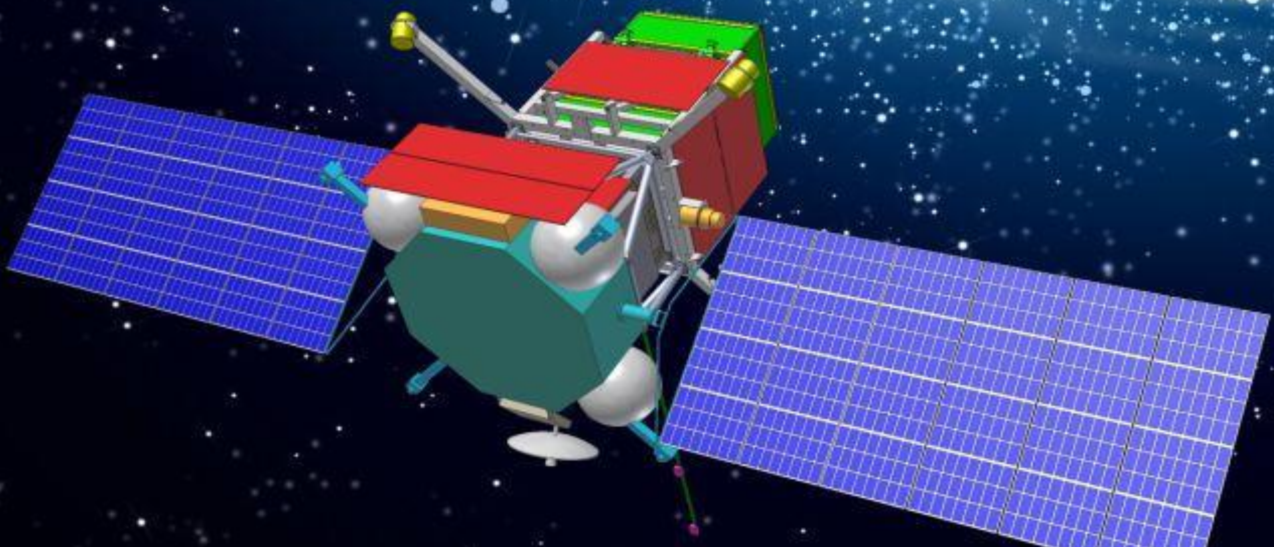
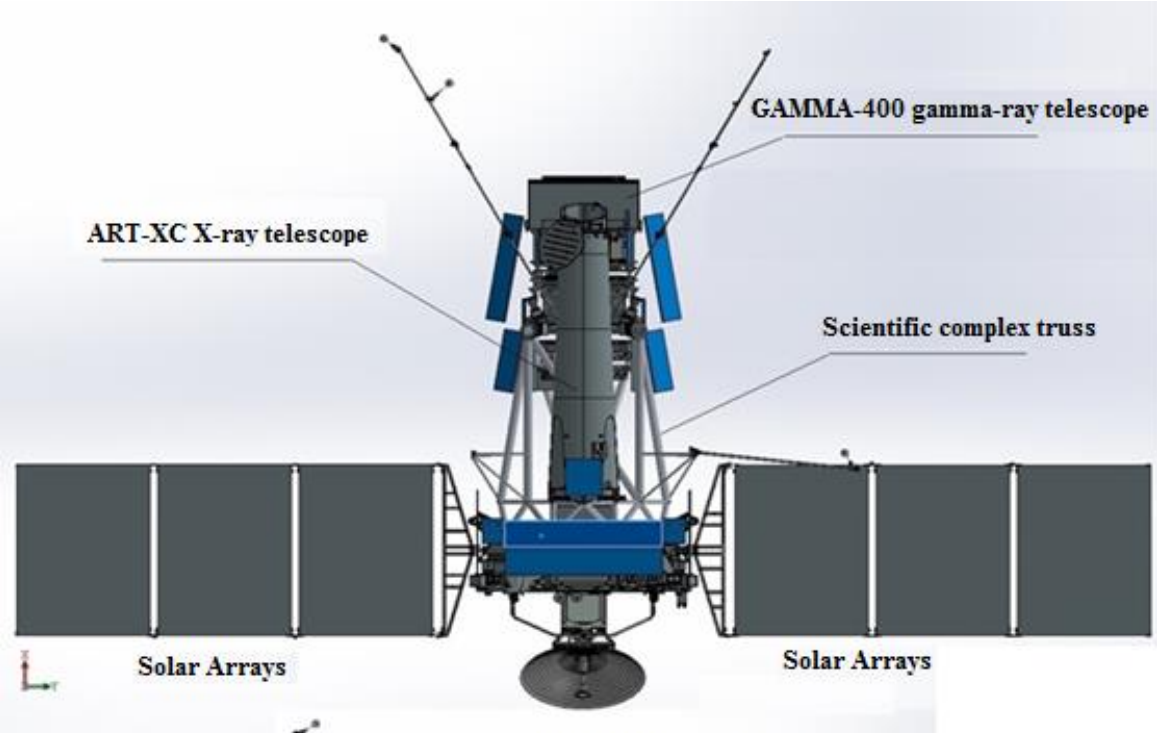
Russian Academy of Sciences
P.N.Lebedev Physical Institute
LPI

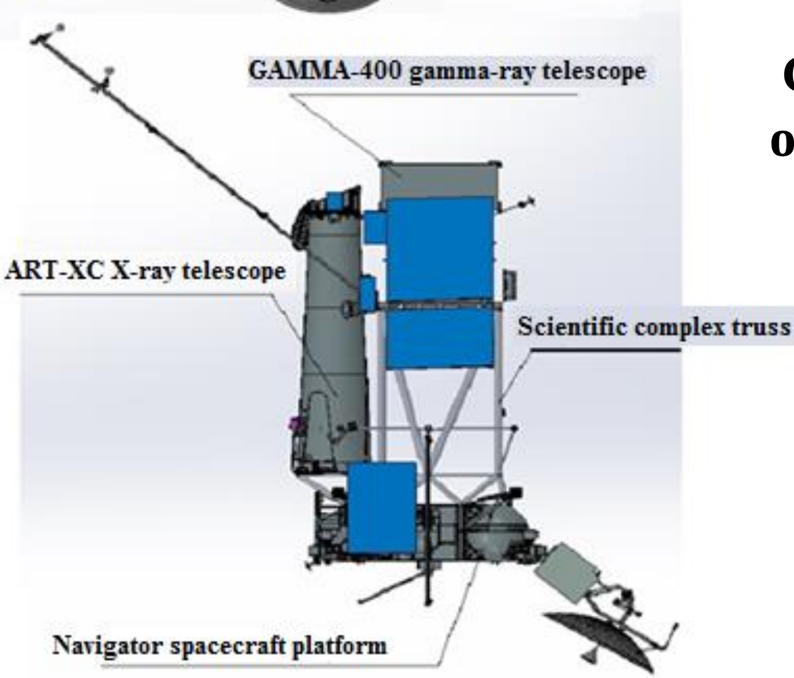
Aleksey Leonov and Nikolay Topchiev
for the GAMMA-400 Collaboration

