Recent results on Dark matter and axion-like particle searches with MAGIC

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Dipartimento di Fisica e Astronomia Galileo Galilei

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Università degli Studi di Padova

Ivana Batković (University of Padova and INFN Padova) for the MAGIC collaboration

Email: ivana.batkovic@phd.unipd.it

33rd Rencontres de Blois, 22-27 May 2022, Blois, France

Image credit: Giovanni Ceribella

The MAGIC experiment

- Two Imaging Atmospheric Cherenkov telescopes located in Observatory Roque del Muchachos on the Canary island of La Palma
- 17 m diameter
- Operating since 2003, in stereo mode from 2009
- At the altitude of ~ 2240 m
- International collaboration of about 300 members from 13 countries

Figure 1: MAGIC telescopes, credit: Robert Wagner

Extensive atmospheric showers

- Cascades of subatomic particles in the atmosphere → Cherenkov light
- Detecting gamma-rays in the energy range of 25 GeV - 100 TeV
- Field of view ~ 3.5°
- Angular resolution ~ 0.1° (energy dependent)

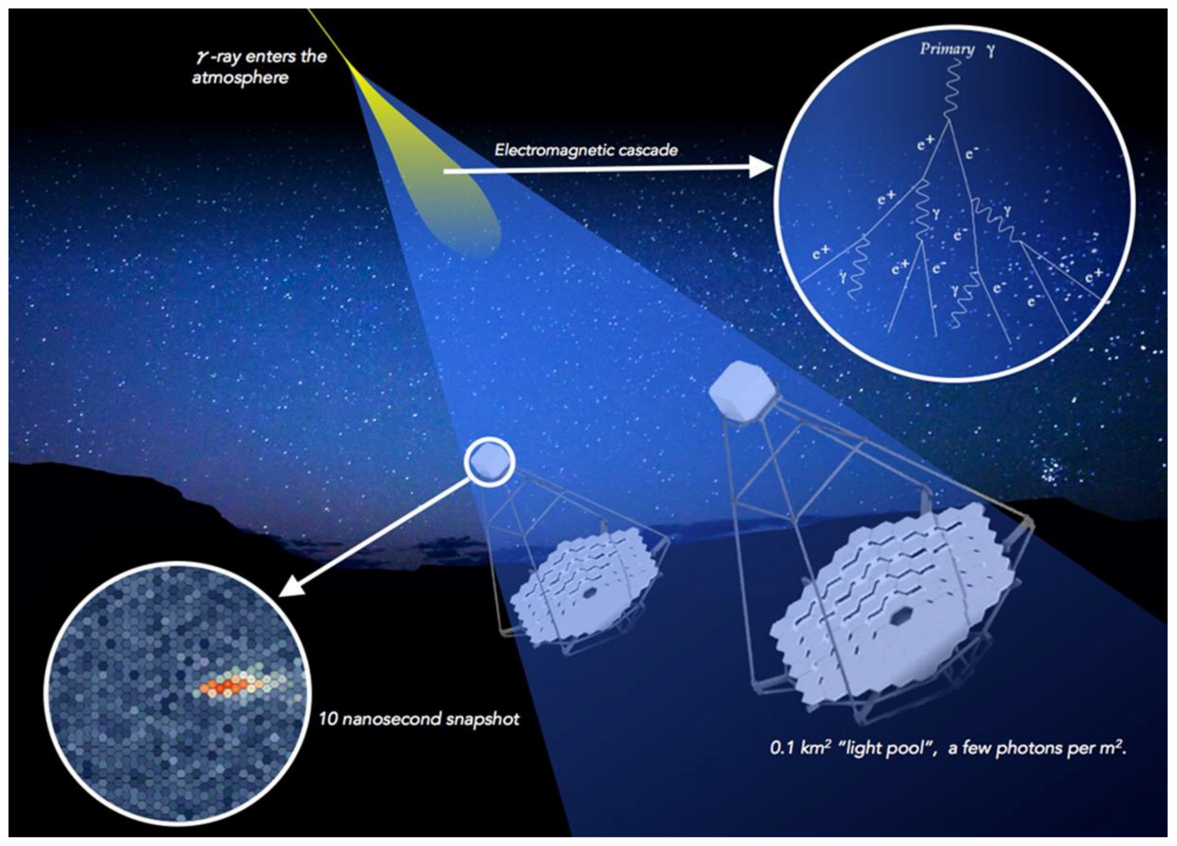


Figure 2: Detection of atmospheric showers, credit: CTA Observatory

