Dark matter search perspectives with GAMMA-400

Alexander Moiseev

CRESST/NASA/GSFC and University of Maryland, College Park, USA

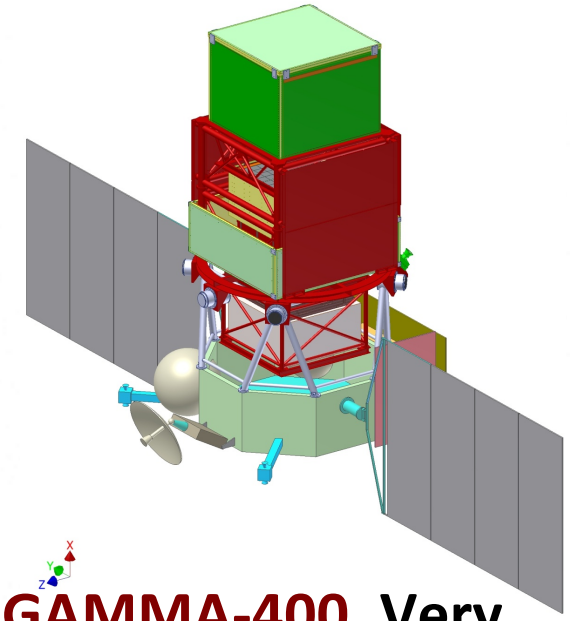
and A.M. Galper

Lebedev Physical Institute and National Research Nuclear University MEPhI, Moscow, Russia

on behalf of the GAMMA-400 team

What is GAMMA-400?

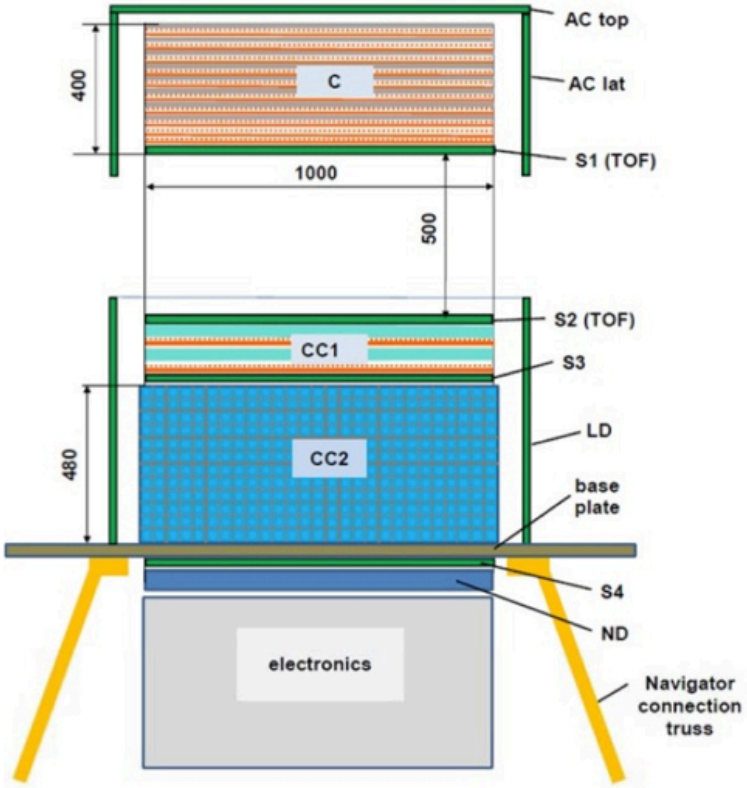
- A new high-energy space γ-ray telescope. Approved and fully funded by Russian Space Agency
- **GAMMA-400 goals:** follow and deepen the findings of Fermi LAT (similar energy range and instrument overall capabilities)



- **Search for dark matter is the main goal for GAMMA-400**. Very suitable for the search for WIMPs. Enhanced performance at high energy (> 10 GeV): PSF and energy resolution
- **Launch is planned for 2018-2019**

Talk by N. Topchiev (ID 264), session GA-IN03, Sunday 5pm

GAMMA-400 Concept



Energy range	**100 MeV – 3000 GeV**
Field-of-view, sr (E > 1 GeV)	**~1.2**
Effective area, cm^2 (E > 1 GeV)	**~5,000**
Energy resolution (E > 10 GeV)	**~1%**
Angular Resolution (E >100 GeV)	**~0.01°**
Converter-tracker thickness	**~ $1X_0$**
Calorimeter thickness	**~ 25 X_0**
Proton rejection factor	**~ 10^6**
Telemetry downlink volume, GB/ day	**100**
Total mass, kg	**2,600**
Maximum dimensions, m	**2.0 x 2.0 x 3.0**
Power consumption, W	**2,000**

