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L P I

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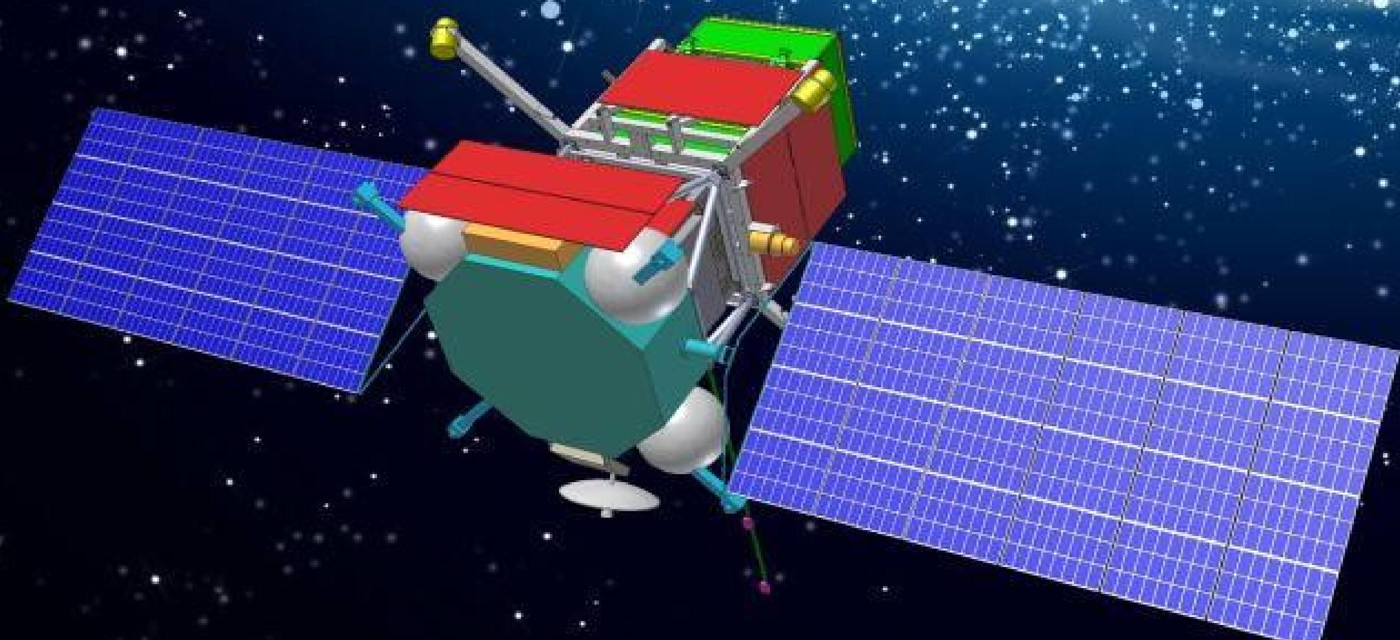
for the GAMMA-400 Collaboration

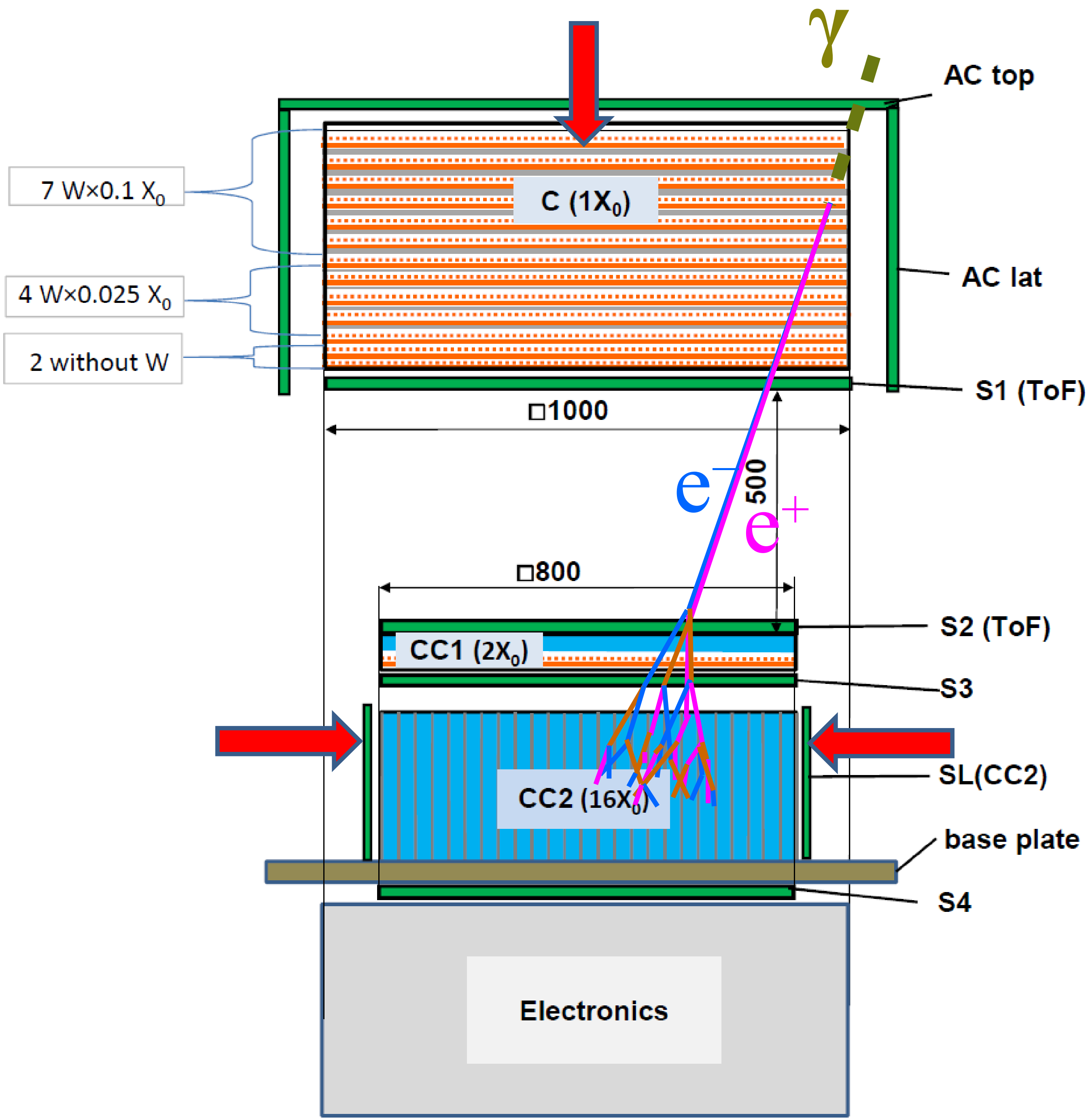
Dark matter searches by means of the GAMMA-400 gamma-ray telescope.



