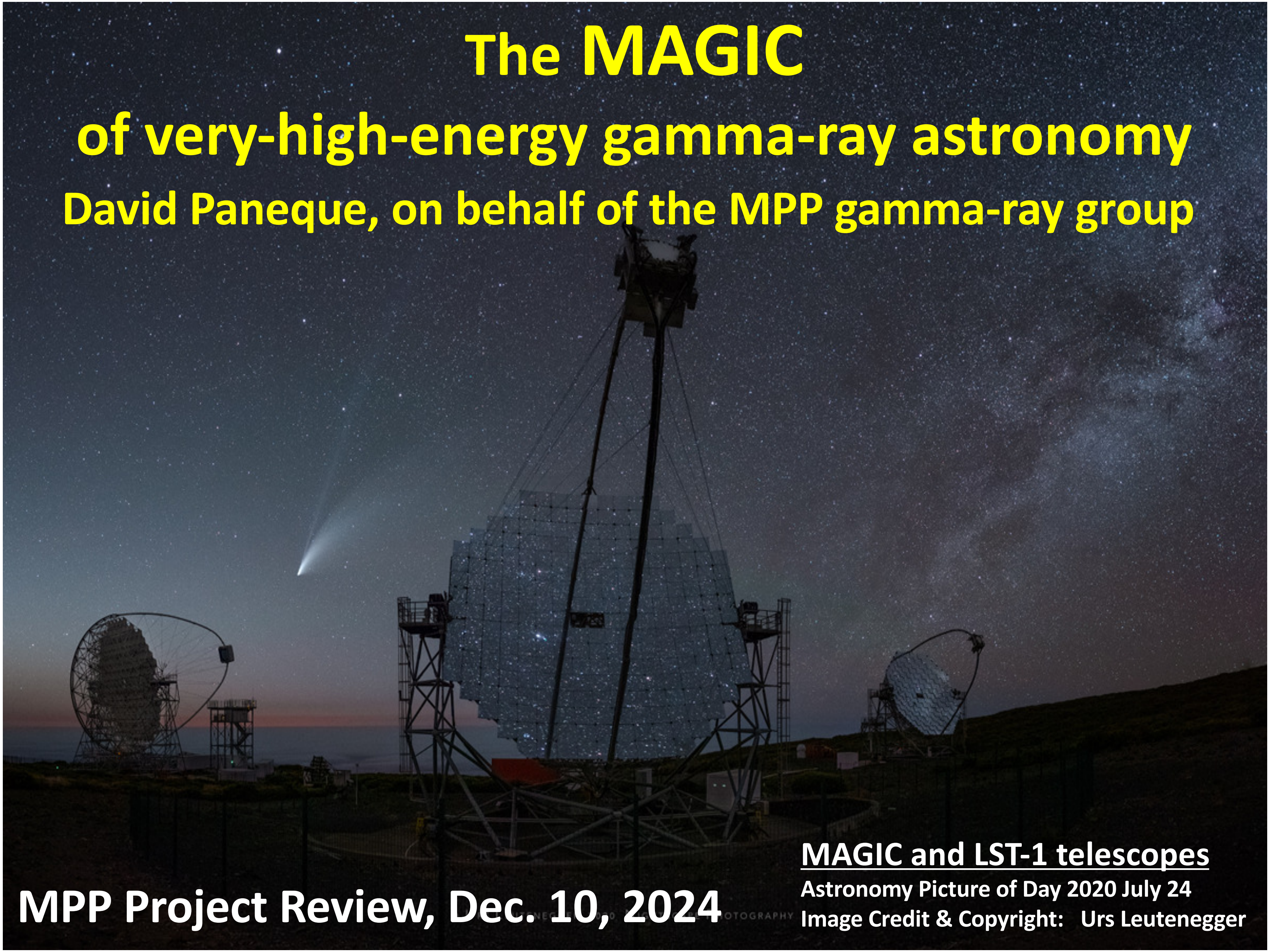
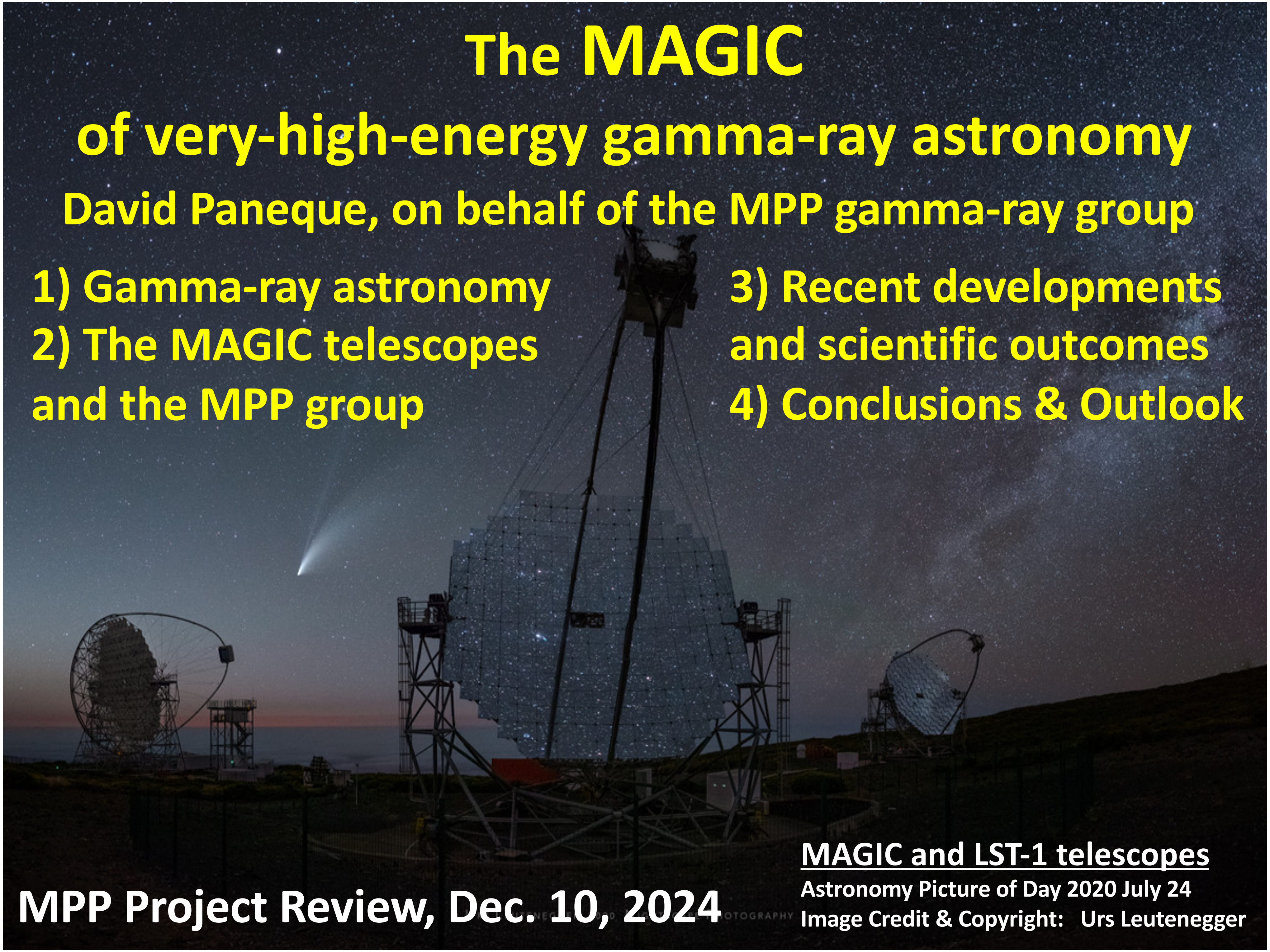
The MAGIC of very-high-energy gamma-ray astronomy

David Paneque, on behalf of the MPP gamma-ray group



MPP Project Review, Dec. 10, 2024

MAGIC and LST-1 telescopes
Astronomy Picture of Day 2020 July 24



The MAGIC of very-high-energy gamma-ray astronomy

David Paneque, on behalf of the MPP gamma-ray group

1) Gamma-ray astronomy
2) The MAGIC telescopes and the MPP group
3) Recent developments and scientific outcomes
4) Conclusions & Outlook

MPP Project Review, Dec. 10, 2024

<u>MAGIC and LST-1 telescopes</u>

Astronomy Picture of Day 2020 July 24

Image Credit & Copyright: Urs Leutenegger

Scientific merits of Gamma-ray astronomy

Experimental basis for studying the *high-energy Universe*

High-Energy particles will end up producing **gamma rays**

Hadronic high-energy particles → $\pi^{o} \rightarrow \gamma\gamma$, $\pi^{\pm} \rightarrow \mu^{\pm}\,\nu$

Leptonic high-energy particles → *Bremsstrahlung*, *Synchrotron*, *Inverse Compton*

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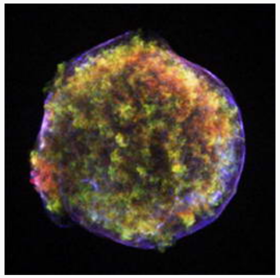
Information that gamma rays bring:

1 – Location (source direction)

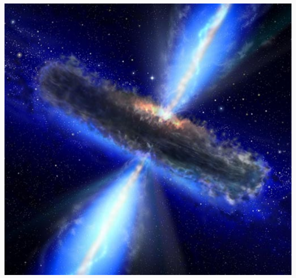
2 - Lower limit to the energy

3 – Temporal evolution

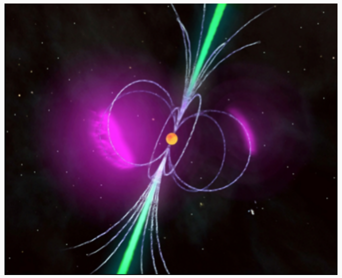
Energy Sources



Explosions



Accretion



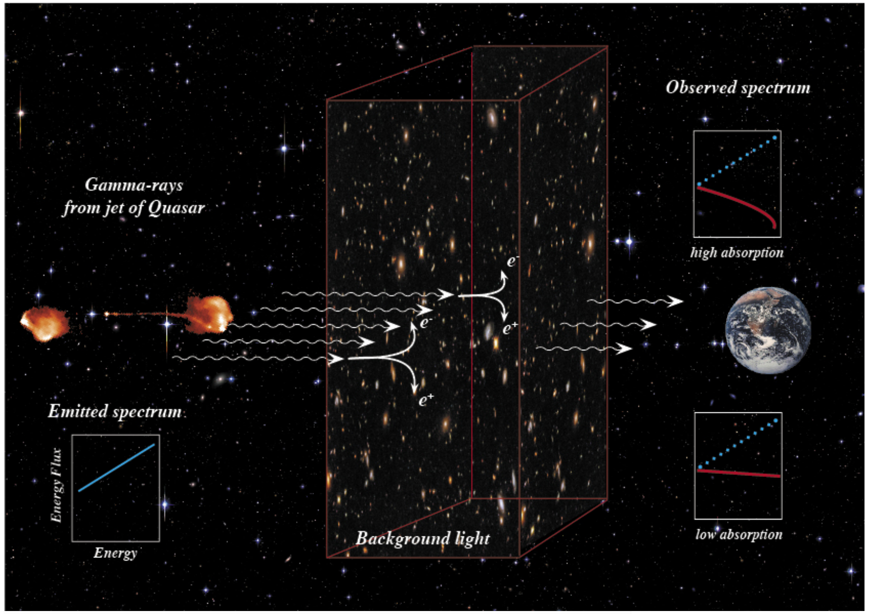
Extreme EM Fields

Many extreme particle accelerators in the Universe

High-energy gamma rays are excellent means to probe these physical conditions, which are *not-reproducible at the Earth*

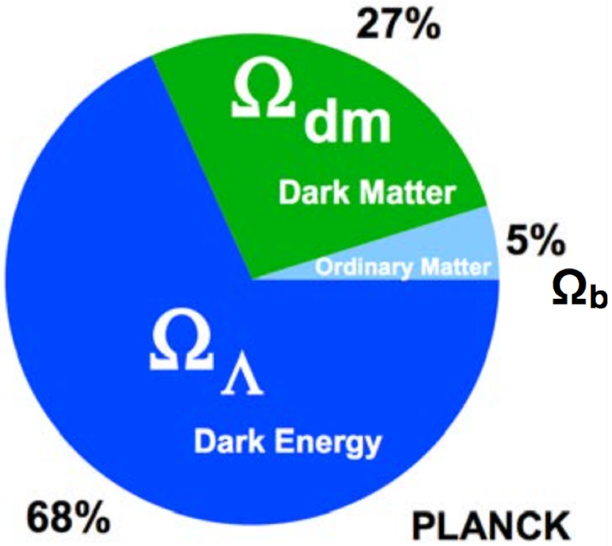
Science with the MAGIC telescopes

Also look for non-conventional astrophysics



Additional fundamental physics related to the propagation of the gamma-rays from the (distant) sources to the Earth

- Extragalactic Background Light (EBL)
- Intergalactic Magnetic Fields (IGMF)
- Lorentz Invariance violation (LIV)
- Search for Axion Like Particles (ALPs)



Indirect searches of DM particles

Indirect searches for DM

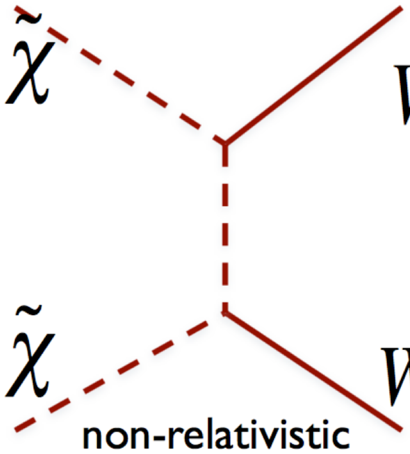
Annihilation Rate $\sim\rho^2$

(Decay Rate $\sim\rho$)

Annihilation Products

Decay

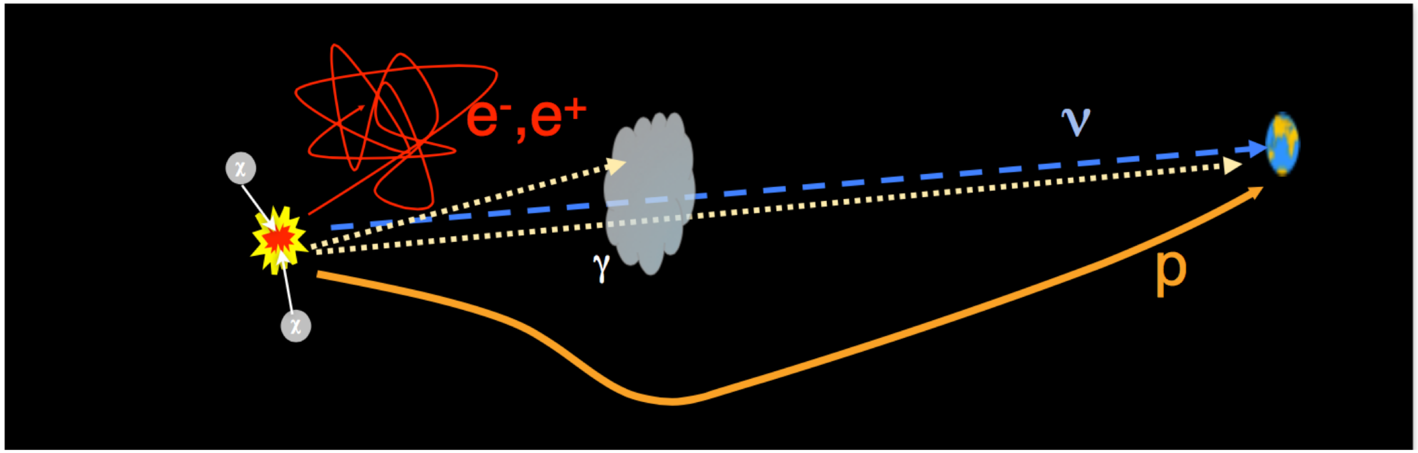
Messengers



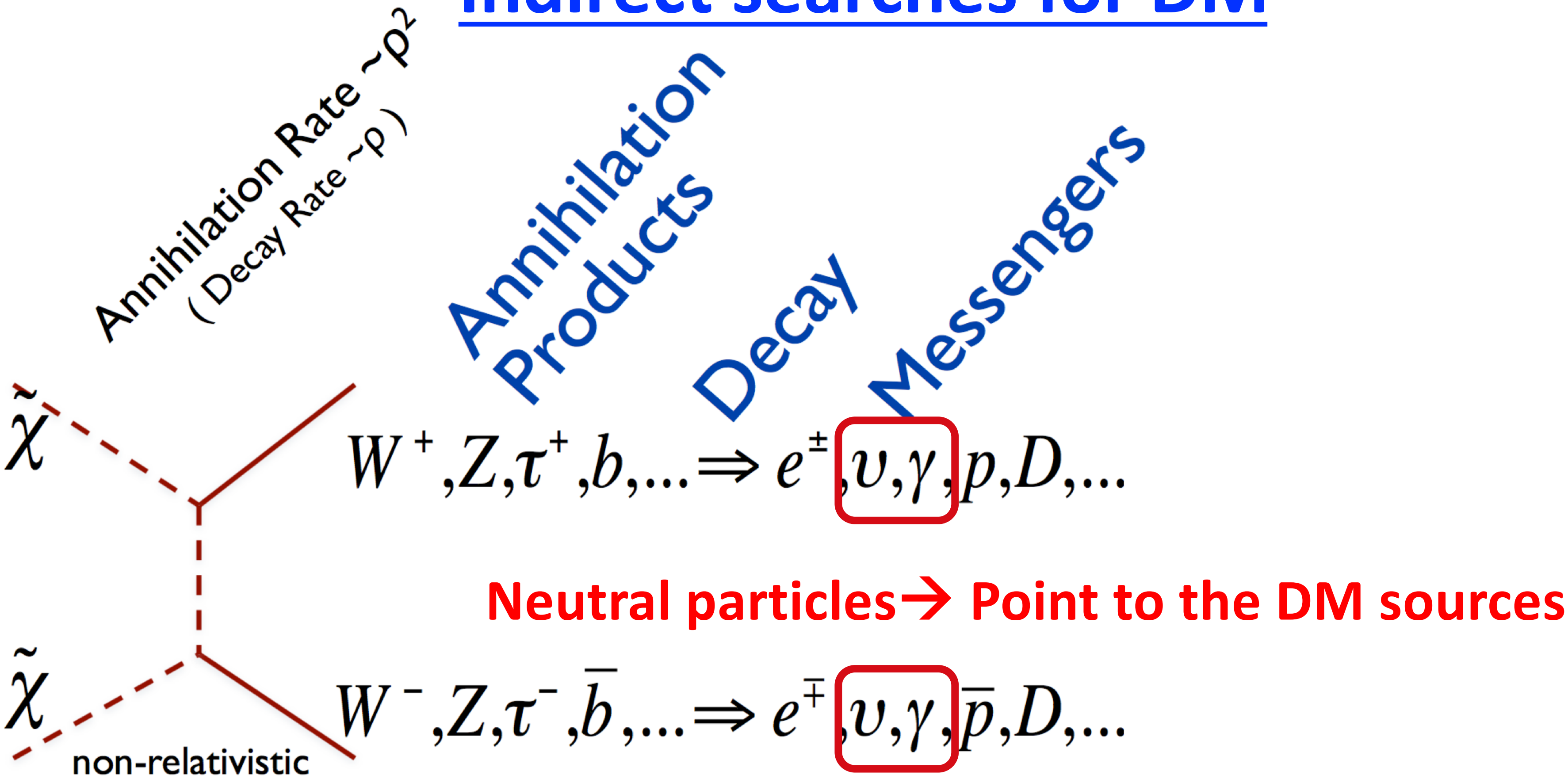
$$W^+, Z, \tau^+, b, \ldots \Rightarrow e^\pm, \upsilon, \gamma, p, D, \ldots$$

Neutral particles→ Point to the DM sources

$$W^-, Z, \tau^-, \bar{b}, \ldots \Rightarrow e^\mp, \upsilon, \gamma, \bar{p}, D, \ldots$$



Indirect searches for DM

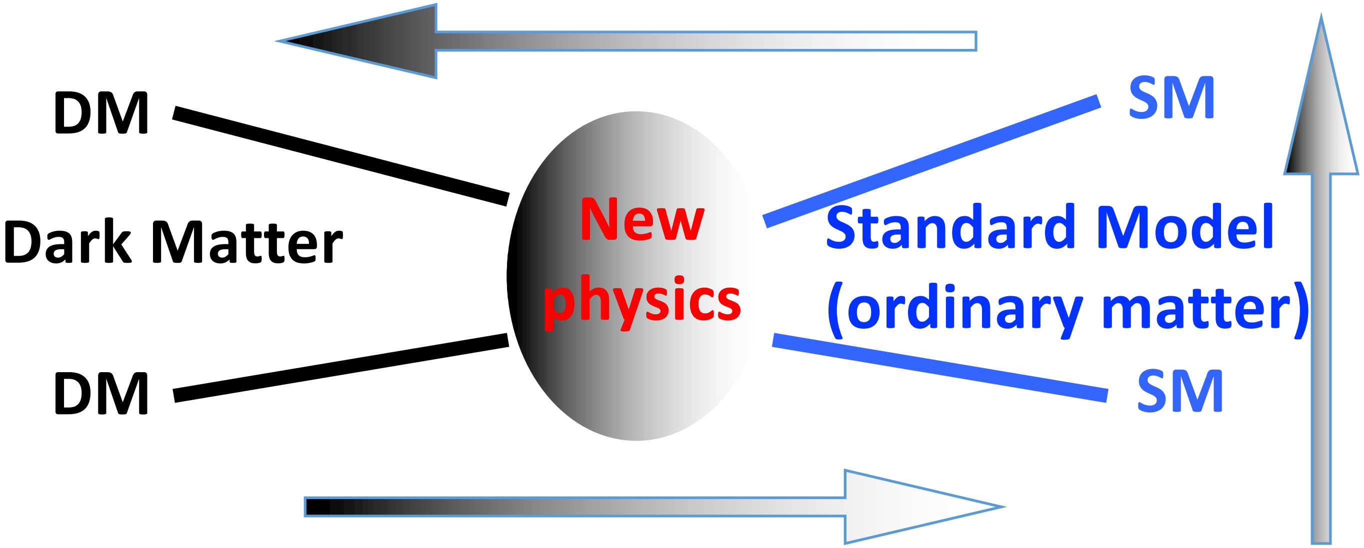


We have instrumentation for neutrinos and gamma rays, and hence the potential to make indirect detection of DM particles from specifically those locations in the Universe where we know there is "matter that we do not see"

The hunt for Dark Matter (DM) Particles

<u>General:</u> **Three different ways of searching for Dark Matter particles**

Collider searches: ATLAS, CMS …



Direct searches:
XENON, **CRESST …**
and in future
COSINUS, MADMAX

Indirect searches: MAGIC, HESS, VERITAS, **Fermi,** IceCube, AMS…
and in the future the **LST-array**

Even if a signal was found in collider experiments or direct detection experiments, we would still **<u>need indirect detection searches in order to</u>**:

1) confirm that whatever we find in the Lab is the same "dark matter" responsible for astrophysical and cosmological observations.

2) access particle information not otherwise available in the Lab (annihilation cross section or decay time, b.r.'s)

Instrumentation for gamma-ray astronomy (the big picture)

	Exploration phase	Established field	"Ultimate" (?) generation (*population + precision studies)*
	~ 10 sources	~ 100 sources	~ 1000-10000 sources
Pair conversion experiments (MeV-GeV) **Space**	*70s (SAS-2, COS-B)*	*90s (EGRET)*	Now **Fermi-LAT**
Ground *Cherenkov Telescopes (GeV-TeV)*	*90s (WHIPPLE, HEGRA,CAT)*	*00s (**Cangaroo, H.E.S.S., MAGIC, VERITAS**)*	Future **CTA**

Now

MAGIC II, H.E.S.S. II
VERITAS upgraded

HAWC, LHAASO ...