MAGIC sensitivity

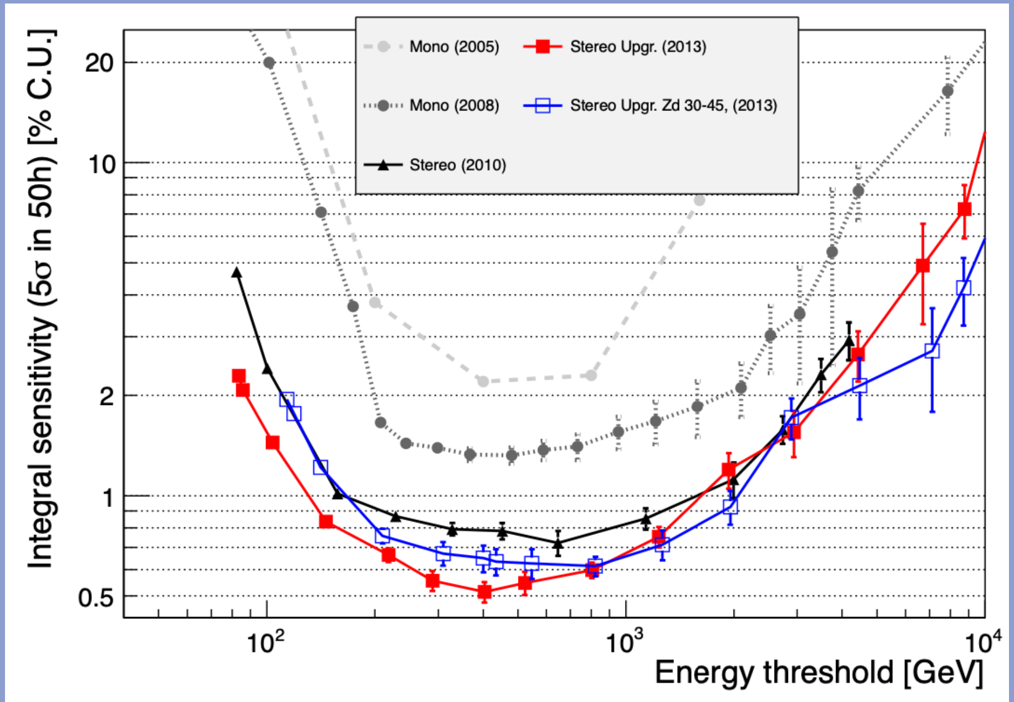


Figure 3: Evolution of integral sensitivity of the MAGIC telescopes. J. Aleksić et al. 2016, Astroparticle Physics 72, 76-94

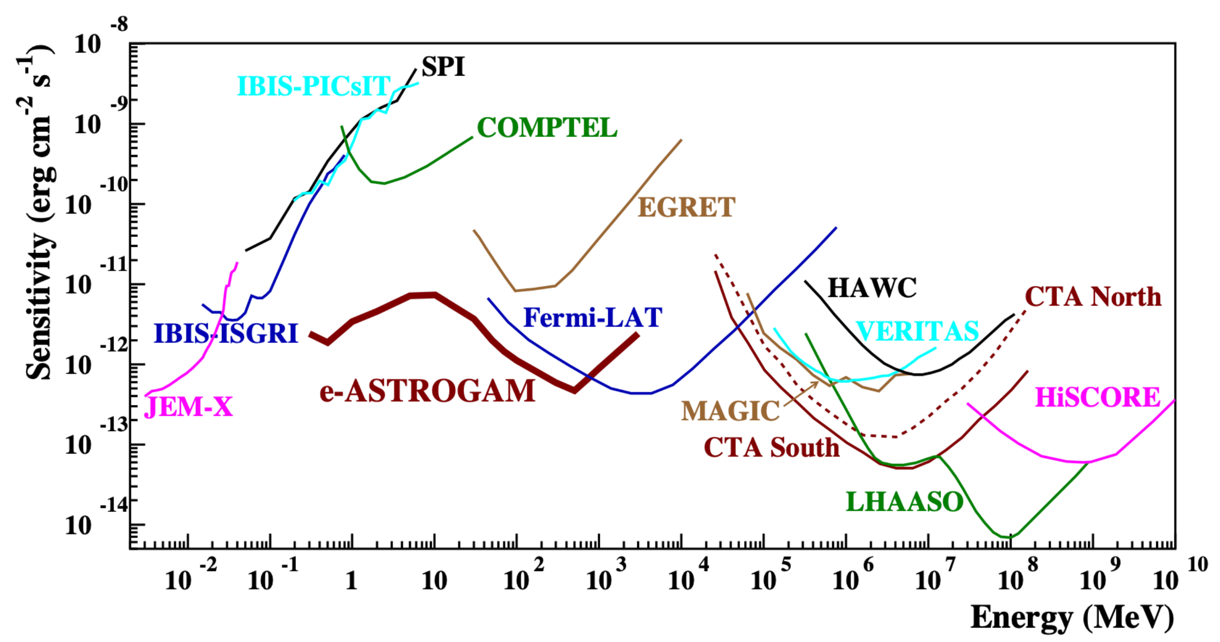


Figure 4: Point source continuum differential sensitivity of different X- and γ-ray instruments, De Angelis et. al, 2017, Experimental Astronomy 44, 25-82

Indirect Dark Matter search

HOW?

- Dark matter signal is expected to be embedded in the spectrum of the astrophysical sources
- Observations of gamma-rays spectra
- Annihilation and decay in the Standard Model particles and other signatures in the spectra

WHAT?

- WIMPs vs. WISPs

WHERE? Classical targets

- The Galactic Centre
- Dwarf spheroidal galaxies
- Galaxy clusters

Dark Matter flux and *J*-factors

Annihilation

velocity – averaged cross section

$$\frac{d\Phi}{dE\,d\Omega} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2\,m_{DM}^2}\frac{dN_\gamma}{dE}\frac{dJ_{ann}}{d\Omega}$$

$$\frac{dJ_{ann}}{d\Omega} = \int_{l.o.s} dl\,\rho^2(l,\Omega)$$

Decay

$$\frac{d\Phi}{dE\,d\Omega} = \frac{1}{4\pi}\frac{1}{\tau_{DM}m_{DM}}\frac{dN_\gamma}{dE}\frac{dJ_{dec}}{d\Omega}$$

