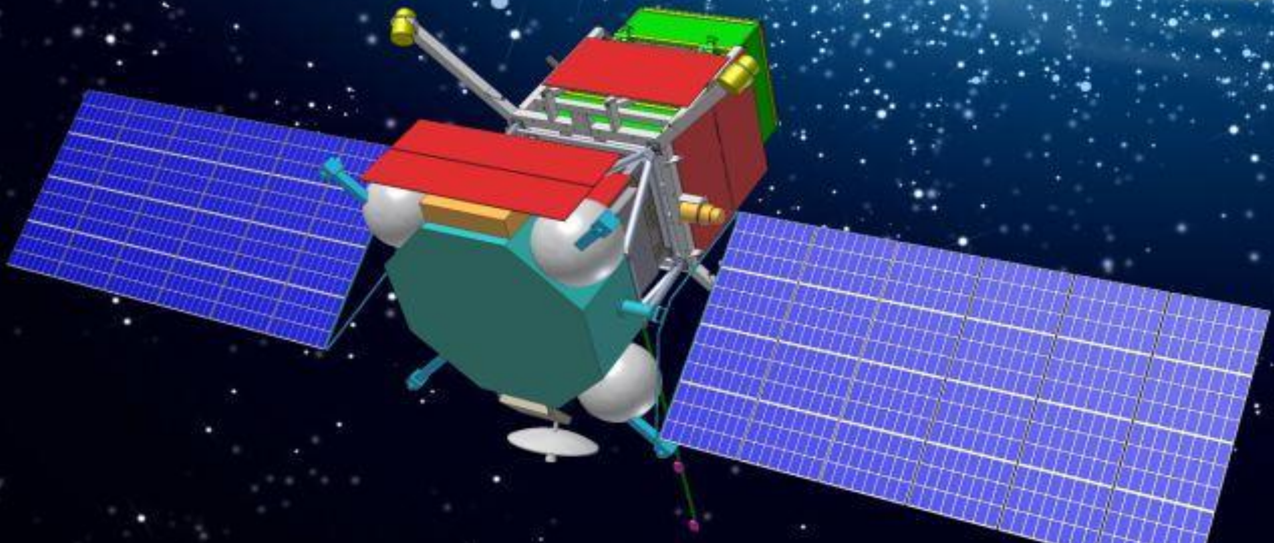
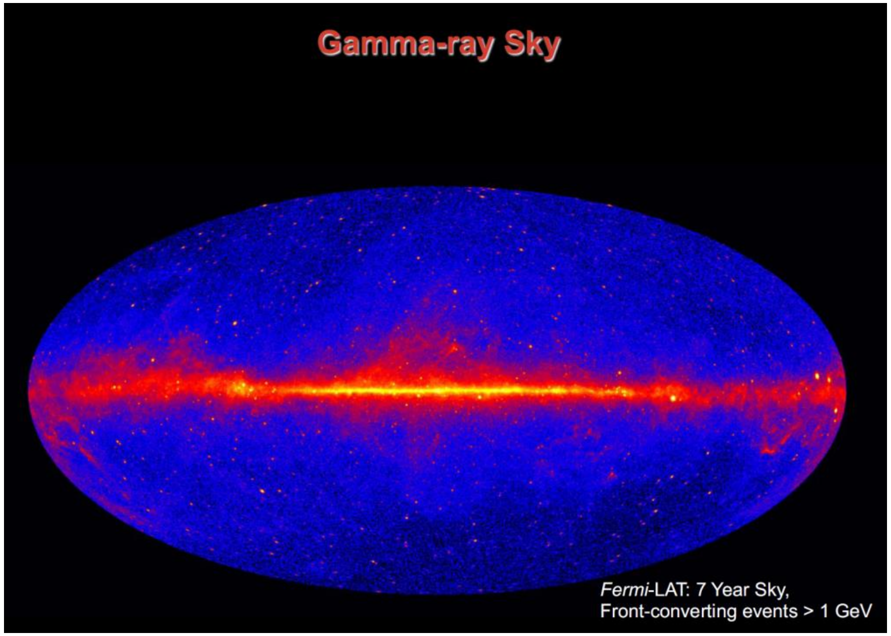
Nikolay Topchiev
for the GAMMA-400 Collaboration

New stage in high-energy gamma-ray studying with GAMMA-400 after Fermi-LAT

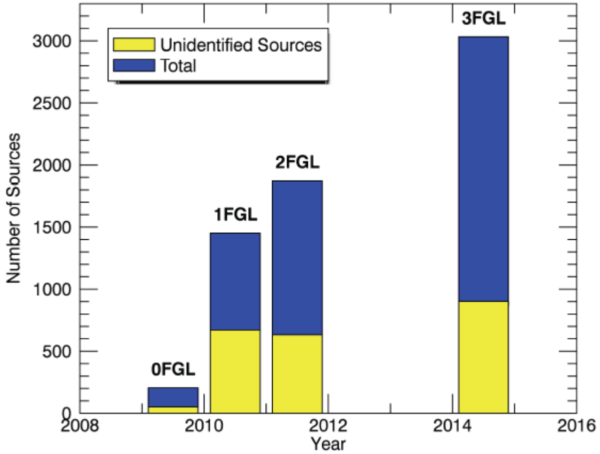


August 23, 2016, LPI, Moscow

Analysis of gamma-ray results of Fermi-LAT and ground-based telescope data



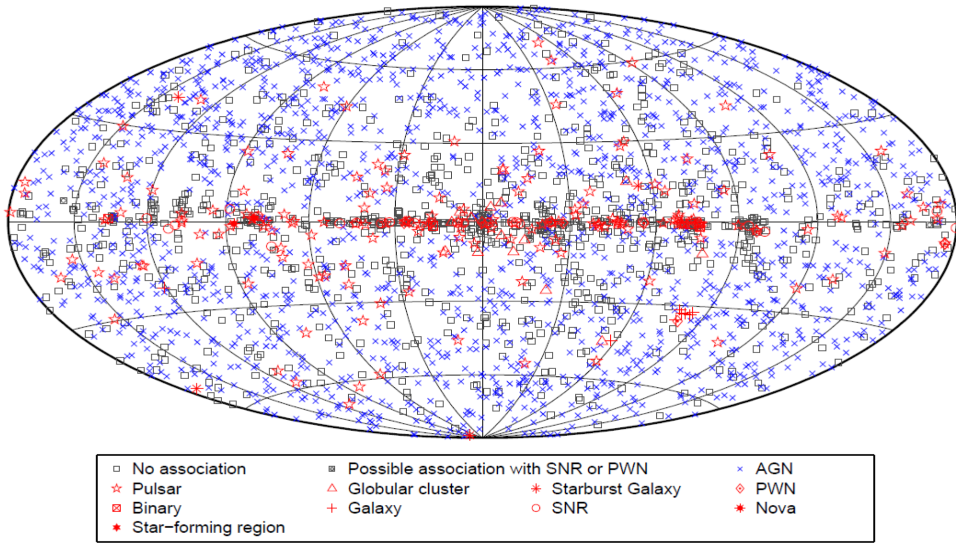
	Energy range, GeV	Number of sources	Number of unidentified sources
Fermi-LAT (3FGL)	0.1-300	3033	**992**
Ground-based (TevCat)	> 100	177	



