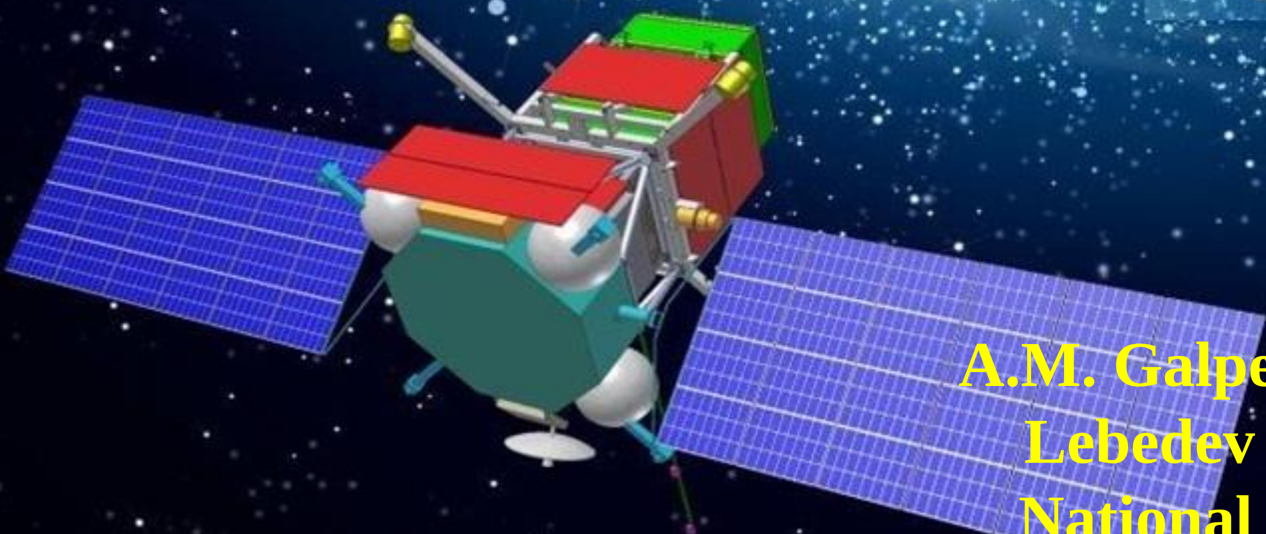
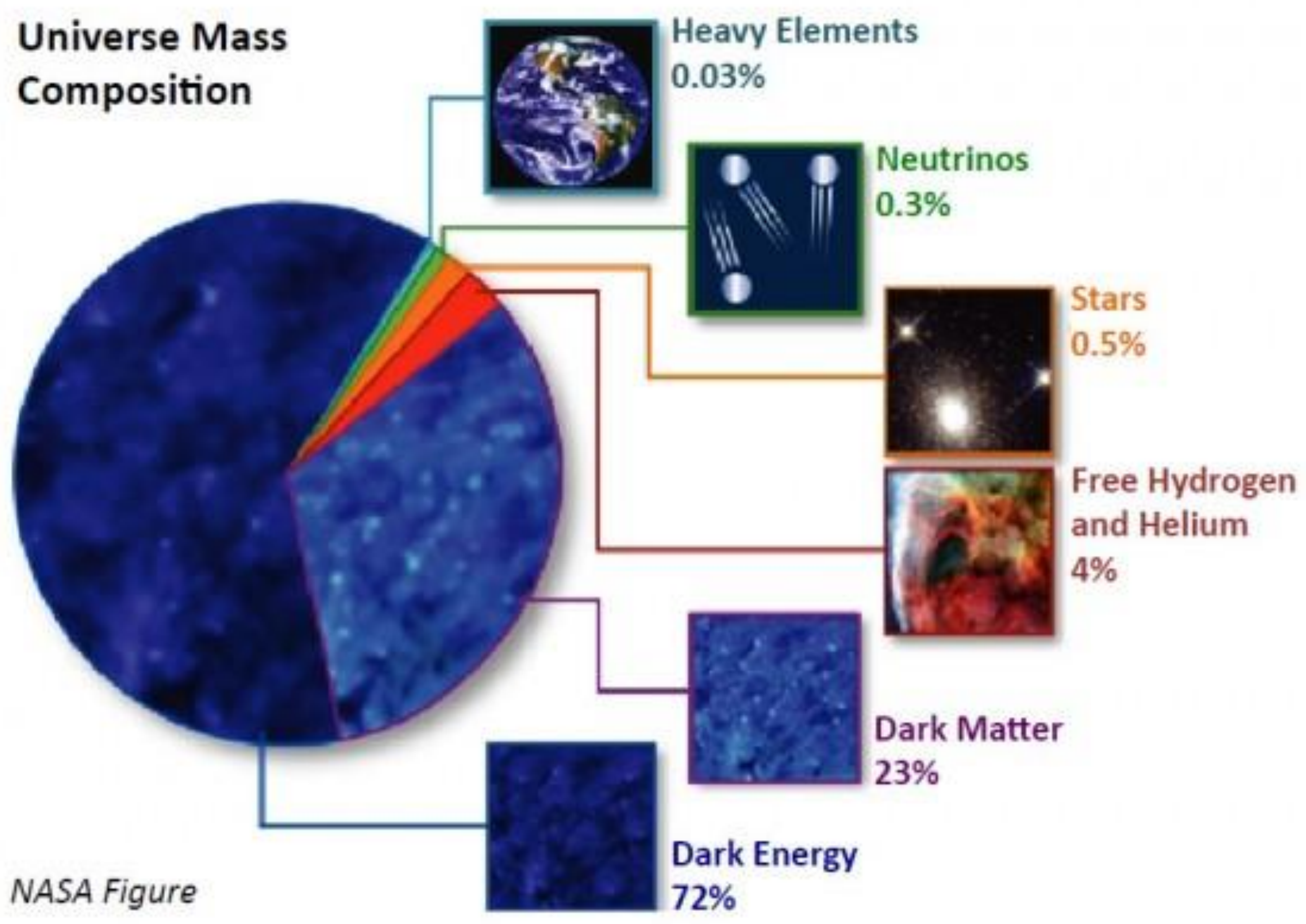
From PAMELA mission to GAMMA-400 project – The indirect search for signatures of dark matter