DM lifetime

$$\frac{dJ_{dec}}{d\Omega} = \int_{l.o.s} dl\,\rho\,(l,\Omega)$$

Dark Matter flux and *J*-factors

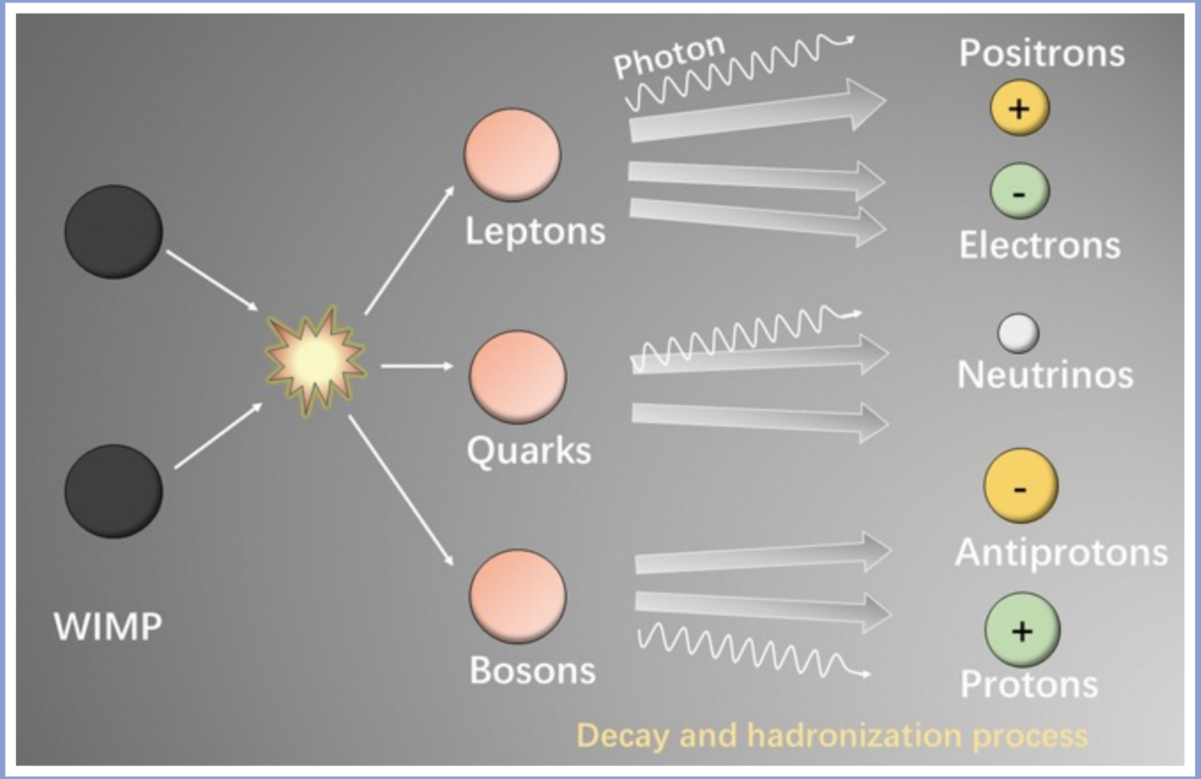


Figure 5: Principle of indirect detection of dark matter, credit: GAO Linqing and LIN Sujie

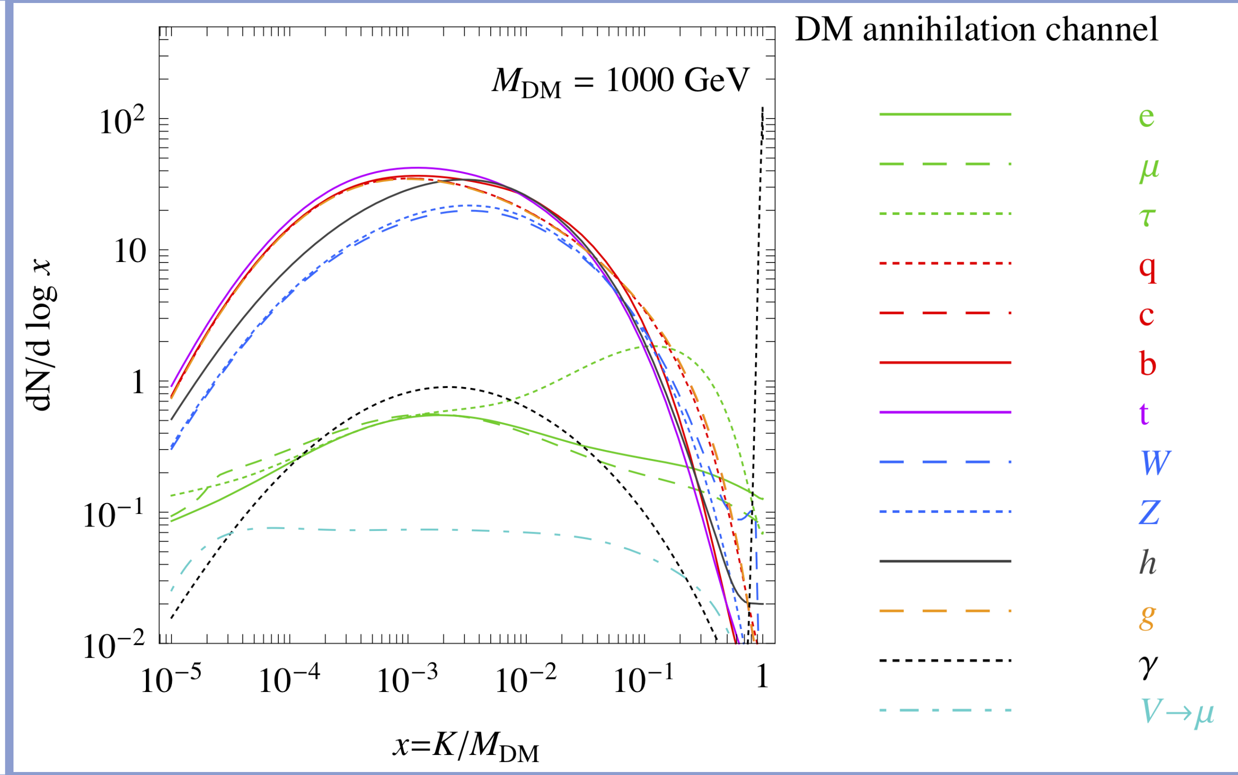


Figure 6: Primary DM gamma-ray spectra for various annihilation models, extracted from: Cirelli et al., JCAP 2011, 1103, 051

WISPs – ALPs

- ALPs → axion - solution to the Strong CP problem
- Photon-ALP mixing in the external magnetic field
- Irregularities (wiggles) in the spectra of astrophysical targets
- Knowledge of the magnetic fields is fundamental for producing the ALPs models

