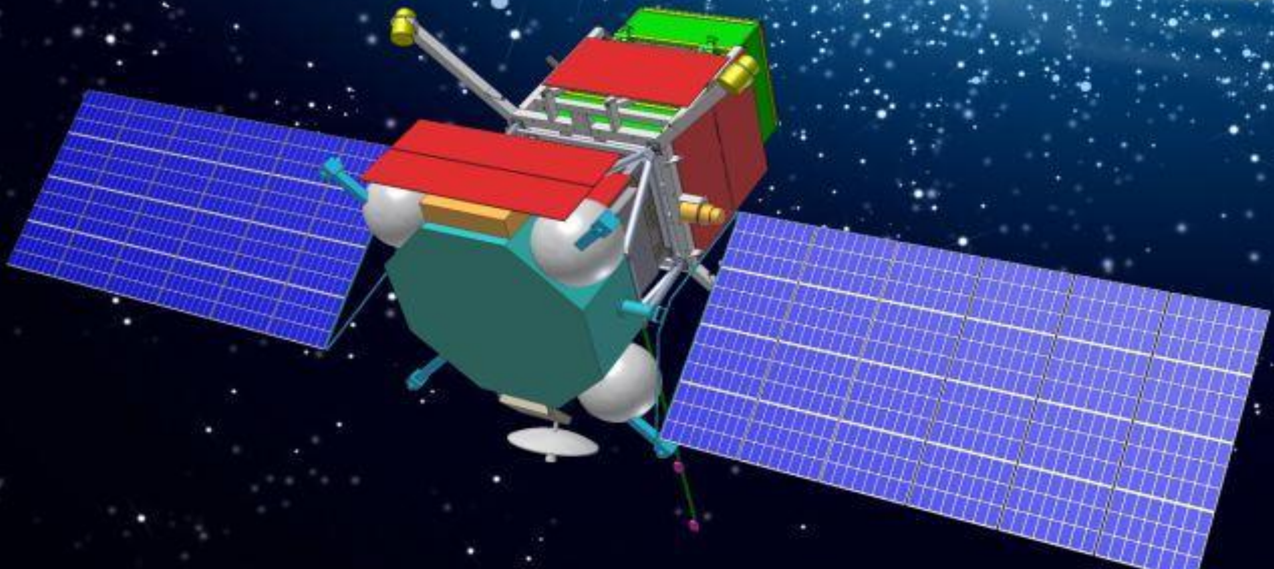
Russian Academy of Sciences
P.N.Lebedev Physical Institute
L P I

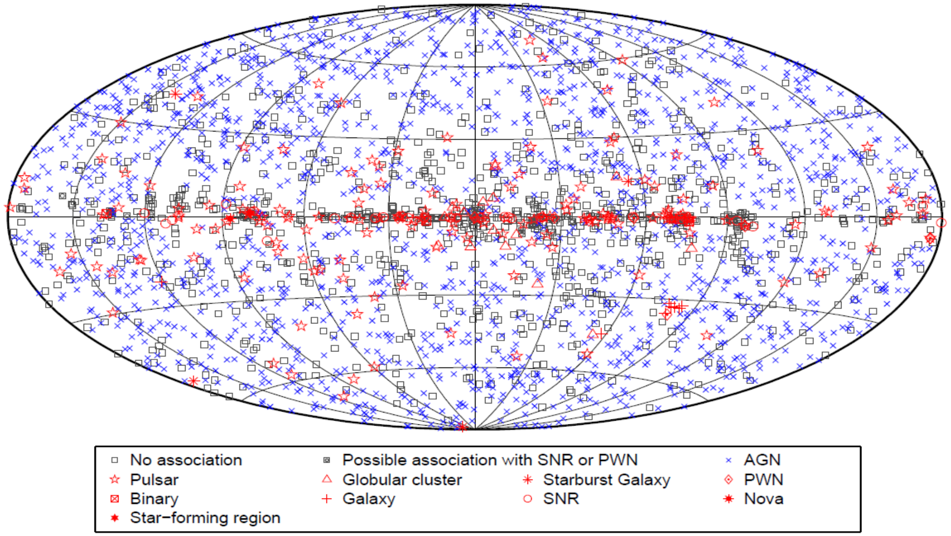
Nikolay Topchiev
for the GAMMA-400 Collaboration

High-energy gamma- and cosmic-ray observations with future space-based GAMMA-400 gamma-ray telescope

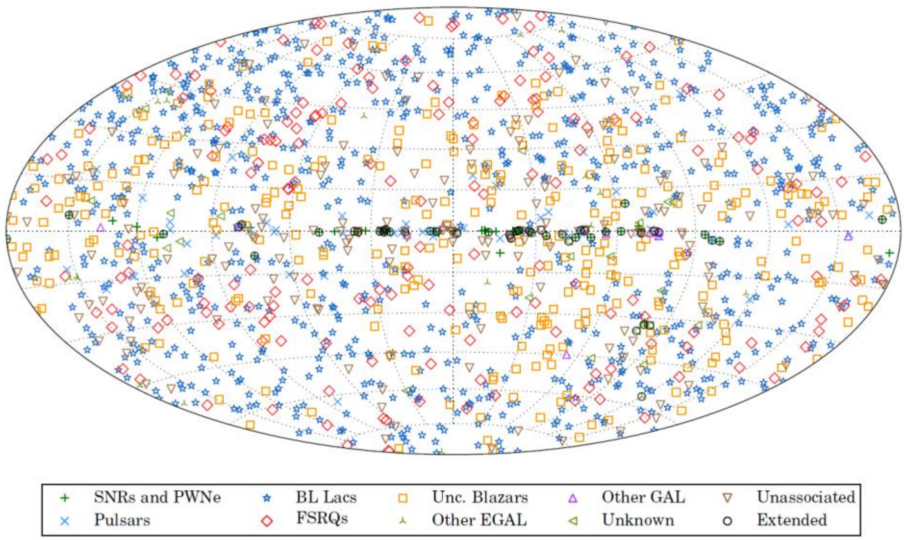


May 21-25, 2018, ISVHECRI, Nagoya University, Nagoya, Japan

High-energy gamma-ray studying



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

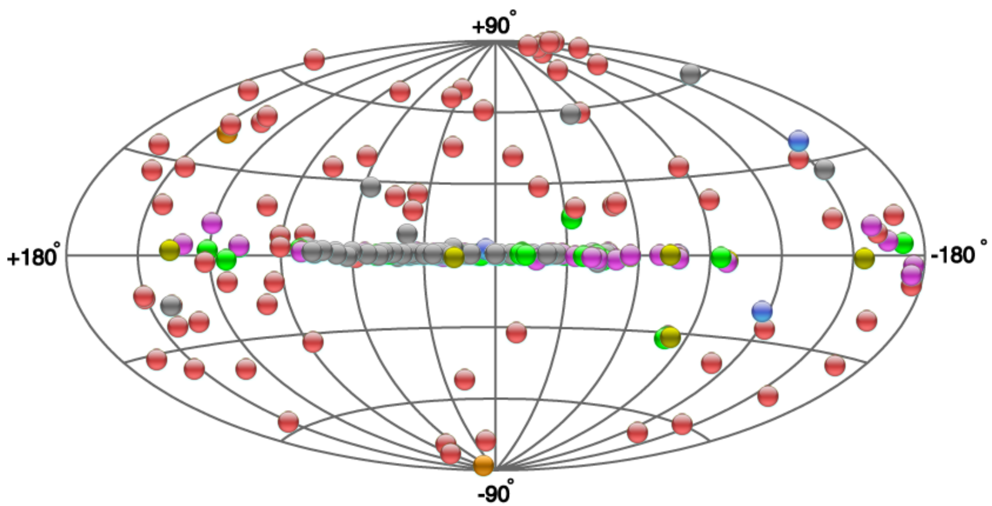


Distribution of 1556 discrete sources
(**3FHL**, E_γ = 10 – 2000 GeV)

