	**~10% (E_γ = 100 MeV)** **~3% (E_γ = 10 GeV)** **~1% (E_γ > 100 GeV)**
Mass	2800 kg	4100 kg
Telemetry downlink volume, Gbytes/day	15 Gbytes/day	100 Gbytes/day



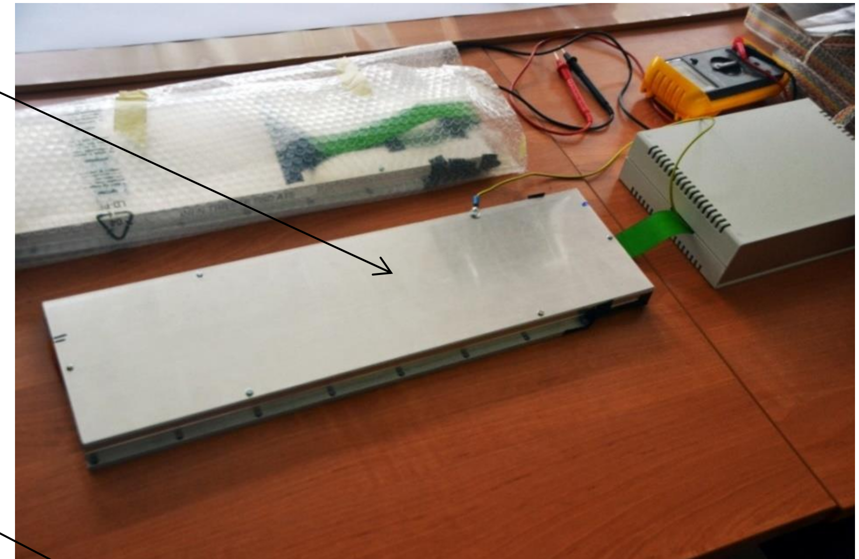
General view of the GAMMA-400 scientific complex

