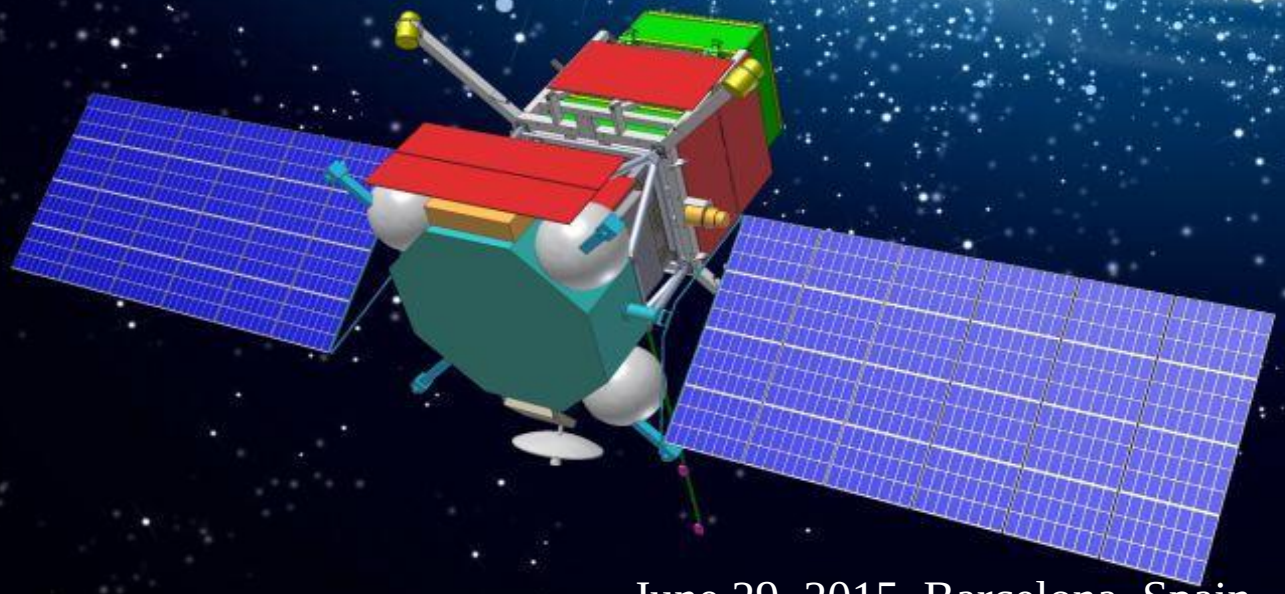
Russian Academy of Sciences
P.N.Lebedev Physical Institute
L P I

Nikolay Topchiev
for the GAMMA-400 Collaboration

Status of the GAMMA-400 project



June 29, 2015, Barcelona, Spain

GAMMA-400 Principal Investigator

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GAMMA-400 Deputy PI

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Dr. Valter Bonvicini
(INFN, Italy)

Dr. Yuriy Yurkin
(NRNU MEPhI, Russia)

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

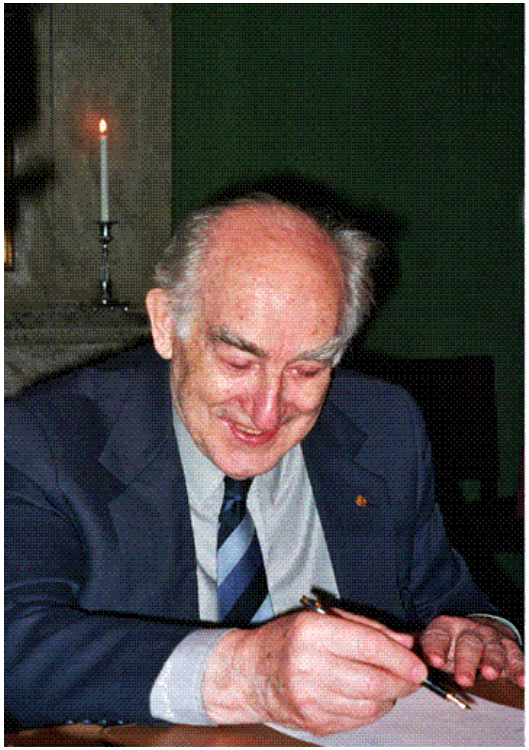
V. A. DOGIEL, M. I. FRADKIN, L. V. KURNOSOVA, L. A. RAZORENOV, M. A. RUSAKOVICH, and N. P. TOPCHIEV

This paper was appeared after operating the US gamma-ray telescope COS-B (1975-1982, $E_{\gamma max}$ = 5 GeV) and before operating the Russian GAMMA-1 (1990-1992, $E_{\gamma max}$ = 5 GeV) and US EGRET (1991-2000, $E_{\gamma max}$ = 30 GeV).

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 research works were funded by the Russian Space Agency (Roscosmos) since 2000 and design and development works only since 2009.

GAMMA-400 was included in the Russian FSP 2006-2015



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.

УТВЕРЖДАЮ

Директор

Учреждения Российской академии наук

Физического института

им. П.Н. Лебедева РАН

академик Месяц Г.А.

____ 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.

Title page of the GAMMA-400 proposal:

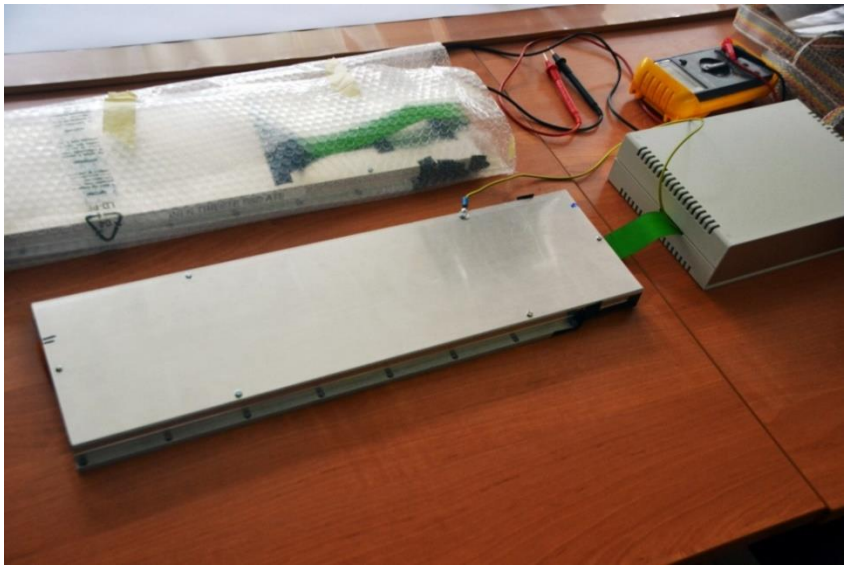
The GAMMA-400 project
Studying space gamma rays and electron + positron fluxes in the energy range of 1-3000 GeV

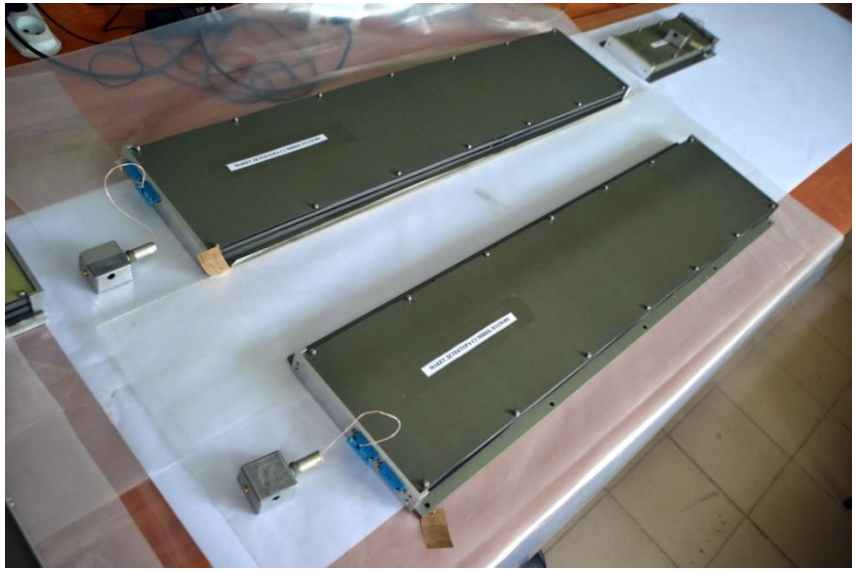
This proposal was signed in May, 2009 by GAMMA-400 PI, Prof. A. Galper, academician V. Ginzburg, and LPI head, academician G. Mesyats

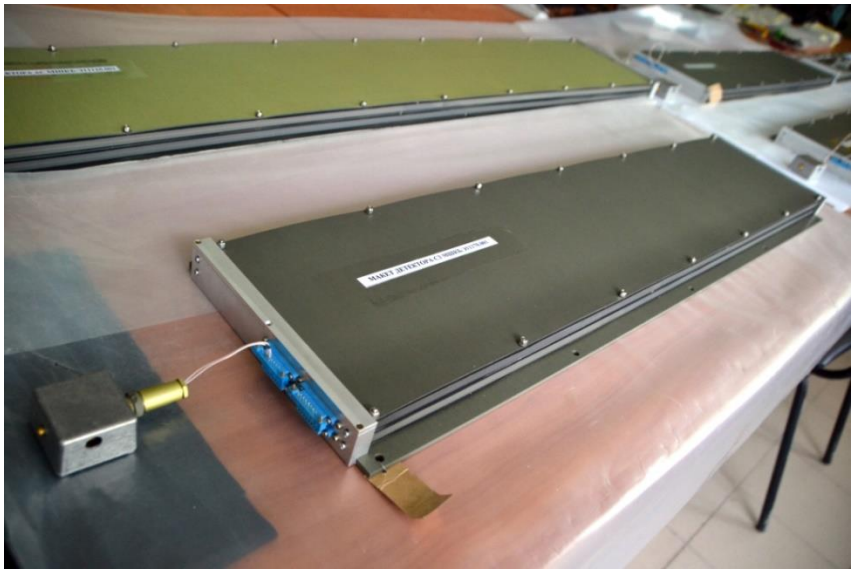
	Phase A (first stage) 2009-2010	**Phase A (second stage) 2011-2012**	**Phase A (third stage) 2013-2014**
Angular resolution (E_γ > 100 GeV)	0.2°	~0.01°	~0.01°
Energy resolution (E_γ > 10 GeV)	~ 3%	~1%	~1%
Energy range (γ)	30-1000 GeV	0.1-3000 GeV	0.1-3000 GeV
Sensitive area	0.44 m^2	0.64 m^2	1.0 m^2
Mass	1700 kg	2600 kg	4100 kg
Power consumption	800 W	2000 W	2000 W
Telemetry downlink volume	500 Mbytes/day	100 Gbytes/day	100 Gbytes/day
Particles	gamma rays, electrons + positrons, protons, nuclei	gamma rays, electrons + positrons, protons, nuclei	gamma rays, electrons + positrons, protons, nuclei