Gamma- and Cosmic-Ray Observations with GAMMA-400 Gamma-Ray Telescope

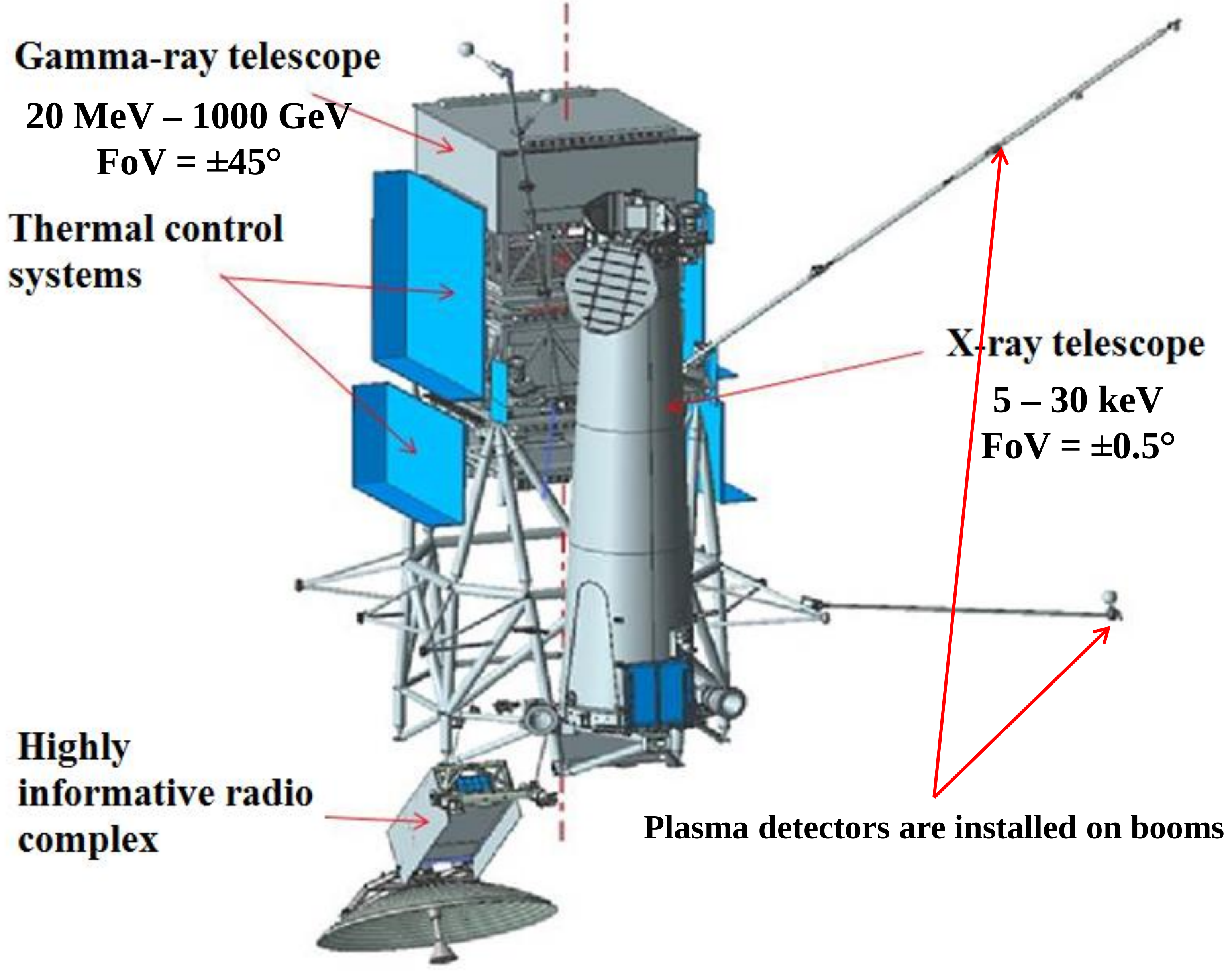


February 2, 2021, 43rd COSPAR





GAMMA-400 scientific complex on Navigator spacecraft platform (Lavochkin Association)