Laboratory prototypes of the GAMMA-400 detector systems

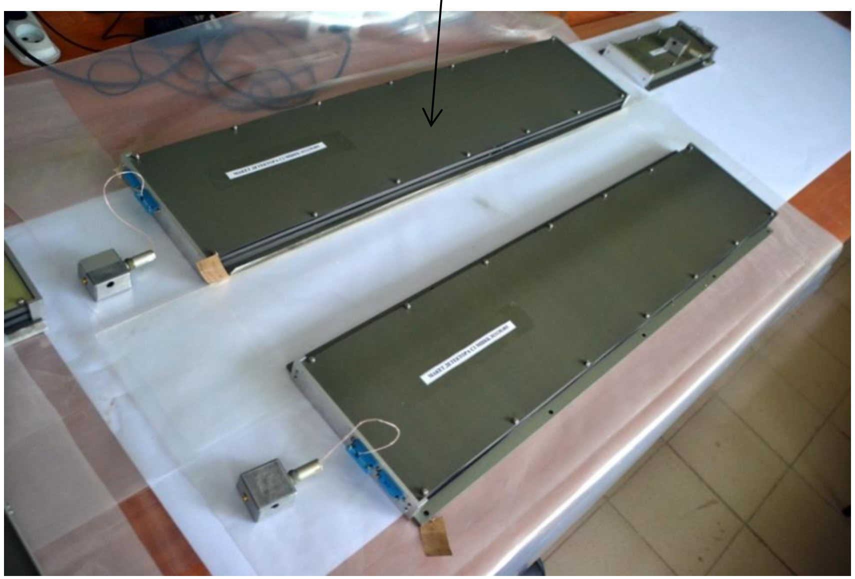


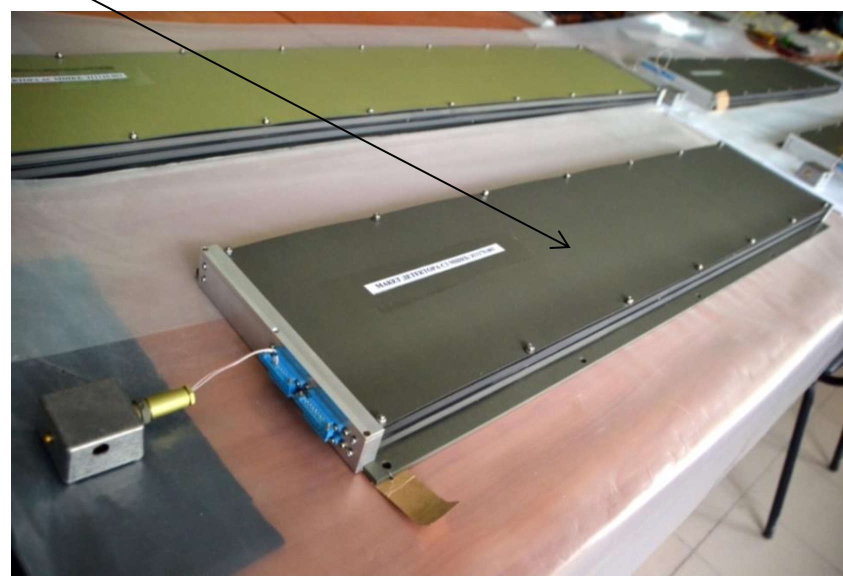
AC

C

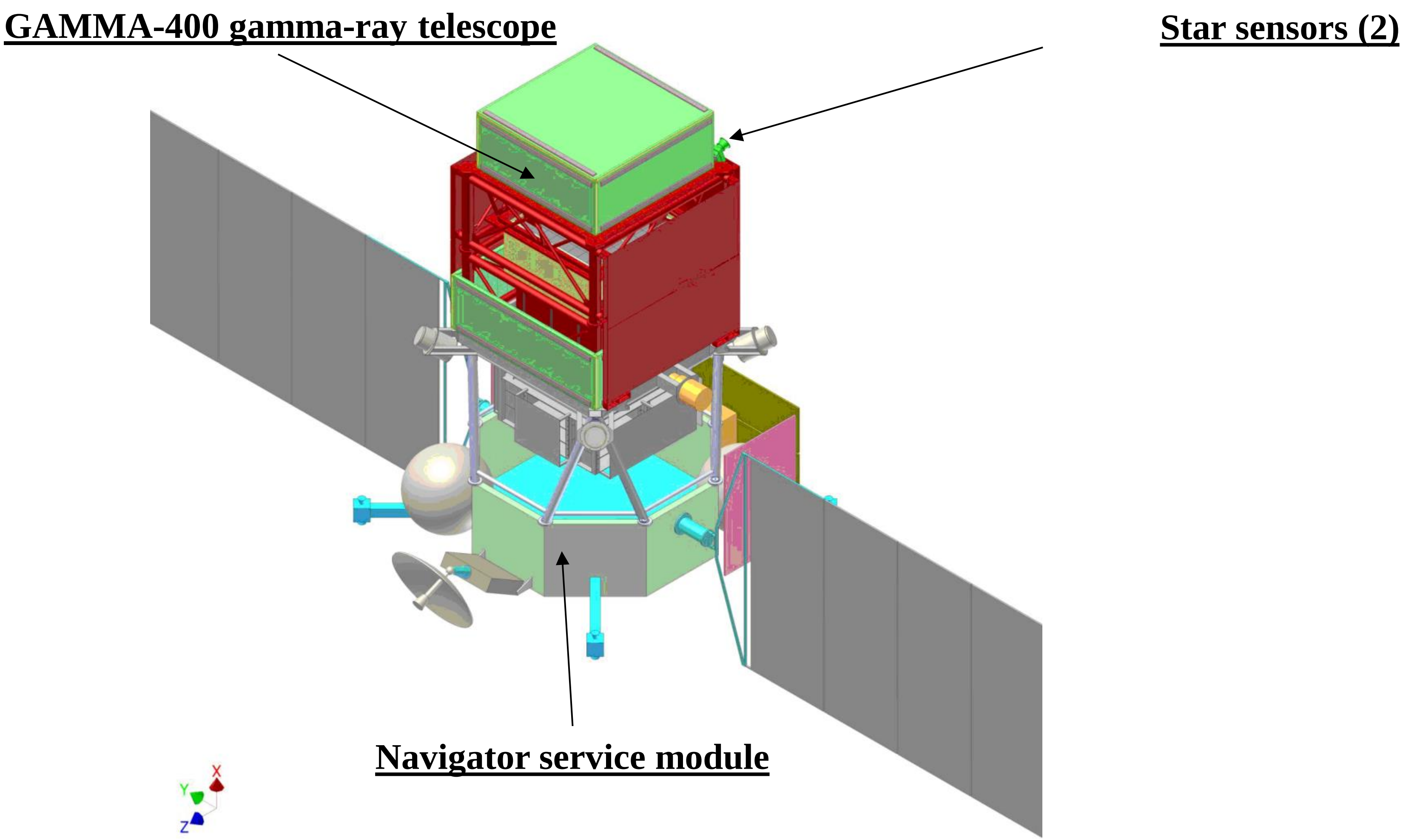


C1, C2, C3



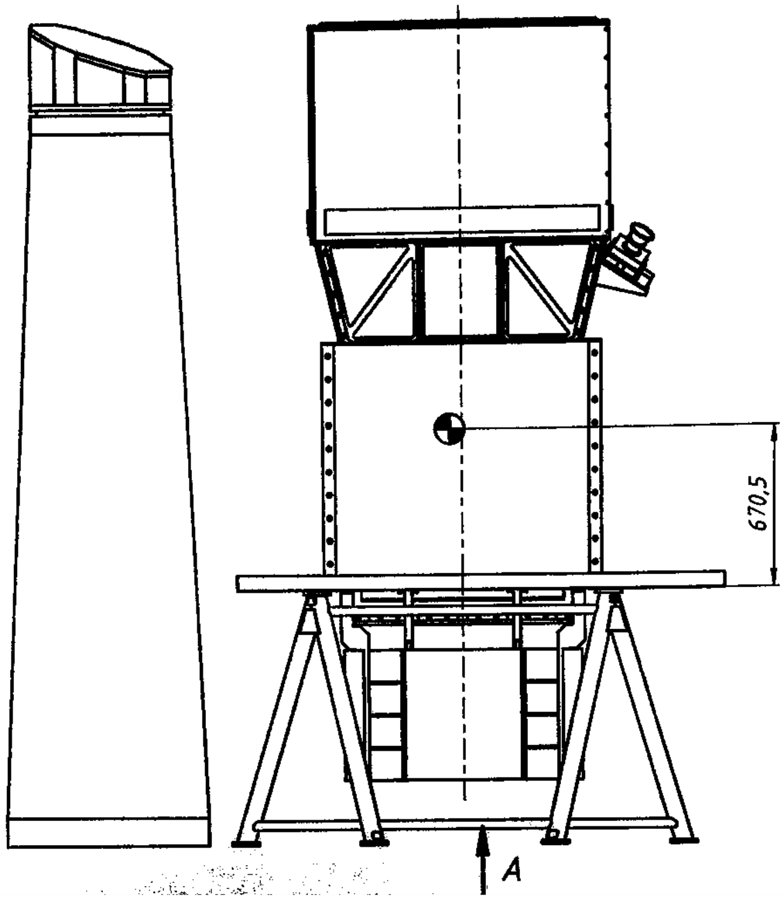


GAMMA-400 scientific complex on Navigator service module



The GAMMA-400 spacecraft and Navigator service module
are designed by Lavochkin Association

