Russian Academy of Sciences

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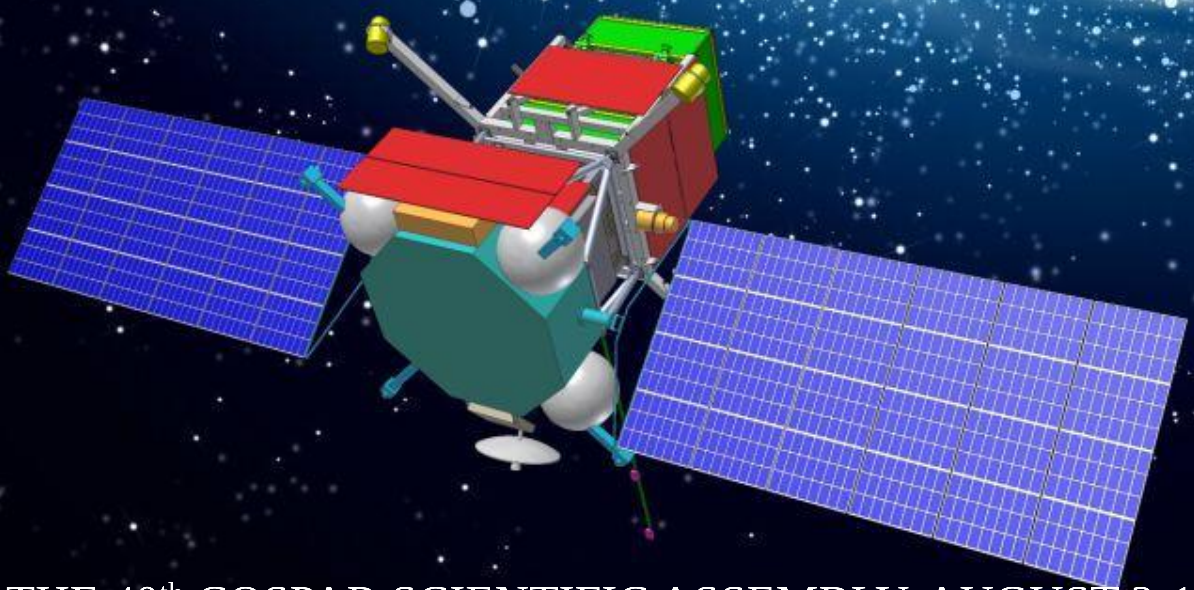
L P I

COSMOS

New generation high-energy space observatory GAMMA-400

Nikolay Topchiev

for the GAMMA-400 Collaboration



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GAMMA-400 TEAM

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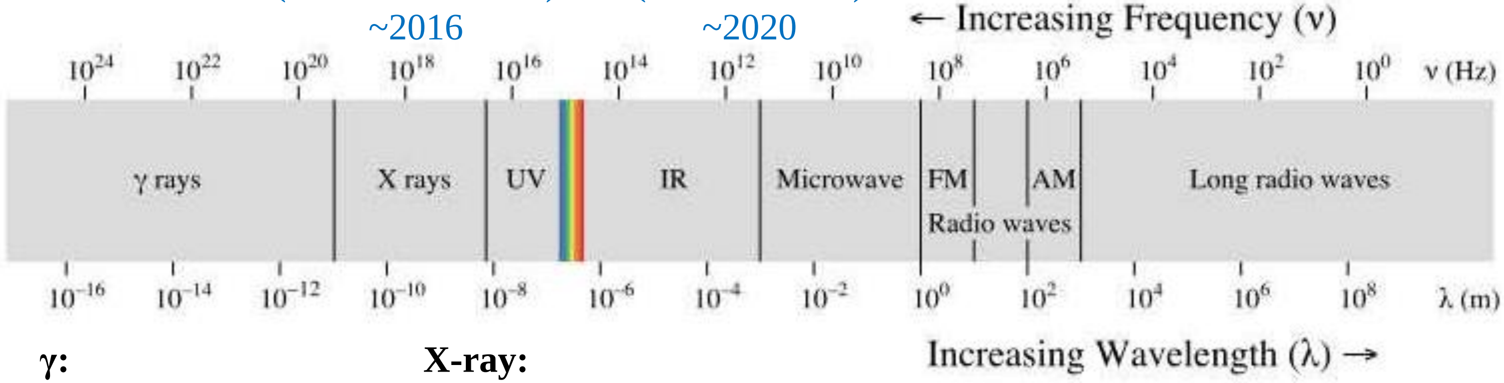
Russian Space Missions for Fundamental Physics in the different EM ranges

GAMMA-400
(100 MeV – 3000 GeV)
~2021

WSO-UV
(100 – 320 nm)
~2019

Spektr-RG
(0.3 keV – 3 MeV)
~2016

Spektr-M
(0.02 – 20 mm)
~2020



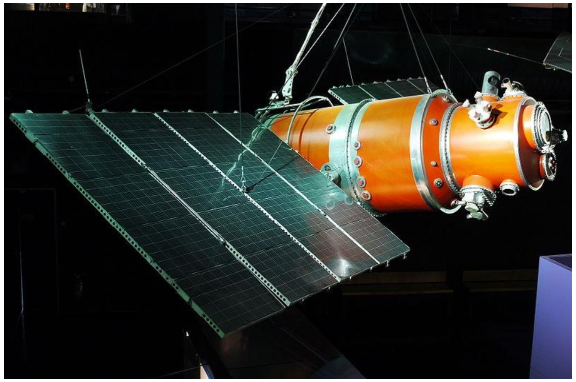
γ:
Anna-3 (1968, 1969)
GAMMA-1 (1990-1992)
CORONAS-PHOTON (2009)
etc.

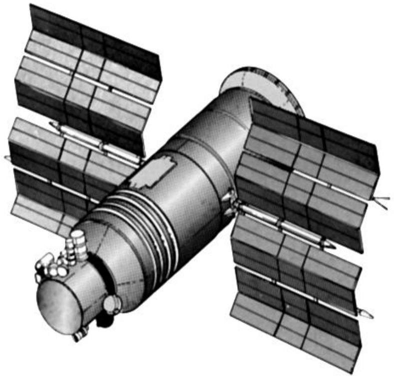
X-ray:
Astron (1983-1989)
GRANAT (1983-1989)
KVANT-1 (1987-2001)
etc.