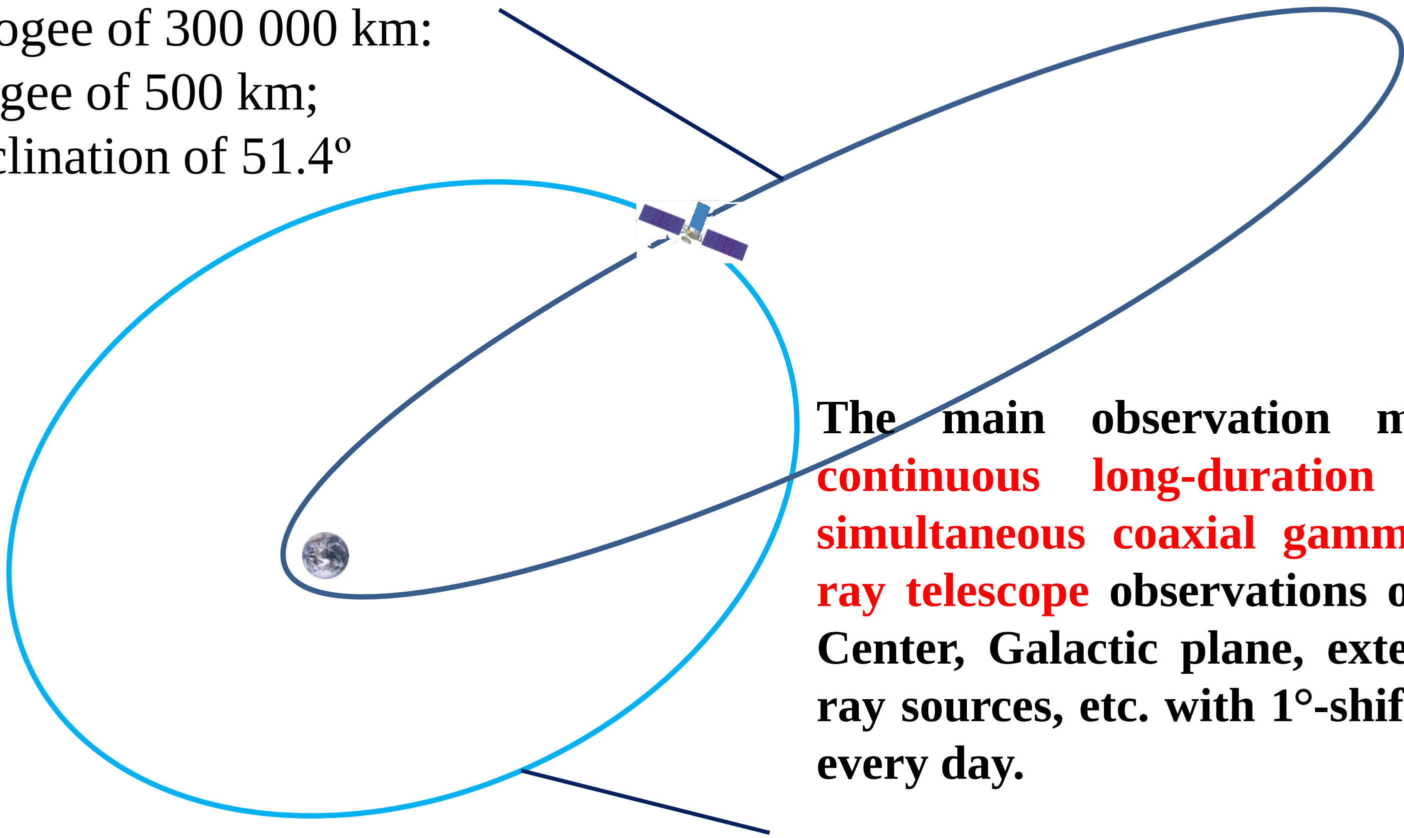


GAMMA-400 scientific complex

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

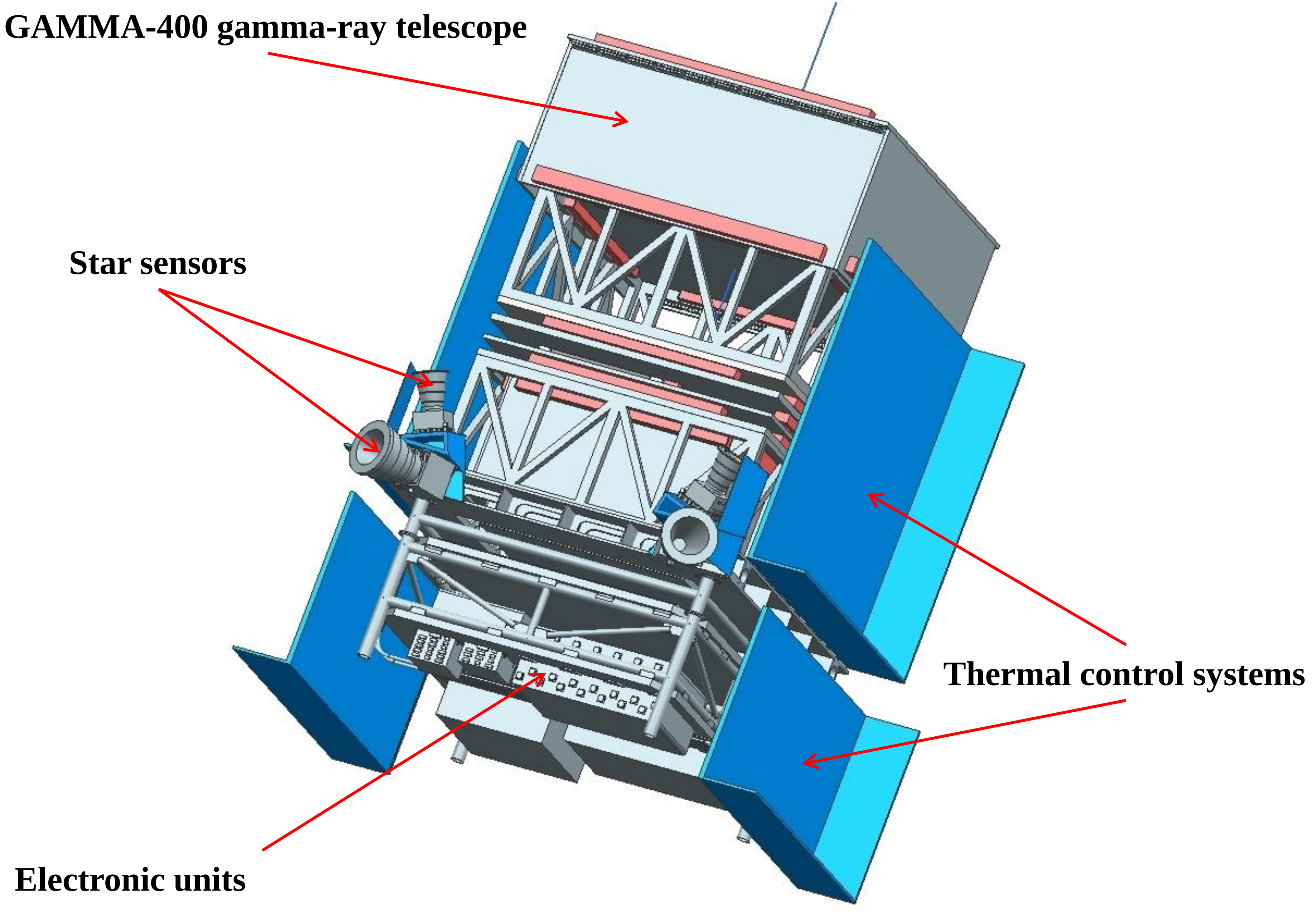
Time of operation will be 7 years



The main observation mode will be continuous long-duration (~100 days) simultaneous coaxial gamma-ray and X-ray telescope observations of the Galactic Center, Galactic plane, extended gamma-ray sources, etc. with 1°-shift of spacecraft every day.

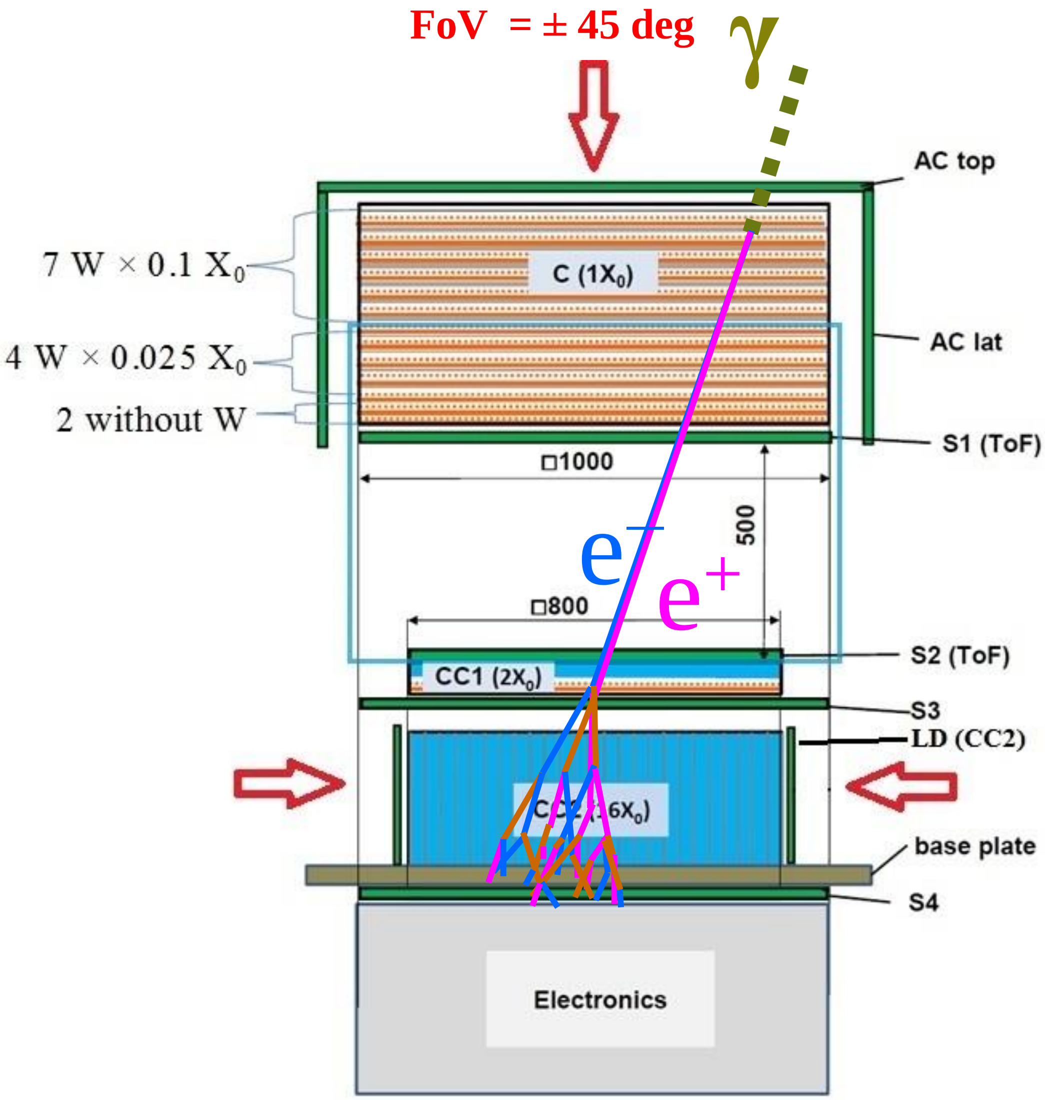
Under the action of gravitational disturbances of the Sun, Moon, and the Earth after ~6 months the orbit will transform to about circular with a radius of ~200 000 km and will be without the Earth's occultation and out of radiation belts.

As a ground receiving station, it is proposed to use the radio-astronomy complex based on the RT-22 radio-telescope in Pushchino (Lebedev Physical Institute), the same station as for Radioastron mission (Spectr-R).



GAMMA-400 gamma-ray telescope

The GAMMA-400 physical scheme



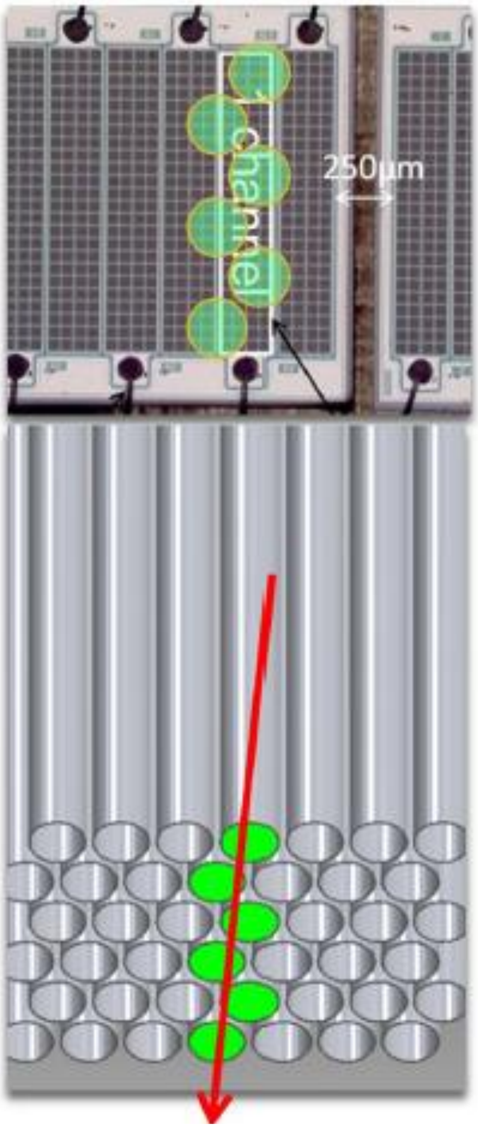
AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter vertical thickness ~2+16=18 X_0
CC2 – lateral thickness ~43 X_0
S3, S4 – scintillation detectors