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

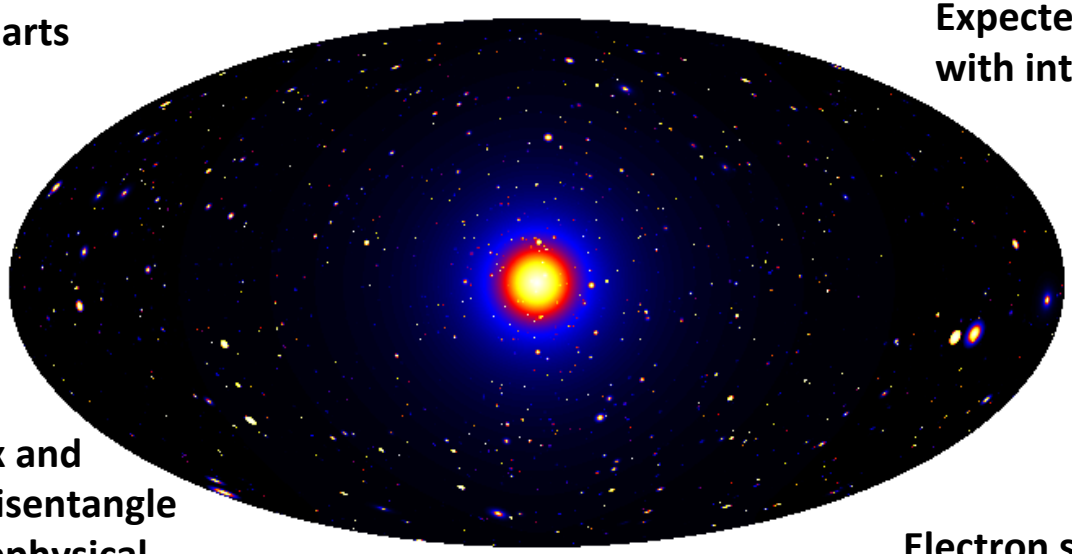
Dark matter signature	=	Observed spectrum / spatial features	-	γ-ray sources	-	Known backgrounds (diffuse γ-radiation etc.)

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

Dark Matter predicted in γ-ray sky

Satellites: Unidentified sources: search for counterparts

Galactic Center: spectrum. Expected large DM signal but with intensive background

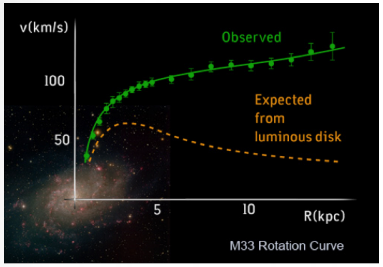


Dwarf spheroidal galaxies and galaxy clusters: flux and spectrum

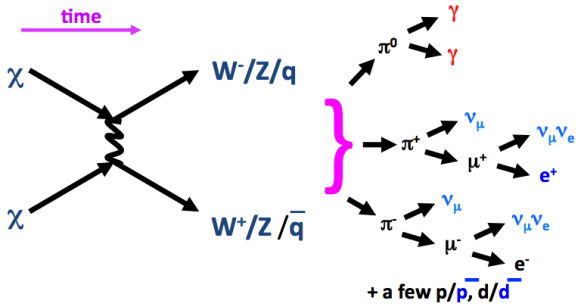
Spectral Lines: Smoking gun ! However low statistics

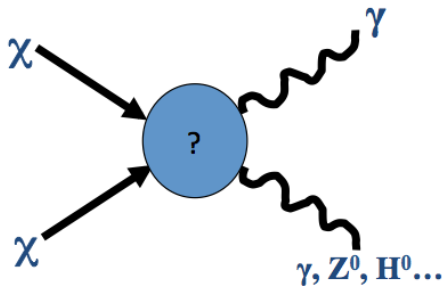
Isotropic diffuse: flux and spectrum. Need to disentangle DM signal from astrophysical origin. Need to resolve all "conventional" sources