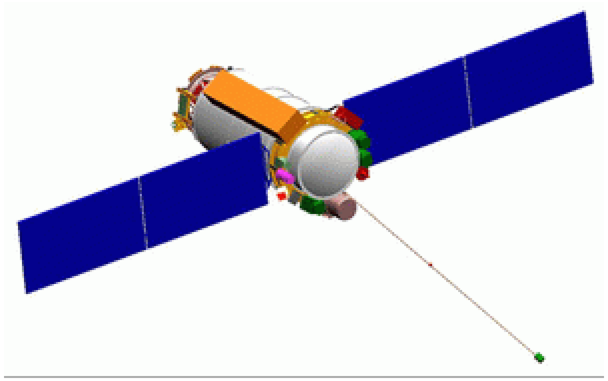
INTEGRAL
(15 keV – 10 MeV)
2002

RadioAstron
(1 – 100 cm)
2011

Russian Space Missions with gamma-ray telescopes







Anna-3 (USSR)
(Kosmos - 251, 264)
1968, 1969
200 MeV – 1 GeV

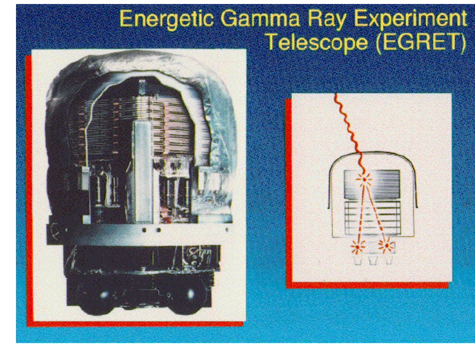
GAMMA-1
(USSR)
1990 – 1992
30 MeV – 5 GeV

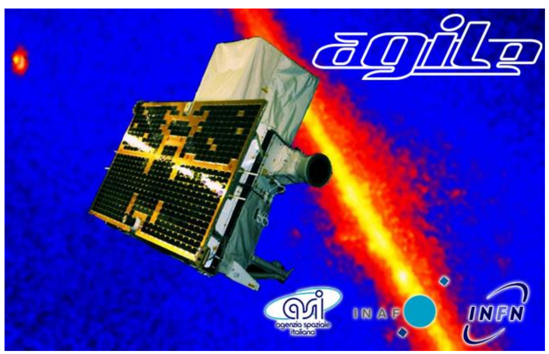
CORONAS-PHOTON
(Russia)
2009
300 MeV – 2 GeV

International Space Missions with gamma-ray telescopes

COS-B (USA)
1975-1982
30 MeV – 5 GeV

EGRET (USA)
1991- 1998
30 МэВ - 30 ГэВ





AGILE (Italy)
2007
100 MeV – 50 GeV

FERMI (USA)
2008
20 MeV – 300 GeV

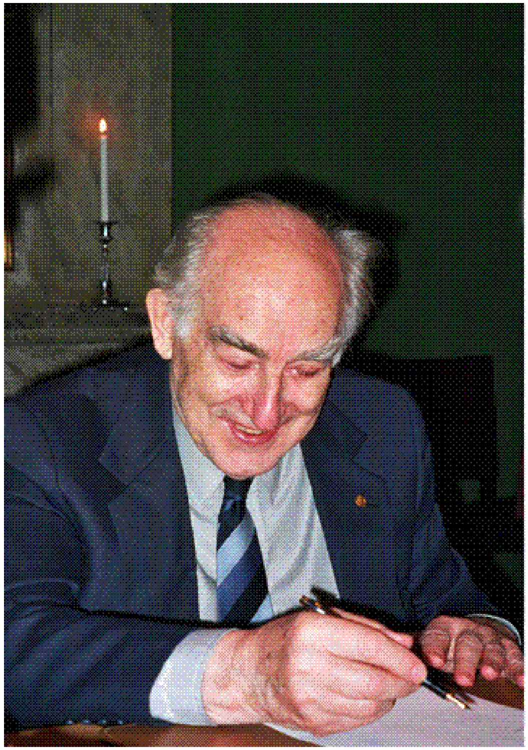
Some historical remarks on GAMMA-400

First ideas and first publications were presented in:
1987 on Moscow 20th ICRC
1988 in Space Science Reviews, 49, 215

After operation of the US gamma-ray telescope COS-B (1975-1982, $E_{\gamma max}$ = 5 GeV) and before operation of 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 funded by Roscosmos began in 2000 and design and development works began only in 2009.



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 astronomy methods. Since 2009, professor Arkadiy Galper is the GAMMA-400 Principal Investigator.

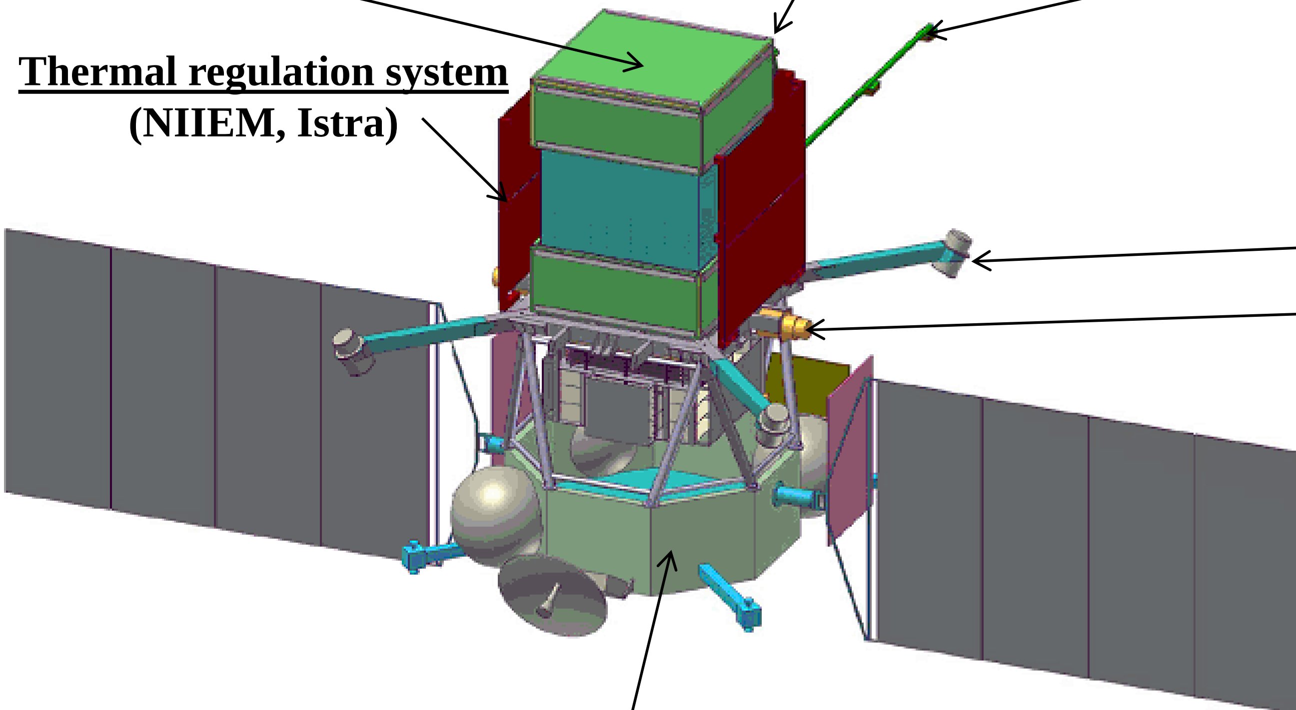
GAMMA-400 SCIENTIFIC GOALS

The GAMMA-400 main scientific goals are: study of the origin of the dark matter by means of gamma-ray astronomy; precise measurements of Galactic and extragalactic discrete astrophysical sources; research of high-energy gamma-ray bursts; research of high energy electron + positron fluxes; research of high-energy nuclei fluxes.

