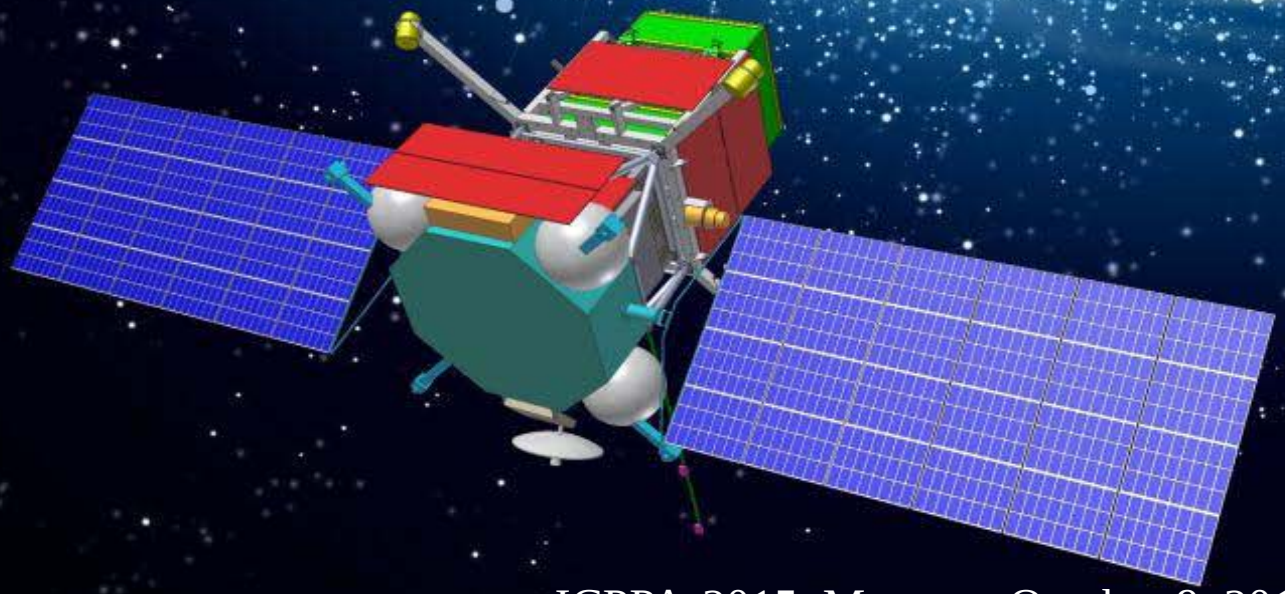
Russian Academy of Sciences
P.N.Lebedev Physical Institute
L P I

Nikolay Topchiev
for the GAMMA-400 Collaboration

The GAMMA-400 gamma-ray telescope for precision gamma-ray emission investigations



ICPPA-2015, Moscow, October 9, 2015

GAMMA-400 TEAM

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Some historical remarks on GAMMA-400

First ideas and first publications were presented in:

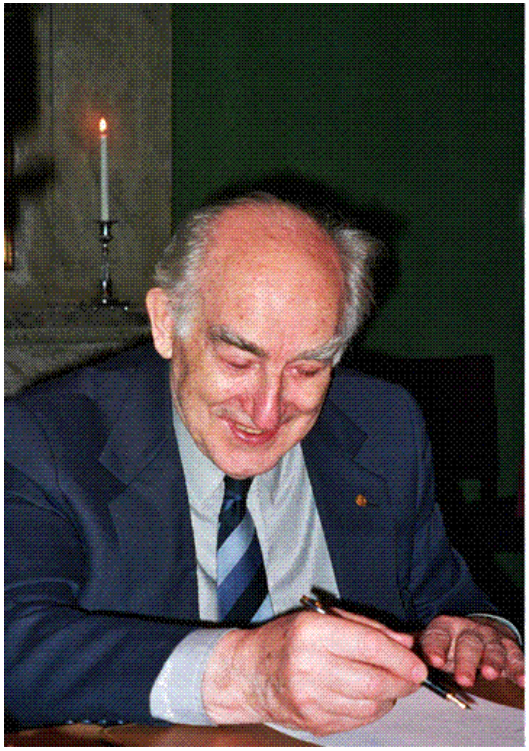
Proc. 20th ICRC (Moscow, 1987), Space Science Reviews, 49, 215 (1988)

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 (but FSP 2016-2025 is not yet approved by the Russian Government).



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.