About the GAMMA-400 performance A. Leonov will talk in more detail

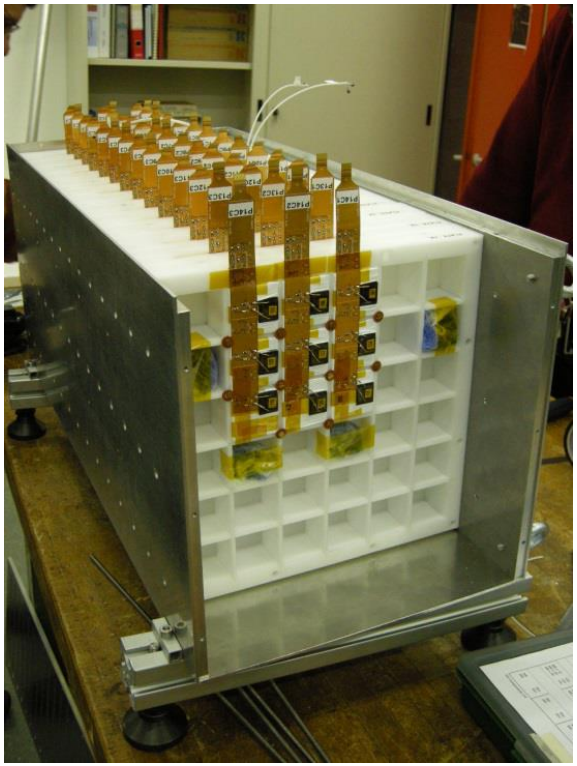
GAMMA-400 laboratory prototype - 1

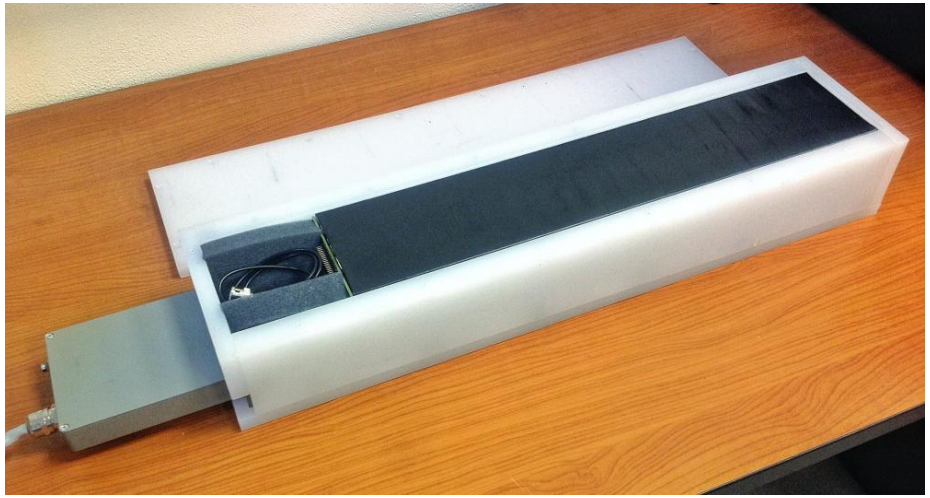




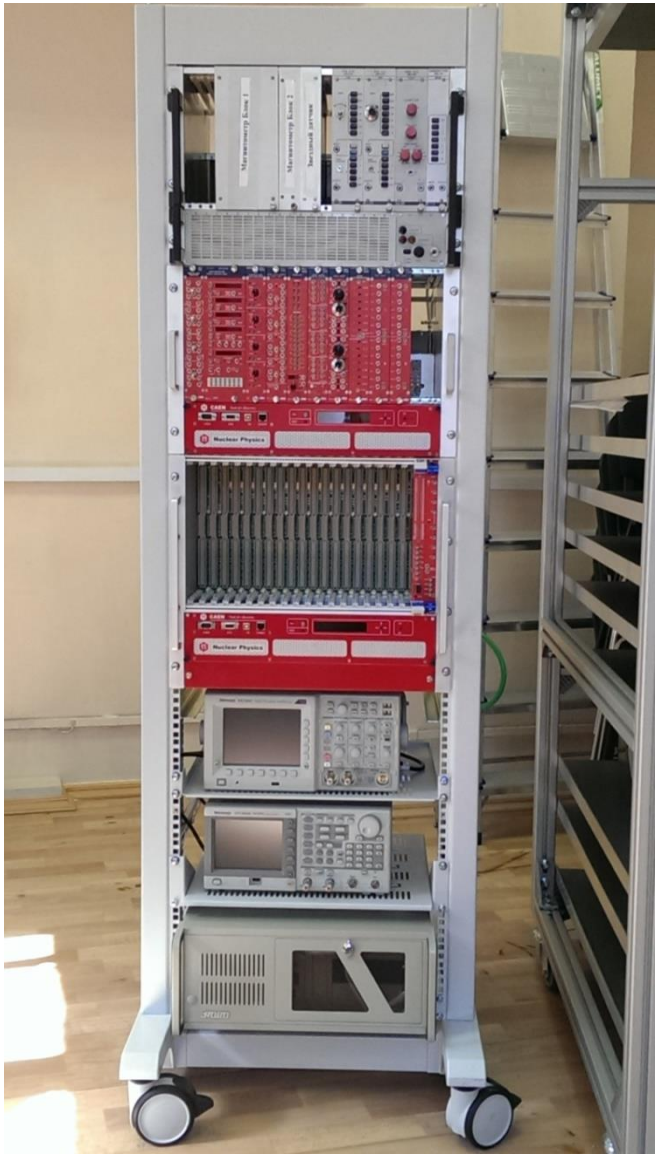


GAMMA-400 laboratory prototype - 2





GAMMA-400 laboratory prototype - 3



Electronic rack

Prototype rack

GAMMA-400 gamma-ray telescope physical scheme

Aperture ±60°

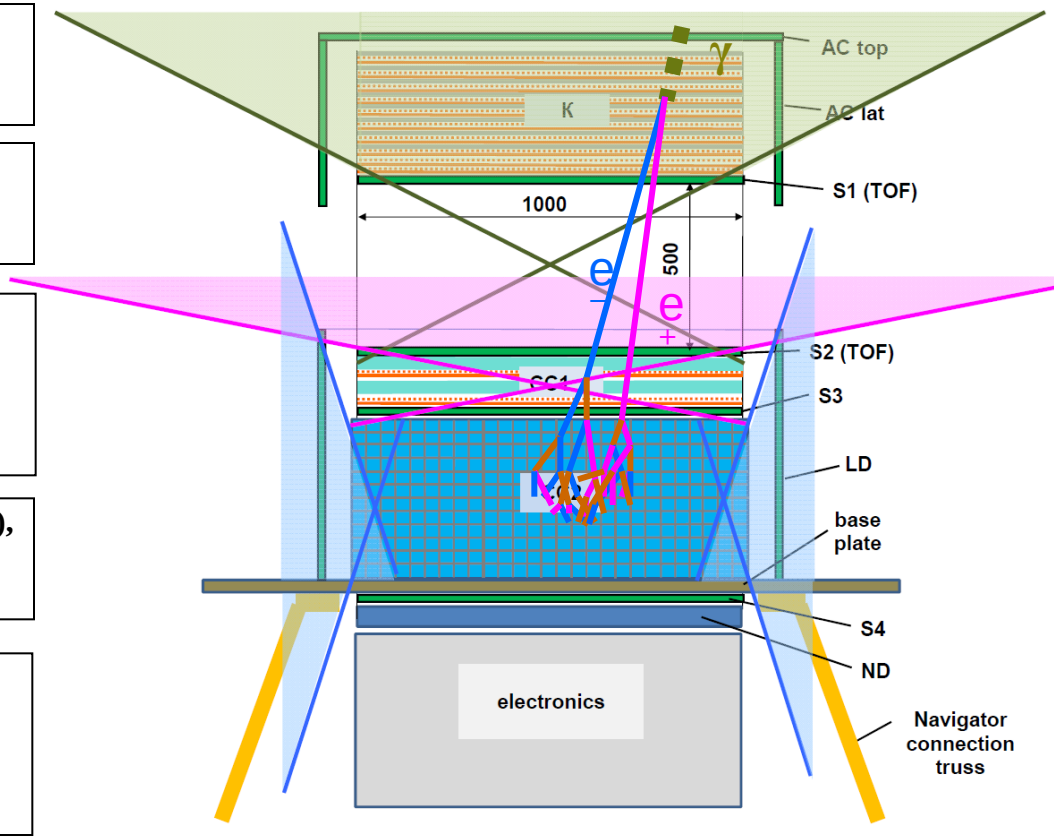
Anticoincedence system (AC), MEPhi

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), W+Si-strips INFN (Italy), (1 X_0)