GAMMA-400 GAMMA-RAY TELESCOPE

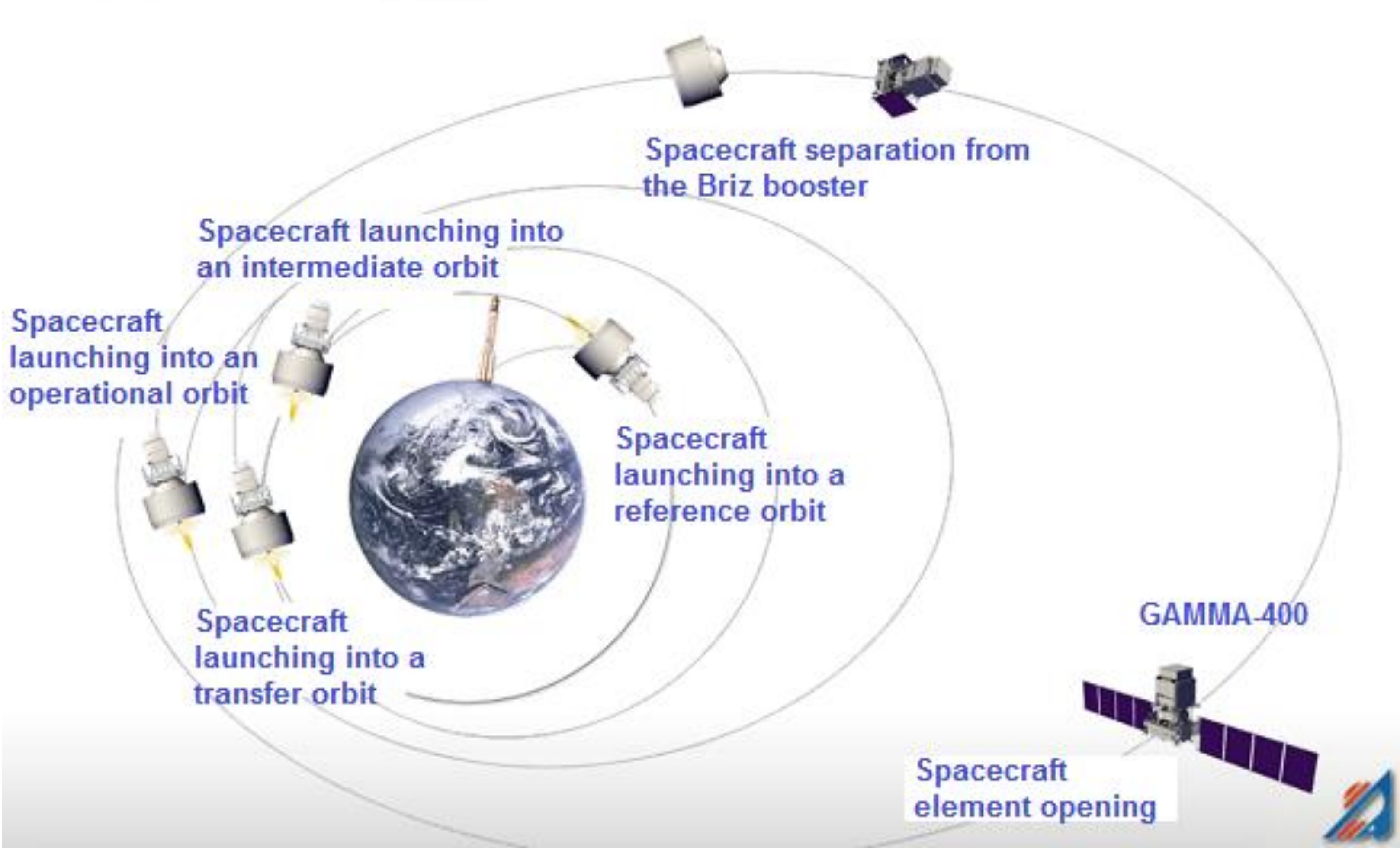
GAMMA-400 is optimized for the energy 100 GeV with the best parameters: the angular resolution ~0.01°, the energy resolution ~1%, and the proton rejection factor ~10^6, but is able to measure gamma-ray and electron + positron fluxes in the energy range from 100 MeV to 10 TeV, as well as high-energy nuclei fluxes. The GAMMA-400 effective area is ~4000 cm^2 at E_γ > 1 GeV, the total mass is 4100 kg, the power consumption is ~2000 W, and a telemetry downlink capability is 100 GB/day. Together with the gamma-ray telescope GAMMA-400, the space observatory will include two star sensors for determining the GAMMA-400 axes with accuracy of approximately 5'', two magnetometers, and the KONUS-FG gamma-ray burst monitor.

At present we finished preliminary design and this year we have to finish technical project, including the creation of the GAMMA-400 laboratory prototype. Next year we have to start the stage of working design documentation.