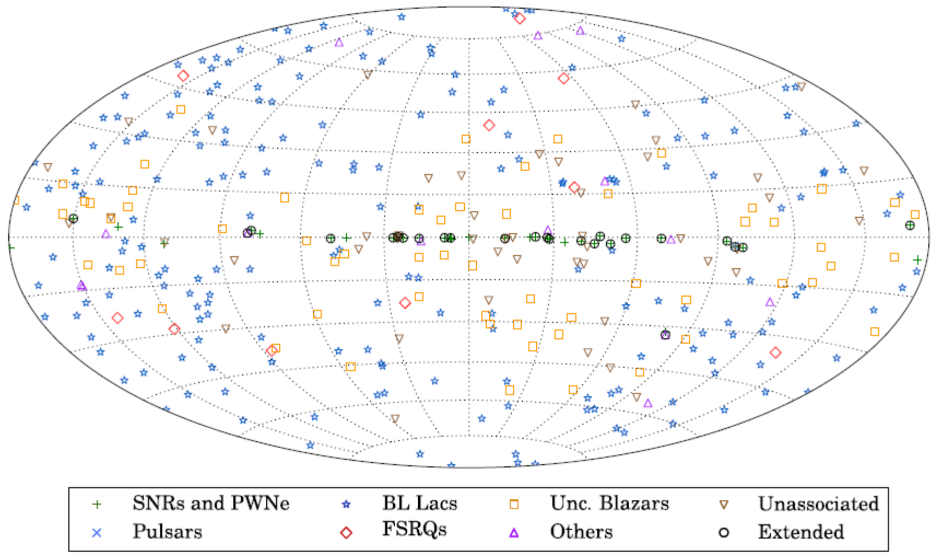
50 GeV – 2 TeV

51,000 photons E > 50 GeV
18,000 photons E > 100 GeV
2,000 photons E > 500 GeV

http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/



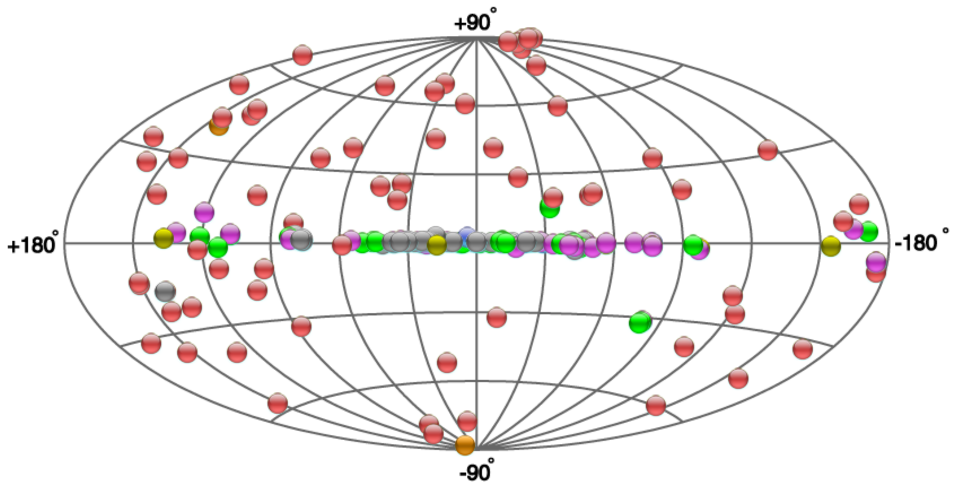
Distribution of 3033 discrete sources
(3FGL, E_γ = 100 MeV – 300 GeV)



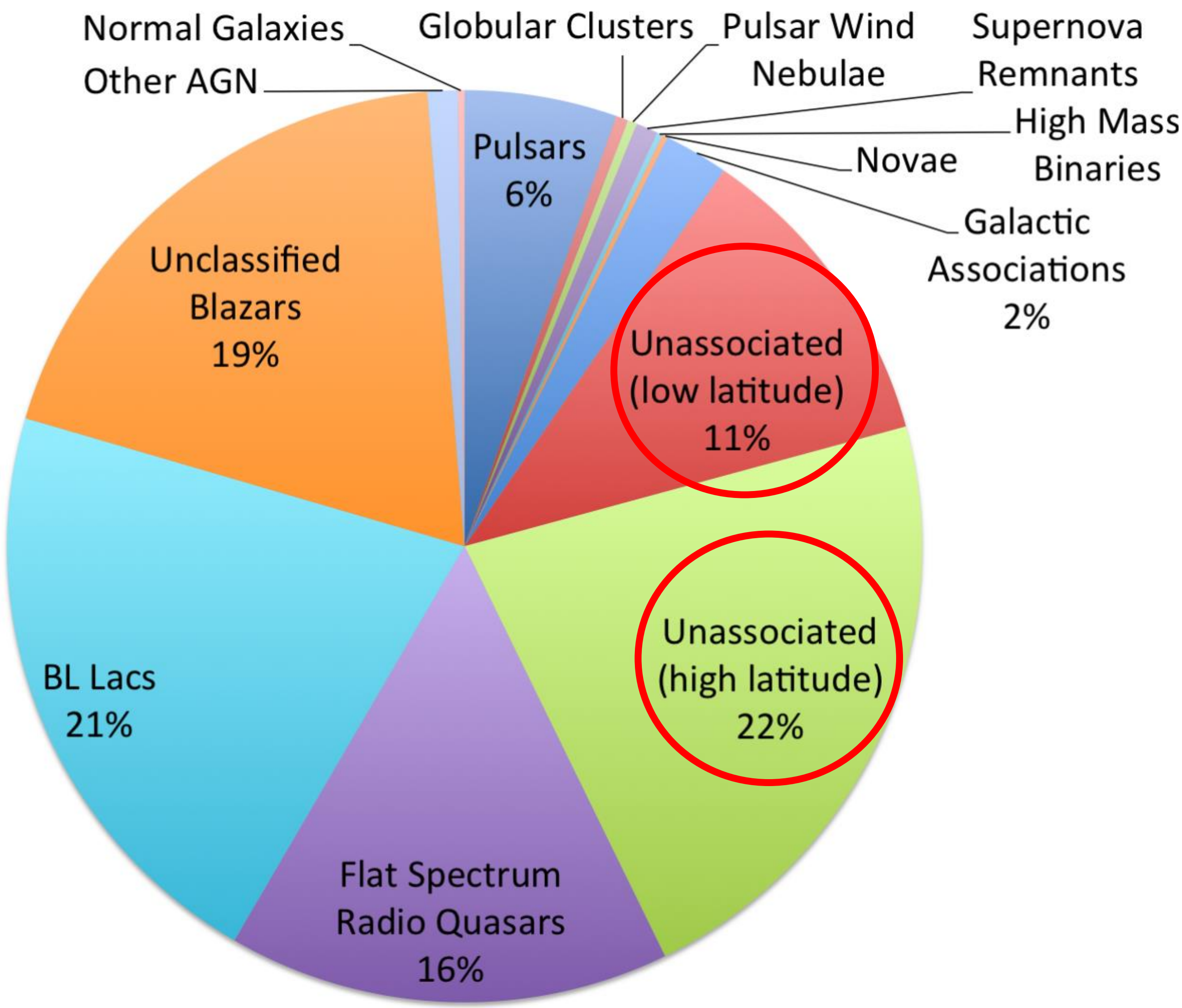
Distribution of 360 discrete sources
(2FHL, E_γ = 50 – 200 GeV)