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

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

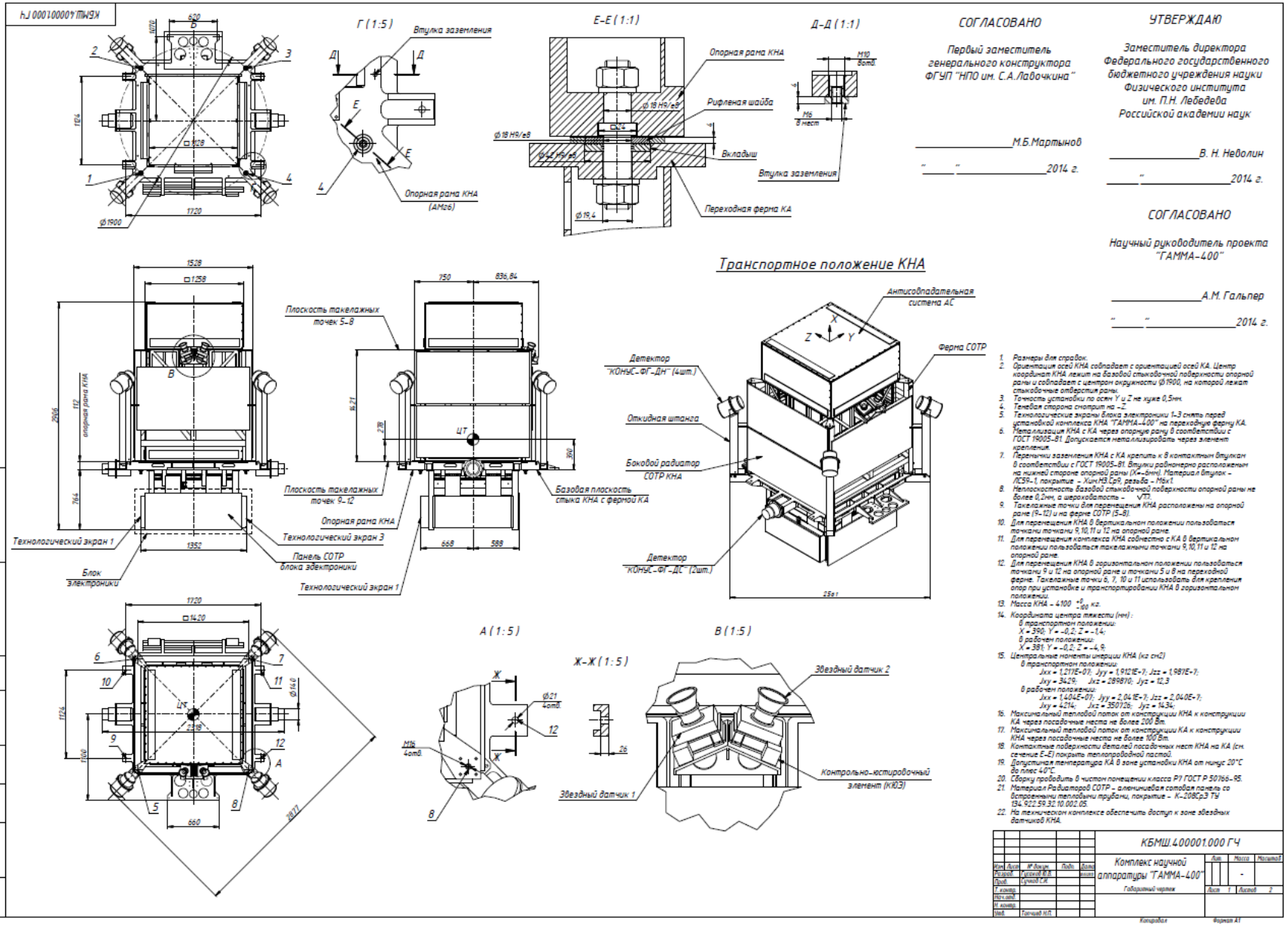
Neutron detector (ND), MEPhI

1 – gamma rays, electrons + positrons
X_0 =1(C)+ 25(CC), λ_0 = 1.2

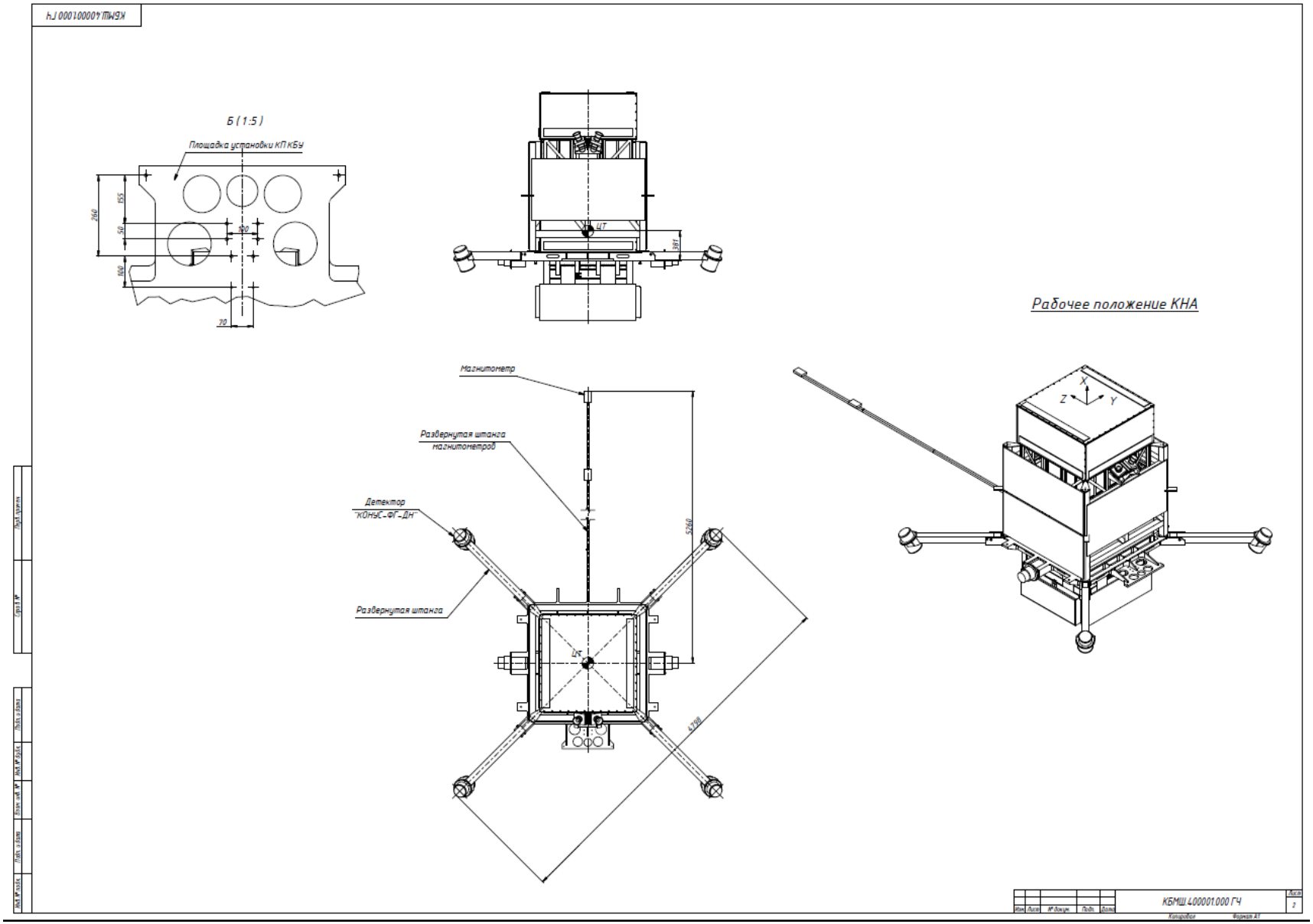
2 – diffuse gamma rays, electrons + positrons