GAMMA-400 gamma-ray telescope physical scheme and fields of view

Full aperture ±60°

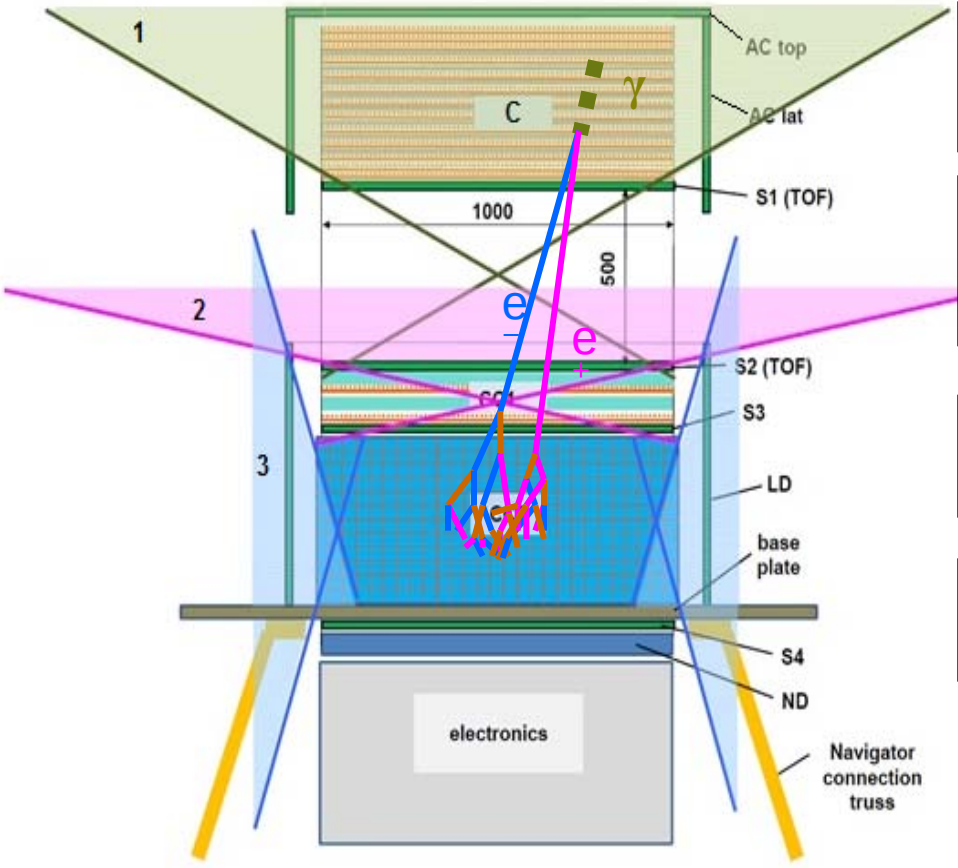
Anticoincedence system (AC), MEPhi

Time-of-flight system (ToF), MEPhI

Construction, thermal regulation system, electrical interface Lavochkin +NIIEM (Istra)

Scintillation detectors (S3, S4), Lateral detectors (LD) MEPhI

Scientific data acquisition system (SDAS), SRISA RAS



Converter-tracker (C), (6Si +(15Si+8W)+5Si strips, 1 X_0), LPI+INFN (Italy)

Calorimeter (CC1) (CsI(Tl)+Si strips, 2 X_0) LPI+INFN (Italy)

Calorimeter (CC2) (CsI(Tl), 23 X_0) LPI+INFN (Italy)

Neutron detector (ND), MEPhI

1 (for vertical events) – gamma rays, electrons + positrons

X_0 =1(C)+ 25(CC), λ_0 = 1.2

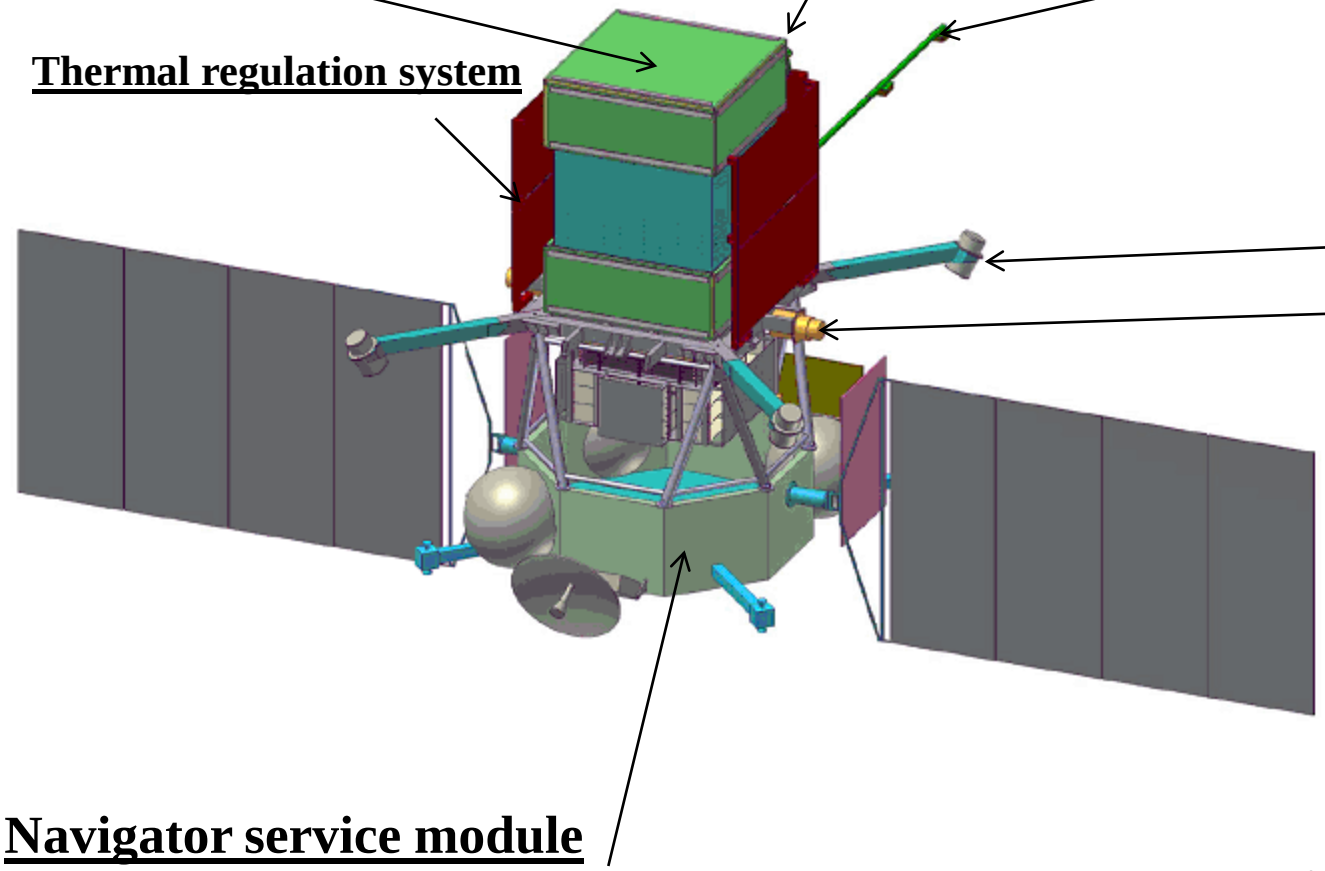
2 (for vertical events) – diffuse gamma rays, electrons + positrons

3 (for lateral events) - diffuse gamma rays, electrons + positrons, nuclei

X_0 =54, λ_0 = 2.5

ΔE = ~20 MeV – 1 TeV (γ), 1 GeV – 10 TeV (e)