GAMMA-400 scientific complex on the Navigator service module

THE GAMMA-400 SPACECRAFT LAUNCHING SCHEME

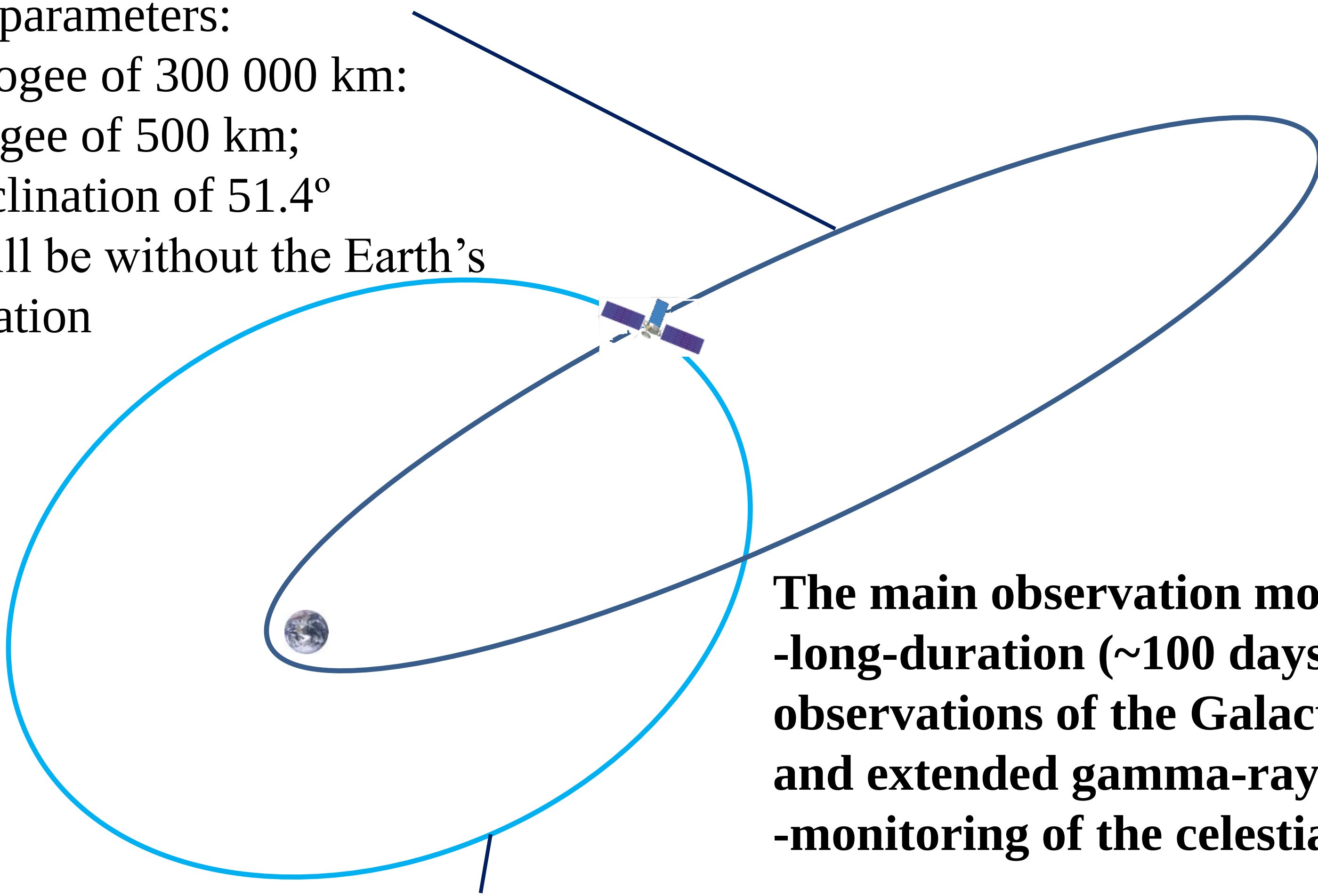


The GAMMA-400 project is included in the Russian Federal Space Program 2009-2015 and in the new planned Russian Federal Space Program 2016-2025 and is funded by the Russian Space Agency. The launch of the GAMMA-400 space observatory is scheduled in about 2021 using the powerful Proton launch vehicle + Briz booster.

The expected mission duration is more than 7 years.

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
and will be without the Earth’s occultation



The main observation modes are:
-long-duration (~100 days) observations of the Galactic Center and extended gamma-ray sources;
-monitoring of the celestial sphere.

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.

GAMMA-400 gamma-ray telescope physical scheme

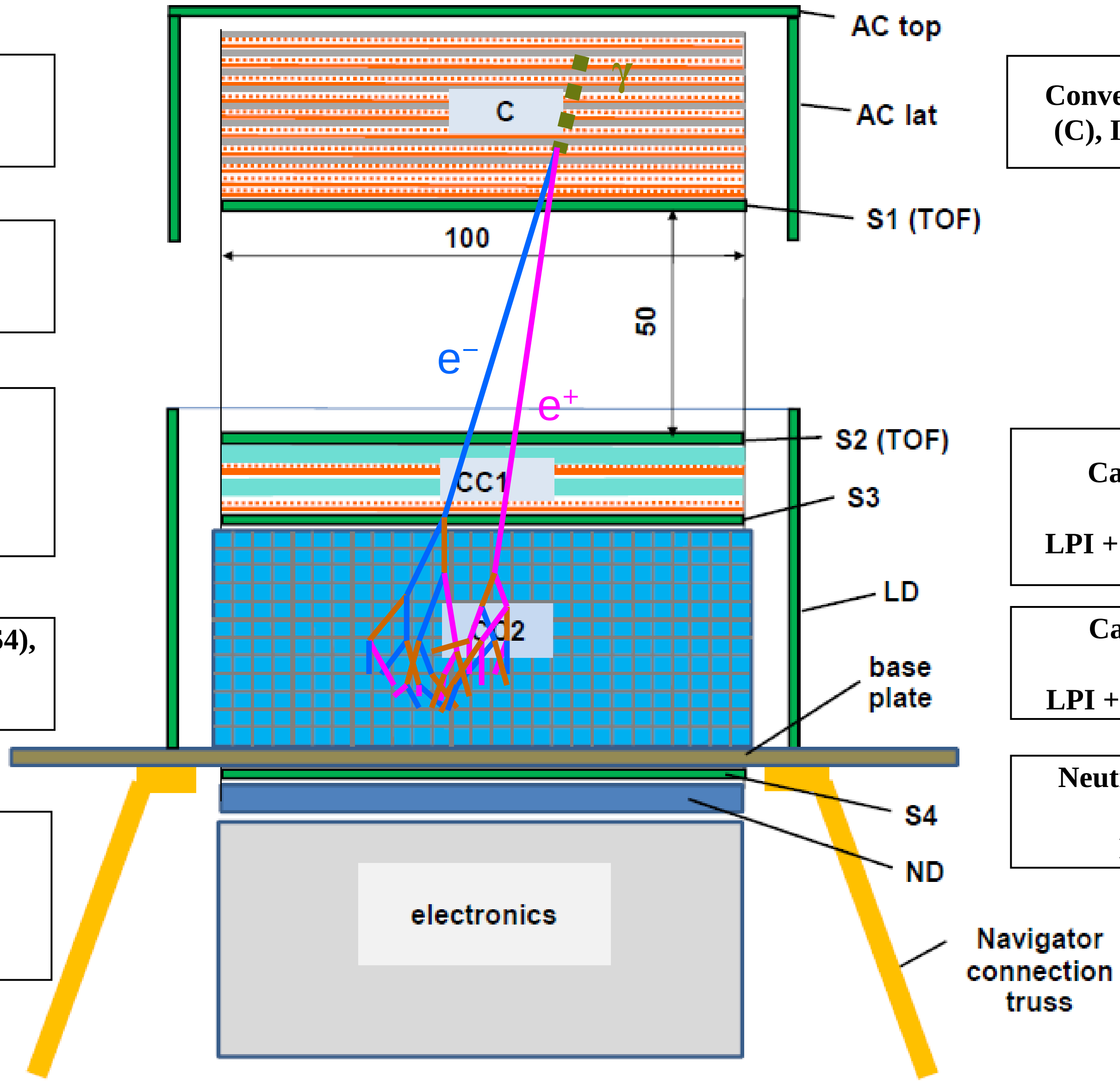
Anticoincedence system (AC), MEPhi

Time-of-flight system (ToF), MEPhI

Construction, thermal regulation system, electrical interface NIIEM, Istra

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

Scientific data acquisition system (SDAS), SRISA RAS



Converter-tracker (C), INFN (Italy)

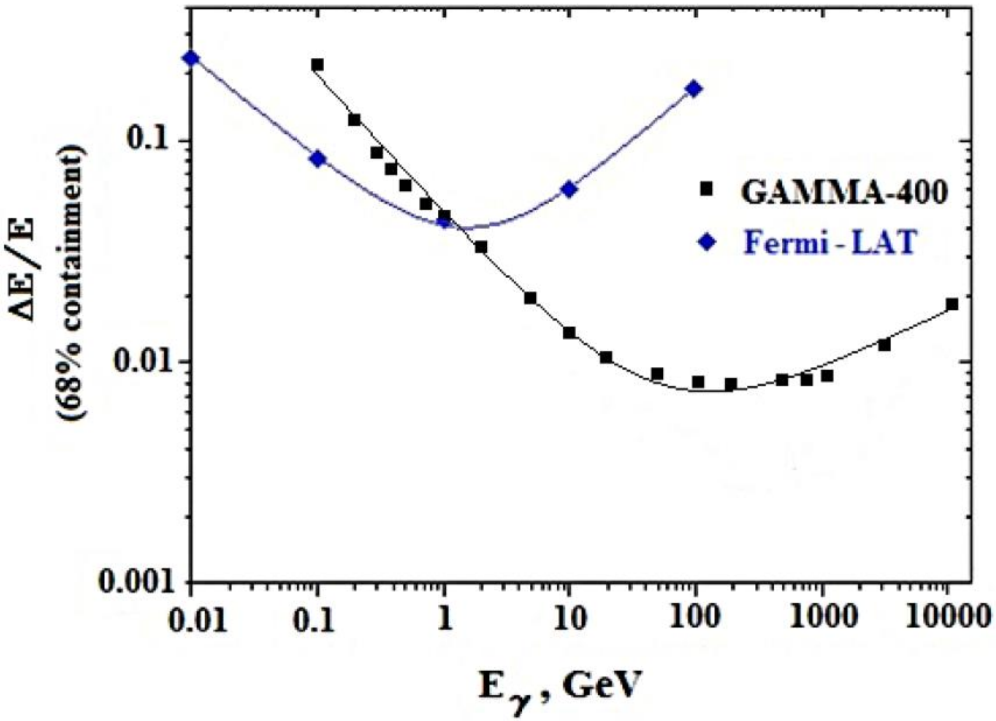
Calorimeter (CC1), LPI + INFN (Italy)