GAMMA-400 and X-ray telescope on the GAMMA-400 space observatory

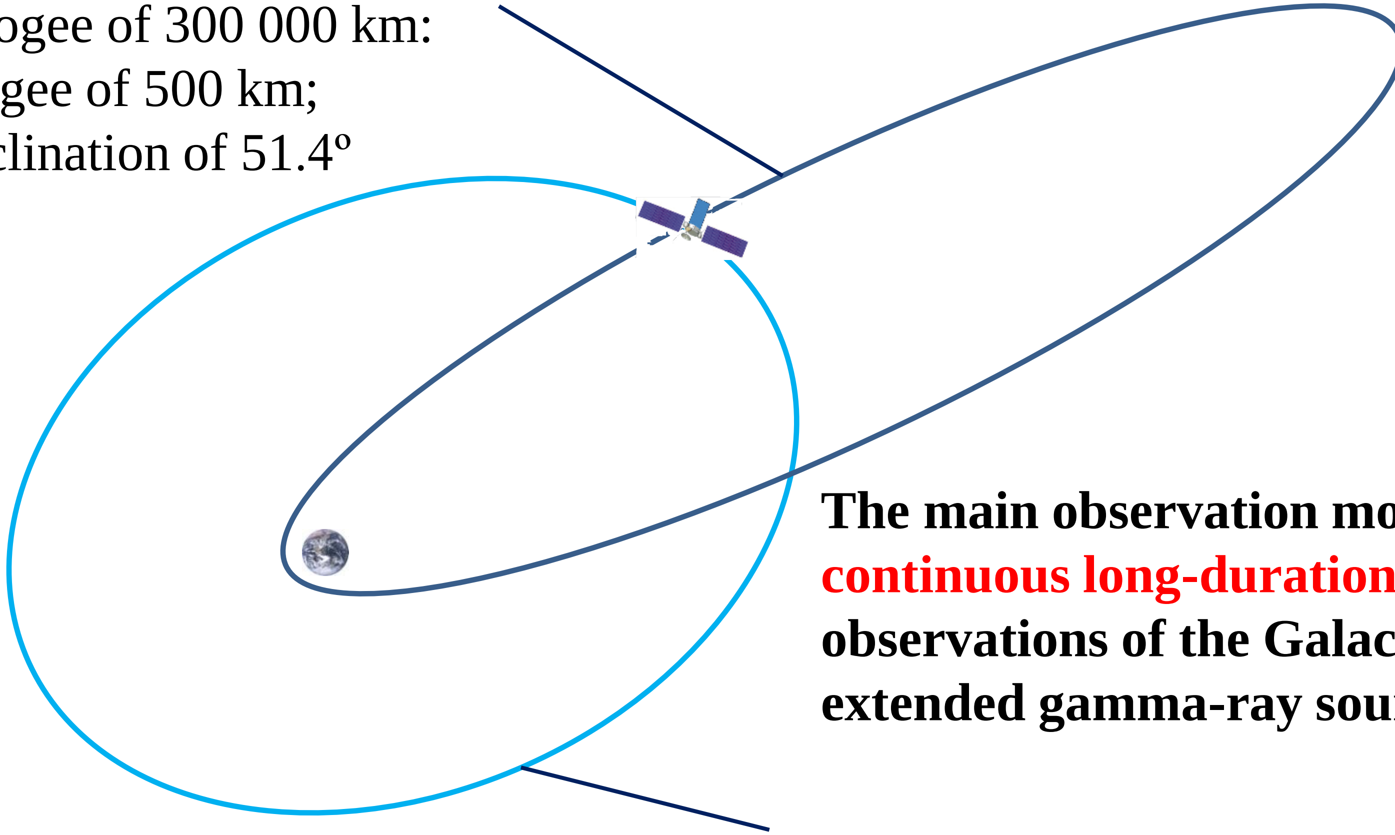


ART-XC (3-30 keV)   GAMMA -400 (~20 MeV - ~1000 GeV)

At the space observatory, together with the GAMMA-400 gamma-ray telescope, an X-ray telescope will be installed. Simultaneous observations in the X-ray and gamma-ray ranges of the Galactic plane, especially, Galactic center, Fermi bubbles, Crab, etc. will greatly improve our understanding of the processes taking place in the astrophysical objects.

The GAMMA-400 orbit evolution and observation modes

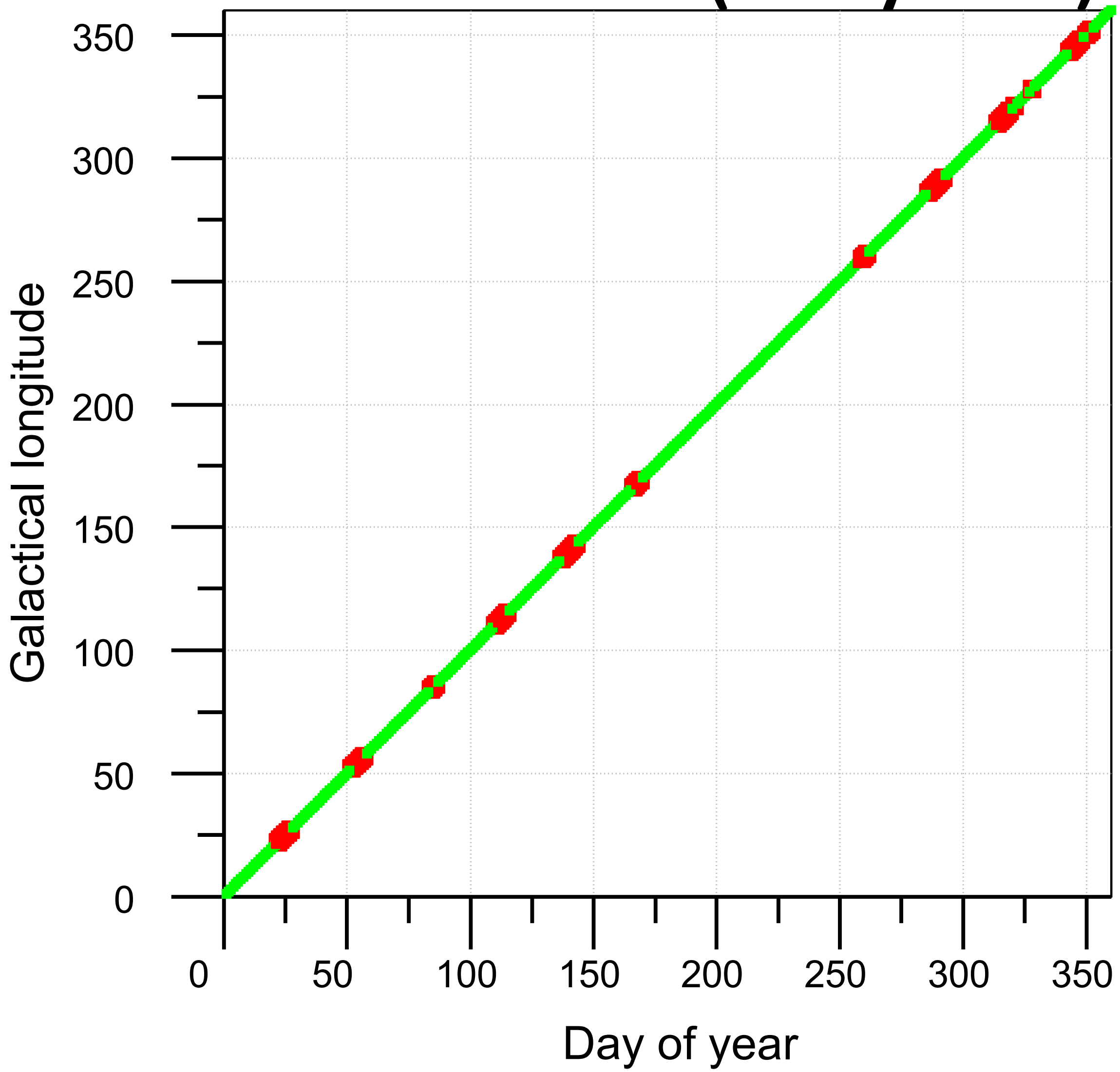
The orbit of the GAMMA-400 space observatory will have the following initial parameters:
-an apogee of 300 000 km:
-a perigee of 500 km;
-an inclination of 51.4º