$\Delta\theta$ = ~0.01° and $\Delta E/E$ = ~1% (E_γ > 100 GeV)

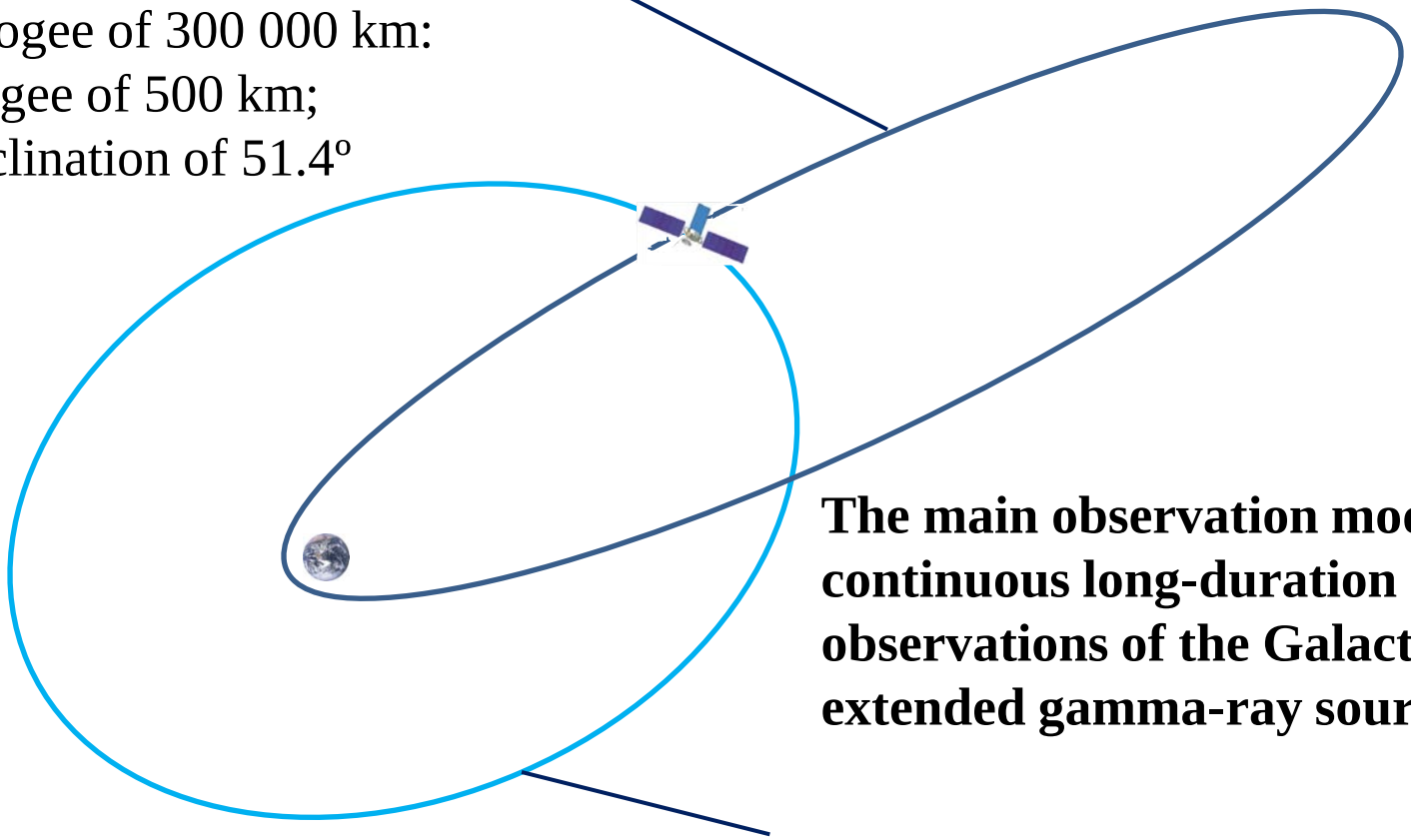


GAMMA-400 scientific complex on the Navigator service module

The GAMMA-400 orbit evolution and observation modes

The highly elliptical orbit will have the following initial parameters:
-an apogee of 300 000 km:
-a perigee of 500 km;
-an inclination of 51.4º

Angara launch vehicle
Vostochny cosmodrome
2023-2025



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.

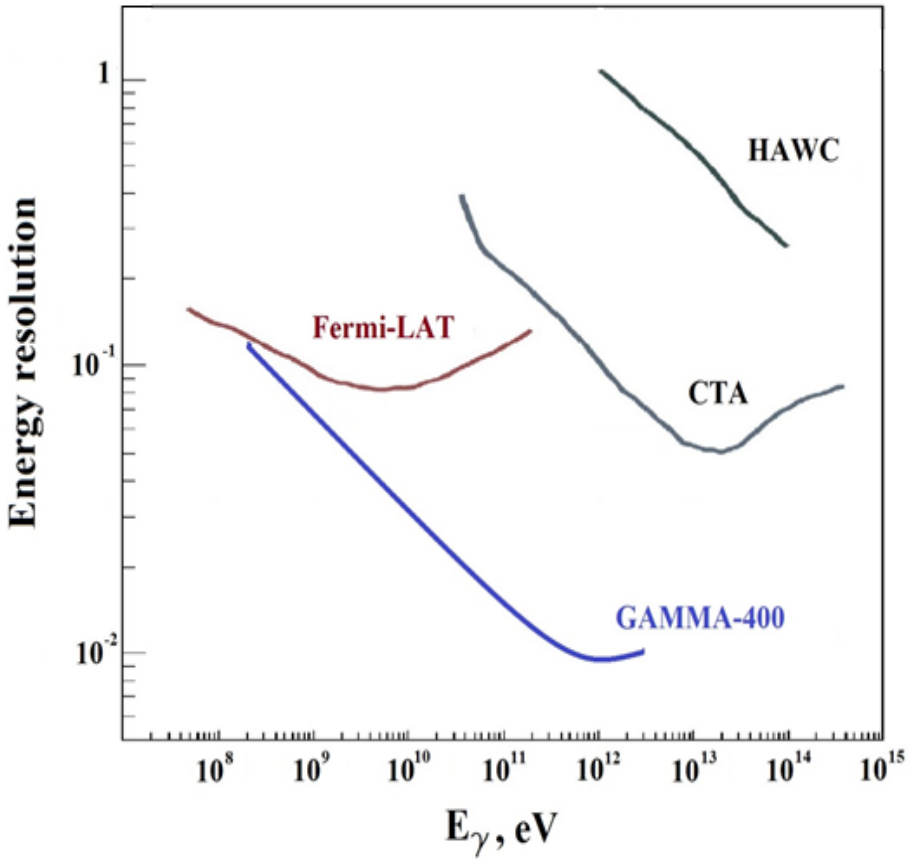
Comparison of the main parameters for Fermi-LAT and GAMMA-400