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

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

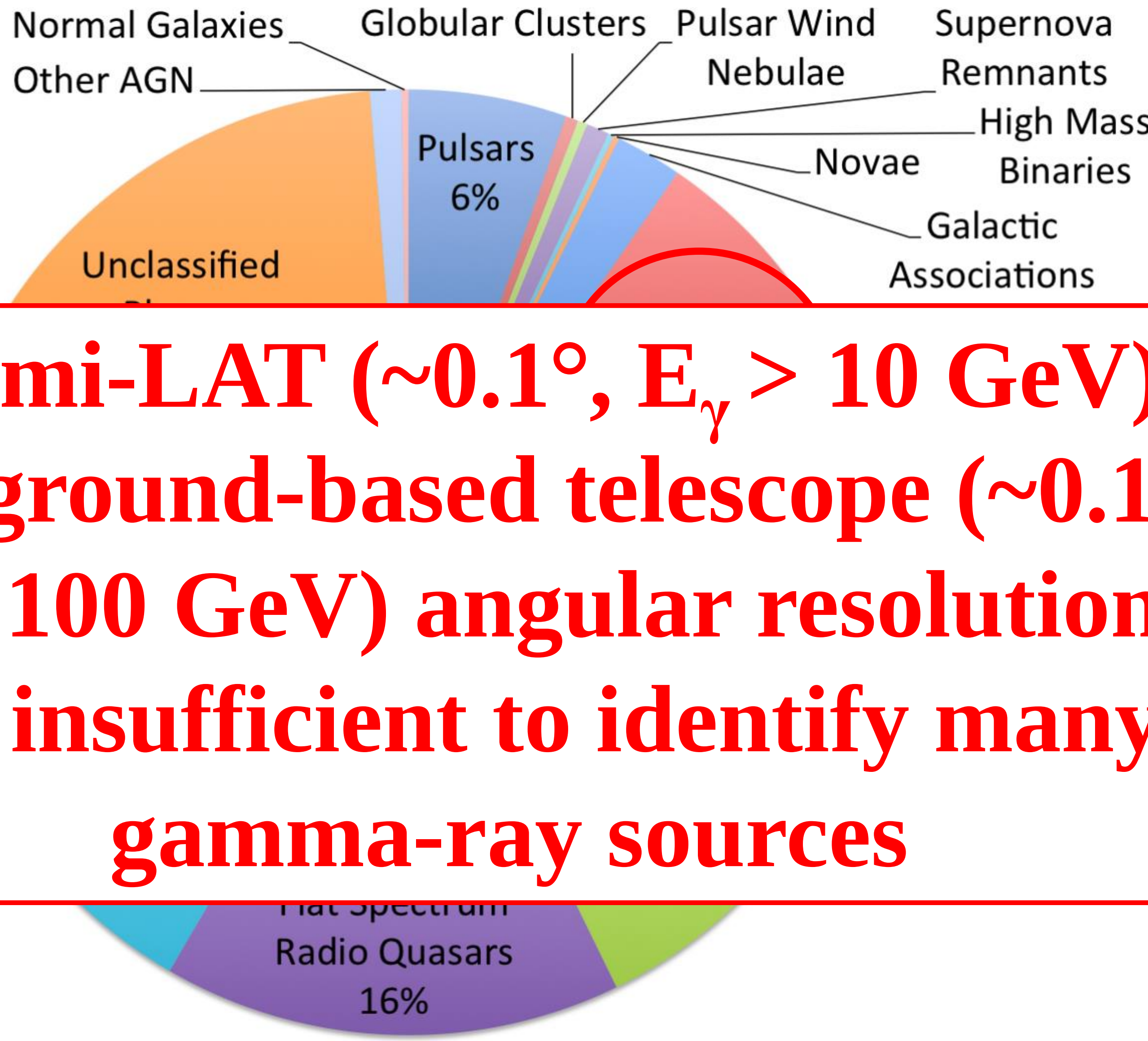


Distribution of 177 discrete sources
(TeVCat, E_γ > 100 GeV)



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

arXiv :1509.00012, 2015



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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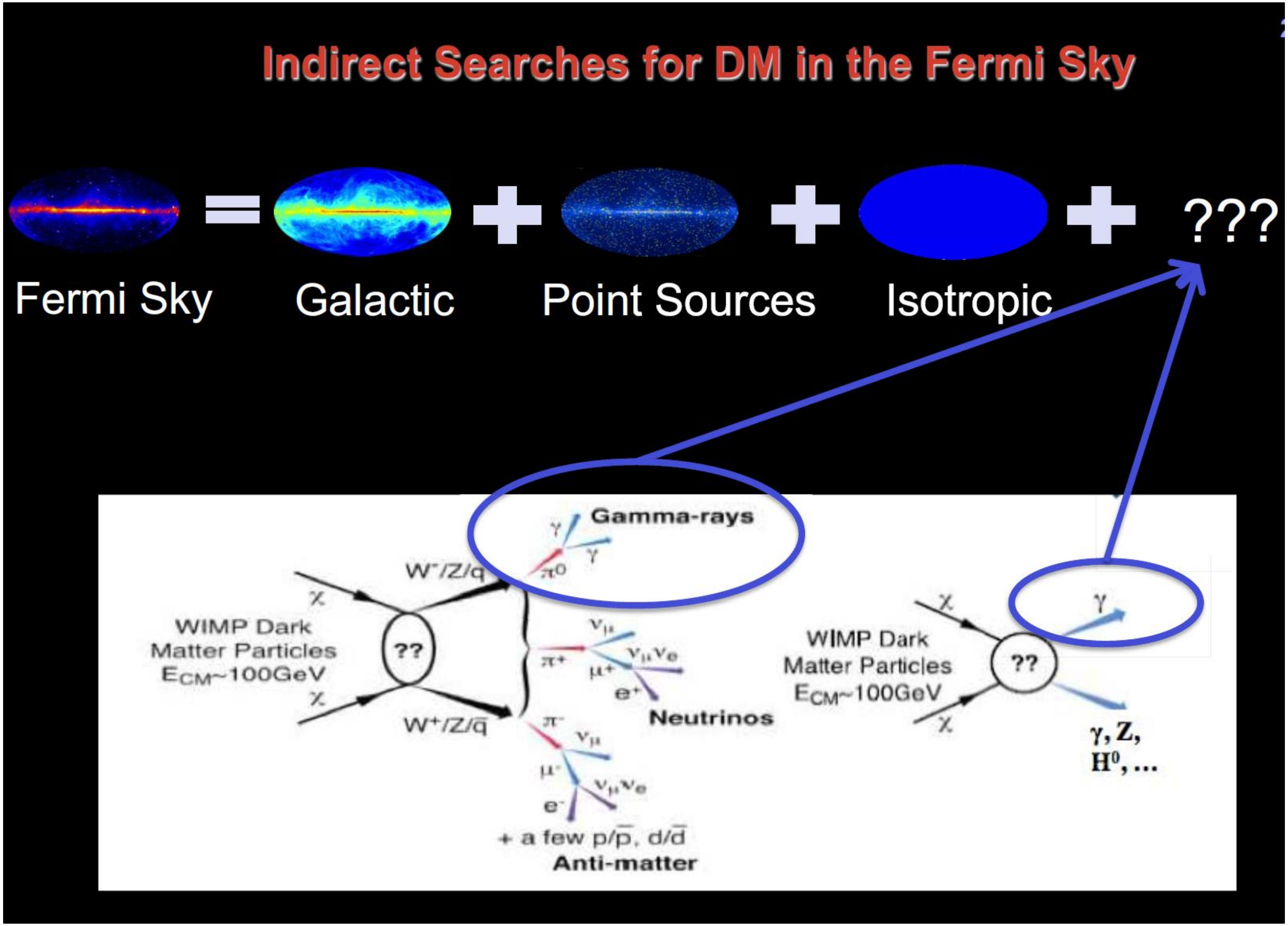


One of the leading candidates for the DM particle are weakly interacting massive particles (WIMPs) producing after annihilation two gamma quants