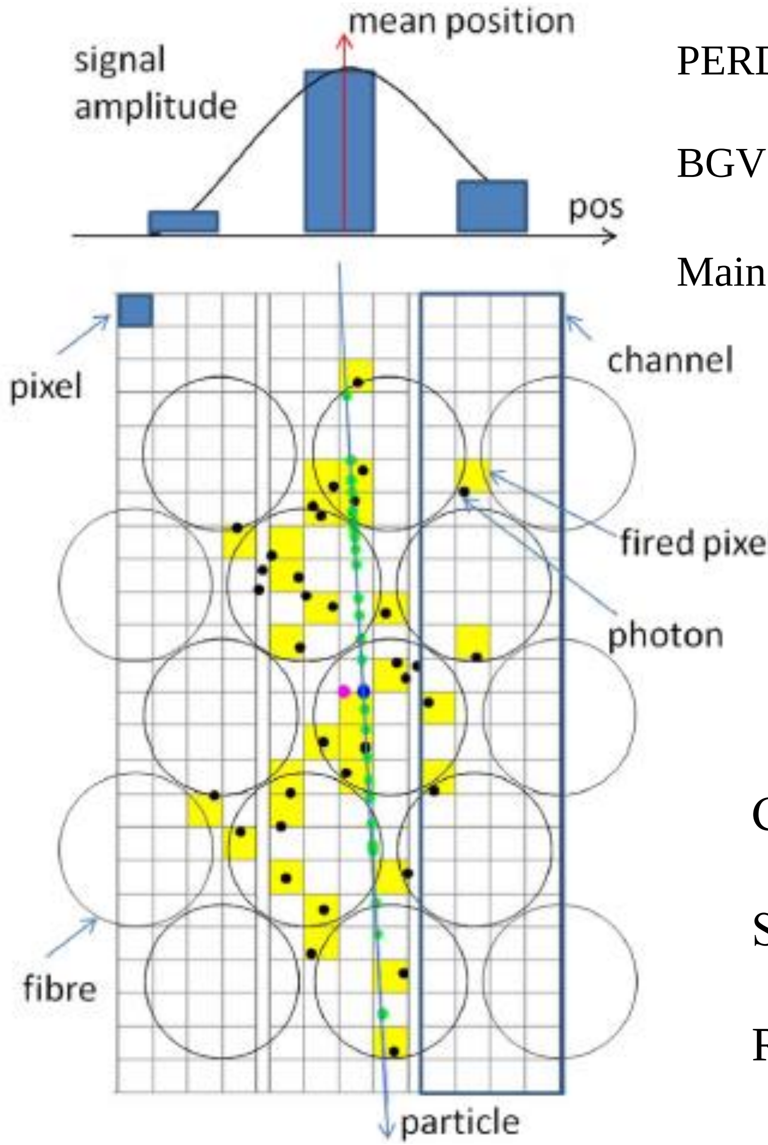
E_γ = ~20 MeV – ~1 TeV
E_e = ~20 MeV – ~10 TeV
$\Delta\theta$ = ~0.01° (E_γ = 100 GeV)
$\Delta E/E$ = ~2% (E_γ = 100 GeV)

Main trigger:

$$(\overline{AC} \times ToF) | (S3(E_{RELEASE} > E_{THRESHOLD}) ToF)$$

Converter-tracker (C) consists from scintillating fibers (SciFi)





Using SciFi technology:

PERDaix (balloon, 2010)

BGV beam monitor (2015)

Main tracker detector, LHCb (2016)

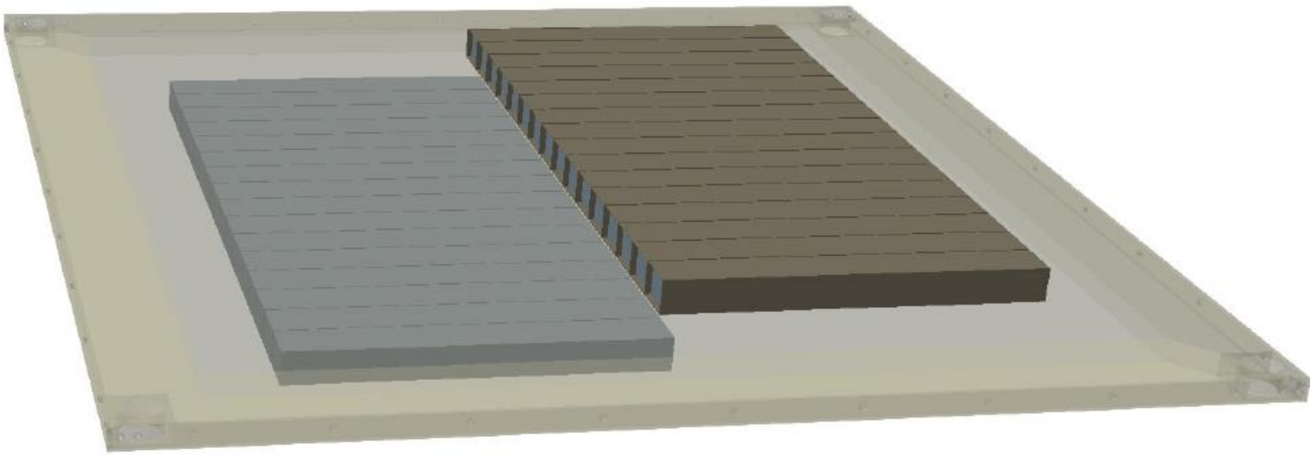
Chanel width is 250 µm

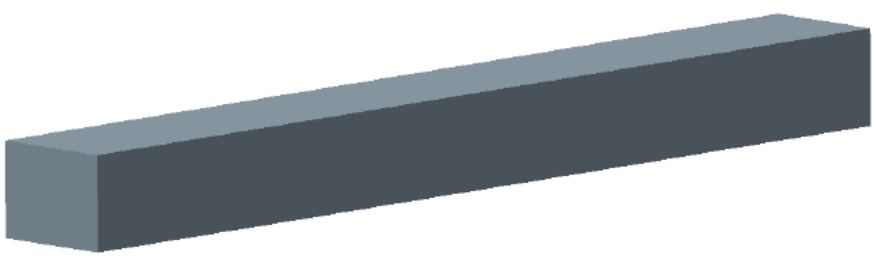
Spatial resolution is 55 µm

Recording efficiency is 99%

Calorimeter consists of Imaging calorimeter (CC1) and Electromagnetic calorimeter (CC2)