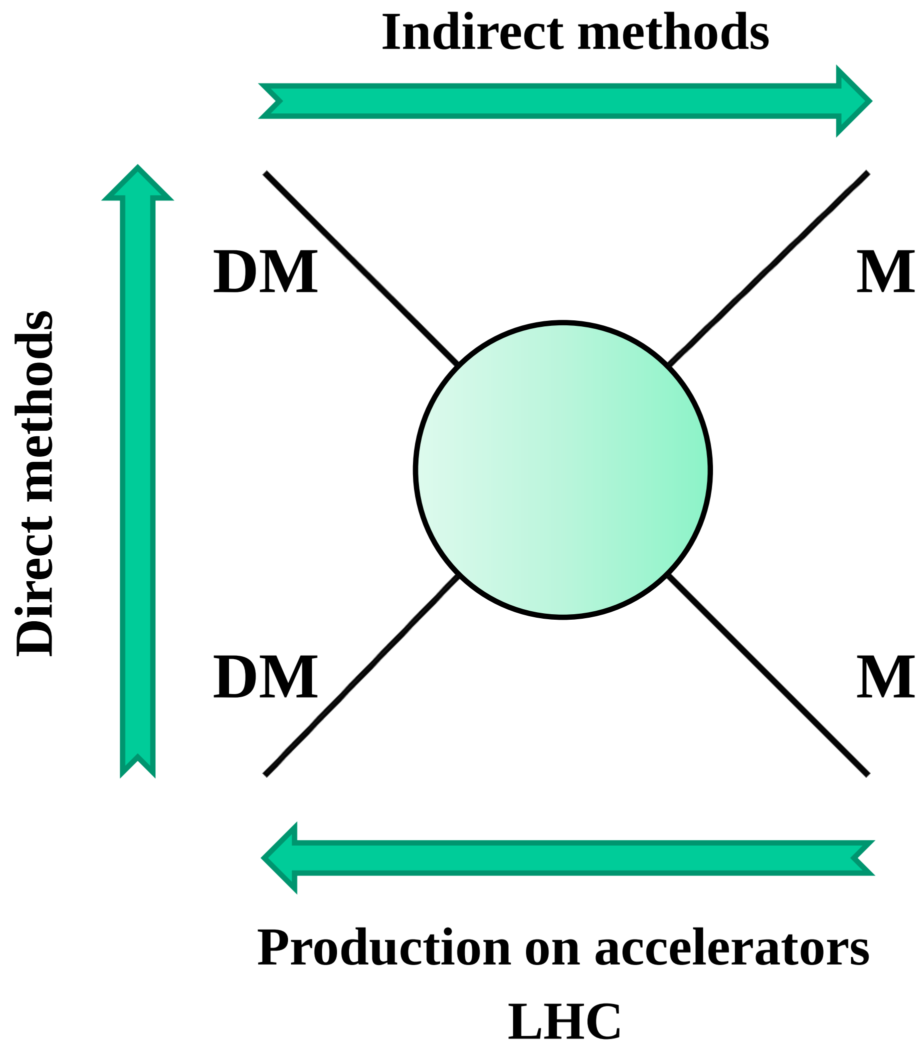
A.M. Galper and N.P. Topchiev
Lebedev Physical Institute
National Research Nuclear University MEPhI

ICPPA-2017, October 3, 2017

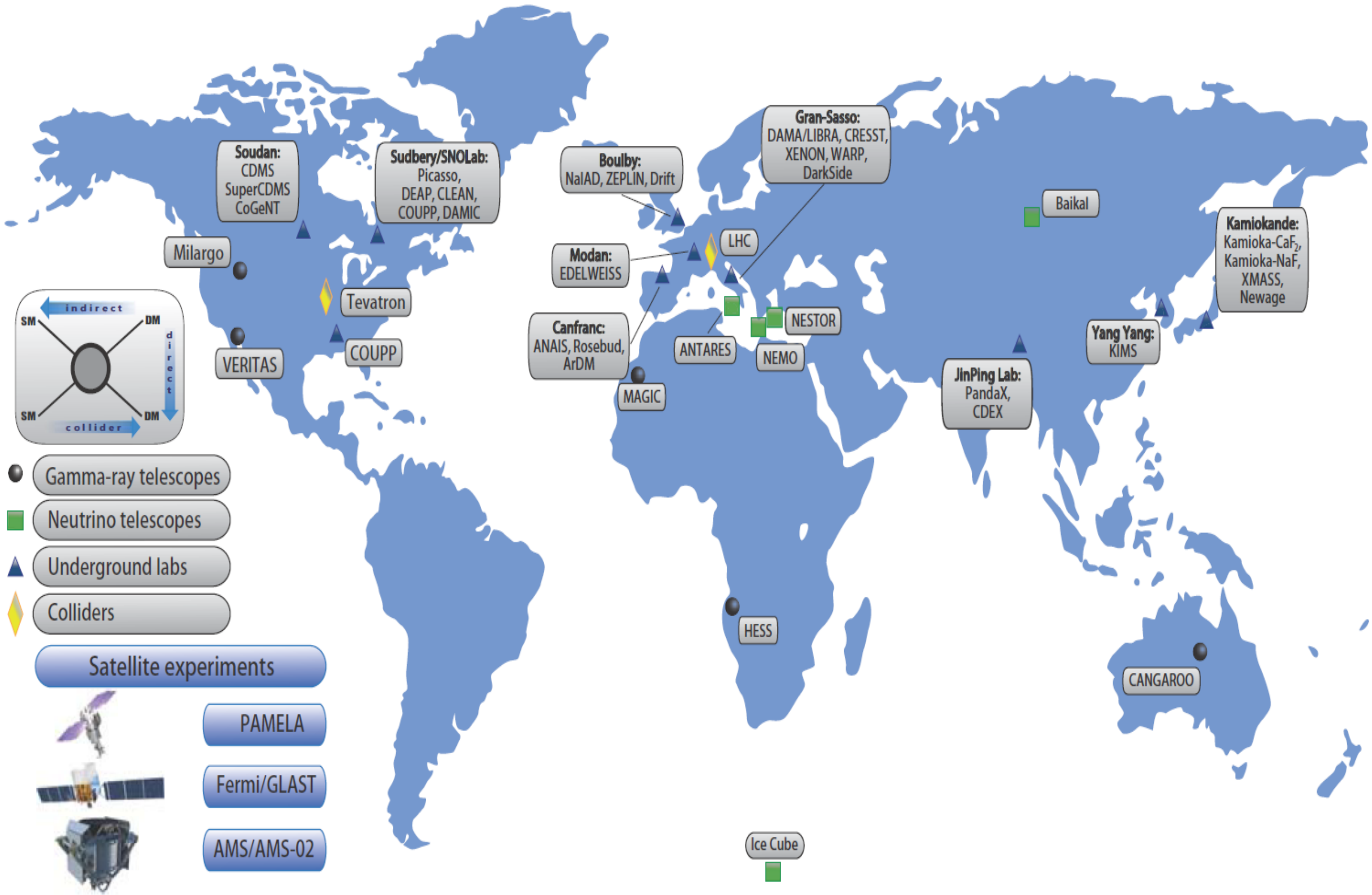


After precision measurements of relic microwave radiation on the WMAP and Planck space missions, the Universe mass composition was determined.