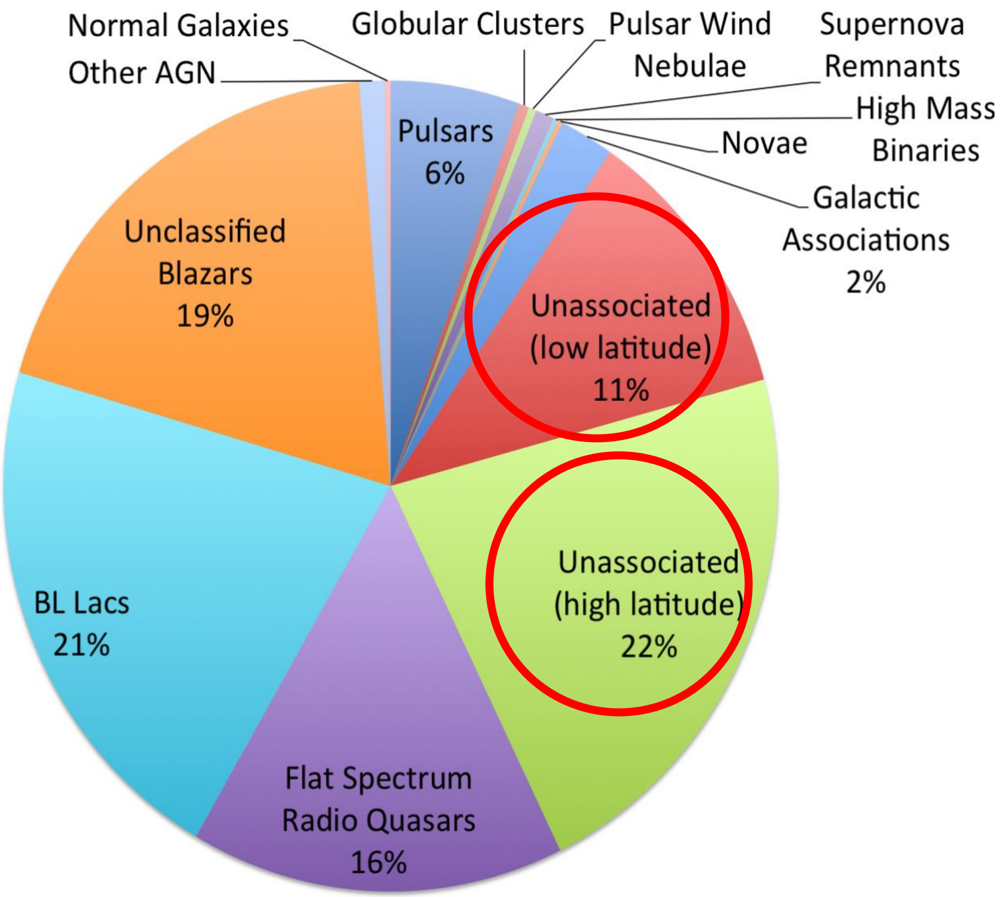
~33% sources are unidentified

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

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

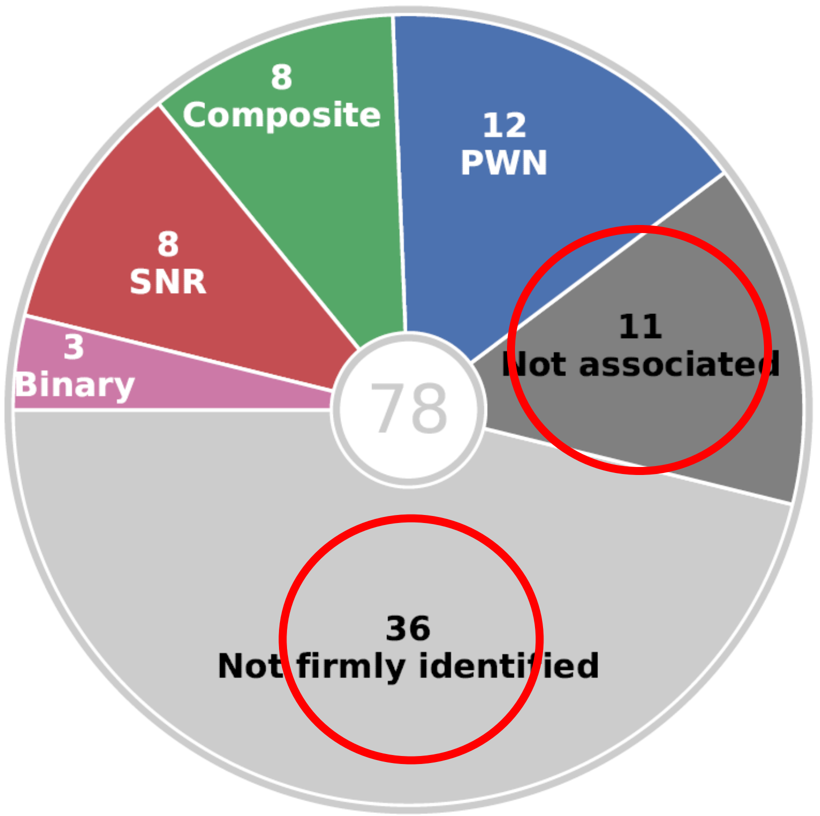


Distribution of 210 discrete sources
(**TeVCat**, E_γ > 100 GeV)



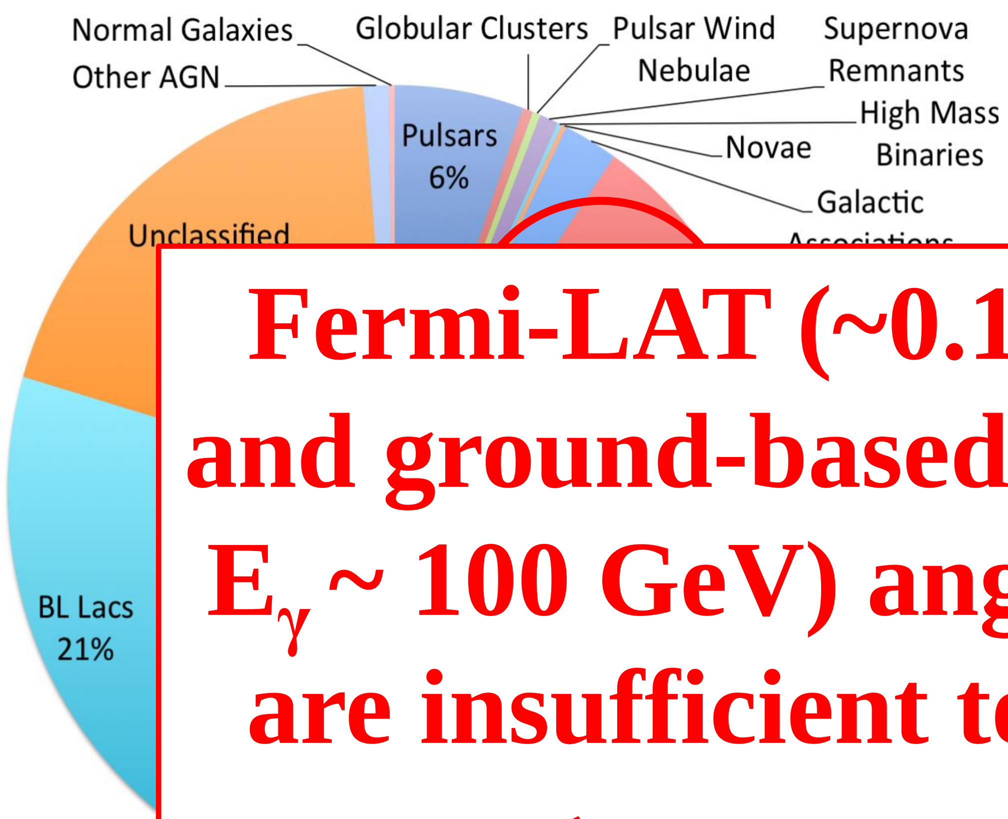
The percentage of the different types of gamma-ray sources according to the 3FGL Fermi-LAT catalogue

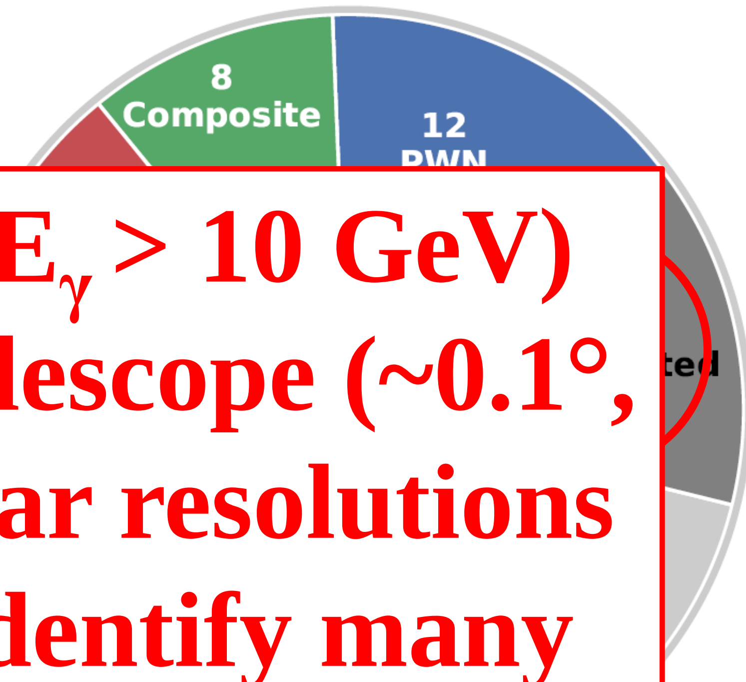
arXiv :1509.00012



Composition of discrete sources recorded by H.E.S.S.

arXiv :1804.02432





Fermi-LAT (~0.1°, E_γ > 10 GeV) and ground-based telescope (~0.1°, E_γ ~ 100 GeV) angular resolutions are insufficient to identify many gamma-ray sources

The percentage of the different types of gamma-ray sources according to the 3FGL Fermi-LAT catalogue