3 - electrons + positrons, nuclei
X_0 =54, λ_0 = 2.5

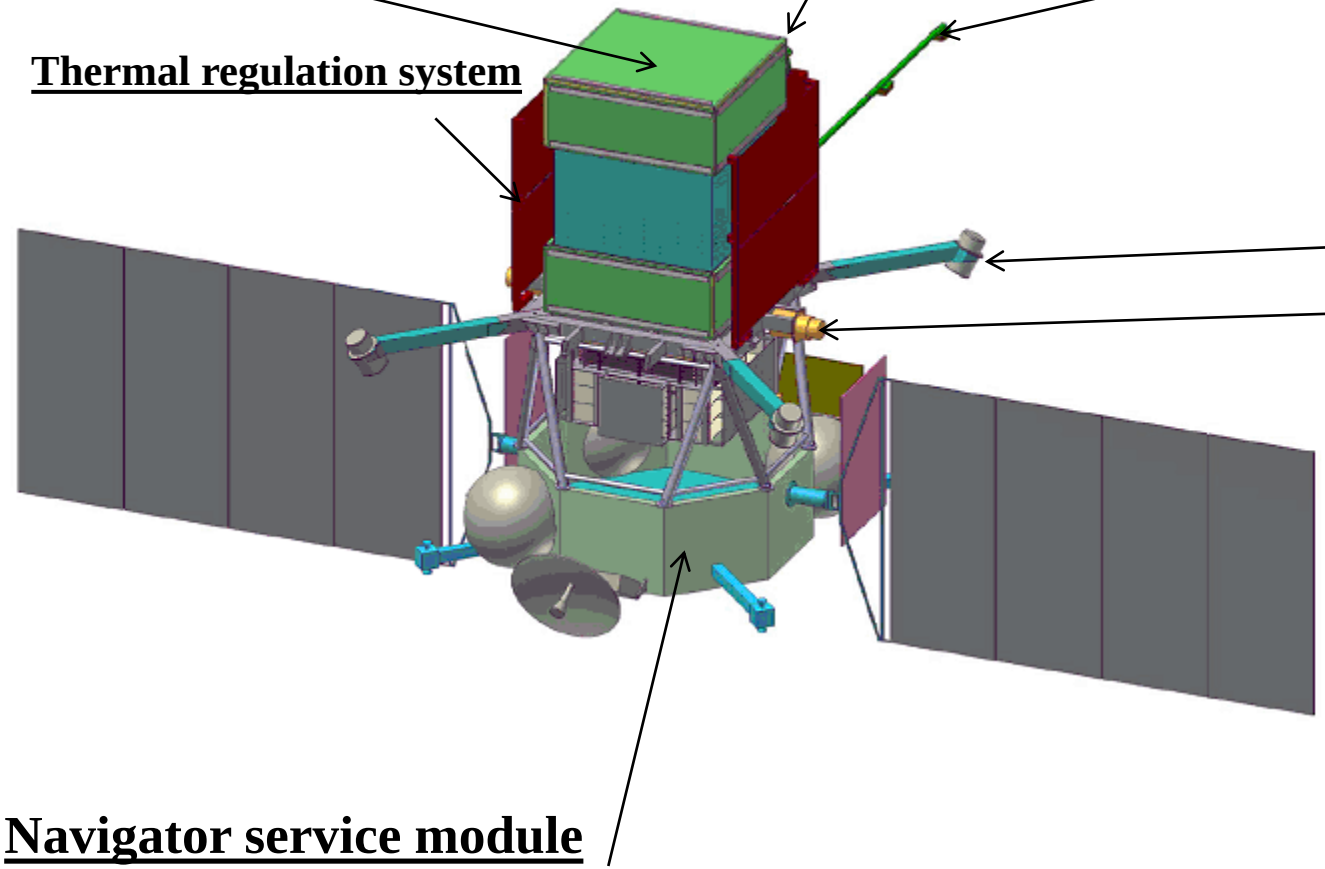
GAMMA-400 drawing - 1



GAMMA-400 drawing - 2



About the GAMMA-400 construction Yu. Gusakov will talk in more detail

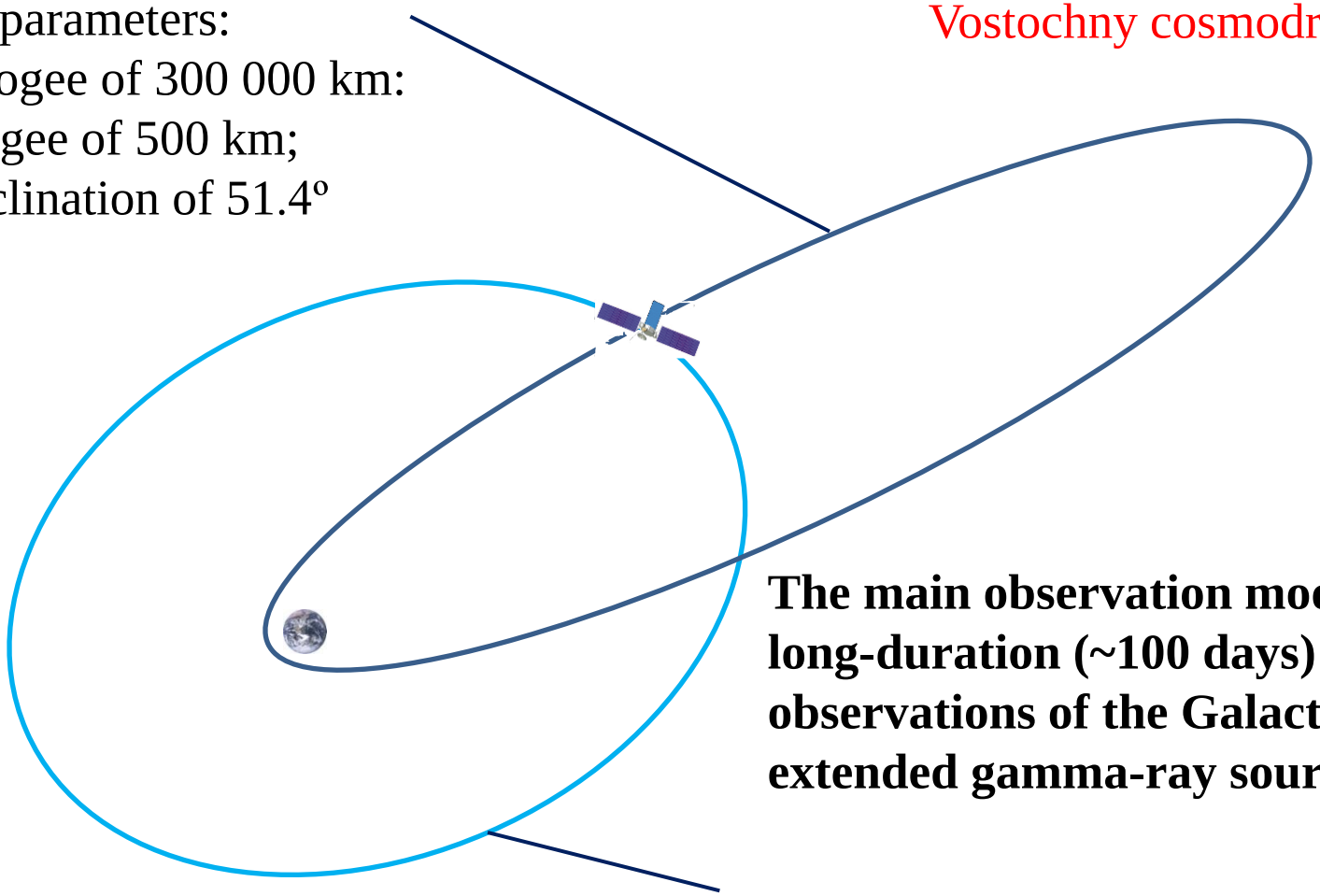


GAMMA-400 scientific complex on the Navigator service module

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

Angara launch vehicle
Vostochny cosmodrome



The main observation mode is 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 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	Survey (3 hours)	Point observation (up to 100 days)
Source exposition	1/7	1
Energy range	20 MeV - 300 GeV (γ, e)	100 MeV – 3 TeV (γ) 100 MeV – 20 TeV (e)
Effective area (E_γ > 1 GeV)	~6500 cm^2 (total) ~4000 cm^2 (front)	~4000 cm^2
Coordinate detectors	Si strips (pitch 0.23 mm)	Si strips (pitch 0.08 mm)
Angular resolution	~0.2° (E_γ = 10 GeV) ~0.1° (E_γ > 100 GeV)	~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	~10^4	~$5x10^5$
Mass	2800 kg	4100 kg
Telemetry downlink volume, Gbytes/day	15 Gbytes/day	100 Gbytes/day

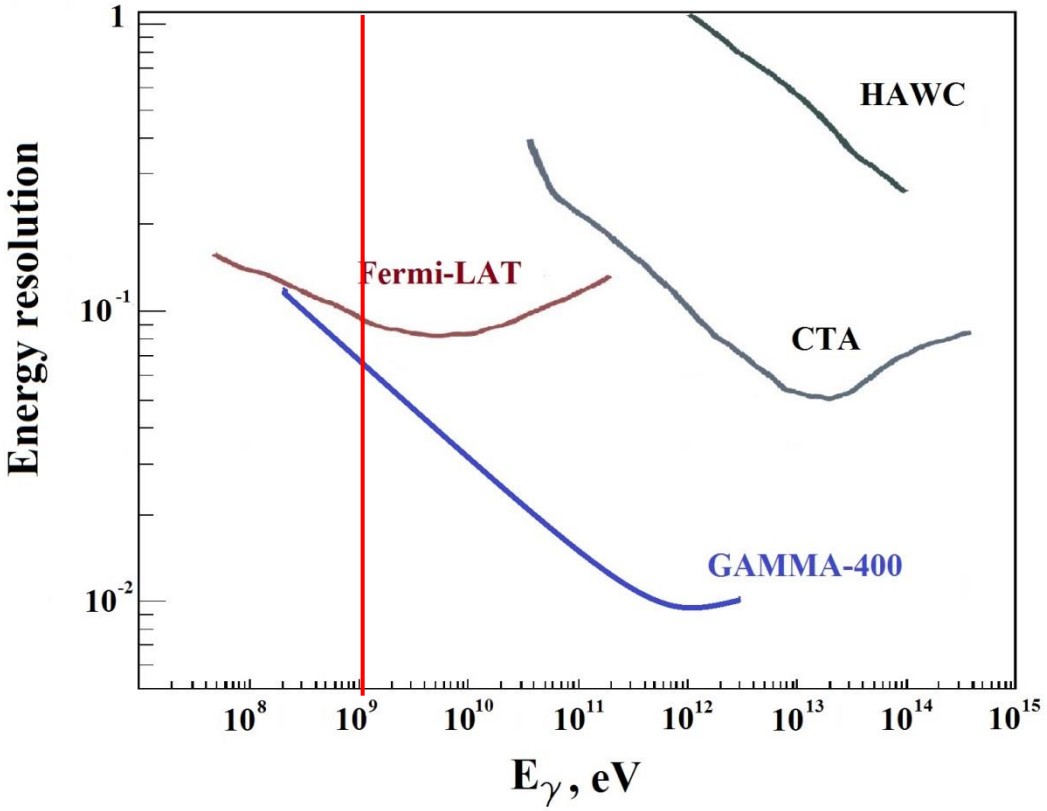
About the new upgrade of GAMMA-400 for LE V. Bonvicini will talk in more detail

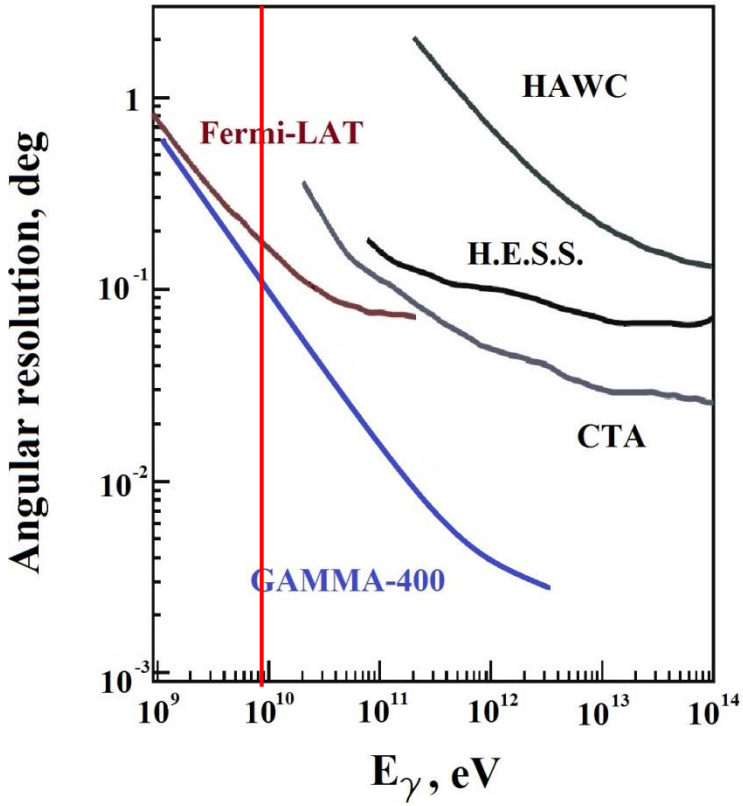
About the GAMMA-400 and Fermi-LAT comparison S. Suchkov will talk in more detail

COMPARISON OF MAIN PARAMETERS OF OPERATED, CURRENT, AND PLANNED SPACE-BASED AND GROUND-BASED INSTRUMENTS

	SPACE-BASED INSTRUMENTS					GROUND-BASED GAMMA-RAY FACILITIES			
	EGRET	**AGILE**	**Fermi-LAT**	**CALET**	**GAMMA-400**	**H.E.S.S.-II**	**MAGIC**	**VERITAS**	**CTA**
Operation period	1991-2000	2007-	2008-	2015	~2023	2012-	2009-	2007-	~2020
Energy range, GeV	0.03-30	0.03-50	0.02-300	10-10000	**0.1-3000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.2º (E_γ~0.5 GeV)	0.1º (E_γ~1 GeV)	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)	15% (E_γ~0.5 GeV)	50% (E_γ~1 GeV)	10%	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