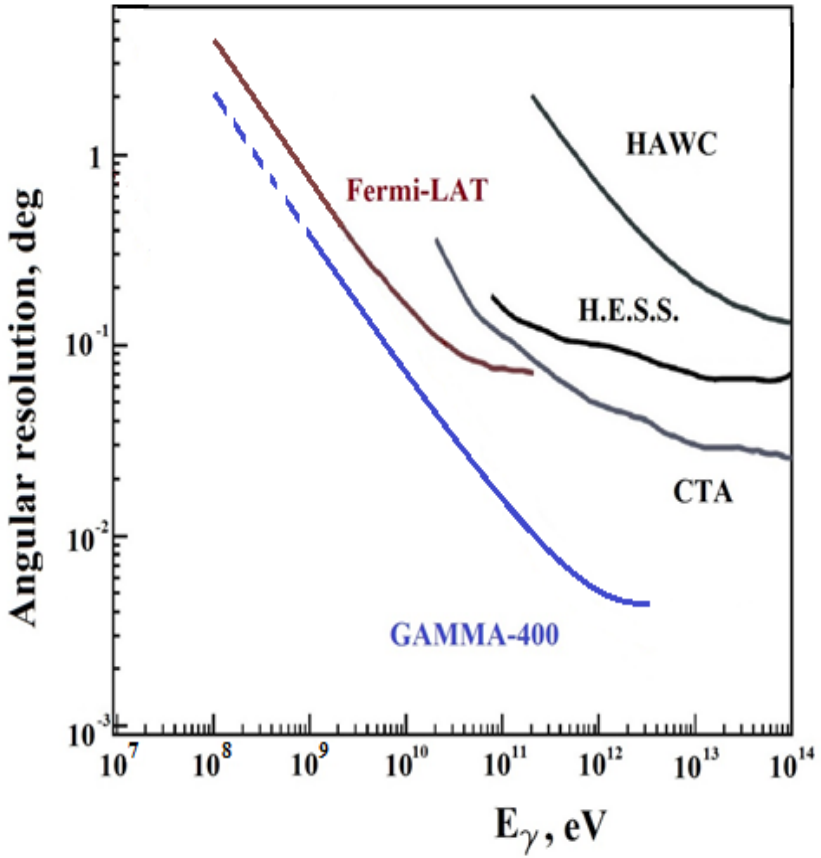
	Fermi-LAT	GAMMA-400
Orbit	circular, 565 km	Highly elliptical, 500-300000 km (without the Earth's occultation)
Operation mode	Sky-survey (3 hours)	Point observation (up to 100 days)
Source exposition	1/7	1
Energy range	20 MeV - 300 GeV (γ, e)	~20 MeV – 1 TeV (γ) 1 GeV – 10 TeV (e)
Effective area (E_γ > 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 ~25X_0
Energy resolution	~10% (E_γ = 10 GeV) ~10% (E_γ > 100 GeV)	~3% (E_γ = 10 GeV) ~1% (E_γ > 100 GeV)
Proton rejection factor	~10^3	~5x10^5
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	e, nuclei, γ	e, nuclei, γ	γ, e, nuclei	γ	γ	γ	γ
Operation period	2007-	2008-	2015	2015	~2023-2025	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) 0.03º (E_γ = 10 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





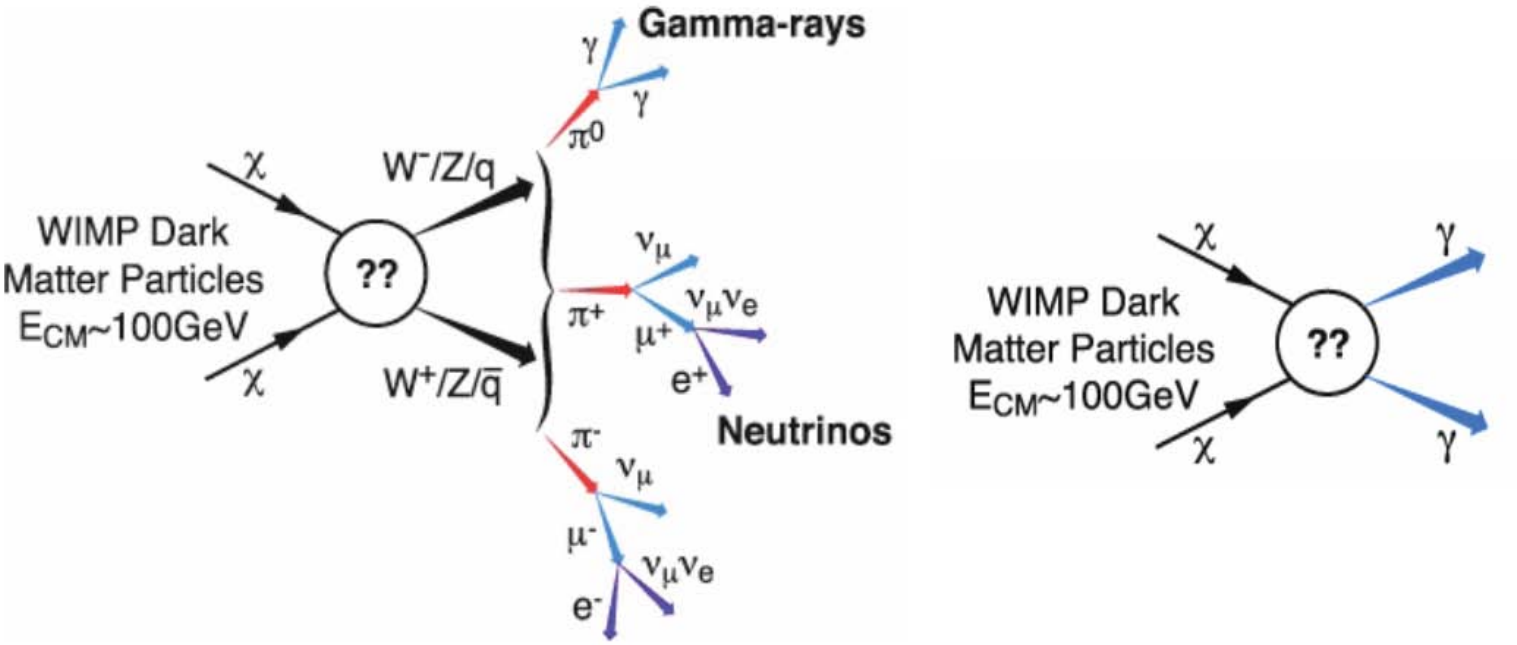
S. Funk , et. for the CTA Consortium, Astroparticle Phys.,2013, 43, 348