Novel discipline

lots of room for improvement and potential discovery

Instrumentation for gamma-ray astronomy (the big picture)

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Involvement of MPP group

Novel discipline

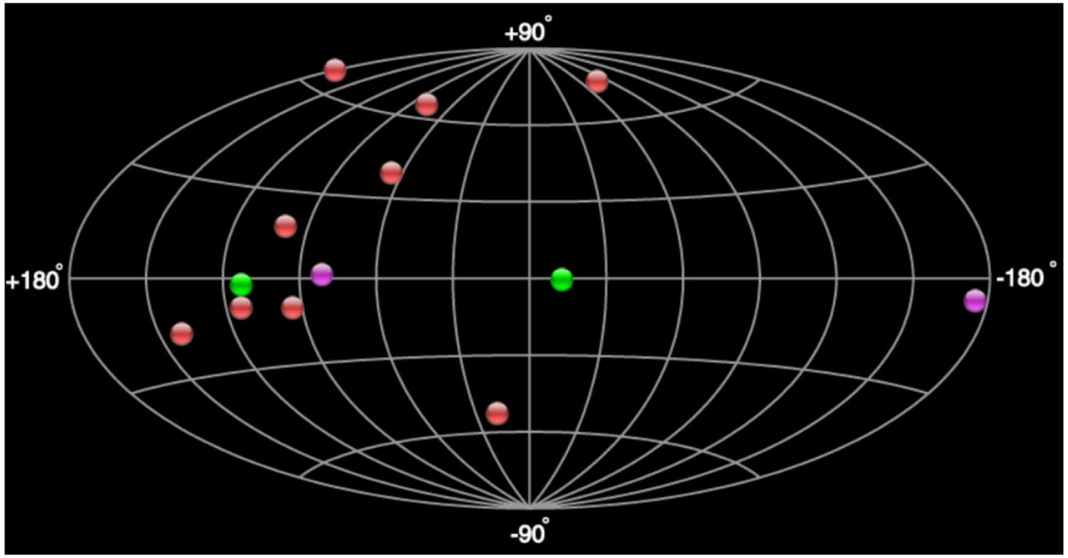
CTA currently under construction (*North+ South*)
CTA-North will be completed first (*approx. 2030*)
→ LST-1 already working
→ 3 additional LSTs in construction (2026)
→ 5 MST telescopes in construction (2030+)

lots of room for improvement and potential discovery

Spectacular improvement of the gamma-ray sky over the last 2 decades

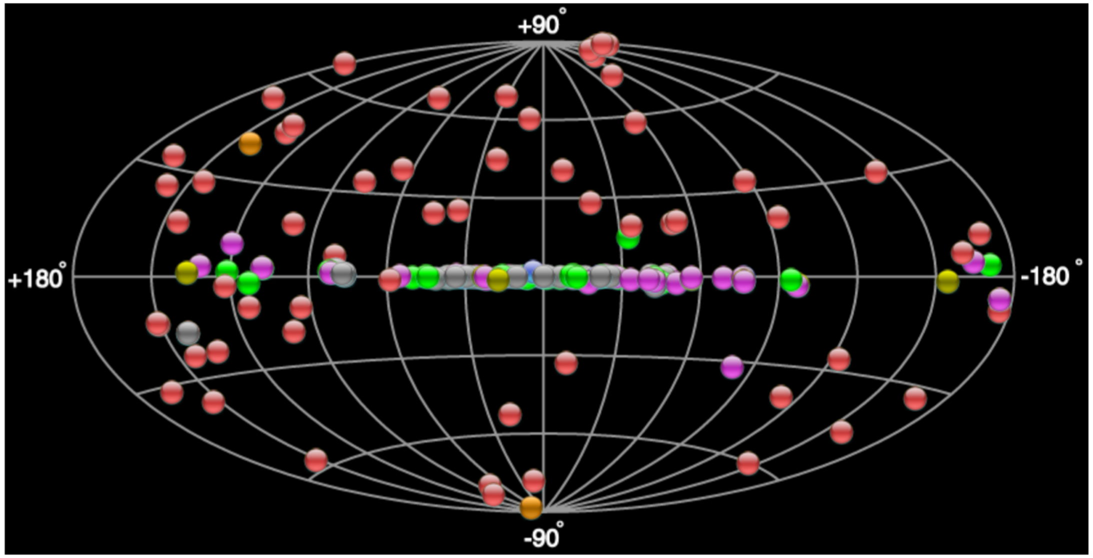
The "TeV" gamma-ray sky : Gamma-rays above 100 GeV

Plots obtained from the TeVCat
http://tevcat.uchicago.edu/



October 2003 (~21 years ago):
MAGIC starts operation
13 sources
10 AGNs

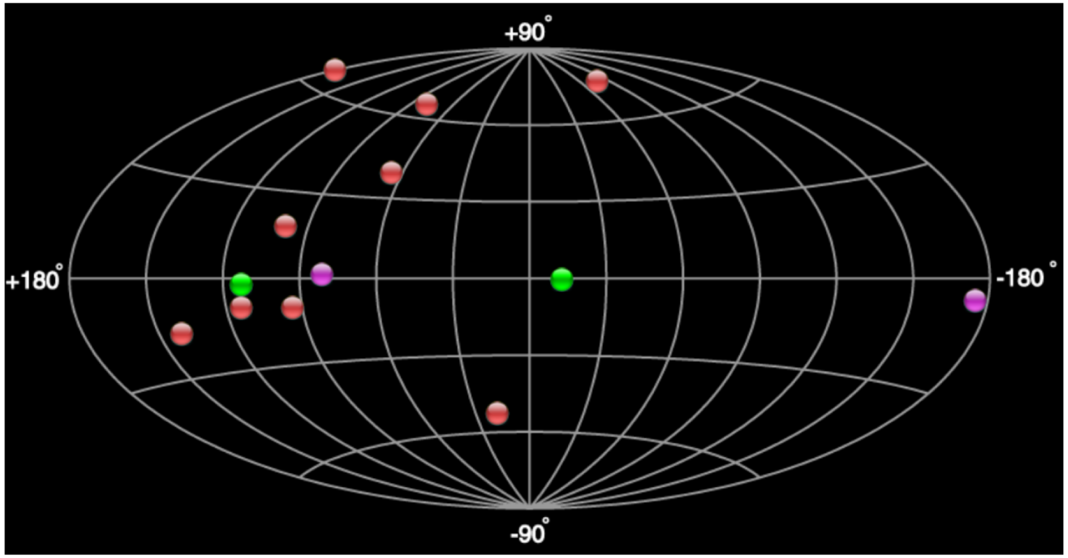
Large improvement in the knowledge of the TeV sky in only ~10 years



October 2014 (~10 years ago) :
176 sources

The “TeV” gamma-ray sky : Gamma-rays above 100 GeV

Plots obtained from the TeVCat
http://tevcat.uchicago.edu/



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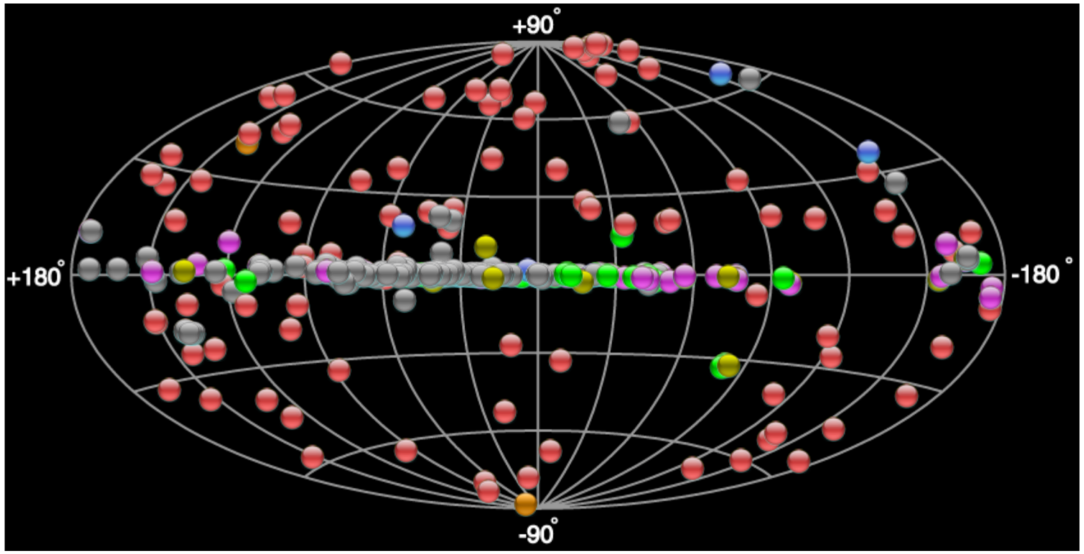

December 2024 (~ TODAY) :
307 sources

2 – The MAGIC telescopes and the MPP group (and overall contributions)

The MAGIC Stereoscopic system

- **MAGIC: Two Imaging Atmospheric Cherenkov Telescopes (IACTs) of 17 meter diameter mirror dish to perform Very High Energy (VHE) gamma-ray astronomy**
  - **Operational energy range: from ~50 (~20) GeV to >100 TeV**
  - Sensitivity: 0.7% the Crab Nebula flux (above 220 GeV) after 50 hours observation

    → About 5% of the Crab Nebula flux in 1 hour of observation

MAGIC-1 **Control house** **MAGIC-2**

Shifters that operate telescopes (and trigger, DAQ …)

The MAGIC Stereoscopic system

- **MAGIC: Two Imaging Atmospheric Cherenkov Telescopes (IACTs) of 17 meter diameter mirror dish to perform Very High Energy (VHE) gamma-ray astronomy, located on the Canary island of La Palma (Spain)**

Observatorio Roque de los Muchachos

One of the best observation sites in the world, populated with large telescopes

The MAGIC collaboration

About 320 members *(includes technicians+associated members)*
About 230 full scientific members *from 13 countries (40+ groups)*

More than 150 Early Career (EC) Members

MAGIC continues to attract young scientists, who learn hardware, software, analysis, and science (*PhD theses & Publications*)

→ **Also get opportunity to take coordinating responsibilities**

Group picture from the collab. meeting (La Palma, October 2023)

The MPP experimental gamma-ray group

About 26 (21+5) Scientists (@2024)

Director: Masahiro Teshima

Senior (3):

Razmik Mirzoyan, Thomas Schweizer, David Paneque

Postdoc (6+1+1+2):

Giovanni Ceribella, Irene Jimenez, Michele Peresano, **Axel Arbet-Engels**

David Green, Alessio Berti, Seiya Nozaki, Gayoung Chon (LMU guest)

Left the MPP group In October 2024:

Partially paid by ORIGINS Excellence Cluster

Martin Will (now @CTAO Bologna), Lea Heckmann, (now @Univ.Paris)

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In 2025 will move to CTAO Bologna

In 2025 will move to ICRR Tokyo

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PhD Students (4+2):

Giorgio Pirola, Jarred Green, Alexander Hahn, Juliane van Schenperberg

Finished PhD in 2024

Yating Chai (March, now@ICRR Tokyo), Felix Schmuckermaier (Nov.)

Undergraduate (5+1): Elli Jobst, Varun Kelkar, Yunhe Wang, Lucas Olivier, Sajena Hamdi

Finished Master thesis in 2024

Angela Bautista (finished in March)

MPP responsibilities within MAGIC

MPP is the group with most resources within the MAGIC collaboration

→ ***MAGIC concept was born at MPP in mid 90s***

→ ***Most hardware was designed, built and now maintained by MPP***

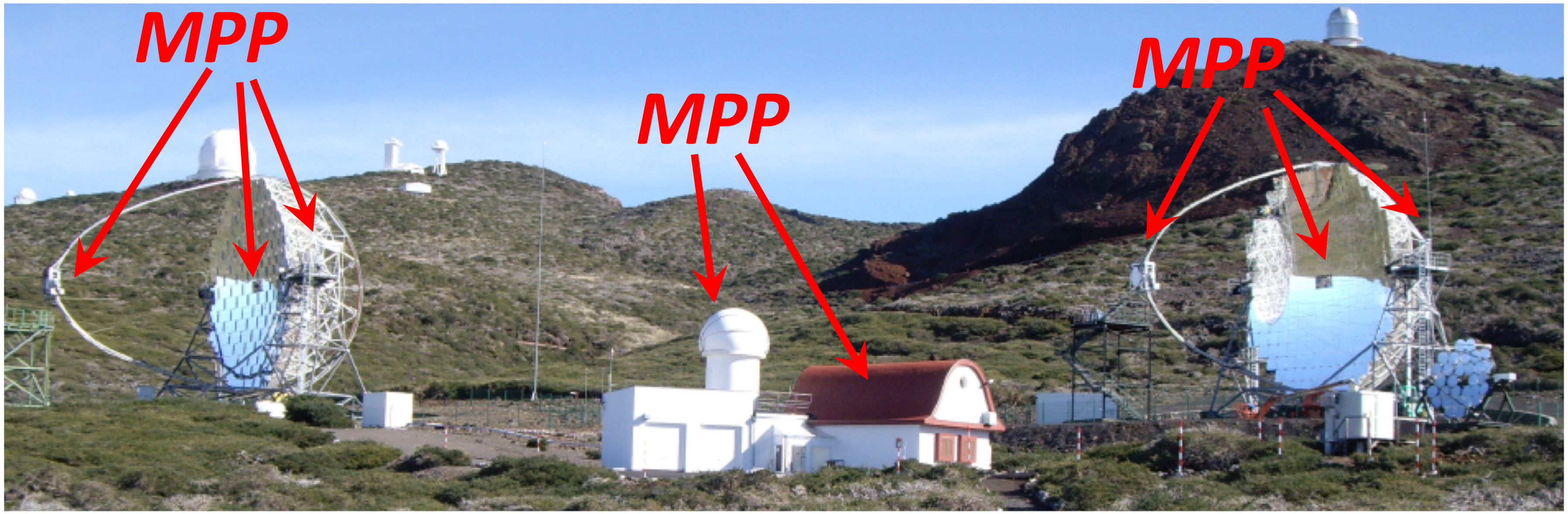
2 Telescope structures (cooperation with company MERO)

2 Telescope cameras + 2 Calibration systems

LIDAR + MAM telescopes (for monitoring atmospheric conditions)

Sum-Trigger-II (for lowering energy threshold)

Mirror production with novel technology (for durability and easy clean)



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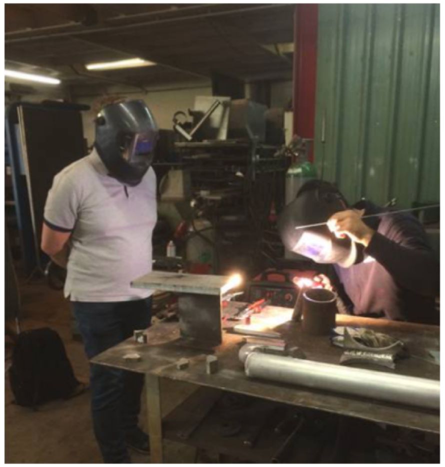
The gamma-ray group gets CRUCIAL SUPPORT from the mechanical and electronic engineer departments from MPP: **absolutely needed for the construction and operation/maintenance of the telescopes**

O. Reimann, A. Eiterer, H. Wetteskind, S. Schmidl, D. Fink, M. Fras, M. Modjesch, T. Dettlaff, A. Sedlak, D. Strom, S. Horn, C. Jablonksi, R. Stadler, W. Haberer, J. Schlammer, J. Besenrieder …



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MPP members have leading positions at all levels:
Organizational, hardware, software, science and outreach

David Paneque **Spokesperson** (*since Jan. 2023*)
Masahiro Teshima **MAGIC-LST contact** (*since 2018*)

Executive Board members (*4 out 10*)

Alessio Berti Coordinator of **Software Board** (*since Jan. 2023*)
Giovanni Ceribella Coordinator of **Technical Board** (*Jan.2023-Sep.2024*)

Axel Arbet Engels Coordinator of Extragalactic group (*since Jan. 2023*)
Irene Jimenez Coordinator of Galactic group (*since Oct. 2024)*

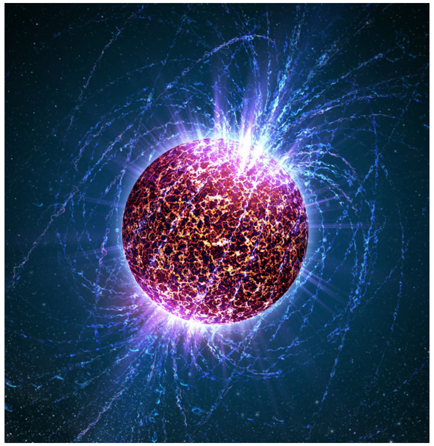
Juliane van Scherpenberg Social Media Manager (Jan. 2023 – Oct.2024)

Developments and scientific outcomes in 2024

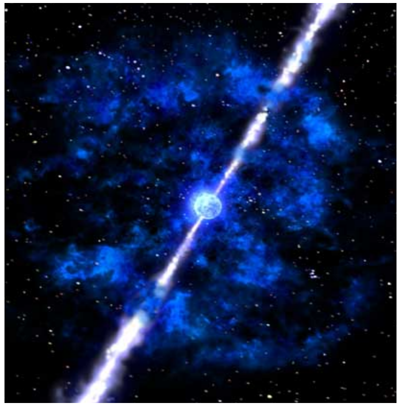
MAGIC publications in peer-reviewed journals

In year 2023, MAGIC turned 20 years & reached milestone of 200 peer-reviewed publications (210 publications in Dec.2024)

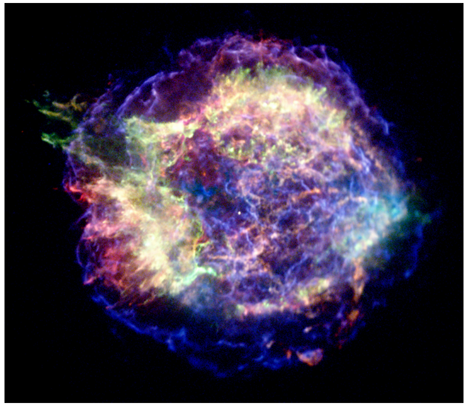
Pulsars



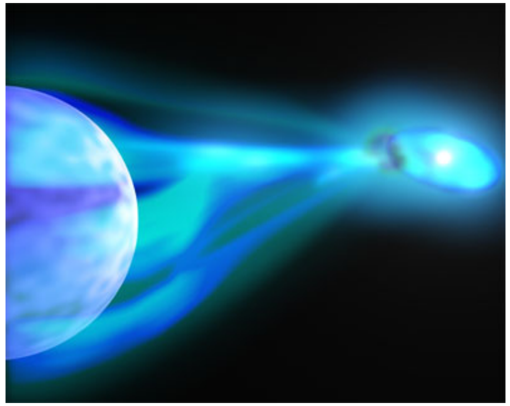
GRBs

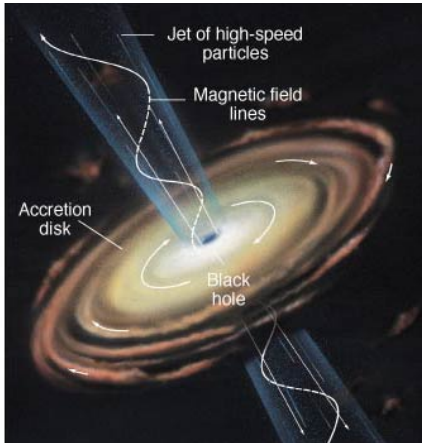


SNR+PWN

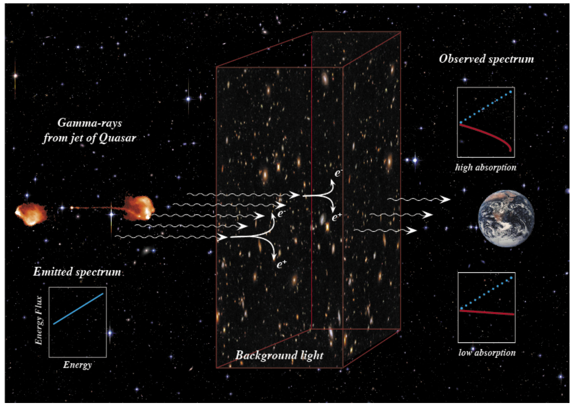


Binary systems & Novae



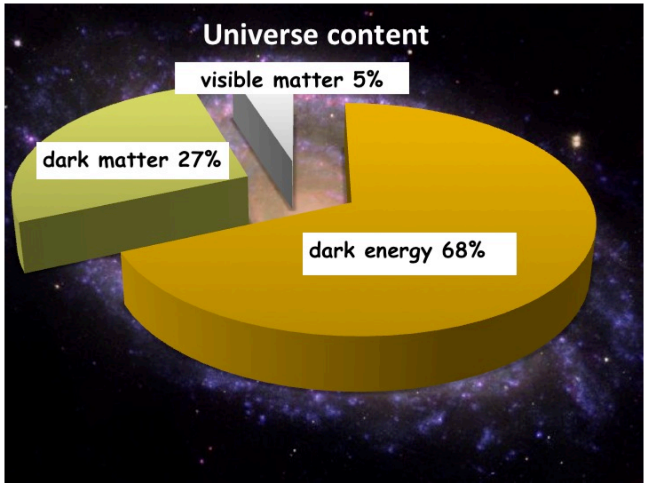


AGNs



EBL
IGMF
ALPs
LIV

Dark Matter searches



Science with the MAGIC telescopes

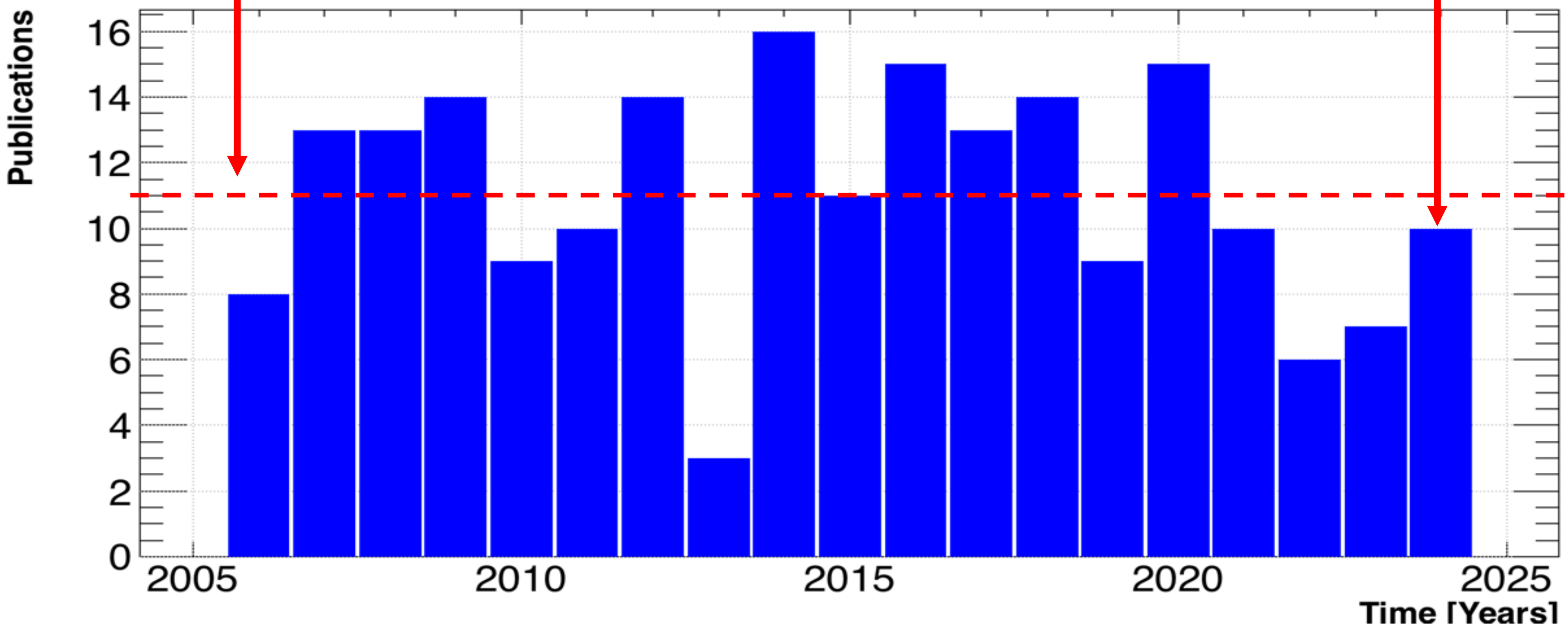
MAGIC refereed papers (published): 210

Broad range of topics: from conventional to exotic (astro)physics

Historical average:
11 papers/year

10 publications in year 2024

Number of publications vs Year (*until 2024/12/09*)