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

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.

Preliminary survey programme (1st year)



Conditions:
Sun < 45°,
Moon < 30°,
Earth < 30°.

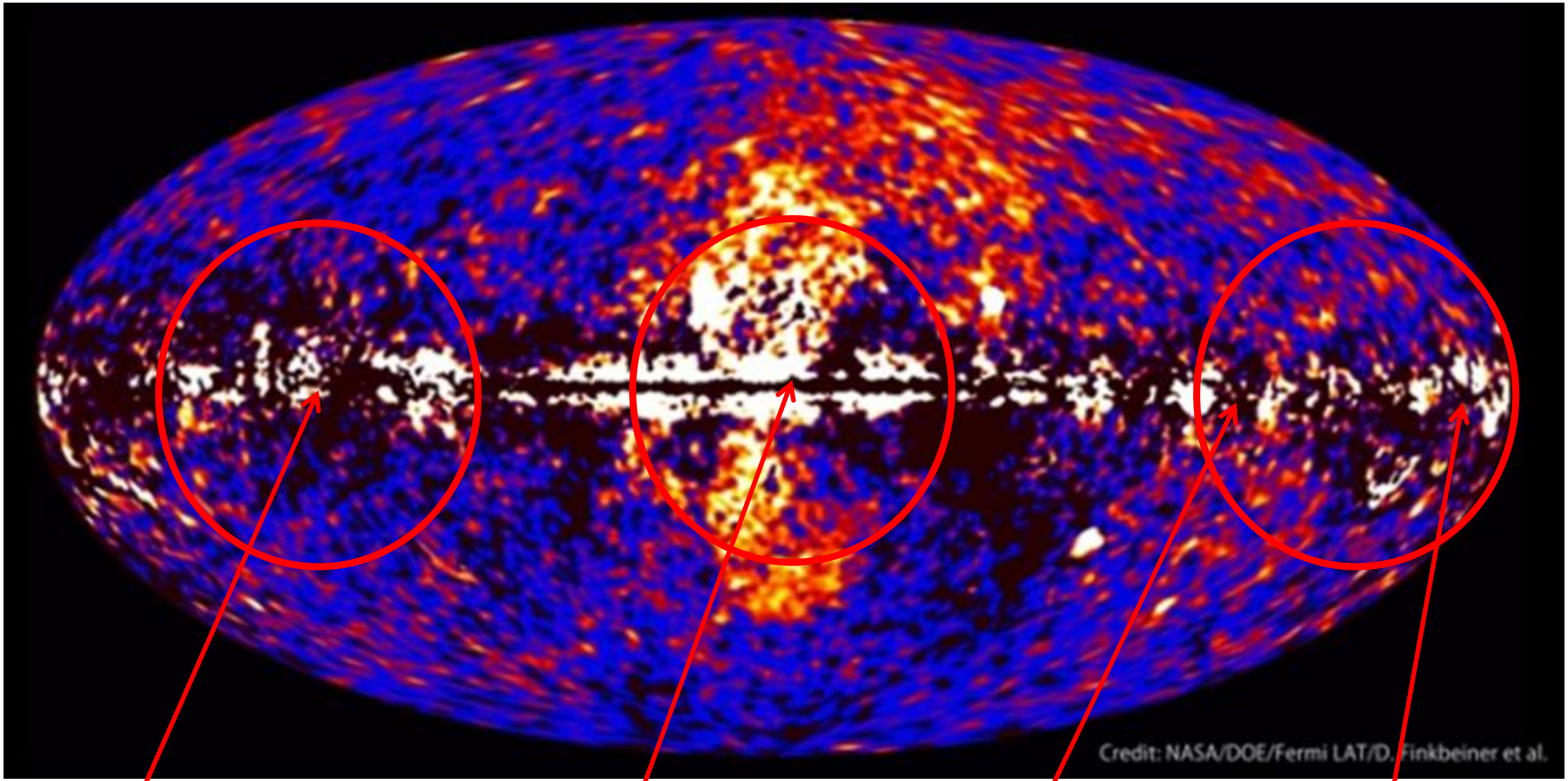
• 306 'clean' days
• 59 days with survey order being changed