23-29 June 2019, 10th A.Friedmann seminar on gravitation and cosmology, Saint Petersburg

Brief overview of the planned GAMMA-400 mission

GAMMA-400 physical scheme: pair-converting calorimetric telescope for γ and $e^{\pm}$ detection



AC – anticoincedence system

C - converter-tracker ~1 X_0

(X_0 ≡ radiation length)

S1, S2 – time-of-flight detectors

CC1, CC2 – calorimeters with vertical thickness ~2+16=18 X_0

CC2 lateral thickness ~43 X_0

S3, S4 – scintillator detectors

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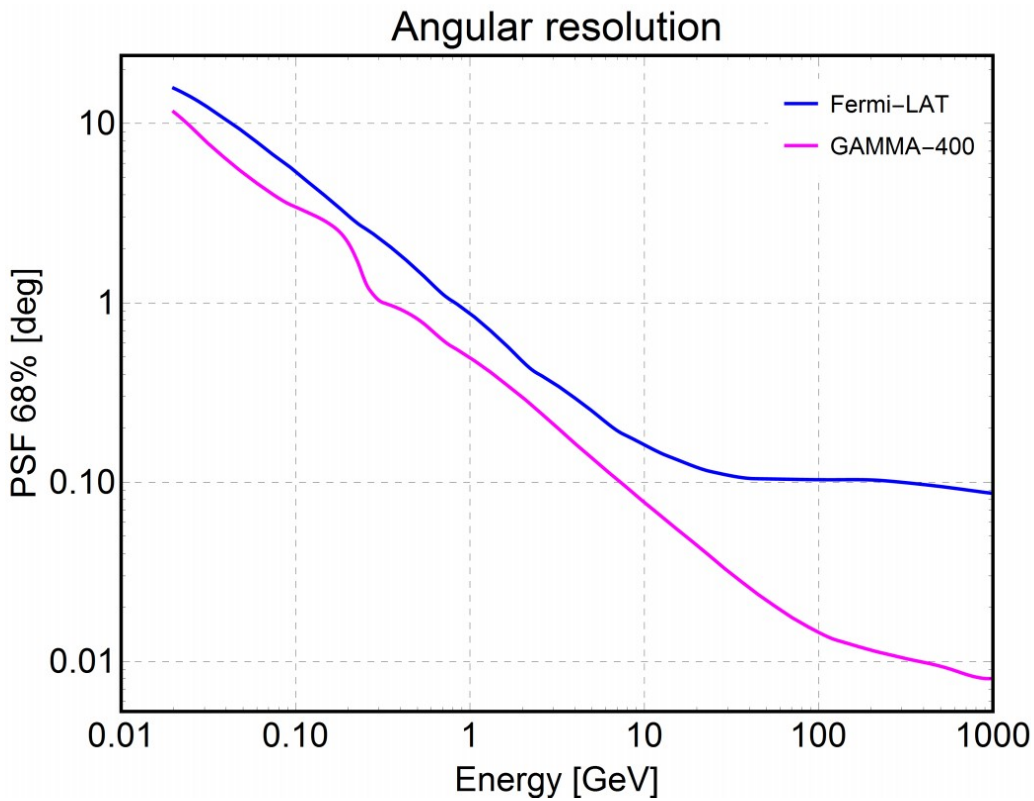
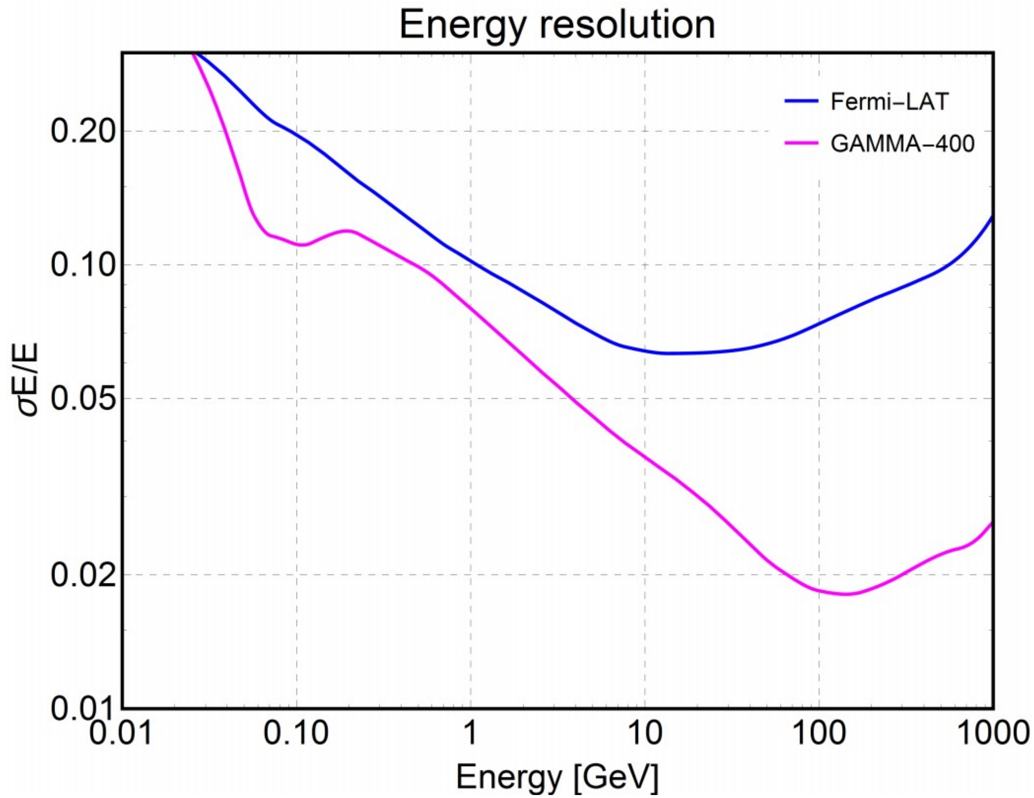
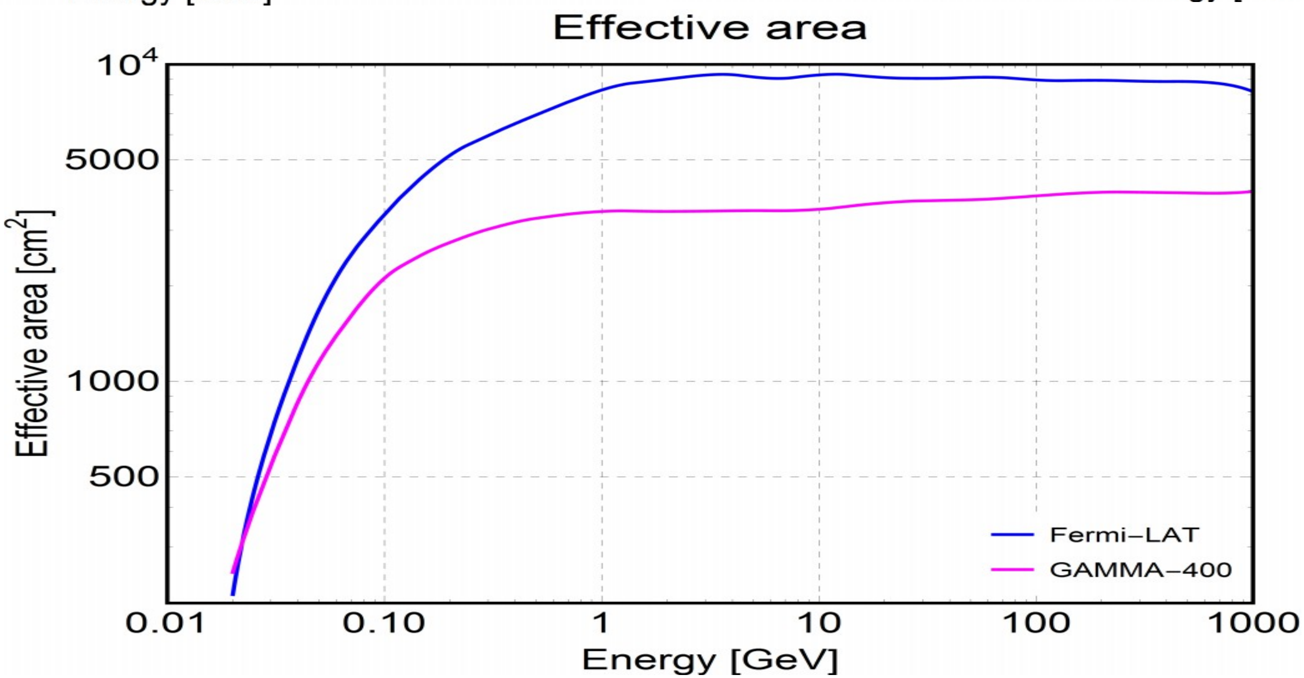
- Working energy range ~20 MeV – ~10 TeV.
- Main field of view ~1 sr.
- Field of view of the lateral aperture ~2 sr.
- Deep pointed observations of a few regions of interest are planned instead of all sky survey by Fermi-LAT.