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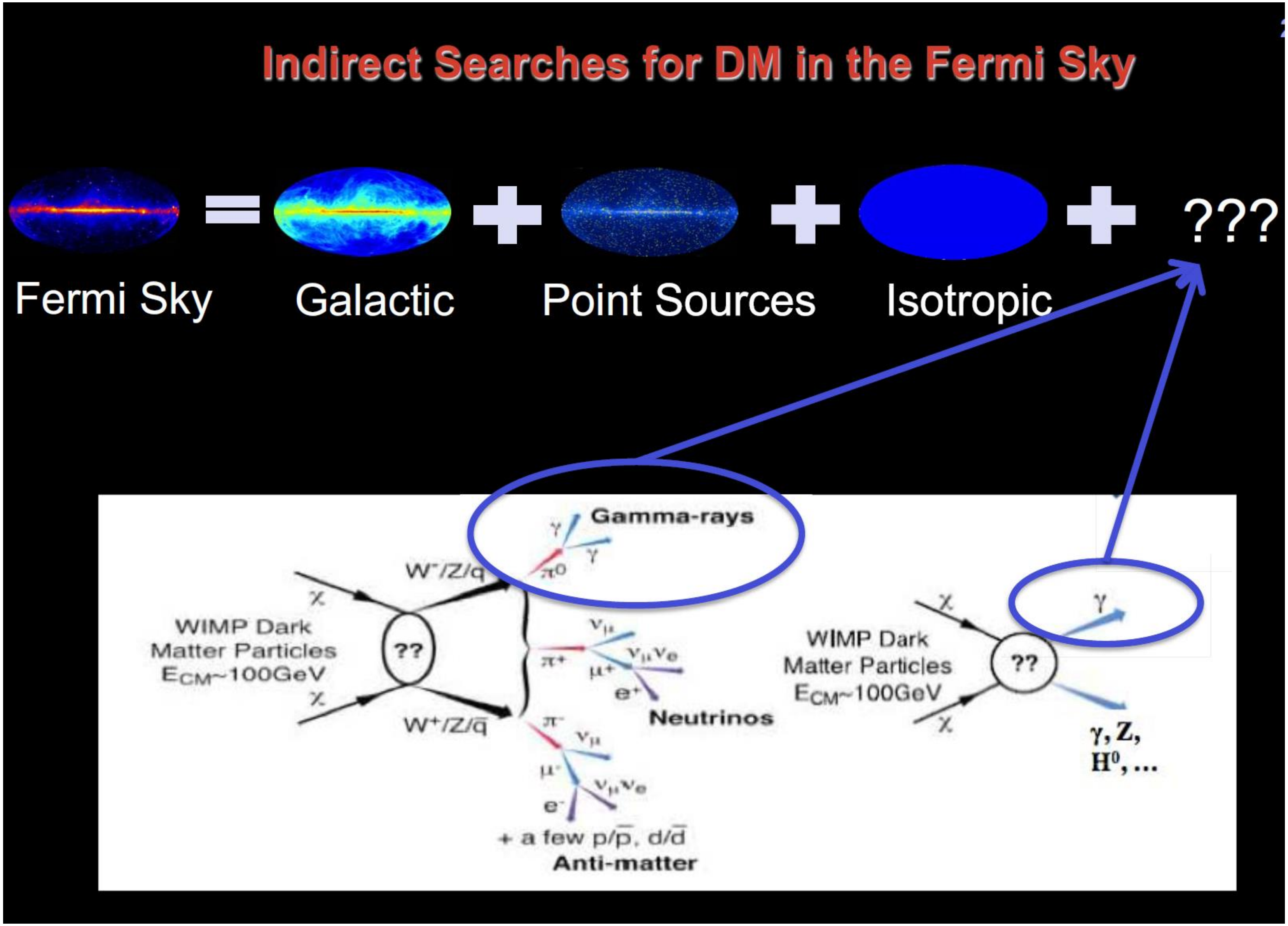
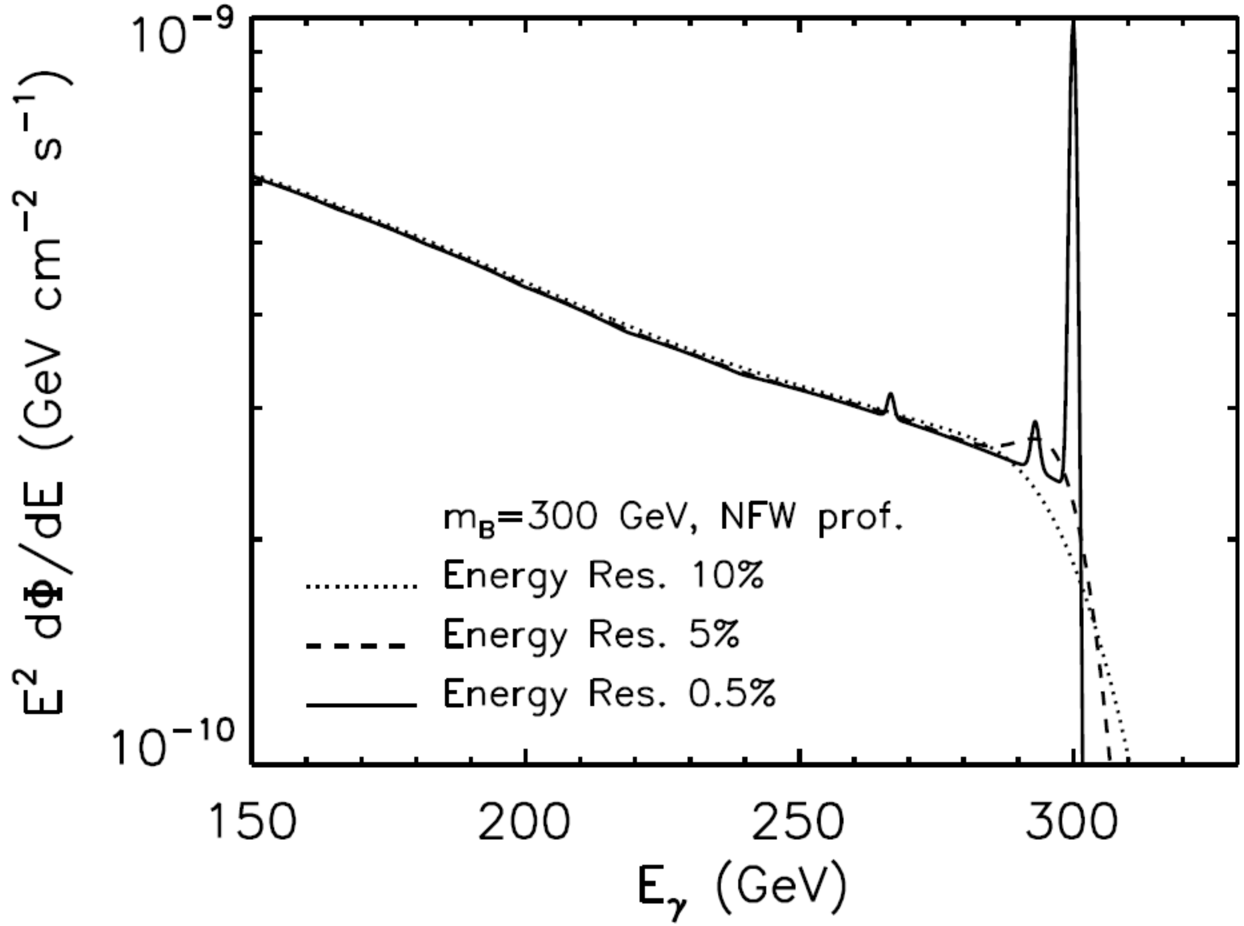


One of the leading candidates for the DM particle are weakly interacting massive particles (WIMPs) producing gamma rays after annihilation or decay

Capabilities of different gamma-ray telescopes to resolve DM lines

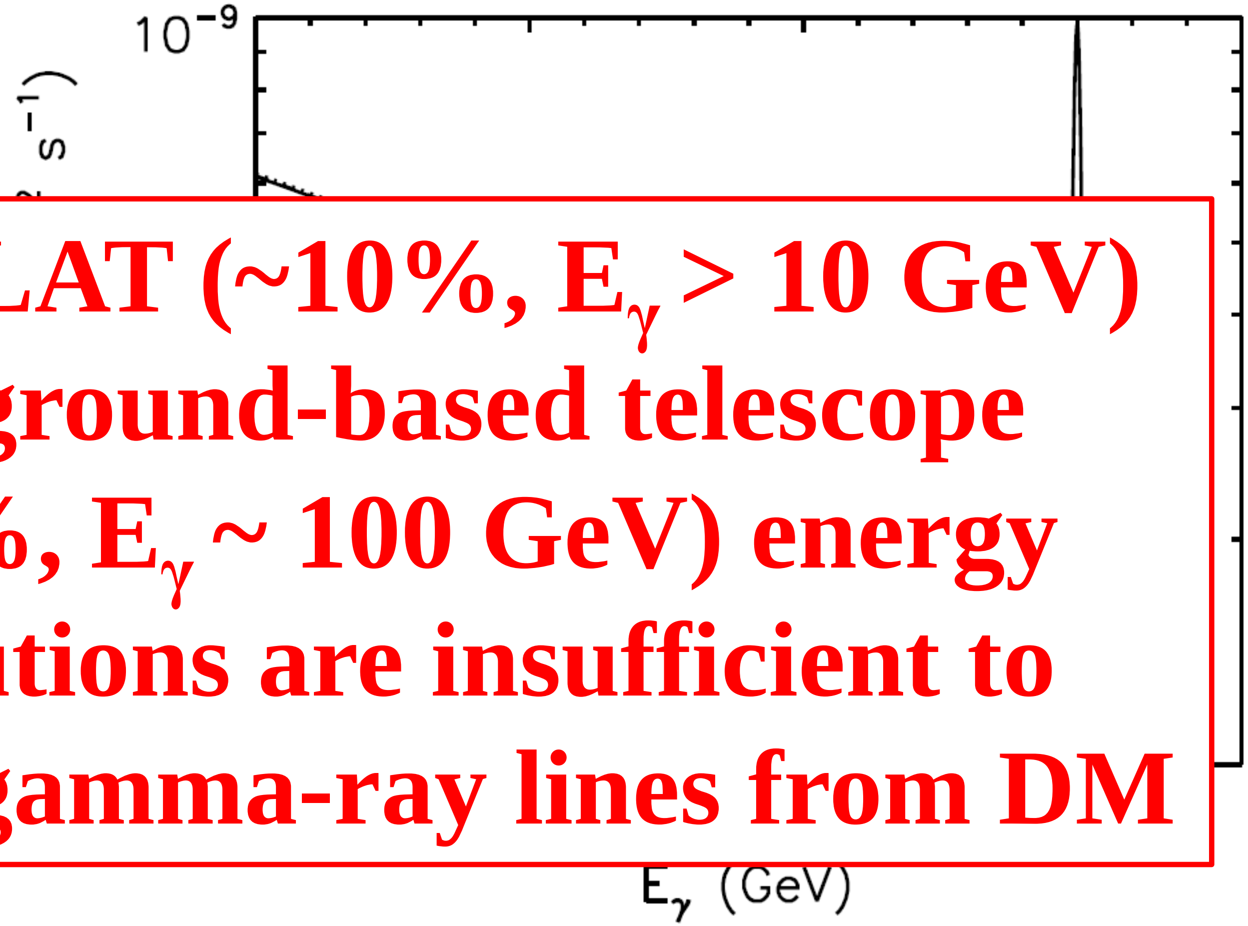


The gamma ray flux as a function of the photon's energy for a WIMP of mass 300 GeV. Shown are three different experimental energy resolutions.