30-day exposition at each point

Minimal flux:

$$10^{-9} \frac{\text{photons}}{\text{cm}^2\ \text{s}}$$

Galactic Center, Fermi Bubbles, Crab, Cygnus, Vela, Geminga, and other regions will be observed with the GAMMA-400 aperture of ±45°

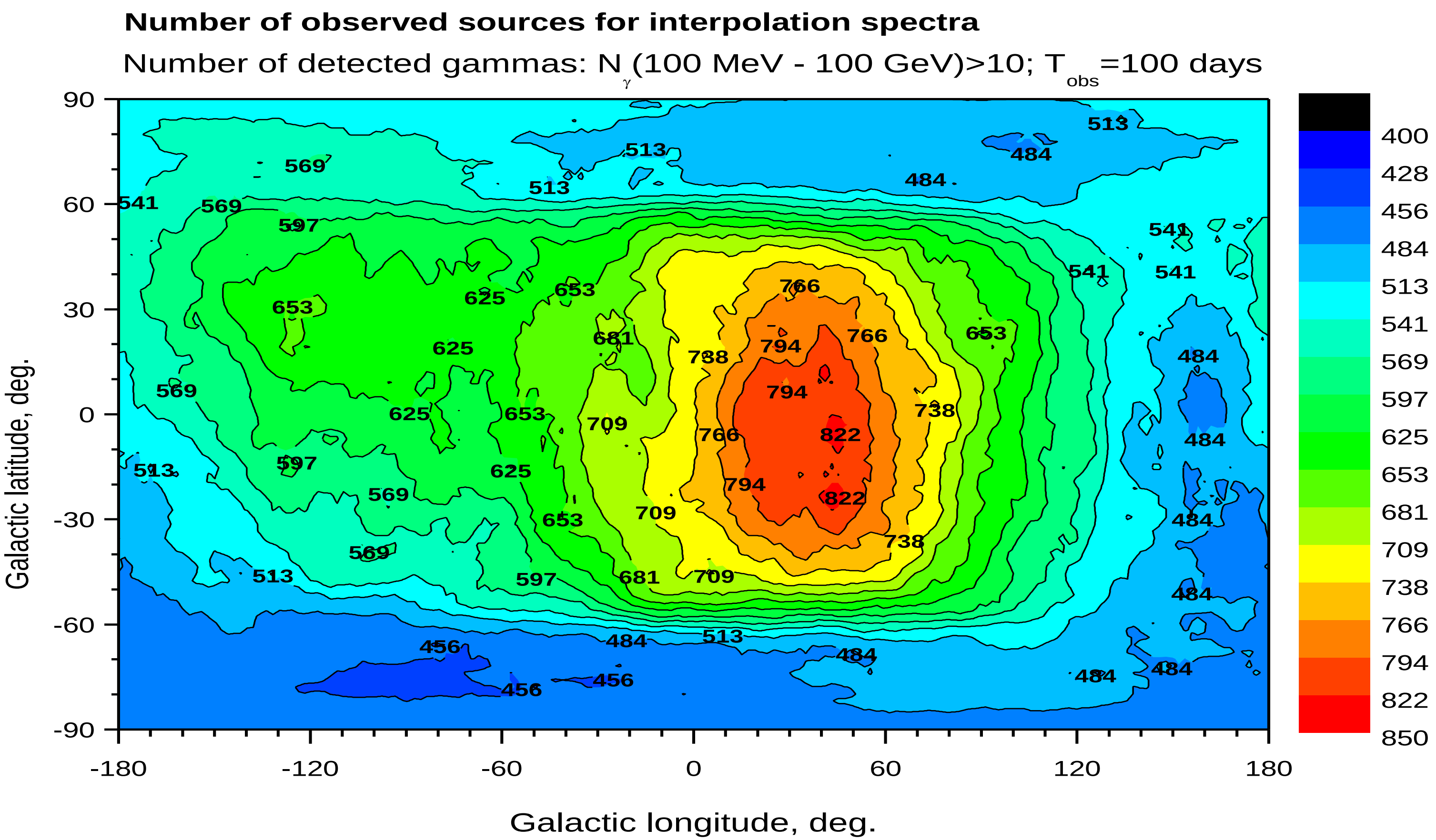


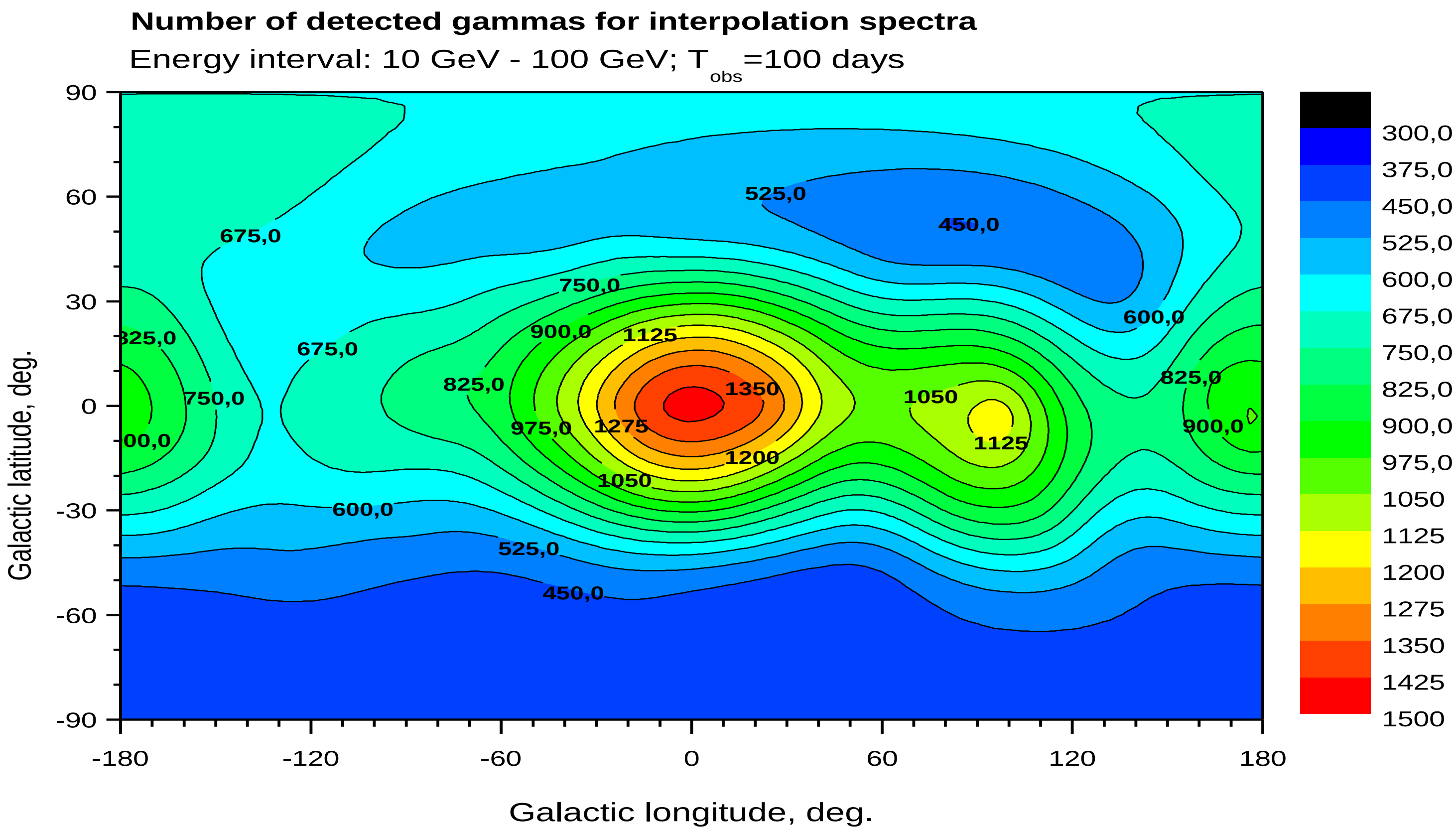
Cygnus

Galactic Center, Fermi Bubbles

Vela

Crab, Geminga


Number of observed sources for interpolation spectra
Number of detected gammas: N_γ(100 MeV - 100 GeV)>10; T_{obs}=100 days
