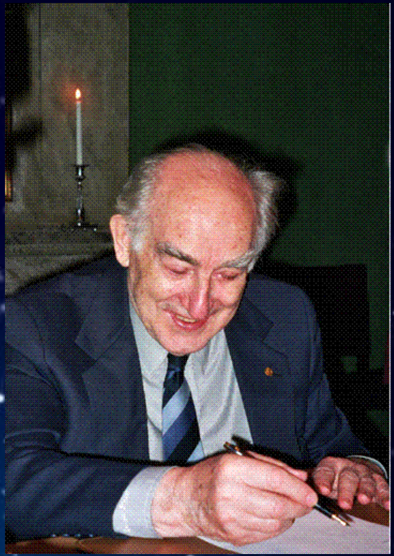
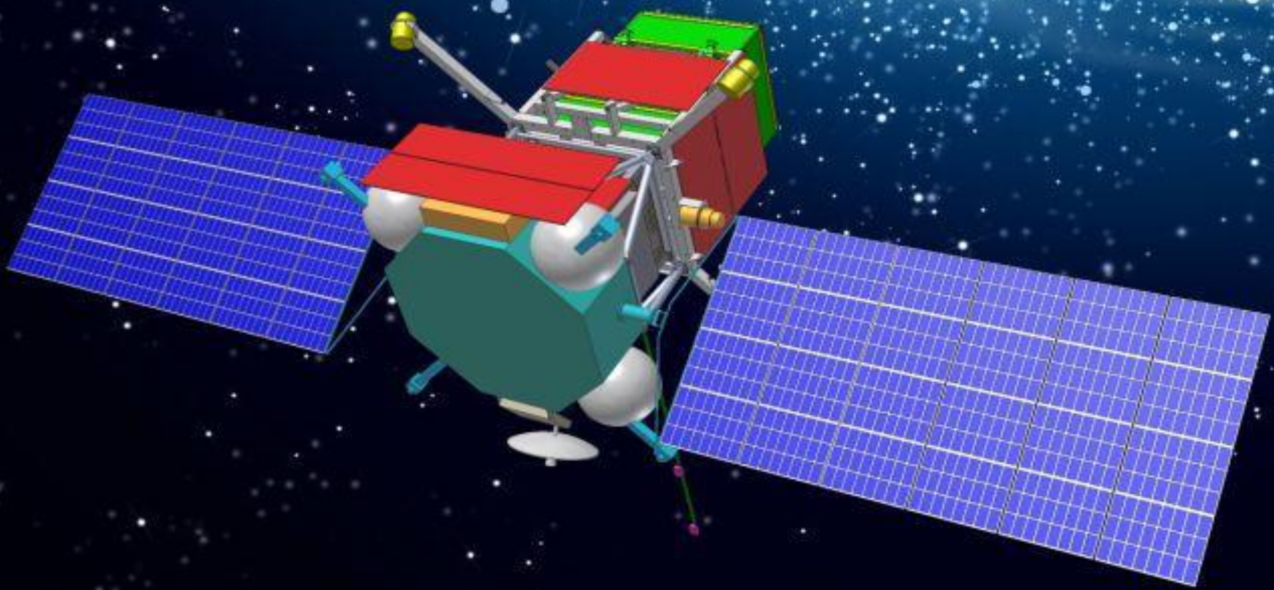
Russian Academy of Sciences
P.N.Lebedev Physical Institute
LPI

A.M. Galper and N.P. Topchiev



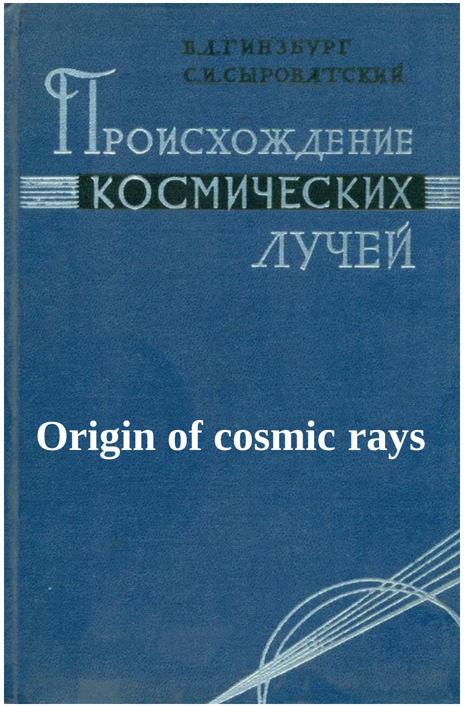
V.L. Ginzburg and gamma-ray astronomy: from GAMMA-1 to GAMMA-400

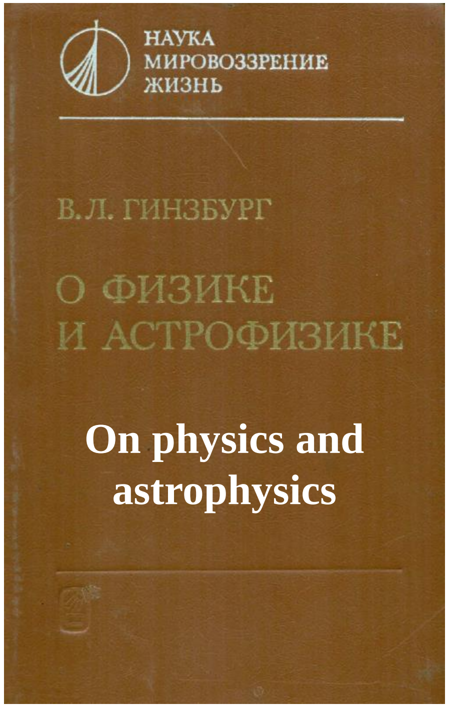


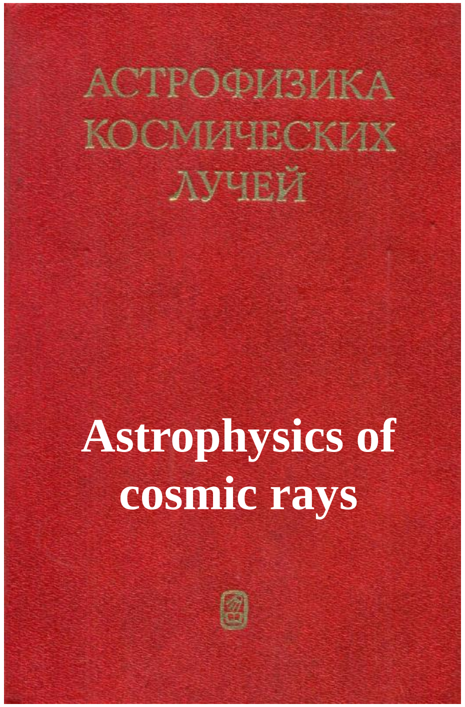
June 2, 2017, LPI, Moscow

One of V.L. Ginzburg's favorite research directions was astrophysics. Among astrophysical directions, V.L. Ginzburg paid much attention to cosmic rays and gamma-ray astronomy. A lot of monographs and papers devoted to cosmic rays and gamma-ray astronomy have been prepared by V.L. Ginzburg.

Among them we mention:







Ginzburg V.L., Syrovatskii S.I.
"Some problems of gamma and X-ray astronomy"
***Sov. Phys. Usp.* 7 696–720 (1965)**

Ginzburg V.L.
"Gamma astronomy and cosmic rays"
***Sov. Phys. Usp.* 15 626–631 (1973)**

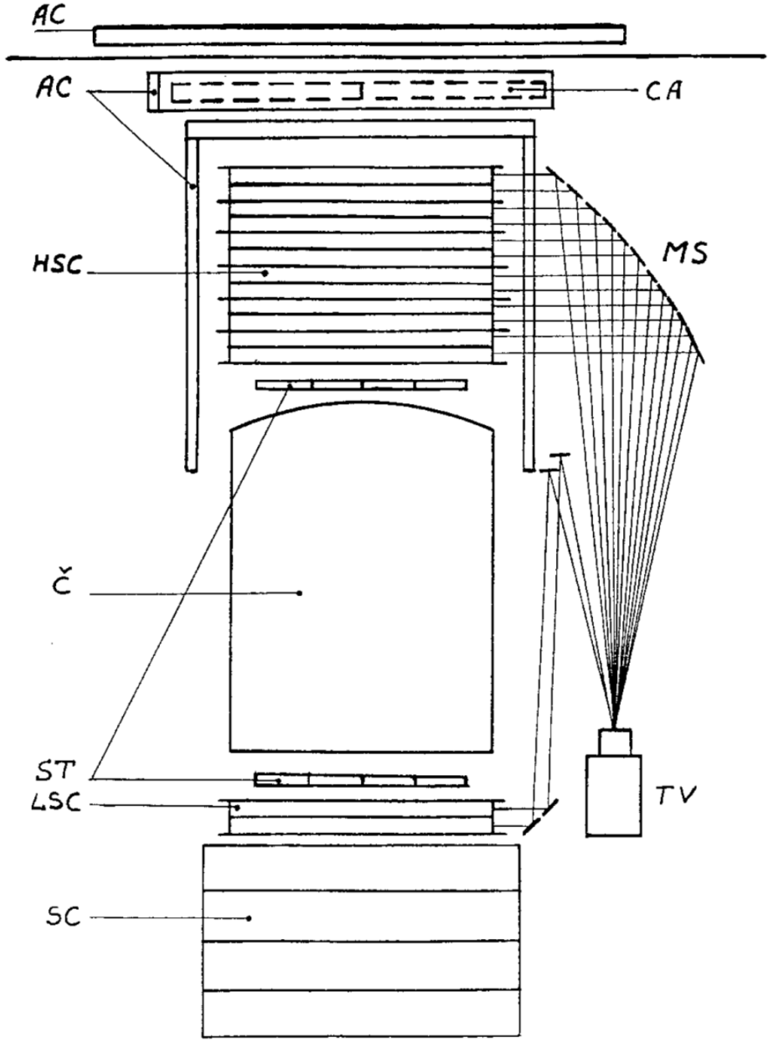
Cooperating closely with V.L. Ginzburg, scientists from MEPhI, LPI, IKI performed experimental studies on gamma-ray astronomy in space and balloons.