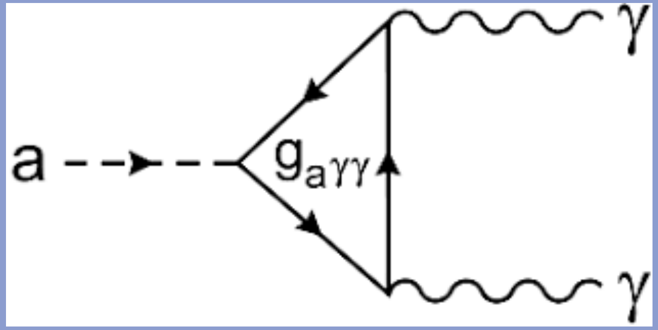


Figure 7: Feynman diagram of photon-axion interaction

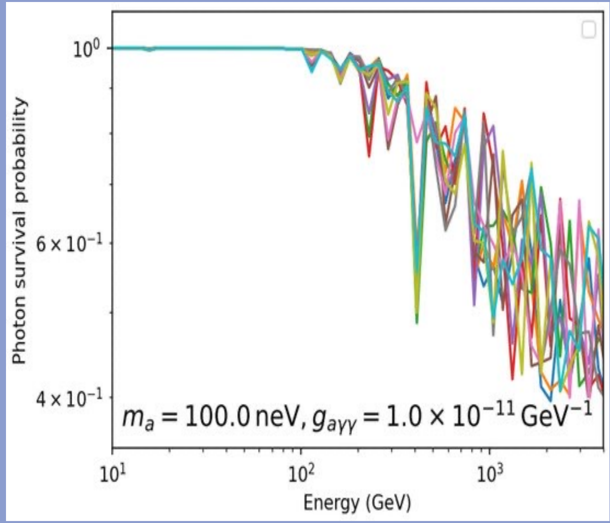


Figure 8: Photon survival probability (https://github.com/me-manu/gammaALPs)

WISPs – ALPs

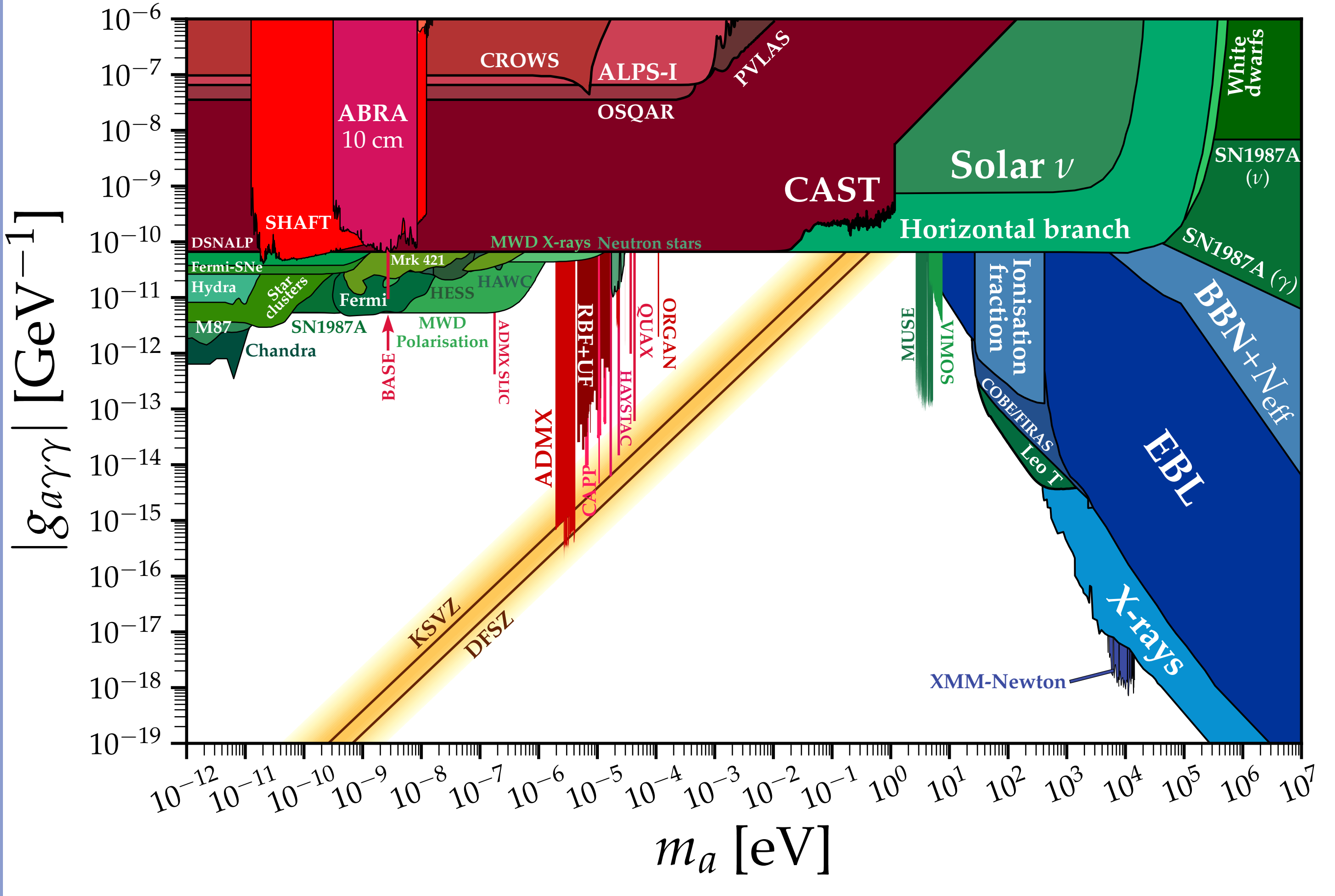


Figure 9: ALPs parameter space with current constraints, (https://cajohare.github.io/AxionLimits/), on the date 16/05/2022