Galactic latitude, deg.
Galactic longitude, deg.
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
400
428
456
484
513
541
569
597
625
653
681
709
738
766
794
822
850

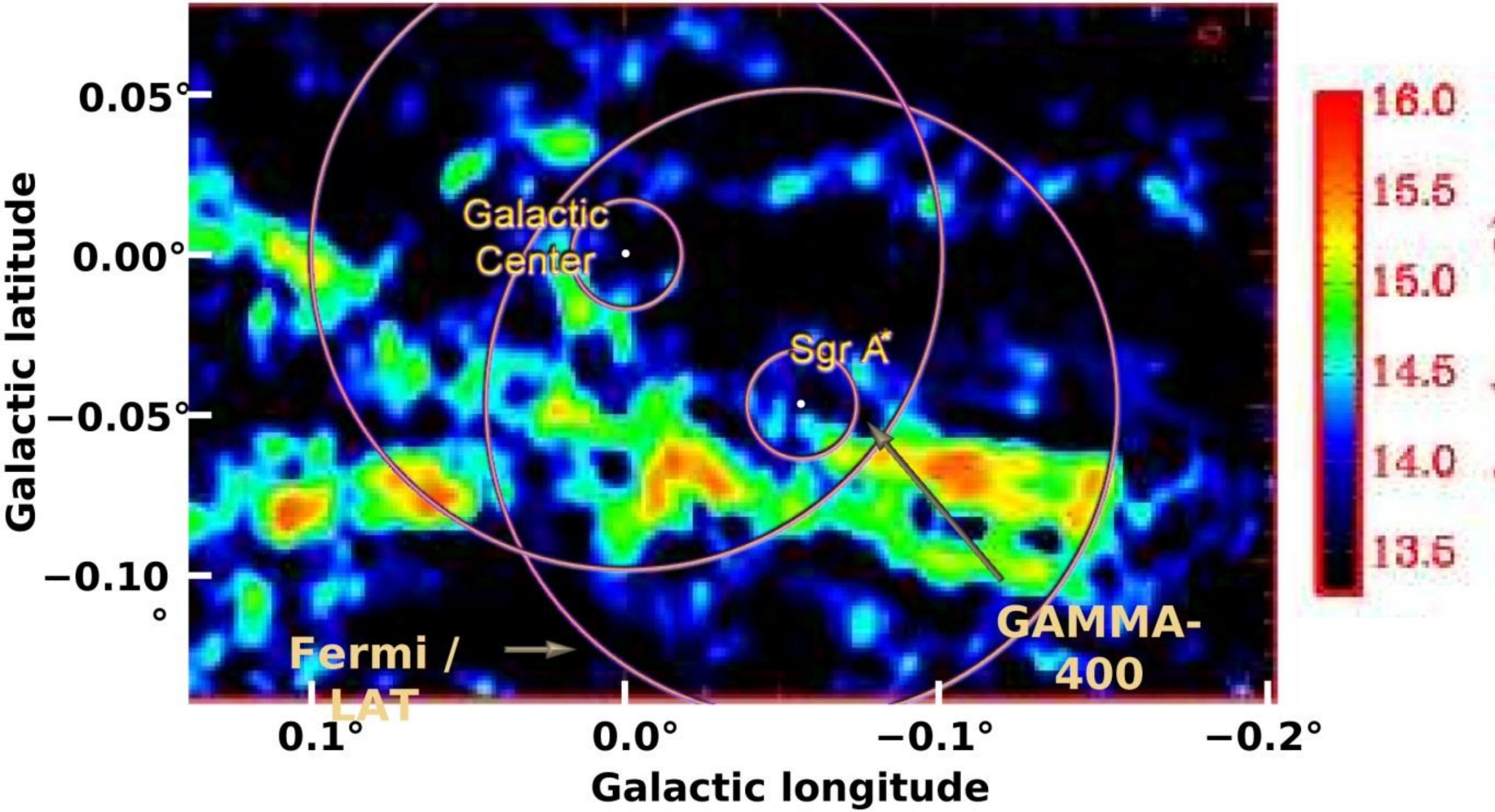


Number of detected gammas for interpolation spectra
Energy interval: 10 GeV - 100 GeV; T obs =100 days
Galactic latitude, deg.
Galactic longitude, deg.
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
525,0
450,0
675,0
750,0
900,0
1125
600,0
825,0
1350
1050
975,0
1275
1200
300,0
375,0
1425
1500