Energy resolution for Fermi-LAT is ~10% (E_γ > 10 GeV) and ground-based gamma-ray telescopes is ~15% (E_γ ~ 100 GeV)

arXiv:1009.5107

Capabilities of different gamma-ray telescopes to resolve DM lines



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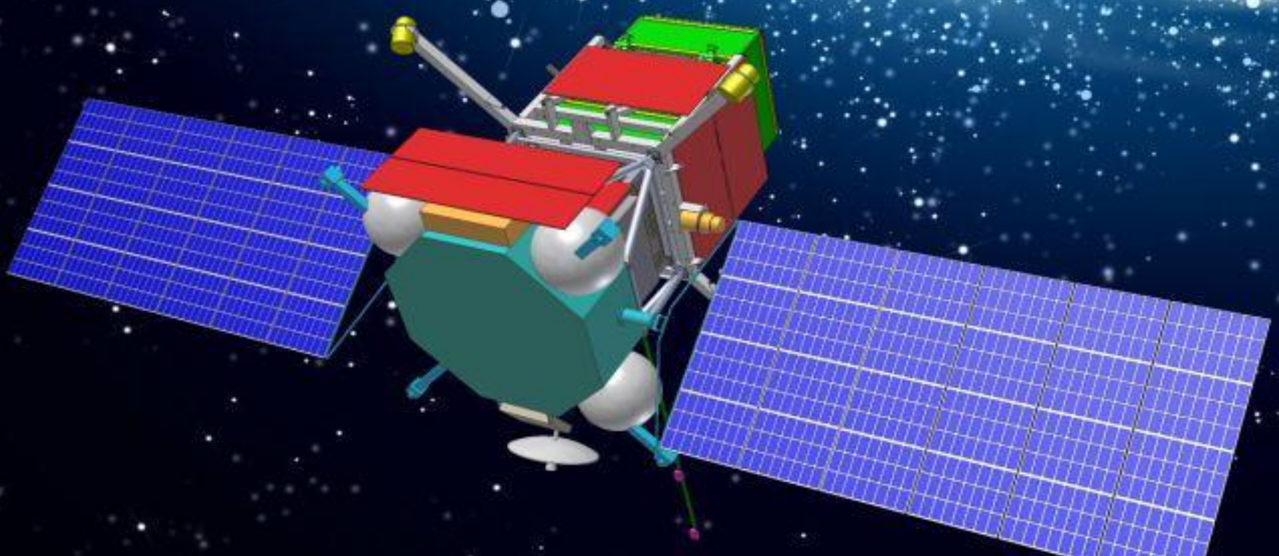
arXiv:1009.5107

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

Such a new generation telescope will be

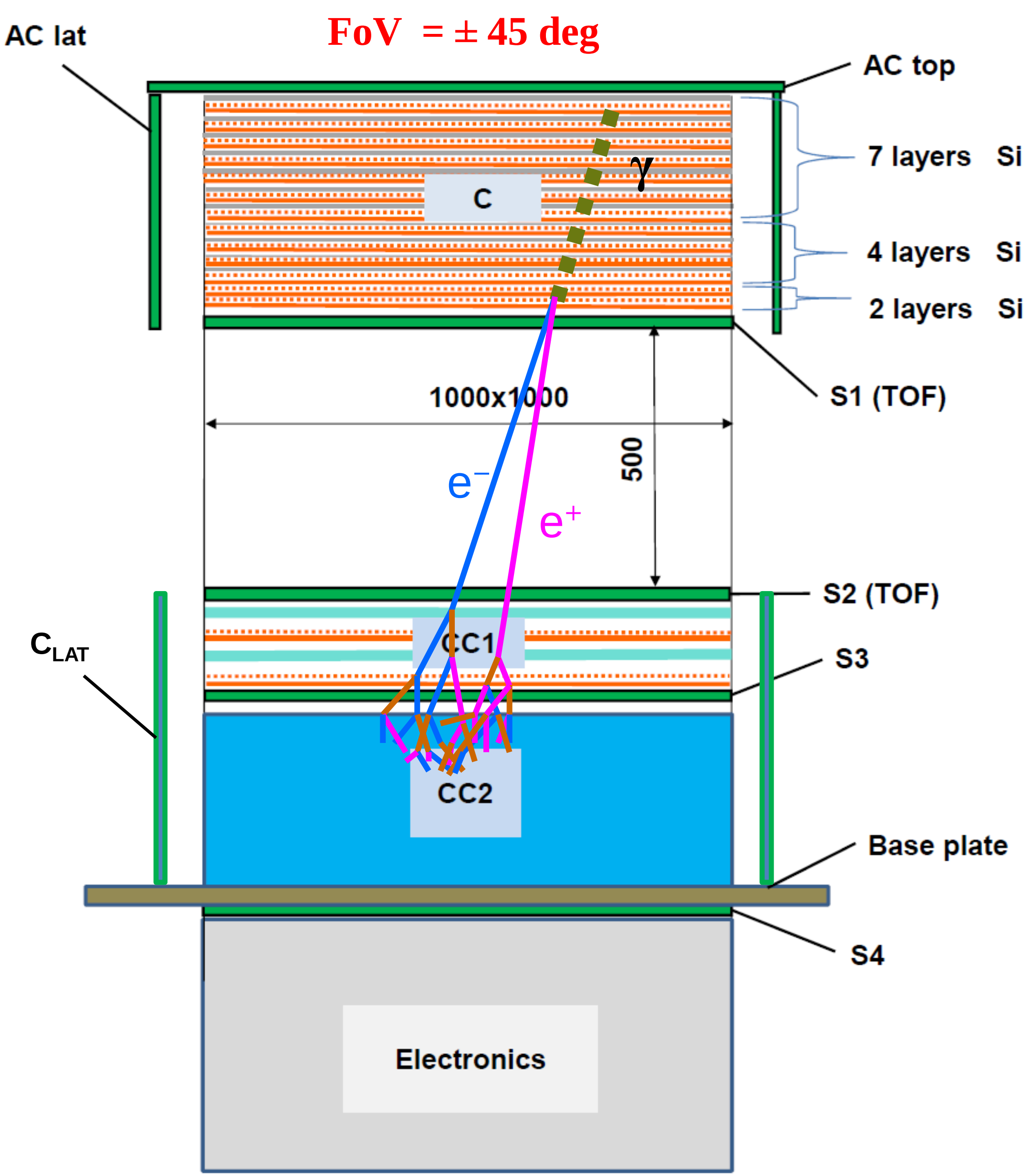
GAMMA-400



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)**, as well as detecting electron + positron fluxes with energies up to 10 TeV.