Dark matter searches

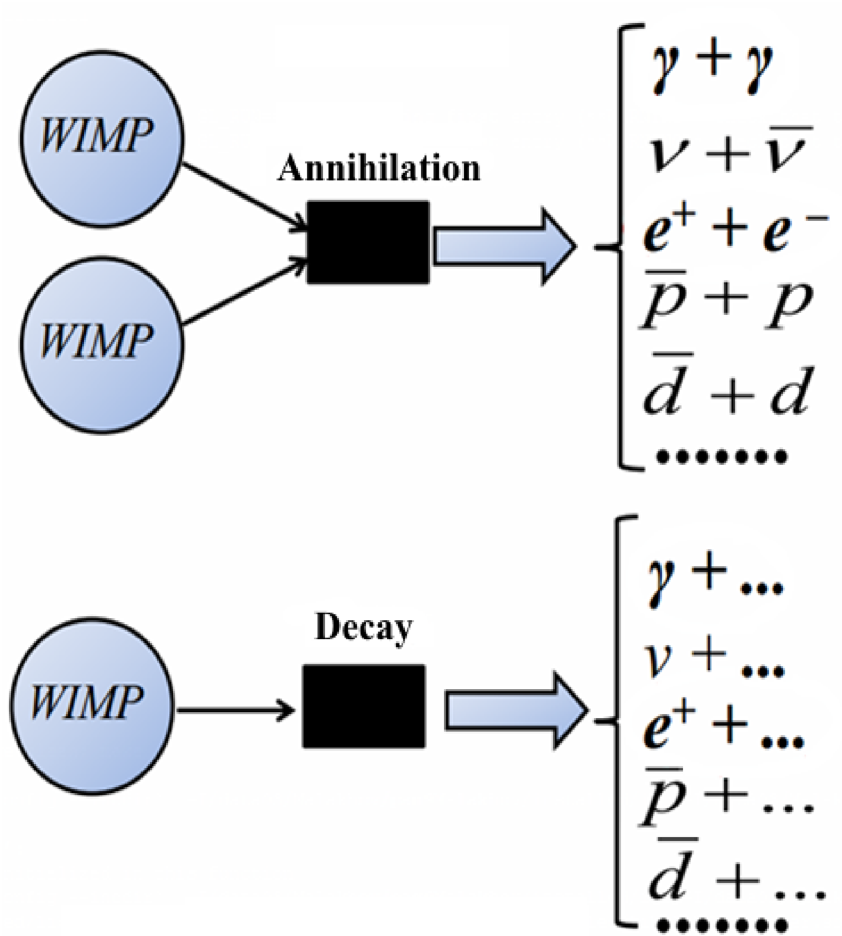


M – baryonic Matter
DM – Dark Matter



Locations of different experiments to search for dark matter particles [arXix:1510.06927]. Direct searching: underground labs, colliders; indirect searching: ground-based gamma-ray telescopes, neutrino telescopes, satellite experiments – PAMELA, Fermi/Glast, AMS/AMS-02.

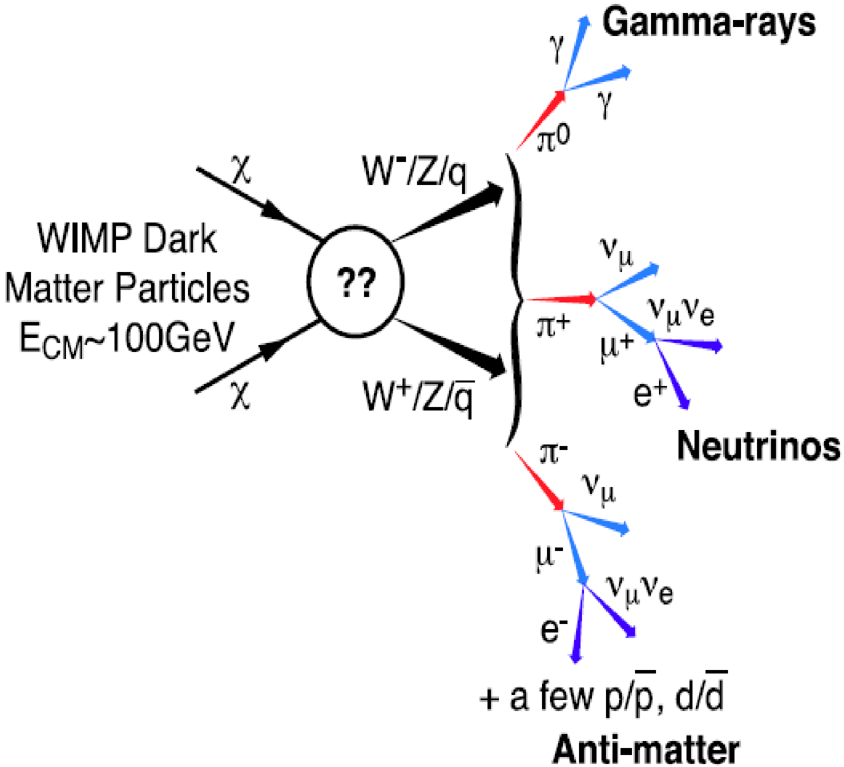
Indirect searches

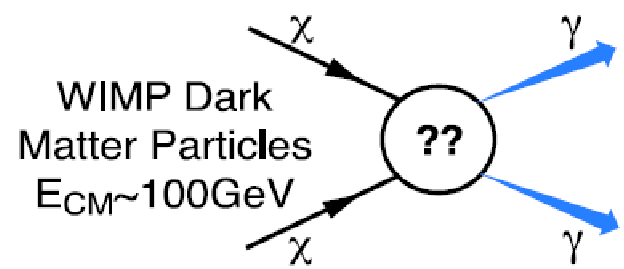


Among the most promising particle candidates are Weakly Interacting Massive Particles (WIMPs), which typically can annihilate or decay to produce electrons + positrons, proton + antiproton, gamma rays, etc.

Possible channels of WIMP annihilation to produce electrons + positrons, proton + antiproton, gamma rays, etc.