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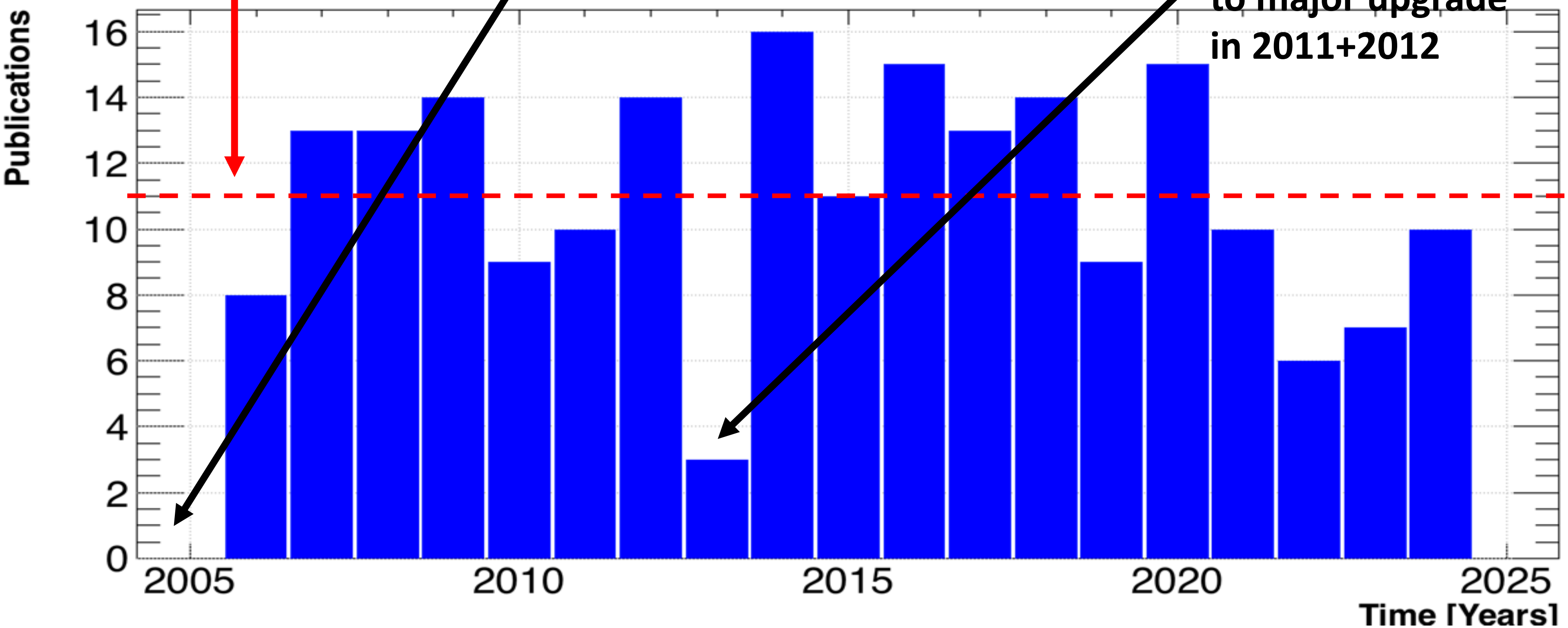
Historical average:
11 papers/year

MAGIC was inaugurated in 2003, commissioned in 2004, but observations typically need 2+ years to get published *(first collaboration publications with data in 2006)*

Drop in 2013 due to major upgrade in 2011+2012

Number of publications vs Year (*until 2024/12/09*)



Timeline of MAGIC publication is 2+ years (*from observation to actual publication*)

Science with the MAGIC telescopes

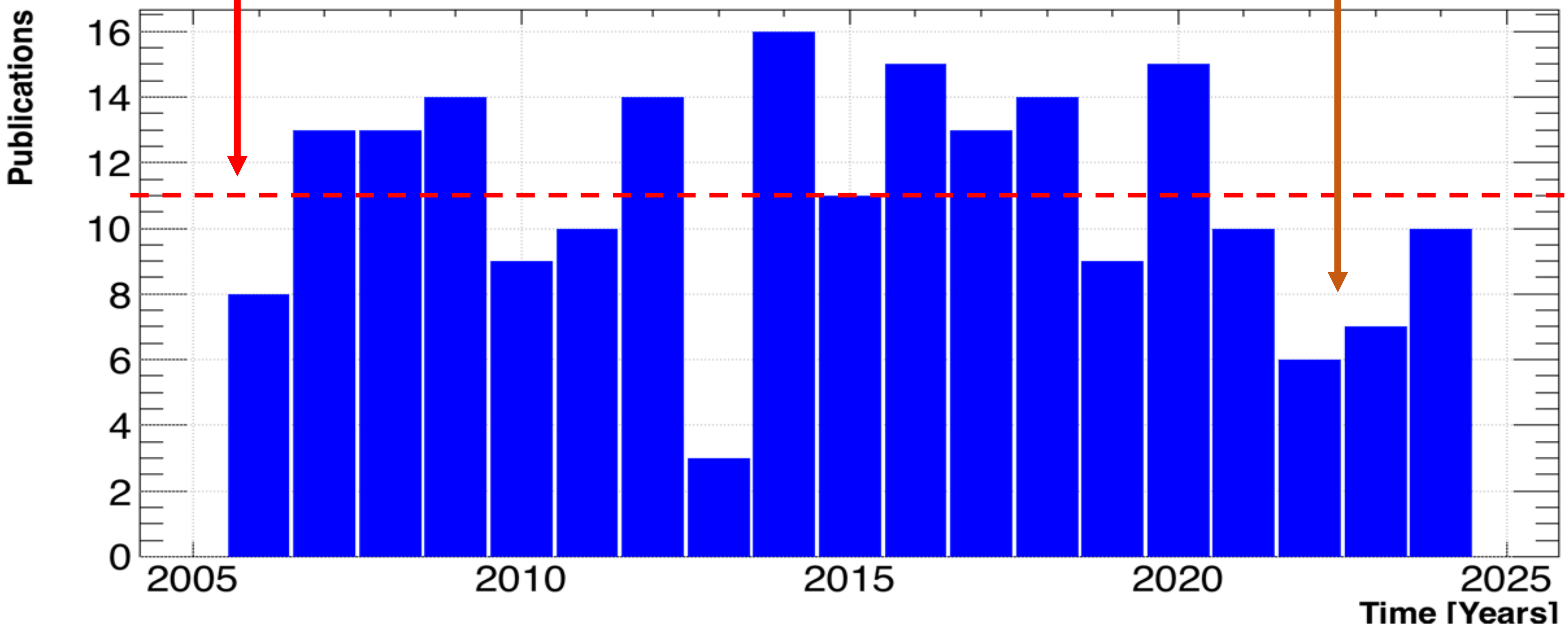
MAGIC refereed papers (published): 210

Broad range of topics: from conventional to exotic (astro)physics

Historical average:
11 papers/year

Drop in publication number in 2022-2023 due to
- Covid-19 (6 months, spring-fall 2020)
- Volcano eruption (3 months, fall 2021)
- Crack in M1 mast (3 months, fall 2022)

Number of publications vs Year (*until 2024/12/09*)



Publication rate in 2024 has essentially recovered, and now close to historical average

MAGIC publications in peer-reviewed journals

Large contribution from MPP members

Leading (corresponding) authors from MPP gamma-ray group

2024MNRAS.527.5856A 2024/01 cited: 9

MAGIC detection of GRB 201216C at z = 1.1

Abe, H.; Abe, S.; Acciari, V. A. *and 217 more*

→ **Alessio Berti, ++**

2024A&A...682A.114M 2024/02 cited: 4

Multi-year characterisation of the broad-band emission from the intermittent extreme BL Lac 1ES 2344+514

MAGIC Collaboration; Abe, H.; Abe, S. *and 238 more*

→ **Axel Arbet-Engels, ++**

2024A&A...684A.127A 2024/04 cited: 3

First characterization of the emission behavior of Mrk 421 from radio to very high-energy gamma rays with simultaneous X-ray polarization measurements

Abe, S.; Abhir, J.; Acciari, V. A. *and 251 more*

→ **Axel Arbet-Engels, Felix Schmuckermaier, David Paneque**

2024MNRAS.529.3894M 2024/04 cited: 1

The variability patterns of the TeV blazar PG 1553 + 113 from a decade of MAGIC and multiband observations

MAGIC Collaboration; Abe, H.; Abe, S. *and 263 more*

2024MNRAS.529.4387A 2024/04 cited: 5

Performance and first measurements of the MAGIC stellar intensity interferometer

Abe, S.; Abhir, J.; Acciari, V. A. *and 219 more*

→ **Irene Jimenez, ++**

MAGIC publications in peer-reviewed journals

Large contribution from MPP members

Leading (corresponding) authors from MPP gamma-ray group

2024A&A...685A.117M 2024/05 cited: 5

Insights into the broadband emission of the TeV blazar Mrk 501 during the first X-ray polarization measurements

MAGIC Collaboration; Abe, S.; Abhir, J. *and 263 more*

Axel Arbet-Engels,
Lea Heckmann,
David Paneque

2024PDU....4401425A 2024/05 cited: 6

Constraints on axion-like particles with the Perseus Galaxy Cluster with MAGIC

Abe, H.; Abe, S.; Abhir, J. *and 211 more*

2024JCAP...07..044A 2024/07 cited: 2

Constraints on Lorentz invariance violation from the extraordinary Mrk 421 flare of 2014 using a novel analysis method

Abe, S.; Abhir, J.; Abhishek, A. *and 216 more*

2024JHEAp..44..266A 2024/11

Standardised formats and open-source analysis tools for the MAGIC telescopes data

Abe, S.; Abhir, J.; Abhishek, A. *and 208 more*

2024MNRAS.535.1484A 2024/12 cited: 1

Constraints on VHE gamma-ray emission of flat spectrum radio quasars with the MAGIC telescopes

Abe, S.; Abhir, J.; Abhishek, A. *and 220 more*

Half of the scientific publications in peer-reviewed journals have leading contributions from MPP members

MAGIC publications in peer-reviewed journals

+3 accepted but not yet published

Leading (corresponding) authors from MPP gamma-ray group

MAGIC Accepted and Published Papers Table

by **admin** » Tue Jan 16, 2018 5:30 pm

2024

Group	Short Title	Main Editor	Team	Multi-Coll	Status
GAL	W44	Alexander Hahn	Marcel Strzys, Leonardo di Venere, David Green		Accepted on A&A
EGAL	M87 with EHT 2018	Alexander Hahn		EHT	Accepted on A&A
EGAL	Discovery of LBL OT 081	Marina Manganaro	Pepa Becerra (MAGIC analysis, Fermi-LAT); Monica Seglar-Arroyo + David Sanchez (Hess); Elina Lindfors	Fermi-LAT; HESS	Accepted on MNRAS

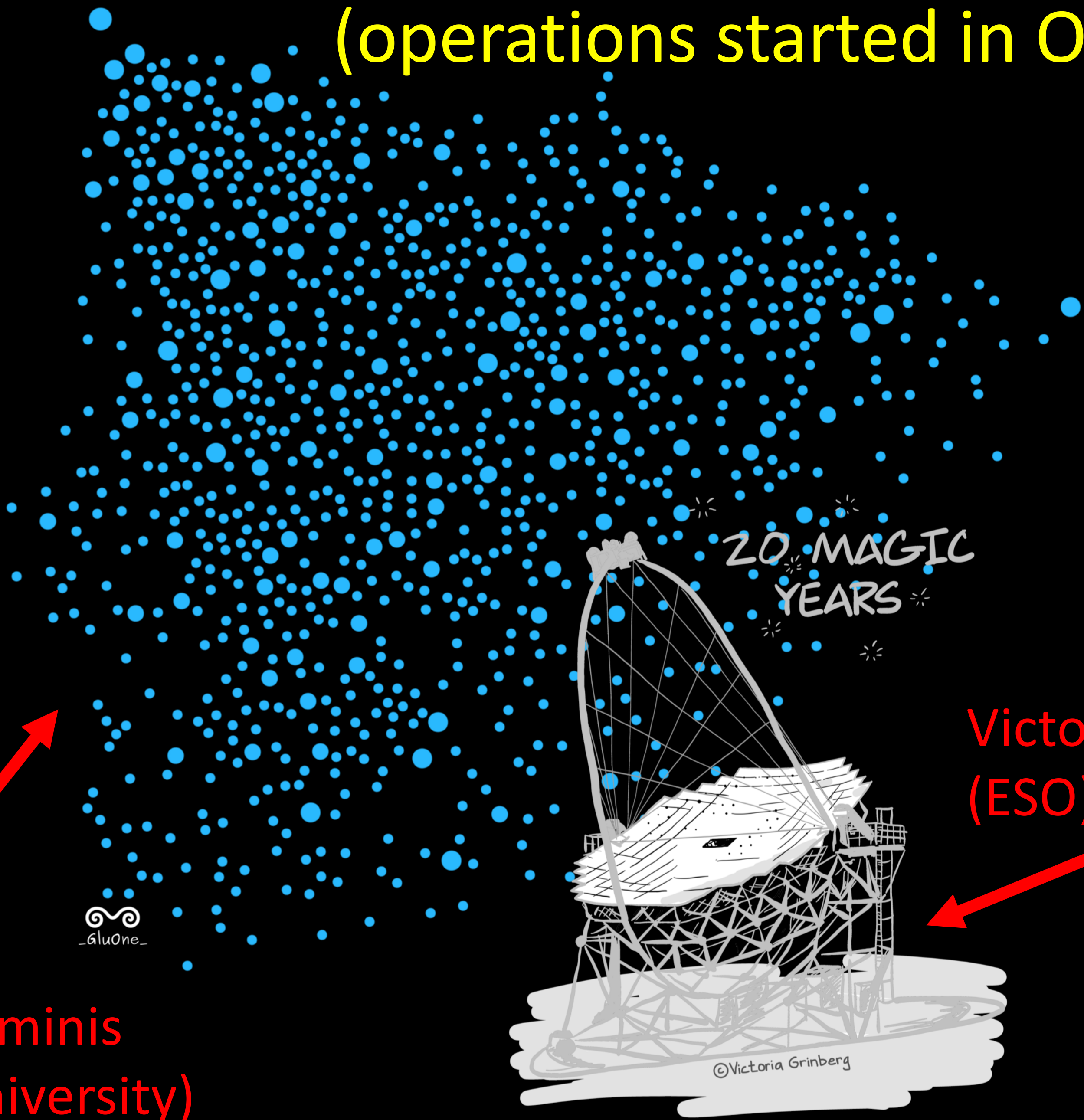
→ **Alexander Hahn, ++**

→ **Alexander Hahn**

More than
Half of the scientific publications in peer-reviewed journals have leading contributions from MPP members

MAGIC is 20+1 years old

(operations started in Oct. 2003)



Victoria Grinberg
(ESO)

Dijana Dominis
(Rijeka University)

Workshop + Ceremony in October 2023

MAGIC dedicated exhibition in the Visitor Center of the Observatory @ La Palma

How a 21+ year old instrument continues to be competitive ?

1) Unique capability among Gamma-ray instruments
   → **Best sensitivity below 200 GeV**

This capability is essential to detect objects with strong internal gamma-gamma absorption, or very distant sources, like Gamma Ray Bursts

First detections of a gamma-ray burst at TeV energies

GRB190114C (z=0.42), **First GRB at TeV**, detected by MAGIC @50 sigma
→ announced with Astronomer's Telegram on **January 20th, 2019**

GRB 180720B (z=0.65), detected by **HESS** at 5 sigma
→ announced at the *CTA symposium*, **May 2019**

GRB 190829A (z=0.08), detected with **HESS** at 22 sigma
→ announced with *Astronomer's Telegram* on **Aug 30th, 2019**

GRB201216C (**z=1.1**), detected with **MAGIC** at 6 sigma
→ announced with *Astronomer's Telegram* on **Dec 17th, 2020**
→ **Most distant VHE gamma-ray source to date**

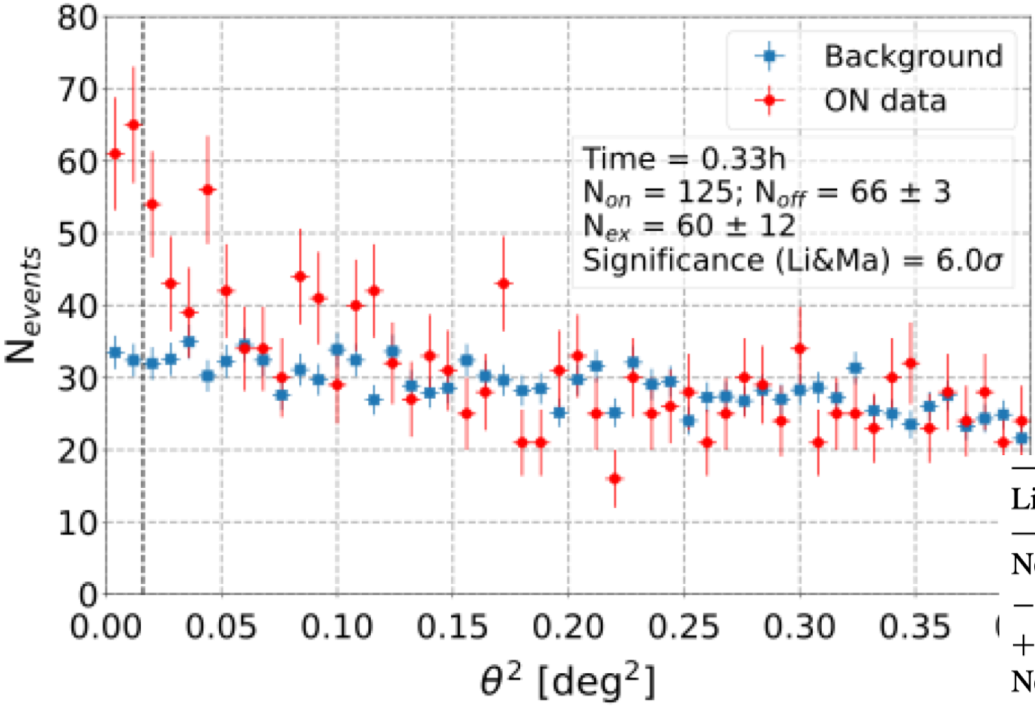
GRB 221009A (z=0.15), detected with **LHAASO** at >200 sigma
(**BOAT** → Brightest Of All Times) → announced with *GCN Circular* on **Oct 11th, 2022**

5 GRBs detected so far at TeV energies, 2 with MAGIC,
2 with H.E.S.S. and 1 with LHAASO

MAGIC detection of GRB 201216C at z = 1.1

(most distant VHE source)

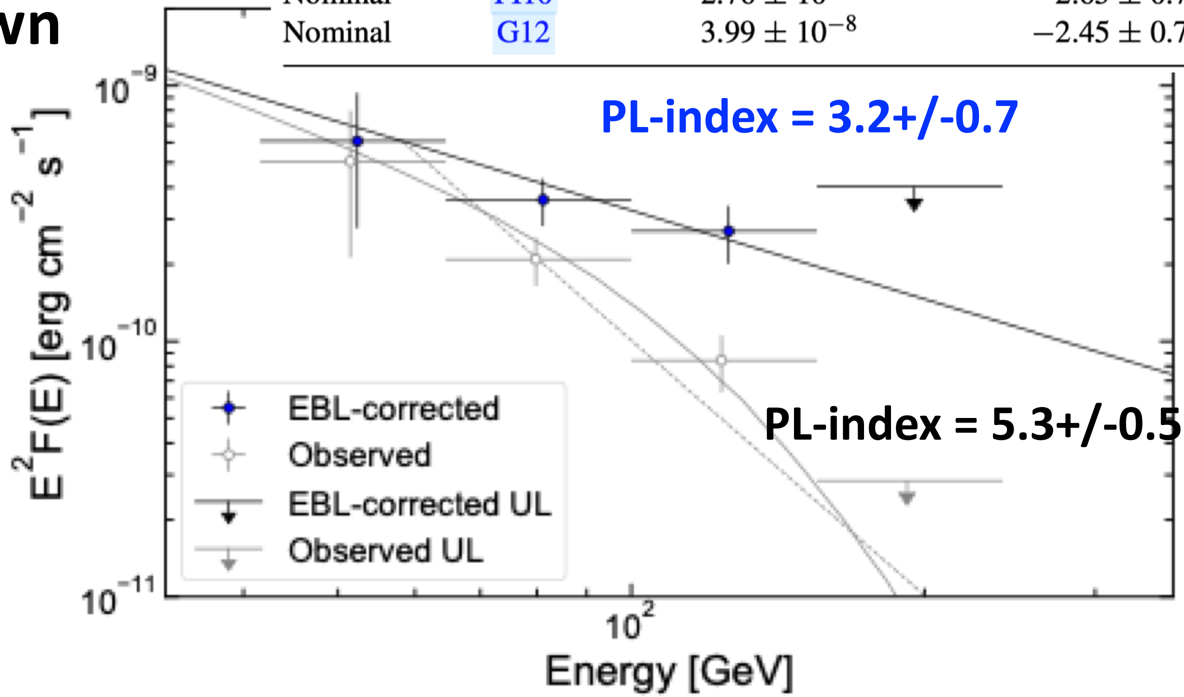
Abe et al., MNRAS 527, 5856–5867 (2024)