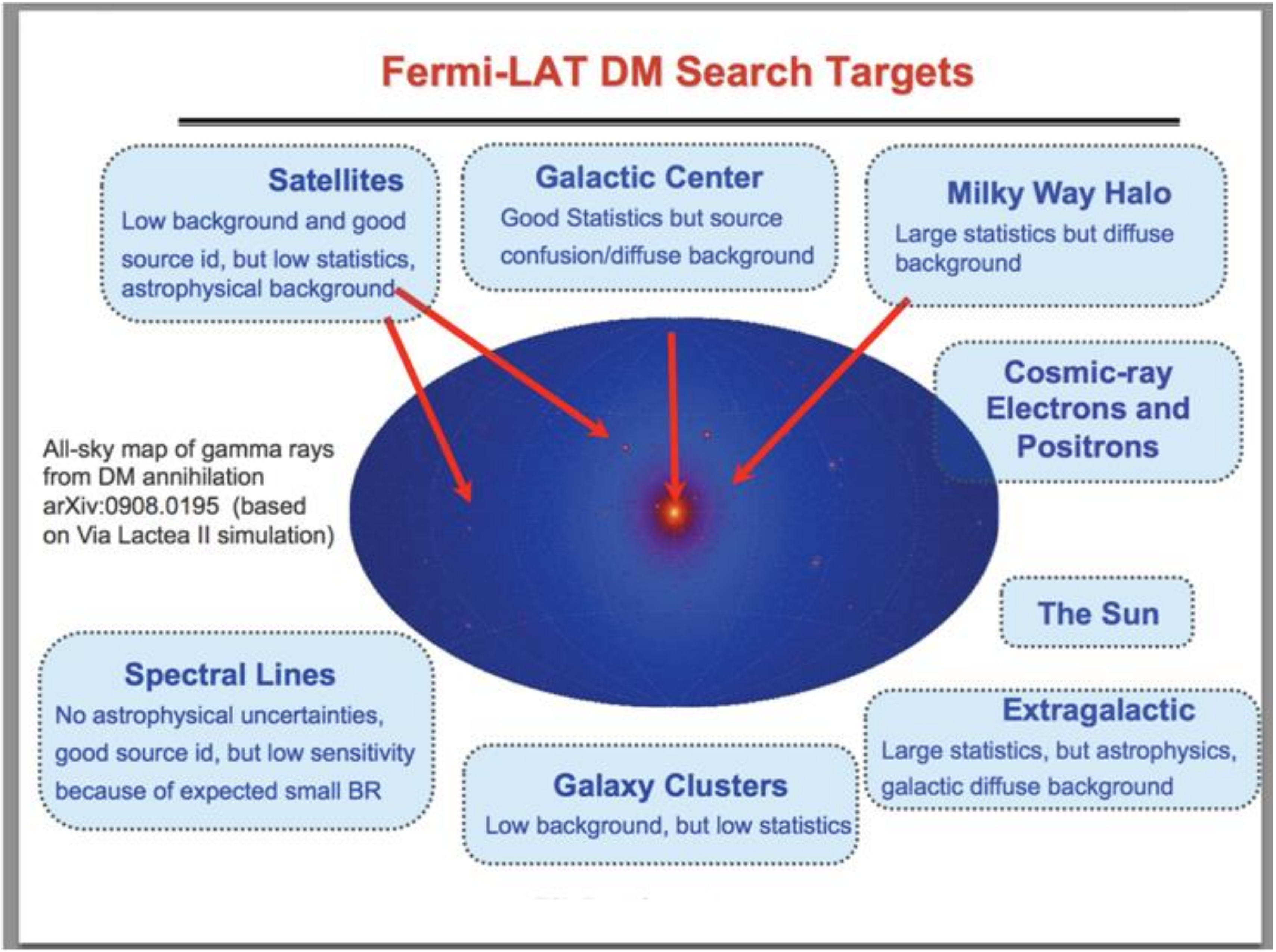
Indirect search for dark matter in γ-ray and cosmic ray radiations

GAMMA-400 will conduct the search in the phase space of γ-rays with E > ~1 GeV and electron + positron spectrum above ~10 GeV.

General Approach: Search for disagreement / difference between observed and predicted by “classical” model CR / γ-ray flux / spectra / spatial distribution

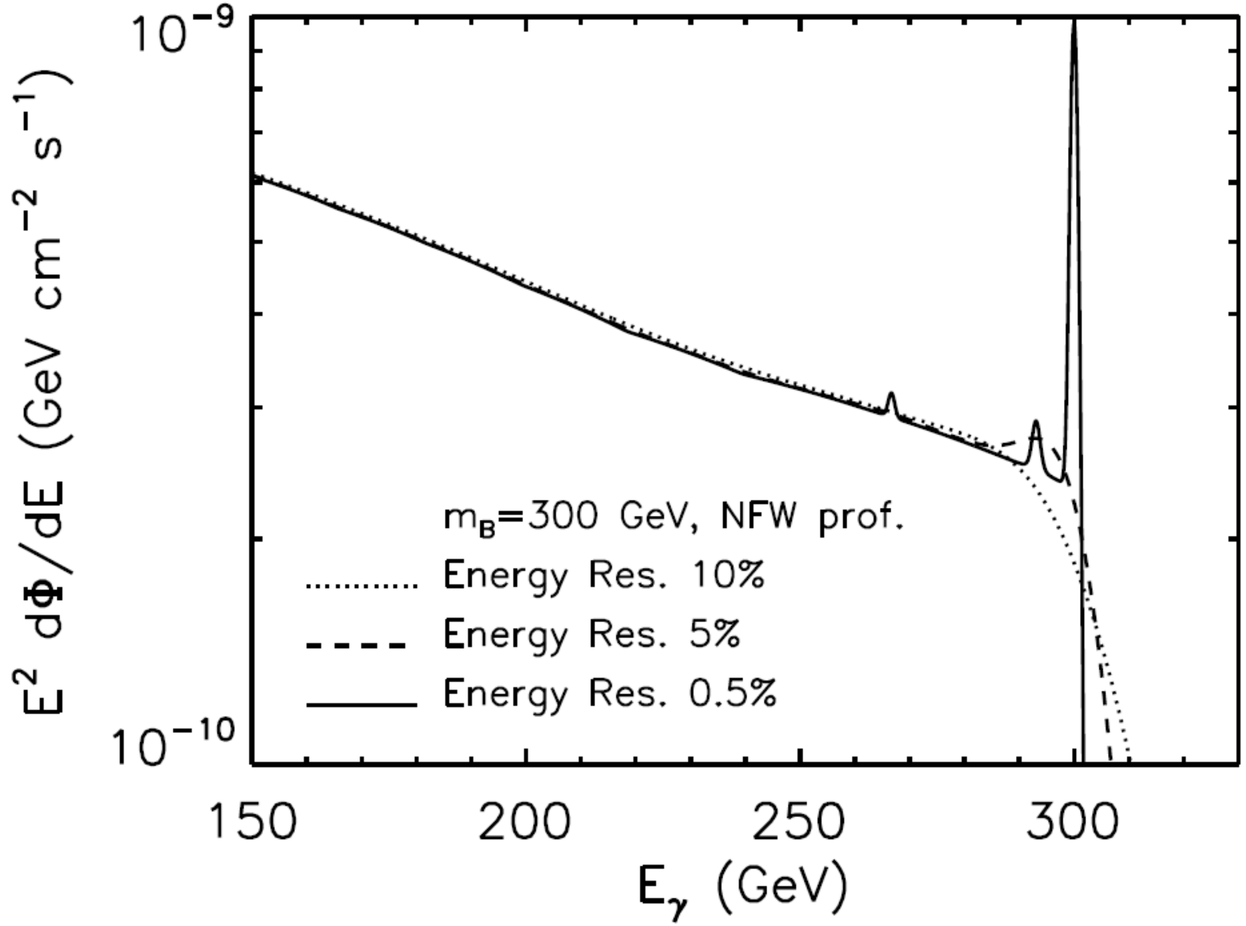
Dark matter signature	=	Observed spectrum / spatial features	-	γ-ray sources	-	Known backgrounds (diffuse γ-radiation etc.)

The sensitivities to a DM signal depend critically on accurate estimates of the backgrounds: diffuse γ-rays, γ- rays from astrophysical sources, and charged particles detected as γ-rays