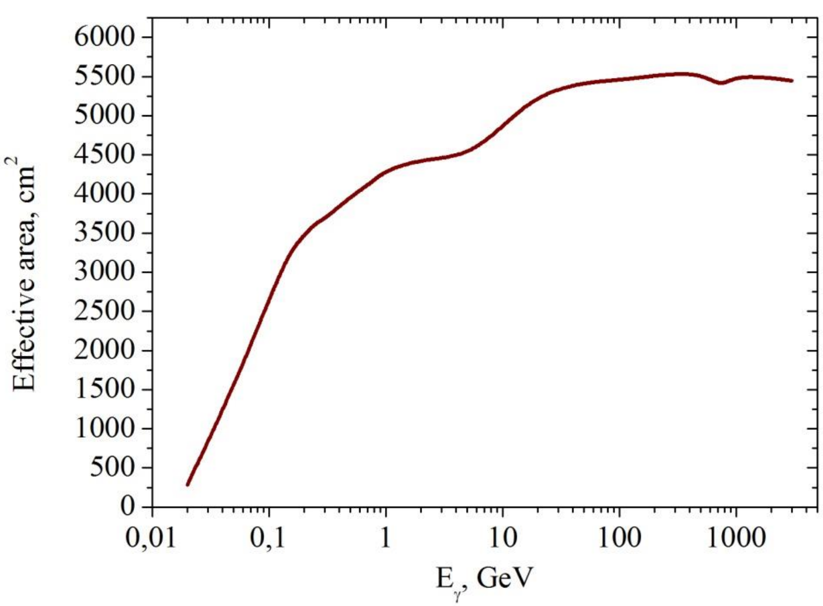
The GAMMA-400 physical scheme

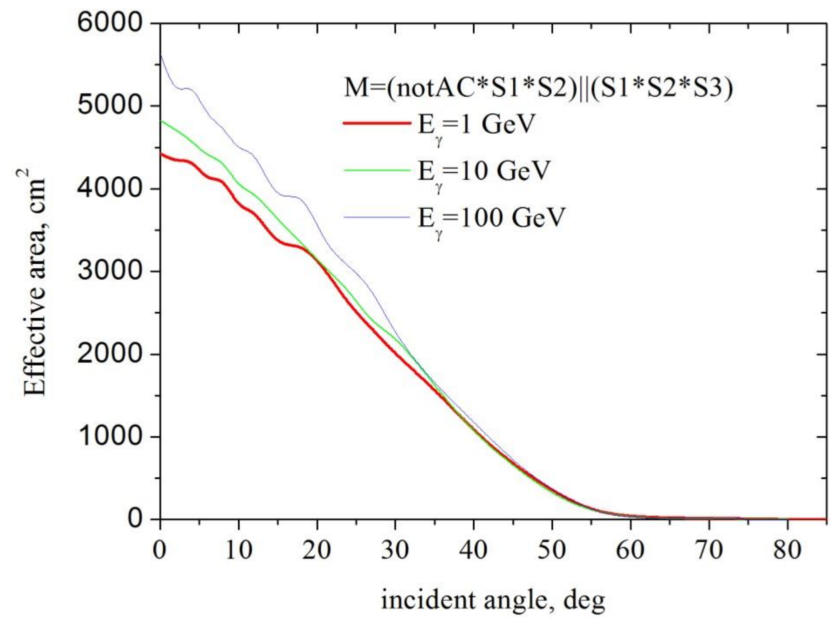


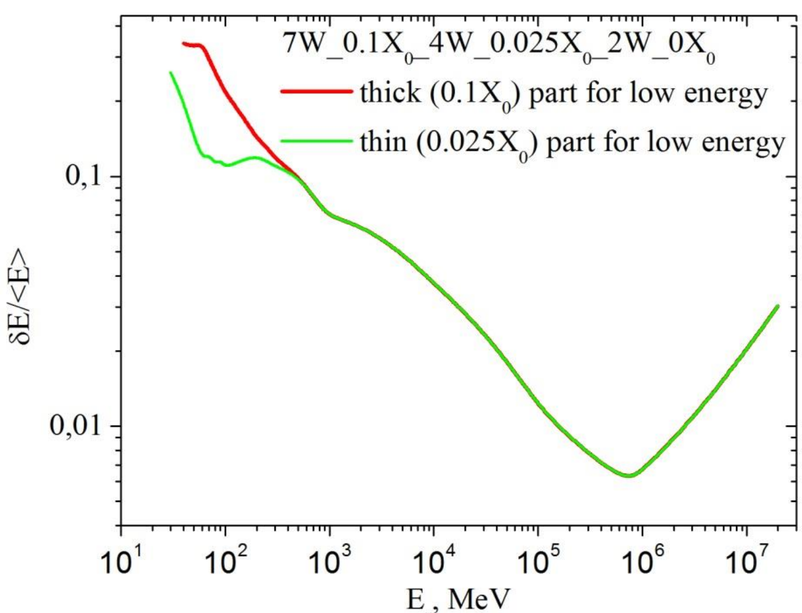
AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter
vertical thickness ~22 X_0
lateral thickness ~54 X_0
S3, S4 – scintillator detectors
C_{LAT} – lateral calorimeter detectors

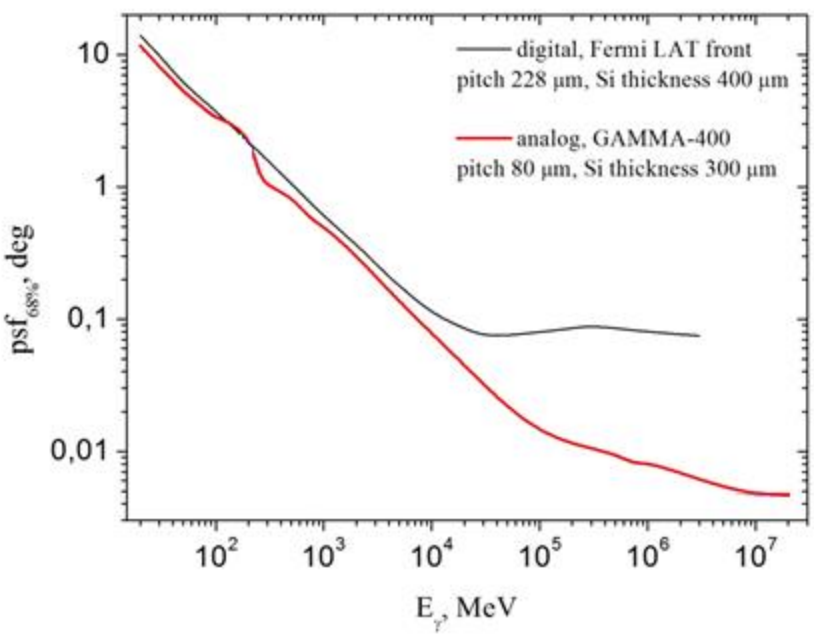
$$M = \overline{AC} \times S1 \times S2$$

GF_{CR} > 3 m^2sr (all sides)
ΔE = ~20 MeV – ~10 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)


Effective area, cm^2
E_γ, GeV


M=(notAC*S1*S2)||(S1*S2*S3)
E_γ=1 GeV
E_γ=10 GeV
E_γ=100 GeV
Effective area, cm^2
incident angle, deg


7W_0.1X$_0$_4W_0.025X$_0$_2W_0X$_0$
thick (0.1X$_0$) part for low energy
thin (0.025X$_0$) part for low energy
δE/<E>
E_γ, MeV


digital, Fermi LAT front
pitch 228 μm, Si thickness 400 μm
analog, GAMMA-400
pitch 80 μm, Si thickness 300 μm
psf$_{68\%}$, deg
E_γ, MeV

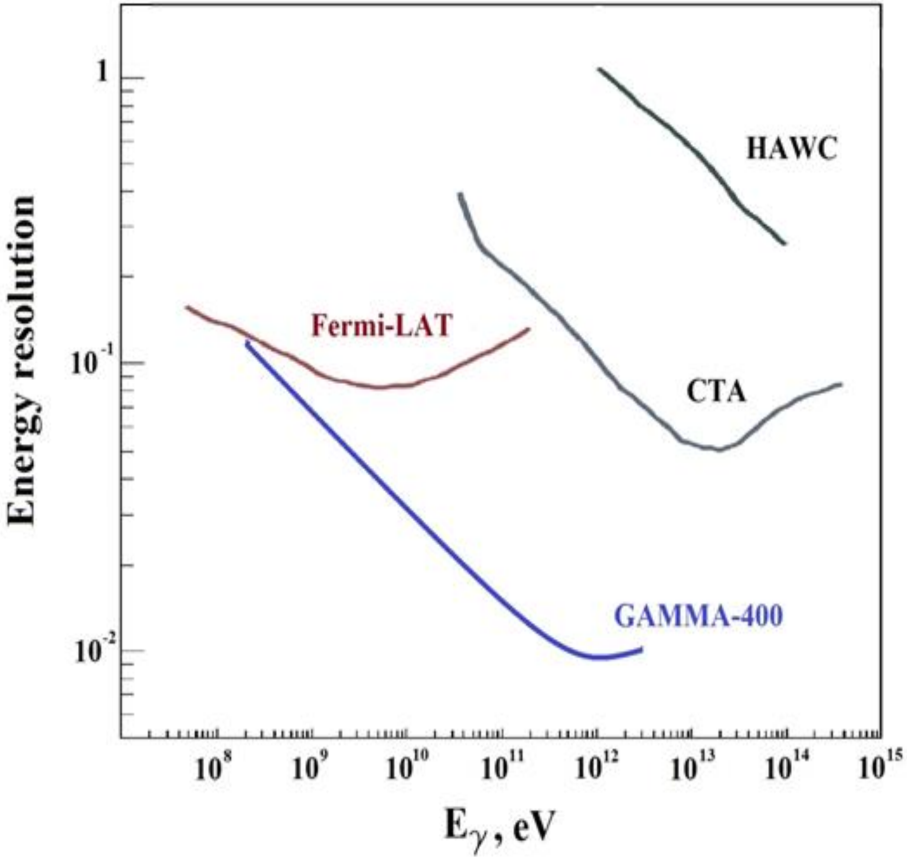
Comparison of the main parameters for GAMMA-400 and Fermi-LAT

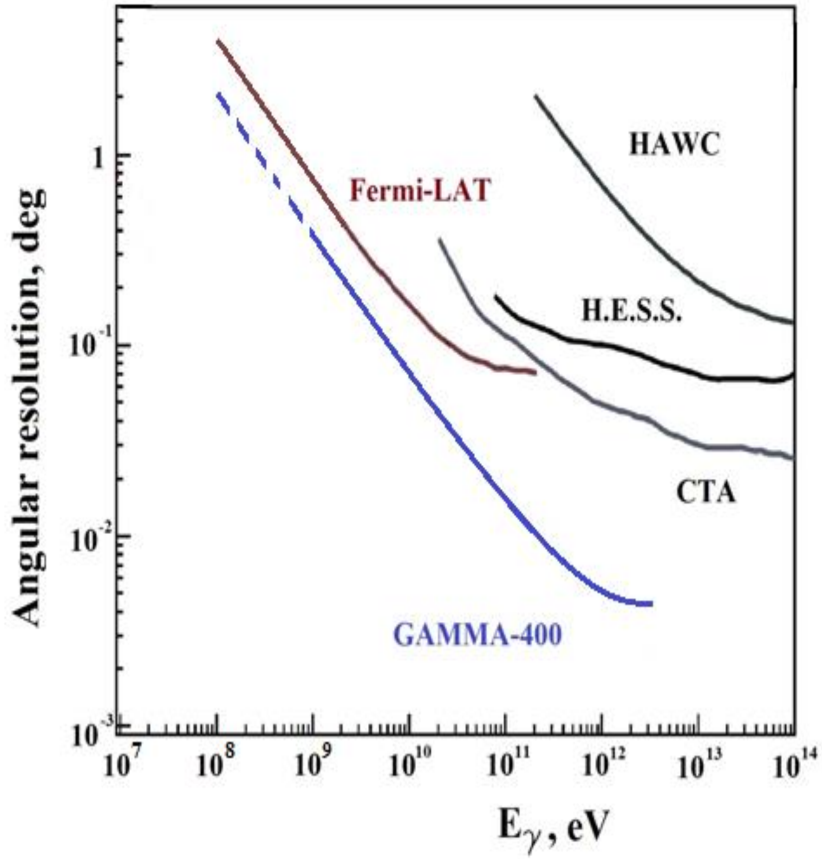
	Fermi-LAT	GAMMA-400
Orbit	Circular, 565 km	Highly elliptical, 500-300000 km **(without the Earth's occultation)**
Operation mode	Sky-survey (3 hours)	**Point observation (up to 100 days)**
Source exposition	1/8	**1**
Energy range	~100 MeV - ~300 GeV	**~20 MeV – ~10 TeV**
Effective area (E_γ > 1 GeV)	~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)**
Proton rejection factor	~10^3	**~5x10^5**
Mass	2800 kg	~4000 kg
Telemetry downlink volume, Gbytes/day	15 Gbytes/day	**100 Gbytes/day**