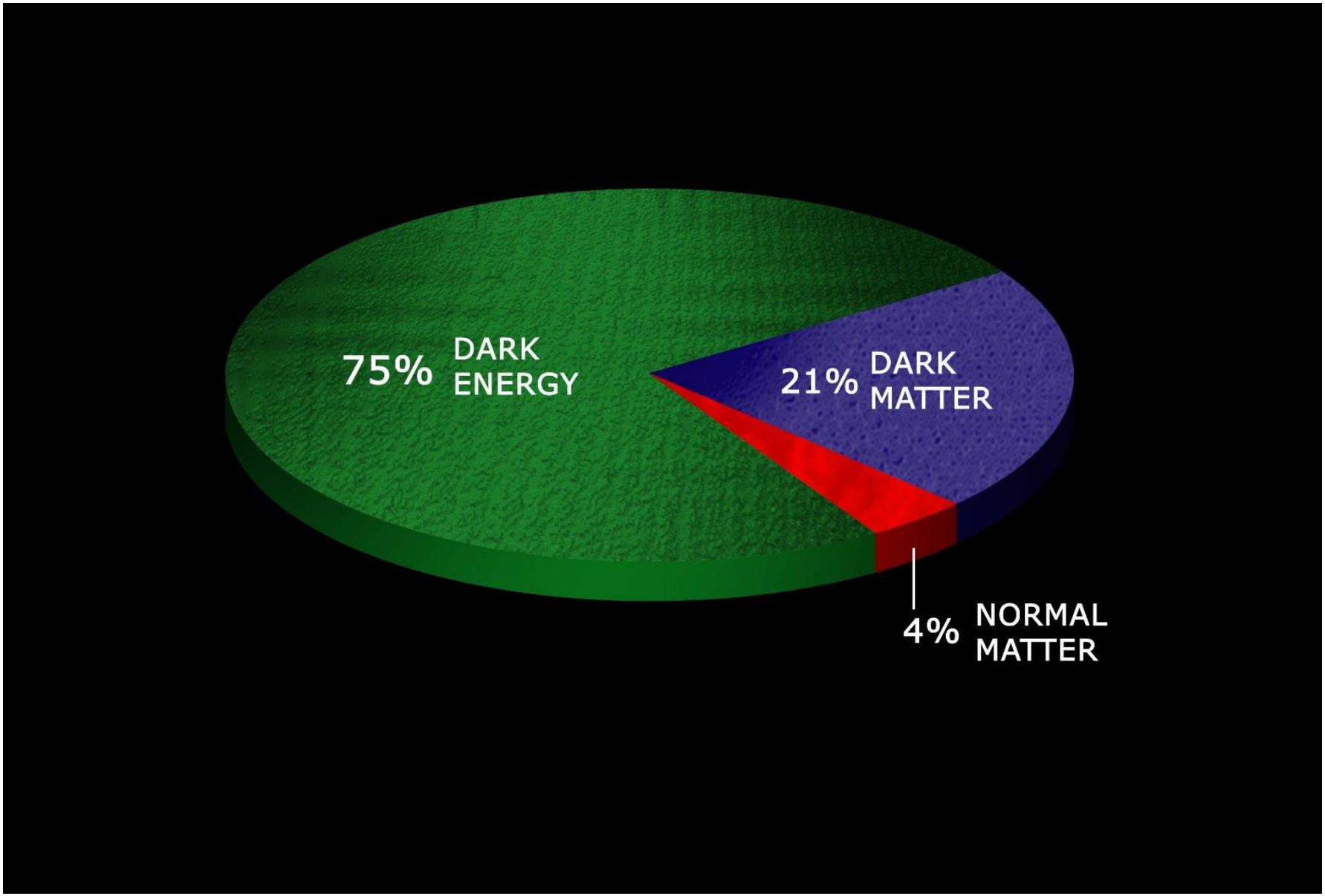


S. Funk , et. for the CTA Consortium, Astroparticle Phys.,2013, 43, 348

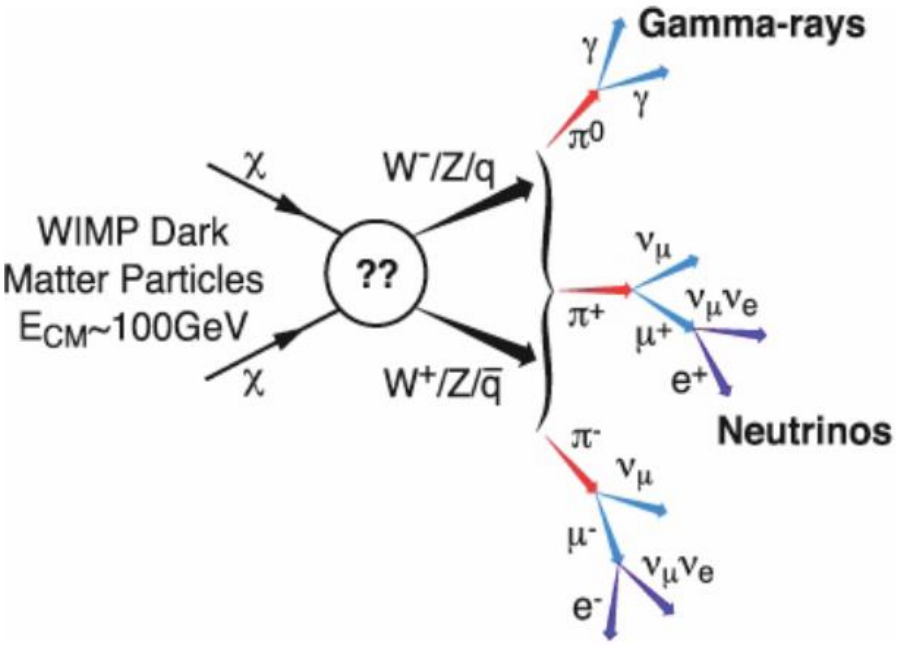
GAMMA-400 SCIENTIFIC GOALS

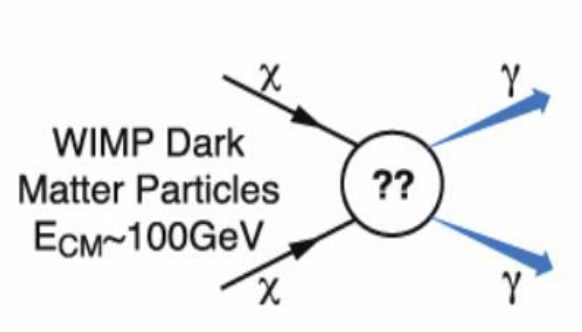
The GAMMA-400 main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise measurements of Galactic Center, Crab, Vela, Cygnus, Geminga, and other regions, extended and point gamma-ray sources, diffuse gamma rays; measuring high energy electron + positron fluxes; measuring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

Dark matter searches



Gamma Production





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

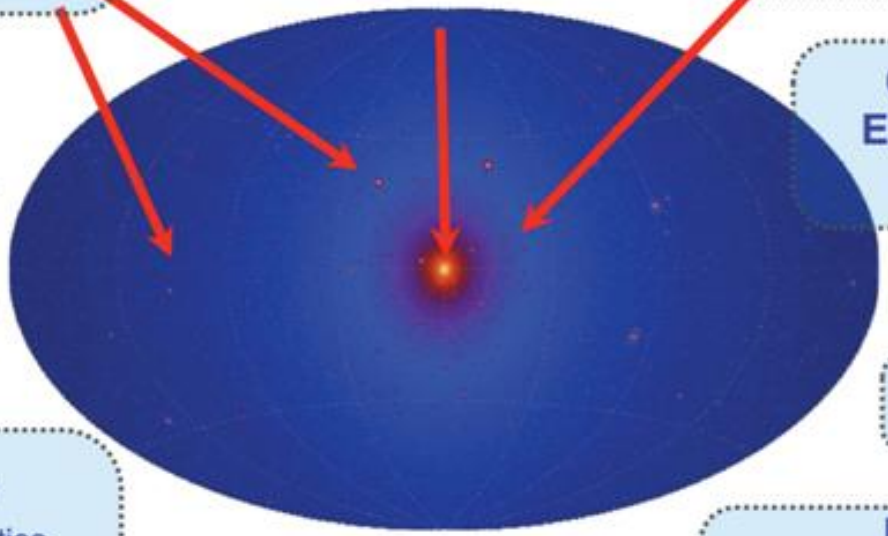
GAMMA-400 will conduct the search in the phase space of γ-rays with E > ~1 GeV and electron + positron spectrum above ~10 GeV.

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



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

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

Cosmic-ray Electrons and Positrons

The Sun

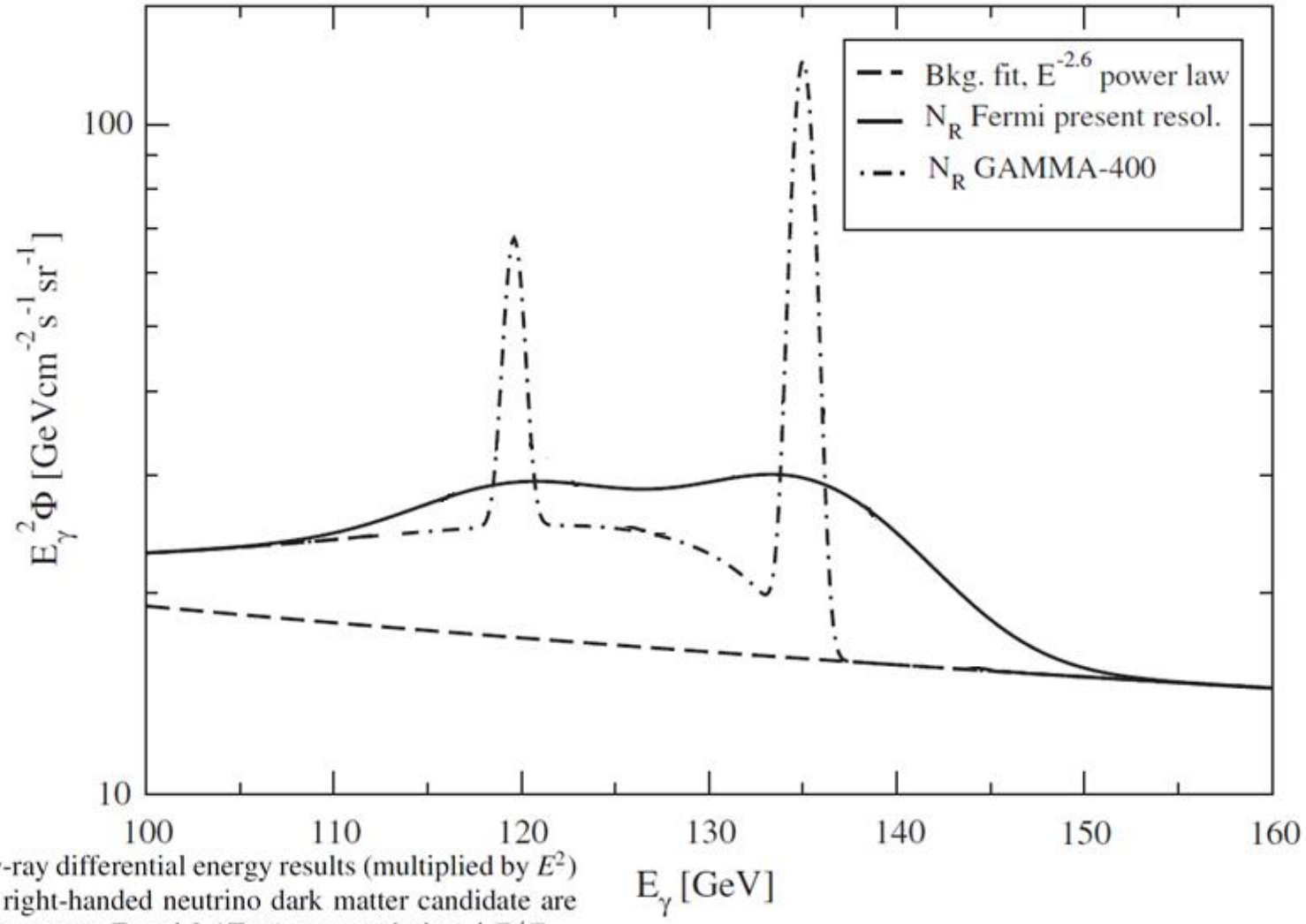
Spectral Lines
No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

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)

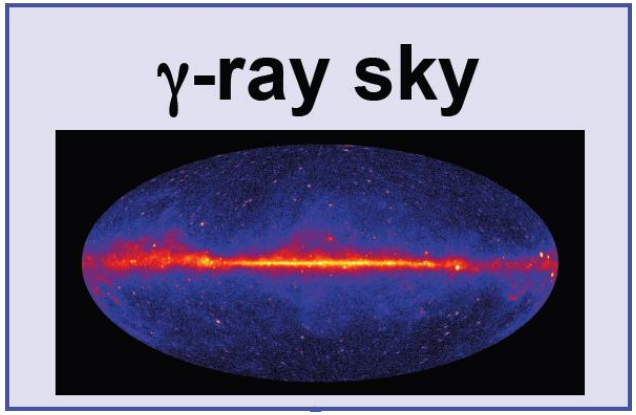
and with a future γ-ray instrument, such as GAMMA-400 [38] (dash-dotted line) with resolution at the one percent level. The extrapolated power-law $\sim E^{-2.6}$ of the presently measured continuous γ-ray background is also shown.