The result of this cooperation was the decision to develop the GAMMA-1 space-based gamma-ray telescope. Almost twenty years ago (in 1972) Academician V.L. Ginzburg made a report at a meeting of the Presidium of the USSR Academy of Sciences, in which he substantiated the need for the development of research in the field of the gamma-ray astronomy. It can be said that from this time the activities began in our country to implement gamma-ray astronomical observations. One of such programs was the GAMMA-1 project, which provides research in the energy range from 50 to 5000 MeV of gamma-ray sources, determination of their coordinates, time and energy characteristics, as well as gamma-ray emission of the Sun, Galaxy and extragalactic objects.

At the same time, the Council on Extraatmospheric Astronomy was established under the Presidium of Russian Academy of Sciences.

GAMMA-1 gamma-ray telescope

July 1990 – February 1992



- the range of recorded energies is from 50 to 5000 MeV. The lower bound is
ermined by the efficiency at low energies and the upper one by the particle energy
ctrum, effective area, and considerations on a reasonable observation time;
- the geometrical area, being 1480 cm^2, is determined by the Čerenkov detector and
ntillation telescope;
- the field of view, a circle with radius 12°, is determined by the Čerenkov detector;
- the angular resolution at E = 300 MeV is 1.2°, is determined by a spark chamber;
en using the coded aperture it is 20′·
- the energy resolution (FWHM) is 35% E = 300 MeV; it is determined by the
ntillation calorimeters;
- the temporal resolution is 10^{-3} s; it is determined by the telemetering data trans-
ssion system;
- the telescope weight is 1650 kg;
- the mean power consumption is 300 W;

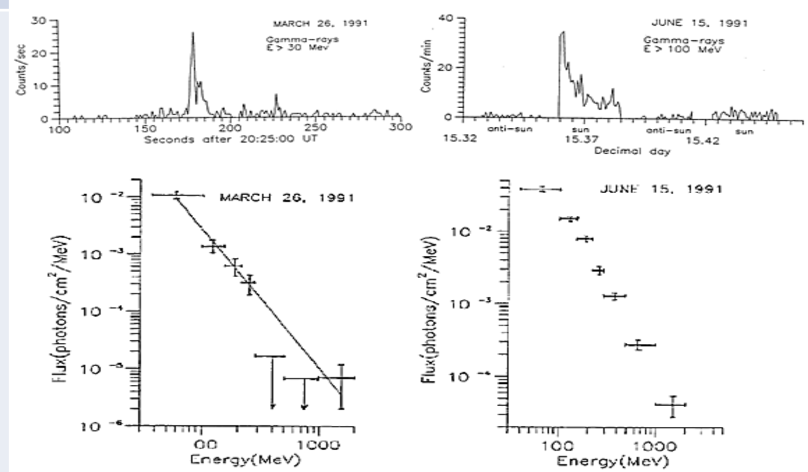
- an anticoincidence counter system (AC);
- a wide gap spark chamber system (HSC, LSC);
- data reading from spark chambers (mirror and TV systems) (MS, TV);
- a principal starting telescope (scintillation and Čerenkov gas counters) (ST, Č);
- a scintillation calorimeter (SC);
- an electronic control and telemetering formation system;
- a coded aperture system (CA);
- a star sensor.

	SAS-2	COS-B	GAMMA-1
Operation period	1972-1973	1975-1982	1990-1992
Energy range	35 MeV – 1 GeV	30 MeV – 5 GeV	50 MeV – 5 GeV
Sensitive area, cm^2	640	570	~1500
Sensitivity, photon/(cm^2 s) (E_γ > 100 MeV, t = 1 year),	~5×10^{-6}	~2×10^{-6}	~3×10^{-7}
Angular resolution, deg (E_γ =300 MeV)	~2,0	~2,0	~1,2
Energy resolution, % (E_γ =300 MeV)	-	~50	~35
- calorimeter thickness, r.l.		4,7	7,4
Time-of-Flight system	-	-	+
Cherenkov detector	Solid	Solid	Gas
- Cherenkov angle	48°	48°	~5°
- threshold energy for electrons	0,7 MeV	0,7 MeV	7 MeV
- threshold energy for protons	1,3 GeV	1,3 GeV	12 GeV

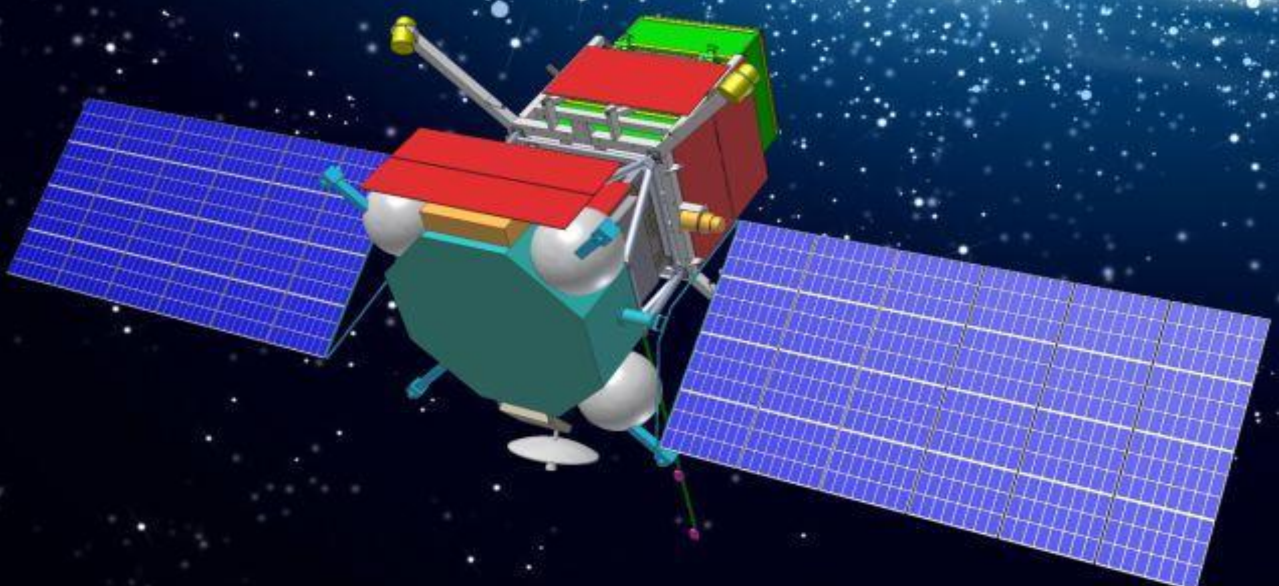
GAMMA-1 main results:
2700 h of total observations

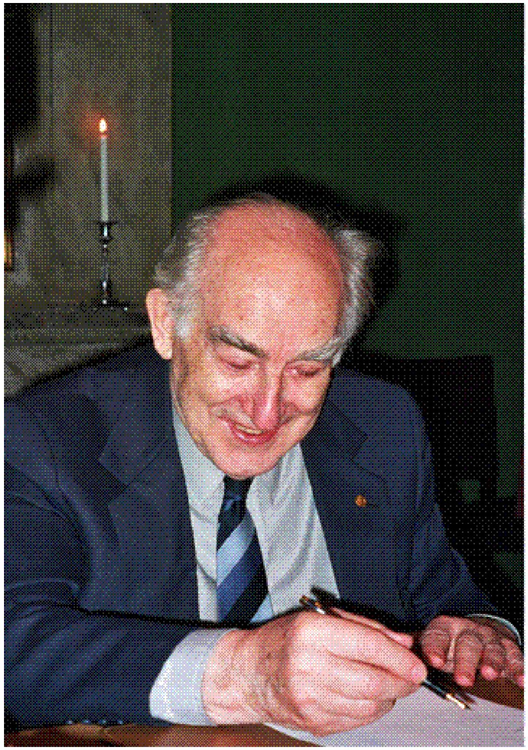
- **950 h of PSR 0833-45 (Vela pulsar)**
- **557 h of Cyg X3**
- **413 h of Hercules X-1**
- **176 h of Geminga pulsar**
- **40 h Galactic center**
- **400 h of Sun**

For the first time, before the EGRET gamma-ray telescope, GAMMA-1 recorded high-energy (up to several GeV) gamma-ray emission from solar flares on March 26, 1991 and June 15, 1991 .



GAMMA-400





Vitaly Ginzburg **Lidiya Kurnosova** **Arkadiy Galper**

The GAMMA-400 founders were the Nobel laureate academician Vitaly Ginzburg (LPI) and professor Lidiya Kurnosova (LPI), which initiated the GAMMA-400 project in Russia to search for dark matter particles using the gamma-ray astronomical methods. Since 2009, professor Arkadiy Galper is the GAMMA-400 Principal Investigator.

Some historical remarks on GAMMA-400

First ideas and first publications were presented in:

Proc. 20th ICRC (Moscow, 1987), Space Science Reviews, 49, 215 (1988)

SOME TASKS OF OBSERVATIONAL GAMMA-RAY ASTRONOMY IN THE ENERGY RANGE 5–400 GeV

V. A. DOGIEL, M. I. FRADKIN, L. V. KURNOSOVA, L. A. RAZORENOV, M. A. RUSAKOVICH, and N. P. TOPCHIEV

GAMMA-400 means Gamma Astronomical Multifunctional Modular Apparatus with the maximum gamma-ray energy of 400 GeV (in 1990's, the range from 30 GeV up to 400 GeV was unexplored).

GAMMA-400 was included in the Russian FSP 2006-2015 and now is included in new FSP 2016-2025.

РОССИЙСКАЯ АКАДЕМИЯ НАУК

Физический институт имени П.Н.Лебедева

ФИАН

V.L. Ginzburg, L.V. Kurnosova, M.I. Fradkin, N.P. Topchiev et al.