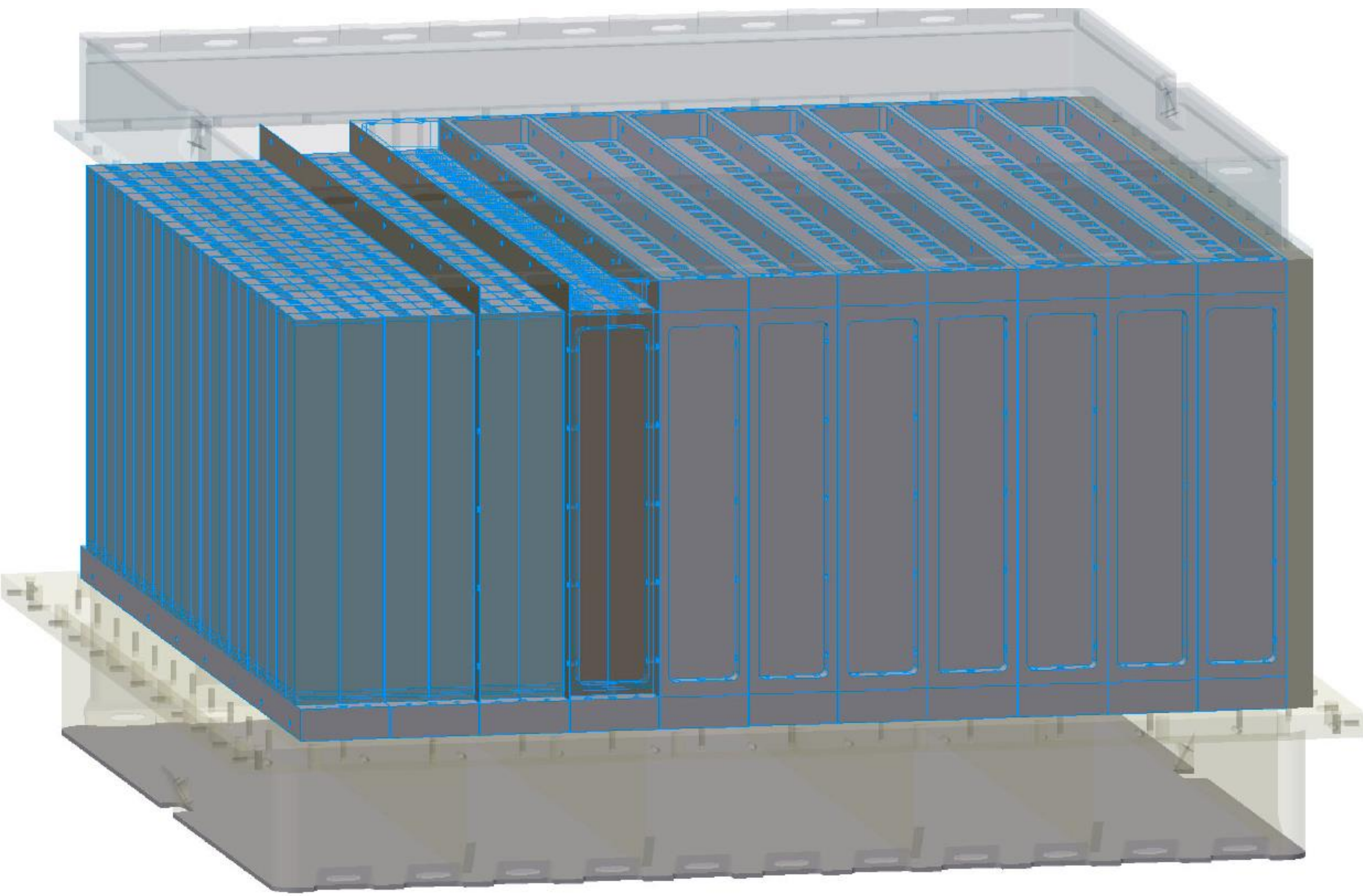
CC1 Imaging calorimeter ($2X_0$ or $0.1\lambda_0$)
consists of 2 modules × 16 CsI(Tl) crystals



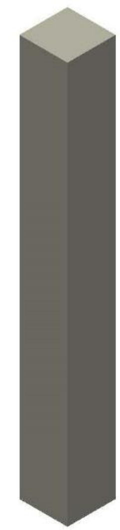


Crystal dimensions are 400×50×37 mm^3

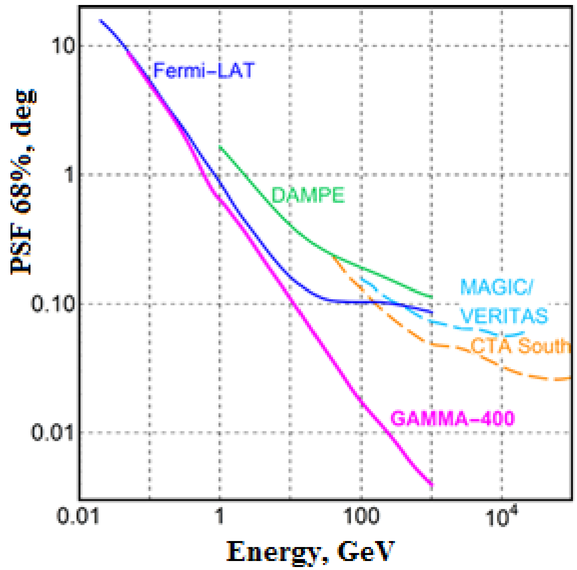
CC2 Electromagnetic calorimeter consists of 22×22 CsI(Tl) crystals with thickness of $16X_0$ or $0.8\lambda_0$



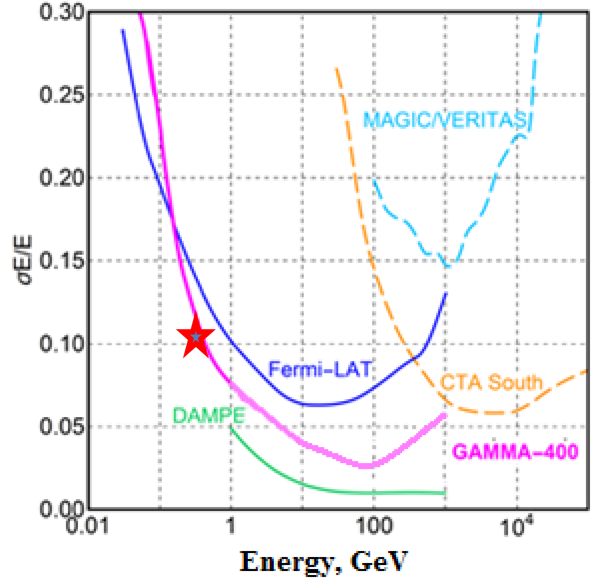
Crystal dimensions are $36\times36\times300$ mm^3

