New TeV gamma-ray Discoveries from the Extreme Blazar Program of MAGIC

Luca Foffano, on behalf of the MAGIC Telescopes Collaboration

TeV Particle Astrophysics
Tendo Japan
August 30 - September 4, 2026

Outline

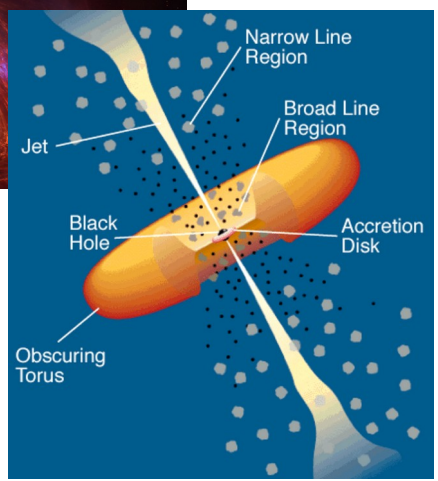
1) What are Extreme Blazars?

2) Opportunities and challenges

3) The MAGIC telescopes and the VHE gamma-ray sky

4) New Extreme Blazars by MAGIC

Blazars

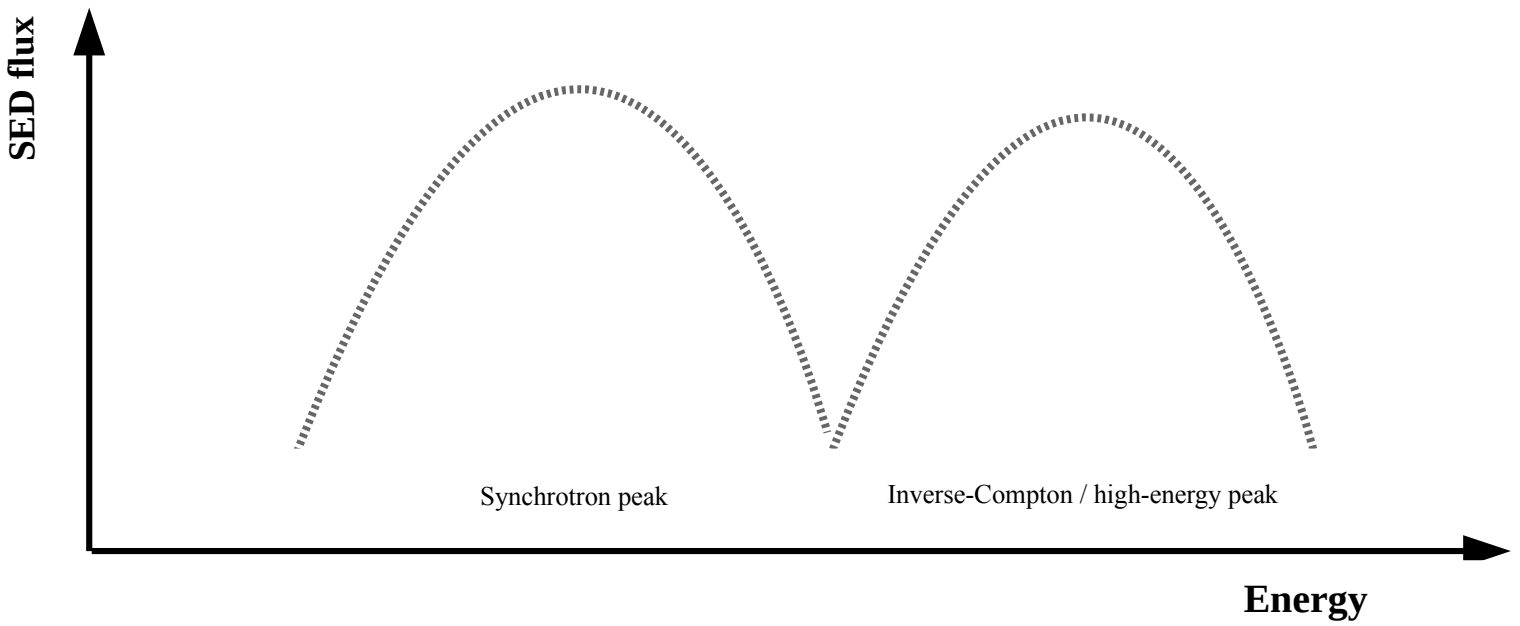


- **Blazars** are active galactic nuclei (AGNs) with relativistic jets closely aligned with our line of sight.
- **BL Lac objects** are a subclass of blazars, characterized by prominent non-thermal jet emission, hiding the thermal emission from the other AGN components.