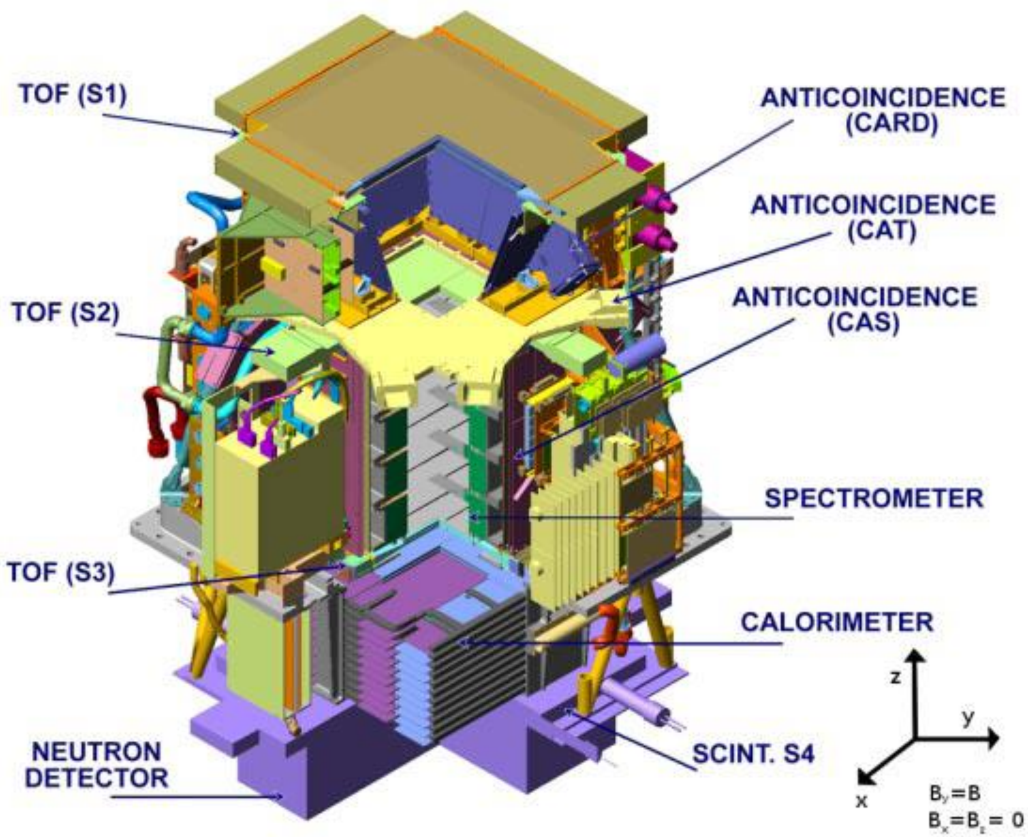
$$b\bar{b}, t\bar{t}, \tau^+\tau^-, \mu^+\mu^-, e^+e^-, Z^0Z^0, Z^0\gamma, W^+W^-, HH, \ldots$$





The main problem is to reveal features in the energy spectra in the form of anomaly (additional) particle flux or monoenergetic gamma-ray lines

PAMELA space mission (2006-2016)

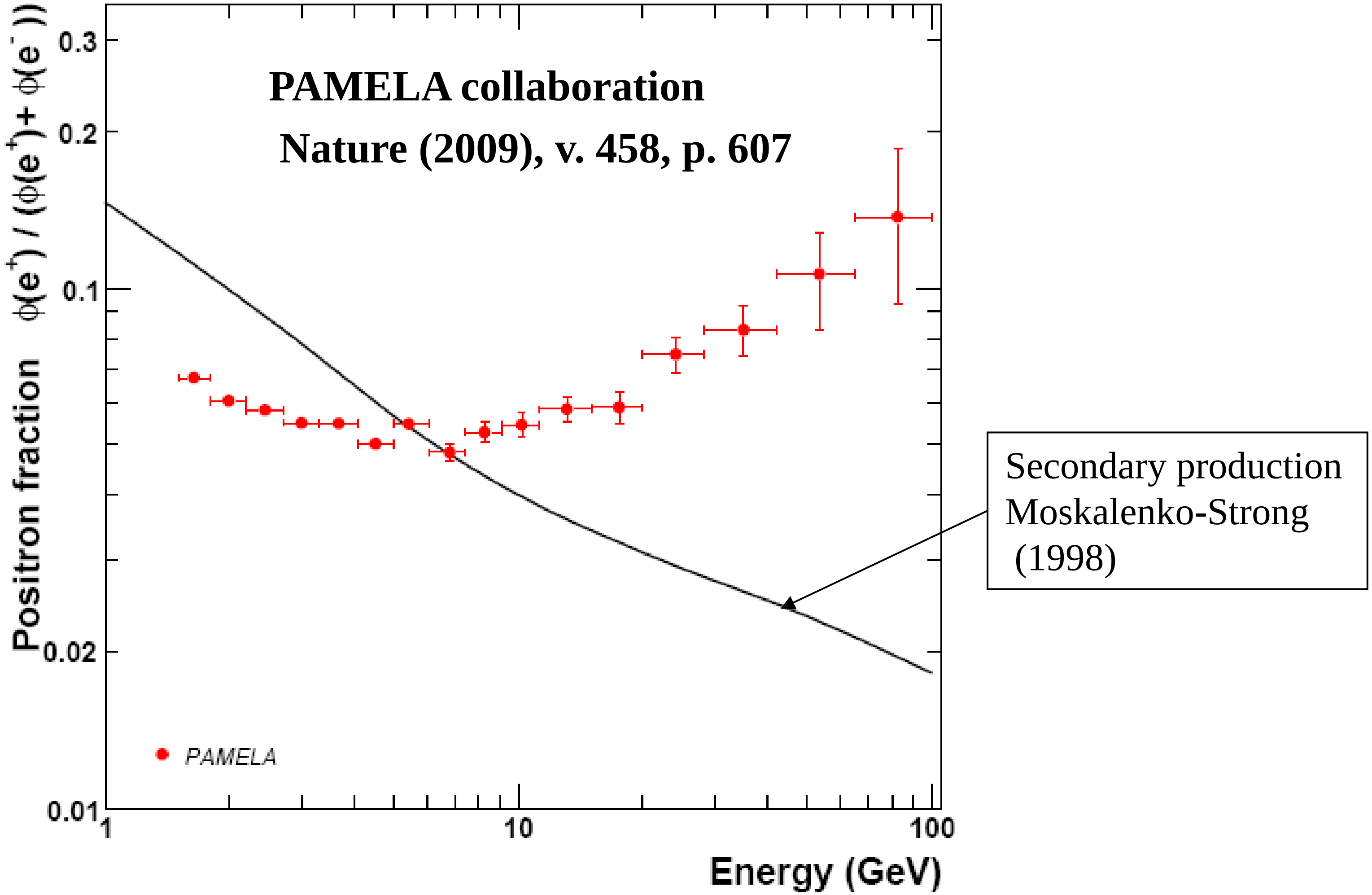


Energy range:

protons	0.08-1000 GeV
antiprotons	0.06-350 GeV
electrons	0.05-650 GeV
positrons	0.05-250 GeV
antinuclei	0.1-45 GeV/nuc.