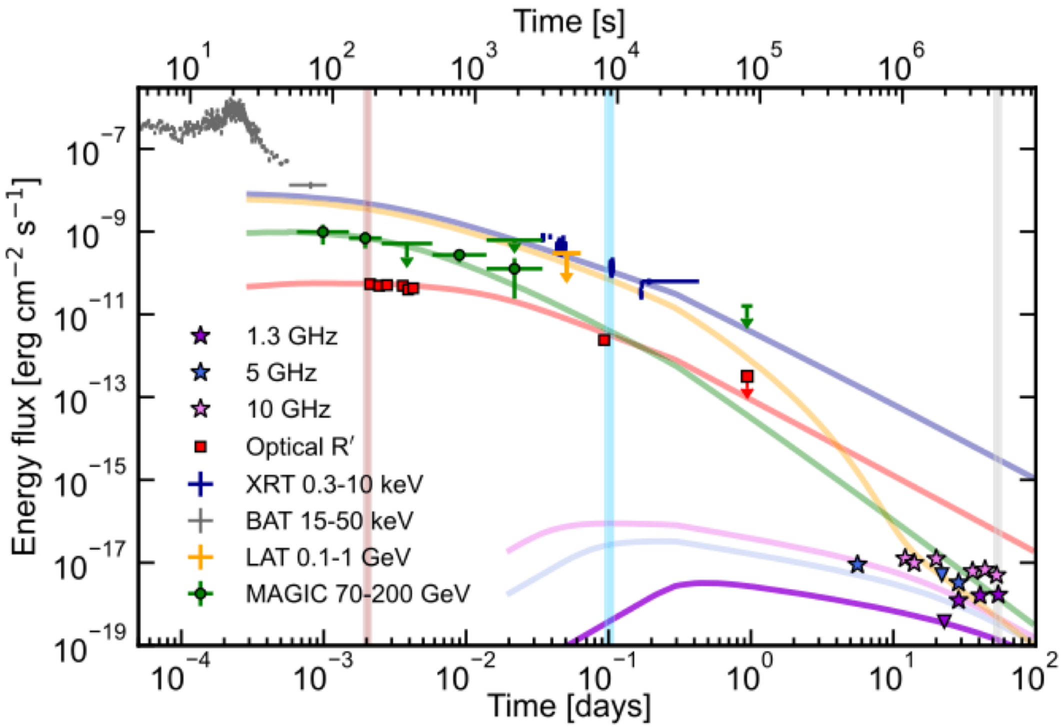


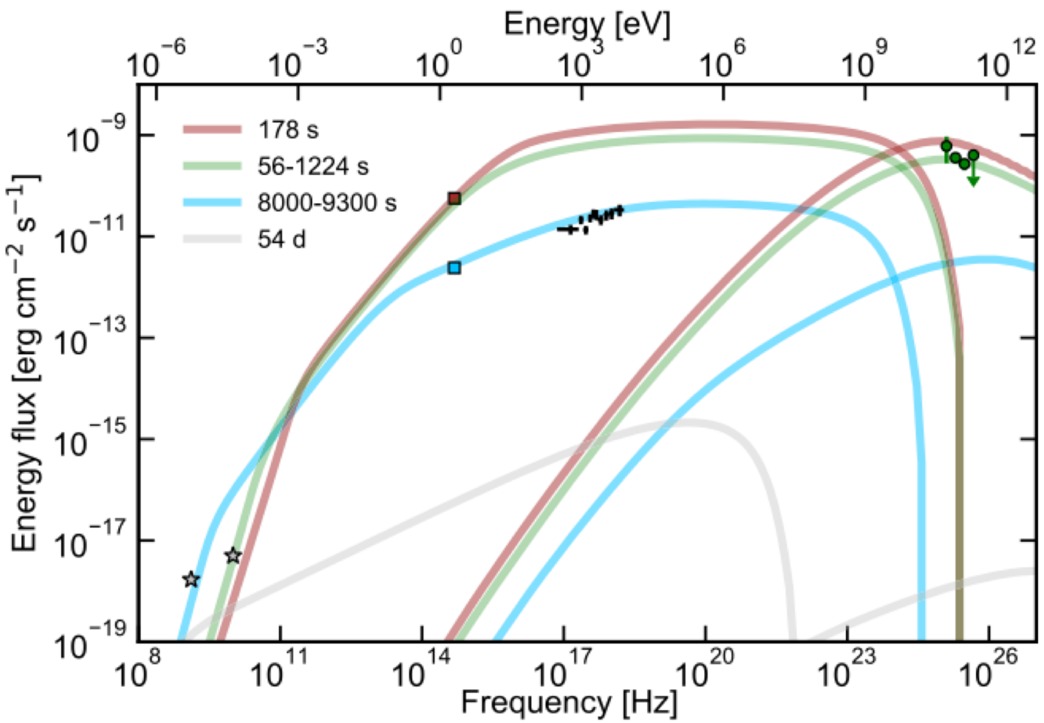
Light scale	EBL	Normalization [TeV^{-1} cm^{-2} s^{-1}]	Index
Nominal	D11	2.03 ± 10^{-8}	-3.15 ± 0.70
−15 per cent	D11	1.14 ± 10^{-8}	-3.19 ± 0.52
+15 per cent	D11	2.99 ± 10^{-8}	-2.17 ± 0.57
Nominal	F08	1.95 ± 10^{-8}	-3.19 ± 0.70
Nominal	FI10	2.76 ± 10^{-8}	-2.65 ± 0.73
Nominal	G12	3.99 ± 10^{-8}	-2.45 ± 0.71

Gamma-ray spectrum down to 40 GeV, and source not visible above 150 GeV

Importance of low energy threshold gamma-ray instruments to observe GRBs (distant sources)







MAGIC detection of GRB 201216C at z = 1.1

(most distant VHE source)

Abe et al., MNRAS 527, 5856–5867 (2024)

One-zone Synchrotron self-Compton can explain the broadband SED, and related temporal evolution, *as MAGIC collaboration claimed in 2019 with the detection of GRB190119C*

Table 2. List of the input parameters for the afterglow model. For each parameter, the range of values investigated by means of the numerical model are listed in the second column. Solutions are not found for an homogeneous density medium (s = 0). The last column list the values that better fit the observations and used to produce the model light curves and model SEDs in Figs 5 and 6.

Parameter	Range	Best fit value
E_k [erg]	$10^{50} - 10^{54}$	4×10^{53}
θ_{jet} [degrees]	0.5 – 3	1
Γ_0	80–300	180
n_0 [cm^{-3}] ($s = 0$)	$10^{-2} - 10^{2}$	-
$A_\star$ ($s = 2$)	$10^{-2} - 10^{2}$	2.5×10^{-2}
p	2.05–2.6	2.1
ϵ_e	0.01–0.9	0.08
ϵ_B	$10^{-7} - 10^{-1}$	2.5×10^{-3}

First detection of a gamma-ray burst at TeV energies

GRB190114C (z=0.42), **First GRB at TeV**, detected by MAGIC @50 sigma

→ announced with Astronomer's Telegram on **January 20th, 2019**

GRB 180720B (z=0.65), detected by **HESS** at 5 sigma

→ announced at the *CTA symposium*, **May 2019**

GRB 190829A (z=0.08), detected with **HESS** at 22 sigma

→ announced with *Astronomer's Telegram* on **Aug 30th, 2019**

GRB201216C (**z=1.1**), detected with **MAGIC** at 6 sigma

→ announced with *Astronomer's Telegram* on **Dec 17th, 2020**

→ Most distant VHE gamma-ray source to date

GRB 221009A (z=0.15), detected with **LHAASO** at >200 sigma

(**BOAT** → Brightest Of All Times) → announced with *GCN Circular* on **Oct 11th, 2022**

After decades of search, many TeV GRBs came „at the same time" !!

They be explained within the Synchrotron self-Compton scenario

It seems SSC component is indeed common among long GRBs

→ Need more TeV GRBs: time will confirm/reject this testable scenario

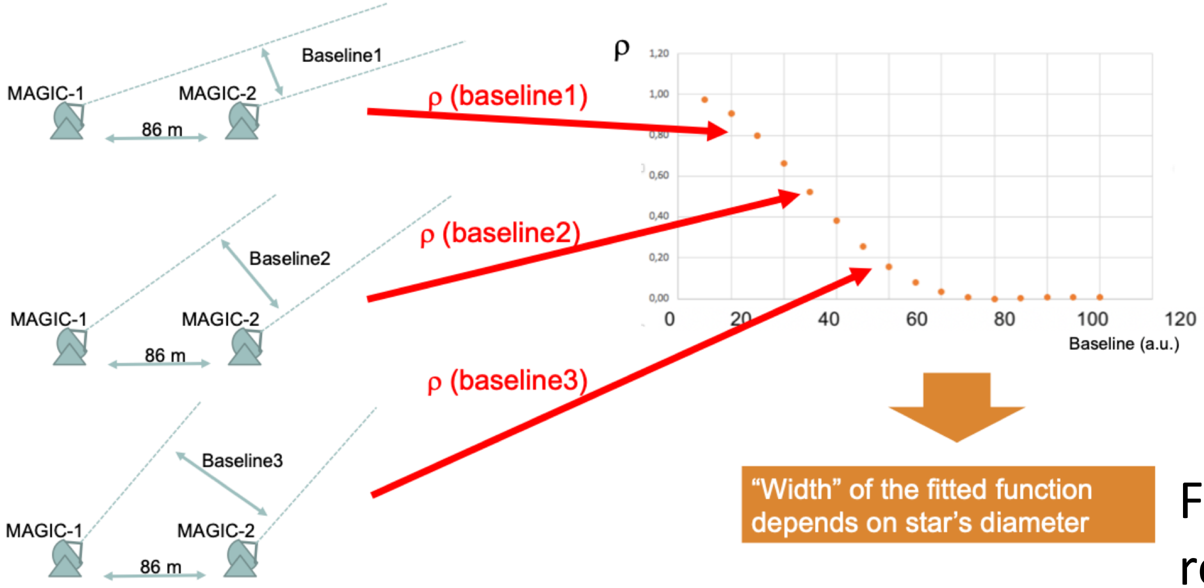
How a 21+ year old instrument continues to be competitive ?

1) Unique capability among Gamma-ray instruments
   → Best sensitivity below 200 GeV

2) Continue to improve/upgrade hardware to explore new things

Intensity interferometry with MAGIC & LST

→ Hardware upgrade to expand physics portfolio of Cherenkov telescopes

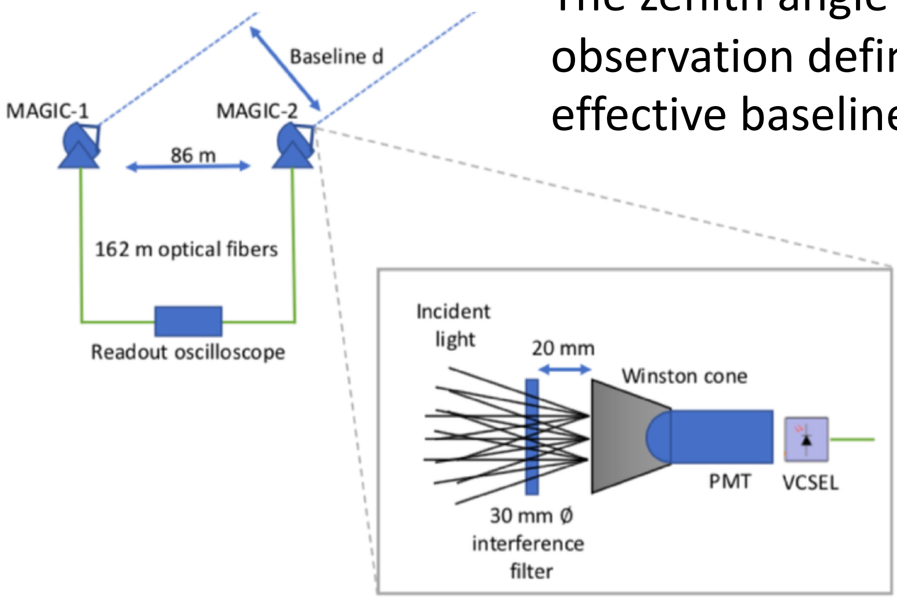


Ideally suited for this task:

- **Large collecting mirrors**
- **Time resolutions of ns**

→ **See Thomas' talk later**

The zenith angle of the observation defines the effective baseline



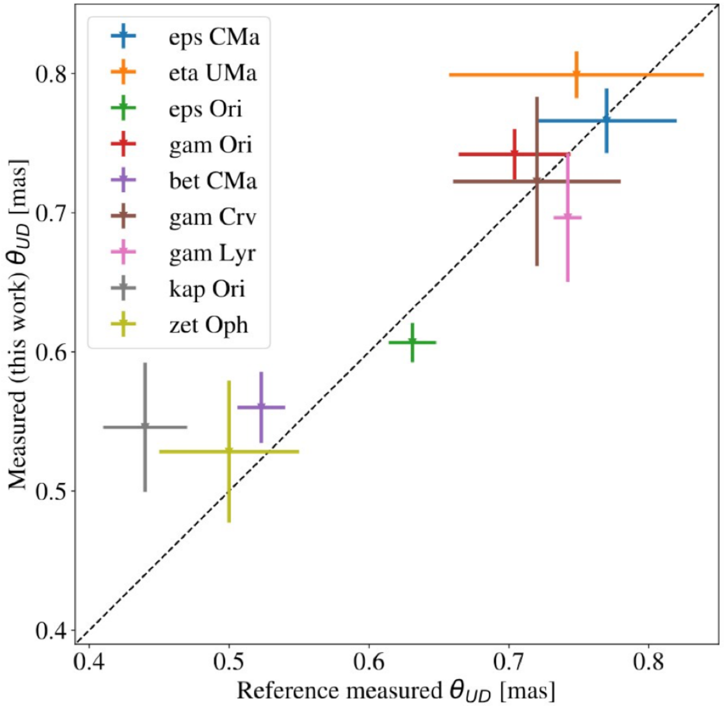
Filters can be set/removed remotely by shifters from control house (no HW intervention needed)

MAGIC-II analysis: Performance paper

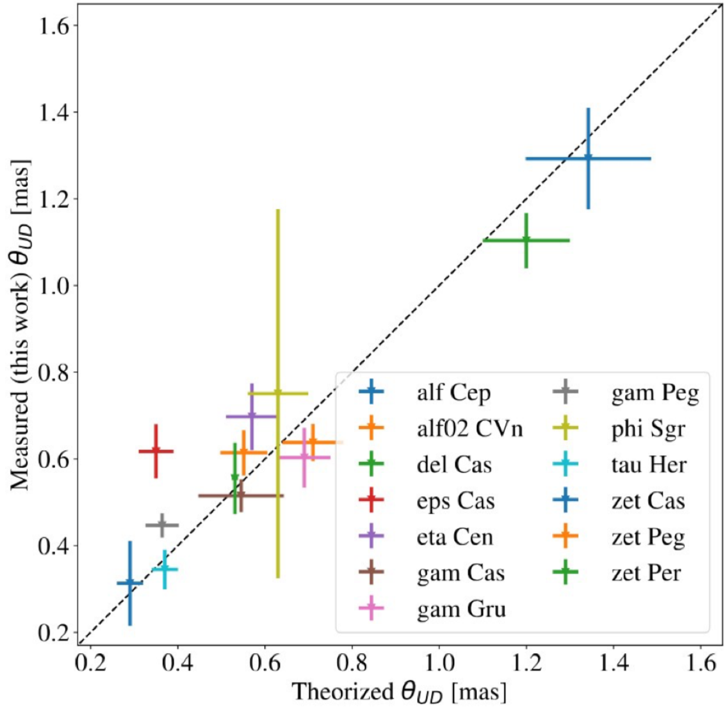
MAGIC collab., MNRAS 529, 4387–4404 (2024)

Study led by T. Hassan, M. Fiori, I. Jimenez, C. Wunderlich

Calibrators



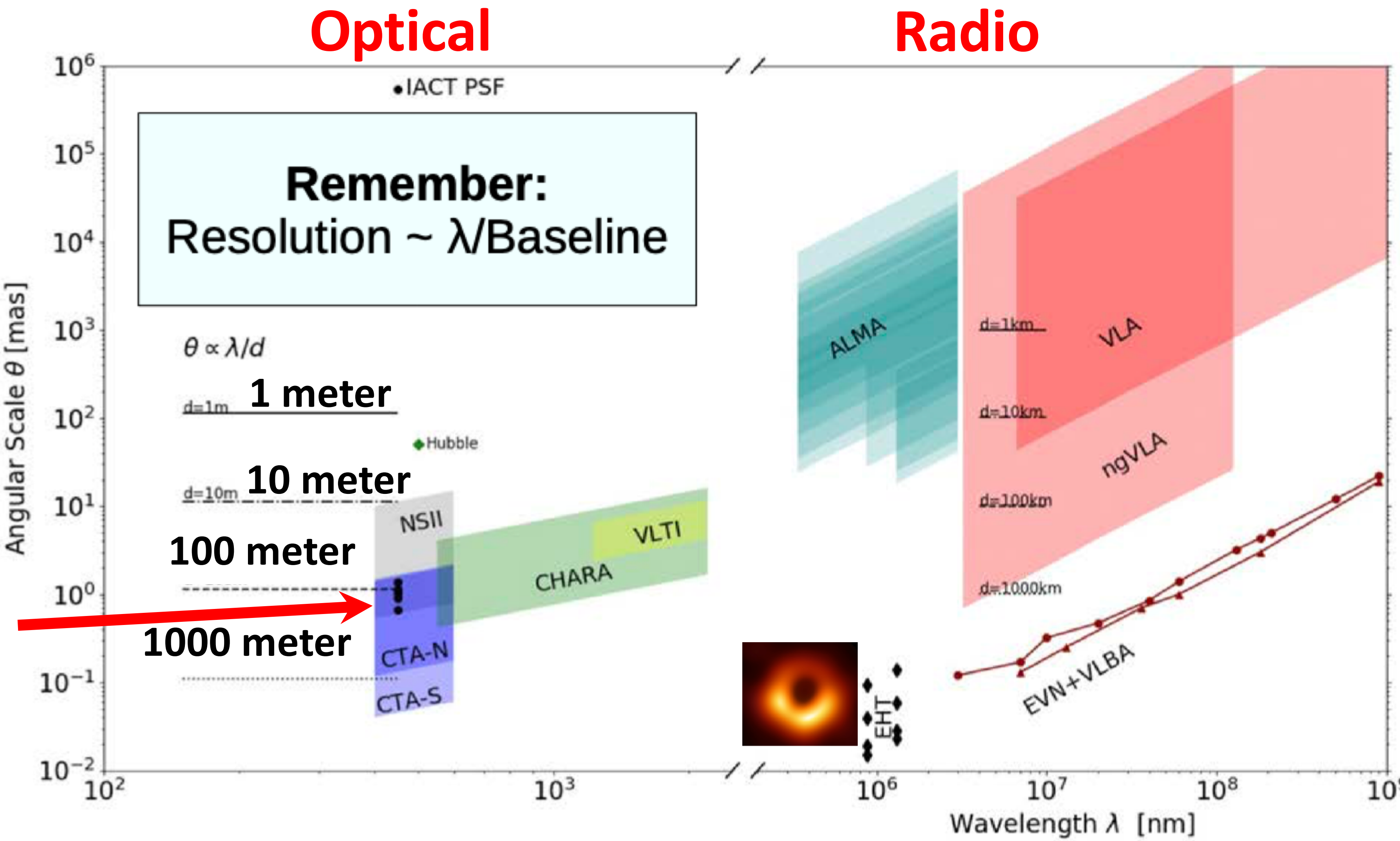
New measurements



Opening yet another window to perform astronomy/astrophysics with the MAGIC telescopes.

Intensity interferometry with MAGIC (& LST in future)

→ Hardware upgrade to expand physics portfolio of Cherenkov telescopes



MAGIC already reaches angular resolutions of below 0.5 mas

Measure diameter & shape of stars, binary systems, Nova explosions …

Next step is to extend the technique to LST1 (already some observations done) and prepare the system to digest ALL LSTs (*as well as MSTs*)

→ See Thomas' talk later

Being done with help of ERC grant
(PI: T. Hassan, MAGIC/LST group from Madrid)

Working to upgrade our correlator

A. Cifuentes

Correlator hardware at La Palma

Photos fron Summer 2024

Boxes everywhere bothering MAGIC crew. Apologies!

New chiller in place

How a 21+ year old instrument continues to be competitive ?

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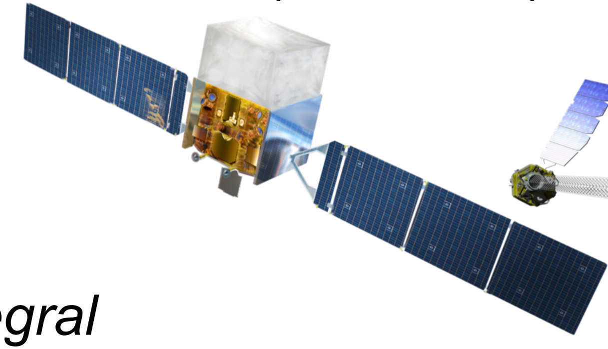
3) Collaborate with other instruments (particularly those which are novel and provide new views)

Multiwavelength and multi-messenger data boosts the scientific potential of the MAGIC data

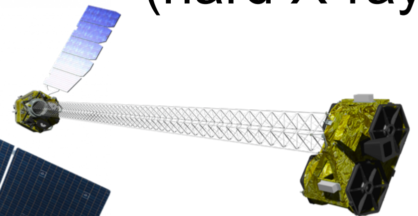
Old instruments get re-vitalized when data put in combination with data from new instruments

MAGIC
(TeV)

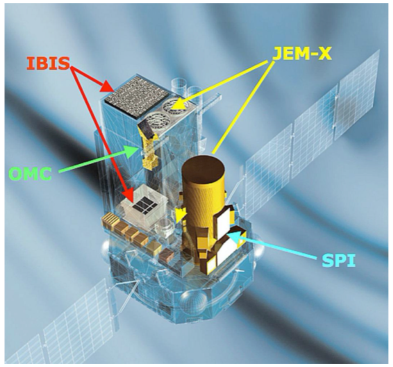
Fermi-LAT (MeV-GeV)



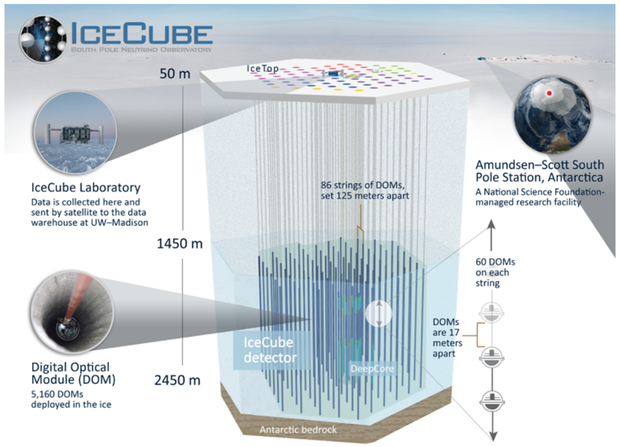
NuSTAR
(hard X-ray)

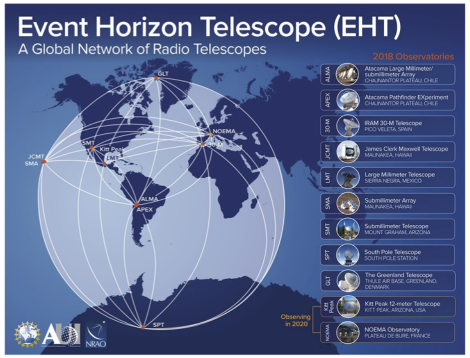


Integral
(X-ray + MeV)



Swift and XMM
(UV/X-ray)

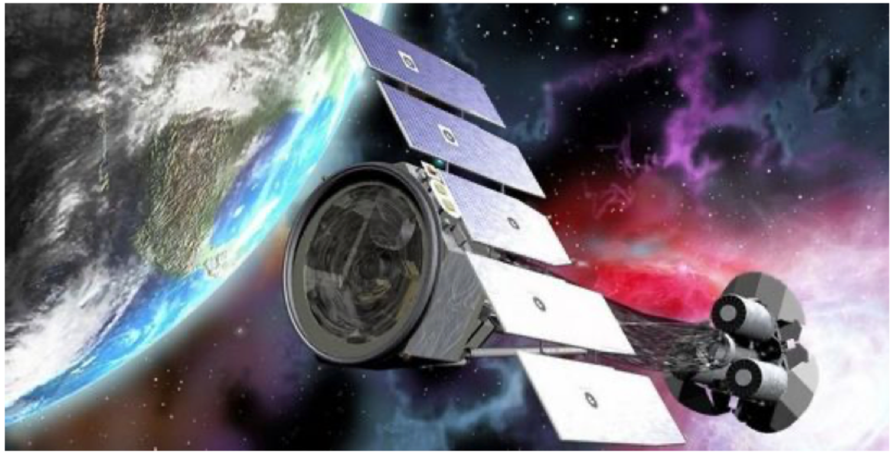




And many more...