Estimate of the number of gammas, which will be detected by GAMMA-400 when observing the Galactic center using the fluxes from 3FGL (effective area = 4000 cm^2, T_{obs} = 1 year, aperture ±45°):

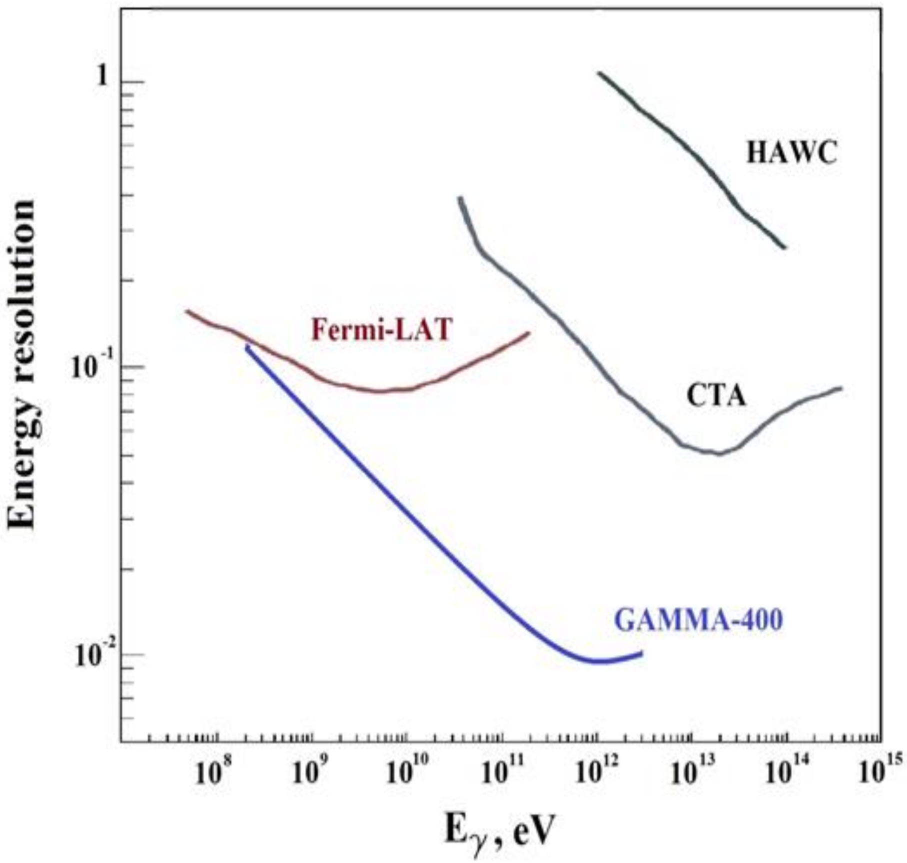
57400 gammas for E_γ > 10 GeV, 1280 gammas for E_γ > 100 GeV

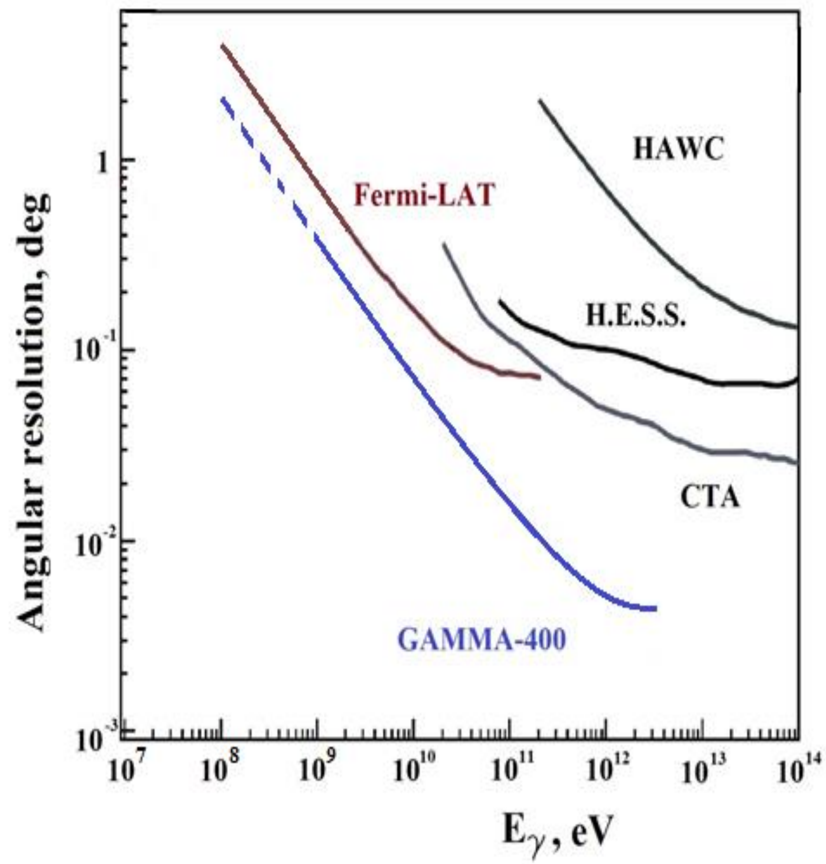
Name (3FGL)	Long	Lat	Name (Tevcat)	Nph (1-100 GeV)	Nph (10-100 GeV)
3FGL J1713.5-3945e	347.3355	-0.4727	RX J1713.7-3946	572	118
3FGL J1802.6-3940	352.4447	-8.4247		1277	28
3FGL J1718.0-3726	349.7233	0.1619	SNR G349.7+00.2	550	36
3FGL J1823.6-3453	358.6796	-9.9341		220	28
3FGL J1745.6-2859c	359.9552	-0.0391	Galactic Center	2748	126
3FGL J1746.3-2851c	0.1488	-0.1029		3472	58
3FGL J1800.8-2402	5.9559	-0.4517	HESS J1800-240	1298	35
3FGL J1809.8-2332	7.3876	-2.0005		8044	76
3FGL J1801.3-2326e	6.5266	-0.251	W 28	6747	137
3FGL J1805.6-2136e	8.6038	-0.2105	HESS J1804-216	3051	142
3FGL J1833.6-2103	12.1671	-5.7051		2585	38
			Sum	**30563**	**822**