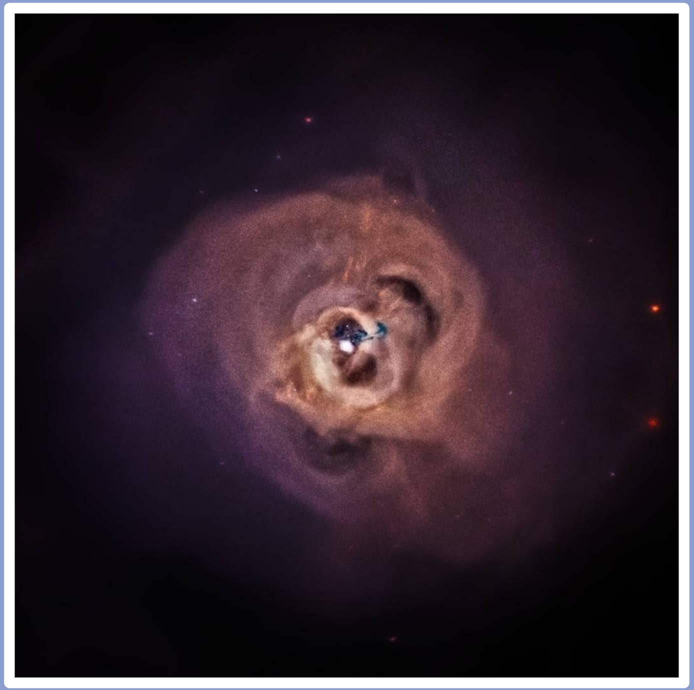
Target sources

Dwarf spheroidal galaxies (dSphs)

Image credit: ESO/Digitized Sky Survey 2

Milky-Way center (GC)

Image credit: X-ray: NASA/CXC/SAO; Optical: Detlef Hartmann; Infrared: NASA/JPL-Caltech



Galaxy clusters

Image credit: NASA/CXC/SAO/E.Bulbul, et al.

MAGIC campaigns for DM searches

Target	Year	Time (h)	Constraint	Reference
		The Milky Way		
MW Outer Halo	2018	10	Decay	Ninci et al., PoS, 2019, ICRC2019, 538
		Dwarf Sattelite Galaxies		
Draco*	2007	7.8	Annihilation	Albert et al., ApJ 200, 679, 428–431
Draco	2018	52.6	Annihilation	Acciari et al., Phys. Dark Univ. 2022, 35, 100912
Wilman 1	2008	15.5	Annihilation	Aliu et al., ApJ 2009, 697, 1299–1304
Segue 1*	2008 - 2009	29.4	Annihilation	Aleksić et al., J., Cosmology Astropart. Phys. 2011, 1106, 035
Segue 1	2010 - 2013	157.9	Annihilation + Decay	Aleksić et al., J. Cosmology Astropart. Phys. 2014, 1402, 008
			Annihilation	Ahnen et al., J. Cosmology Astropart. Phys. 2016, 1602, 039
Coma Berenices	2018	50.2	Annihilation	Acciari et al., Phys. Dark Univ. 2022, 35, 100912
Ursa Major II	2014 - 2016	94.8	Annihilation	Ahnen et al., JCAP 951, 2018, 1803, 009
Triangulum II	2014 - 2016	62.4	Annihilation	Acciari et al., Phys. Dark Univ. 2020, 28, 100529

Extracted from: arXiv:2111.01198, * monoscopic observations

MAGIC campaigns for DM searches

Target	Year	Time (h)	Limit	Reference
Dark Sattelites				
1FGL J2347.3+0710	2010	8.3	–	Nieto et al. arXiv e-prints 2011, p. arXiv:1109.5935
1FGL J0338.8+1313	2010 - 2011	10.7	–	Nieto et al., arXiv e-prints 2011, p. arXiv:1109.5935
Intermediate Mass Black Holes				
Galactic Plane*	2005 -2006	25	Annihilation	Doro et al., Proceedings of the 30th ICRC, 2007
Galaxy Clusters				
Perseus (Abell 426)	2008	24.4	Annihilation	Aleksić et al., ApJ 2010, 710, 634–647
Perseus (Abell 426)*	2009 - 2017	202.2	Decay	Acciari et al., Phys. Dark Univ. 2018, 22, 38–47
Line searches				
MW Inner Halo	2013 - 2019	204	Annihilation	Inada et al., PoS 2021, ICRC2021, 520
Segue 1 dSph	2010 - 2013	157.9	Annihilation	Aleksić et al., J. Cosmology Astropart. Phys. 2014, 1402, 008

Extracted from: arXiv:2111.01198 , * monoscopic observations

Searches for DM in dSphs with MAGIC

Target	$\log_{10} J(\theta_{max})$ [$GeV^2 cm^{-5}$]	θ_{max} [deg]	$\theta_{0.5}$ [deg]	T_{eff} [h]	Year
Coma Berenices	$19.02^{+0.37}_{-0.41}$	0.31	$0.16^{+0.02}_{-0.05}$	49.5	2019
Draco	$19.05^{+0.22}_{-0.21}$	1.30	$0.40^{+0.16}_{-0.15}$	52.1	2018
Ursa Major II	$19.42^{+0.44}_{-0.42}$	0.53	$0.24^{+0.06}_{-0.11}$	94.8	2016–2017
Segue 1	$19.36^{+0.32}_{-0.35}$	0.35	$0.13^{+0.05}_{-0.07}$	157.9	2011–2013

Figure 10: Table of sources and corresponding info, Acciari at al. 2022, Phys. Dark Universe 35, 100912, leading author: Camilla Maggio

- 4 dSphs, combination of data from a multi-year observation program
- Total of 354.3 hours of good quality data
- Increasing the statistics → better sensitivity
- 95% CL upper limits on velocity – averaged annihilation cross section for 9 channels are obtained