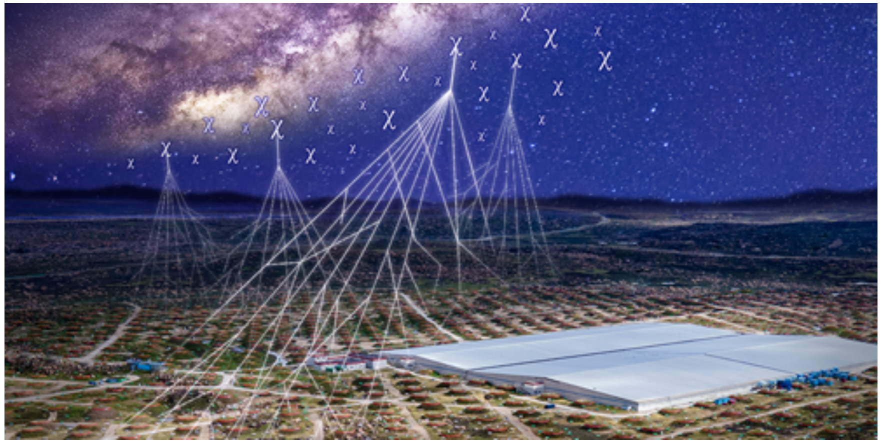
Publications/Collaborations with novel instruments

Imaging X-ray Polarimeter Explorer (IXPE)

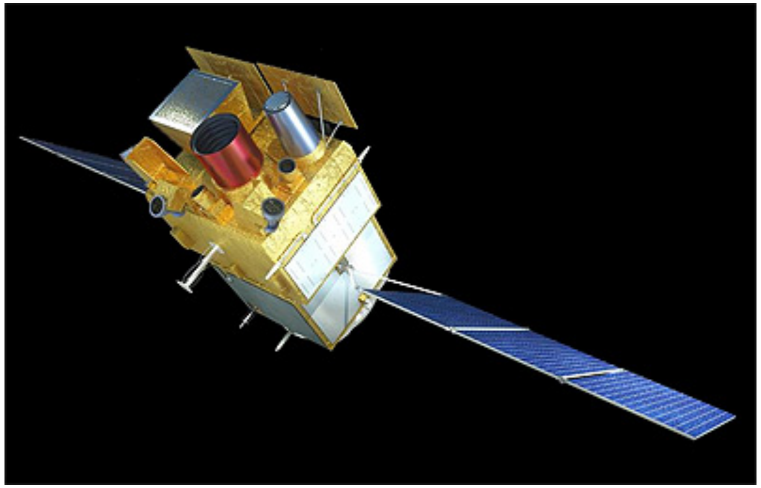


Credit: http://ixpe.iaps.inaf.it/

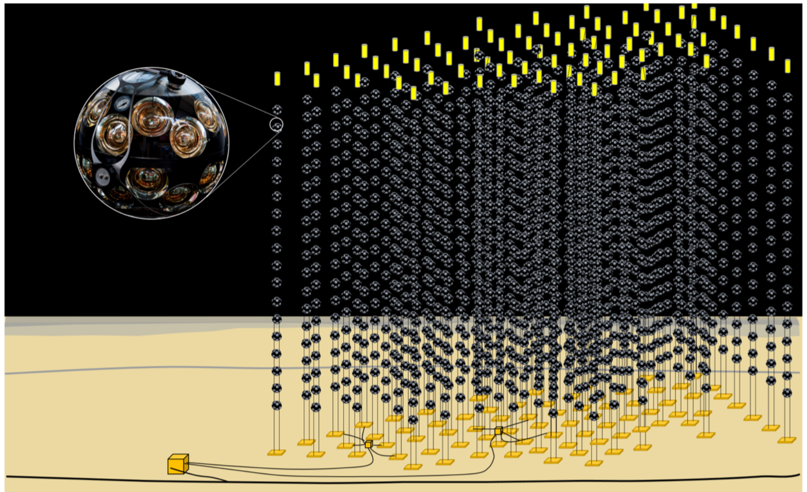
LHAASO



Space Variable Objects Monitor (SVOM)



KM3NeT



MAGIC has established collaborations and/or MoUs with all them

How a 21+ year old instrument continues to be competitive ?

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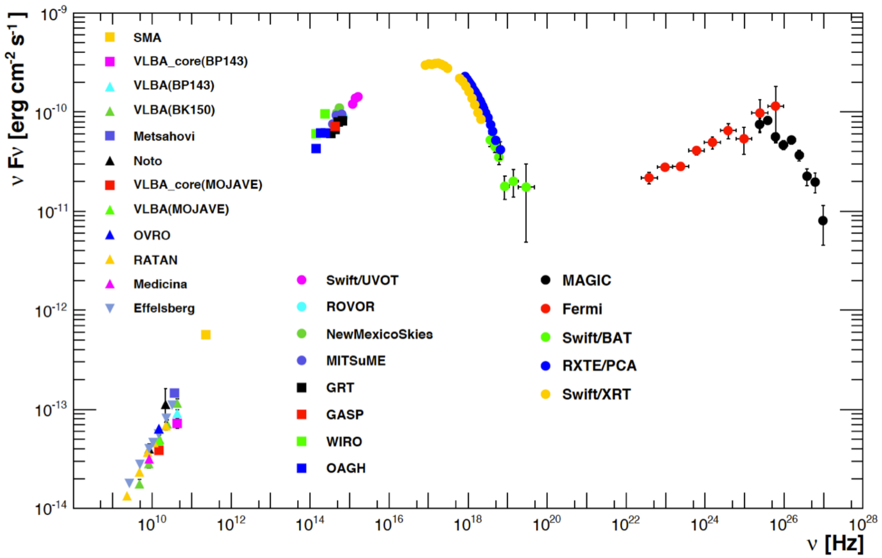
4) Combine data with other gamma-ray instruments to make a more powerful instrument

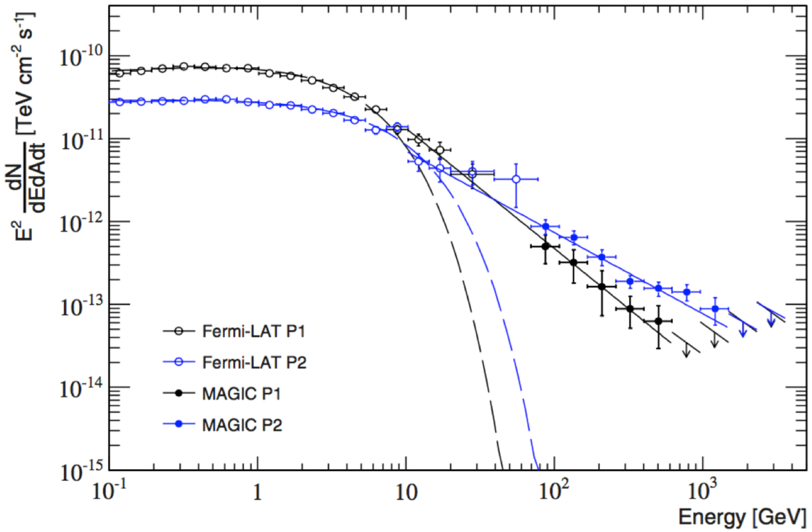
Synergy between *Fermi*-LAT and MAGIC

The GeV and TeV bands are complementary (wealth of behaviours)

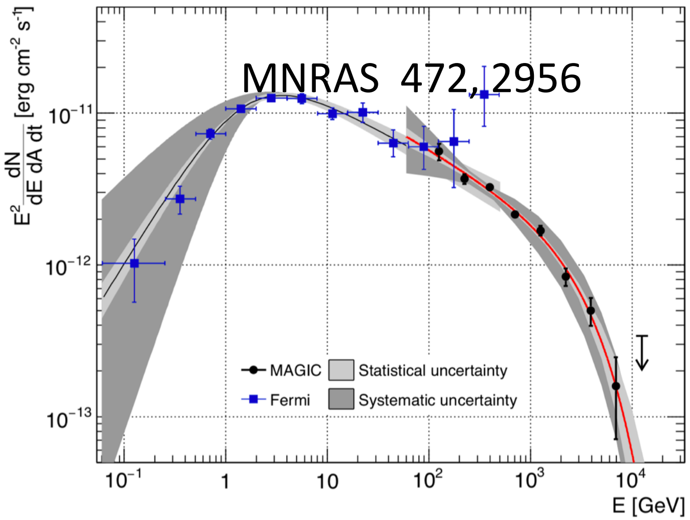
Mrk421 (blazar): Abdo et al 2011, ApJ 736, 131

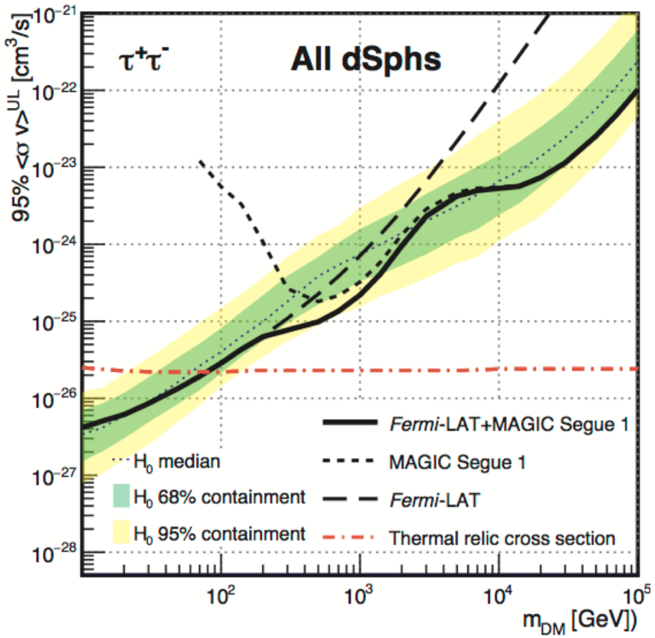


Crab pulsar: Ansoldi et al 2016, A&A 585, 133



Cassiopea A (SNR): Ahnen et al 2017, MNRAS 472, 2956





Dark Matter searches: Ahnen et al., 2016, JCAP 02, 039

Most competitive search with dSphs from Combined analysis from many instruments

Manuscript close to submission

- **Initiative by 5 gamma-ray experiments to combine their observations of dwarf galaxies:**
  - Fermi-LAT
  - HAWC
  - H.E.S.S.
  - MAGIC
  - VERITAS

Most competitive search with dSphs from Combined analysis from many instruments

Multi-instrument observations of dSphs

- **In this project we use a list of 20 dwarf galaxies for which individual collaborations already published results**
- **In total, 45 different data sets used**

Fermi, HAWC, HESS, MAGIC, VERITAS
Manuscript close to submission

	Fermi-LAT	HAWC	H.E.S.S, MAGIC, VERITAS		
Source name	Exposure (10^{11} s m^2)	$\|\Delta\theta\|$ (°)	IACT	Zenith (°)	Exposure (h)
Boötes I	2.6	4.5	VERITAS	15 – 30	14.0
Canes Venatici I	2.9	14.6	–	–	–
Canes Venatici II	2.9	15.3	–	–	–
Carina	3.1	–	H.E.S.S.	27 – 46	23.7
Coma Berenices	2.7	4.9	H.E.S.S.	47 – 49	11.4
			MAGIC	5 – 37	49.5
Draco	3.8	38.1	MAGIC	29 – 45	52.1
			VERITAS	25 – 40	49.8
Fornax	2.7	–	H.E.S.S.	11 – 25	6.8
Hercules	2.8	6.3	–	–	–
Leo I	2.4	6.7	–	–	–
Leo II	2.6	3.1	–	–	–
Leo IV	2.4	19.5	–	–	–
Leo V	2.4	–	–	–	–
Leo T	2.6	–	–	–	–
Sculptor	2.7	–	H.E.S.S.	10 – 46	11.8
Segue I	2.5	2.9	MAGIC	13 – 37	158.0
			VERITAS	15 – 35	92.0
Segue II	2.7	–	–	–	–
Sextans	2.4	20.6	–	–	–
Ursa Major I	3.4	32.9	–	–	–
Ursa Major II	4.0	44.1	MAGIC	35 – 45	94.8
Ursa Minor	4.1	–	VERITAS	35 – 45	60.4

Most competitive search with dSphs from Combined analysis from many instruments

Combined likelihood analysis

- **Expected gamma-ray flux from DM annihilation:**

$$\frac{d\Phi(\Delta\Omega)}{dE} = \frac{1}{4\pi} \frac{\langle \sigma_{\rm ann} v \rangle}{2 m_{\rm DM}^2} \frac{dN}{dE} \times \int_{\Delta\Omega} d\Omega' \int_{\rm l.o.s.} dl\, \rho^2(l, \Omega')$$

- **Using as many common ingredients as possible:**
  - Common range of channels and DM masses:
    - From 5 GeV to 100 TeV using the DM spectra from Cirelli et al. [JCAP 1103:051, 2011]
    - Studied 7 annihilation channels in total
  - Same J-factor values and statistical uncertainties

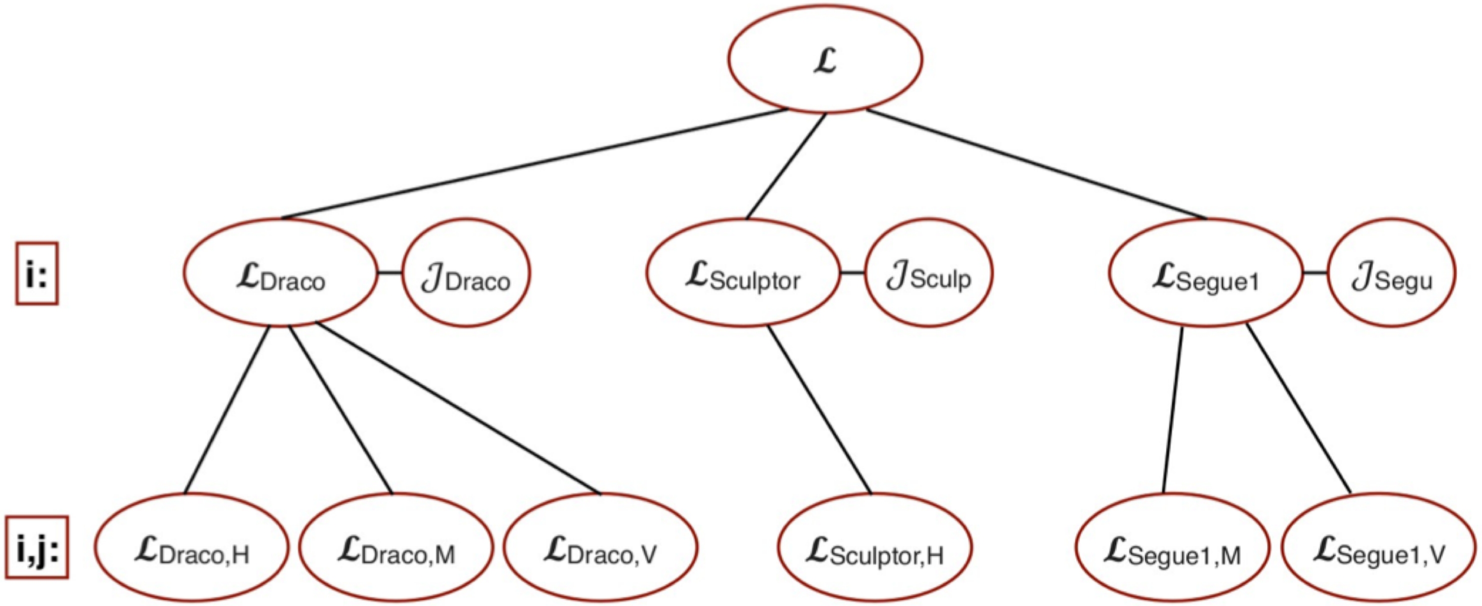
- **Individual experiments shared likelihood profile for each dSph/channel/mass combination for a fixed value of the J-factor**
  - statistical uncertainties on the J-factor are taken into account (the J-factor being a **nuisance parameter** in the combined likelihood)

Most competitive search with dSphs from Combined analysis from many instruments

Combined likelihood analysis

- **Combined likelihood:**

$$\mathcal{L}\left(\langle\sigma v\rangle;\boldsymbol{\nu}\mid\boldsymbol{\mathcal{D}}_{\mathrm{dSphs}}\right)=\prod_{l=1}^{N_{\mathrm{dSphs}}}\mathcal{L}_{\mathrm{dSph},l}\left(\langle\sigma v\rangle;J_l,\boldsymbol{\nu_l}\mid\boldsymbol{\mathcal{D}_{l,\mathrm{measured}}}\right)\times\mathcal{J}_l\left(J_l\mid J_{l,\mathrm{obs}},\sigma_{\log J_l}\right)$$

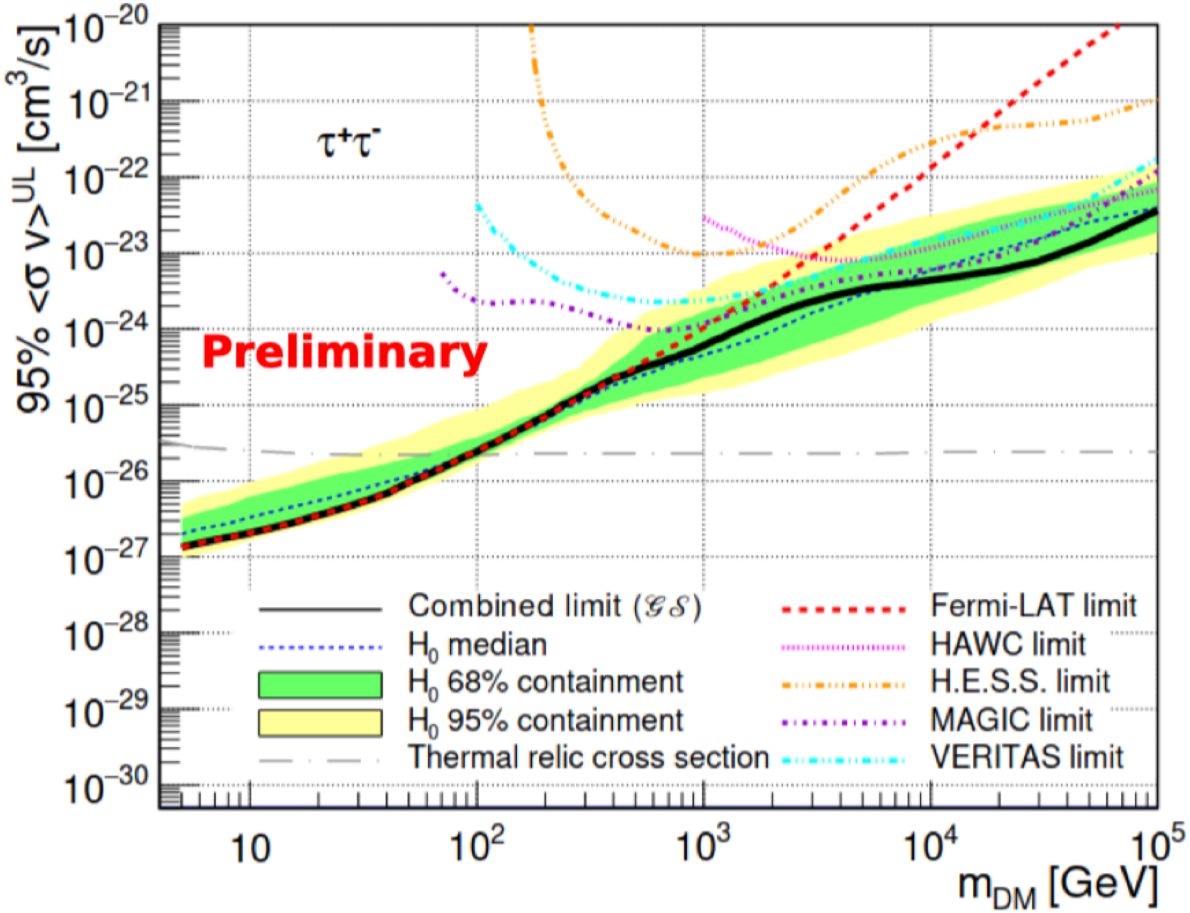


- **The combination was performed with two independent softwares:**
  - glike: https://doi.org/10.5281/zenodo.4028908
  - LklCombiner: https://doi.org/10.5281/zenodo.4450884

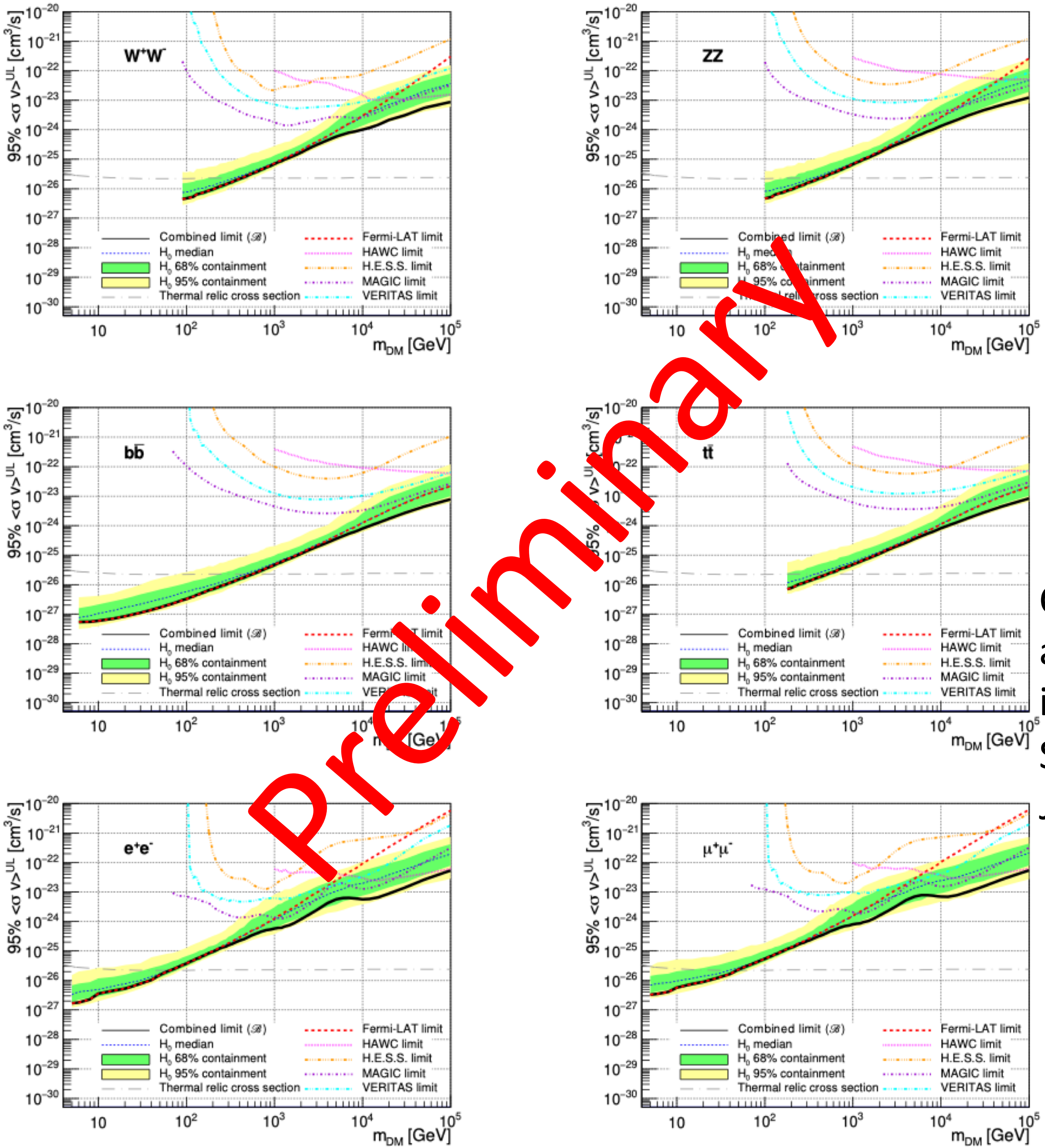
Most competitive search with dSphs from Combined analysis from many instruments

Combined limits for one channel

Fermi, HAWC, HESS, MAGIC, VERITAS Manuscript close to submission



Combined limits are up to a factor 2-3 more constraining



Combined analysis from many instruments

Combined limits for the other six channels

Combining many targets allows to minimize the importance of single dSphs. Specially relevant when J-factor is (very) uncertain

Fermi, HAWC, HESS, MAGIC, VERITAS

Manuscript close to submission

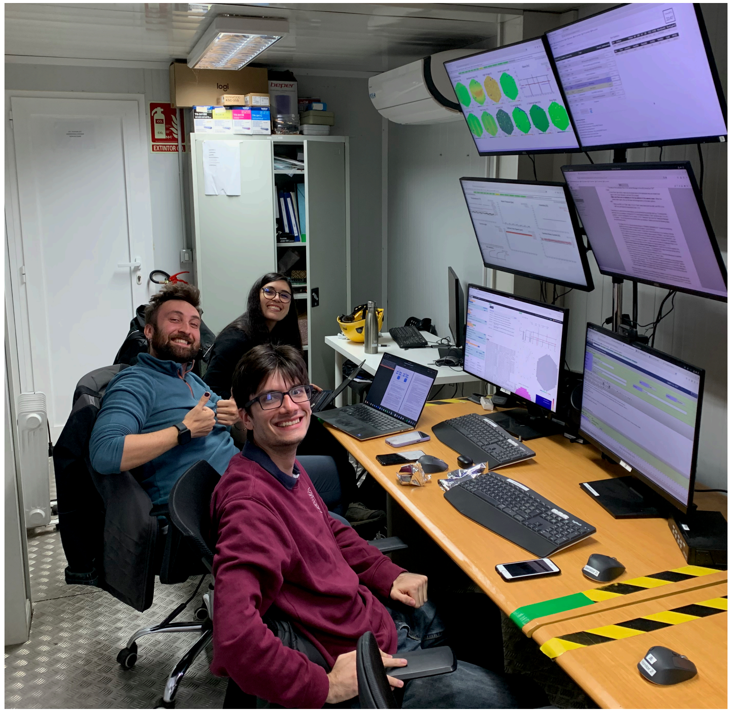
Joint observations with LST-1

MAGIC-LST1 proximity allows joint observations for better angular & energy resolution, and better sensitivity (*Soft. and Hard. trigger*)

Abe H. et al (LST+MAGIC collab.), 2023, A&A, 680A, 66A

About 1.3-1.5 better sensitivity → *reduction of obs. time by ~2.0*

→ New opportunities to detect faint or very distant sources



- Already performing MAGIC-LST1 obs.