  → unique laboratories to study relativistic jets and their extreme particle acceleration processes

- BL Lacs are commonly classified according to the frequency of the synchrotron peak in their spectral energy distribution (SED): LBL, IBL, HBL, and EHBL (extreme blazars!)

What are Extreme Blazars?

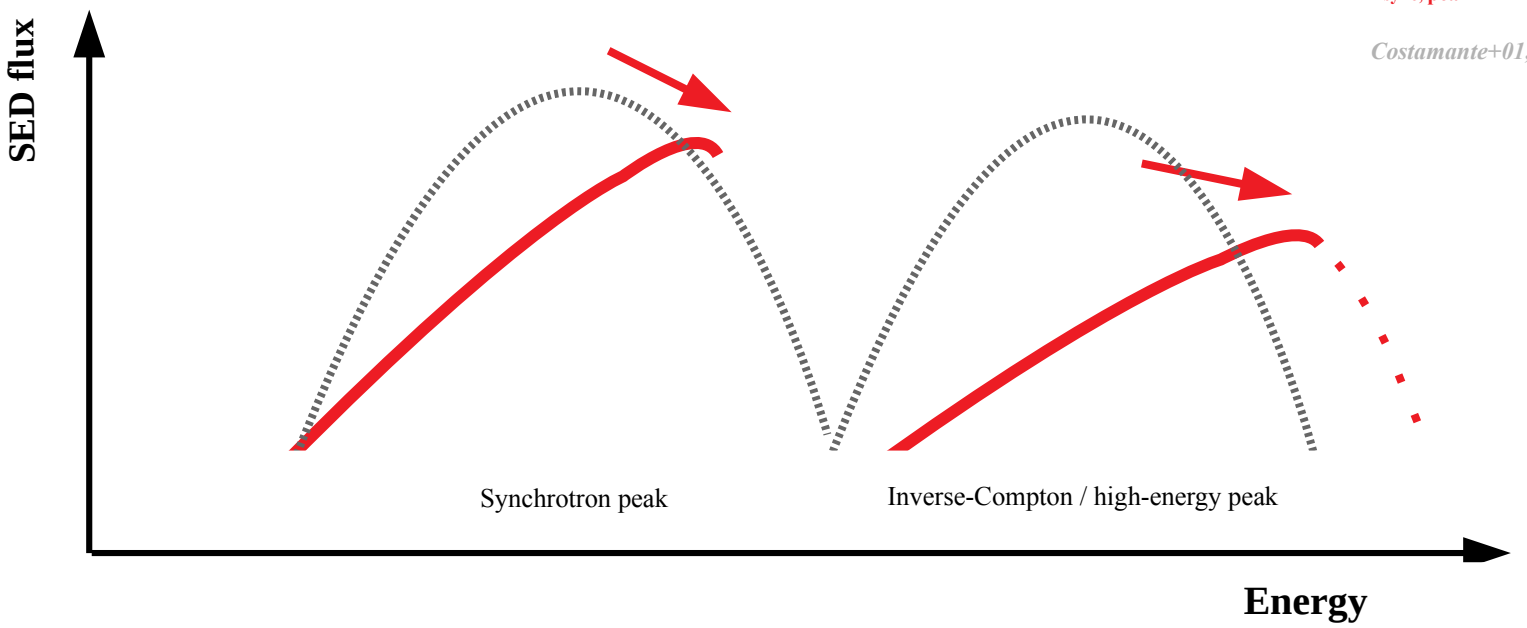


Typical spectral energy distribution of extreme blazars compared to other blazars

What are Extreme Blazars?

Extreme blazars definition:
$\nu_{sync,\,peak} > 10^{17}$ Hz

Costamante+01, Abdo+10



Typical spectral energy distribution of extreme blazars compared to other blazars

What are Extreme Blazars?