Electron spectrum: difficult to disentangle DM signal from astrophysical origin, but good complementary to γ-ray results

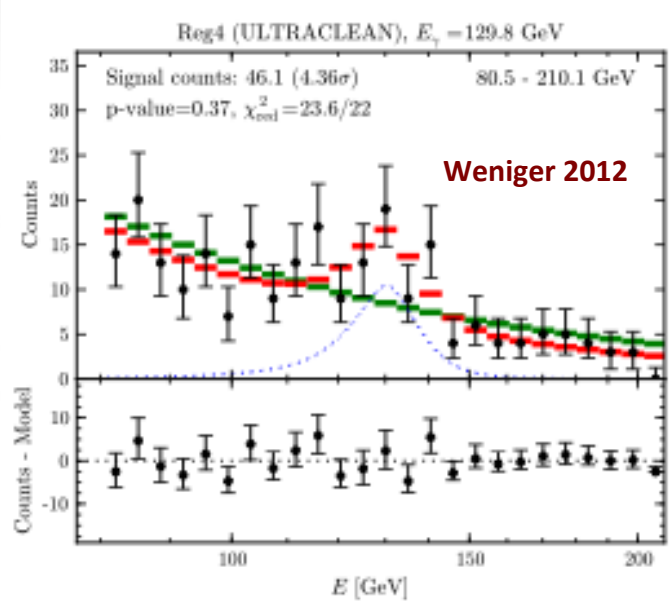


Large halos around Galaxies: Rotation Curves





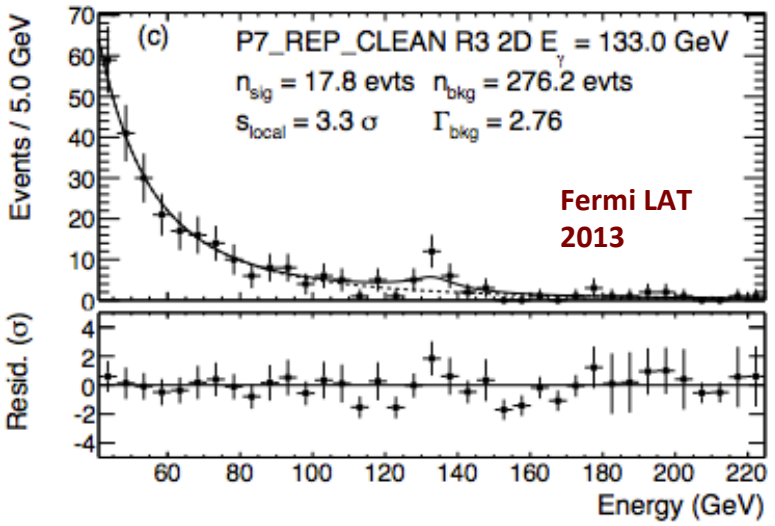
Probably the most exciting recent result in the indirect search for Dark matter: Fermi LAT 135 GeV line



- **Smoking gun, if found**
- **Search for the line in isotropic radiation; also from Galactic Center**
- **First reported by C. Weniger and T.Bringmann et al. in 2012, coming from Galactic Center. It has been widely discussed by scientists of different fields**

Fermi LAT 135 GeV line

- **Fermi LAT team performed careful analysis of this result:**
  - **feature is also seen in Earth Limb control sample, but not large enough to explain all of Galactic Center signal**
  - **Significance of feature decreases with analysis improvements**



- **Current result: global significance of 1.6 σ (with local significance 3.3 σ) and energy 133 GeV**
  - **We can not rule out earlier claims, but also can not claim globally significant signal. Intense work continues**
- **GAMMA-400, with its high energy and angular resolution, is the only currently planned experiment with good perspectives to resolve the situation**

Fermi LAT collaboration: M. Ackermann et al., arXiv:1305.5597, submitted to PRD

γ-ray lines in diffuse radiation : Perspectives for GAMMA-400

Sensitivity to the γ-ray line (flux) in the diffuse radiation can be expressed in simplified form as: $$I_\gamma = \frac{n_\sigma}{0.68}\sqrt{\frac{2F_{bck}\eta E_\gamma}{GT}}$$

where n is a number of σ , F_{bck} is a (diffuse) background, ηEγ is an energy bin width, which depends on η (energy resolution), G is a geometric factor, T is an observation time

Comparison of Fermi LAT and GAMMA-400 sensitivity:

- ηEγ for GAMMA-400 is ~10X less than that for Fermi LAT at E>100 GeV,
- G for GAMMA-400 is ~ 0.5 of that for Fermi LAT,
- the sensitivity for GAMMA-400 for the same observation time is expected to be ~ 2 better than for Fermi LAT.