Searches for DM in dSphs with MAGIC

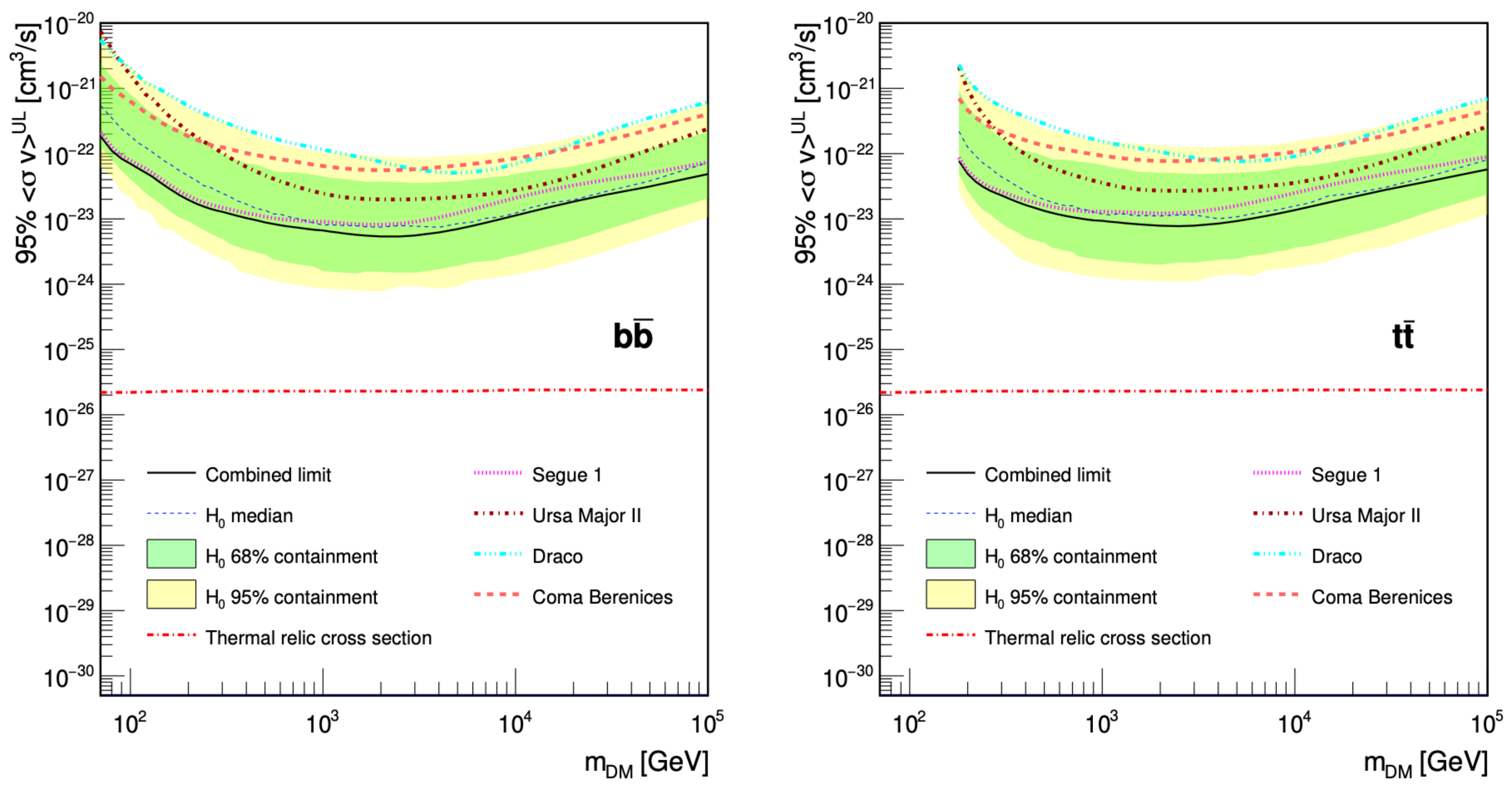


Figure 11: 95% CL ULs for $\langle\sigma_{ann}v\rangle$ for DM annihilation into $b\bar{b}$ and $\tau^+\tau^-$ pairs, Acciari at al. 2022, Phys. Dark Universe 35, 100912, leading author: Camilla Maggio