Photo shows LST shift crew from October, before performing MAGIC-LST observations on 1es1959+650

Joint observations with LST-1

Decided to better coordinate these observations next year with a joint call for proposals (and joint TAC+scheduling)

The MAGIC Telescopes

Gamma-ray astronomy at low energies with high sensitivity

https://magic.mpp.mpg.de/public/magicop/

HOME | GENERAL INFORMATION | SCIENCE WITH MAGIC | MAGIC MEMBERS | MAINTENANCE

MAGIC > MAGIC observation proposals

MAGIC observation proposals (Cycle 20)

MAGIC OBSERVATIONS PROPOSED BY EXTERNAL SCIENTISTS

The MAGIC collaboration encourages external scientists to propose observations using the MAGIC telescopes, with observation time granted by the Time Allocation Committee (TAC) based on scientific merit. **There is no predefined allocation of time between internal or external collaborators.**

Observing Cycle

The observing cycle 20 spans 12 moon periods, from April 14, 2025 (MAGIC Period 276) to March 30, 2026 (MAGIC Period 287). The deadline to submit the MAGIC proposals is January 31, 2025 at 23:59 UT. Following submission, the TAC will evaluate propo...
joint MAGIC+LST TAC, comprising members from both MAGIC and the LST (the Large-Sized Telescope...
Principal Investigators (PI) or co-Investigators (coI) on MAGIC-only proposals. They can act as coI on LS...
provided they agree to a Non-Disclosure Agreement with the LST collaboration, (see below "Guide for p...
PIs will be informed of the evaluation outcome by mid-March 2025, following the TAC meeting and final...
Board and the LST Steering Committee.

Joint MAGIC-LST1 physics meeting in Januury 13-17 2025

https://indico.mpp.mpg.de/event/10300/

CTAO Large Sized Telescope | MAGIC

MAGIC-LST F2F Science Meeting

13–17 Jan 2025
New
Europe/Monaco timezone

Enter your search term

- Overview
- Timetable
- Registration
- Participant List
- Conference Fee
- How to reach Garching
- DEI Workshop
- Social Activities
- Local Organizing Committee
- Remote Connection

Contact

How a 21+ year old instrument continues to be competitive ?

1) Unique capability among Gamma-ray instruments
   → Best sensitivity below 200 GeV

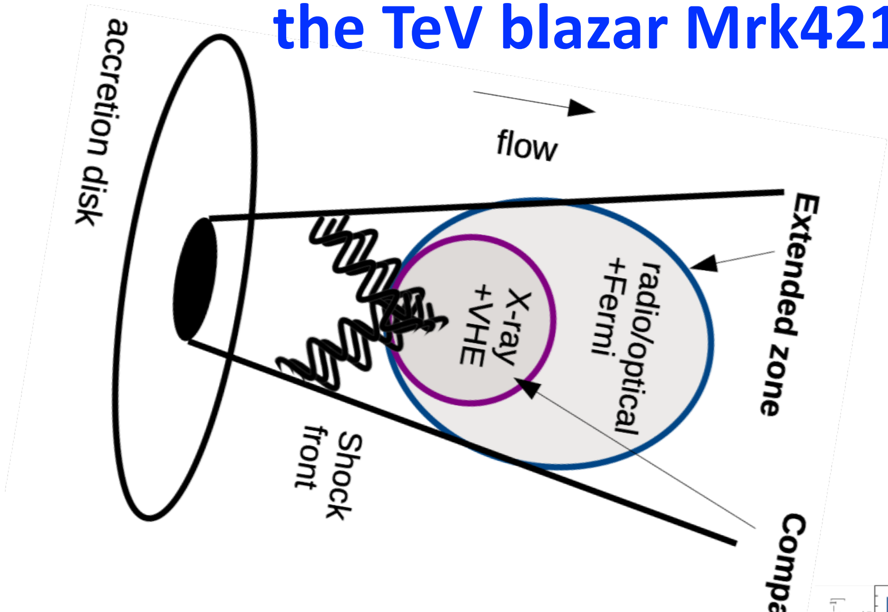
2) Continue to improve/upgrade hardware to explore new things

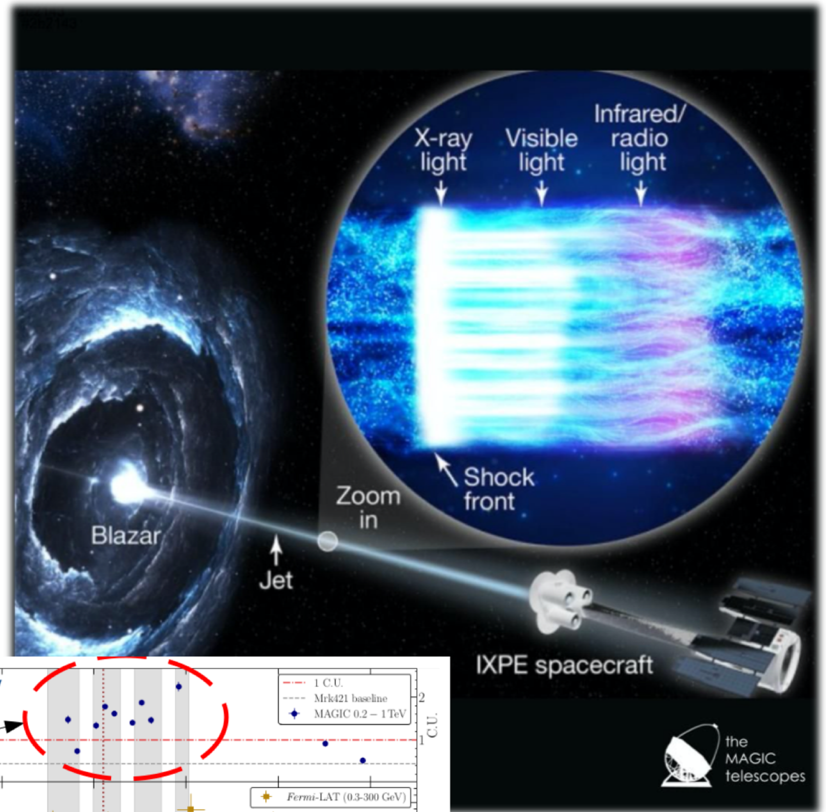
3) Collaborate with other instruments (particularly those which are novel and provide new views)

4) Combine data with other gamma-ray instruments to make a more powerful instrument

5) Keep monitoring the transient/variable gamma-ray sky (nature does not stop providing exciting events)

Flare in December 2023 for the TeV blazar Mrk421



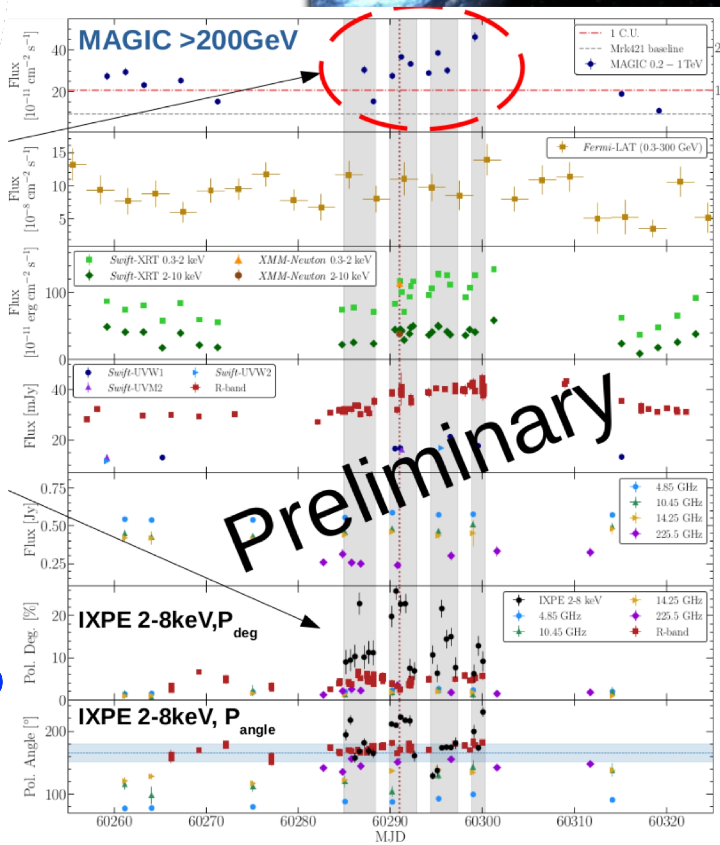


Strong variability in VHE flux measured with **MAGIC** (> 4 times "typical" flux)

Strong variability in polarization degree+angle @ X-ray with **IXPE**

First VHE flaring event with simultaneous X-ray polarization → Shock acceleration (with magnetic field stronger closer to the shock + turbulence)

Submitted to A&A



Flare in December 2024 for the TeV blazar 1es1959+650 SVOM+MAGIC

SVOM detected major X-ray outburst from the blazar 1es1959+650 on December 6th, MAGIC observed in December 7th and detected TeV flaring activity *(despite presence of moon and large zenith angle).* Data analysis will not be easy… but this is the beginning of first publication with SVOM+MAGIC data

X-ray outburst of the TeV blazar 1ES 1959+650 observed by SVOM

ATel #16935; *A. Coleiro (APC, France), P. Maggi (ObAS, F), D. GÃ¶tz (CEA, F), F. Cangemi (APC, F), A. Foisseau (APC, F), S. Le Stum (APC, F), S. Schanne (CEA, F.) SVOM JSWG: J.-Y. Wei (NAOC, China), B. Cordier (CEA, F), Shuang-Nan Zhang (IHEP, C), S. Basa (LAM, F), O. Godet (IRAP, F), A. Claret (CEA, F), Z.-G. Dai (USTC, C), F. Daigne (IAP, F), J.-S. Deng (NAOC, C), A. Goldwurm (APC, F), X.-H. Han (NAOC, C), C. Lachaud (APC, F), E.-W. Liang (GXU, C), Y.-L. Qiu (NAOC, C), S. Vergani (Obs. Paris, F), J. Wang (NAOC, C), C. Wu (NAOC, F), L.-P. Xin (NAOC, C), B. Zhang (UNLV, C)*

*on **7 Dec 2024; 10:57 UT***

Distributed as an Instant Email Notice Transients

Credential Certification: Floriane Cangemi (cangemi@apc.in2p3.fr)

Subjects: X-ray, Blazar

Referred to by ATel #: 16939

X Post

X-ray outburst of the TeV blazar 1ES 1959+650 observed by SVOM

On Friday December 6th at 15:08:48 UT (Tb), the on-board trigger software of the SVOM/ECLAIRs telescope (currently in its commissioning phase, instrument energy range 4-150 keV), detected and localized a long duration soft X-ray transient at RA, Dec = 300.202 deg, 65.182 deg (J2000) with 9.3 arcmin uncertainty radius in the 5-8 keV energy band during a 22 min exposure starting at Tb (best alert with SNR=9.3, see GCN 38450); another alert with SNR=7.2 was produced in 5-8 keV during 11 min starting at 15:14:15, the sub-image transmitted in near real-time over the SVOM VHF network showed a clear point-like source not present in the onboard source catalog.

Following this detection, SVOM/MXT (0.2-10 keV) performed a ToO observation of the source starting at 16:47:41 UT for an exposure time of 3.6 ks. A single source was detected in the image at coordinates R.A. = 20h 00mm 03ss DEC. = +65 deg 09mm 07ss (J2000) with an uncertainty of 25 arc sec at 90% c.l. (systematic+statistical). This position lies at 22 arcsec from the BL Lac blazar 1ES 1959+650 (GCN 38452).

These observations hence suggest that 1ES 1959+650 is currently exhibiting a major X-ray outburst.

[Previous]

Observations of increased very-high-energy gamma-ray emission from 1ES1959+650 with the MAGIC telescopes

ATel #16939; *David Paneque (Max Planck Institute for Physics), Axel Arbet-Engels (Max Planck Institute for Physics), Giacomo Bonnoli (INAF) and Jayant Abhir (ETH Zurich) , on behalf of the MAGIC collaboration*

*on **9 Dec 2024; 18:27 UT***

Credential Certification: David Paneque (dpaneque@mppmu.mpg.de)

Subjects: Gamma Ray, TeV, VHE, Blazar

X Post

Following the recent detection of an X-ray flare reported by SVOM (ATel #16935), the MAGIC telescopes observed 1ES1959+650 (300.202 deg, 65.182, J2000.0) on Saturday 7th December 2024. The observations took place in sub-optimal conditions due to the high zenith distance of the source in the sky (between 50deg and 70deg) and the presence of a strong night-sky background light caused by the Moon. During the first hour, which is the part of the observations at the lowest zenith distance (below 60 deg), the preliminary and online analysis yielded a gamma-ray excess with a significance exceeding 8 sigma, indicating an enhanced state at TeV energies.

Related

16939 Observations of increased very-high-energy gamma-ray emission from 1ES1959+650 with the MAGIC telescopes

16935 X-ray outburst of the TeV blazar 1ES 1959+650 observed by SVOM

The next (expected) Explosive result:

Thermonuclear explosion in T Corona Borealis

T Coronae Borealis (T CrB), is recurrent symbiotic nova.

Erupted in 1866 and 1946 (**80years**), and predicted (AAVSO) to explode in the year 2024 (because of pre-eruption dip in optical LC)

T CrB is 3 times closer to the Earth than RS Oph (0.9kpc vs 2.7kpc)

→ 9 times brighter !

→ once in a lifetime opportunity !

→ Large expectation and commitment to observe from many groups

T CrB also caught attention of Neil deGrasse Tyson

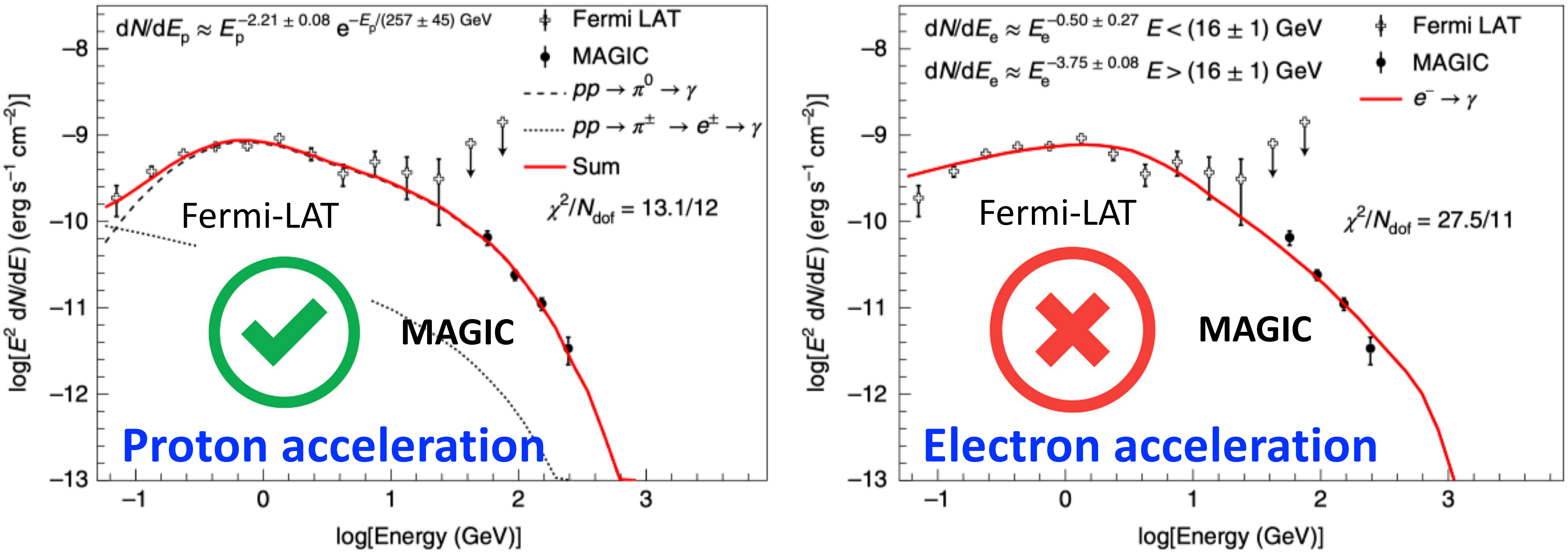
→ youtube video with more than 3+ Million visits in 4 months

https://www.youtube.com/watch?v=5i6aEA-RkOQ&list=PLnaXrumrax3Wyn1oMYWYlpcwrc76Nm40Q

Gamma rays reveal proton acceleration in nova explosion RS Ophiuchi (August 2021)

MAGIC coll. (Acciari) at al 2022, Nature Astronomy, Vol. 6, p. 689-697

Fig. 3 | Gamma-ray spectrum of RS Oph observed over the first 4 d of the outburst, and modelled with both a hadronic and a leptonic scenario. Observations are averaged over the first 4 d of the outburst. Left: a hadronic model. Right: a leptonic model. The dashed line shows the gamma rays from the π^0 decay and the dotted line shows the inverse Compton contribution of the secondary $e^{\pm}$ pairs produced in hadronic interactions. dN/dE_p and dN/dE_e report the shapes of the proton and electron energy distributions obtained from the fit.