Comparison of main parameters of operated, current, and planned space-based and ground-based instruments

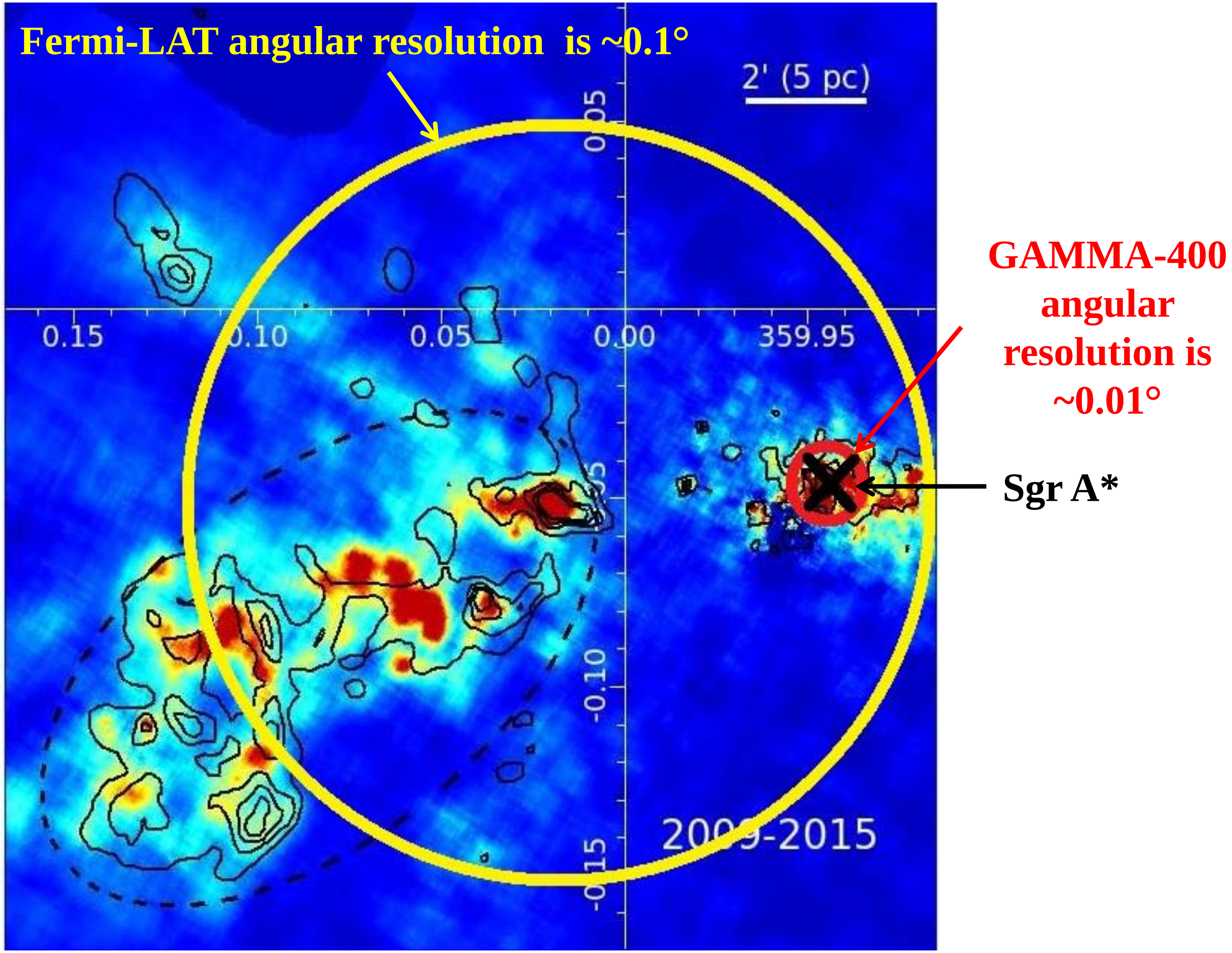
	SPACE-BASED INSTRUMENTS					GROUND-BASED GAMMA-RAY FACILITIES			
	AGILE	**Fermi-LAT**	**DAMPE**	**CALET**	**GAMMA-400**	**H.E.S.S.-II**	**MAGIC**	**VERITAS**	**CTA**
Particles	γ	γ	e, nuclei, γ	e, nuclei, γ	γ, e	γ	γ	γ	γ
Operation period	2007-	2008-	2015	2015	~2025	2012-	2009-	2007-	~2020
Energy range, GeV	0.03-50	0.02-300	5-10000	10-10000	**0.02-~10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ = 100 GeV)	0.1º (E_γ~1 GeV)	0.1º	0.1º	0.1º	**~0.01º**	0.07º	0.07º (E_γ = 300 GeV)	0.1º	0.1º (E_γ = 100 GeV) 0.05º (E_γ > 1 TeV)
Energy resolution (E_γ = 100 GeV)	50% (E_γ~1 GeV)	10%	1.5%	2%	**~1%**	15%	20% (E_γ = 100 GeV) 15% (E_γ = 1 TeV)	15%	20% (E_γ = 100 GeV) 5% (E_γ = 10 TeV)
Sensitive area, m^2	0,36	1,8	0,36	0,1	**1**				

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



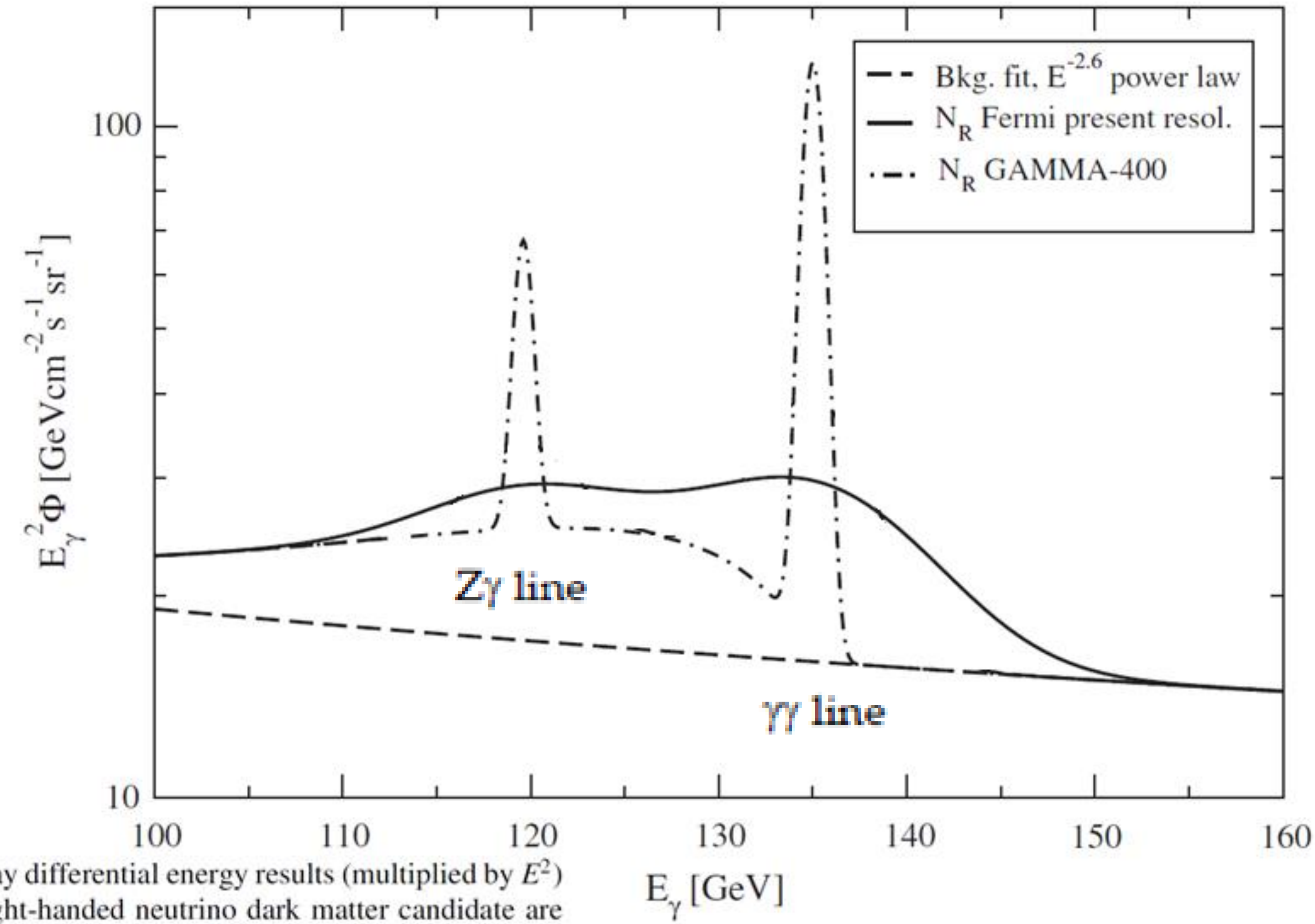


S. Funk , et. for the CTA Consortium, Astroparticle Phys.,2013, 43, 348



Comparison of the capabilities to study Galactic Center by Fermi-LAT with the angular resolution of ~0.1° for E_γ = 100 GeV (yellow circle) and GAMMA-400 with the angular resolution of ~0.01° for E_γ = 100 GeV (red circle), using Chandra X-ray observation. The Sgr A* position is marked by cross.