http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/

Capabilities of different gamma-ray telescopes to resolve DM lines

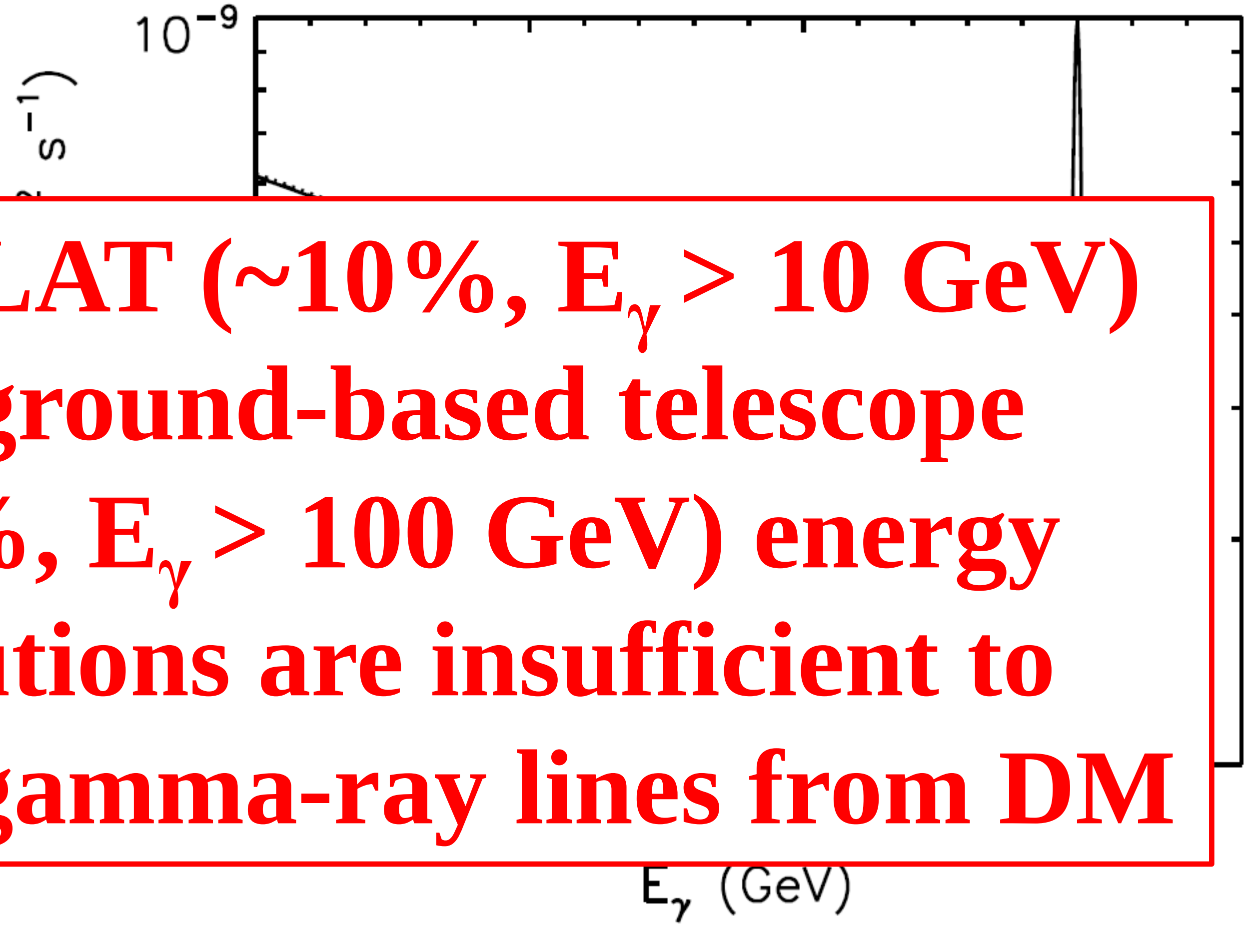


The gamma ray flux as a function of the photon's energy for a WIMP of mass 300 GeV. Shown are three different experimental energy resolutions.

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



Fermi-LAT (~10%, E_γ > 10 GeV) and ground-based telescope (~15%, E_γ > 100 GeV) energy resolutions are insufficient to resolve gamma-ray lines from DM

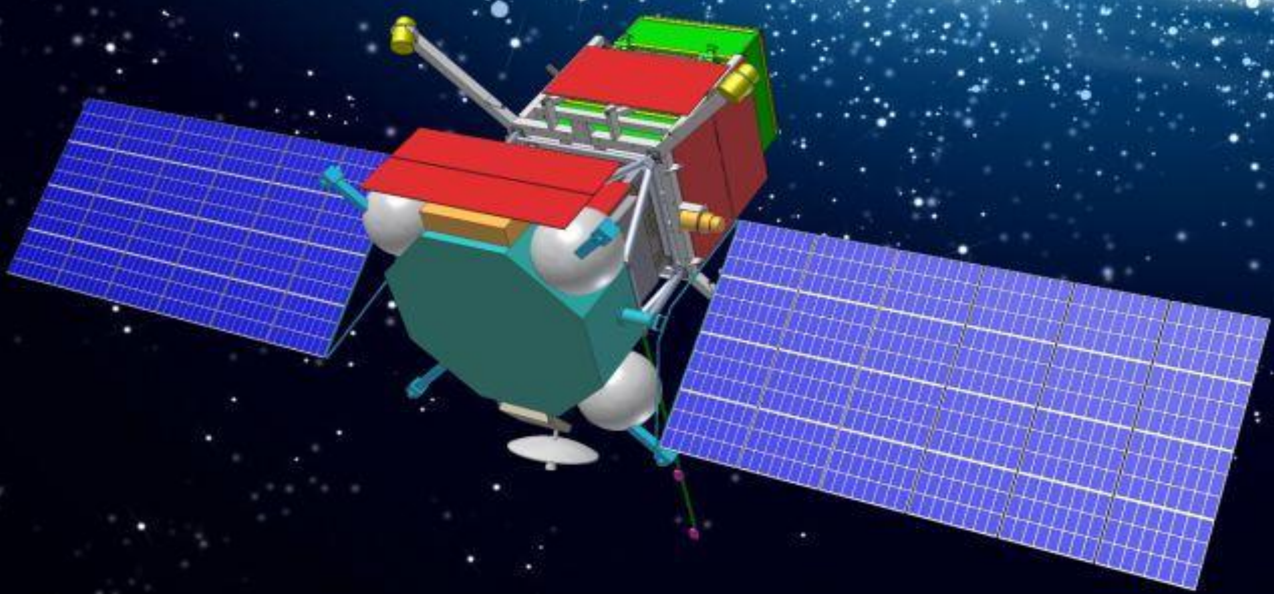
Energy resolution for Fermi-LAT is ~10% (E_γ > 10 GeV) and ground-based gamma-ray telescopes is ~15% (E_γ > 100 GeV)

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.