GAMMA-400 SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise measurements of Galactic Center, Crab, Vela, Cygnus, Geminga, and other regions, extended and point gamma-ray sources, diffuse gamma rays; measuring high energy electron + positron fluxes; measuring high-energy nuclei fluxes, research of high-energy gamma-ray bursts.

Dark matter searches

Gamma Production



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

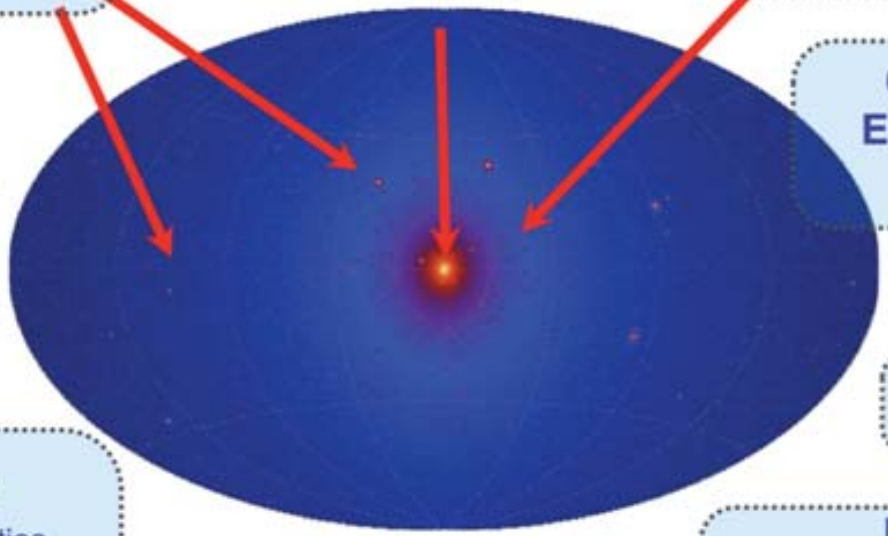
The sensitivities to a DM signal depend critically on accurate estimates of the backgrounds: diffuse γ-rays, γ- rays from astrophysical sources, and charged particles detected as γ-rays

Fermi-LAT DM Search Targets

Satellites
Low background and good source id, but low statistics, astrophysical background

Galactic Center
Good Statistics but source confusion/diffuse background

Milky Way Halo
Large statistics but diffuse background



All-sky map of gamma rays from DM annihilation arXiv:0908.0195 (based on Via Lactea II simulation)

Cosmic-ray Electrons and Positrons

The Sun

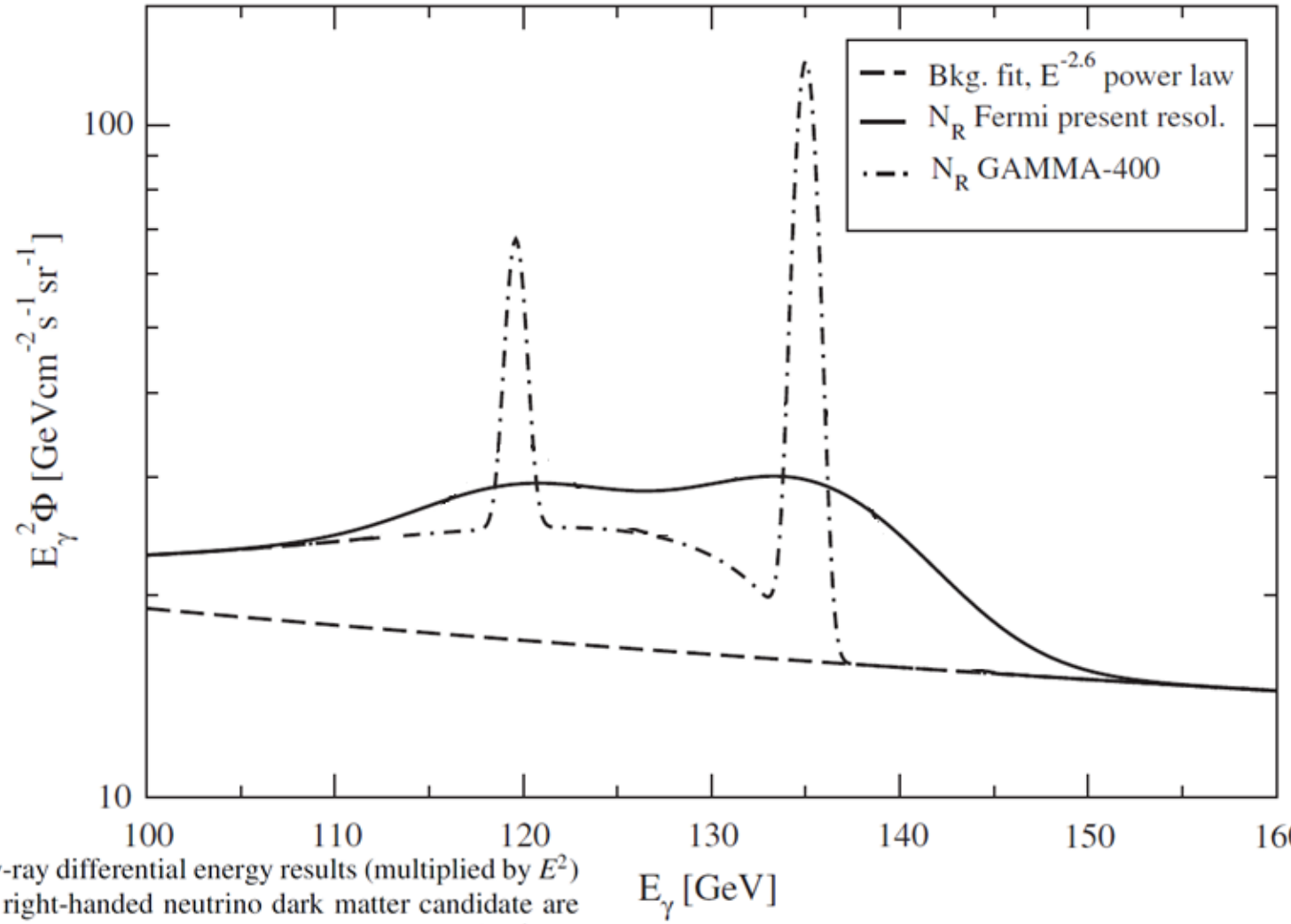
Spectral Lines
No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Galaxy Clusters
Low background, but low statistics