GAMMA-400 expected performance







Comparison of GAMMA-400 with other telescopes

	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, e	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%	1-2%	1-2%	**~2%**	15%	20% (E_γ = 100 GeV) 15% (E_γ = 1 TeV)	15%	20% (E_γ = 100 GeV) 5% (E_γ = 10 TeV)
Sensitive area, m^2	0,36	1,8	0,36	0,1	**0,64**				

Key scientific objectives of GAMMA-400 mission

1) Dark matter (DM) search program:

- revelation of an exact physical nature of the GeV excess in the Galactic center with possible detection of annihilating WIMPs as contributors to the excess;
- search for narrow gamma-ray lines from annihilating DM particles in the Galactic center region;
- search for WIMPs in other objects – dwarf satellites, dark subhalos, M 31;
- search for ALP signatures in the spectra of gamma pulsars and gamma-bright galaxies;
- search for ALP signatures from nearby supernova explosion.

2) Study of gamma-ray bursts (GRBs) and other transients:

- simultaneous observations of binary mergers with GW antennas (!) - short GRBs. Only one such event (NS+NS) has been detected so far by Fermi-GBM and INTEGRAL. After 2025 few space gamma-ray telescopes are expected to operate – thus, this is a unique niche for GAMMA-400.
- Simultaneous observations of blazars with neutrino telescopes;
- search for gamma-ray counterparts of Fast Radio Bursts.

3) Other gamma-ray astrophysics:

- Sun (quite from CRs + flares);
- study of unidentified Fermi-LAT discrete sources;
- Fermi Bubbles and Galactic gas;
- pulsar nebulae – outputs for CR propagation physics etc.

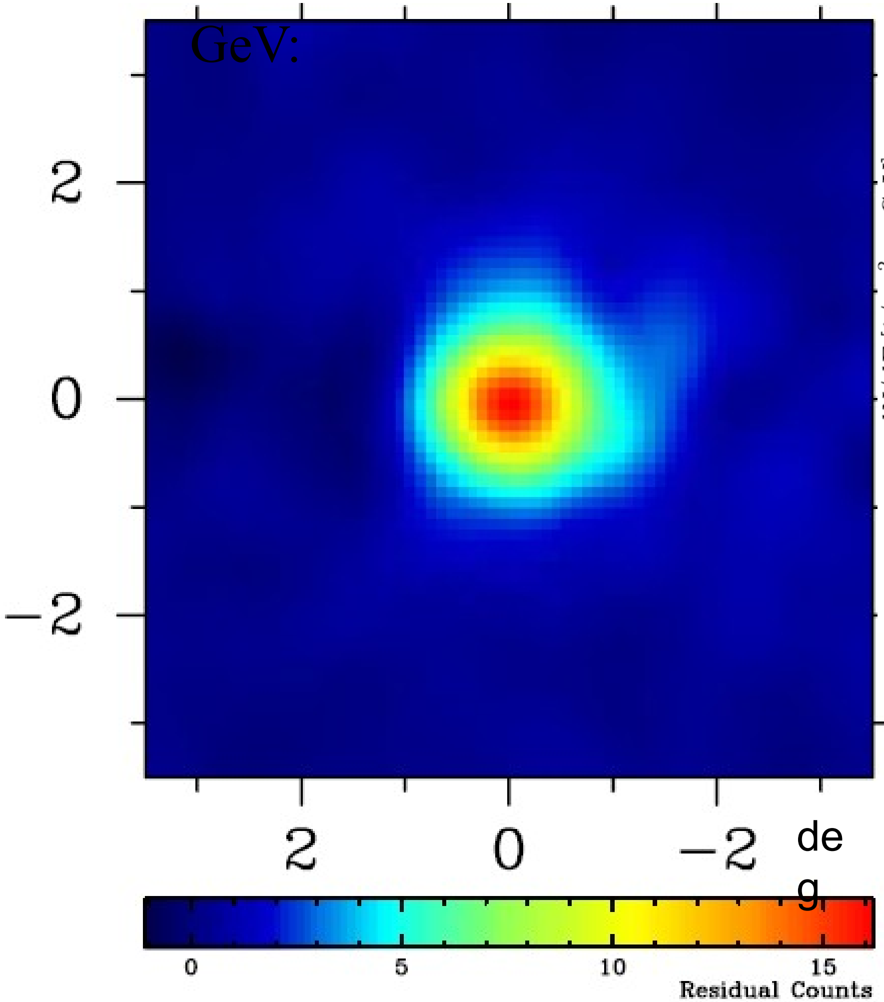
4) Electrons + positrons.

GAMMA-400 dark matter search program

DM candidates: GAMMA-400 targets WIMPs and ALPs

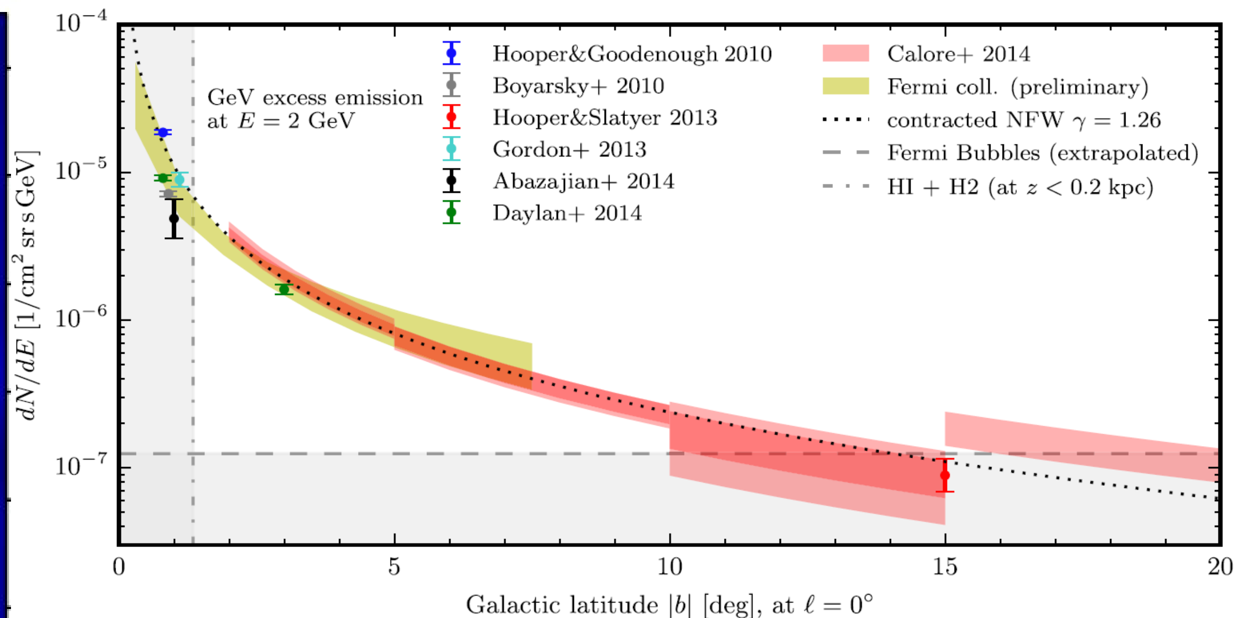
WIMPs (in the form of neutralinos): Galactic center GeV excess