Comparison of the capabilities to study Galactic Center by Fermi-LAT with the angular resolution of ~0.1° for E_γ = 100 GeV and GAMMA-400 with the angular resolution of ~0,01° for E_γ = 100 GeV, using Chandra X-ray observation.

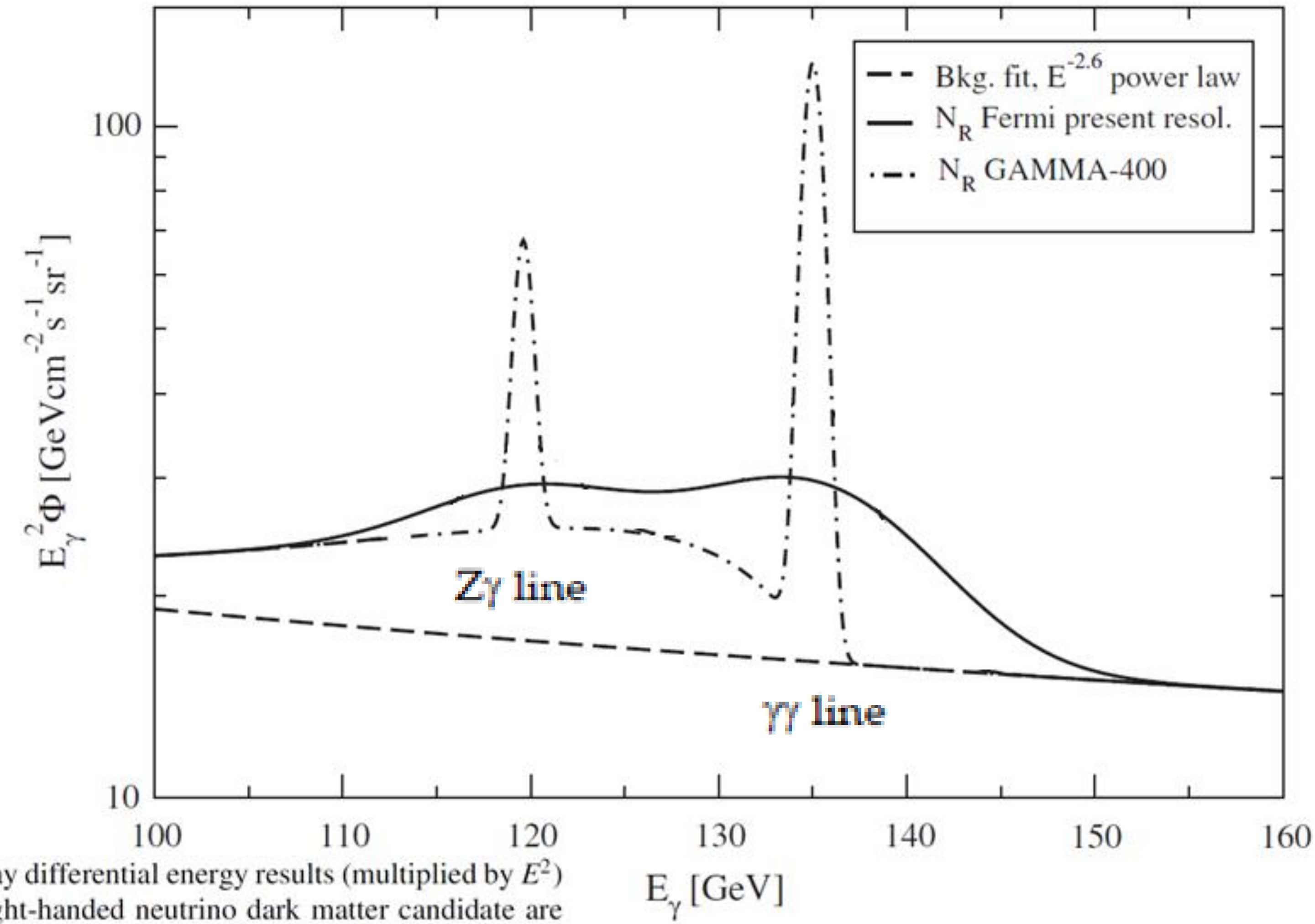
Comparison of the energy and angular resolutions for GAMMA-400, Fermi-LAT, HAWC, and CTA





S. Funk , et. for the CTA Consortium, Astroparticle Phys.,2013, 43, 348

Comparison of the Fermi-LAT and GAMMA-400 capabilities to resolve gamma-ray lines from dark matter particles



ΔE/E
10%
1%

FIG. 3. The γ-ray differential energy results (multiplied by E^2) for a 135 GeV right-handed neutrino dark matter candidate are shown, with the present Fermi-LAT energy resolution $\Delta E/E = 10\%$ FWHM (solid line)

and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

PHYSICAL REVIEW D **86,** 103514 (2012)

130 GeV fingerprint of right-handed neutrino dark matter

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Conclusions

- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to significantly improve the data of LE+HE gamma rays and X-rays with unprecedented angular and energy accuracy.**
- According the new approved Russian Federal Space Program 2016-2025 the GAMMA-400 space observatory is scheduled to launch in 2025-2026.

GAMMA-400 site - http://gamma400.lebedev.ru/