Calorimeter (CC2), LPI + INFN (Italy)

Neutron detector (ND), MEPhI

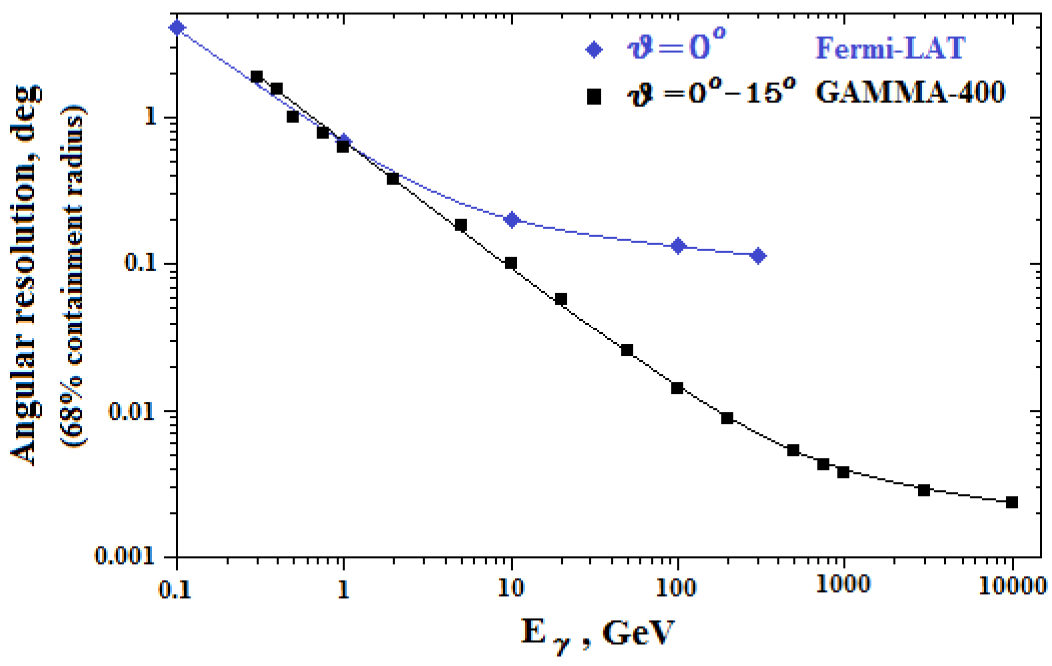
Comparison of the main parameters for GAMMA-400 and Fermi-LAT

	Fermi-LAT	GAMMA-400
Orbit	circular, 565 km	high-elliptical, 500-300000 km (without the Earth's occultation)
Energy range	20 MeV - 300 GeV	100 MeV – 10 000 GeV
Effective area (E_γ > 1 GeV)	~8000 cm^2	~4000 cm^2
Coordinate detectors	Si strips (pitch 0.23 mm)	Si strips (pitch 0.1 mm)
Angular resolution (E_γ > 100 GeV)	~0.1°	~0.01°
Calorimeter - thickness	CsI ~8.5X_0	CsI(Tl)+Si strips ~25X_0
Energy resolution (E_γ > 100 GeV)	~10%	~1%
Proton rejection coefficient	~10^4	~10^6
Mass	2800 kg	4100 kg
Telemetry downlink capability	15 GB/day	100 GB/day



Energy resolution vs. energy for normal incidence for Fermi-LAT and GAMMA-400

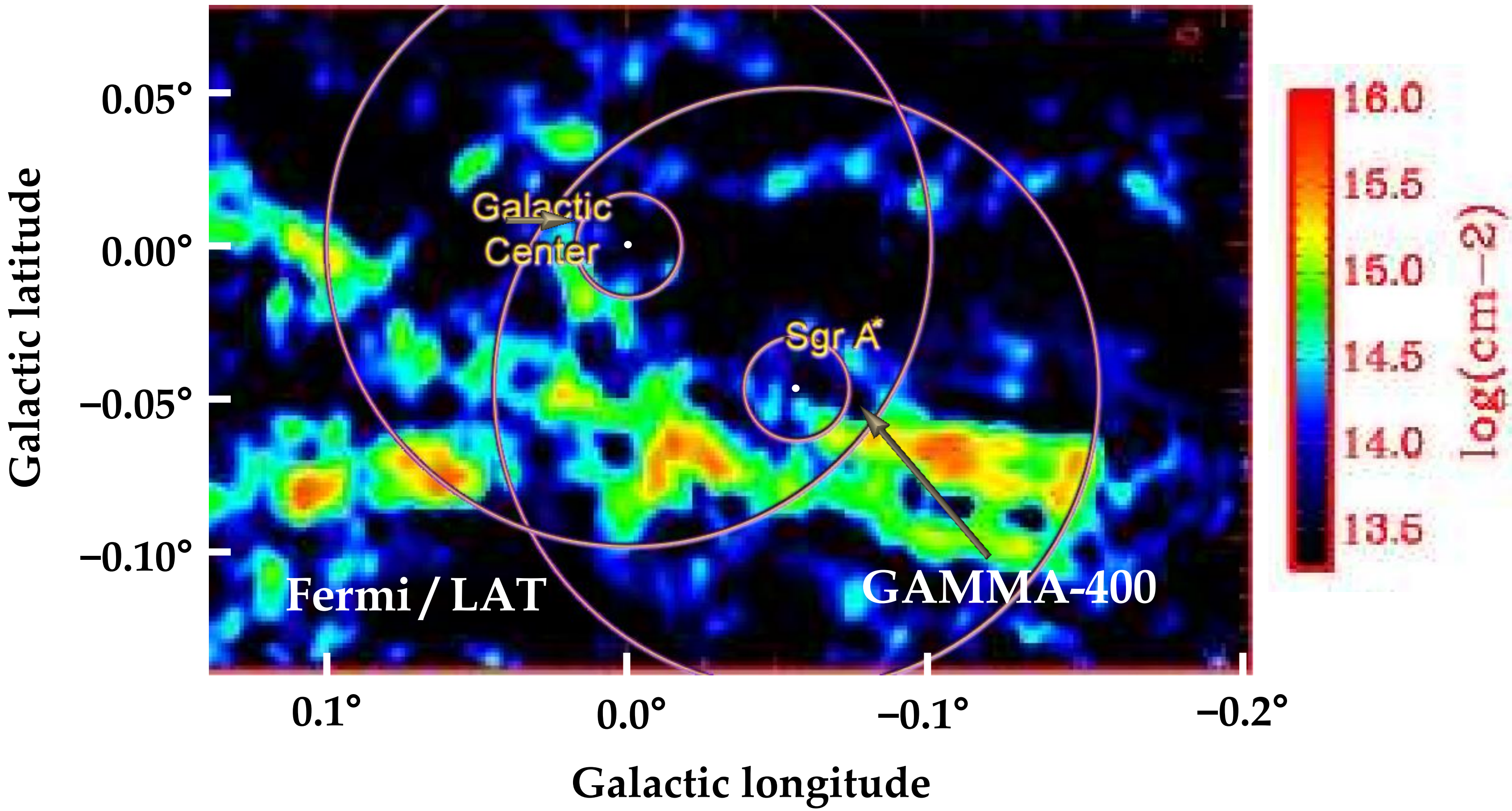
Angular resolution vs. energy for Fermi-LAT (for normal incidence) and GAMMA-400 (for θ=0°-15°)