ПРЕПРИНТ

3

Коллаборация ГАММА - 400
(ФИАН, МИФИ, НИИЯФ МГУ, ЦСКБ)

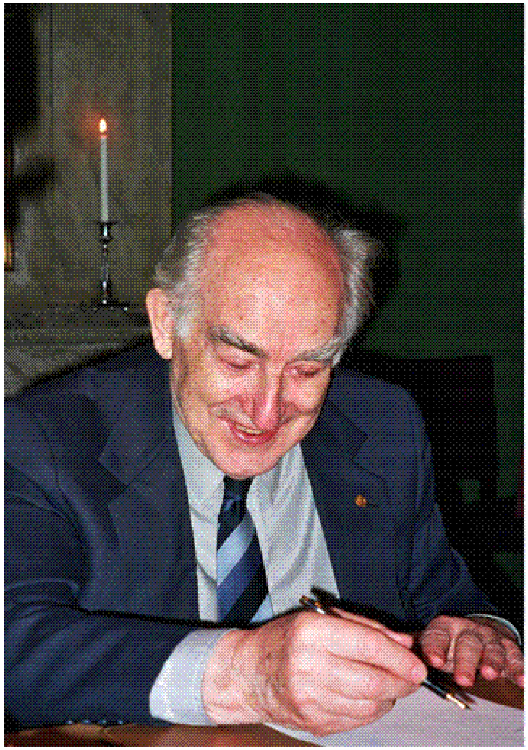
КОСМИЧЕСКОЕ ГАММА-ИЗЛУЧЕНИЕ ВЫСОКОЙ ЭНЕРГИИ И ПРОЕКТ ГАММА-ТЕЛЕСКОПА ГАММА-400

GAMMA-400 COLLABORATION

COSMIC HIGH-ENERGY GAMMA-RADIATION AND PROJECT OF THE GAMMA-RAY TELESCOPE GAMMA-400

Москва 1995

The importance of studying the nature of dark matter was confirmed by V.L. Ginzburg in a Nobel lecture in 2003



List of especially important and interesting problems at the beginning of the XXI century

25. Black holes. Space strings
26. Quasars and galactic nuclei. Galactic formation
27. Dark matter problem and its detection
28. Origin of very high-energy cosmic rays
29. Gamma-ray burst

УТВЕРЖДАЮ

Директор

Учреждения Российской академии наук

Физического института

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

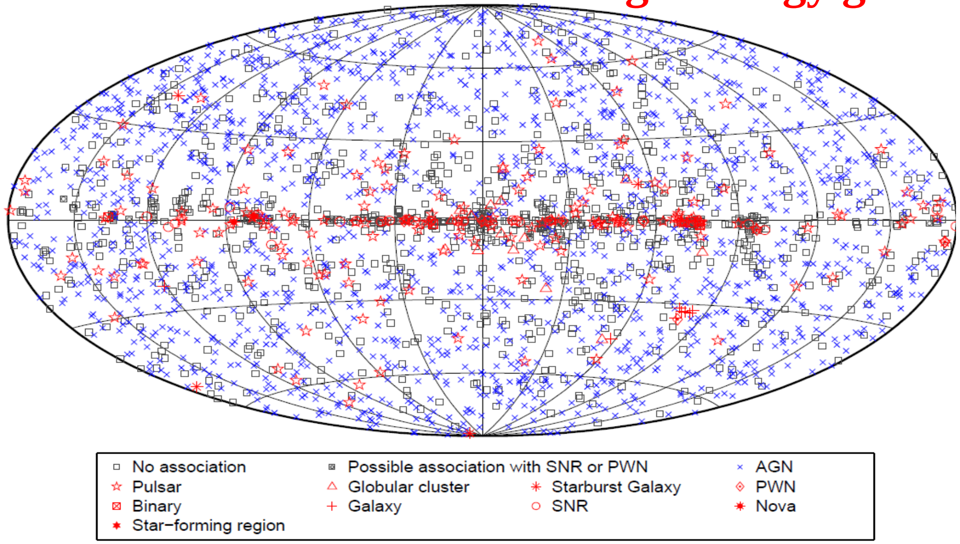
Study of cosmic gamma rays and electron/positron fluxes in the energy range of 1-3000 GeV

Academician V.L. Ginzburg

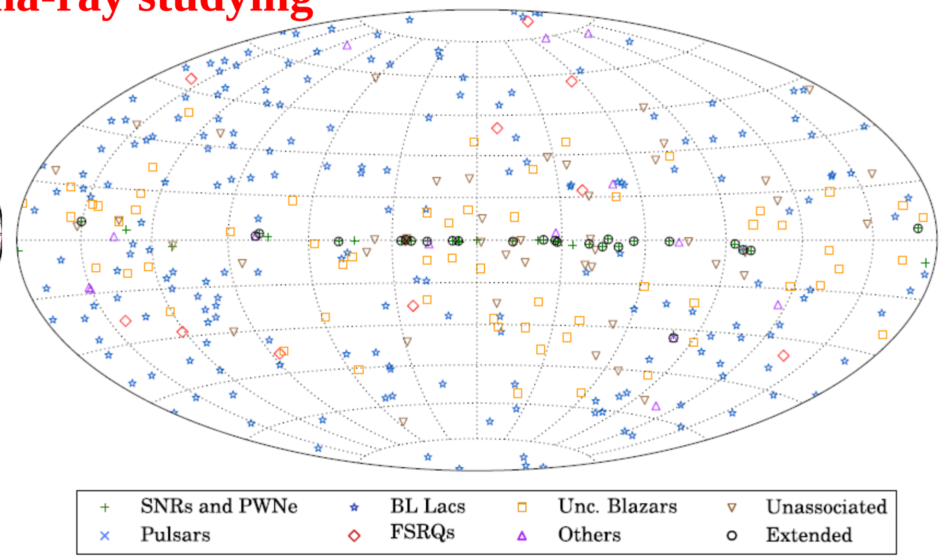
PI GAMMA-400 Project A.M. Galper

Moscow, 2009

High-energy gamma-ray studying



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

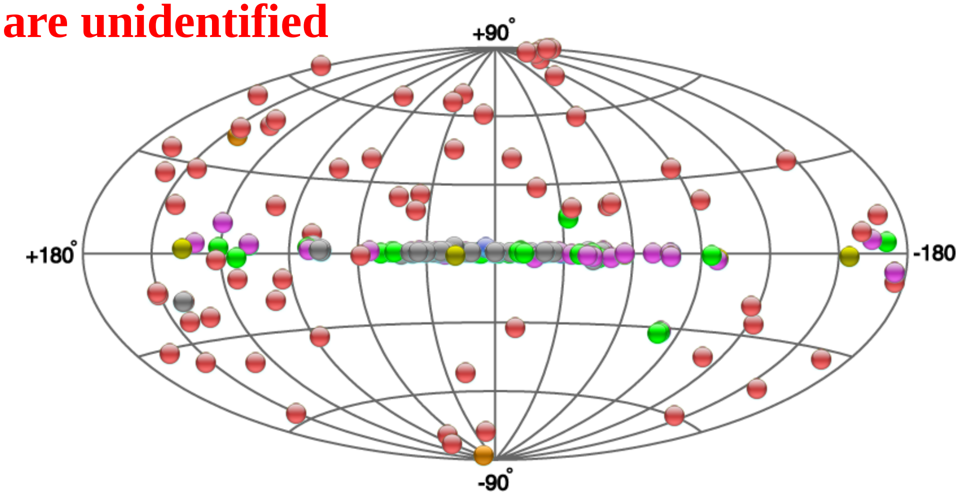


Distribution of 360 discrete sources
(**2FHL**, E_γ = 50 – 200 GeV)