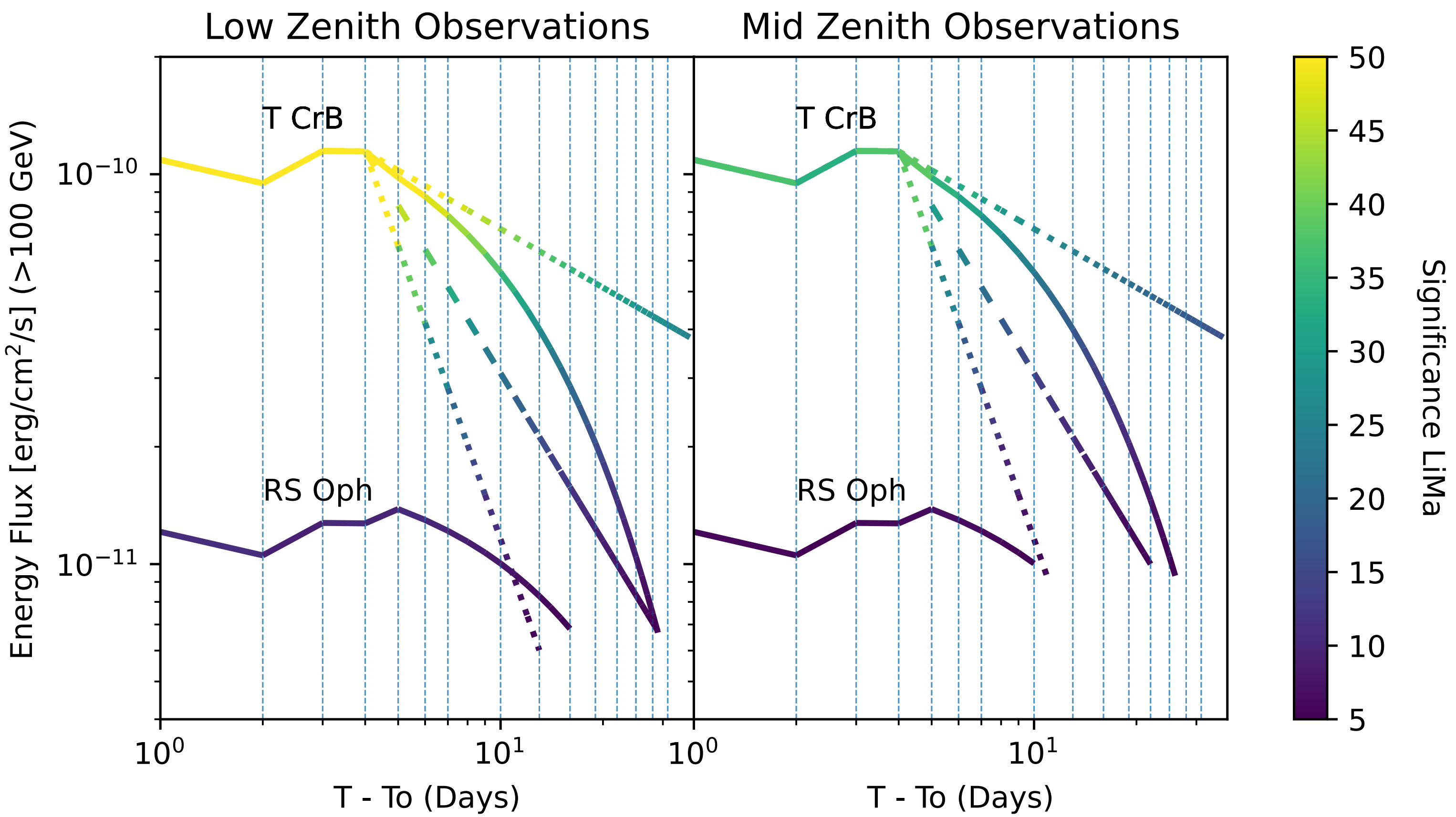
Scenario with proton acceleration (with natural PL index of ~2) provides a better description of the gamma-ray emission than scenario with electron acceleration (that needs an additional break in the high-energy particle population)

Estimated LC for T CrB with the MAGIC telescopes

- Scaled RS Oph flux by a factor of 9
- Different estimates assumed for the flux of T CrB after 4th day
- 5-hour observing window used to compute the significance

(used program mss.py)

Result (and observing campaign with MAGIC) organized by David Green

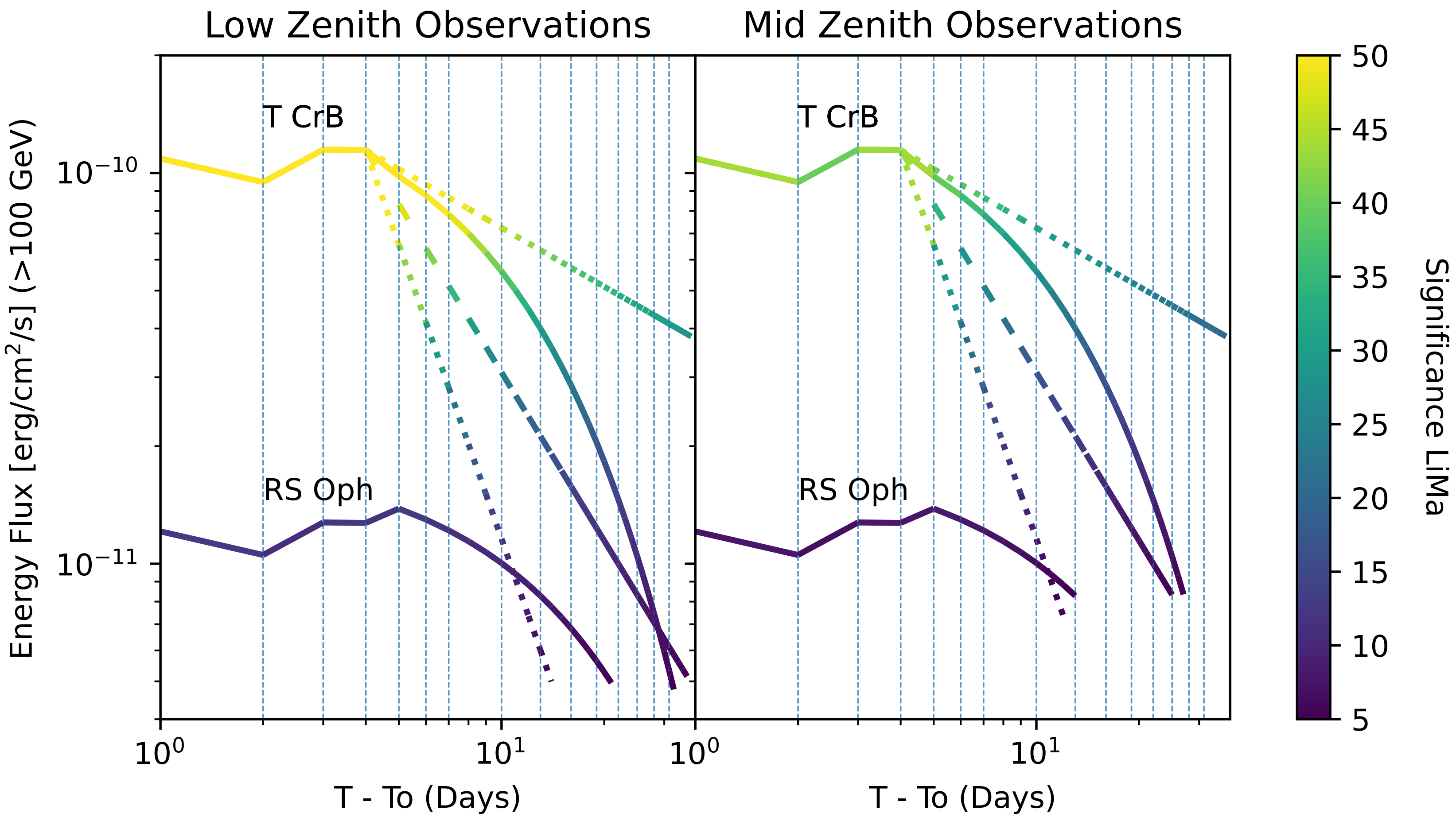


It can be significantly (>5 sigma) detected 1 month after optical trigger

Estimated LC for T CrB with LST1-MAGIC

- Scaled RS Oph flux by a factor of 9
- Different estimates assumed for the flux of T CrB after 4^{th} day
- 5-hour observing window used to compute the significance

Result (and observing campaign with LST1-MAGIC) organized by David Green



It can be significantly (>5 sigma) detected 1 month after optical trigger

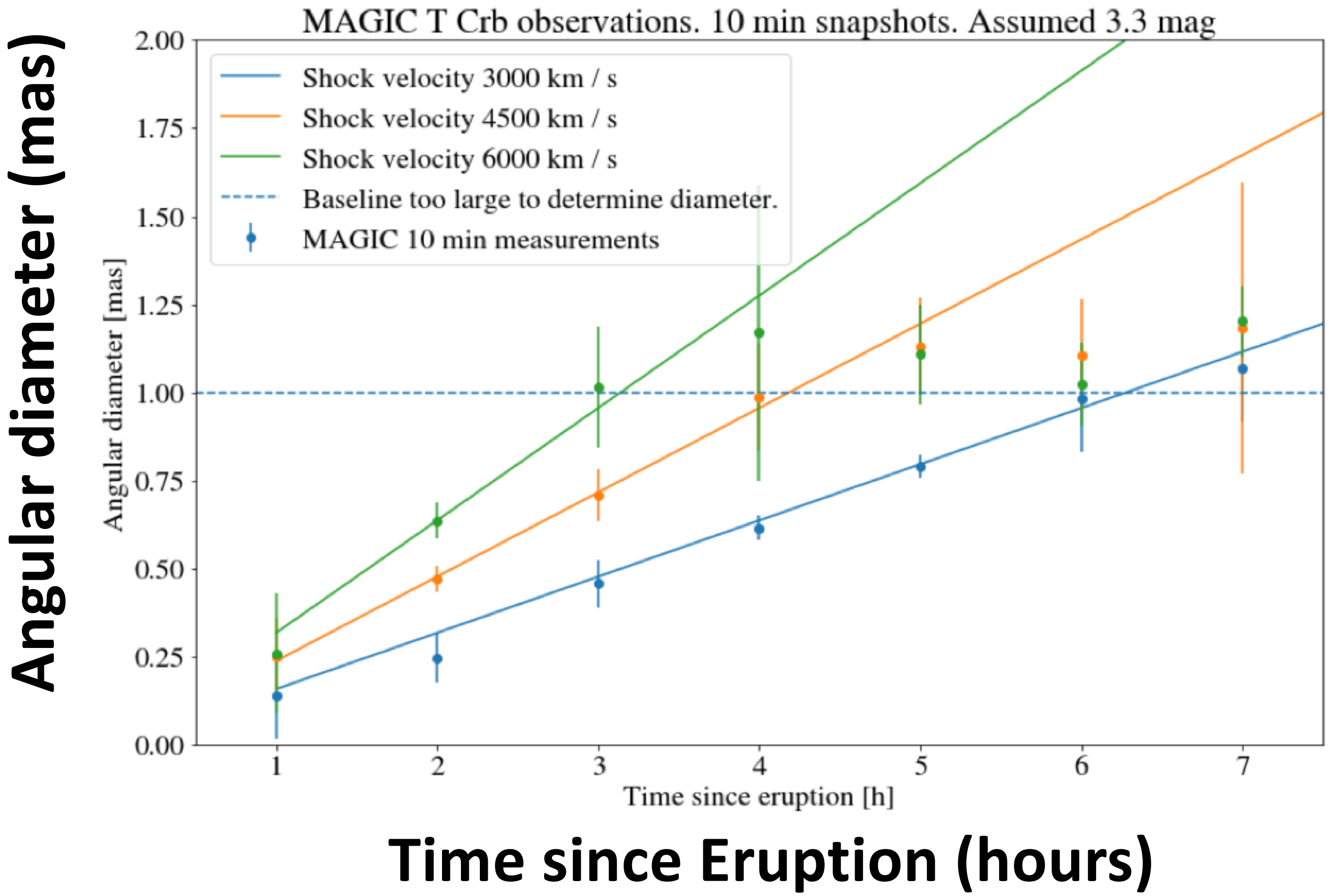
The size of the photosphere with the MAGIC-II

The MAGIC Intensity Interferometry (MAGIC-II) may measure the size of the expanding photosphere during the first hours after explosion.

→ Important physical parameter for understating the seed photon density, and compute contribution of leptons to non-thermal emission

→ **MAGIC-II can be performed any time** (no hardware intervention required)

→ **Need >4 mag** (*T Crb is expected to reach V-Band ~ 2.5*)



- 10 min observation
- 3.3 mag assumed for optical peak

Cortina et al., CTA0 symposium 2024

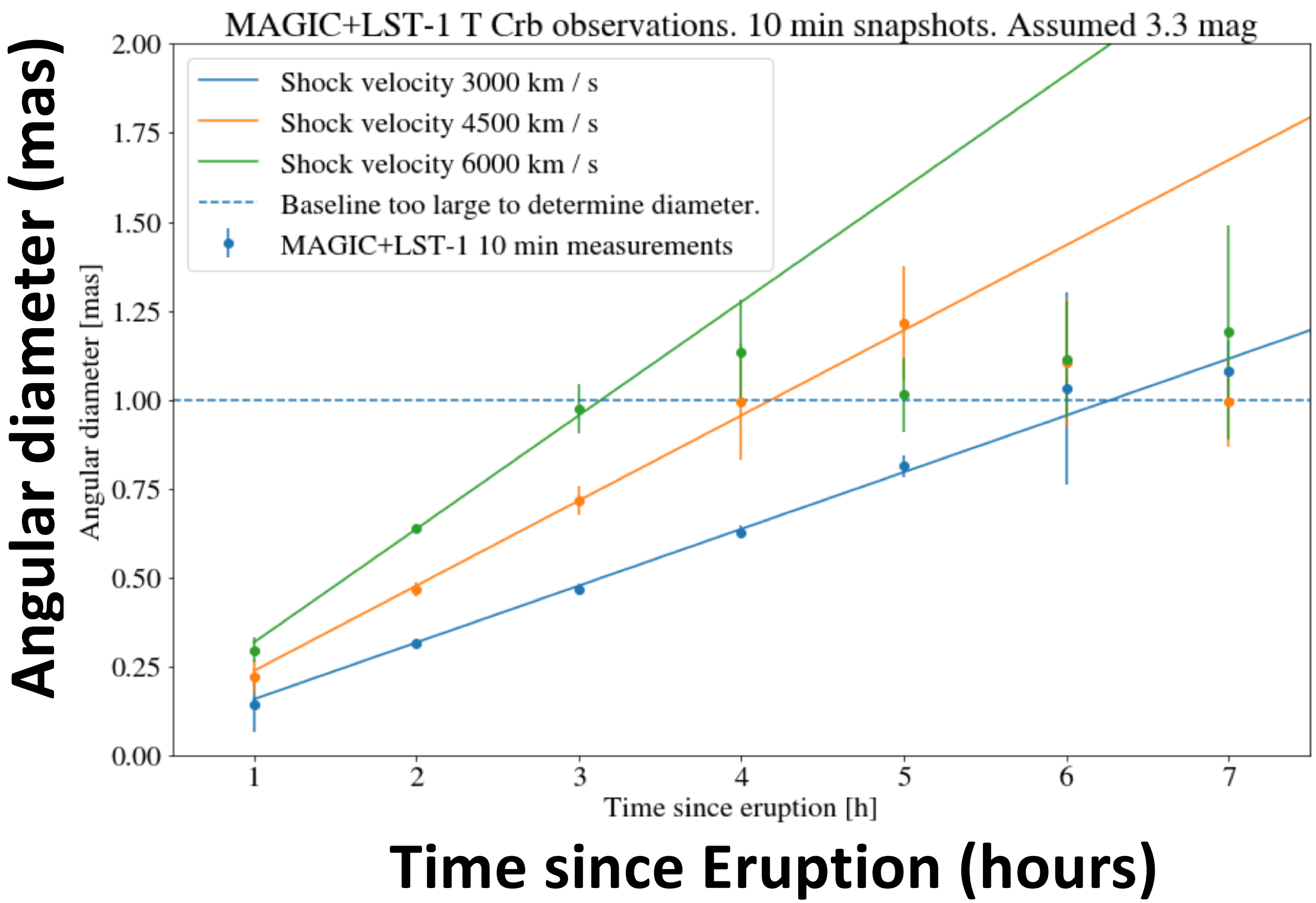
The size of the photosphere with LST1+MAGIC

Intensity Interferometry observations with LST1+MAGIC may measure the size of the expanding photosphere after the explosion

→ Important physical parameter for understating the seed photon density, and compute contribution of leptons to non-thermal emission

→ **MAGIC-II can be performed any time** (no hardware intervention required)

→ **Need >4 mag** (*T Crb is expected to reach V-Band ∼ 2.5*)



- 10 min observation
- 3.3 mag assumed for optical peak

Cortina et al., CTAO symposium 2024

Period of highest chance for explosion of TcrB was April-October 2024. **<u>But it did not happen !</u>**

Now visibility for MAGIC is terrible... And hence better that it does not explode until February 2024

In any case, **we should continue monitoring the gamma-ray sky, the known variable/transients, and also expect the unexpected**

Sustainability is one of the important goals within the Max Planck Society, as reported in a video blog from Patrick Cramer

MPG PRESIDENT'S VIDEO BLOG

https://max.mpg.de/Organe/Praesident/Pages/video-blog_EN.aspx

President

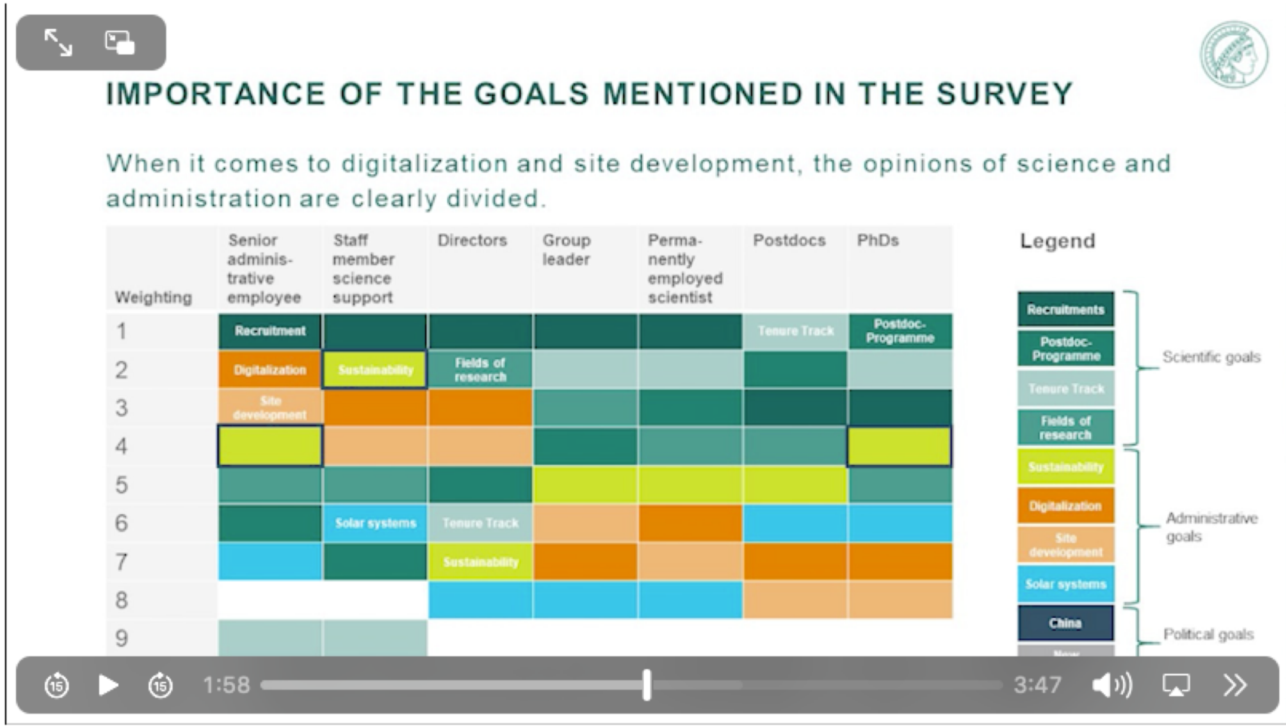
President's office

Video blog

Vice Presidents

VIDEOBLOG ‣ EPISODE 2

The president reported the results from an internal MPG survey in Sumer 2023



Within MAGIC collaboration, we also think we should be doing more for the environment

The **VEGA** Project:
Very **E**co-friendly **G**amma-ray **A**stronomy

Considering to install solar panels at the MAGIC site to reduce consumption of regular electricity (@ Palma island, it mostly comes from burning oil)

→ Can benefit from large subsidies from Canarian government
(60% for batteries, 40% for solar panels)

→ Possibility to access additional funding for testing technology at high altitude.
(and provide large visibility, owing to importance of observatory @LaPalma)

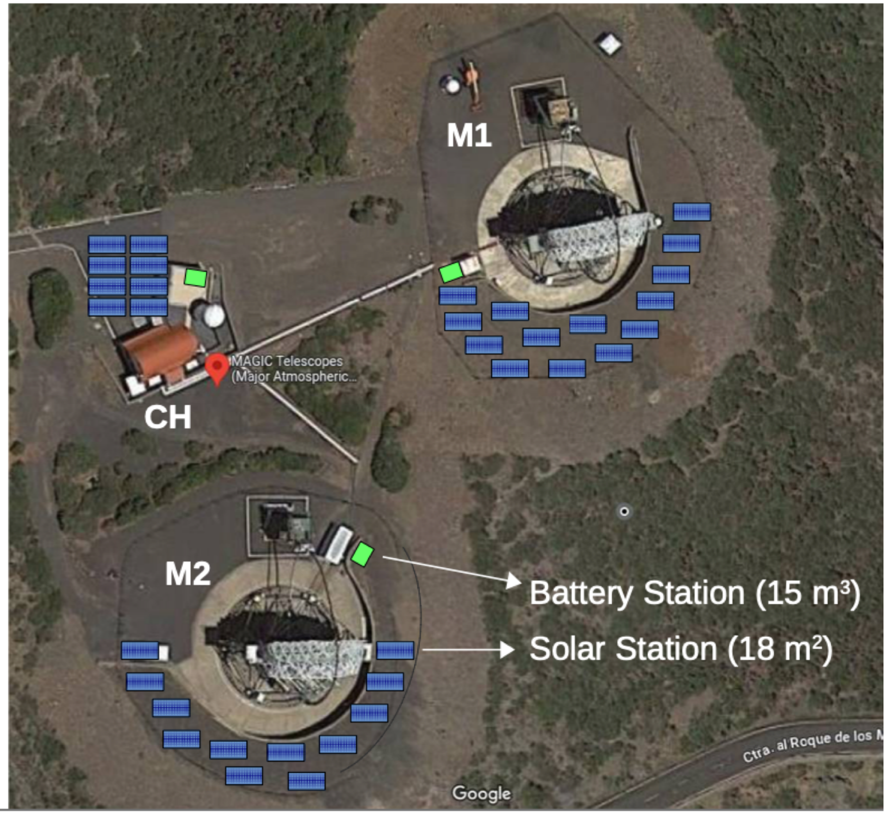
Solar Array:
Ground-Mounted
and Panel Canopy

Installed power:

$P_{M1} = 50.4\ kW_p$

$P_{M2} = 43.2\ kW_p$

$P_{CH} = 28.8\ kW_p$



Concluding Remarks

MAGIC collaboration has published 210 (+3) scientific publications, and continues to be a competitive instrument after 21+ years of operation *(and a dynamic and young collaboration)* with ***clear MPP leadership***

Extended MoU (until June 2029)

Besides regular gamma-ray observations, we will
- Establish collaborations/projects with novel instruments
- Perform MAGIC and CTA-LST1 joint observations, MAGIC-LST TAC, and hence joint (partial) physics program being worked out
- Expand the physics portfolio through intensity interferometry

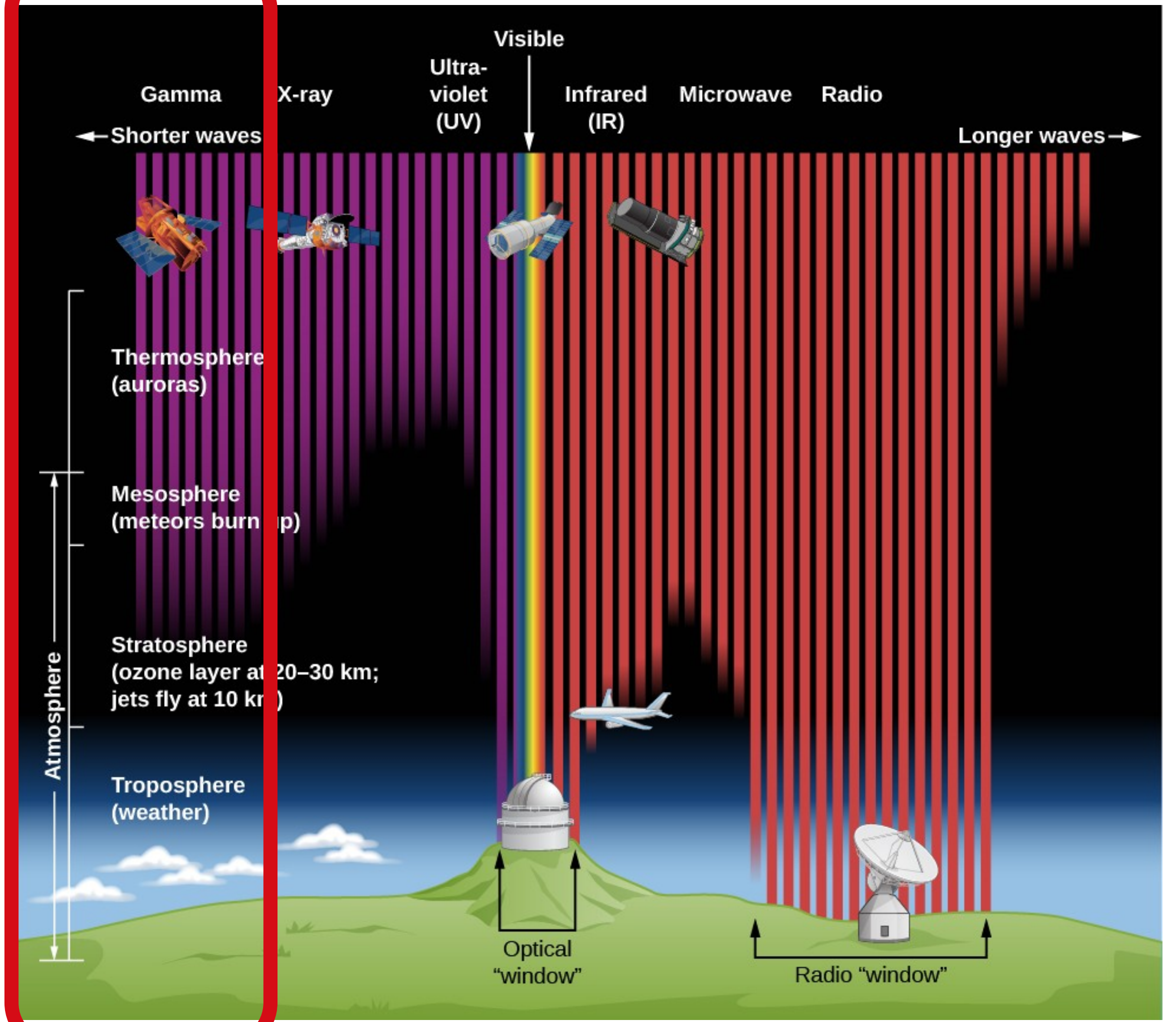
Exciting years ahead !!