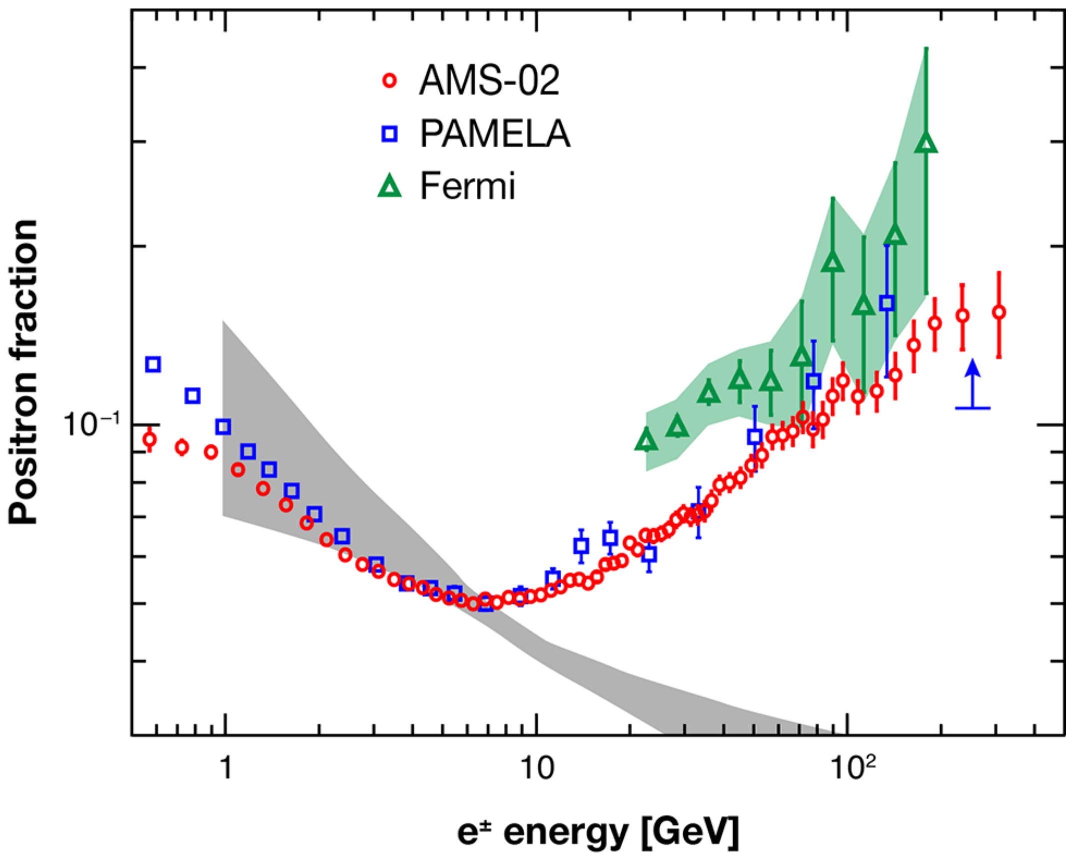
Mass	450 kg
Dimensions	1 m × 1 m ×1.25 m
Magnetic induction	0.48 T
Power	350 W

Positron to electron + positron ratio



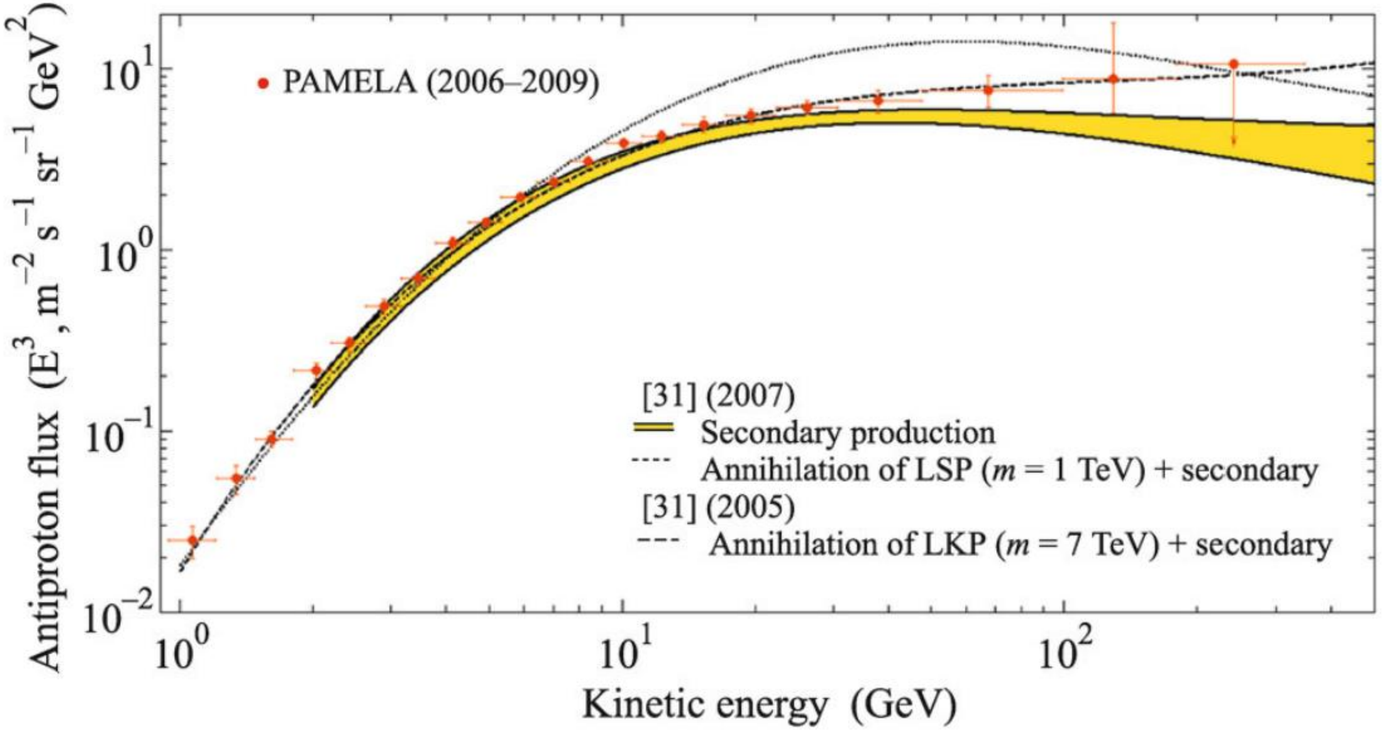
In 2008, PAMELA has discovered unpredicted abundance of the ratio of the galactic positron flux to the total positrons and electrons flux at high energies. It does not agree with the cosmic-ray fluxes calculated using GALPROP code. This abundance was called the “anomalous effect PAMELA” and one of the explanations of this effect was the appearance of the additional electrons and positrons flux due to annihilation or decay of the dark matter particles.