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)

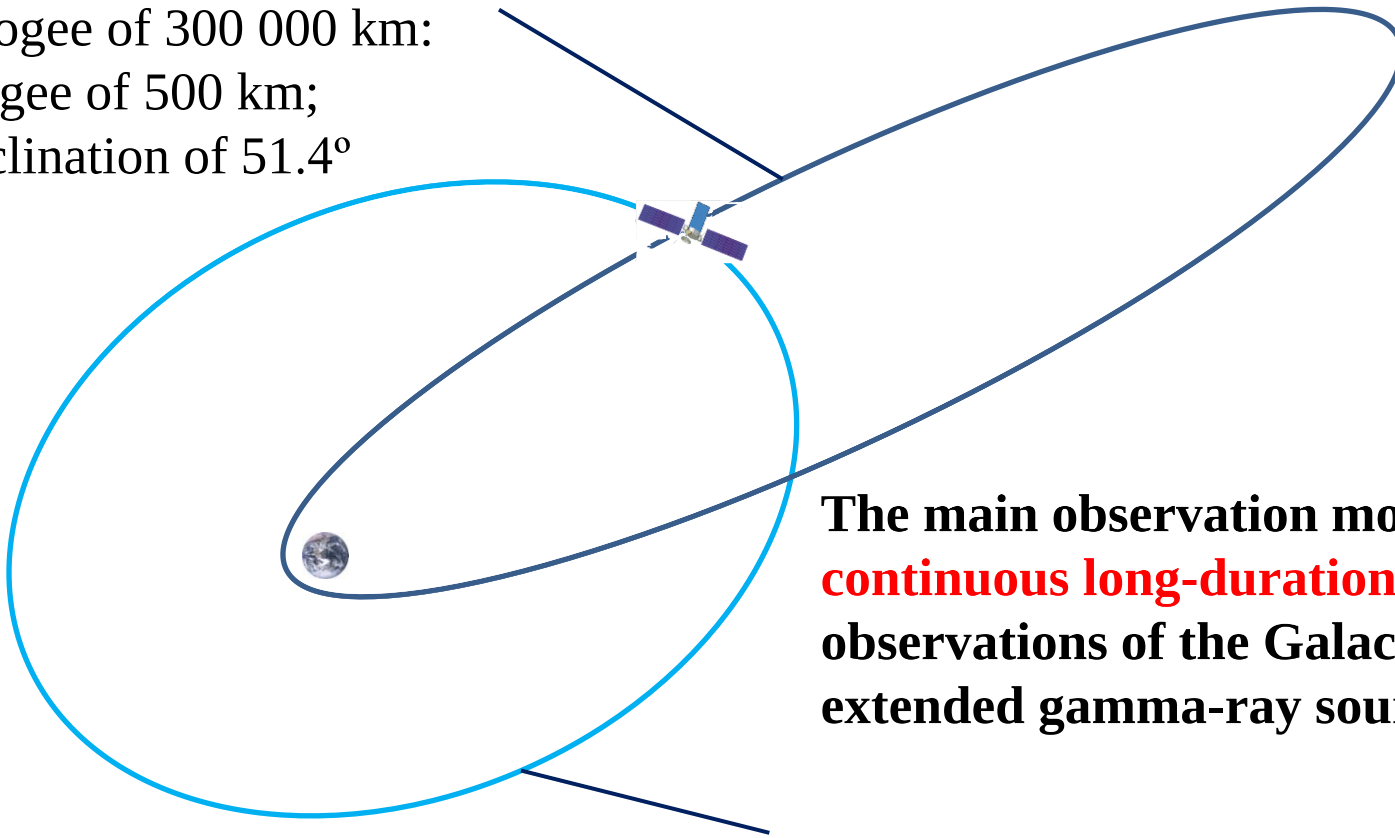
130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

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

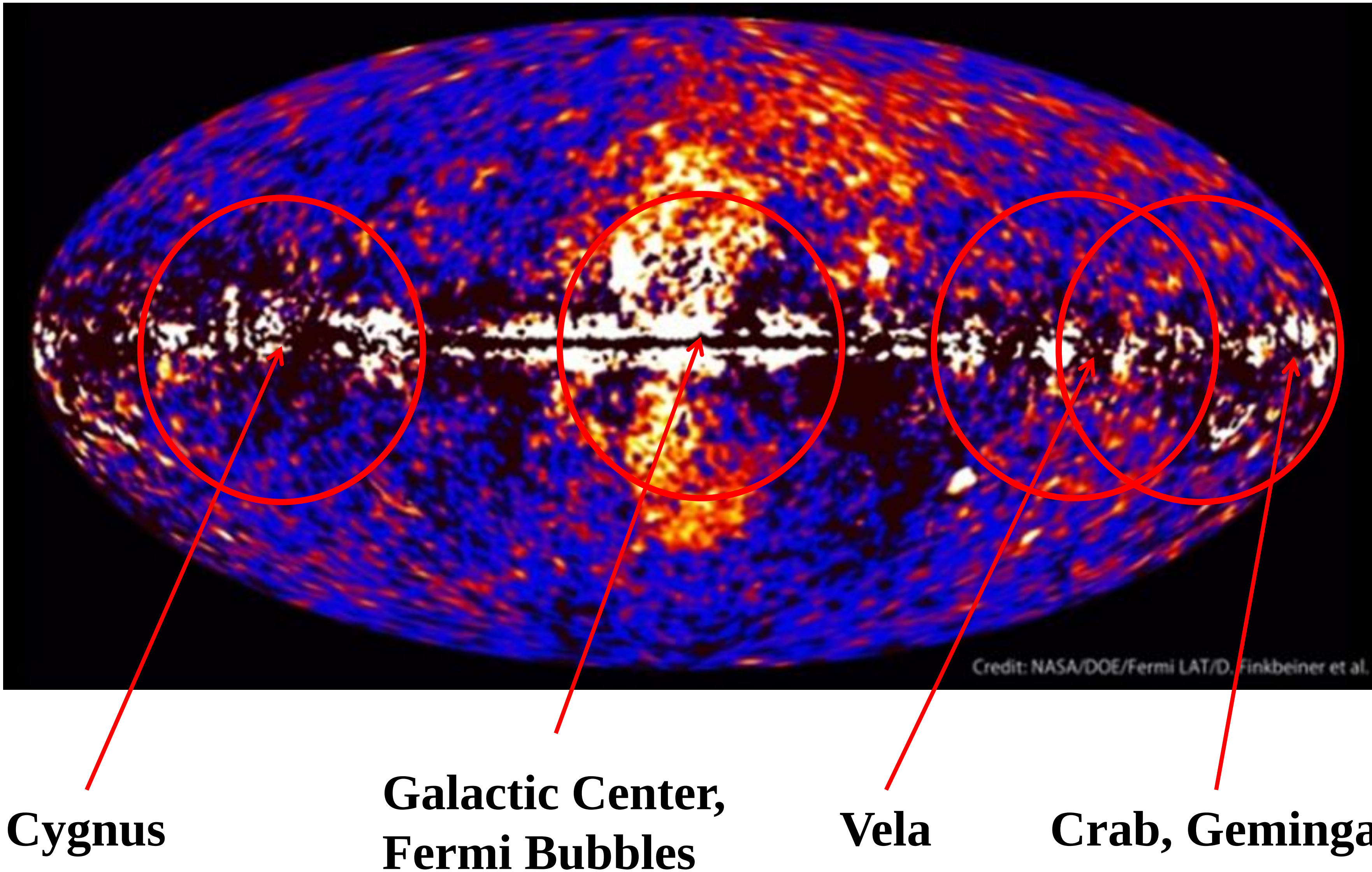
Time of operation will be 7-10 years



The main observation mode will be 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.