Very grateful to the mechanical and electronic departments, as well as MPP administration (IT, purchase, travels …) that make all this possible

Thank you very much !!

Backup

Photons as messengers from Cosmic Sources



Optical Telescopes

First instruments in 17th century, with spectrographs in late 19th century

Radio Telescopes

First instruments in 1930s, but big push happened in the 1950s

X-ray Telescopes

First instruments in 1960s, but big push happened in the 1970s and 1980s

Gamma-ray Telescopes

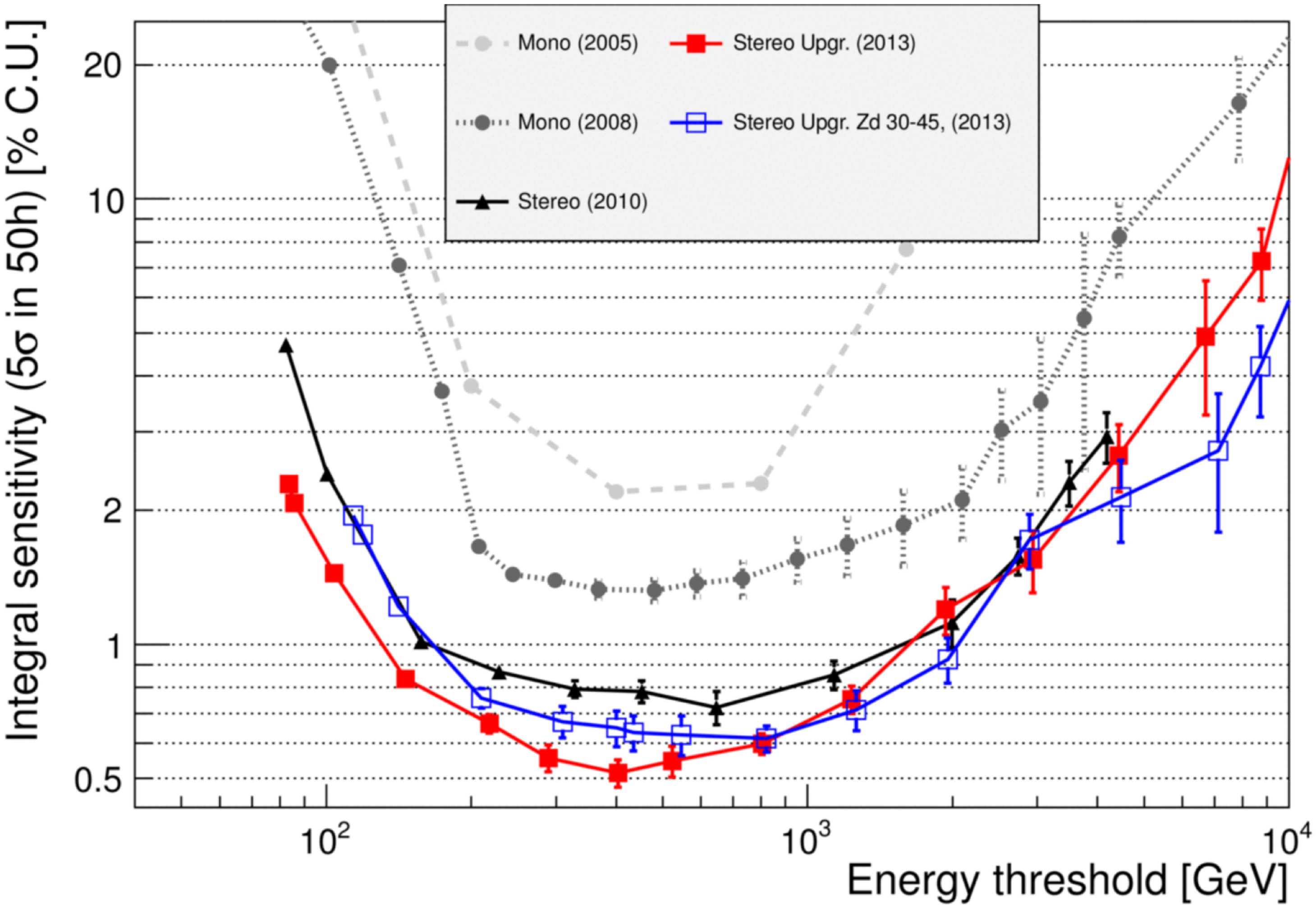
In space, first instruments in 1970s, while on ground (*indirect !!*), first significant signal in late 1980s. Big push happened in 2000s

The MAGIC collaboration

Evolution of the MAGIC Performance

4-fold improvement in sensitivity over the last 20 years

The multiple improvements vs time is one of the reasons why MAGIC has maintained competitivity over the last two decades



Aleksic et al., (MAGIC collab.) Astroparticle Physics 72, 76-92, 2016

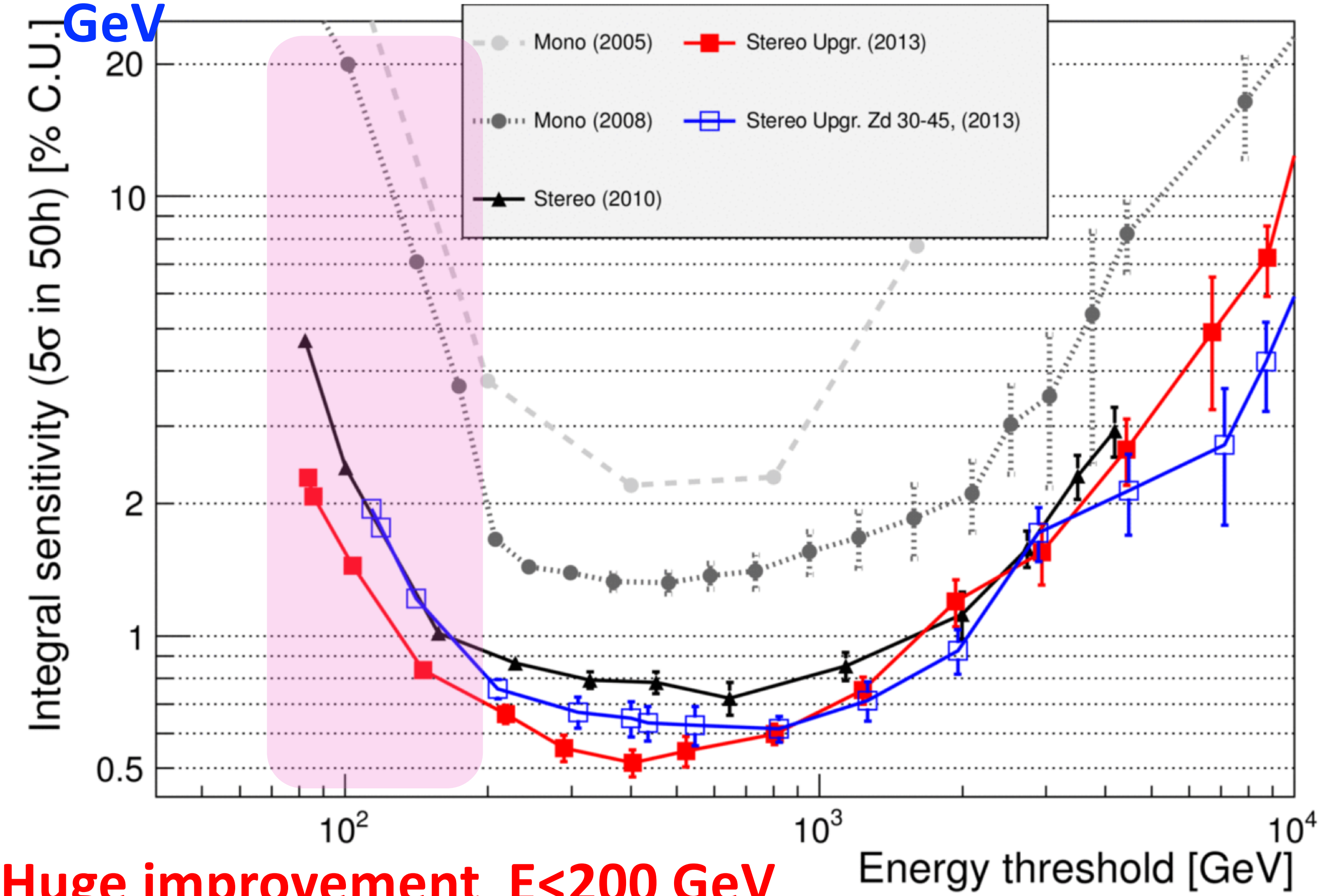
Better sensitivity + Lower energy threshold = More science !!

Evolution of the MAGIC Performance

4-fold improvement in sensitivity over the last 20 years

→ More than 10-fold improvement below 200 GeV

→ Obs. time for detection reduced 100 times below 200 GeV



Aleksic et al., (MAGIC collab.) Astroparticle Physics 72, 76-92, 2016

Huge improvement E<200 GeV

Better sensitivity + Lower energy threshold = More science !!

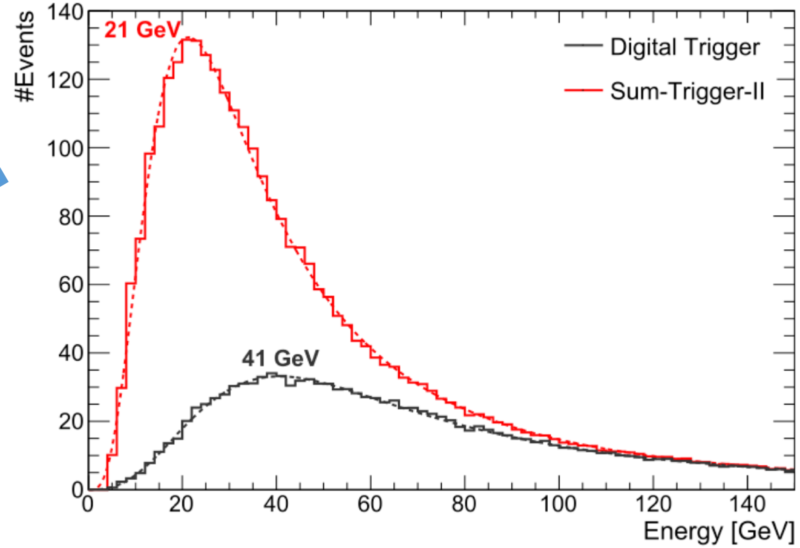
Performance improvements in last years

(non standard observations)

Sum-Trigger-II

→ Decrease energy threshold (from ~40 GeV to ~20 GeV) and improve sensitivity below 100 GeV

[Dazzi et al. 2021](), IEEE Transactions on Nuclear Science, 68, 1473

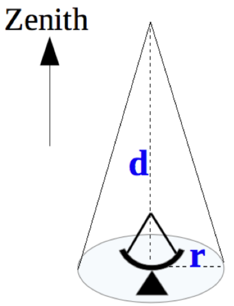


Very Large Zenith angle

→ Increase sensitivity for multi-TeV energies

Vertical observations

typical for IACTs

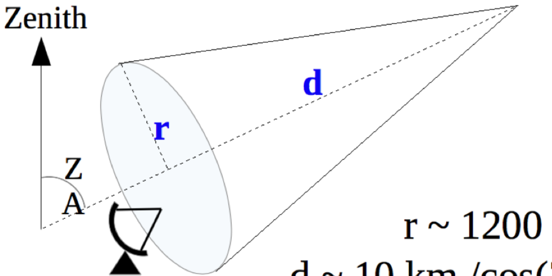


d ~ 10 km

r ~ 120 m

Large zenith angle observations

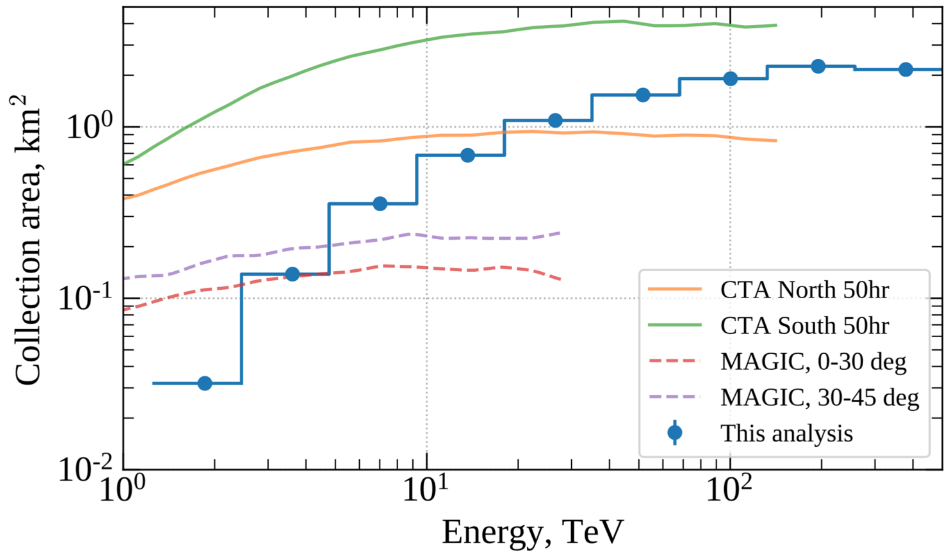
proposed



r ~ 1200 m

d ~ 10 km /cos(ZA) ~ 100 km

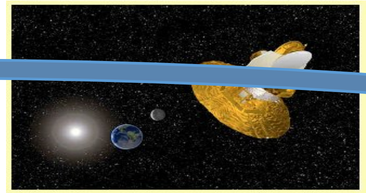
Acciari et al., 2020, A&A, 635, A158.



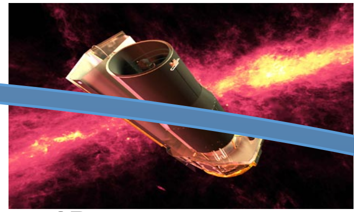
Need small pixels and good time information

Detection and energy of gamma rays, crucial link between time domain astronomy and multi messenger astrophysics

Radio:



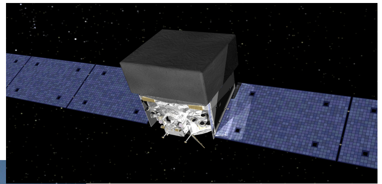
Microwave:



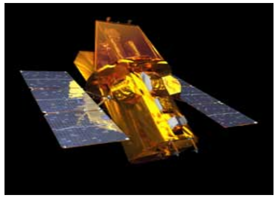
IR:

Electromagntic emission (from radio to VHE gamma rays)

TeV



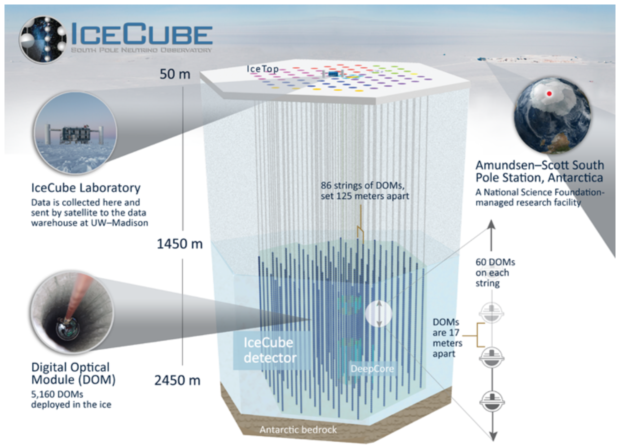
GeV



X-ray:

Optical:

Trajectory deflections preclude usage for individual sources



Gravitational Waves (e.g. advanced Ligo)

High-Energy Cosmic Rays (e.g. Pierre Auger & Tel. Array)

High-Energy Neutrinos (e.g. IceCube)

Gamma rays play a fundamental role in the time domain & multi-messenger astronomy

The three most relevant (significant) multi-messenger sources reported in the last years “benefit from gamma-rays"

→ GW170817 (*GW+Photons, year **2017***)

Merger of two neutron starts, observed with Advanced Ligo and Fermi/INTEGRAL

Abbott et al. 2017, Astrophisical Journal Letters Vol. 848, 12

→ IceCube170922 (*Nu+Photons, **2017***)

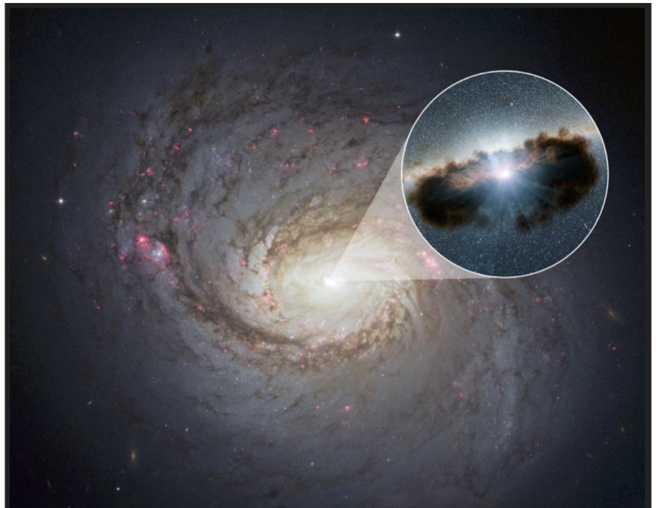
High-energy neutrino from IceCube arrived during gamma-ray enhanced activity of the blazar TXS 0506+056, as measured with Fermi and **MAGIC**.

Aartsen et al. 2018, Science, Vol. 861, 1378

→ NGC1068 (*Nu+**Lack** of TeV Photons, Flux ULs, **year 2022***)

Starburst galaxy detected with IceCube (4+ sigma). The lack of TeV photons (strong upper limits with **MAGIC**) essential for interpretation of the results.

Abbasi et al. 2022, Science, Vol. 378, 538



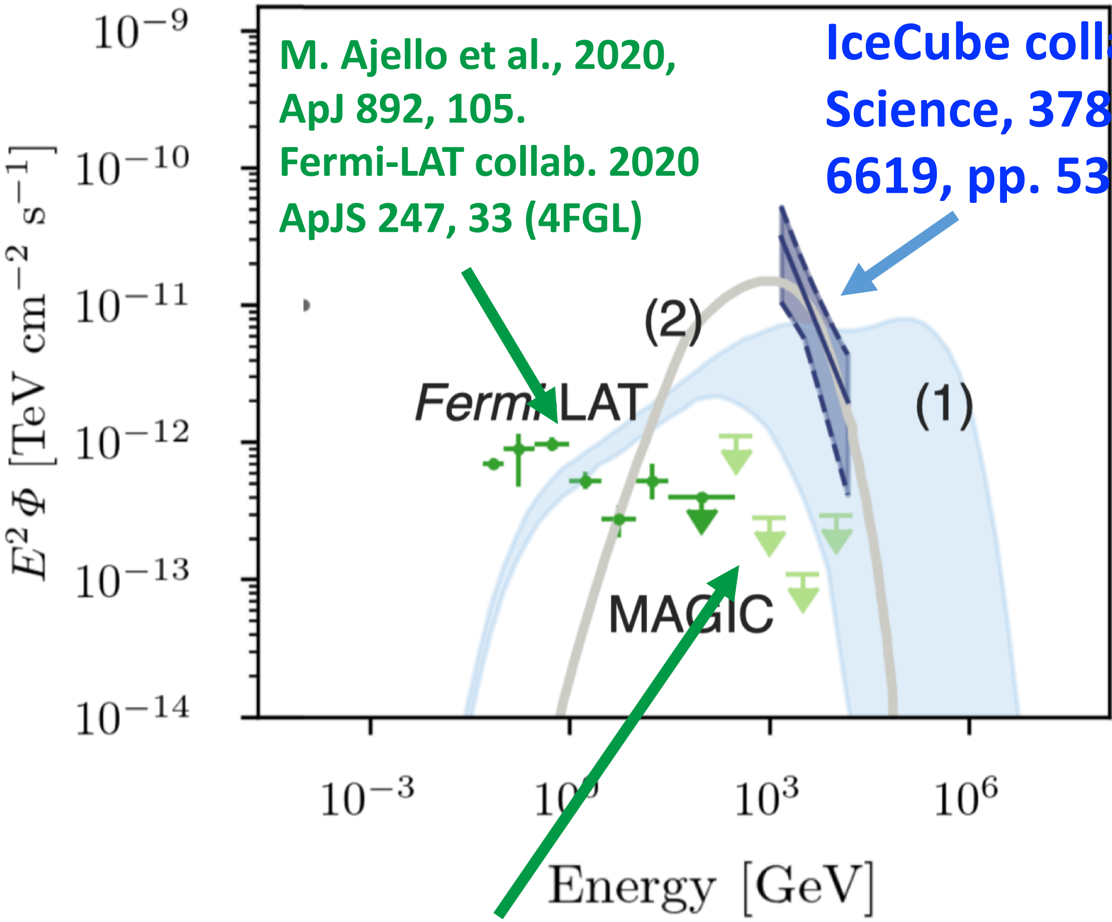
NGC 1068 as seen by Hubble Space Telescope (HST) with an artistic impression zoom-in on the central active galactic nucleus. Image credit: NASAESA/JPL-Caltech.

Composite Starburst/Seyfert 2 Galaxy NGC1068: the hottest spot in the IceCube data (2011-2020)

Global significance: 4.2σ

Astrophysical neutrino events = 79^{+22}_{-20}
Spectral index = 3.2 ± 0.2

MAGIC upper limits on NGC1068 (95% C.L.) imply strong gamma ray absorption, and hence crucial for the interpretation of the IceCube neutrino excess



M. Ajello et al., 2020, ApJ 892, 105.
Fermi-LAT collab. 2020 ApJS 247, 33 (4FGL)

IceCube collab., 2022, Science, 378, Issue 6619, pp. 538-543

MAGIC collaboration, 2019, ApJ 883, 135

Theoretical models for neutrino flux prediction

(1) Y. Inoue et al., ApJL'20
(2) K. Murase et al., PRL'20

MAGIC started operations in October 2003

A few major historical breakthrough observations published by MAGIC

Detection of minute timescale variability from Mrk501 in 2005, **First** time observed in BL Lacs
→ **2007ApJ...669..862A**

Detection of 3C279 in 2006, **First** detection of a Flat Spectrum Radio Quasar (FSRQ) at VHE
→ **2008Sci...320.1752M**

Detection of pulsed emission from Crab in 2008, **First** detection of pulsed VHE emission
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Detection of QSO B0218+357 (z=0.944) in 2014, the **First** gravitationally lensed blazar at VHE
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Detection of TeV pulsed emission from Crab, announced in 2015, **First** time for a pulsar
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Detection of TXS 0506+056 in 2017, **First** 3+sigma association of neutrino and a VHE source
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GRB190114C in 2019, **First** GRB at TeV energies & **First** measurement of GRB inverse-Compton
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MAGIC telescopes, an instrument to explore & measure new things