γ-ray line from source : Perspectives for GAMMA-400

Assumptions: a) point source; b) The line is a δ-function in energy spectrum

Significance estimate: Significance of the line detection can be taken similarly to the confidence in detection of point source (probability for the background to fluctuate to create a "feature")

$$C = \frac{N_{sig}}{\sqrt{N_{bkg}}}$$

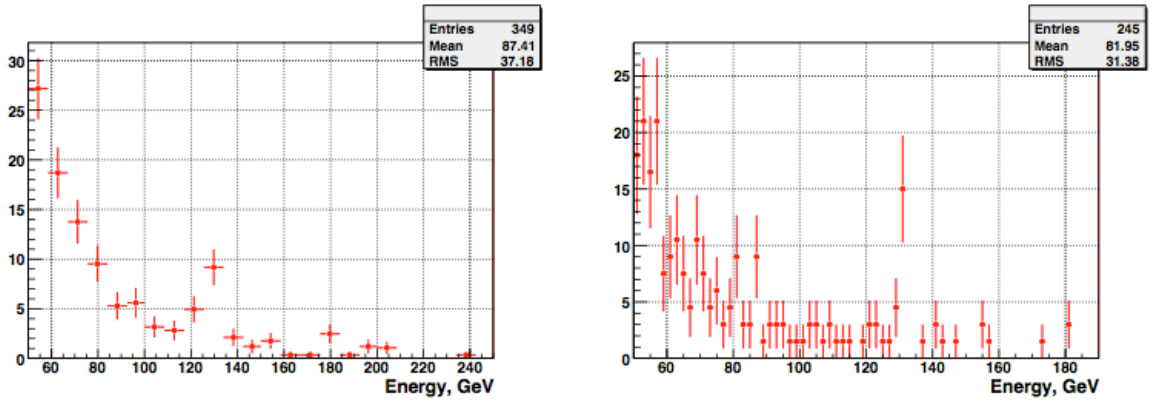
where N_{sig} is a number of events from the "line" (source), and N_{bkg} is a number of background (diffuse) events

With 10X better PSF for Gamma-400:

- N_{bkg} can be ~100X less,
- detection significance C will be ~5X larger, assuming twice less events from the "line" N_{sig} detected (due to smaller A_{eff})

γ-ray line from extended source

- A more likely scenario is that the line is produced in extended source, likely at Galactic center.
- High angular resolution will be helpful in resolving the structure of the source(s).
- High energy resolution will allow to use fine energy binning in reconstructing the spectrum, significantly increasing the line detection significance.



Simulated with toy model. Left : for Fermi LAT (4 years), ~300 events; right: GAMMA-400, 10X better dE/E and twice fewer events

Galactic Center

- **Expected to be the strongest source of γ-rays from DM annihilation.**
- **Intense background from unresolved sources remains the main problem, assuming that the part of background created by CR interactions with the matter, is much better known and can be accounted for**
- **Potential perspectives for GAMMA-400: having >10 times better angular resolution at high energy, faint sources in dense GC area can be localized and their radiation can be removed as a background, and better model of diffuse radiation can be built.**

Satellites (clumps)

Features to search for:

- Hard (Not power-law) energy spectrum
- Extended spatial dimensions
- Lack of counterparts in other wavelengths

Approach:

- Check among non-ID Fermi LAT γ-sources to meet the above criteria

Fermi LAT (Ackermann et al., ApJ 747, 121, 2012):

- 2 DM satellite candidates were found out of 385 un-ID high latitude sources, 1FGL J1302.3-3255 and 1FGL J2325.8-4043
- 1FGL J1302.3-3255 was later associated with a millisecond pulsar (by radio observations)
- 1FGL J2325.8-4043 was found to have a high probability association with two AGN: 1ES 2322-409 and PKS 2322-411
- Conclusion: no viable DM satellite candidate was found so far
- Upper limit for $<\sigma v>$ is set to 1.95 x 10^{-24} cm^3 s^{-1} for a 100 GeV WIMP annihilation through bb channel