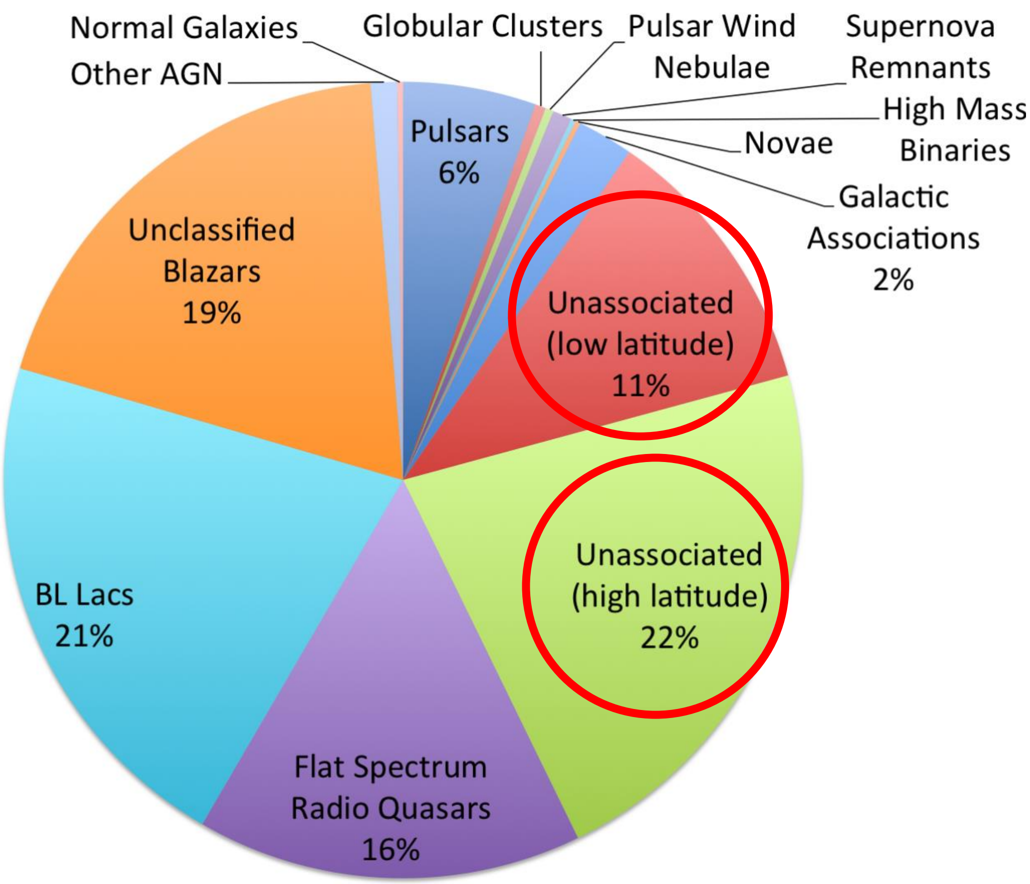
~33% sources are unidentified

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

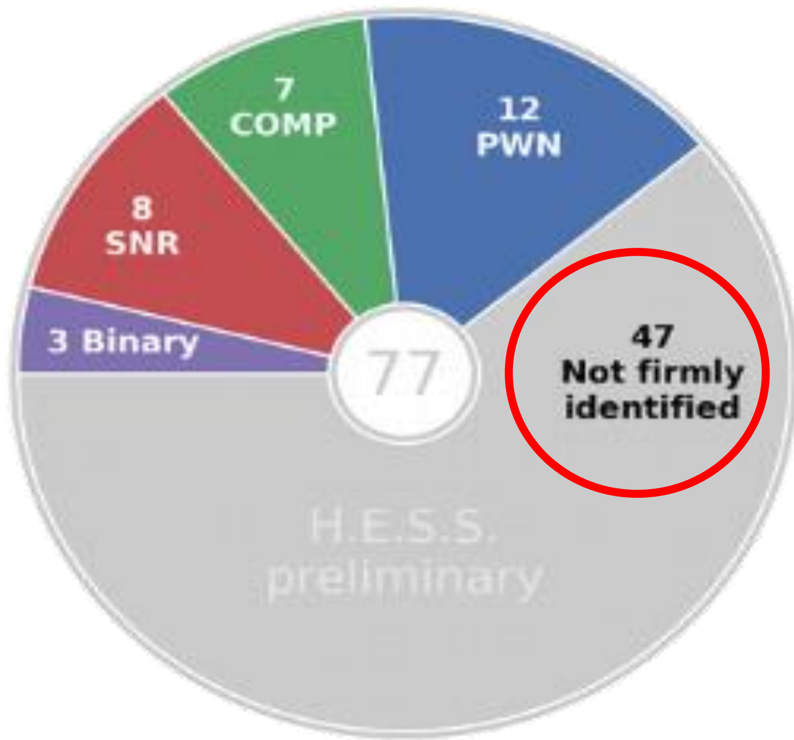
Ground-based telescope angular resolution is ~0.1° (E_γ ~ 100 GeV)



Distribution of 181 discrete sources
(**TeVCat**, E_γ > 100 GeV)



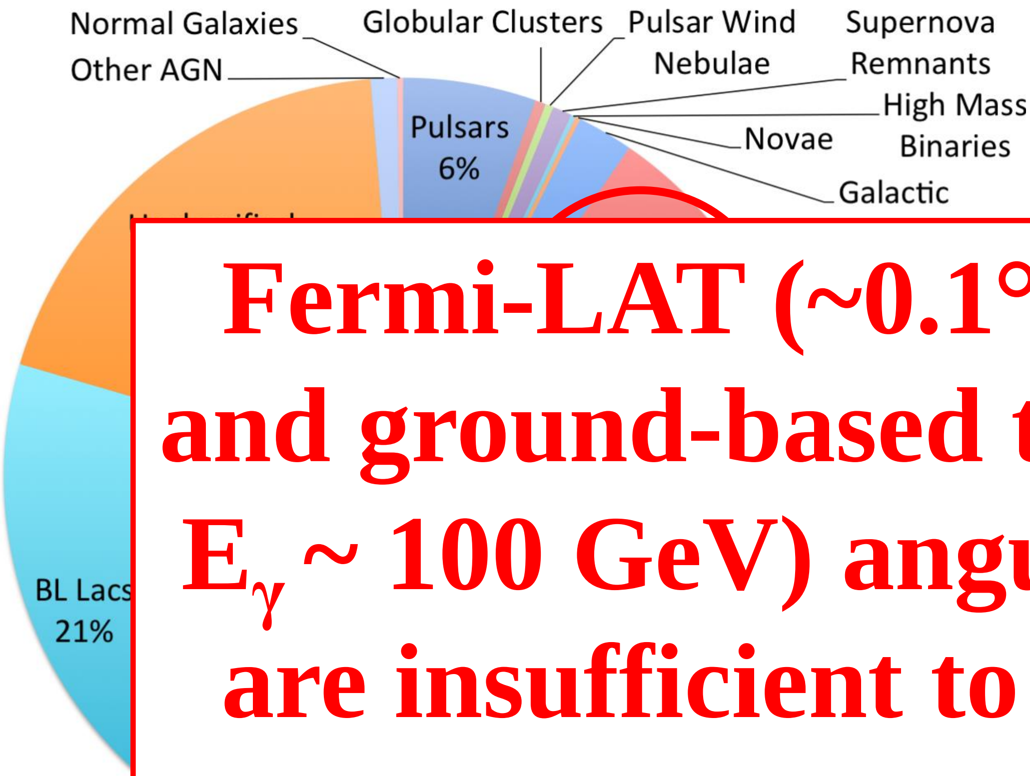
The percentage of the different types of gamma-ray sources according to the 3FGL Fermi-LAT catalogue

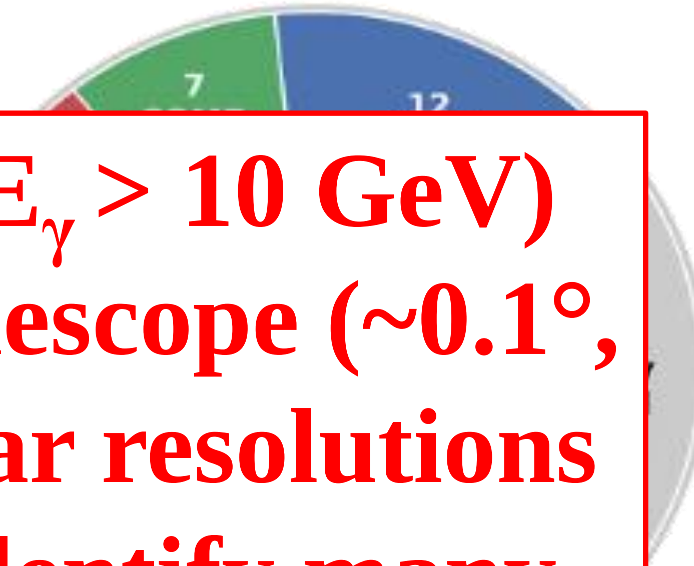


Composition of discrete sources, recorded by H.E.S.S.

arXiv :1509.00012, 2015

https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2016/01/





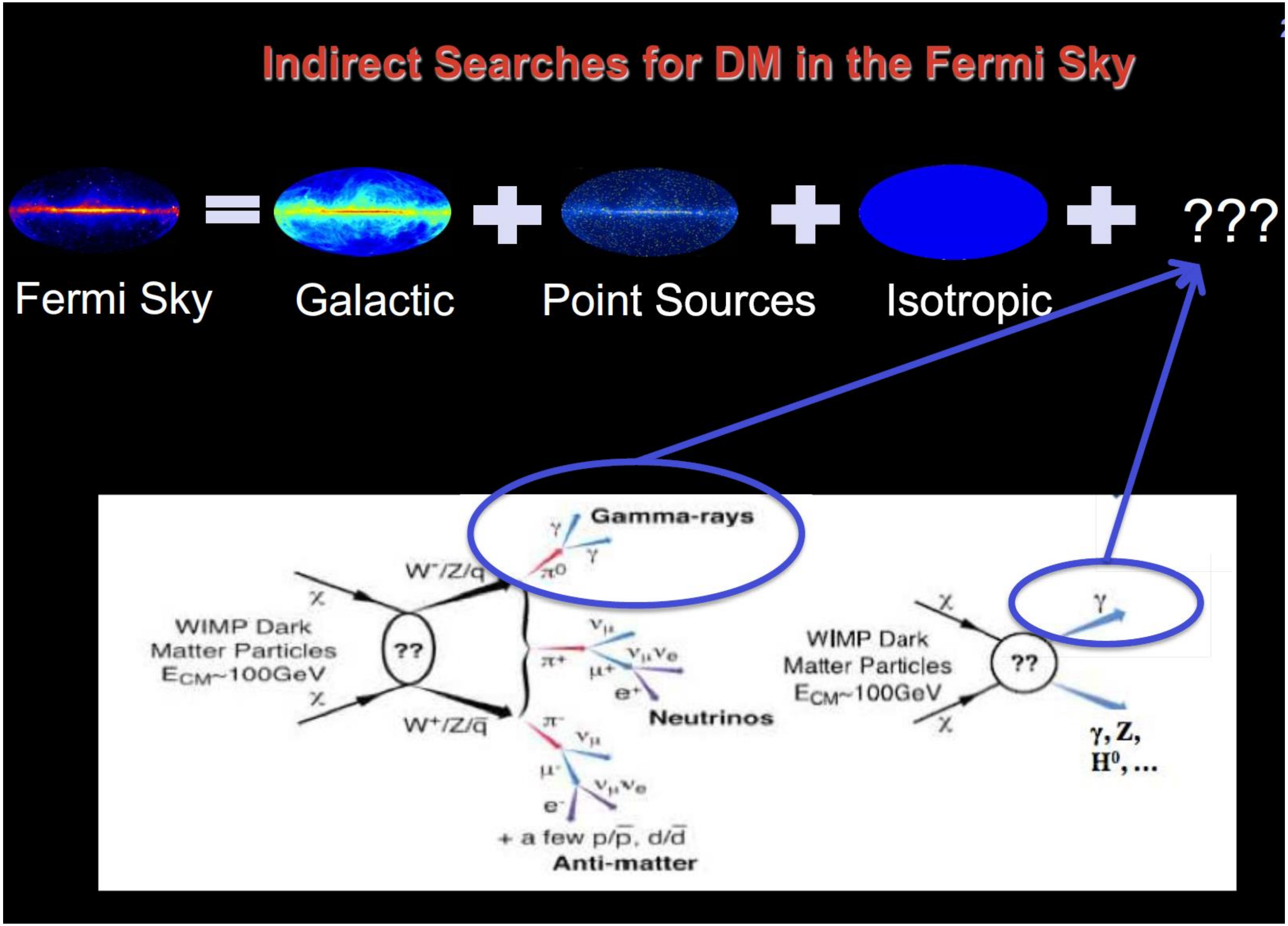
Fermi-LAT (~0.1°, E_γ > 10 GeV) and ground-based telescope (~0.1°, E_γ ~ 100 GeV) angular resolutions are insufficient to identify many gamma-ray sources