arXiv:1009.5107

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

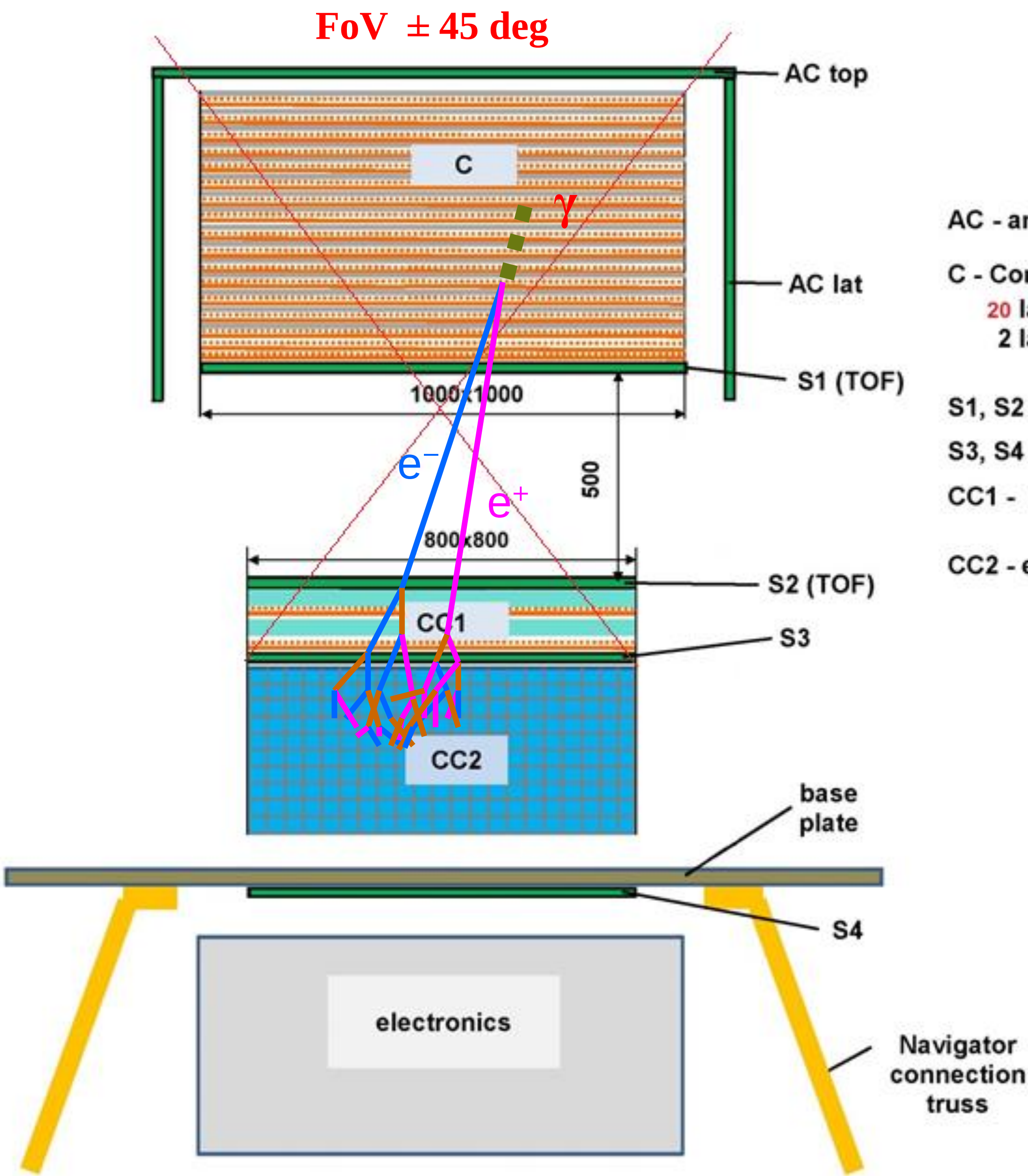
GAMMA-400



GAMMA-400
MAIN SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise measurements of 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)**.

GAMMA-400 physical scheme



AC - anticoincidence detectors (AC top, AC lat)

C - Converter-Tracker - total 0.9 Xo
20 layers Si (x,y) (pitch 0.1mm) + W 0.025 Xo
2 layers Si (x,y) (pitch 0.1mm) no W

S1, S2 - TOF detectors

S3, S4 calorimeter scintillator detectors

CC1 - imaging calorimeter (2Xo)
2 layers: CsI(Tl) 1Xo + Si(x,y) (pitch 0.1 mm)

CC2 - electromagnetic calorimeter 19 Xo
CsI(Tl) 3.6x3.6x3.6 cm^3 - 22x22x10=4840 crystals

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

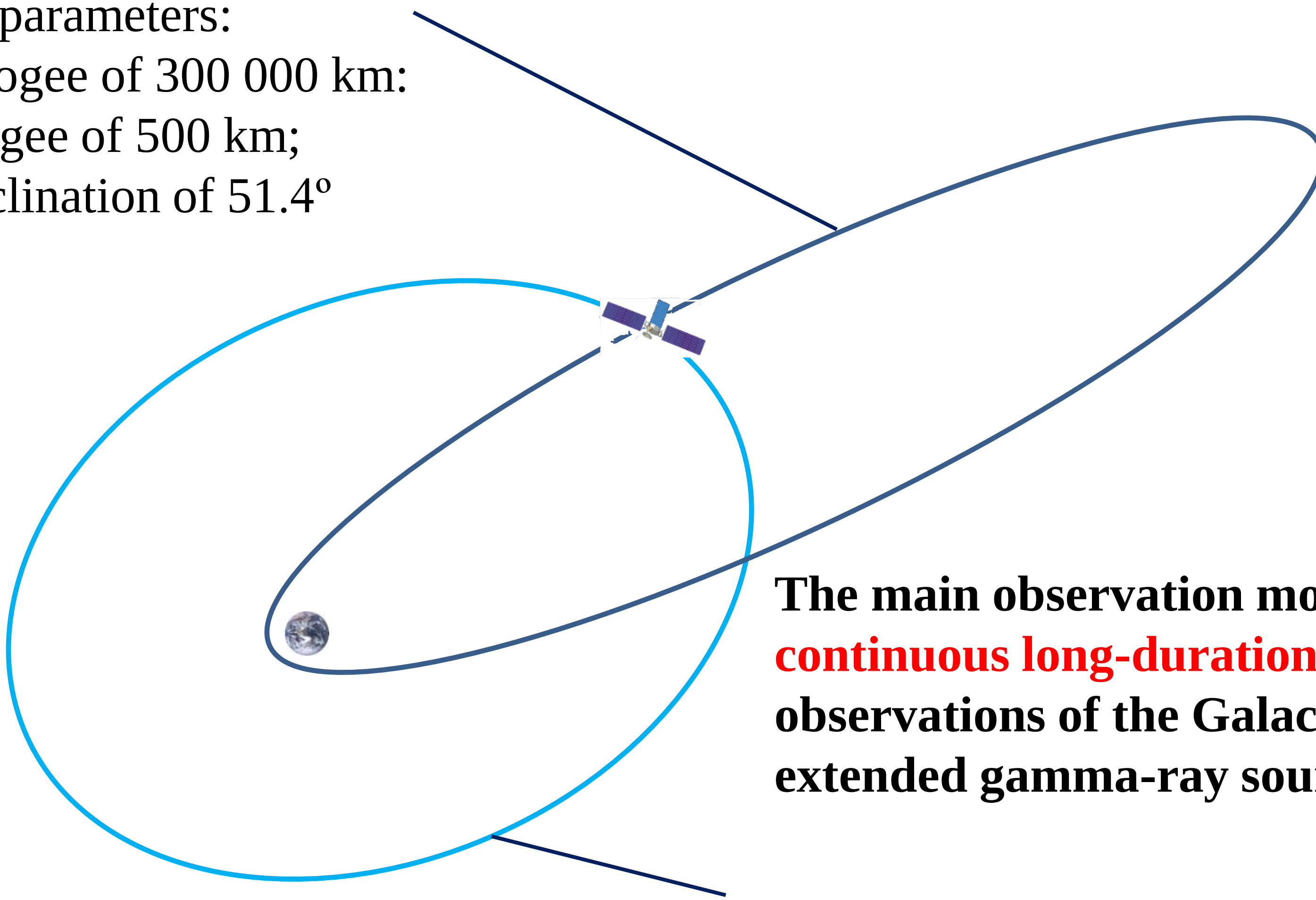
The GAMMA-400 orbit evolution and observation modes

The orbit will have the following initial parameters:

-an apogee of 300 000 km:

-a perigee of 500 km;