Satellites : Perspectives for GAMMA-400

Features to search for:

- Hard (Not power-law) energy spectrum
- Extended spatial dimensions
- Lack of counterparts in other wavelengths

Approach:

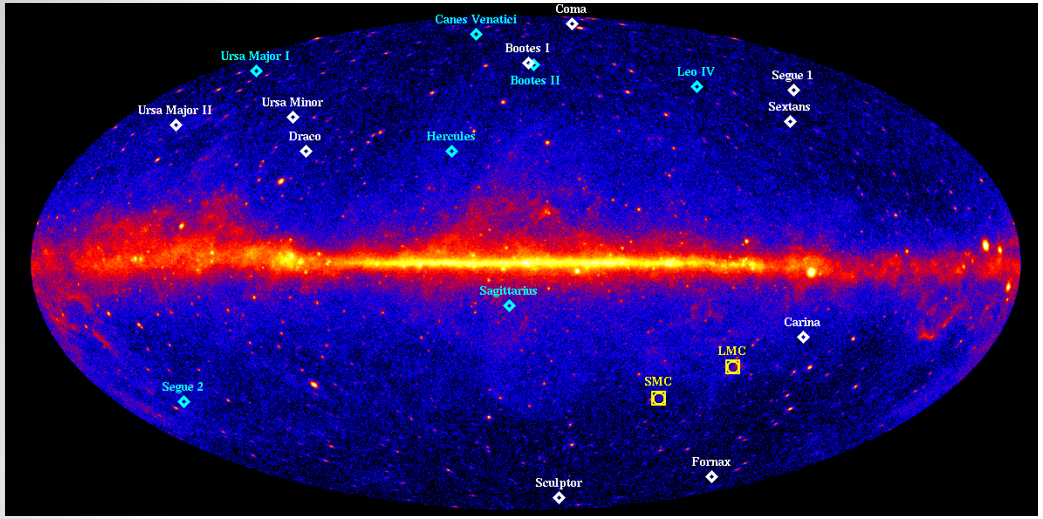
- Check among available by that time non-ID Fermi LAT and GAMMA-400 (if found) *γ*-sources to meet the above criteria

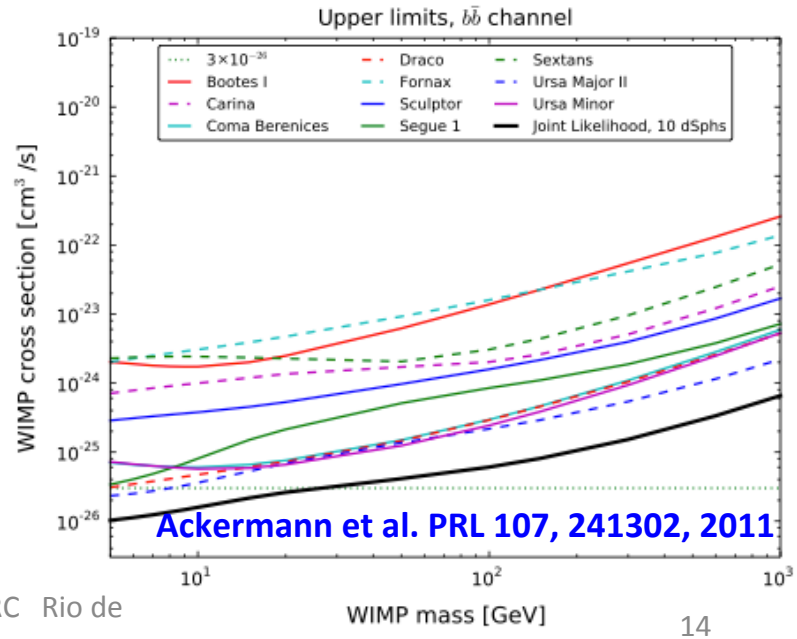
Perspectives:

- Better energy resolution will allow to better distinguish between power-law "normal source" and hard DM spectra, potentially increasing the number of satellite candidates
- Better angular resolution will allow to better distinguish between point and extended sources, also potentially increasing the number of satellite candidates
- Larger number of available by that time non-ID Fermi LAT sources shall also increase the number of satellite candidates