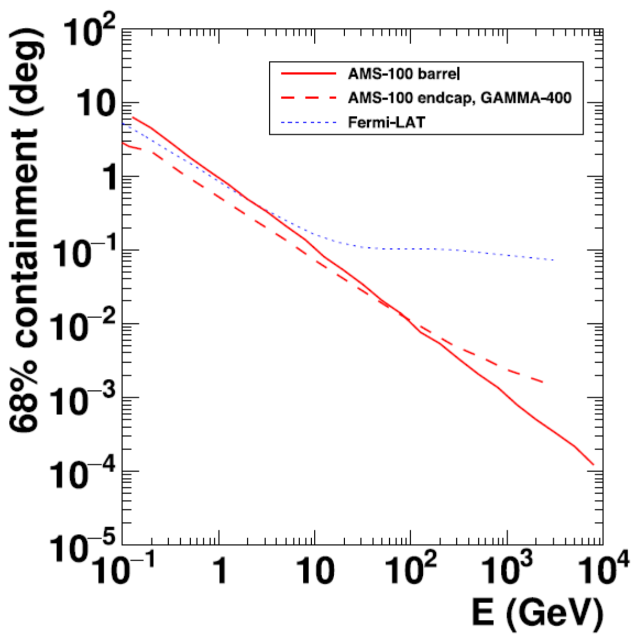


Angular resolution



Energy resolution





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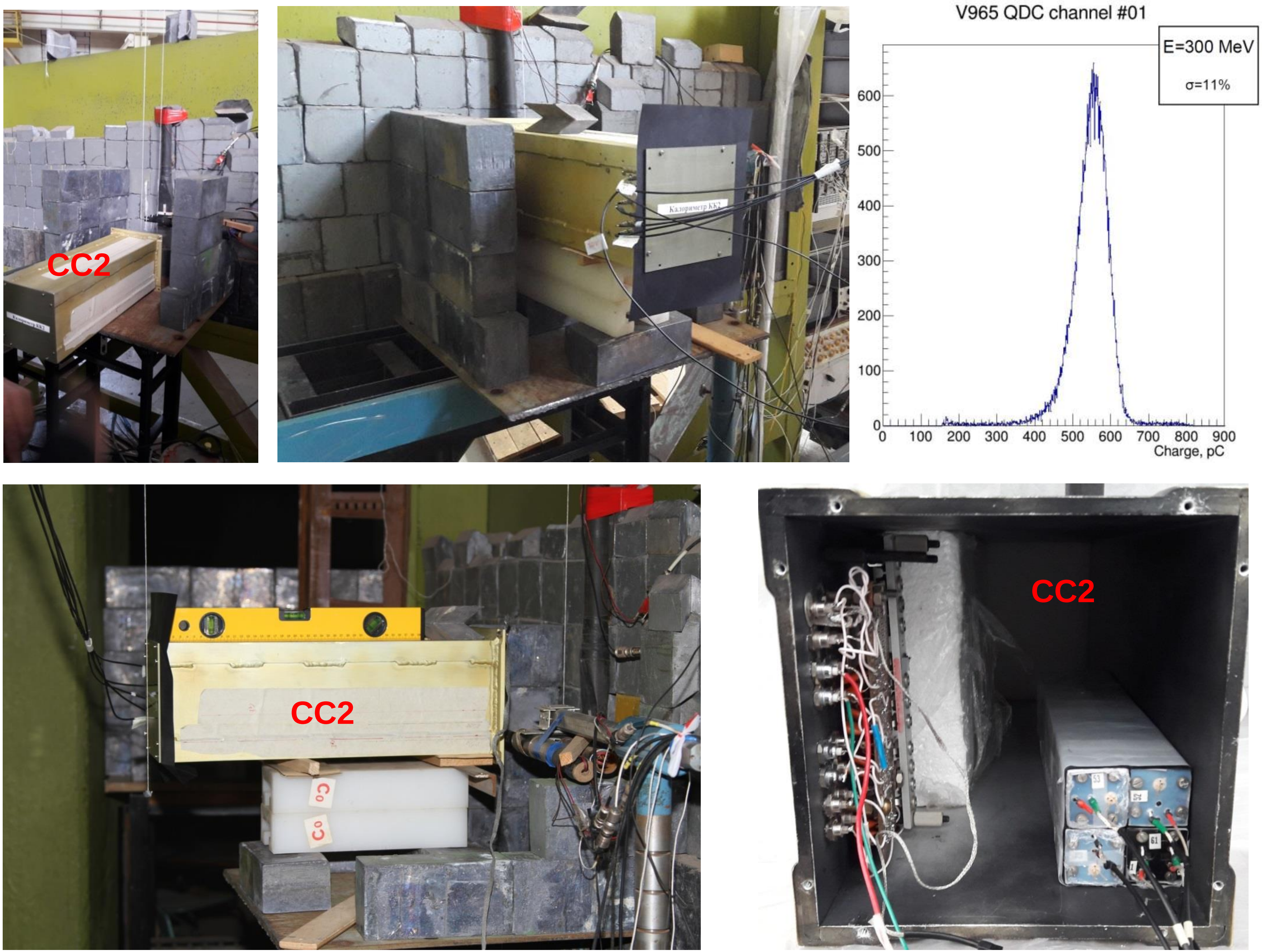
GAMMA-400 calculated angular and energy resolutions vs energy.

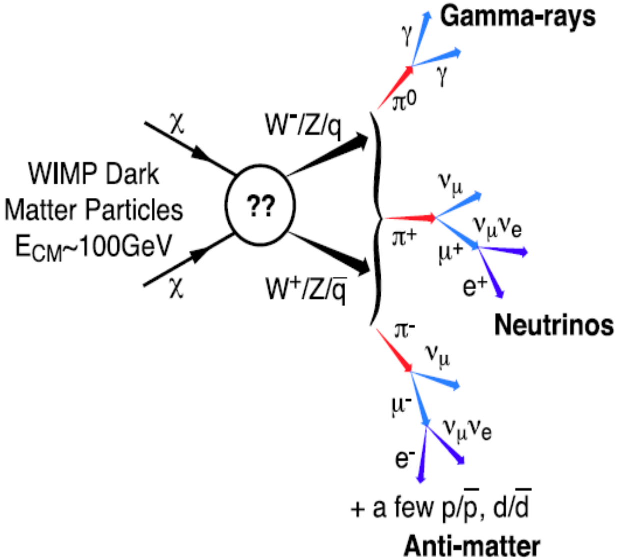
★ GAMMA-400 experimental energy resolution for the energy of 300 MeV at LPI electron synchrotron in Troitsk.


CC2
V965 QDC channel #01
E=300 MeV
σ=11%
0
100
200
300
400
500
600
0
100
200
300
400
500
600
700
800
900
Charge, pC
CC2
Co
Co
CC2

GAMMA-400 gamma-ray telescope main scientific goals

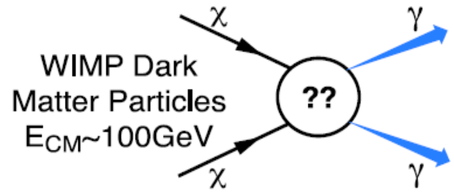
with unprecedented angular **(~0.01° at E_γ = 100 GeV)** and energy resolutions **(~2% at E_γ = 100 GeV)**

1. Dark matter searching by means of gamma-ray astronomy (~10-1000 GeV)

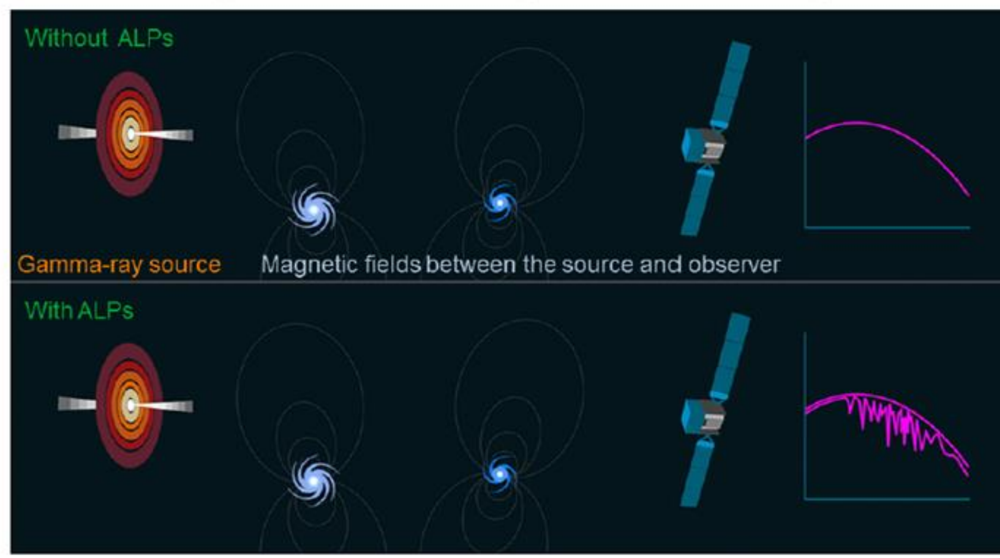


secondary gamma rays

primary monoenergetic gamma rays



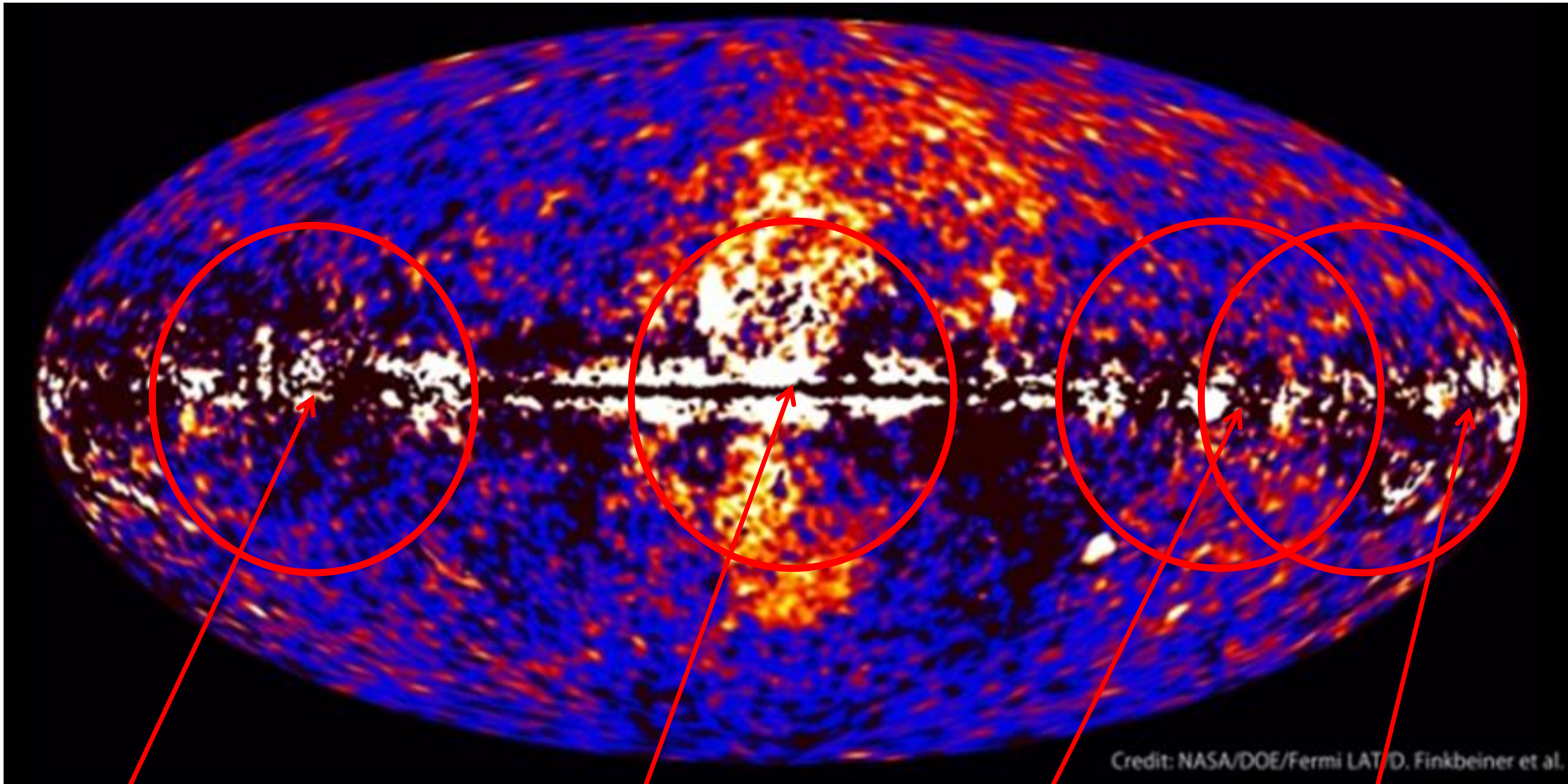
ALP signature searches in pulsar and blazar spectra