Extragalactic
Large statistics, but astrophysics, galactic diffuse background

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

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)

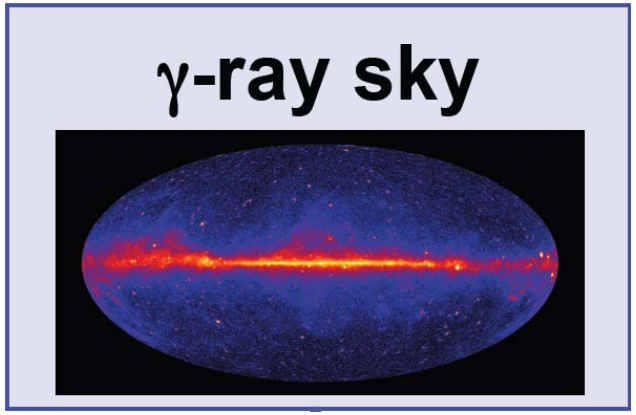
and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

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

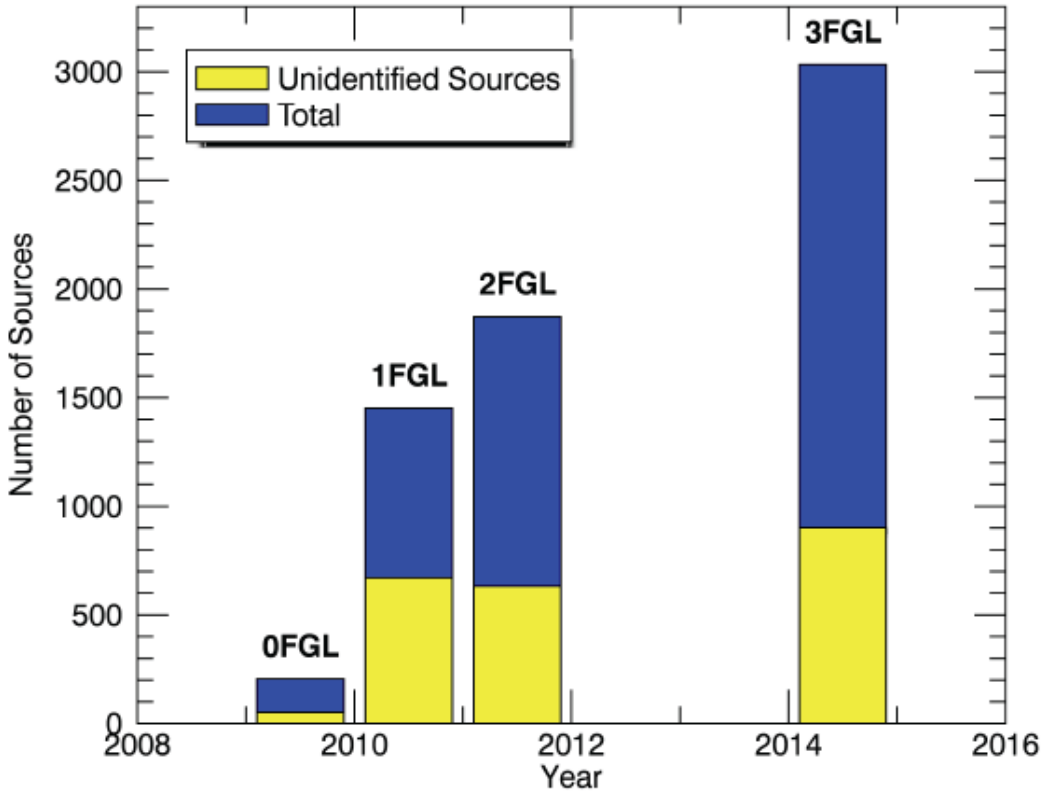
130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

Analyze of gamma-ray results



	Energy range	Number of sources	Number of unidentified sources
Fermi (3FGL)	0,1-300 GeV	3033	**992**
AGILE	0,03-50 GeV	47	**8**
TevCat	> 100 GeV	158	



50 GeV – 2 TeV

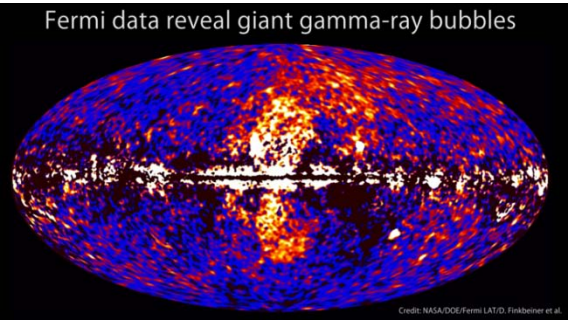
51,000 photons E > 50 GeV
18,000 photons E > 100 GeV
2,000 photons E > 500 GeV