PAMELA vs AMS-02: electron to positron ration



Later the anomalous effect of PAMELA was confirmed by the Fermi-LAT gamma-ray telescope and the AMS-02 magnetic spectrometer.

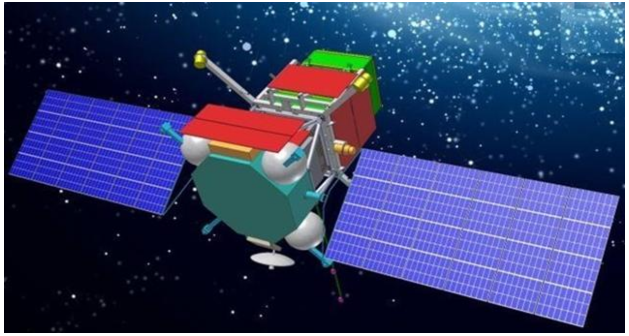
Antiproton to proton ratio

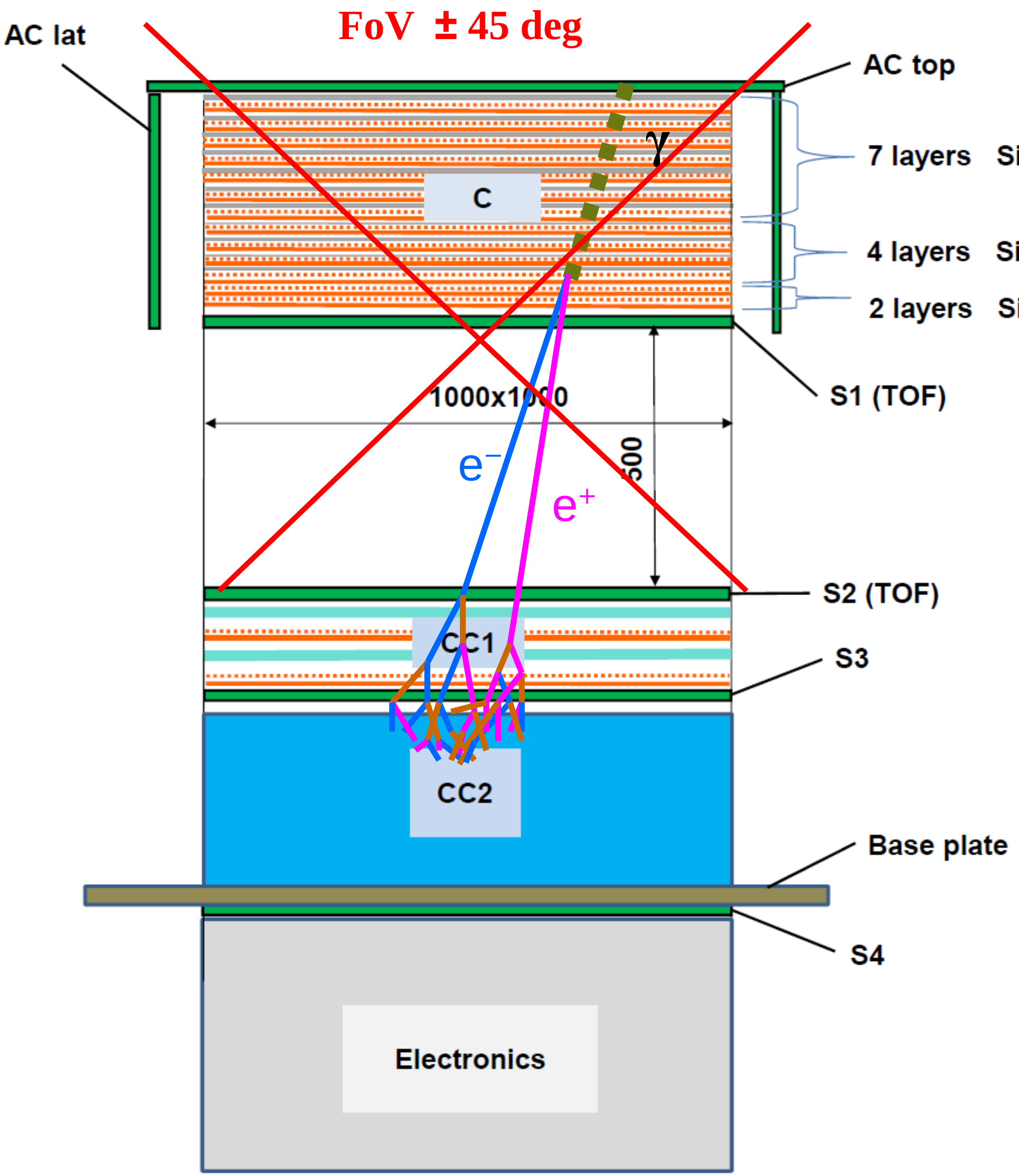


Adriani O., et al. JETP Lett. 96 (2013) 621-627

According the PAMELA data the antiproton to proton ratio in the energy range > 10 GeV has some excess in comparison with theoretical calculations. This can be explained by the contribution of dark matter particles.