THE GALACTIC CENTER IS THE MAIN GAMMA-400 GOAL TO SEARCH FOR DARK MATTER

Galactic center of Milky Way ($b < 1°$, $l < 1°$) is the unusual, very interesting place, where the main directions of the Universe investigations are crossed:
cosmology, relativistic astrophysics, extension of the standard model of high-energy physics (dark matter), processes of particle acceleration up to 10^{18-20} eV, etc.
The high-energy gamma-ray observation (> 1 GeV) gives the unique information on the existence of supermassive black hole and accordingly accretion disc, which possibly consisting from dark matter. At present, they are one point object, but, from accretion disc, linear gamma rays from self-annihilation and decay dark matter particles should be observed .
In order to resolve this linear gamma-ray emission on the background of other emission sources in the Galactic center it is necessary to have very high angular and energy resolutions. The GAMMA-400 gamma-ray telescope has both the best angular and energy resolutions.

Demonstration of the GAMMA-400 angular resolution possibility



Background: Integrated intensity map of the NH_3 (1,1) emission (1.2652 cm wavelength) from [arXiv:1402.4531].

Circles: point spread functions for Fermi/LAT (outer: 0.1° or 15 pc) and GAMMA-400 (inner: 0.01° or 1.5 pc) at $E_\gamma \sim 100$ GeV.

Demonstration of the GAMMA-400 energy resolution possibility

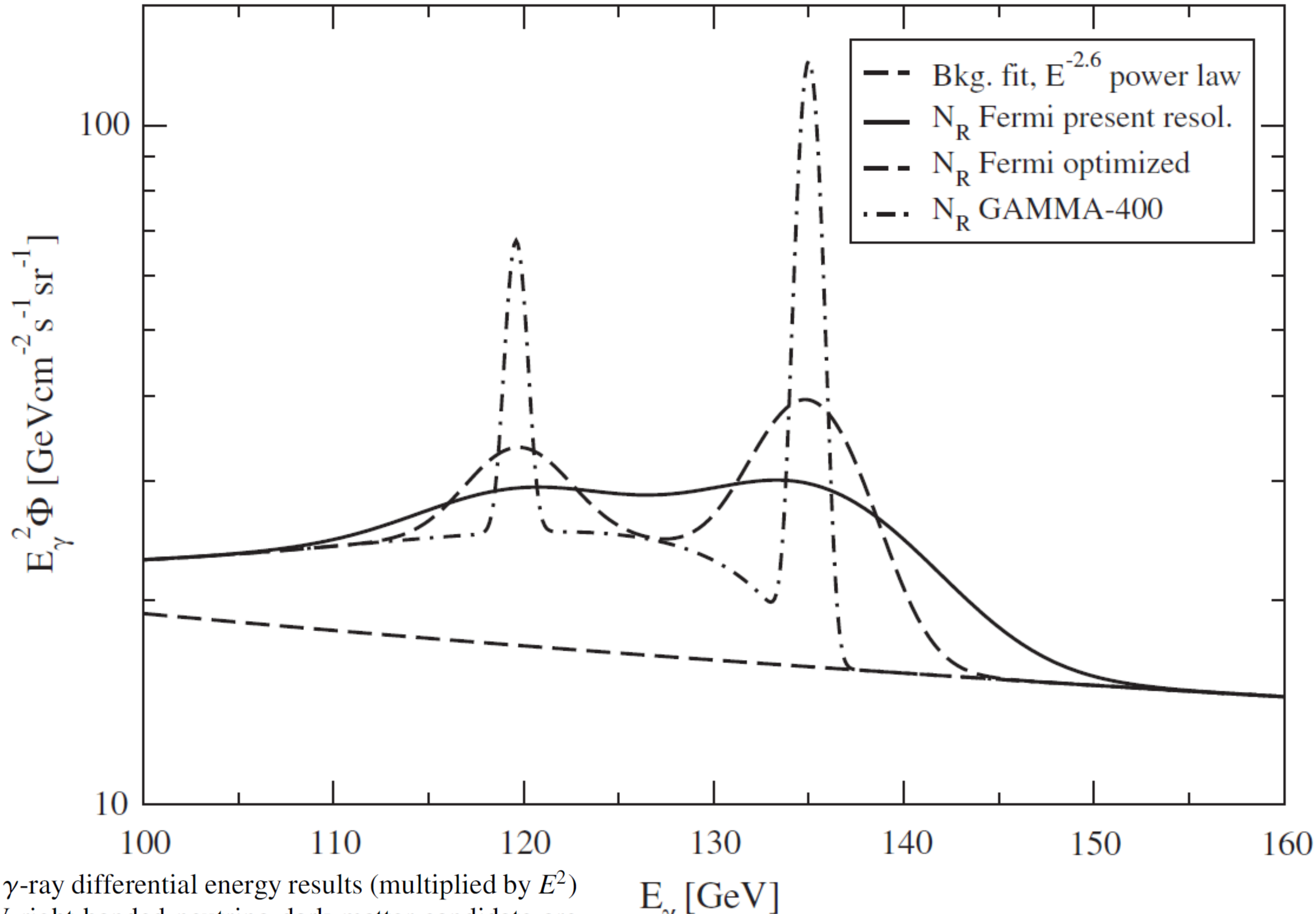


FIG. 3. The γ-ray differential energy results (multiplied by E^2) for a 135 GeV right-handed neutrino dark matter candidate are shown, with the present Fermi-LAT energy resolution $\Delta E/E =$ 10% FWHM (solid line), with a factor of 2 improvement (dashed line) and with a future γ-ray instrument, such 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)