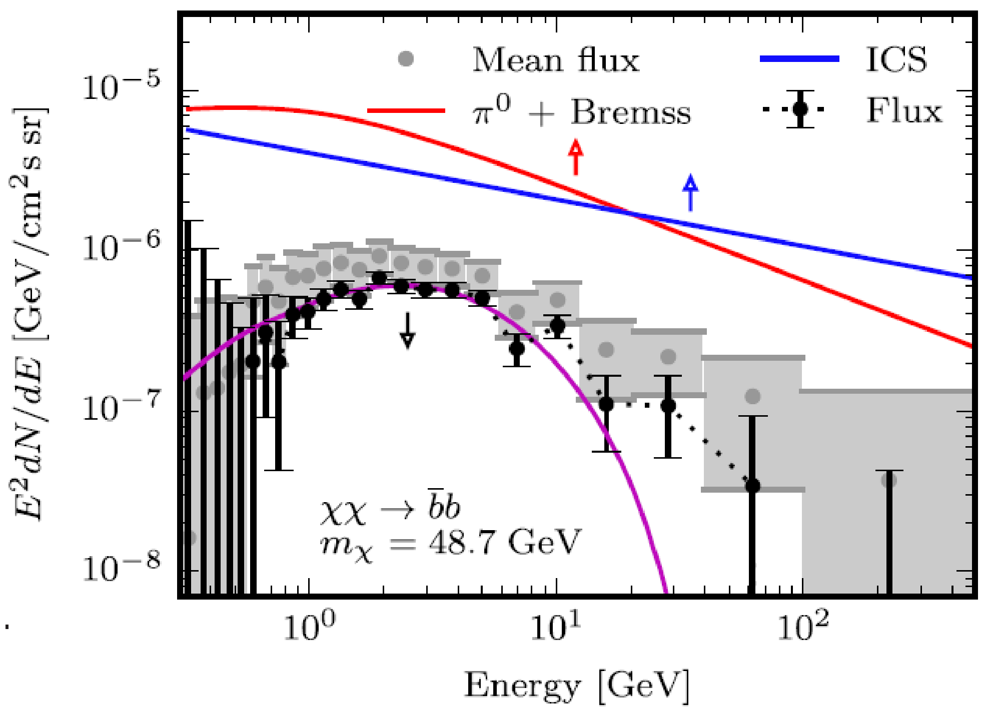
Fermi excess at 1.76-2.40 GeV:



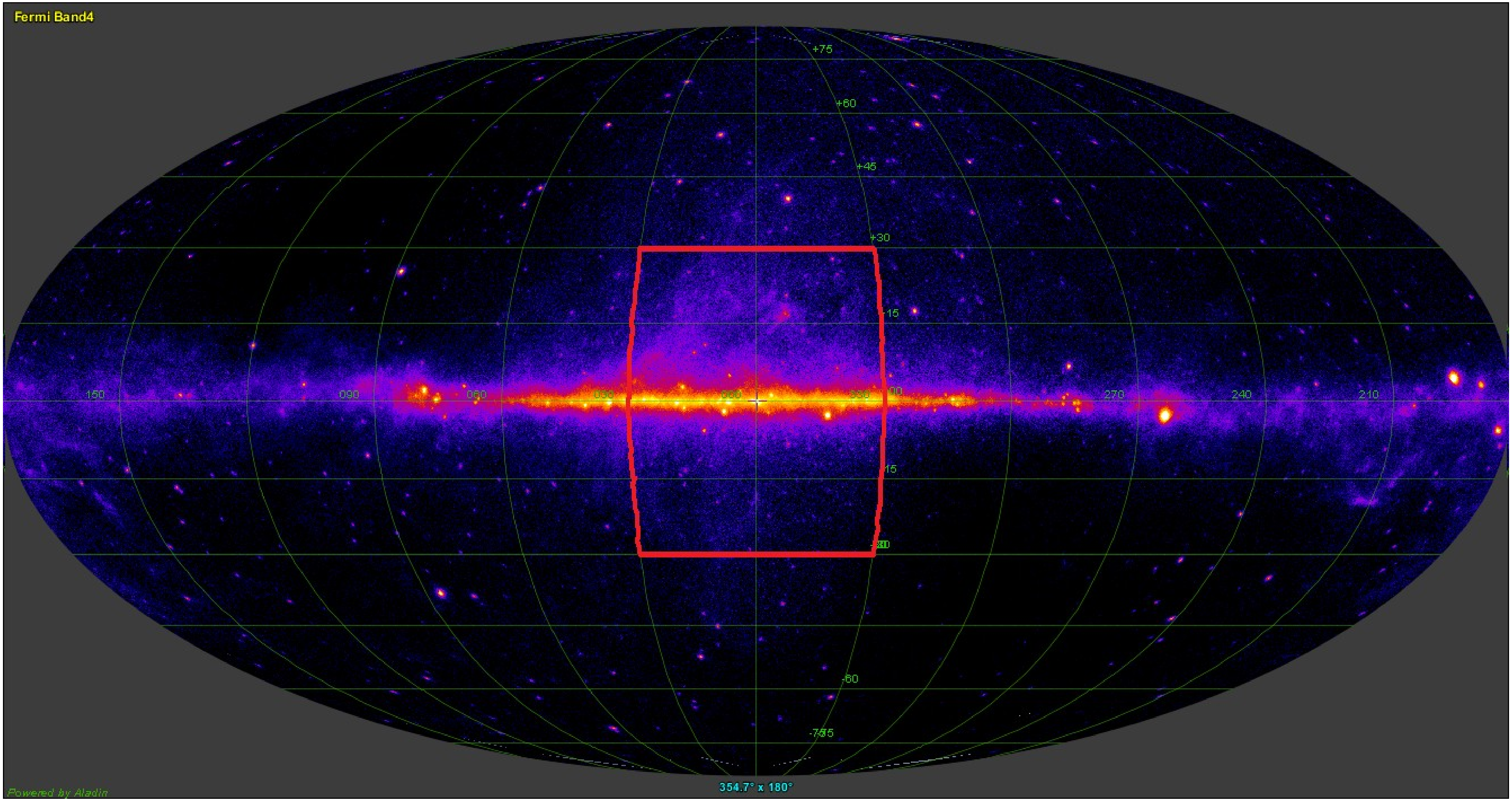
(from K.Abazajian & M.Kaplinghat, Phys. Rev. D 86, 083511 (2012)).

Degeneracy with millisecond pulsars still has not been reliably broken!