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

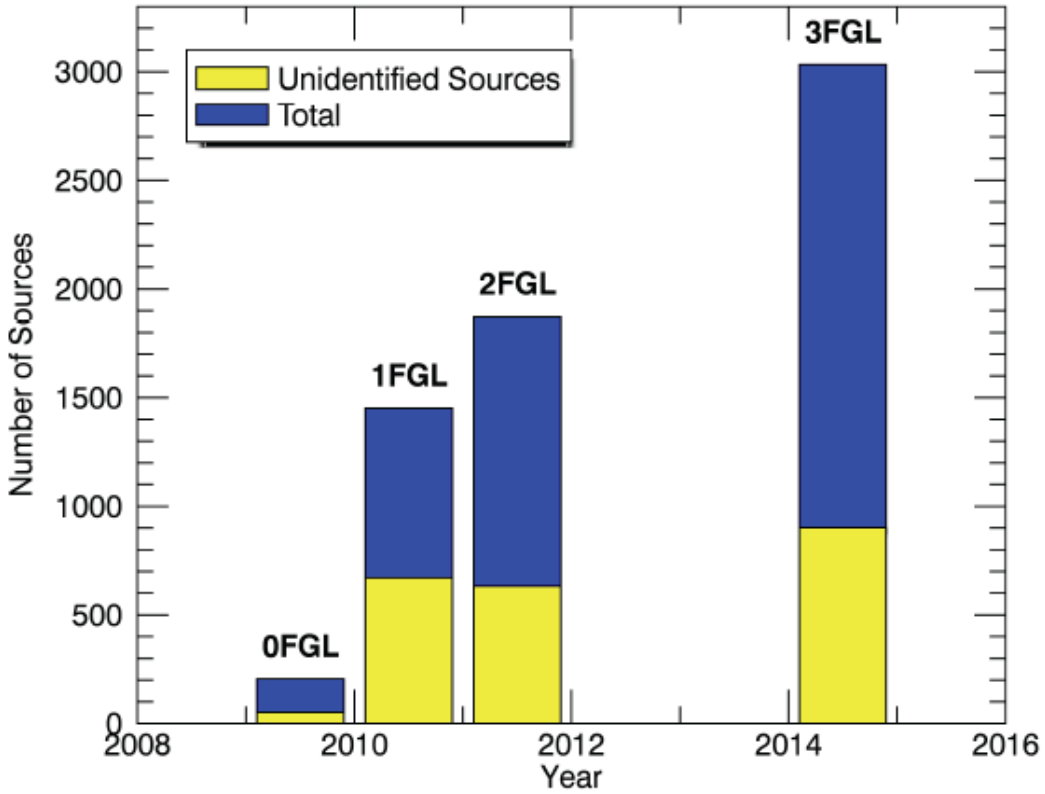
130 GeV fingerprint of right-handed neutrino dark matter

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	



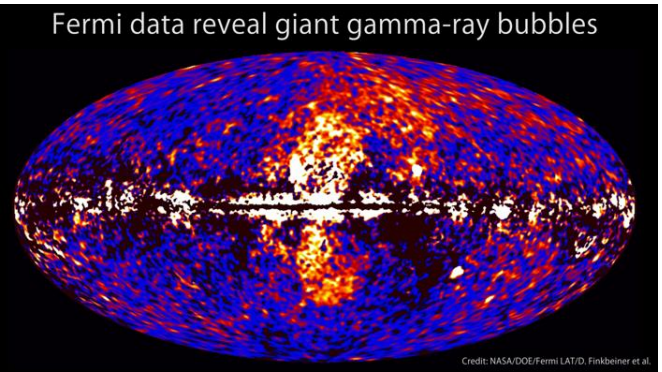
50 GeV – 2 TeV

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/

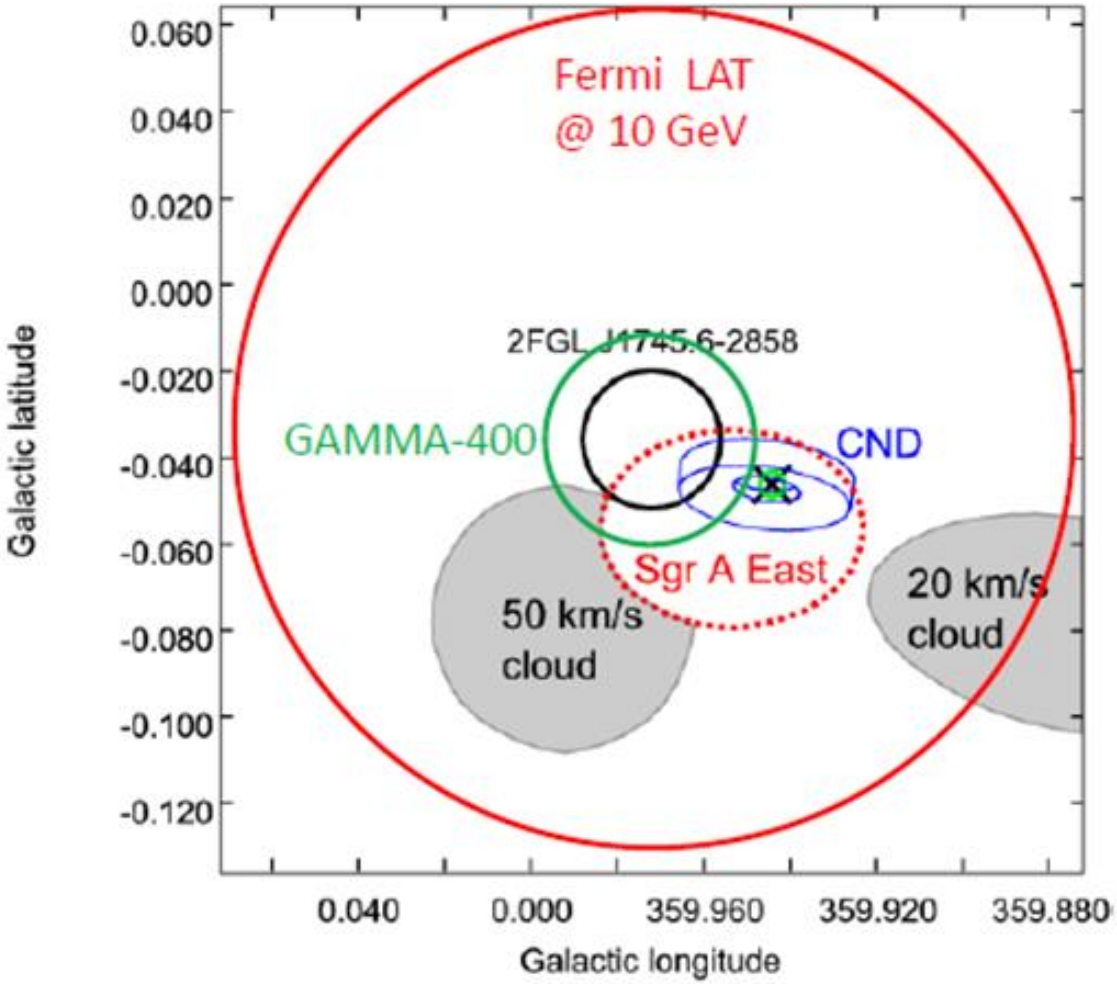
Estimate of the number of gammas, which will be detected by GAMMA-400 when observing the Galactic center using the fluxes from 3FGL (Effective area = 4000 cm^2, T_{obs} = 1 year)

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 Centre	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**