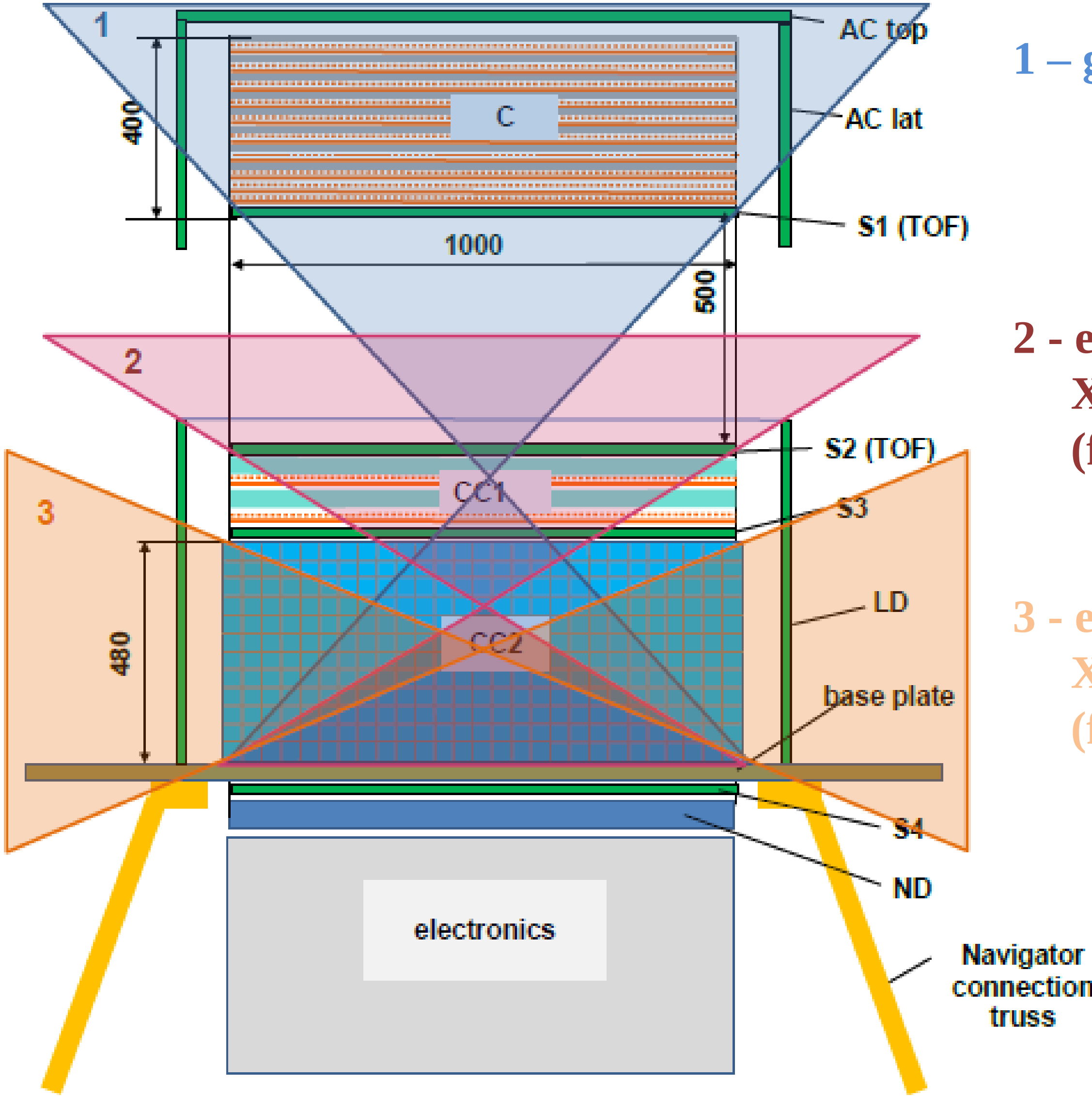
130 GeV fingerprint of right-handed neutrino dark matter

Lars Bergström*

COMPARISON OF BASIC PARAMETERS OF OPERATED, EXISTING, 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-	2014	~2021	2012-	2009-	2007-	2018
Energy range, GeV	0.03-30	0.03-50	0.02-300	10-10000	**0.1-10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.2° (E_γ~0.5 GeV)	0.1° (E_γ~1 GeV)	0.1°	0.1°	~**0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.03° (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)

GAMMA-400 fields of view for gamma rays, electrons + positrons, and nuclei

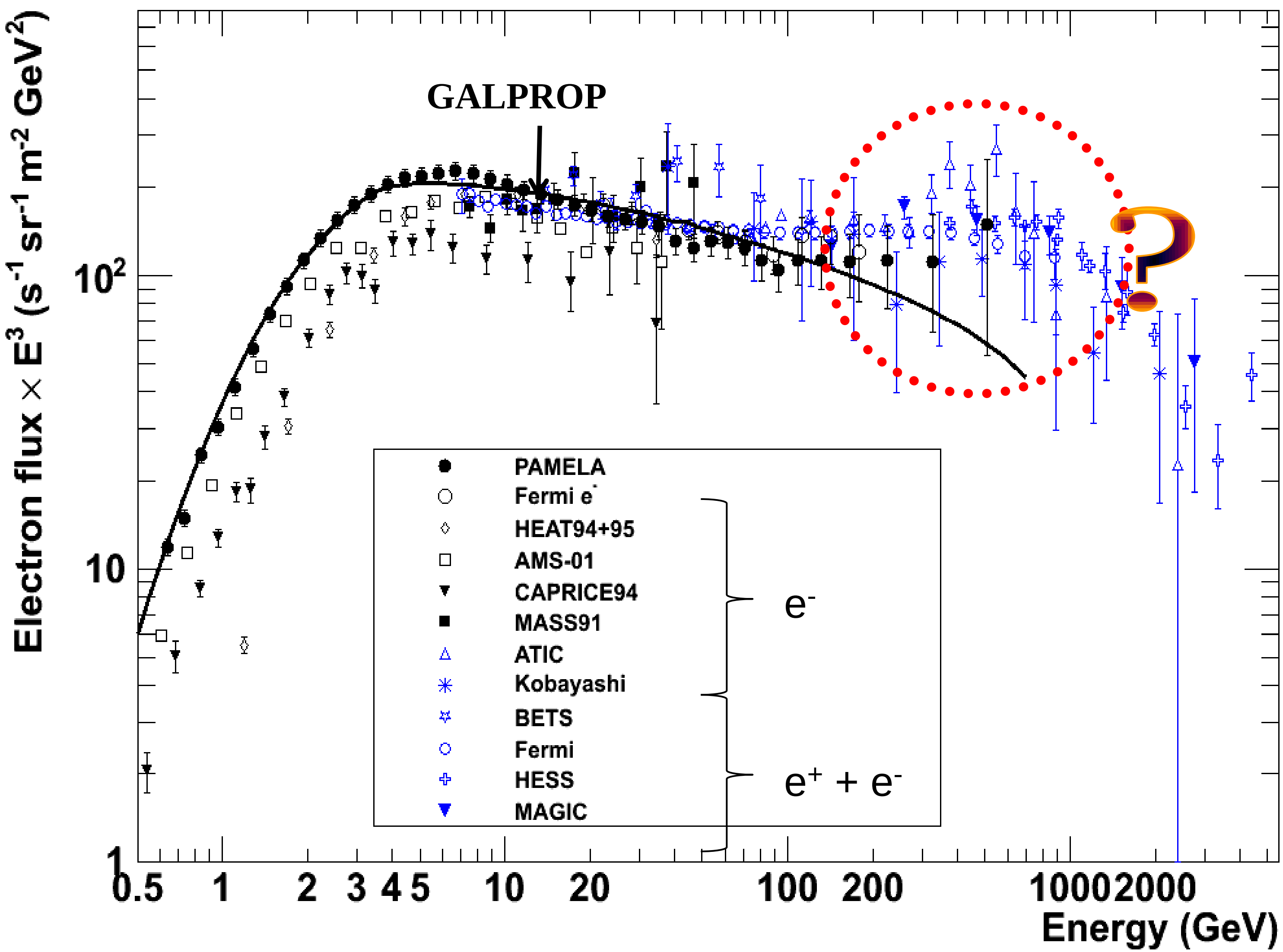


1 – gamma rays

2 - electrons + positrons, and nuclei
X_0 = 25 r.l., λ_0 = 1.2 i.l.
(for vertical events)