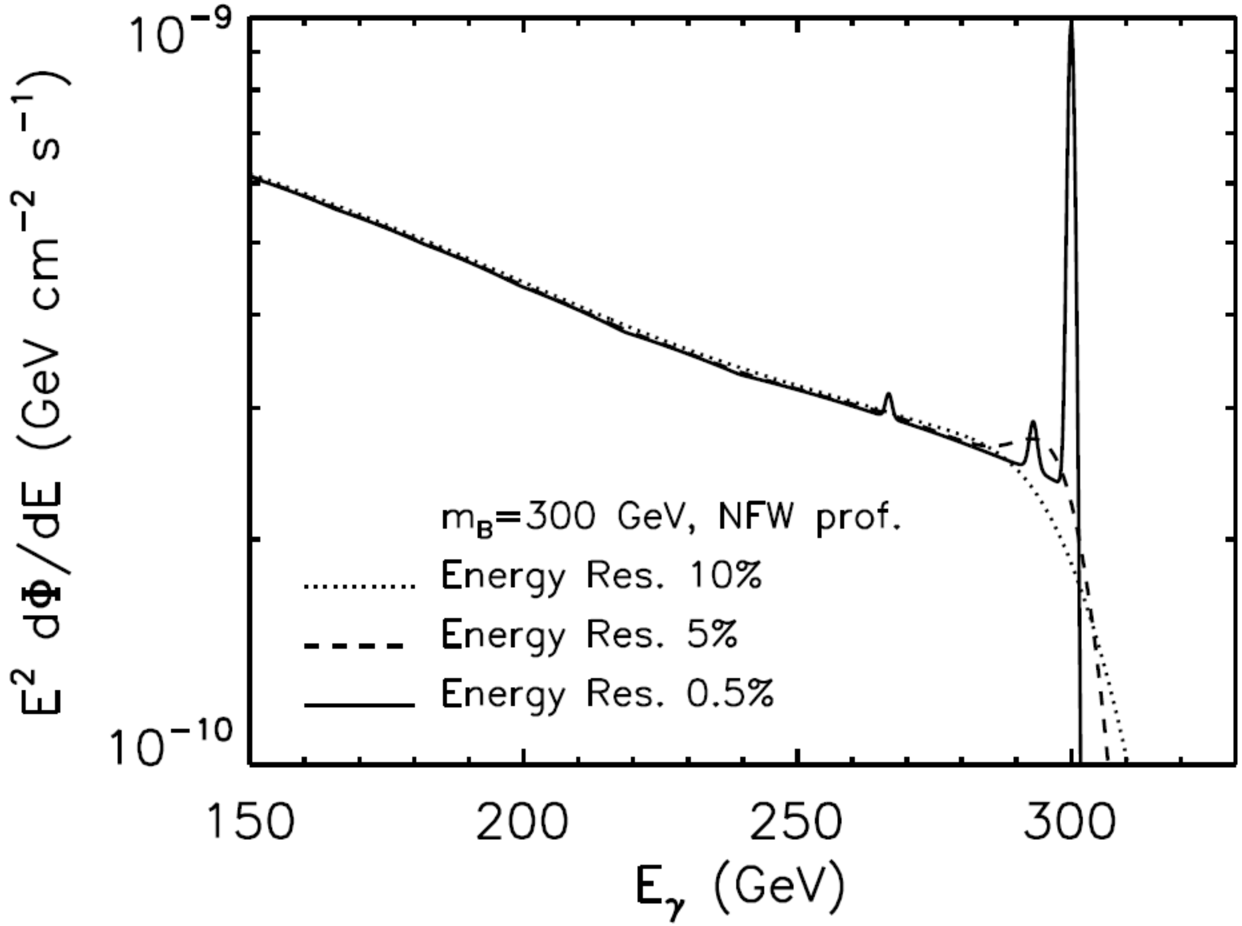
GAMMA-400 field of view ≈ 1 sr



- Good coverage of the Galactic center area;
- Deep 1-2 year exposure is planned, which will allow to gain significant new set of higher-quality photons on top of those collected by Fermi-LAT. Then joint analysis is possible, which may ***finally determine the origin of the GC excess.***

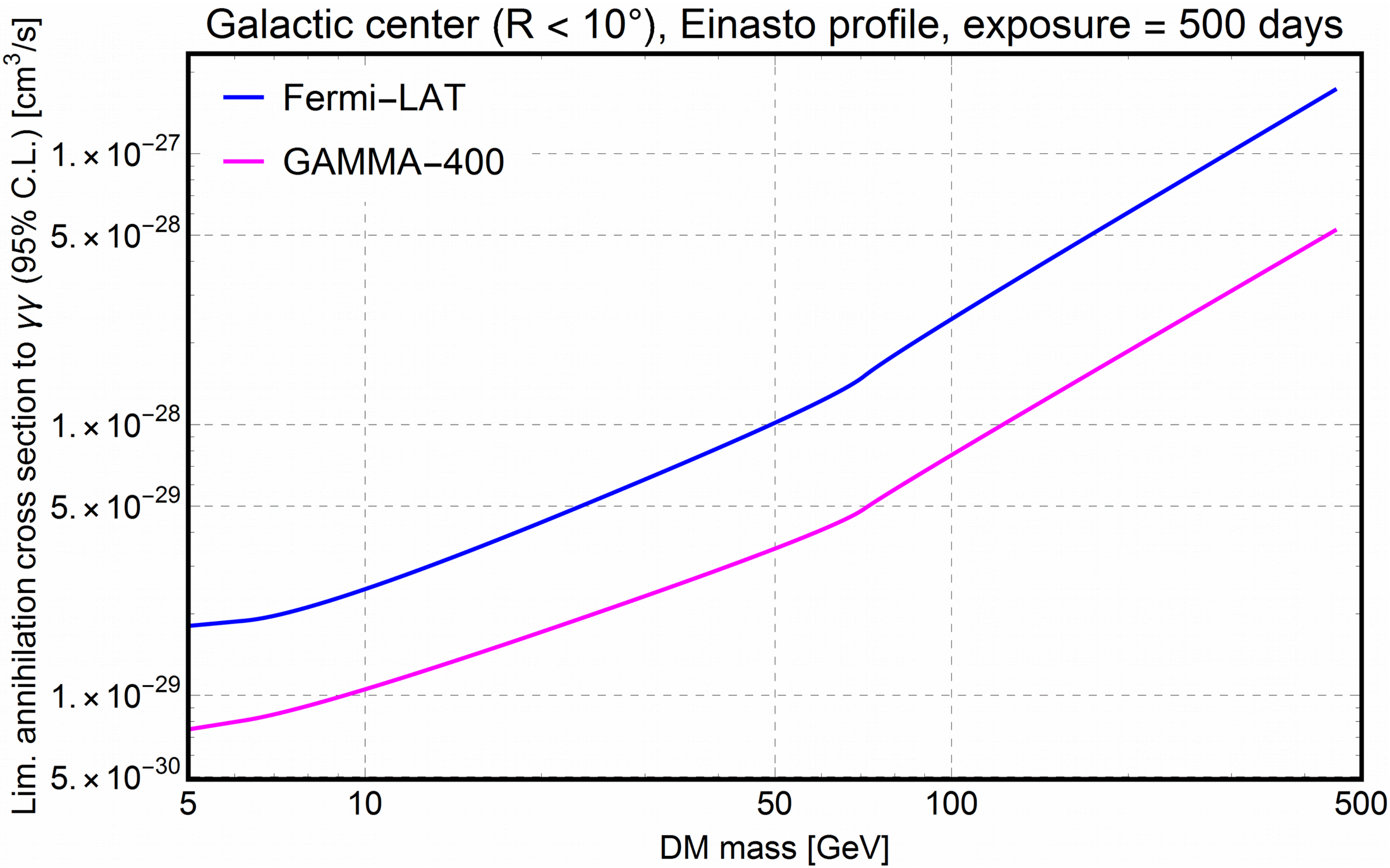
Search for narrow gamma-ray lines due to DM annihilation

Line search is not tied to any specific DM models. Below is an illustrative example of spectral lines seen with various energy resolutions from annihilating KK particles (from G.Bertone et al., JCAP 03, 020 (2012)):