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

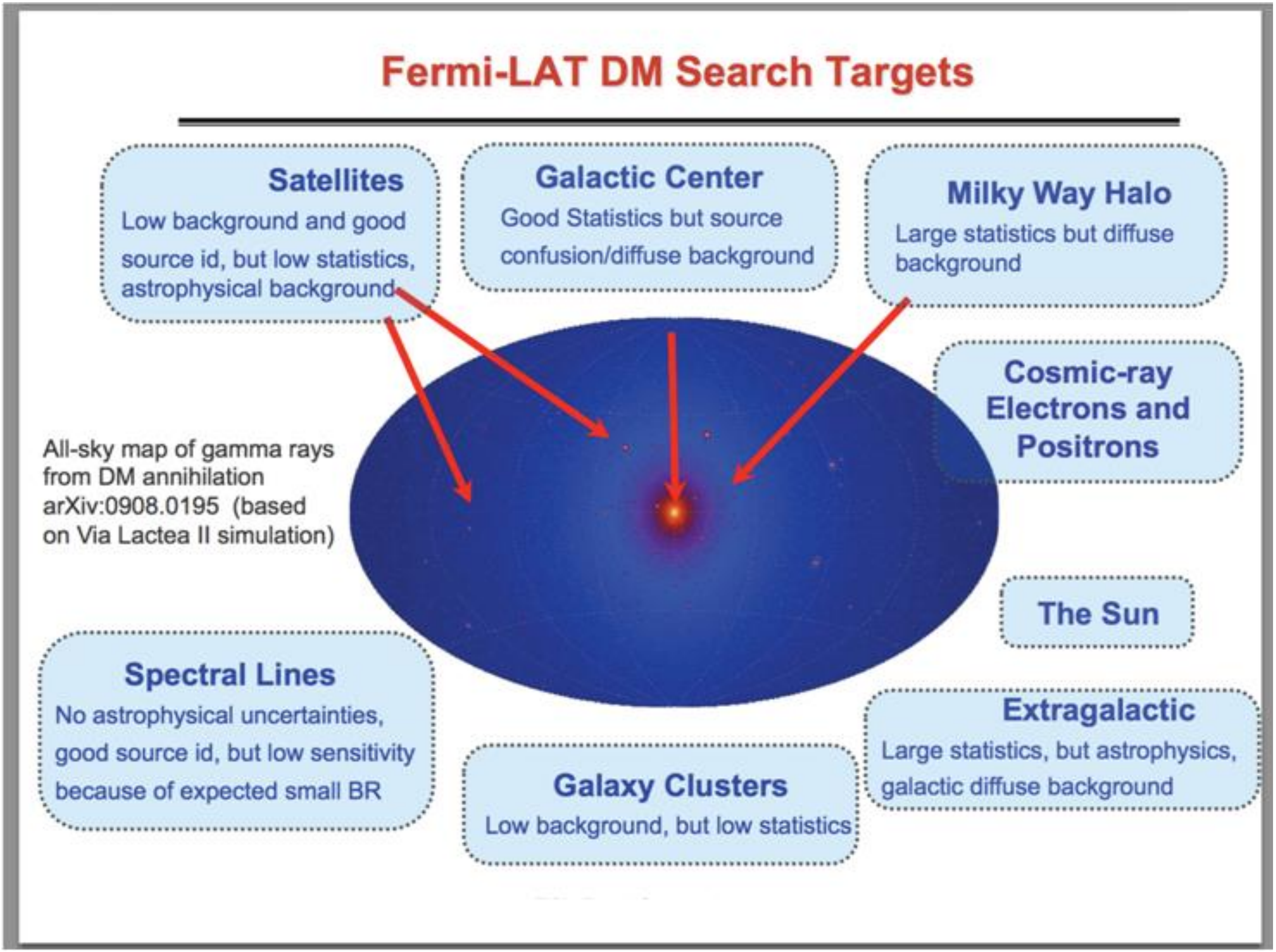
Composition of discrete sources, recorded by H.E.S.S.

arXiv :1509.00012, 2015

https://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2016/01/

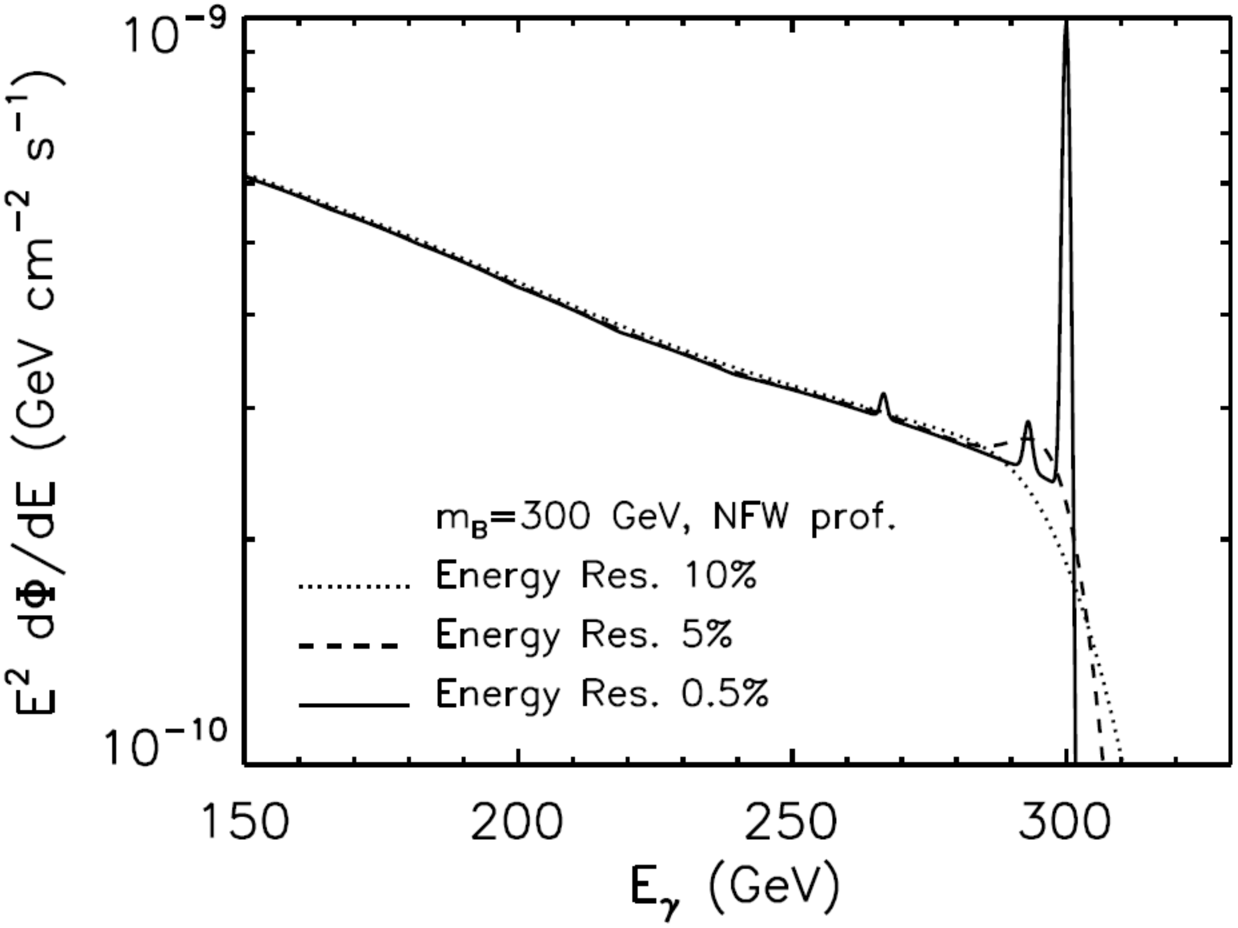


One of the leading candidates for the DM particle are weakly interacting massive particles (WIMPs) producing after annihilation or decay gamma rays