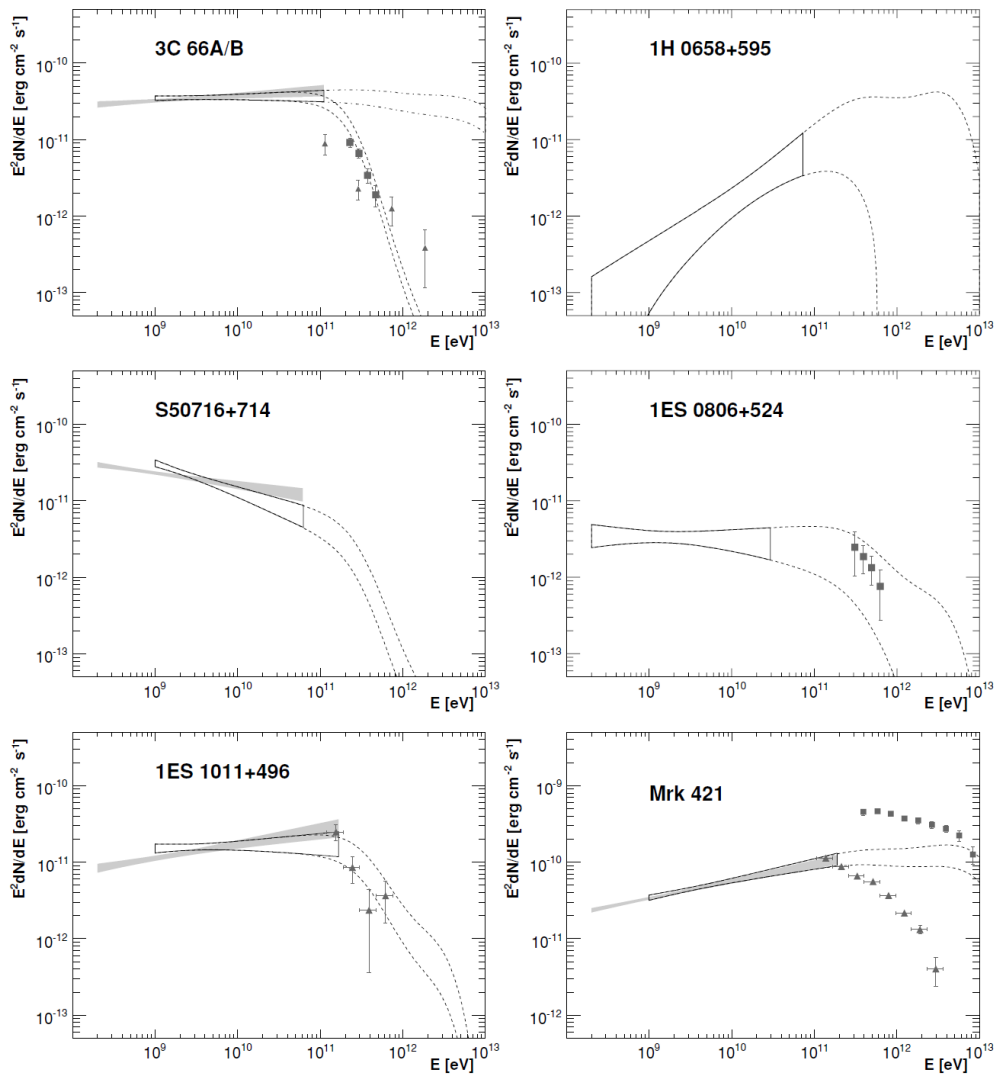


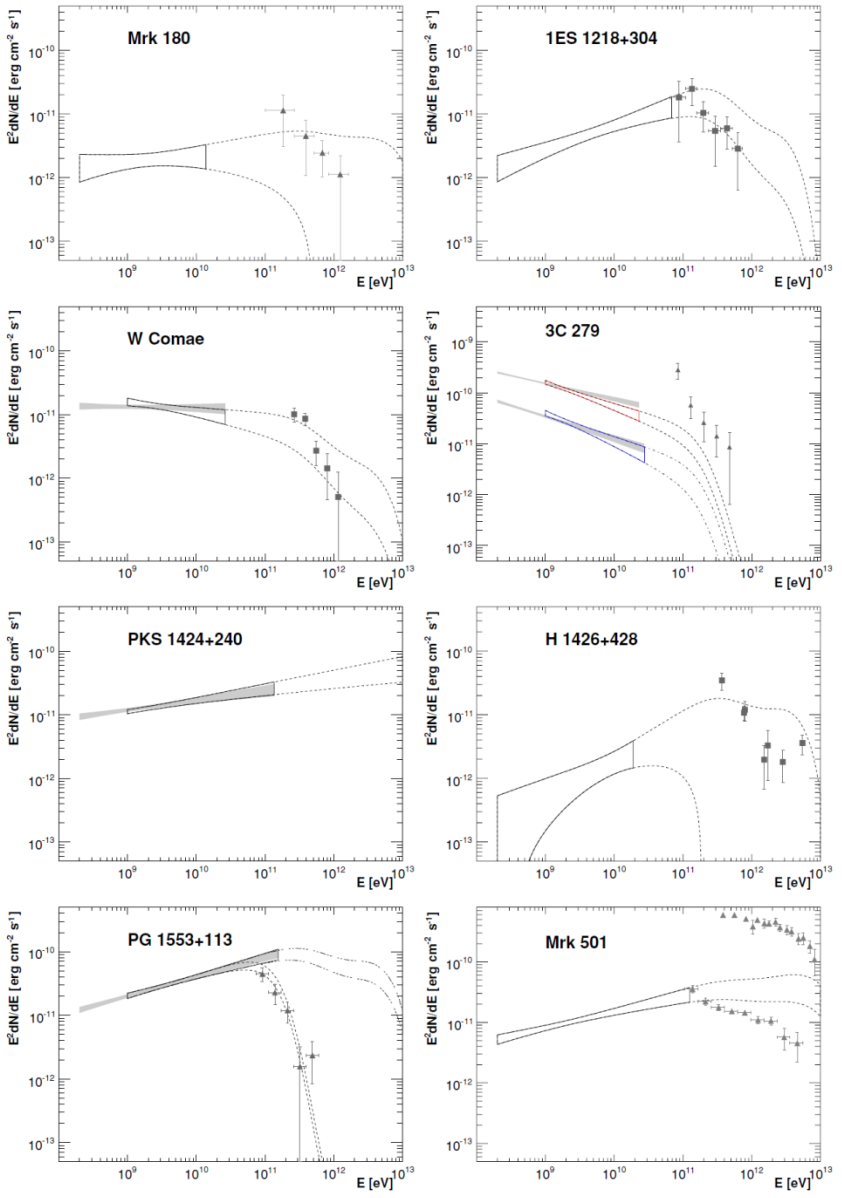
Moreover, Crab, Cygnus, Vela, Geminga, and other regions will be observed

J 1745.6-2858



V. Dogiel and D. Chernyshev





A. Abdo et al. AJ, 2009, 707, 1310.

Figure 2. (Continued)

Figure 2. Spectra for the 21 GeV–TeV detected objects. The GeV spectrum derived from *Fermi*-LAT observations is indicated as a "butterfly" contour (solid line). For brighter sources (those in Table 6), the contours correspond to the high-energy band ($E > 1$ GeV), with the fits over the full energy range shown as gray bands. For the weaker sources, only the fits over the full range (given in Table 5) are shown. TeV spectral measurements published by H.E.S.S. (circles), VERITAS/Whipple (squares) and MAGIC (triangles) are also shown. An extrapolation of the *Fermi* spectrum to the TeV regime is shown (dashed line), assuming absorption with the EBL as described in the text. In the panel for the 3C 66A/B region, the extrapolation is shown for $z = 0.444$ (3C 66A – dashed line) and $z = 0.021$ (3C 66B – dash-dotted line). In the case of PG 1553+113 extrapolations with $z = 0.78$ (dashed line) and $z = 0.09$ (dash-dotted line) are shown.

June 27, 2015
Dear Prof. Galper,
Dear Nikolay Topchiev,

One of our worries in terms of maximising the science output of CTA is the coverage of the GeV domain - that is crucial for interpretation of sources - after the termination of Fermi. Obviously, Gamma-400 is very well suited to fill that gap, and joint observations or joint projects seem very natural.
We are currently slightly reorganising our science groups, and one essential element of CTA science planning in the next years will be to set up relations with other instruments aiming to coordinate multiwavelength observations, ultimately with the goal to aim for MoUs where appropriate. We are certainly be very happy to interact with your team on this (our yet-to-be appointed new science coordinator would be the prime contact).

With best regards,
Werner Hofmann
CTA Spokesperson

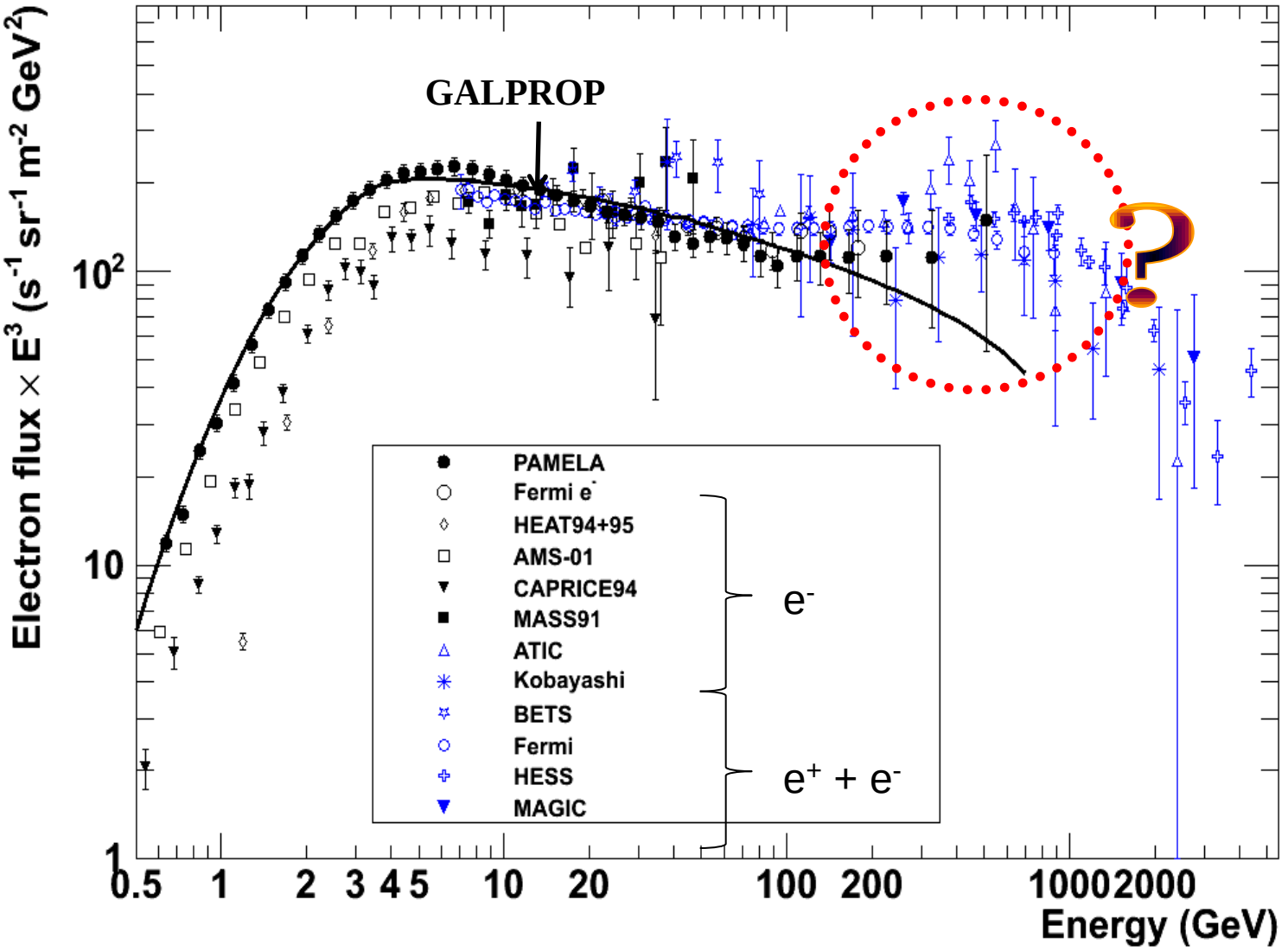
GAMMA-400 will deliver a gamma-ray line sensitivity that is better than the current HESS-II limits at energies below ~500 GeV. **CTA will of course further improve on that at higher energies, but I think GAMMA-400 will be the best instrument in the energy range ~10 - ~100 GeV, even after CTA.** However, the CTA collaboration has not shown detailed results for line sensitivities yet (I have seen some preliminary plots, but they looked somewhat too optimistic), so take that with a grain of salt (October, 2014)