$\gamma + \boldsymbol{B} \leftrightarrow \gamma + ALP$ — conversion

The key relevant parameters of ALP are its mass m_a and electromagnetic coupling constant $g_{a\gamma}$. These parameters define the character of spectral features due to conversion.

2. Precise and detailed observations of Galactic plane, especially, Galactic Center, Fermi Bubbles, Crab, Vela, Cygnus, Geminga, and other regions with aperture of ±45°



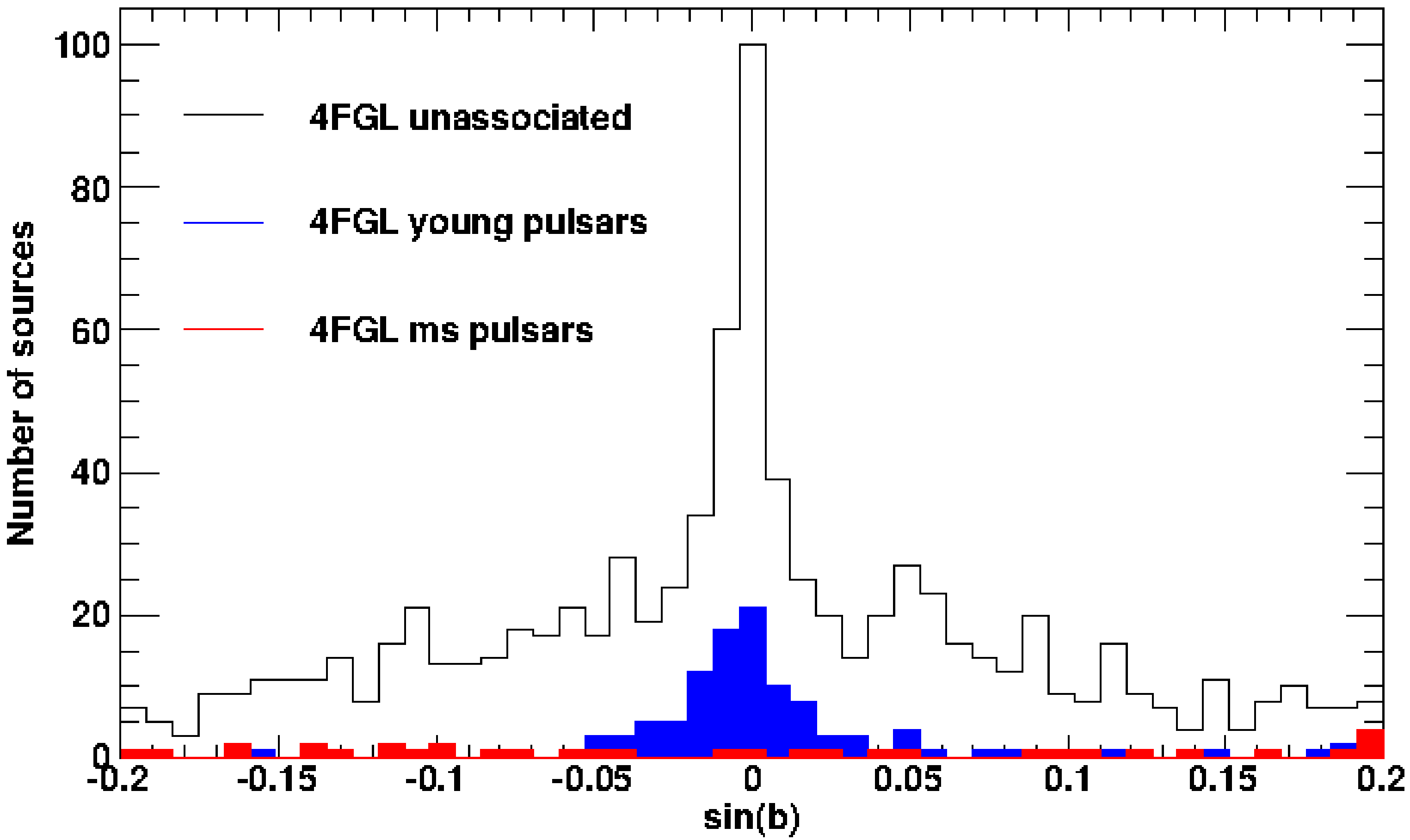
Cygnus

Galactic Center, Fermi Bubbles

Vela

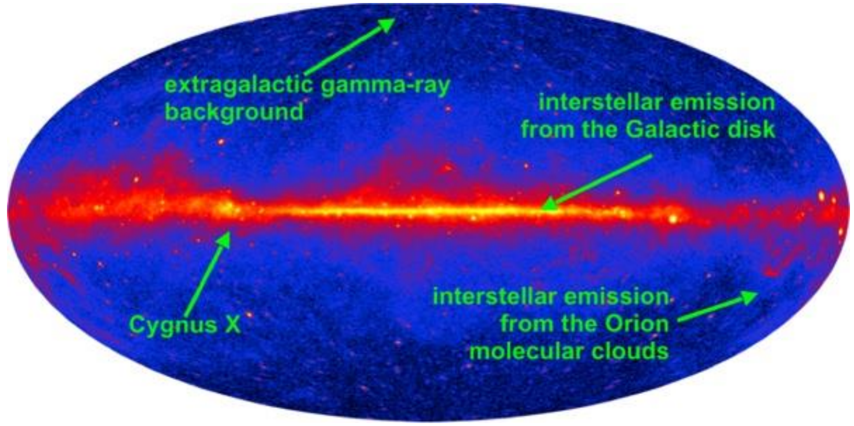
Crab, Geminga

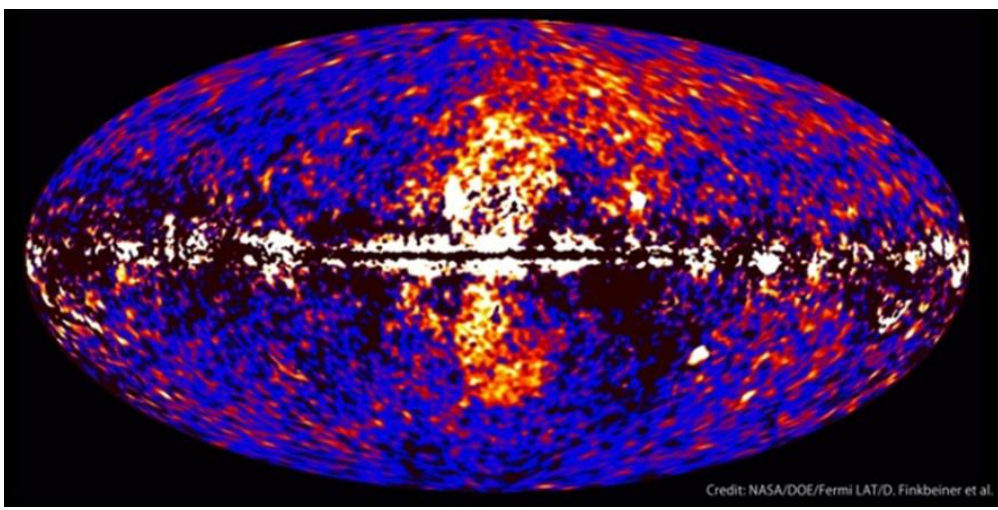
3. Identification of ~1350 (especially in Galactic plane) from 5064 discrete sources (according to 4th Fermi-LAT catalog), precise studying extended sources, studying detail structure and HE processes in active sources, studying gamma-rays from the Sun