3 - electrons + positrons, and nuclei
X_0 = 54 r.l., λ_0 = 2.5 i.l.
(for lateral events)

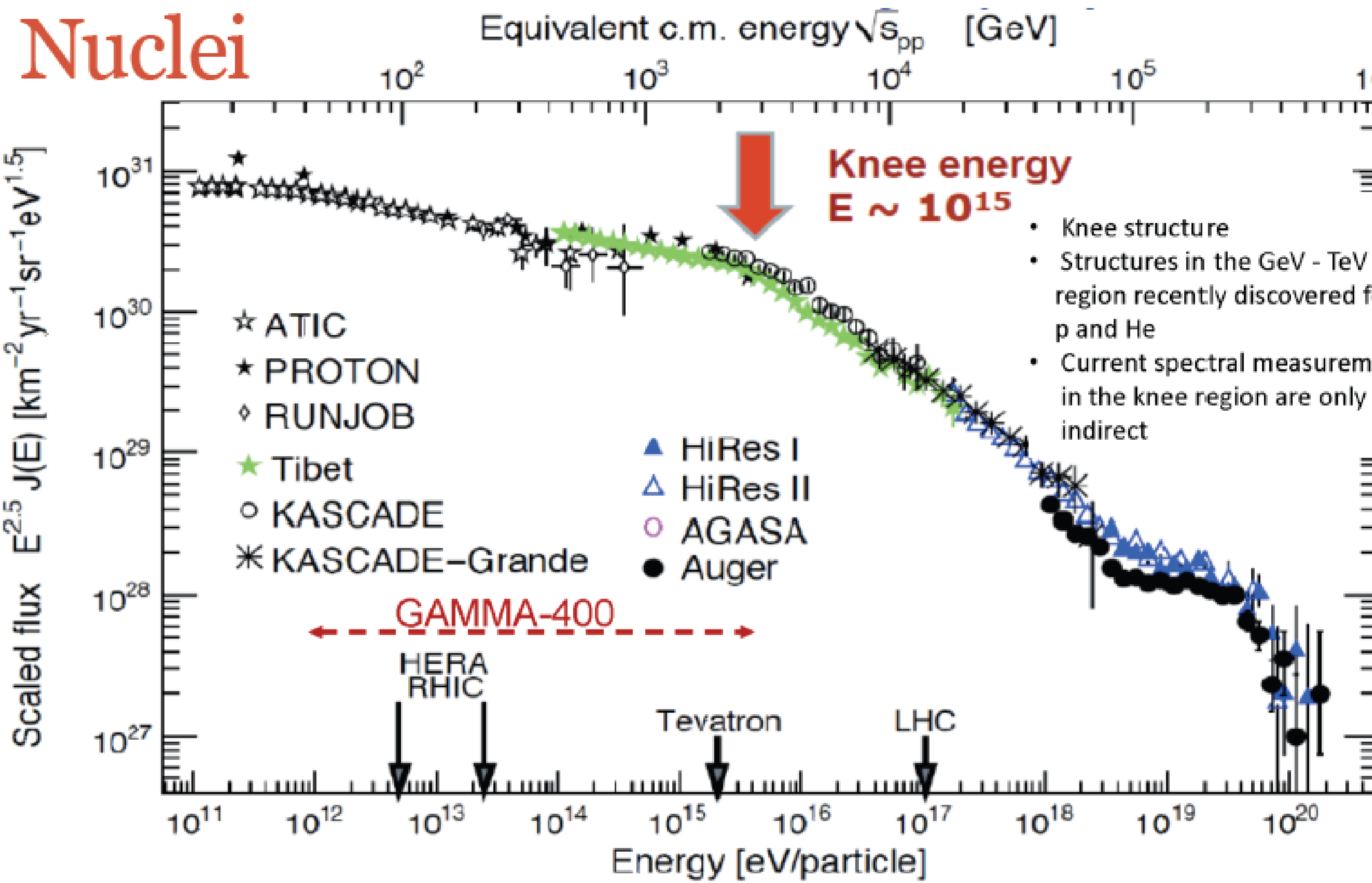
Electron Spectrum



Electron count estimation

Experiment	Duration	GF (m^2 sr)	Calo σ(E)/E	Calo depth	e/p rejection factor	E>0.5 TeV	E>1 TeV	E>2 TeV	E>4 TeV
CALET	5 y	0.12	~2%	30 X_0	10^5	7982	1527	238	25
AMS02	10 y	0.5	~2%	16 X_0	10^3	66515	12726	1986	211
ATIC	30 d	0.25	~2%	18 X_0	10^4	273	52	8	1
FERMI	10 y	1.6 @ 300 GeV 0.6@ 800 GeV	~15%	8.6 X_0	10^4	59864	6362	NA	NA
G400	10 y	3.9	~ 1%	25.4 X_0	10^5	518819	99266	15488	1647

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

p and He count estimation

~knee ↓ (E>4 PeV)

Experiment	Duration	GF (m^2 sr)	Calo σ(E)/E	Calo depth	ε sel	E>0.1 PeV		E>0.5 PeV		E>1 PeV		E>2 PeV		E>4 PeV	
						p	He	p	He	p	He	p	He	p	He
CALET	5 y	0.12	~40%	30 X_0 1.3 λ_0	0.8	292	276	17	19	5	6	1	2	0	0
CREAM	180 d	0.43	~45%	20 X_0 1.2 λ_0	0.8	103	97	6	7	2	2	0	1	0	0
ATIC	30 d	0.25	~37%	18 X_0 1.6 λ_0	0.8	10	9	1	1	0	0	0	0	0	0
G400	10 y	3.9	~ 35%	25.4 X_0 1.2 λ_0	0.8	18951	17921	1123	1242	300	374	69	106	11	24

Nuclei count estimation

~knee

Experiment	Duration	GF (m^2 sr)	Calo $\sigma(E)/E$	Calo depth	ε sel	E>0.1 PeV		E>0.5 PeV		E>1 PeV		E>2 PeV		E> 4 PeV	
						^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr	^{3}Li to ^{9}F	^{10}Ne to ^{24}Cr
CALET	5 y	0.12	~30%	30 X_0 1.3 λ_0	0.8	136	140	9	10	3	3	1	1	0	0
CREAM	10 y	0.46	~45%	20 X_0 1.2 λ_0	0.8	51	53	4	4	1	1	0	0	0	0
ATIC	30 d	0.25	~37%	18 X_0 1.6 λ_0	0.8	5	5	0	0	0	0	0	0	0	0
TRACER	30 d	5	-	TRD	0.8	93	96	6	7	2	2	1	1	0	0
G400	10 y	3.9	~40%	25.4 X_0 1.2 λ_0	0.8	8830	9073	612	636	193	206	58	69	17	20

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 2021.
- GAMMA-400 will provide in-depth investigations on some of the most challenging physics items, such as:
  - DM search in γ and high-energy electron spectra;
  - CR origin, production and acceleration to the highest energies.