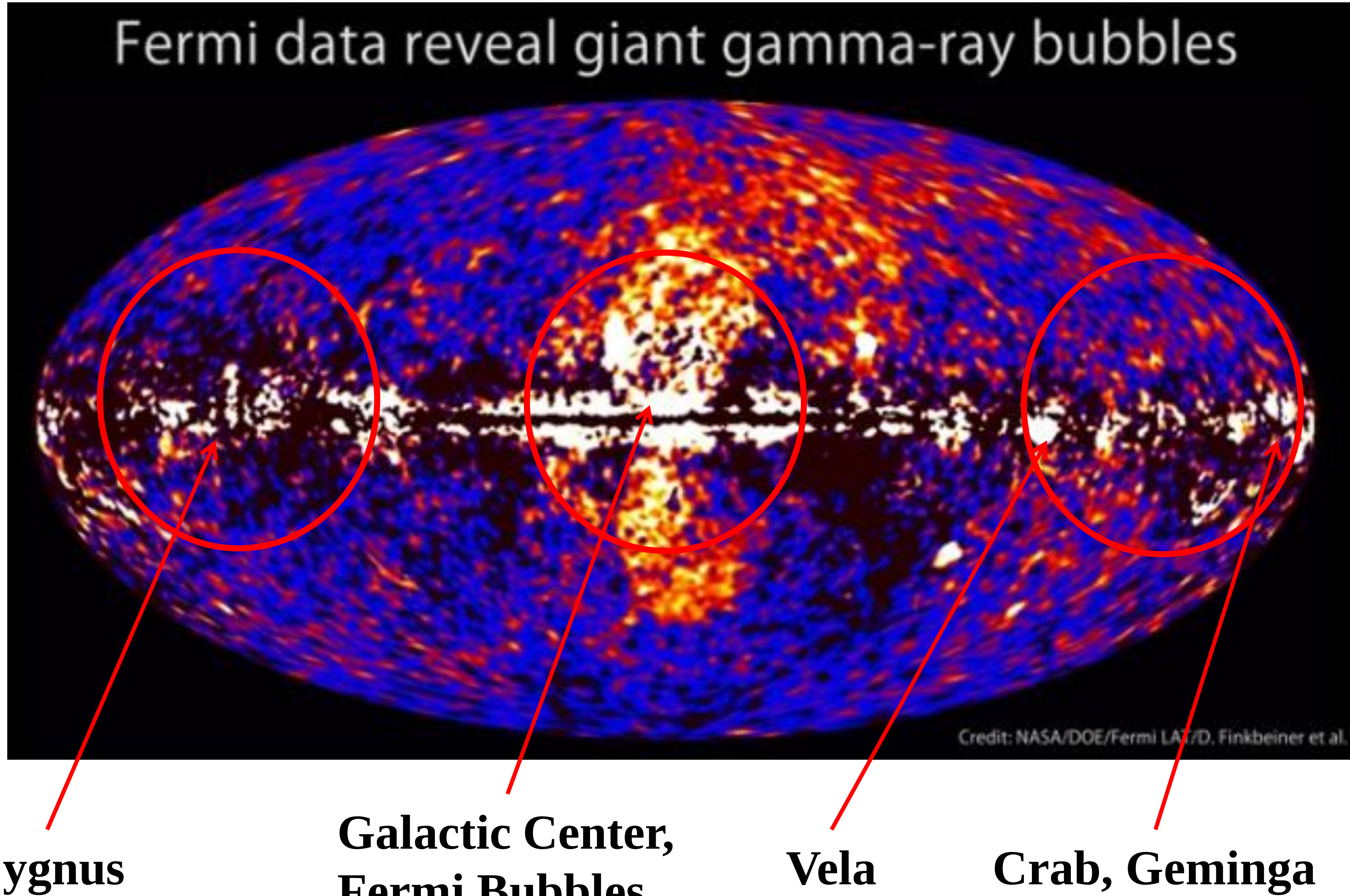
-an inclination of 51.4º



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.

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



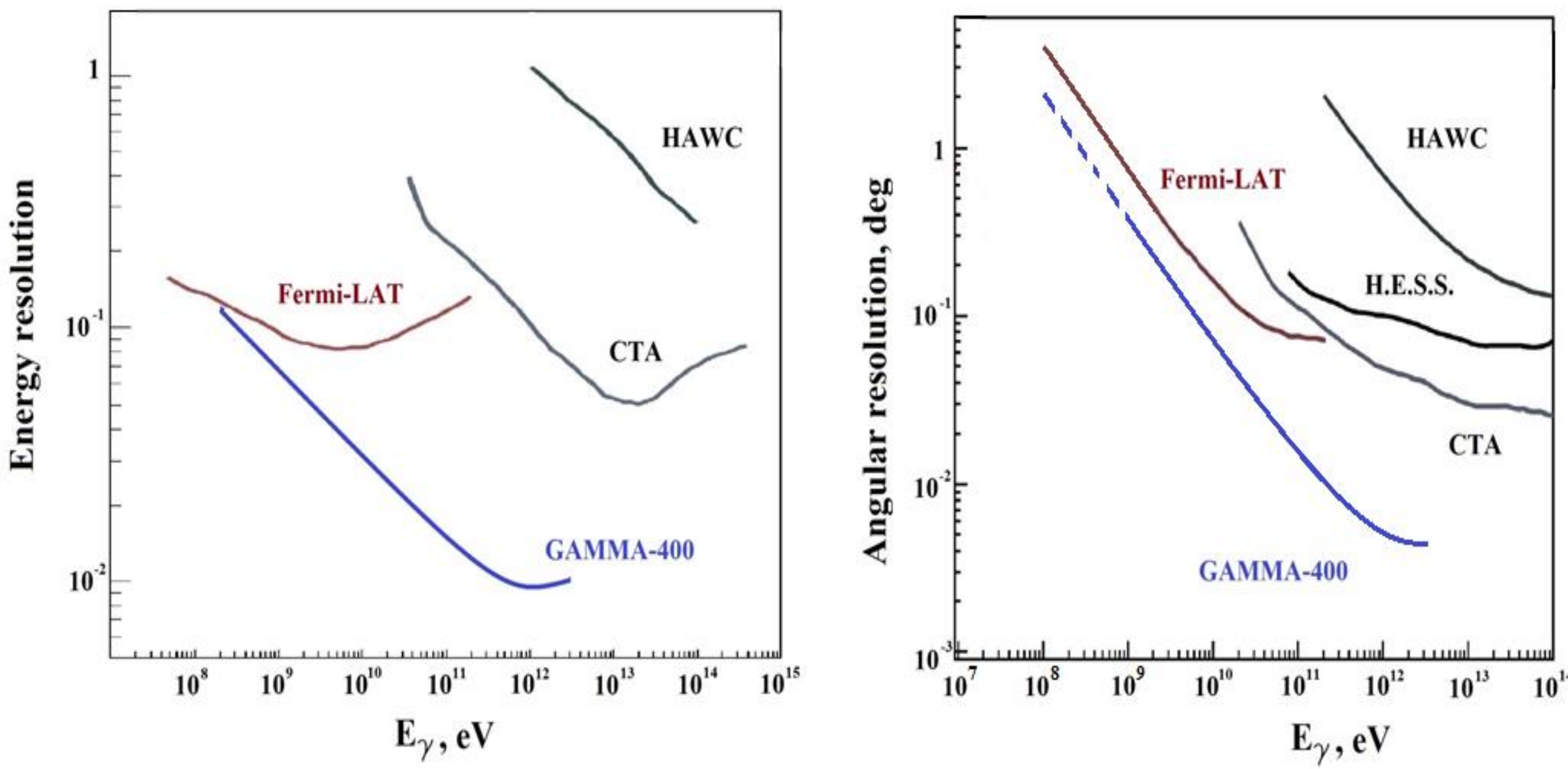
Comparison of the main parameters for GAMMA-400 and Fermi-LAT

	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	1/7	1
Energy range	20 MeV - 300 GeV	**~20 MeV – ~1000 GeV**
Effective area (E_γ > 1 GeV)	~6500 cm^2 (total) ~4000 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	~4° (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 **~21X_0**
Energy resolution	~10% (E_γ = 10 GeV) ~10% (E_γ > 100 GeV)	~3% (E_γ = 10 GeV) **~1% (E_γ > 100 GeV)**
Mass	2800 kg	2500 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	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-~1000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.1° (E_γ~1 GeV)	0.1°	0.1°	0.1°	**~0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.05° (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)