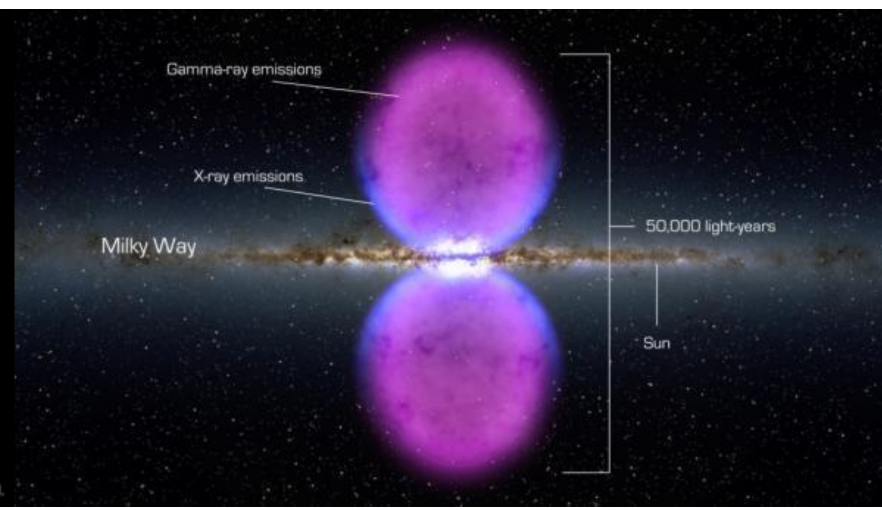


4. Searching for and studying gamma-ray bursts

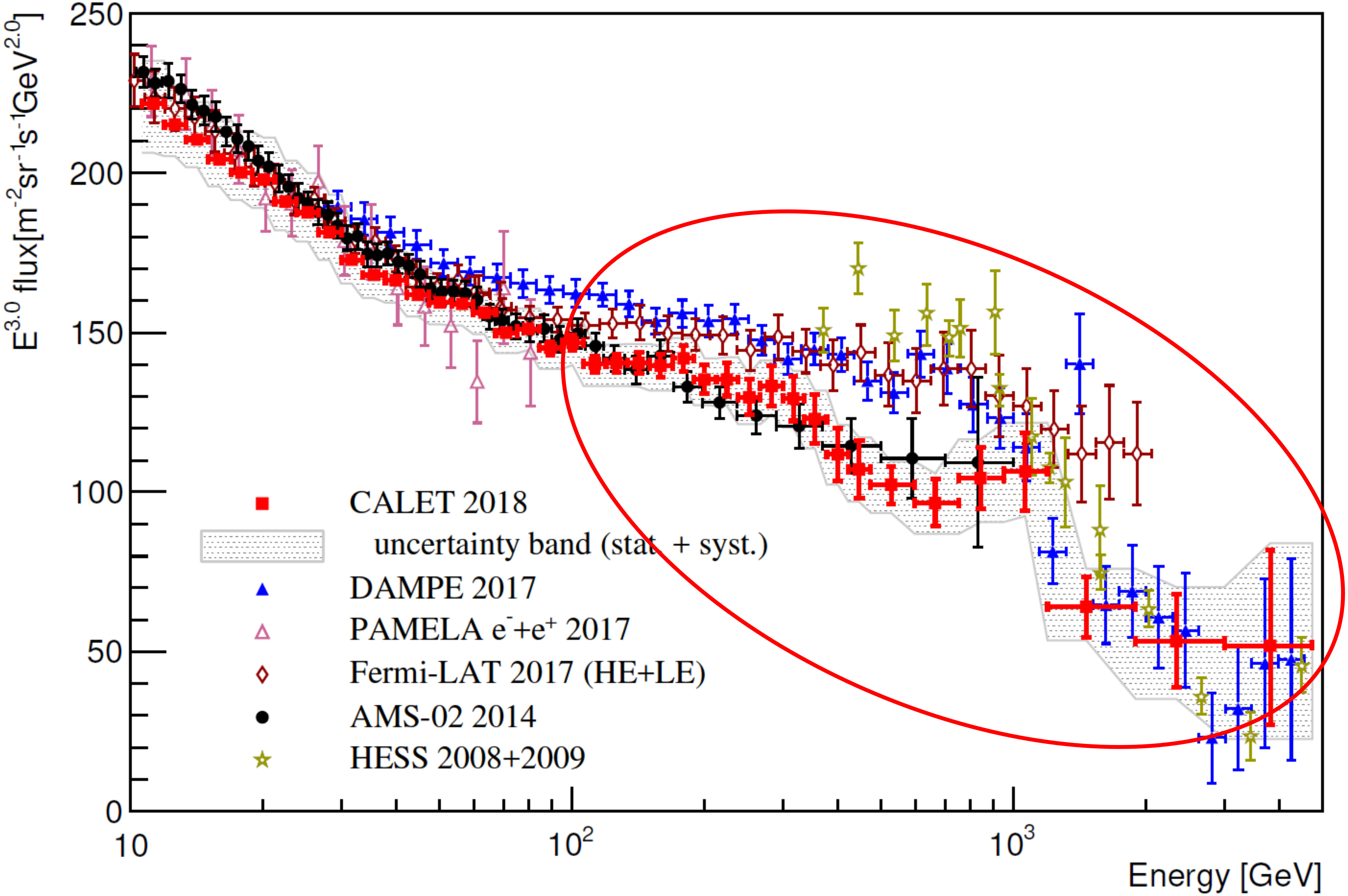
5. Studying diffuse gamma rays







6. Clarification of electron + positron spectrum due to best energy resolution and thicker (18-43 X_0) calorimeter



arXiv:1806.09728

	Space-based gamma-ray telescope						Ground-based facilities
	Medium energy			High-energy			
	ASTROGAM	AMEGO	Fermi-LAT	GAMMA-400	HERD	AMS-100	CTA
Country	Europe	USA	USA	**Russia**	China	Europe +USA	
Energy range, γ rays	0.3 MeV – 3 GeV	0.2 MeV - 10 GeV	50 MeV – 1000 GeV	**20 MeV – 1 TeV**	0.5 GeV – 10 TeV	1 GeV – 10 TeV	> 50 GeV
Observation mode	Scanning	Scanning	Scanning	**Source**	Scanning	Scanning	Scanning
Orbit	Circular, ~550 km	Circular, ~550 km	Circular, ~550 km	**Highly elliptical, 500-300 000 km**	Circular, ~400 km	L2	
Angular resolution	0.1°	1°	0.1°	**~0.01°**	0.1°	~0.01°	0.1°
Energy resolution	20%	10%	10%	**~2%**	1-2%	1-2%	15%

Performance of future gamma-ray telescopes in comparison with Fermi-LAT

Conclusions

- **After Fermi-LAT the GAMMA-400 mission represents a unique opportunity to significantly improve the direct data of LE+HE gamma rays and electron + positron fluxes due to unprecedented angular and energy resolutions, large area, and continuous long-term simultaneous coaxial gamma-ray and X-ray telescope observations.**

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

ROSCOSMOS

GAMMA-400 is funded by the Russian Space Agency and the GAMMA-400 space observatory is scheduled to launch in ~2030 with Angara-A5M launch vehicle from Vostochniy cosmodrome (contract no. 024-5004/16/224)

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