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

Capabilities of different gamma-ray telescopes to resolve DM lines

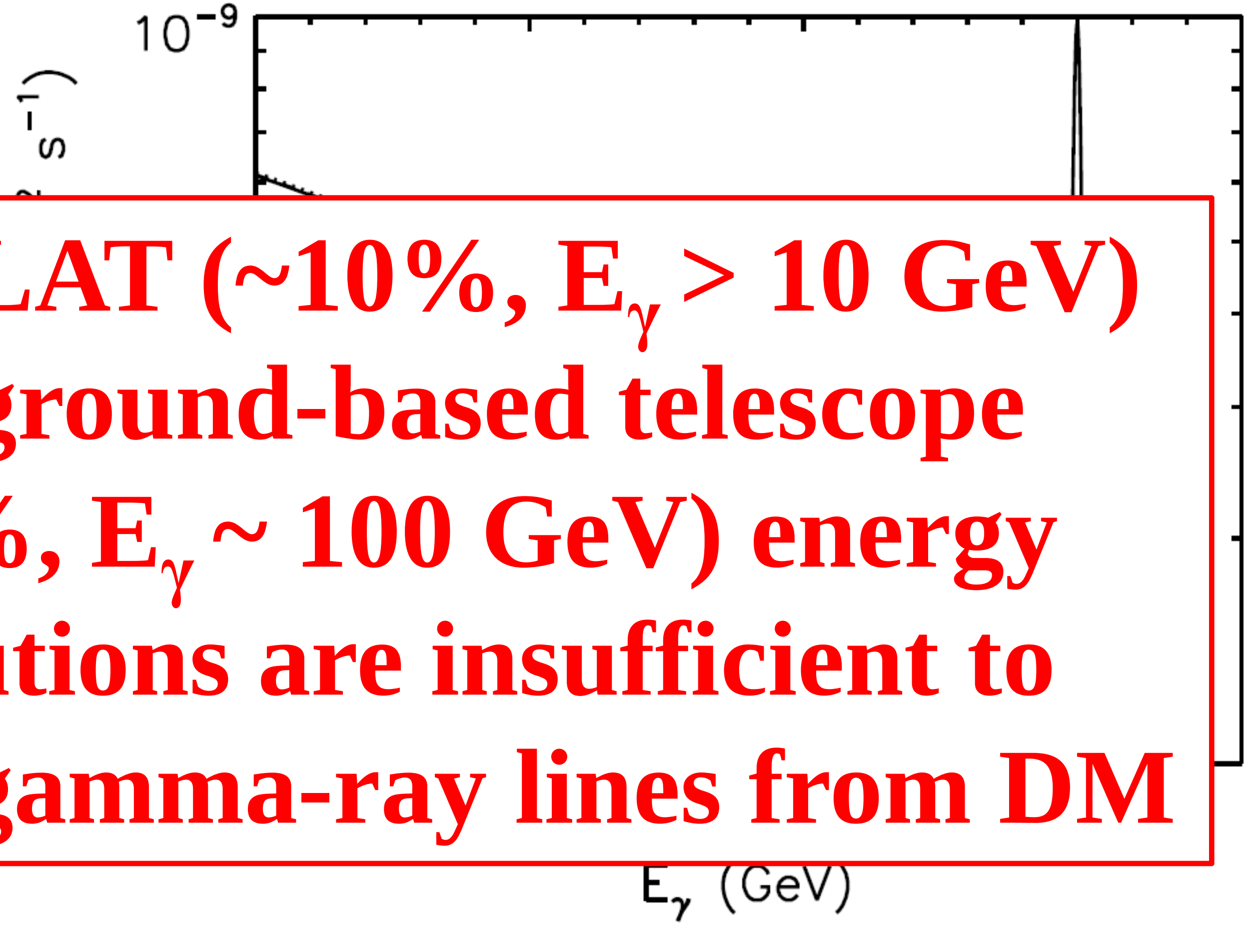


The gamma ray flux as a function of the photon's energy for a WIMP of mass 300 GeV. Shown are three different experimental energy resolutions.

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

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.

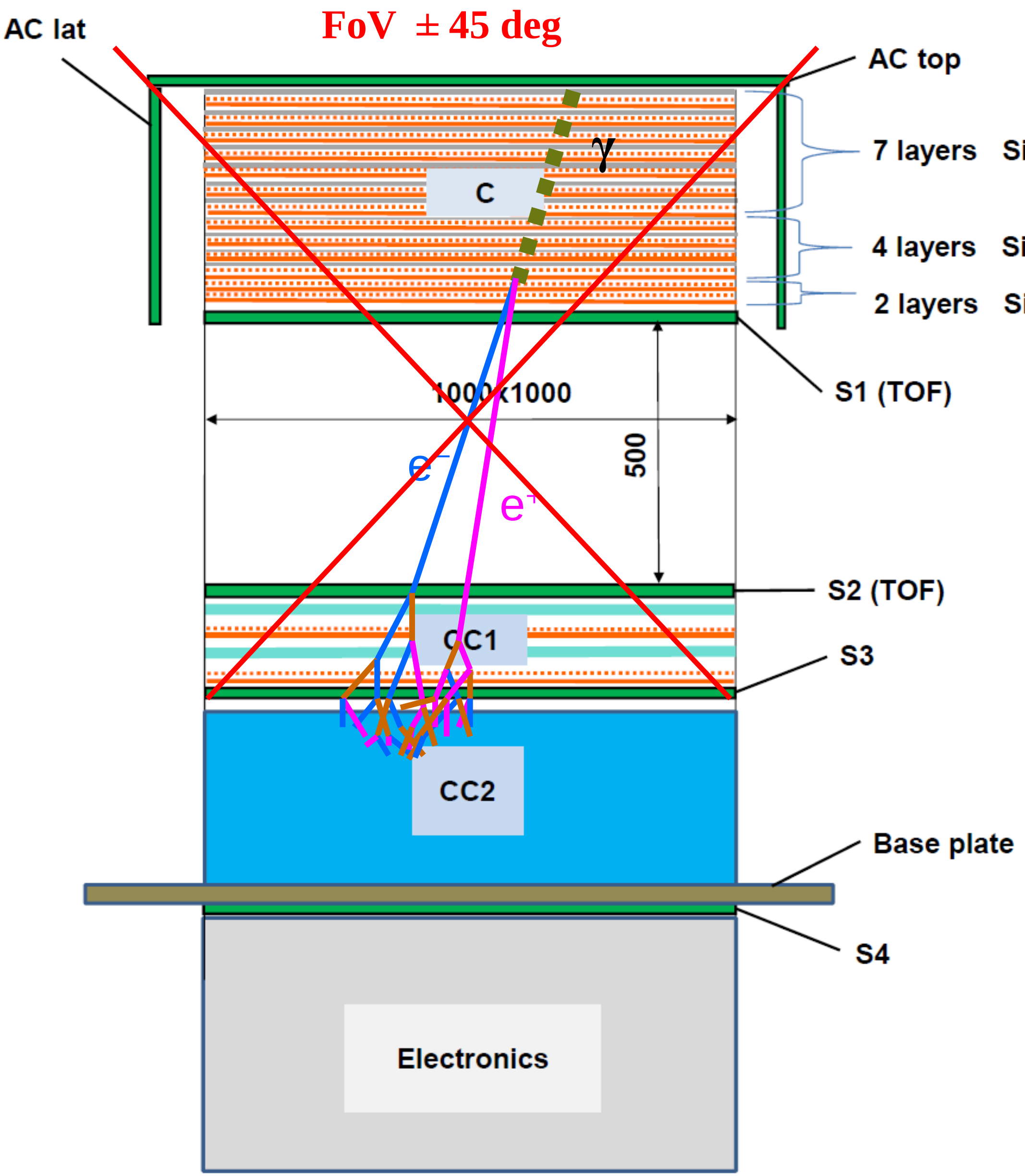
Energy resolution for Fermi-LAT is ~10% (E_γ > 10 GeV) and ground-based gamma-ray telescopes is ~15% (E_γ ~ 100 GeV)

arXiv:1009.5107

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 plane, Galactic Center, Fermi Bubbles, Crab, Vela, Cygnus, Geminga, Sun, and other regions, extended, binary, and point gamma-ray sources, diffuse gamma rays with unprecedented angular **(~0.01° at $E_\gamma > 100$ GeV)** and energy resolutions **(~1% at $E_\gamma > 100$ GeV)**.

The new preliminary 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

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

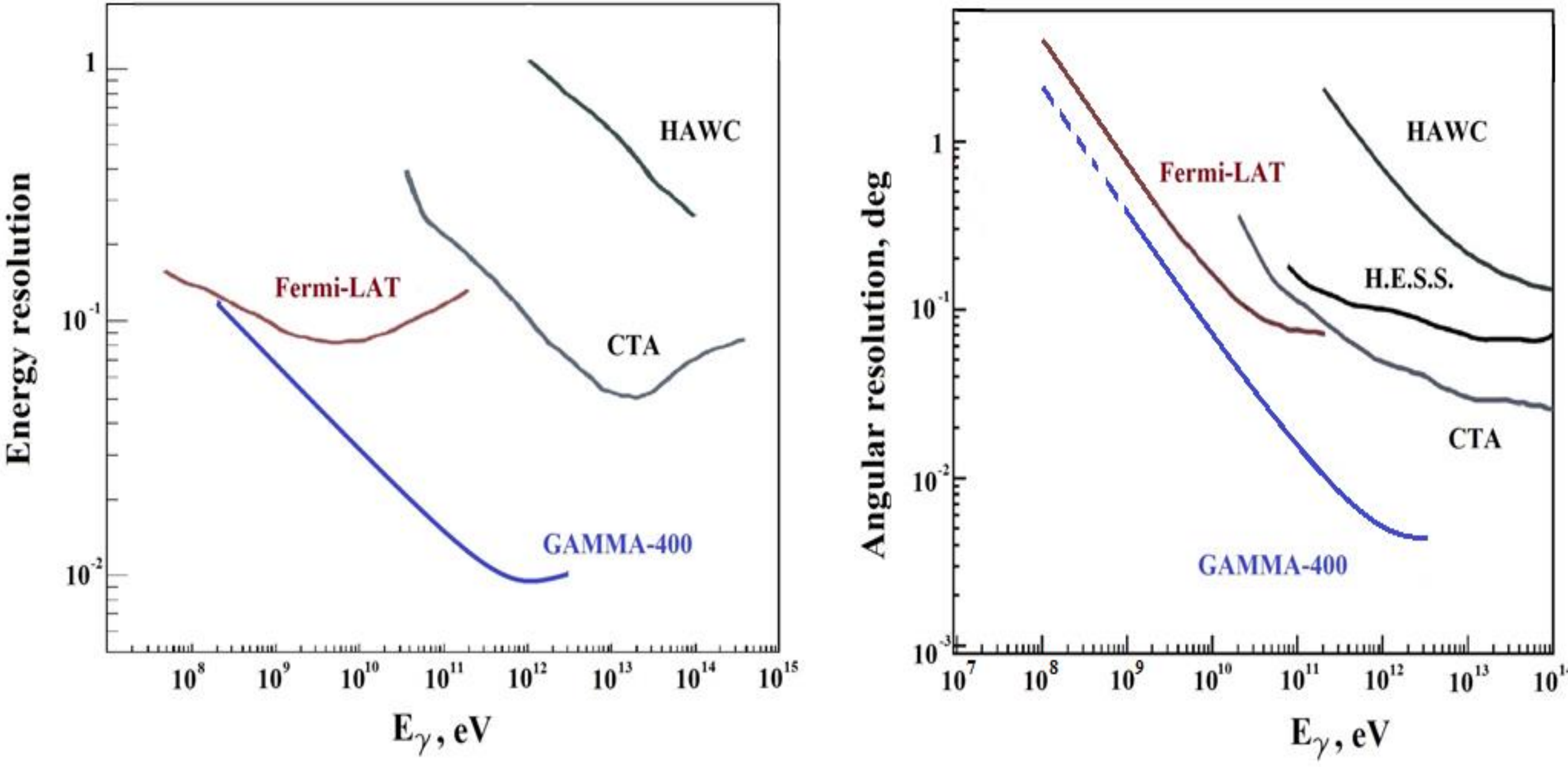
Comparison of the main parameters for GAMMA-400 and Fermi-LAT