GAMMA-400 space mission (~2025)





AC – anticoincedence system
C - converter-tracker ~1 X_0
S1, S2 – TOF detectors
CC1, CC2 – calorimeter ~22 X_0
S3,S4 – scintillator detectors

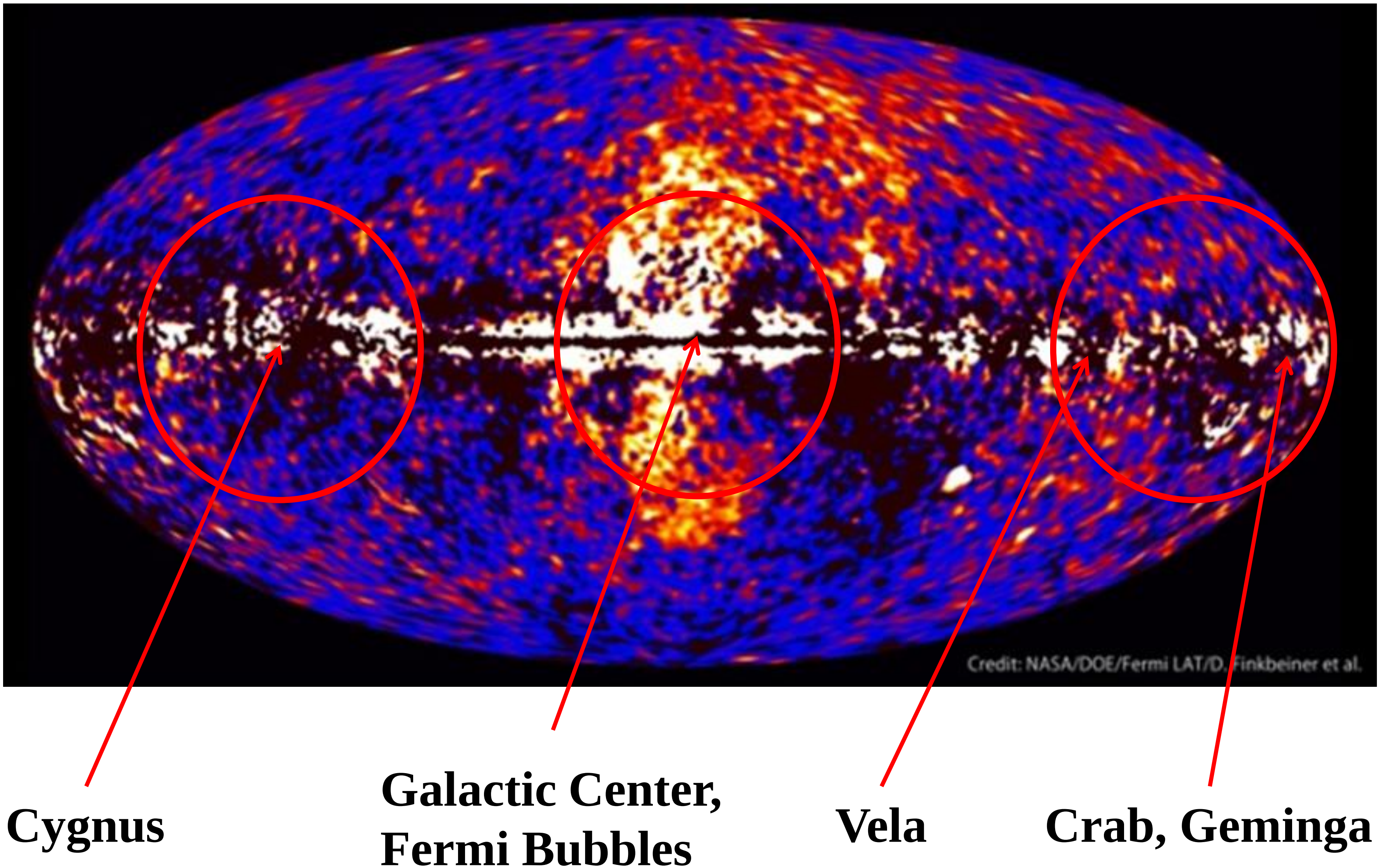
$$\overline{AC} \times S1 \times S2$$

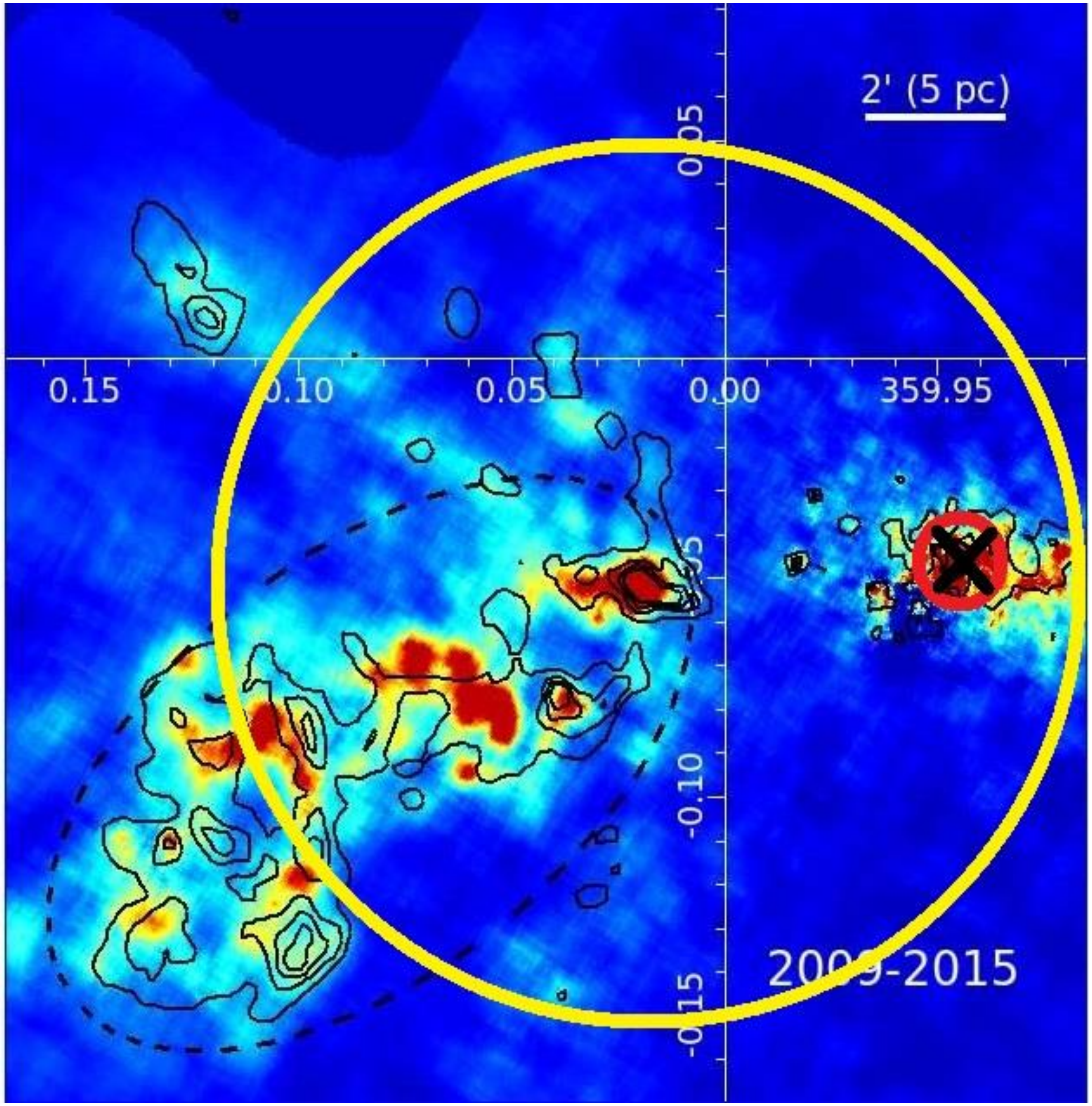
ΔE = ~20 MeV – ~10 TeV
$\Delta\theta$ = ~2° (E_γ = 100 MeV)
$\Delta\theta$ = ~0.01° (E_γ = 100 GeV)
$\Delta E/E$ = ~10% (E_γ = 100 MeV)
$\Delta E/E$ = ~1% (E_γ = 100 GeV)