Dr. Christoph Weniger
GRAPPA, University of Amsterdam
Science Park 904, C4.171
1098XH Amsterdam, NL

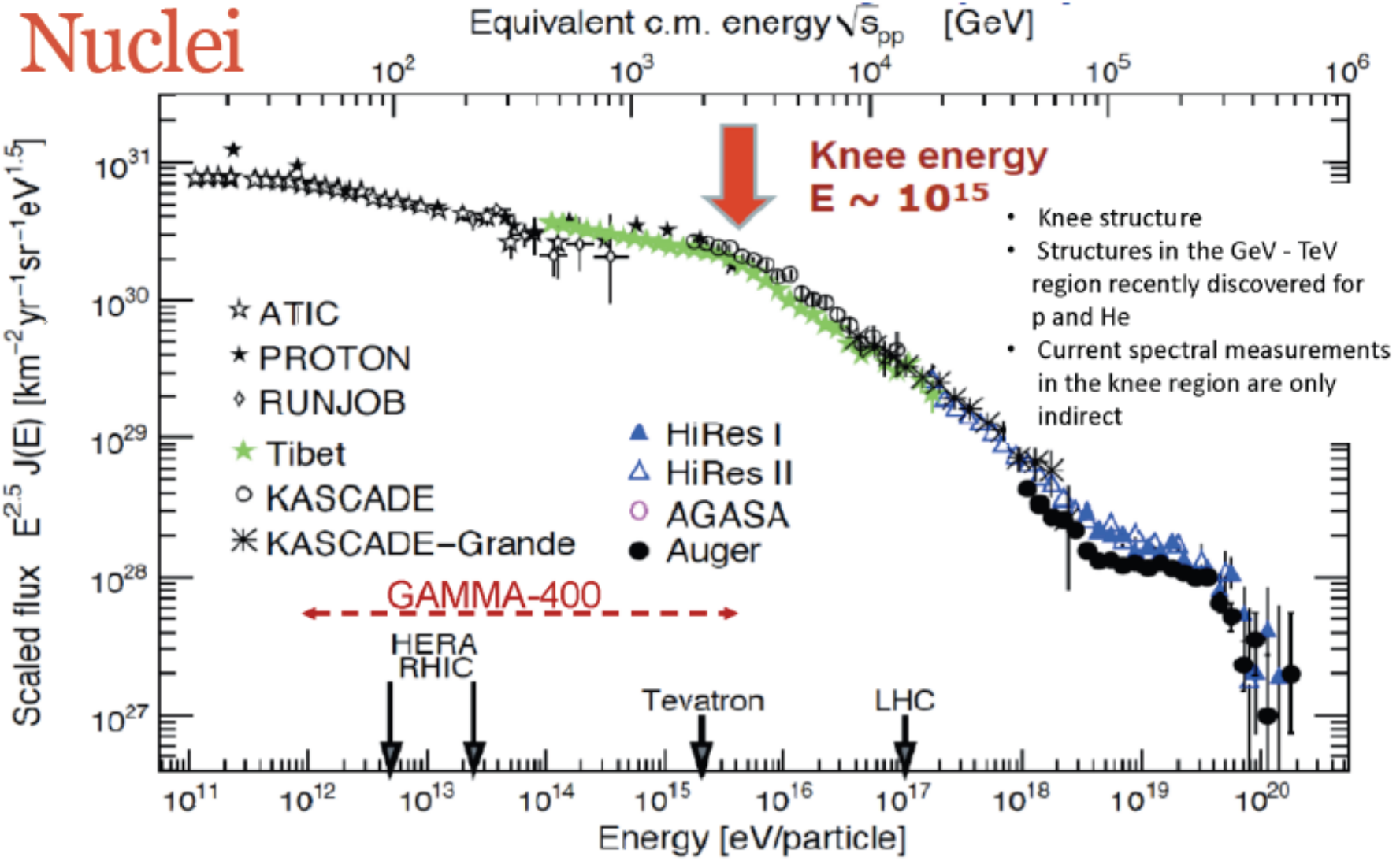
The sensitivity and the angular resolution achievable by the Silicon detectors' analog readout will be very good. At 100 MeV, we can estimate an effective area near 1500-2000 cm^2, and a 68% containment radius near 3 degrees. **This expected performance, already realized in the AGILE instrument, will ensure a competitive sensitivity compared to Fermi-LAT, especially for prolonged (weeks, months) pointings. I find the opportunities of GAMMA-400 for gamma-ray detection very important in the context of the high-energy astrophysics of the next decade.**

Prof. Marco Tavani, PI AGILE
Istituto Nazionale di Astrofisica – IASF and Physics Department of University of Rome "Tor Vergata",
Via della Ricerca Scientifica 1,
I-00133 Rome, Italy

Electron Spectrum



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

Status of GAMMA-400 in Russia and Italy

- At nearest time, “Letter of Intent” between the Russian and Italian Space Agencies on the cooperation in the GAMMA-400 mission will be signed,
- as well as the official Agreement between Lebedev Physical Institute and INFN.

LETTER OF INTENT

BETWEEN

THE ITALIAN SPACE AGENCY (ASI)

AND

THE FEDERAL SPACE AGENCY (ROSCOSMOS)

ON COOPERATION IN

THE GAMMA-400 MISSION

1. The purpose of this Letter of Intent is to support the involvement of INFN in the GAMMA 400 mission.
2. INFN, under the coordinating role of ROSCOSMOS in the GAMMA 400 mission, will plane to provide to LPI RAS the system of silicon tungsten tracker and will contribute to the project in scientific, technological and economic terms.
3. The specific role and responsibilities of INFN will be spelled out in a separate document between INFN and LPI RAS.
4. ASI and ROSCOSMOS agree that this LOI does not entail any exchange of funds between the Parties;
5. ASI and ROSCOSMOS agree to keep each other informed on the pursuing of the cooperation activities in the GAMMA 400 mission between the respective Russian and Italian research institutions.

For ROSCOSMOS
I. Komarov

For ASI
R. Battiston

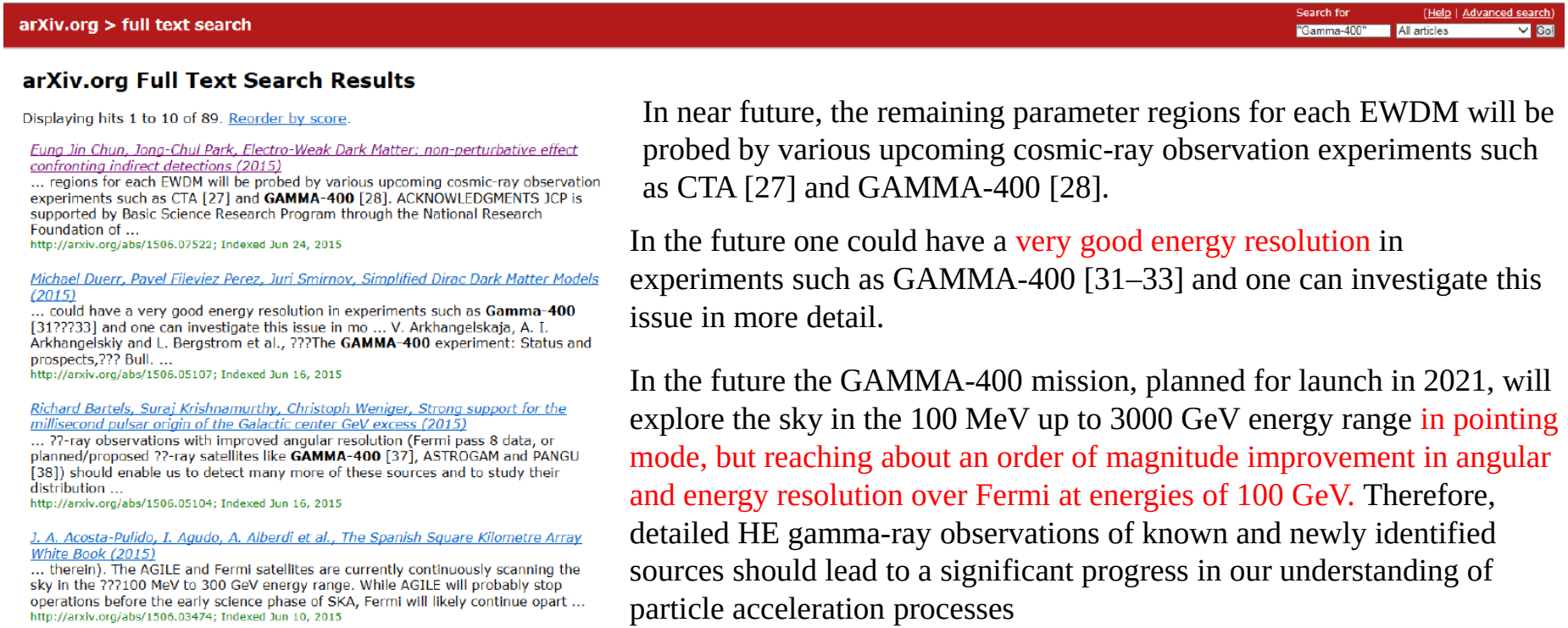
Project

Agreement
of Scientific Cooperation
between
the Lebedev Physical Institute of the Russian Academy of Sciences (LPI) and the Istituto Nazionale di Fisica Nucleare (INFN)

Appendix 1

to the Agreement between LPI and INFN

Design and manufacturing of converter-tracker and strip part of imaging calorimeter CC1 for the GAMMA-400 gamma-ray telescope



In near future, the remaining parameter regions for each EWDM will be probed by various upcoming cosmic-ray observation experiments such as CTA [27] and GAMMA-400 [28].

In the future one could have a very good energy resolution in experiments such as GAMMA-400 [31–33] and one can investigate this issue in more detail.

In the future the GAMMA-400 mission, planned for launch in 2021, will explore the sky in the 100 MeV up to 3000 GeV energy range in pointing mode, but reaching about an order of magnitude improvement in angular and energy resolution over Fermi at energies of 100 GeV. Therefore, detailed HE gamma-ray observations of known and newly identified sources should lead to a significant progress in our understanding of particle acceleration processes

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

Conclusion

- The GAMMA-400 mission represents a unique opportunity to perform simultaneous measurements of gamma rays, electrons, and nuclei with unprecedented accuracy. The GAMMA-400 space observatory is scheduled to launch in about 2023-2025.
- GAMMA-400 will provide in-depth investigations on some of the most challenging physics items, such as:
  - DM search for γ and high-energy electron spectra;
  - CR origin, production and acceleration to the highest energies.