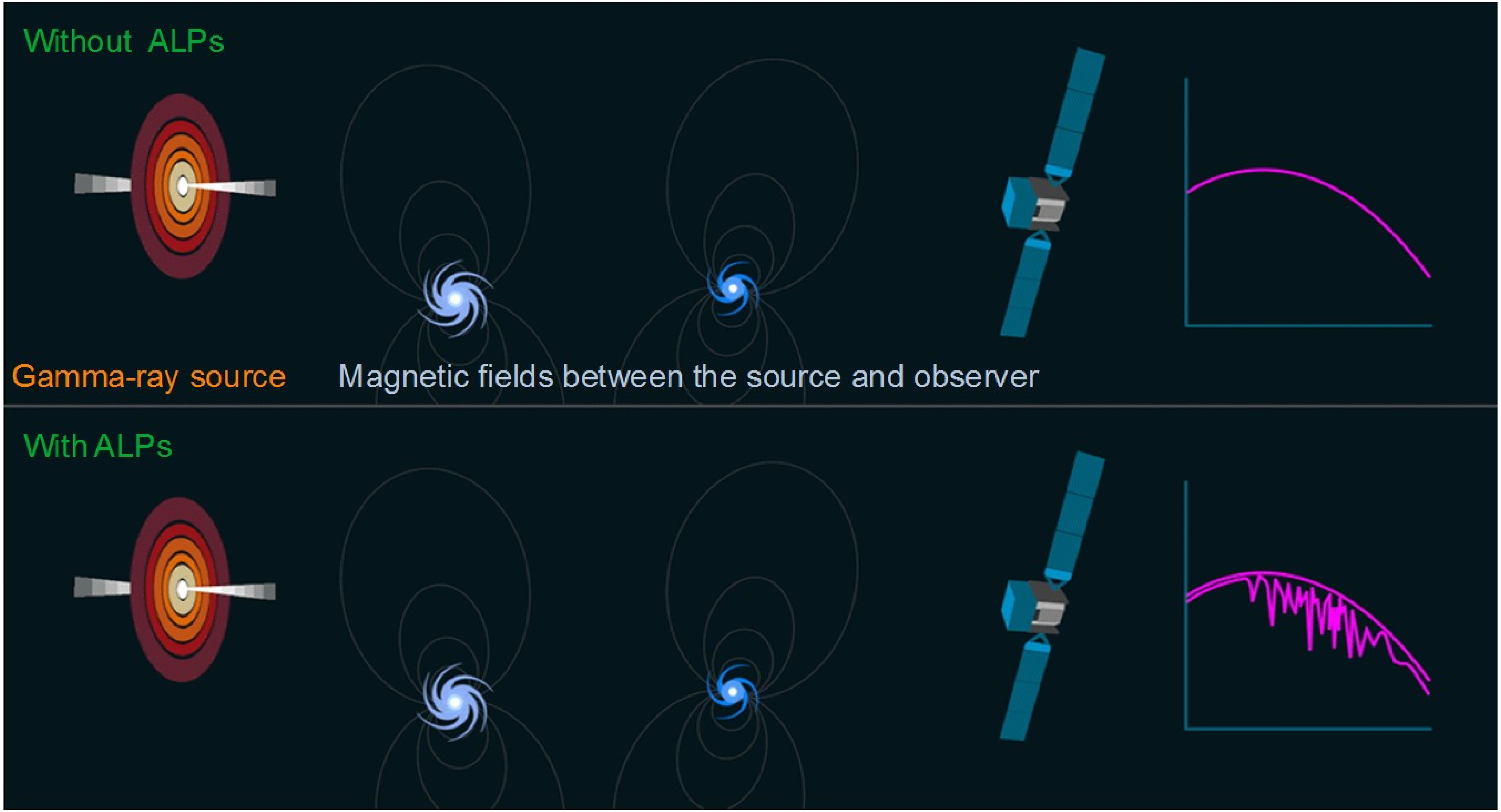
Thus the energy resolution of Fermi-LAT and ground-based telescopes at the level ~10% is NOT sufficient for the narrow line identification. ~1% level resolution is necessary, which will be realized by GAMMA-400.

Preliminary estimate of GAMMA-400 line sensitivity — joint data analysis with Fermi-LAT



GAMMA-400 will be potentially able to strengthen the current Fermi-LAT limits on the annihilation cross section to gammas by ≈(2-3) times. The theory basically allows any values below ~10^{-27} cm^3/s on the plot above.

Axionlike Particle (ALP) searches in pulsar and AGN spectra



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

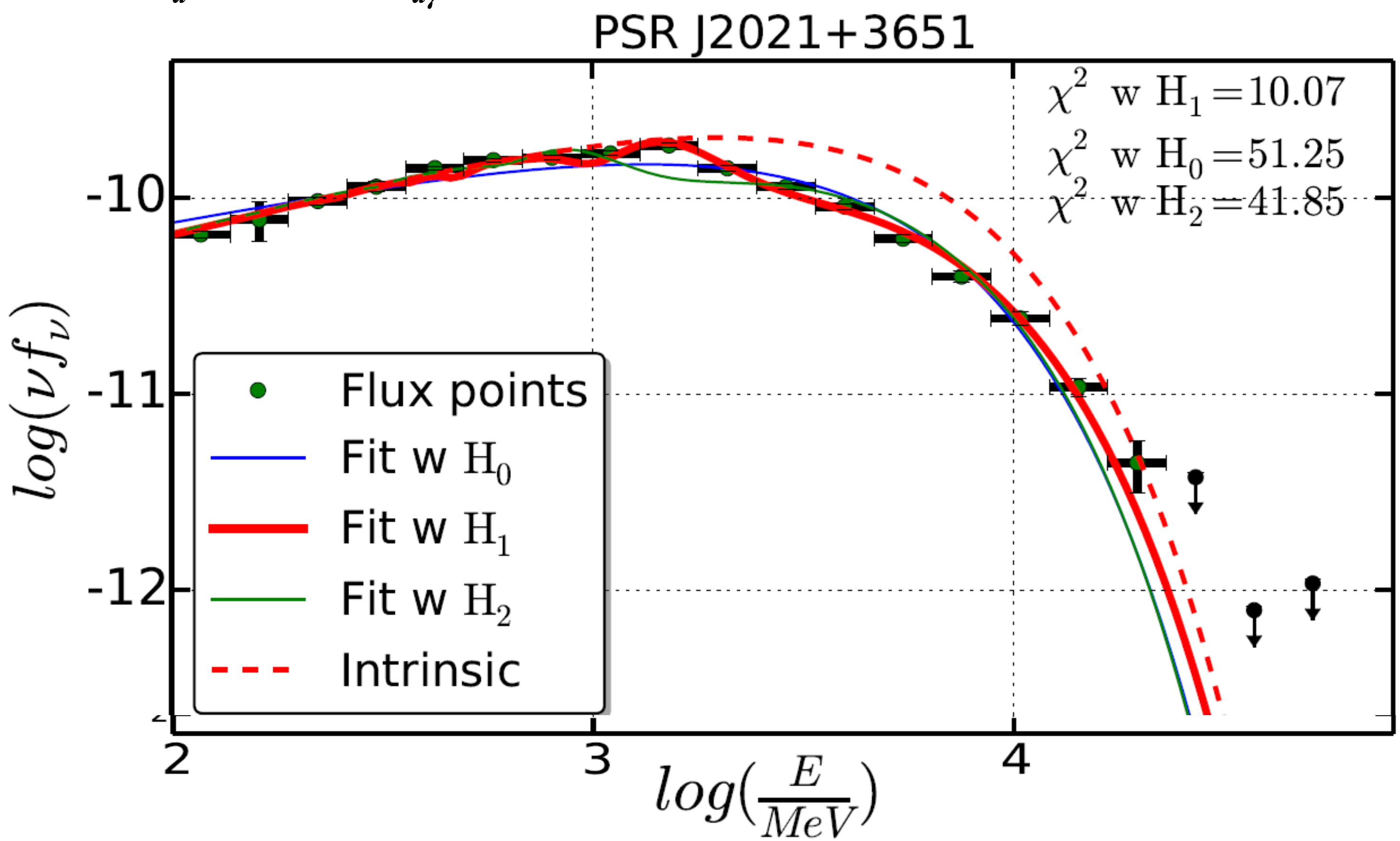
The key relevant parameters of ALP are its mass m_a and electromagnetic coupling constant $g_{a\gamma}$. These parameters define the character of spectral features due to conversion.