	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	20 MeV - 300 GeV	**~20 MeV – ~1000 GeV**
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	~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 **~22X_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	4100 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)	0.1º (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)

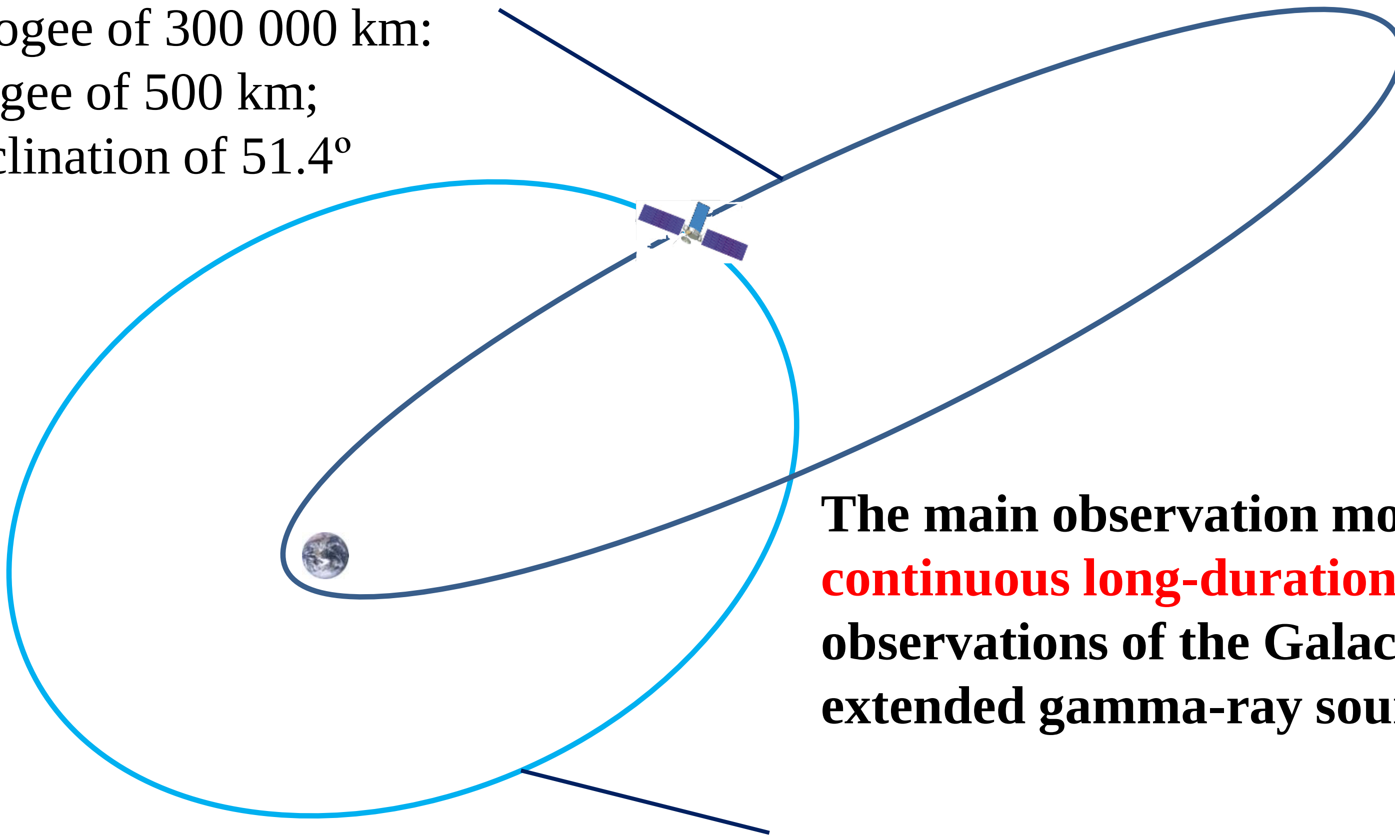
Comparison of the energy and angular resolutions for GAMMA-400, Fermi-LAT, HAWC, and CTA



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

The GAMMA-400 orbit evolution and observation modes

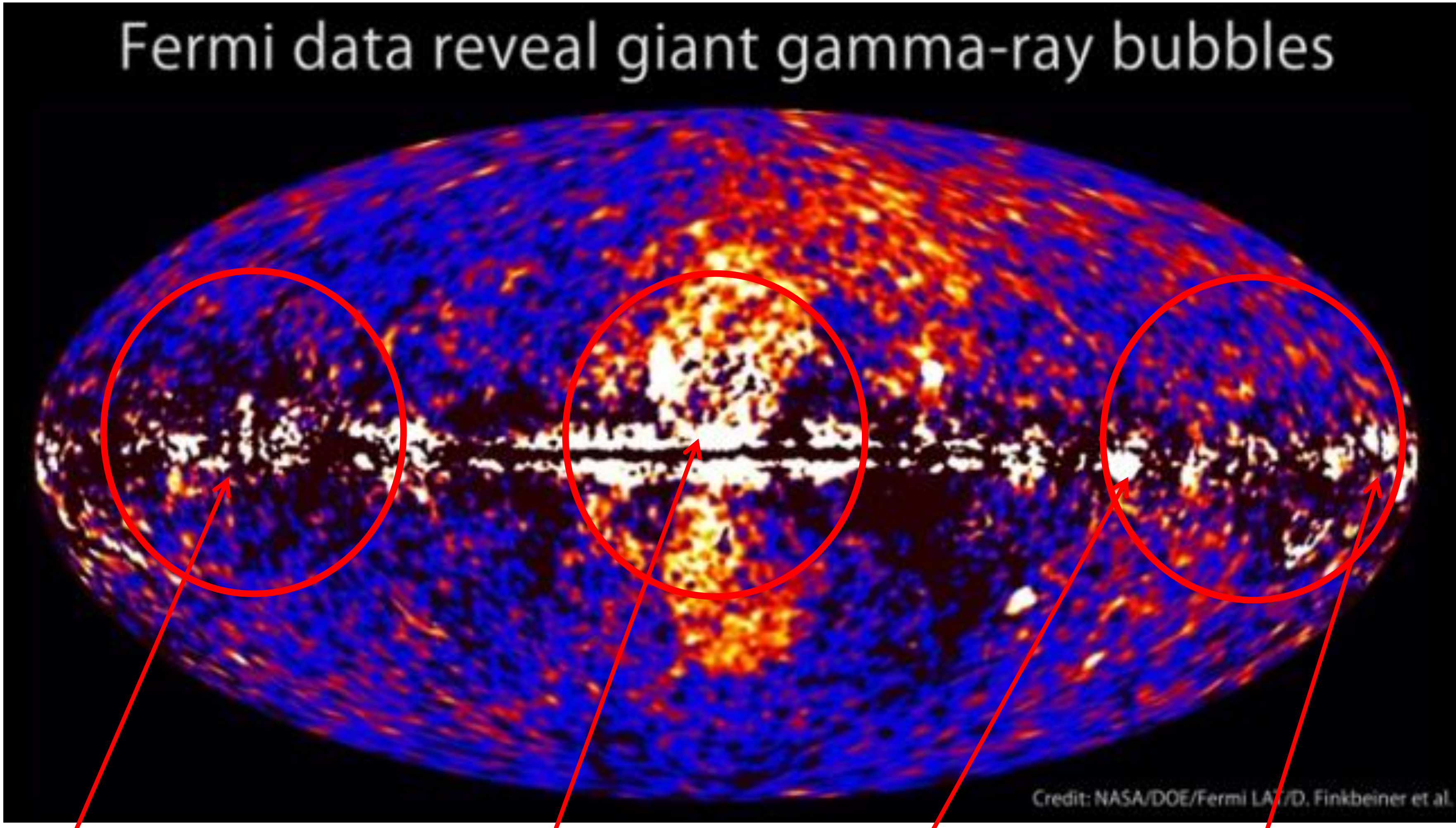
The orbit of the GAMMA-400 space observatory will have the following initial parameters:
-an apogee of 300 000 km:
-a perigee of 500 km;
-an inclination of 51.4º



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.