Searches for DM in dSphs with MAGIC

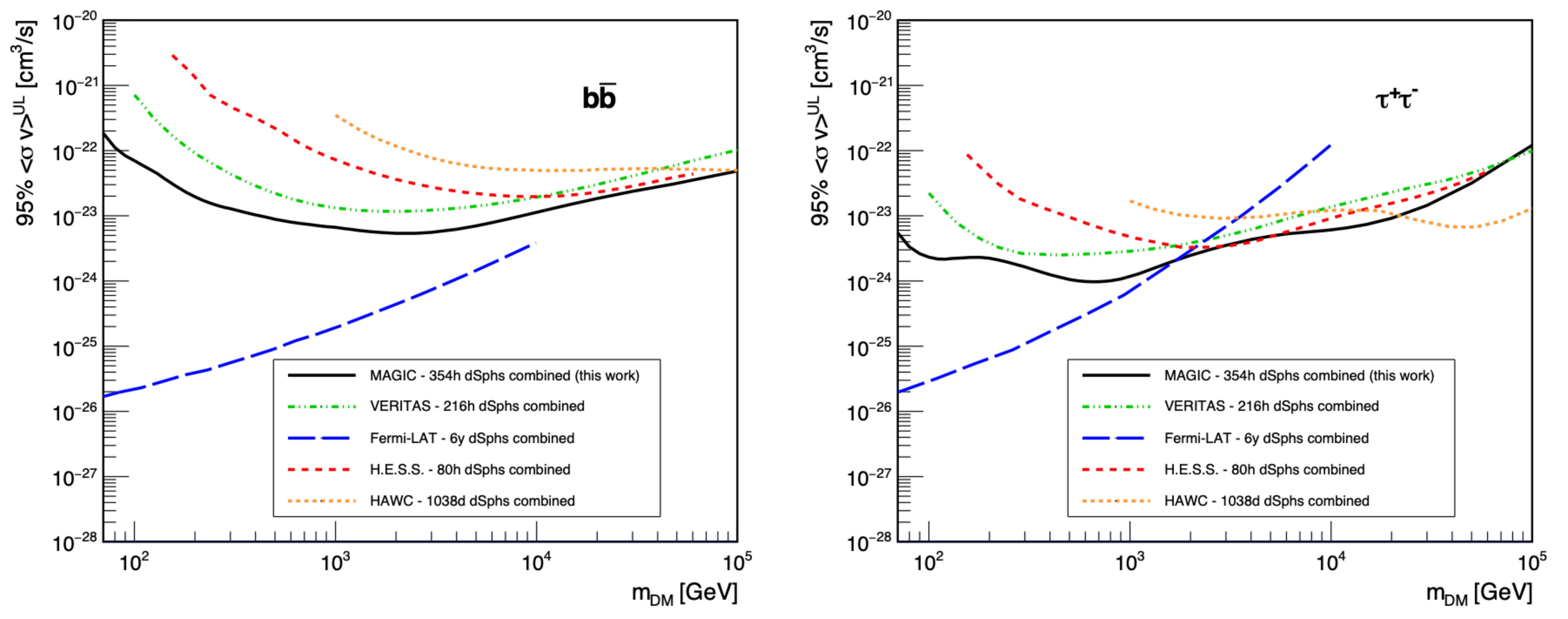


Figure 12: 95% CL ULs for $\langle\sigma_{ann}v\rangle$ for DM annihilation into $b\bar{b}$ and $\tau^+\tau^-$ pairs, compared with the results from other experiments, Acciari at al. 2022, Phys. Dark Universe 35, 100912, leading author: Camilla Maggio

Line-like features in GC with MAGIC

- 223 hours of observations of the Galactic Centre region
- Energies reaching up to 100 TeV
- High zenith angles increase the energy threshold
- Unbinned likelihood analysis
- No significant excess detected
- Constraints on the cross section for dark matter annihilation into two photons are obtained

Line-like features in GC with MAGIC

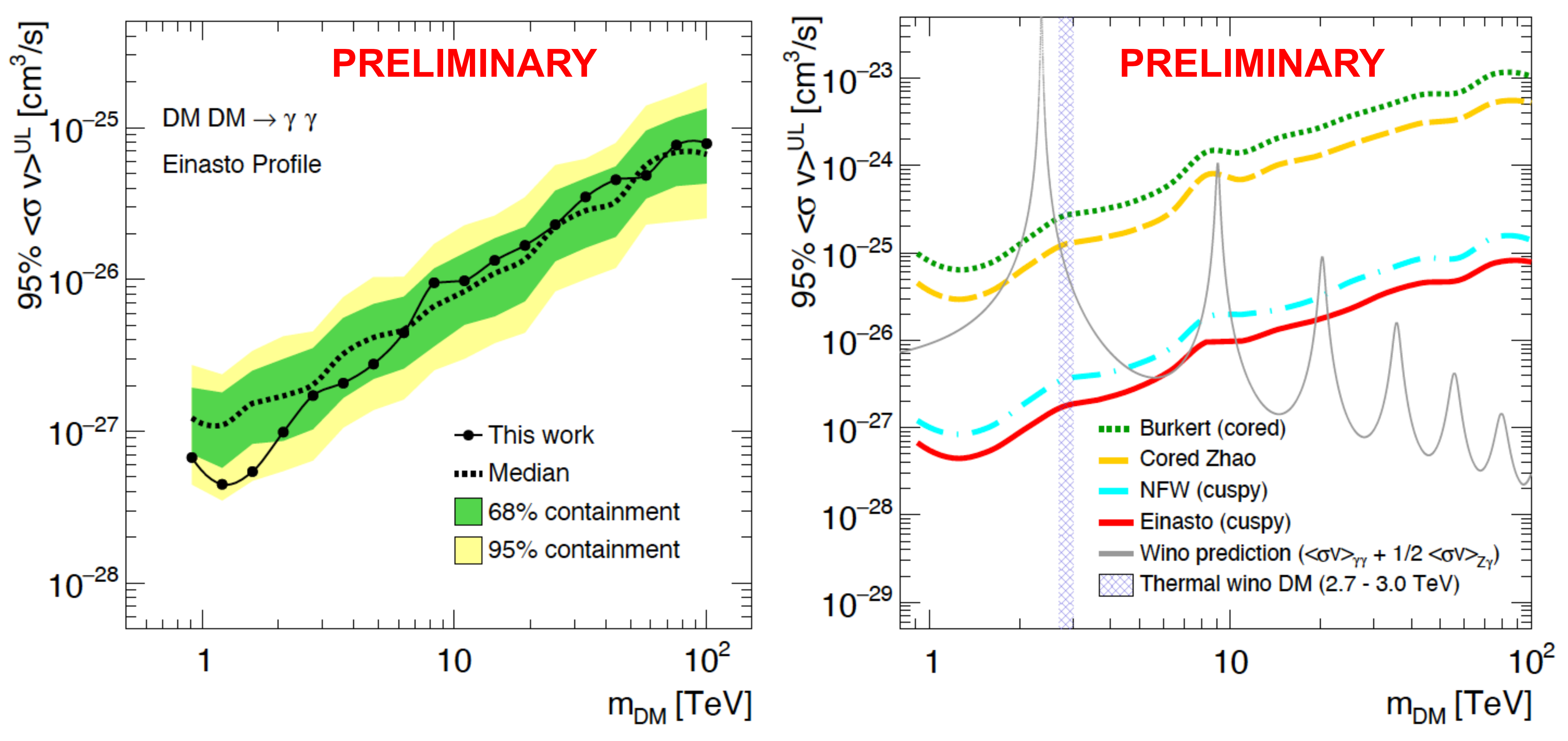


Figure 13:, 95% CL upper limits on the annihilation cross section (left) and upper limits for the four DM density profiles (right) credit: MAGIC collaboration, in preparation, 2022, leading author: Tomohiro Inada

ALPs searches in Perseus cluster

- Photon – ALP mixing → external magnetic field
- Flaring states → increased constraining power
- 40.2 hours of NGC1275 data & 3.5 hours of IC310 data