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-~10000**	> 30	> 50	> 100	> 20
Angular resolution (E_γ > 100 GeV)	0.1° (E_γ~1 GeV)	0.1°	0.1°	0.1°	**~0.01°**	0.07°	0.07° (E_γ = 300 GeV)	0.1°	0.1° (E_γ = 100 GeV) 0.05° (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)

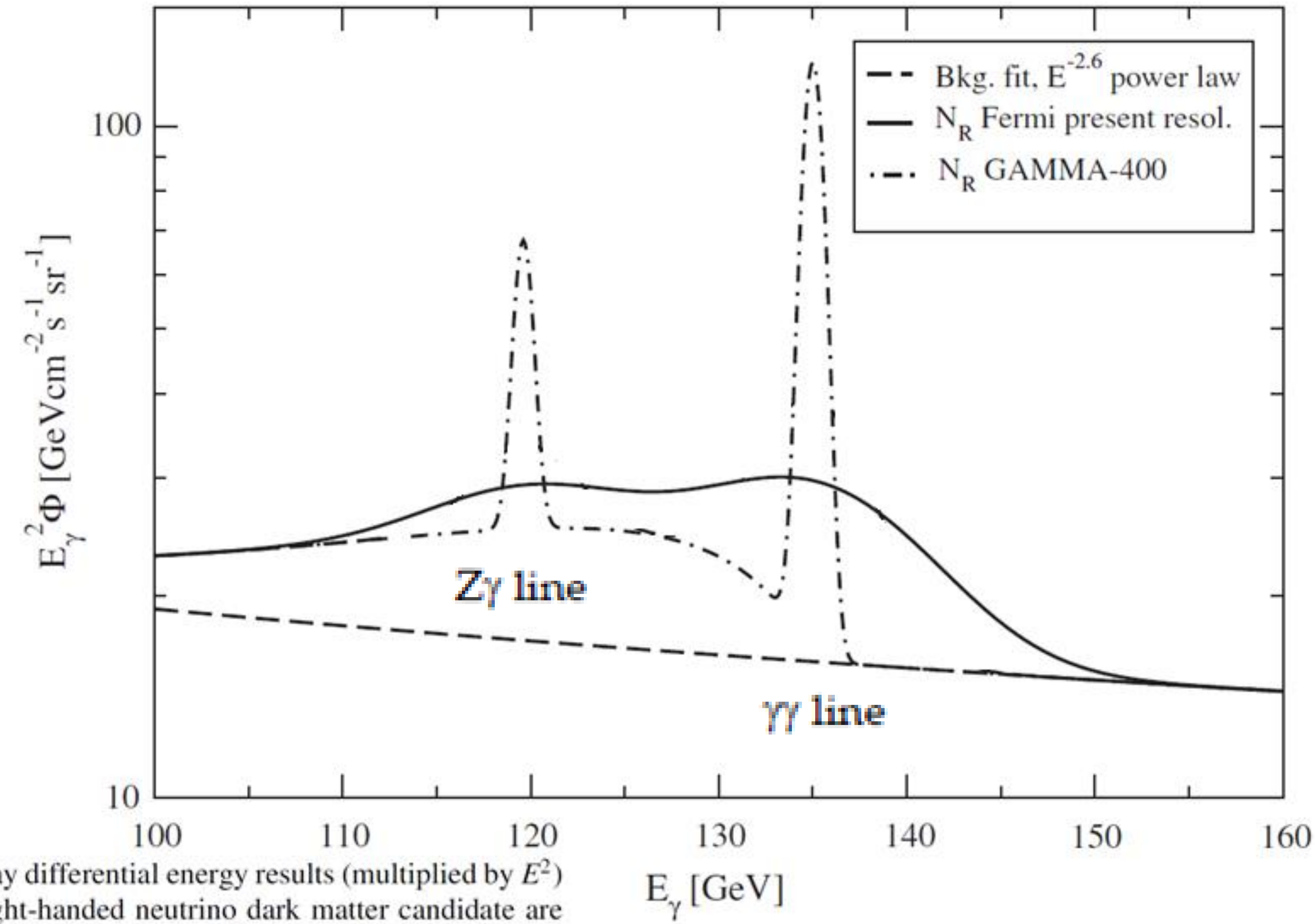
Galactic Center, Fermi Bubbles, Crab, Cygnus, Vela, Geminga, and other regions will be observed with the GAMMA-400 aperture of ±45°





Comparison of the capabilities to study Galactic Center by Fermi-LAT with the angular resolution of ~0.1° for E_γ = 100 GeV (yellow circle) and GAMMA-400 with the angular resolution of ~0.01° for 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*

Conclusions

- **PAMELA mission has made a significant contribution to search for dark matter particles.**
- **GAMMA-400 mission represents a unique opportunity to continue the search for dark matter particles in the LE+HE gamma-ray energy range with unprecedented angular and energy accuracy.**
- According the new approved Russian Federal Space Program 2016-2025 the GAMMA-400 space observatory is scheduled to launch in 2025-2026.