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

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°):

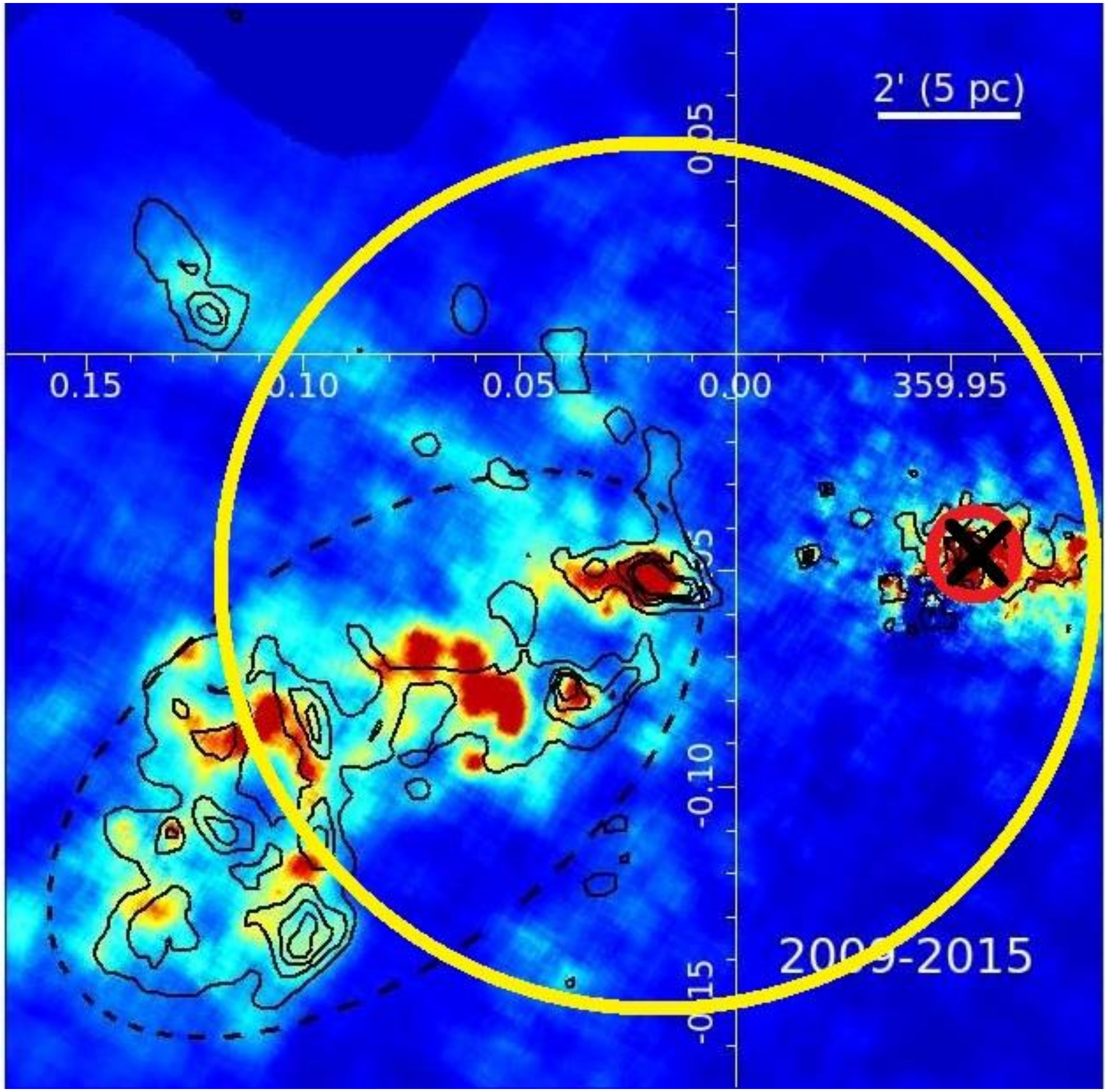
57400 gammas for E_γ > 10 GeV, 1280 gammas for E_γ > 100 GeV

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**

Fermi-LAT

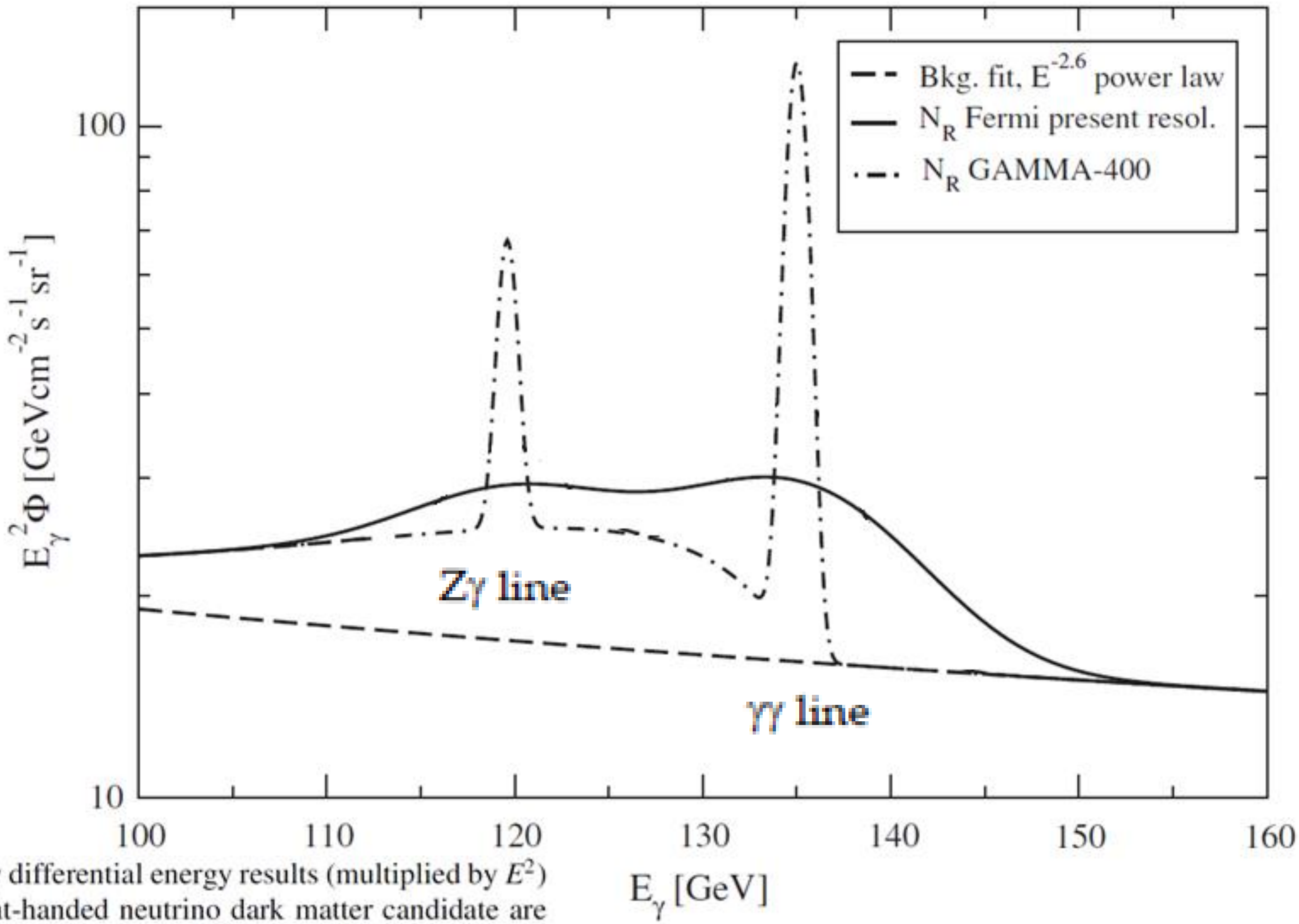
50 GeV – 2 TeV

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



Comparison of the capabilities to study Galactic Center by Fermi-LAT (angular resolution ~0,1°, E_γ = 100 GeV, yellow circle) and GAMMA-400 (angular resolution ~0,01°, 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)

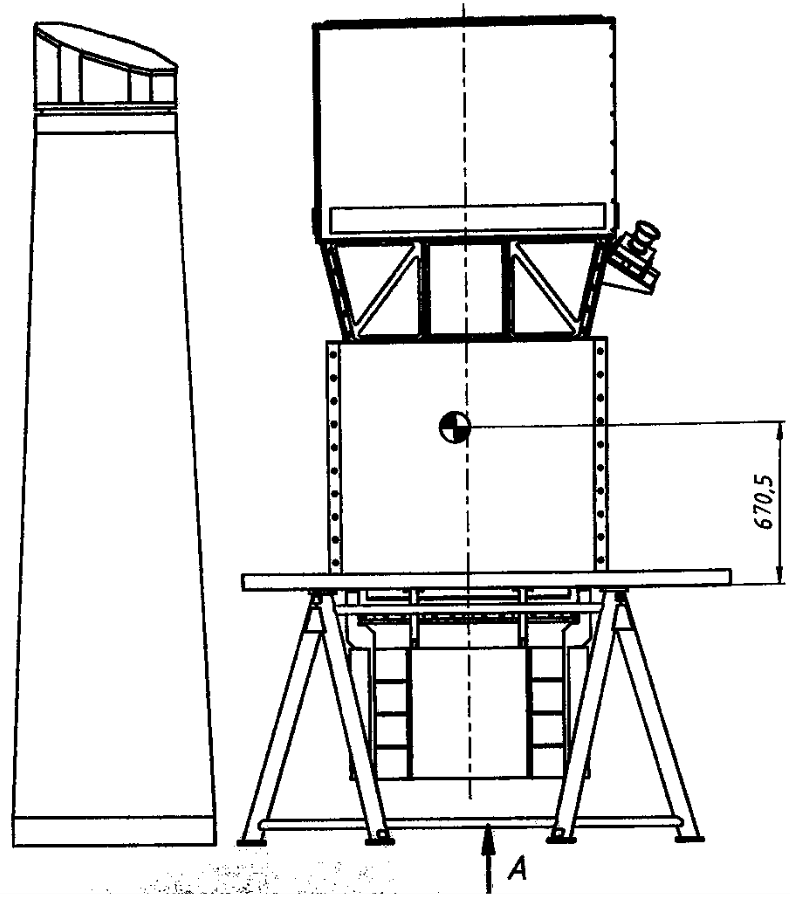
and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

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

130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

Ginzburg V.L., Syrovatskii S.I.
"Some problems of gamma and X-ray astronomy"
***Sov. Phys. Usp.* 7 696–720 (1965)**



ART-XC **GAMMA -400**

GAMMA-400 and X-ray telescope on space observatory

Conclusions

- **The role of V.L. Ginzburg in the development of gamma-ray astronomy is extremely large.**
- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to improve the data of LE+HE gamma rays and X-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).**
- 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/