Dwarf Spheroidal Galaxies: prominent DM candidates

- Search for γ–ray emission from Dwarf Spheroidal Galaxies (satellite galaxies) with large J-factor (line-of-sight integral of the squared DM density)
- Fermi LAT applied a joint likelihood analysis to 10 satellite galaxies: no dark matter signal was detected. Upper limit for $\langle \sigma v \rangle$ is set to ~10^{-26} cm^3 s^{-1} at 5 GeV and 5 x 10^{-23} cm^3 s^{-1} at 1 TeV (Ackermann et al. PRL 107, 241302, 2011)
- This is the first result using γ-rays, that rules out the models with the most generic cross section ~ 3 × 10^{-26} cm^3 s^{-1}





Dwarf Spheroidal Galaxies: Perspectives for GAMMA-400

Joint likelihood (for 10 dSphs) of agreement between observed *γ*-radiation and that predicted by DM model:

Energy-binned *γ*-ray data; should be better for Gamma-400

$$L(D|\mathbf{p}_{\mathrm{W}}, \{\mathbf{p}\}_i) = \prod_i L_i^{\mathrm{LAT}}(D|\mathbf{p}_{\mathrm{W}}, \mathbf{p}_i) \times \frac{1}{\ln(10) J_i \sqrt{2\pi}\sigma_i} e^{-[\log_{10}(J_i) - \overline{\log_{10}(J_i)}]^2/2\sigma_i^2},$$

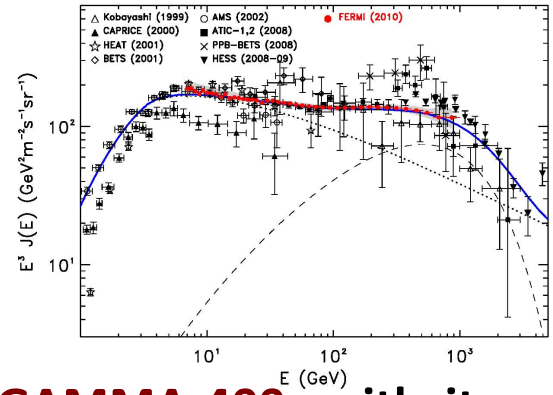
Binned Poisson likelihood fully accounting of the PSF (E); should be better for Gamma-400

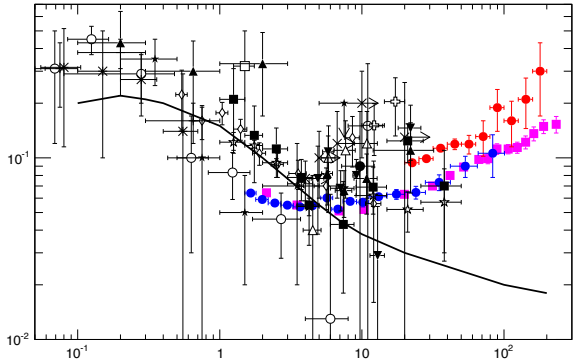
Improved dE/E and PSF for GAMMA-400 should provide better sensitivity for this analysis

Cosmic rays: Electrons and Positrons

Current data on the inclusive electron spectrum (Fermi LAT, H.E.S.S., PAMELA) and positron fraction (PAMELA, Fermi LAT, AMS-02) cannot be explained within conventional single-component model,

- **introduction of an additional e^+e^- component with hard spectrum can resolve the problem,**
- **This component can be astrophysical (many different scenarios have been considered) or "exotic", such as dark matter clump. Needs data from other experiments**





GAMMA-400: with its superior energy range and resolution can provide important information on the spectral structure and spectral index drop above ~1 TeV (as reported by H.E.S.S.)

SUMMARY

- **GAMMA-400 will be a very important successor of the Fermi LAT and will provide important observations of *γ*-rays and cosmic rays in synergy with ground-based *γ*-ray telescopes and other wavelength instruments. After the end of the Fermi LAT mission, GAMMA-400 will be the only flying *γ*-ray observatory**
- **GAMMA-400 main differences from Fermi LAT are ~10 times better angular and energy resolution at energy > 100 GeV**
- **The main objective for GAMMA-400 is to conduct an accurate measurement of the *γ*-radiation to search for the dark matter smoking gun: *γ*-ray lines. It will be at least twice more sensitive in this search compared to Fermi LAT**
- **Significant contributions to the dark matter constraints will be made with the study of *γ*-ray clumps, satellite galaxies, and Galactic Center. Also important results are expected with cosmic ray electrons and positrons**
- **Stay tune !**

THANK YOU !