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



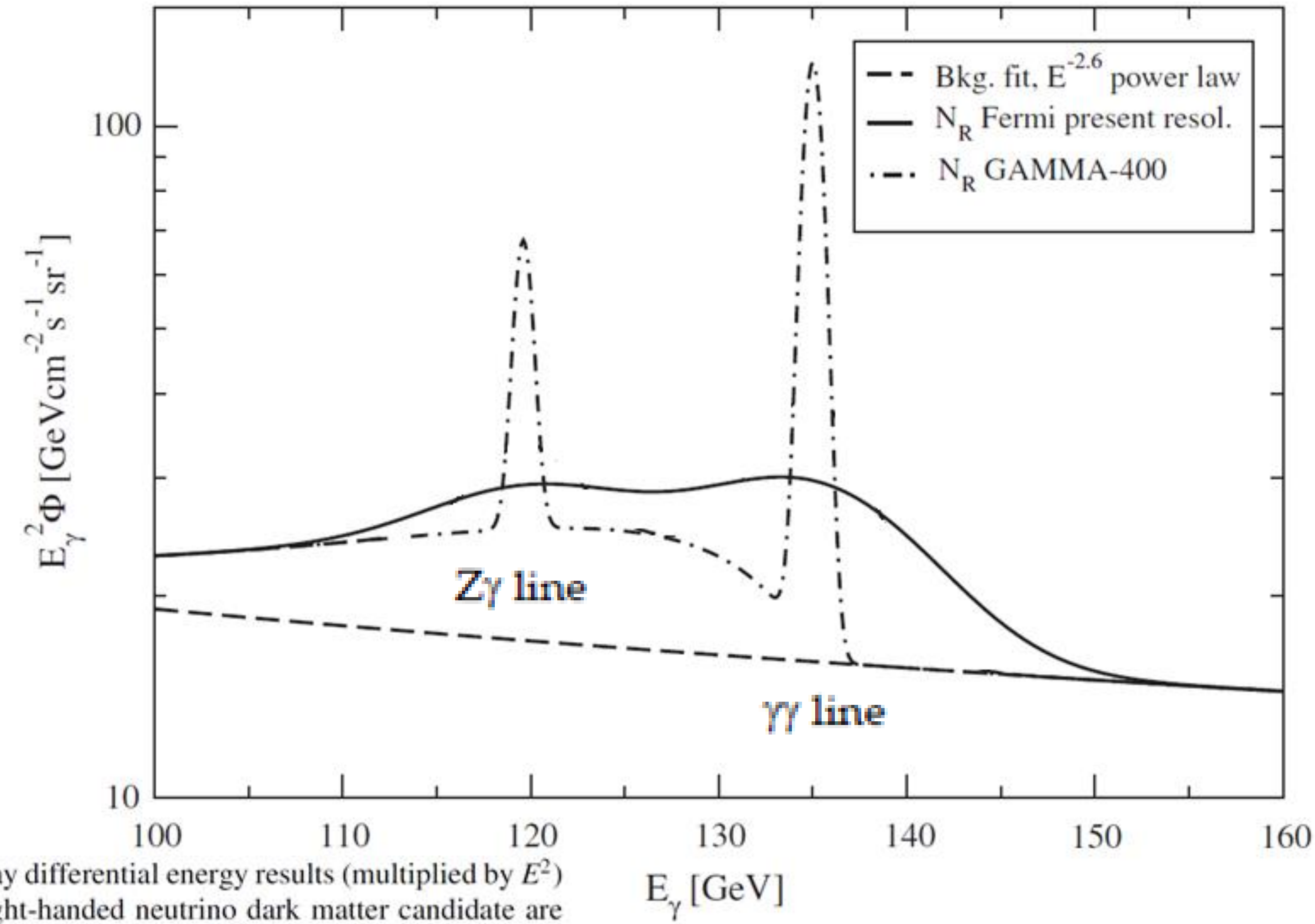
S. Funk , et. for the CTA Consortium, Astroparticle Phys.,2013, 43, 348

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 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.

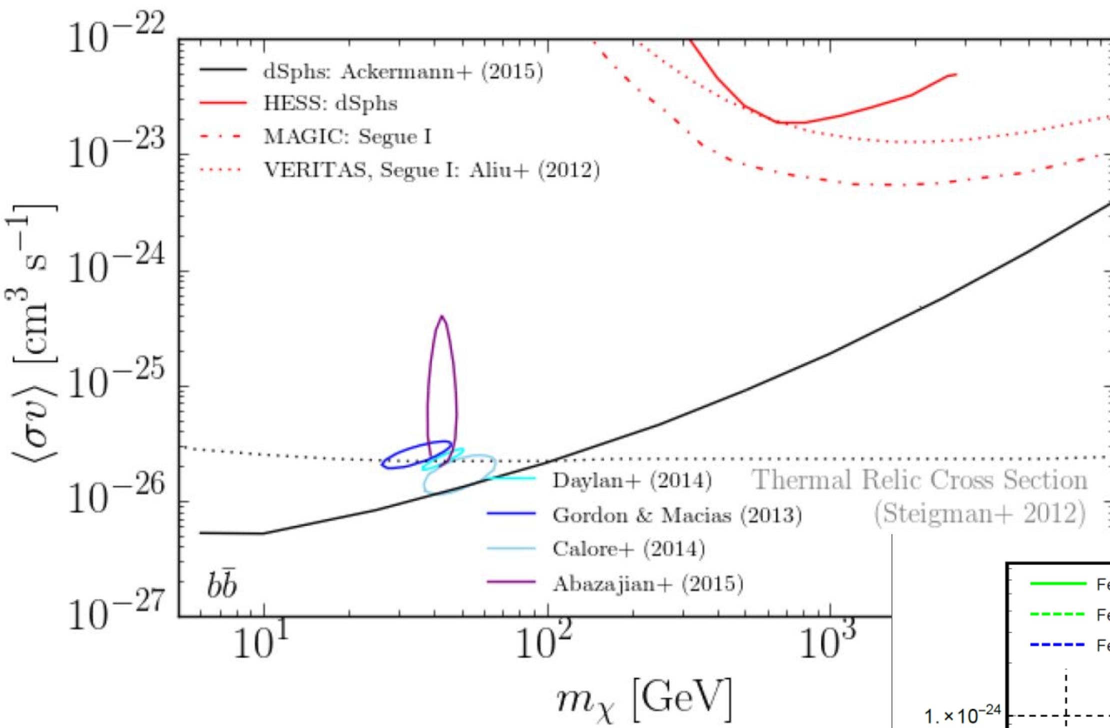
PHYSICAL REVIEW D **86**, 103514 (2012)

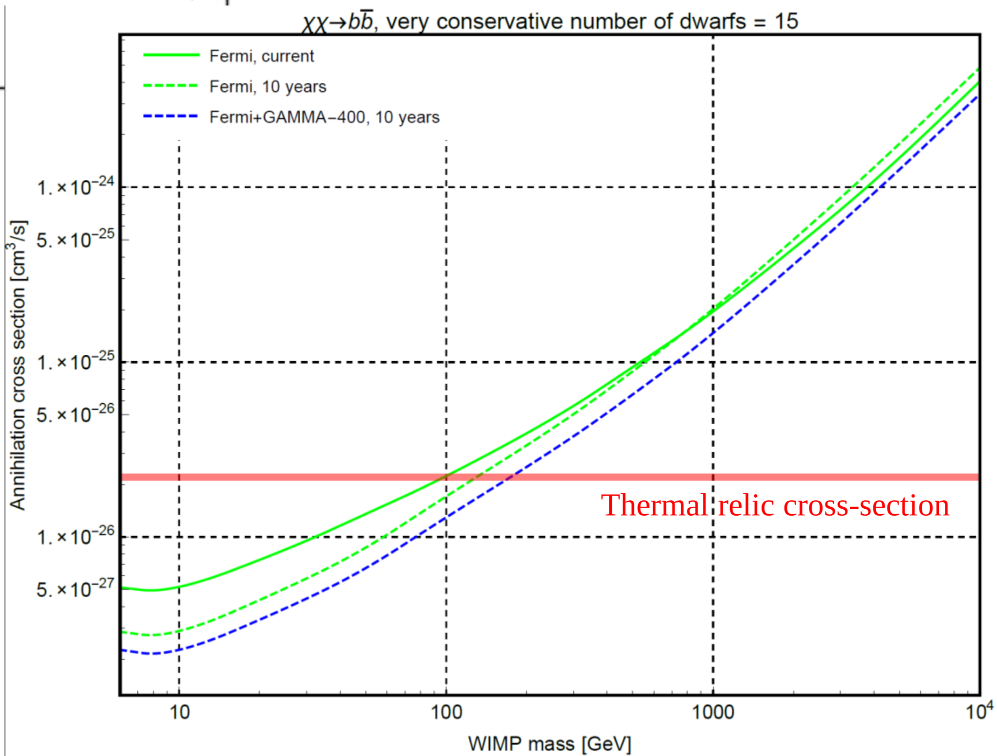
130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

Published Upper Limits from Dwarf Galaxies

χχ -> bb channel





Conclusions

- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to improve the data of LE+HE gamma rays with unprecedented accuracy. "The improvement in the accuracy will provide new insight" (S. Ting). "GAMMA-400 is very well suited to fill the gap (between space- and ground-based instruments), and joint (with CTA) observations or joint projects seem very natural" (W. Hoffman). It can then be used to provide a trigger for observations of transients from the ground with telescopes such as the future CTA.**
- 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/