Fermi-LAT detected tentative ALP signatures in the spectra of gamma pulsars located near the Galactic plane

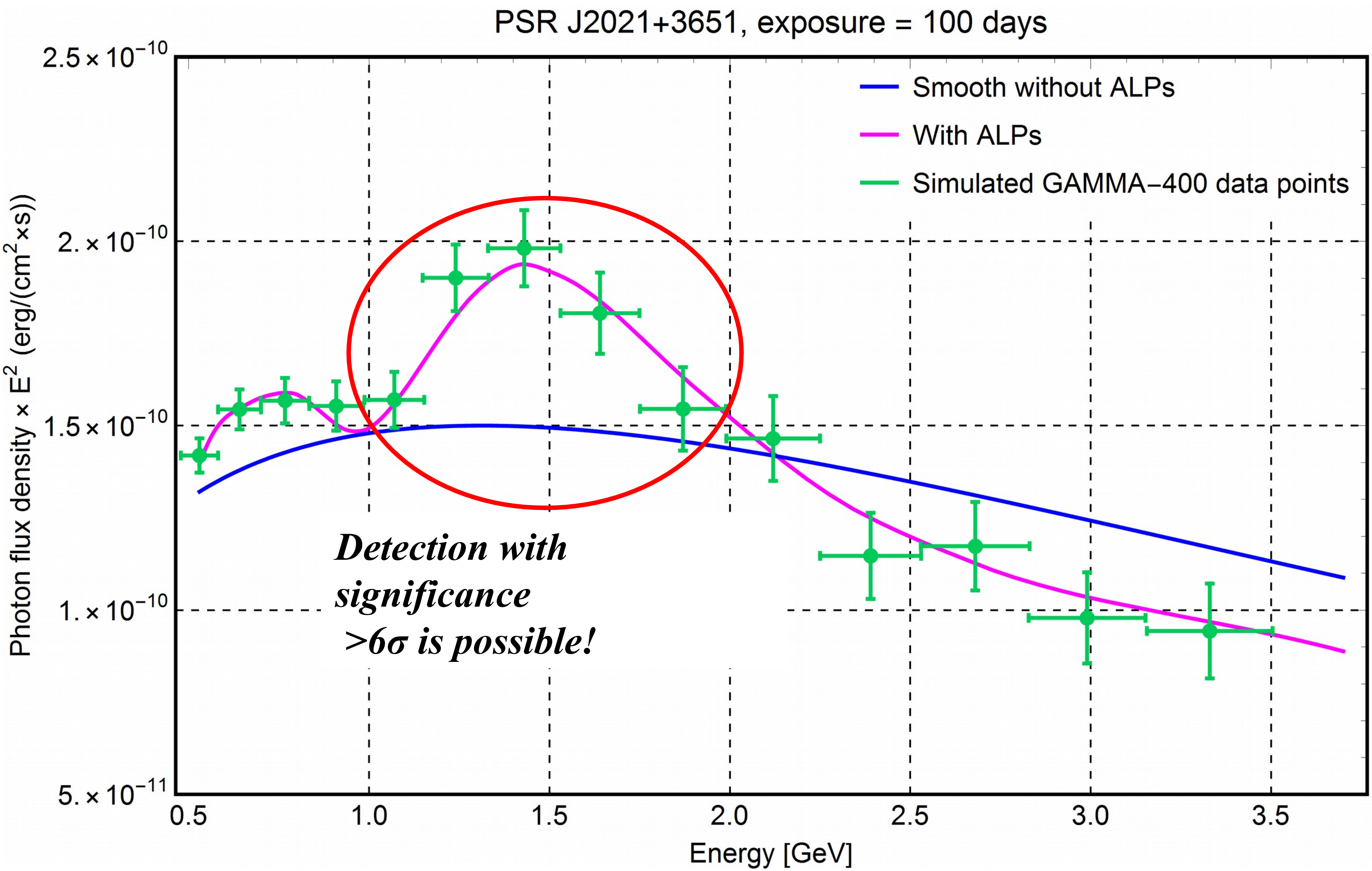
$$P_{\gamma\to a}(\mathcal{E},y) = \left(\frac{g_{a\gamma\gamma}B_T l_{\rm osc}(\mathcal{E})}{2\pi}\right)^2 \sin^2\left(\frac{\pi y}{l_{\rm osc}(\mathcal{E})}\right)$$, where

$$l_{\rm osc}(\mathcal{E}) = 2\pi\left(\left\{\frac{m_a^2-\omega_{\rm pl}^2}{2\mathcal{E}} + \left[1.42\times10^{-4}\left(\frac{B_T}{B_{\rm cr}}\right)^2 + 0.522\times10^{-42}\right]\mathcal{E}\right\}^2 + (g_{a\gamma\gamma}B_T)^2\right)^{-1/2}$$

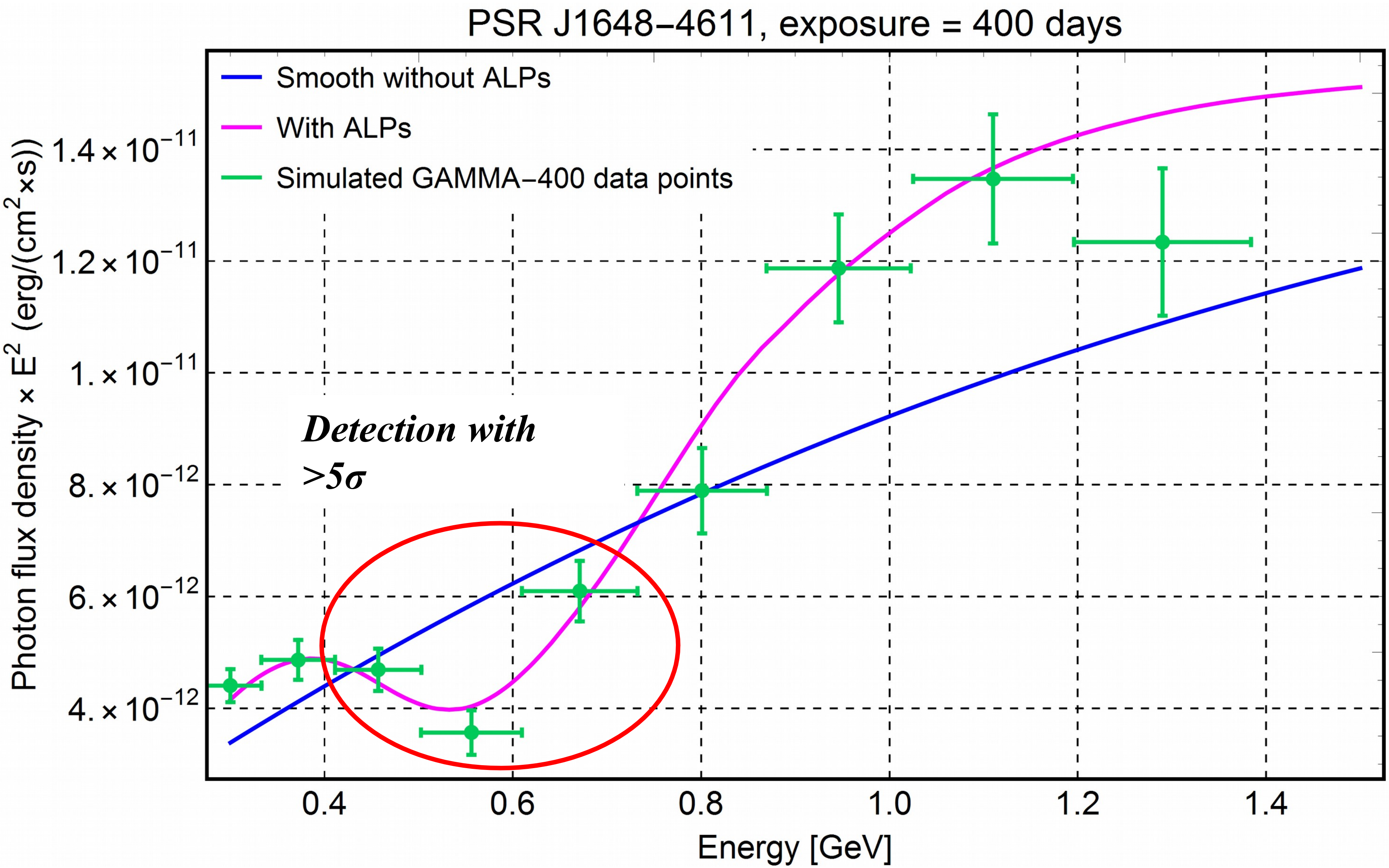
From J.Majumdar et al., JCAP 04, 048 (2018): spectra fits prefer the presence of ALPs (model H_1) with $\boldsymbol{m_a \approx 4}$ **neV,** $\boldsymbol{g_{a\gamma} \approx 4\times10^{-10}}$ **GeV^{-1}** instead of their absence (model H_0).