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

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°):

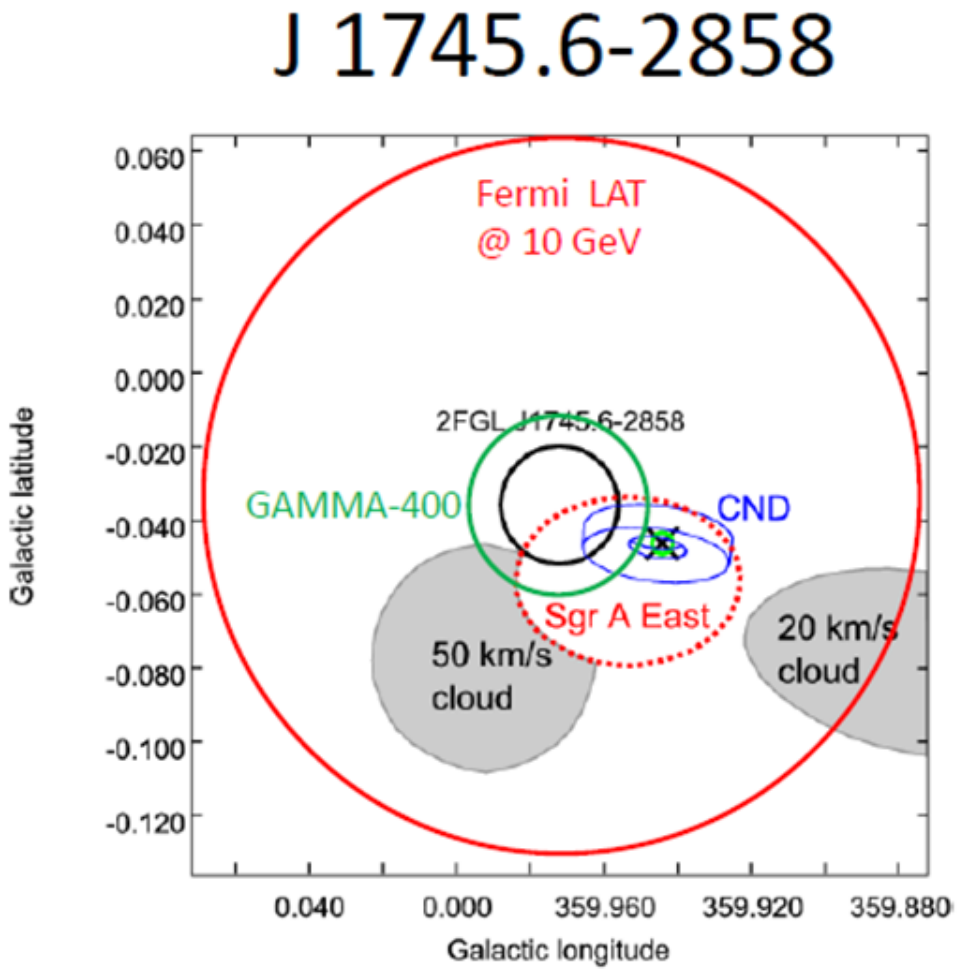
57400 gammas for E_γ > 10 GeV, 1280 gammas for E_γ > 100 GeV

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**



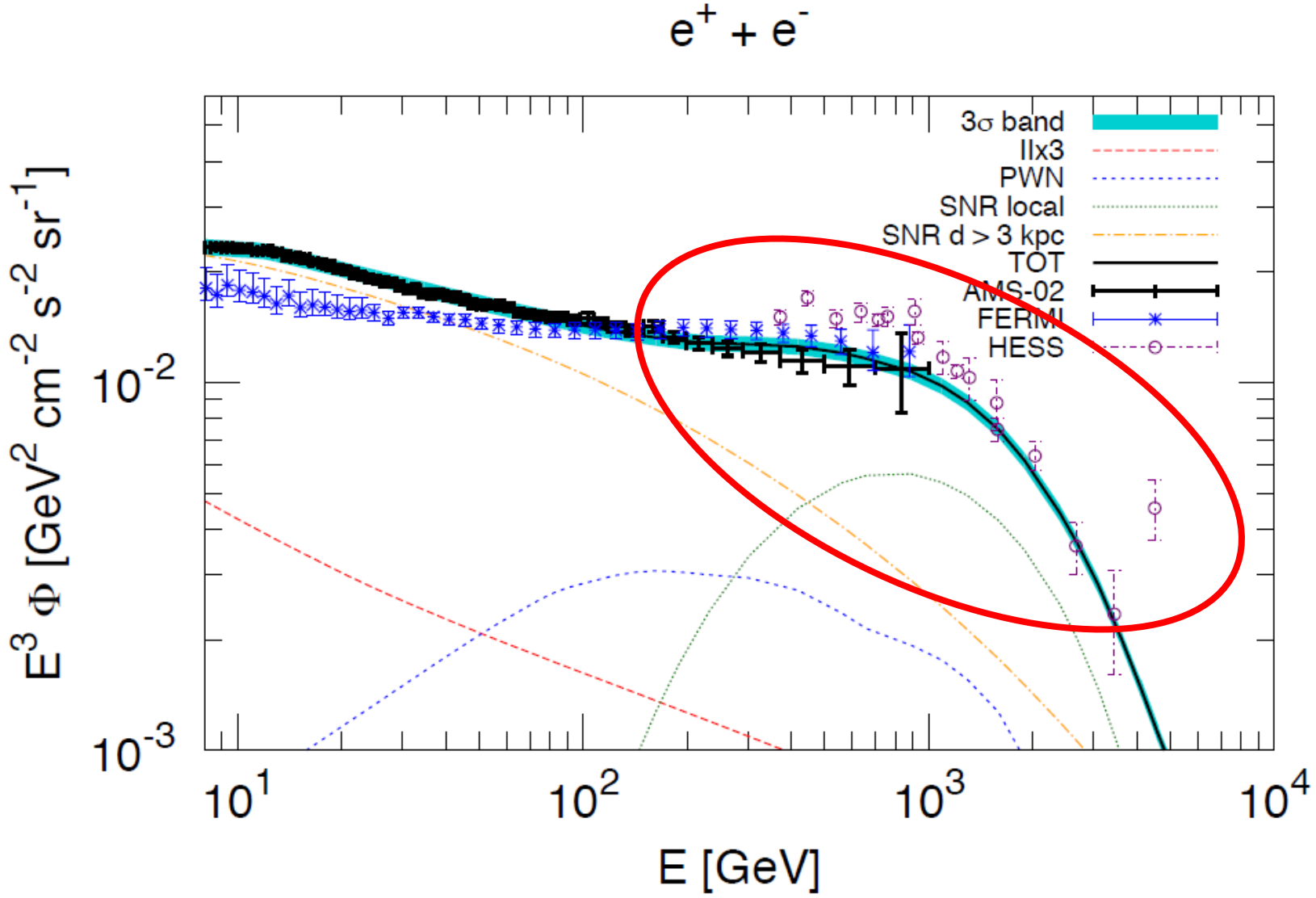
Moreover, Crab, Cygnus, Vela, Geminga, and other regions will be observed