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



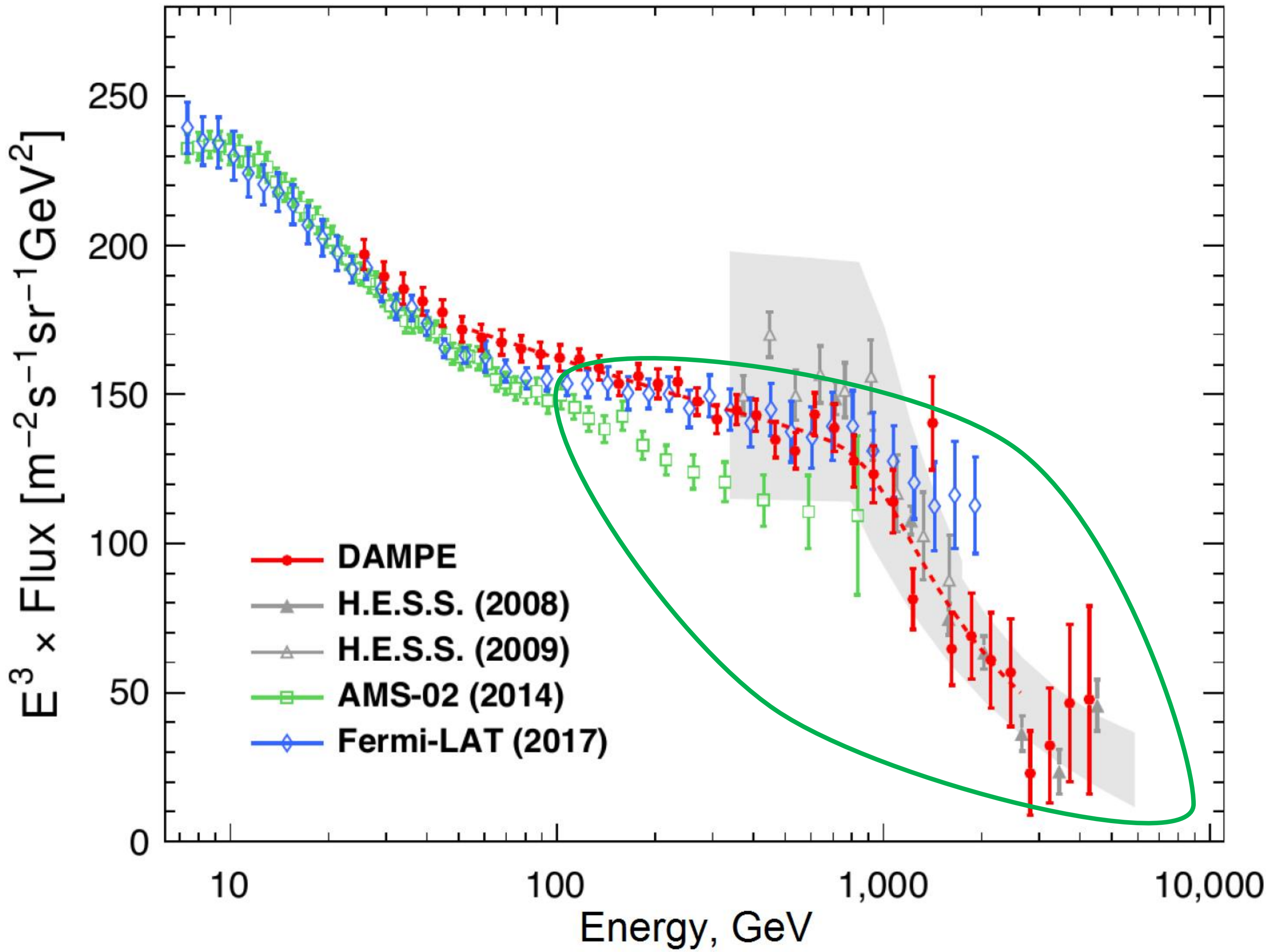
Number of simultaneously and uninterruptedly observed sources (at $N_{\gamma} > 10$ for each source) and number of gammas, when observing Galactic center, Crab + Geminga, Vela, and Cygnus regions by GAMMA-400 (effective area = 4000 cm^2, T_{obs} = 100 days, aperture ±45°), using the data from 3FGL for different energy ranges

Energy range / Direction	100 MeV-100 GeV		1 GeV-100 GeV		10 GeV-100 GeV	
	$N_{sources}$	N_{γ}	$N_{sources}$	N_{γ}	$N_{sources}$	N_{γ}
Galactic center b=0°, l=0°	723	523146	422	47505	21	1364
Crab + Geminga b=0°, l=190°	495	310384	175	39163	11	1020
Vela b=0°, l=265°	649	523077	280	63253	9	1163
Cygnus b=0°, l=75°	604	318788	269	30941	12	1007

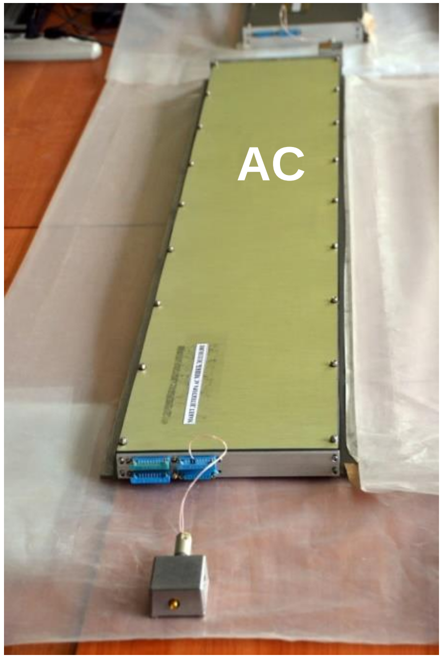
Estimate of the number of gammas, which will be detected by GAMMA-400 when observing the Galactic center using the fluxes from 3FGL (effective area = 4000 cm^2, T_{obs} = 1 year, aperture ±45°): 57400 gammas for E_γ > 10 GeV, 1280 gammas for E_γ > 100 GeV

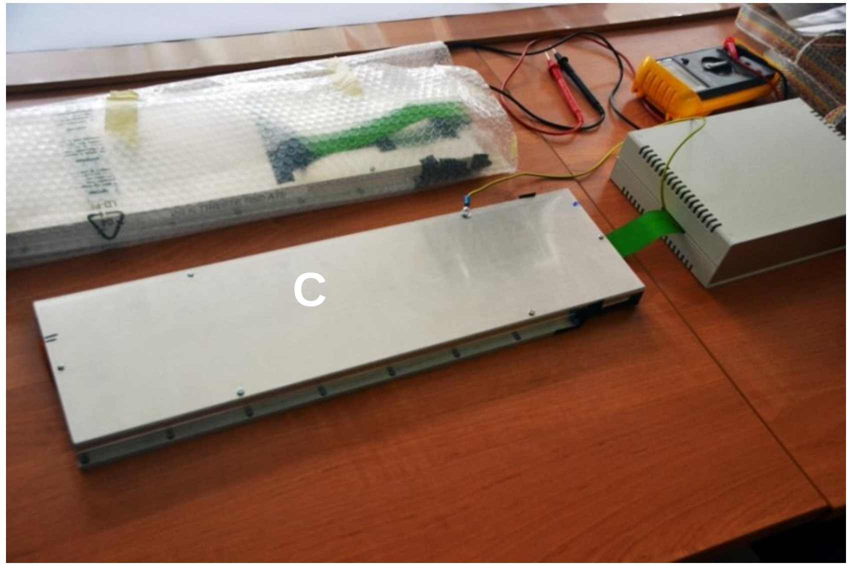
Name (3FGL)	Long	Lat	Name (Tevcat)	Nph (1-100 GeV)	Nph (10-100 GeV)
3FGL J1713.5-3945e	347.3355	-0.4727	RX J1713.7-3946	572	118
3FGL J1802.6-3940	352.4447	-8.4247		1277	28
3FGL J1718.0-3726	349.7233	0.1619	SNR G349.7+00.2	550	36
3FGL J1823.6-3453	358.6796	-9.9341		220	28
3FGL J1745.6-2859c	359.9552	-0.0391	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**

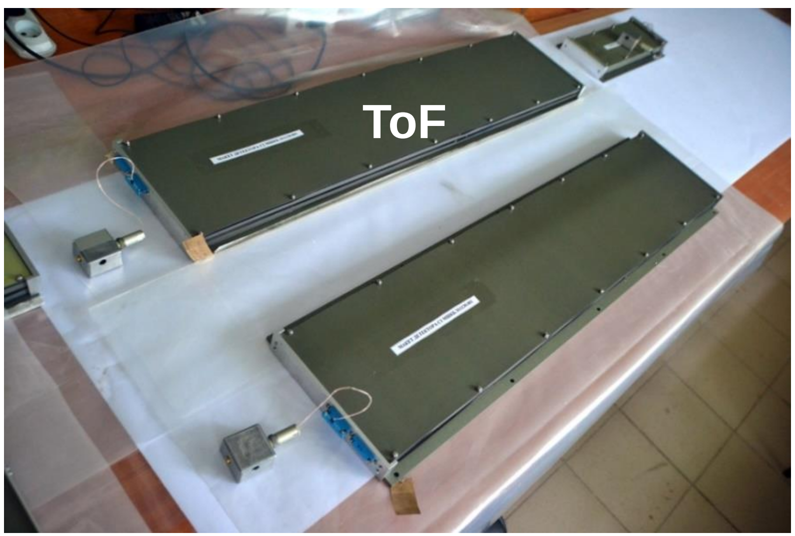
Electron + positron spectrum

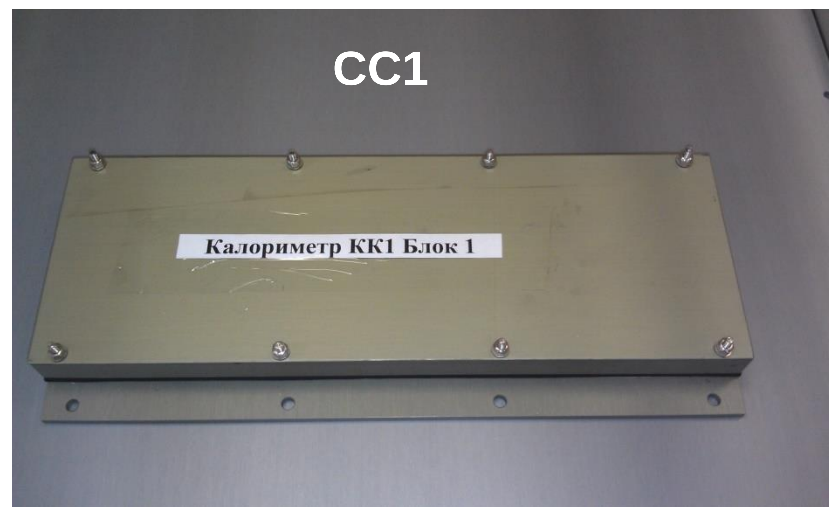


GAMMA-400 laboratory prototypes of detector systems









Calibration of prototypes on electron beam (100-300 MeV) at LPI accelerator

Conclusions

- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to significantly improve the data of LE+HE gamma rays and electron + positron fluxes with unprecedented angular and energy accuracy.**
- GAMMA-400 is funded by the Russian Space Agency and according to the Russian Federal Space Program 2016-2025 the GAMMA-400 space observatory is scheduled to launch in ~2025.
- We are open to the participation of foreign scientists in the manufacture of some detector systems.

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