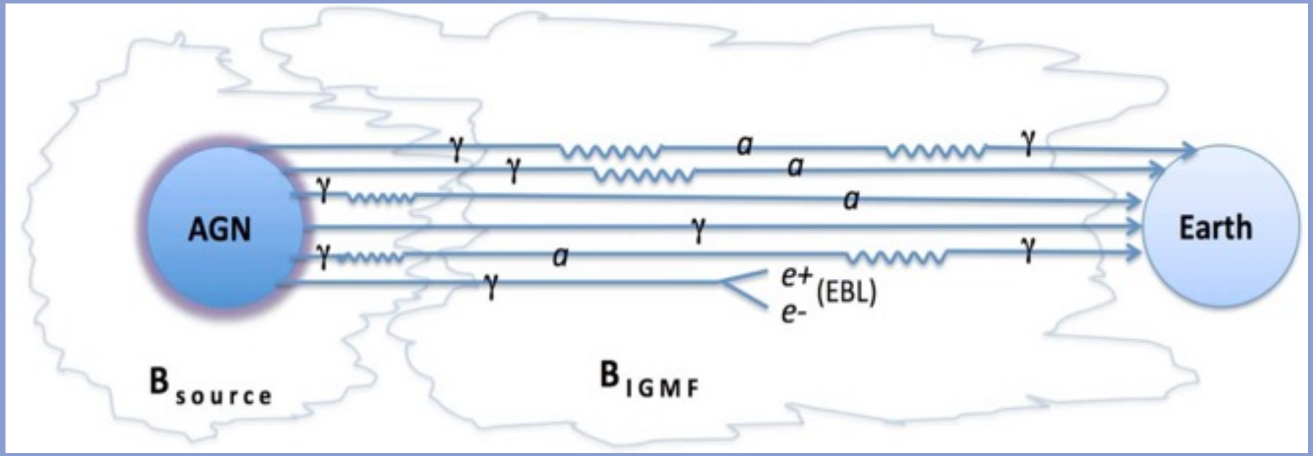
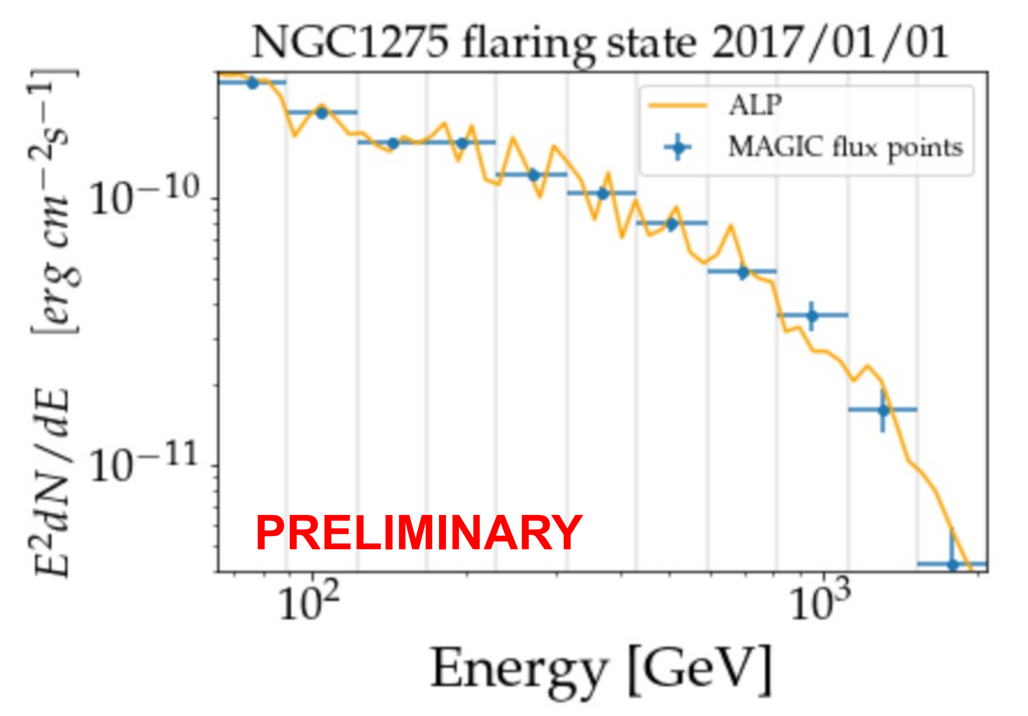


Figure 14: Photon-ALP mixing in the magnetic field, credit: M.A. Sanchez Conde et al., 2009, Phys.Rev.D79:123511

- mixing in the blazar + jet
- mixing in the magnetic field of the galaxy cluster
- mixing in the extragalactic magnetic field + ($\gamma + \gamma \rightarrow e^+ + e^-$)
- back-conversion in the galactic magnetic field

ALPs searches in Perseus cluster

Binned likelihood – $\mathcal{L}(\theta, b) = \mathcal{L}\left(\underbrace{m_a, g_{a\gamma}; B, \Gamma, \Phi_0, E_c}_{\text{model parameters}} \middle| b\right)$



- Model with fixed magnetic field realisation
- In the case of ALPs, due to the unknown magnetic field, random magnetic field realisations have to be employed to calibrate the test statistics for excluding the ALPs parameters.

Figure 15: Comparison of the MAGIC flux points with and w/out the ALPs model included. MAGIC collaboration, in preparation, 2022.

CONCLUSIONS

- MAGIC has been very active in the DM searches with several DM campaigns over the years

- Study of the data from dSphs gave the most stringent limits in the TeV regime
- Results agree with the constraints set with other gamma-ray experiments
- Advancement of the multi-instrument analysis allows for more detailed studies

- Studies of the galactic centre are limited by the high energy threshold, but results in the boosted DM line-like signal
- Constraints on both cuspy and core profiles are set

- Axion-like particle searches show the potential on constraining the ALPs parameter space
- Irregularities (wiggles) in the spectra of astrophysical targets are investigated
- Knowledge of the magnetic fields is fundamental for producing the ALPs models

THANK YOU FOR YOUR ATTENTION

“Recent results on Dark matter and axion-like particle searches with MAGIC”

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