Comparison of the Fermi-LAT and GAMMA-400 capabilities to resolve gamma-ray sources in the Galactic Center



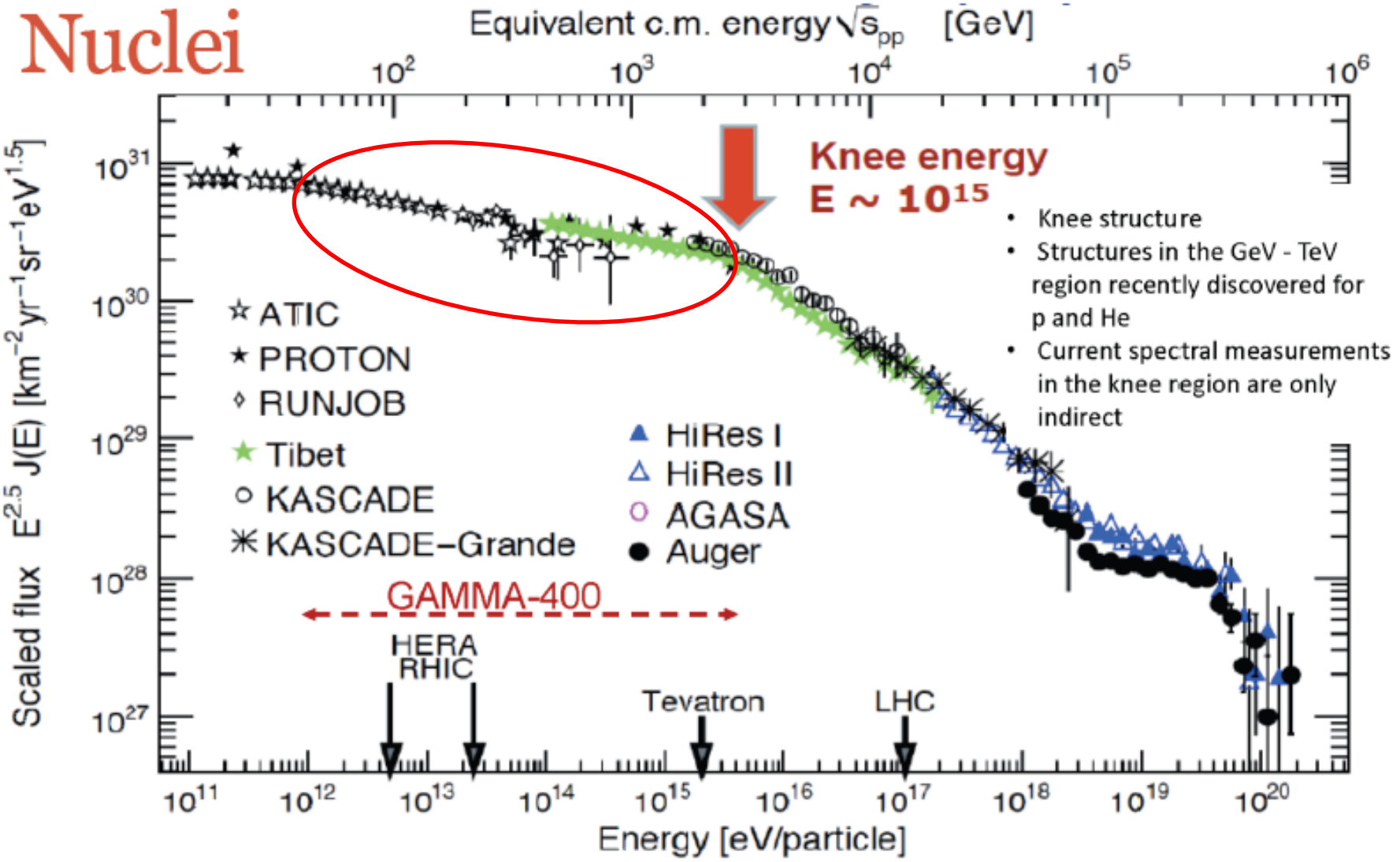
V. Dogiel and D. Chernyshev

Electron + positron spectrum
1 GeV – 10 TeV



Mattia Di Maduro et al., arXiv:1507.07001

Nuclei



- Knee structure
- Structures in the GeV - TeV region recently discovered for p and He
- Current spectral measurements in the knee region are only indirect

Conclusions

- **The GAMMA-400 mission represents a unique opportunity to perform simultaneous measurements of gamma rays, electrons, and nuclei with unprecedented accuracy. "The improvement in the accuracy will provide new insight" (Samuel 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" (Werner Hoffman).**
- **We hope that the GAMMA-400 space observatory will be launched in 2023-2025.**
- GAMMA-400 will provide in-depth investigations on some of the most challenging physics items, such as:
  - DM search for in high-energy gamma rays and electron + positron spectra;
  - CR origin, production and acceleration up to the highest energies.

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