Simulation of GAMMA-400 observation of the same pulsar



Simulation of GAMMA-400 observation of another similar pulsar near GC, which can be observed during more than a year



Combined analysis with the Fermi-LAT data will enhance significance of (non-)detection much further!

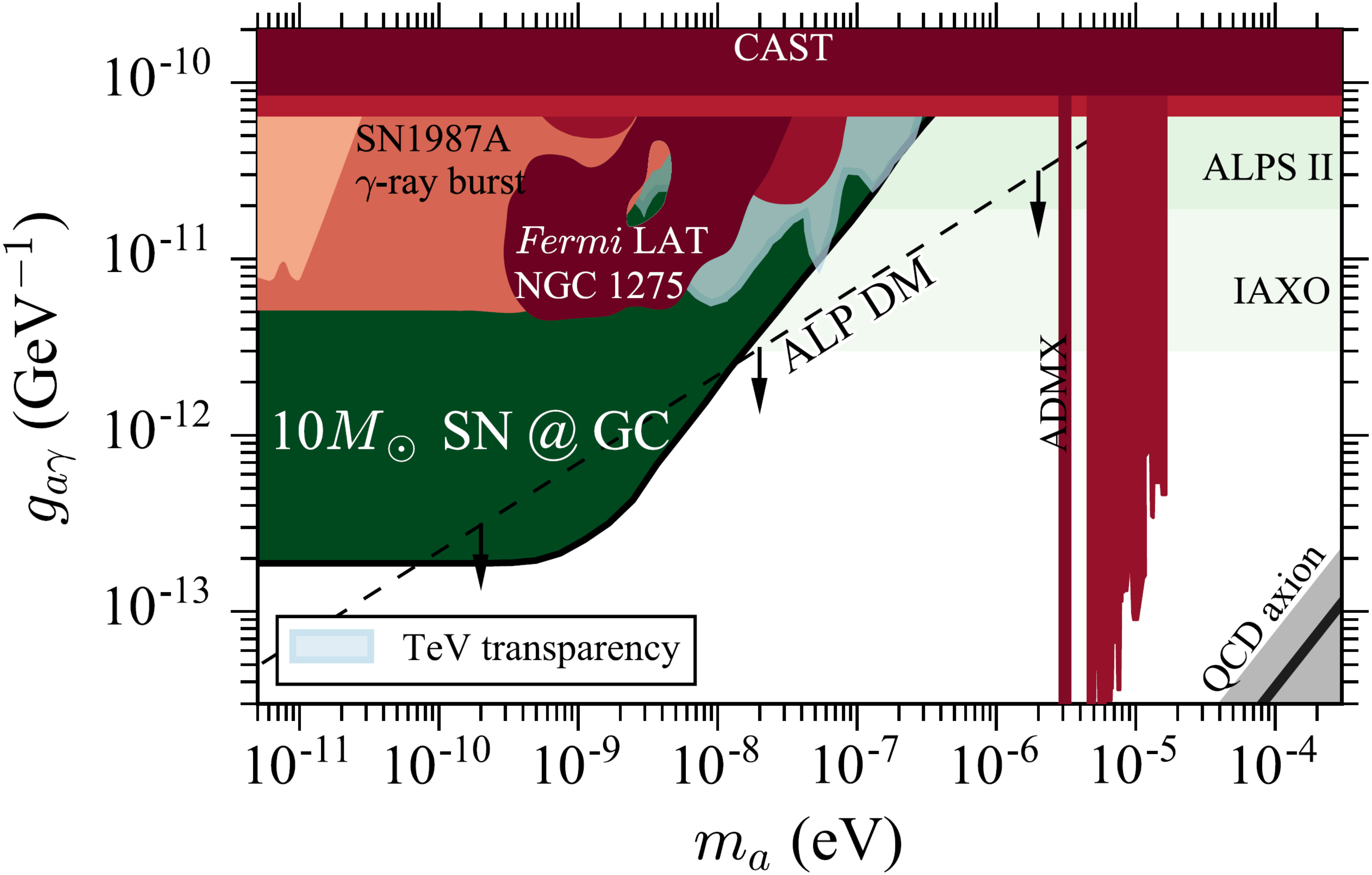
ALP signature from a supernova explosion in the Local group

- Thermal photons in the supernova (SN) core may copiously convert to ALPs in the electric field of nuclei (Primakoff process).
- The temperature in the SN core (protoneutron star) reaches decades of MeVs, and ALPs produced with such energies freely escape the core.
- ALPs convert to gamma-ray photons in the Galactic magnetic field on their way to an observer. Hence, we may expect to see a burst of ~(50-100) MeV emission accompanying first seconds of SN explosion, which is marked by the neutrino signal.
- Non-observation of gammas from a nearby SN – in the Local group – may place very strong constraints on ALP parameters.
- Fortunately, the limiting value of the ALP-photon coupling constant $g_{a\gamma}$ depends on the detector effective area A very mildly:

$$\textit{gamma-ray fluence} \propto g_{a\gamma}{}^{4} \rightarrow g_{a\gamma} \propto A^{1/4}.$$

- This practically implies for us, that **GAMMA-400 sensitivity to $g_{a\gamma}$ differs from Fermi-LAT sensitivity by no more than just ~10%!**
- GAMMA-400 will have a great capability for detection of transients like SN, since besides the main aperture of 1 sr the lateral aperture of ≈2 sr may detect them too. This makes the **total field of view ≈3 sr (quarter of the whole sky) – greater than that for Fermi-LAT (≈2 sr)!** And the effective area of lateral aperture is comparable to that of the main one.

Constraints on ALP parameters from a nearby supernova



From M.Meyer et al., PRL 118, 011103 (2017) for Fermi-LAT.

Observation of such SN may provide:

- the strongest constraints on $g_{a\gamma}$ for m_a < 10 neV;
- probing a very interesting parameter zone, where ALPs can explain all DM;
- ruling out the explanation of anomalous TeV transparency of the Universe by ALPs.

Conclusions

- Thanks to better characteristics in comparison with Fermi-LAT, GAMMA-400 will potentially unveil finally an exact origin of the Galactic center GeV excess detecting the possible contribution from annihilating WIMPs to it.
- Search for narrow spectral lines: joint analysis of GAMMA-400 and Fermi-LAT data from Galactic center region is expected to strengthen the current limits on DM annihilation cross section directly to gammas by 2-3.
- GAMMA-400 will confirm or disprove the tentative features in the gamma pulsar spectra due to ALPs.
- Has a great potential to constrain ALP properties in case of an observation of the supernova explosion in the Local group!

Project website - http://gamma400.lebedev.ru/