- **Extreme particle accelerators:**

  → The most energetic end of the blazar population

  → but emission mechanism still debated

- **New!** They are **not a homogeneous population** [LF+19]

  → multi-wavelength approach is essential

- Ideal probes to verify presence of **spectral absorption features at gamma rays** [LF+22]

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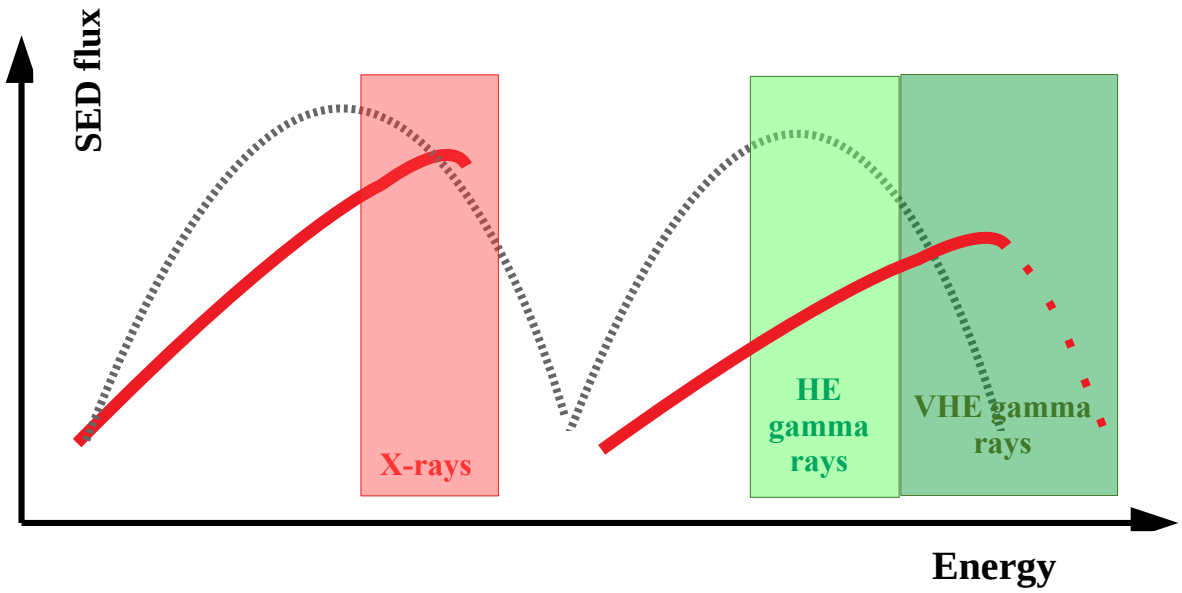
$\nu_{sync,\,peak} > 10^{17}$ Hz



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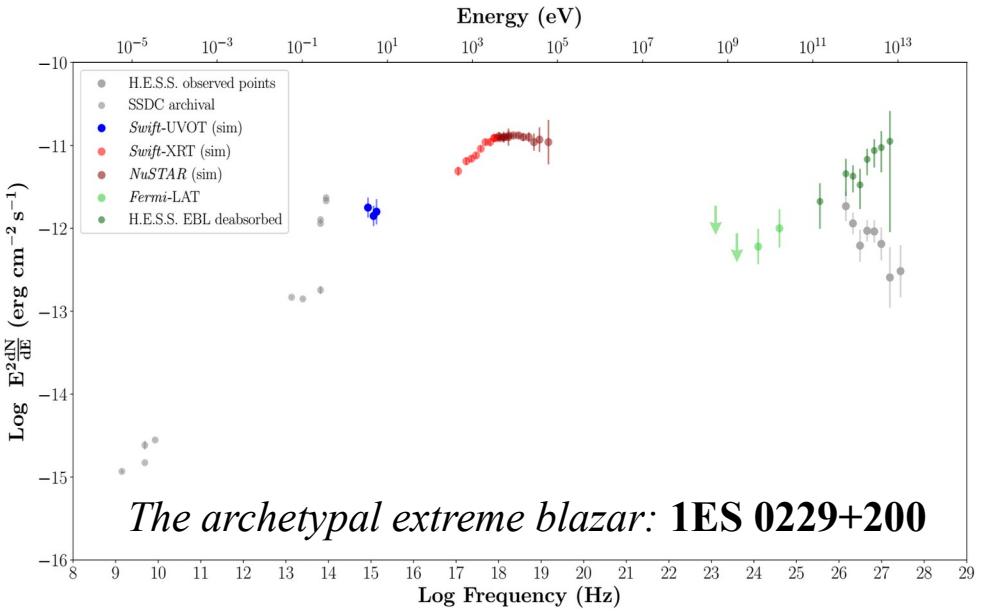
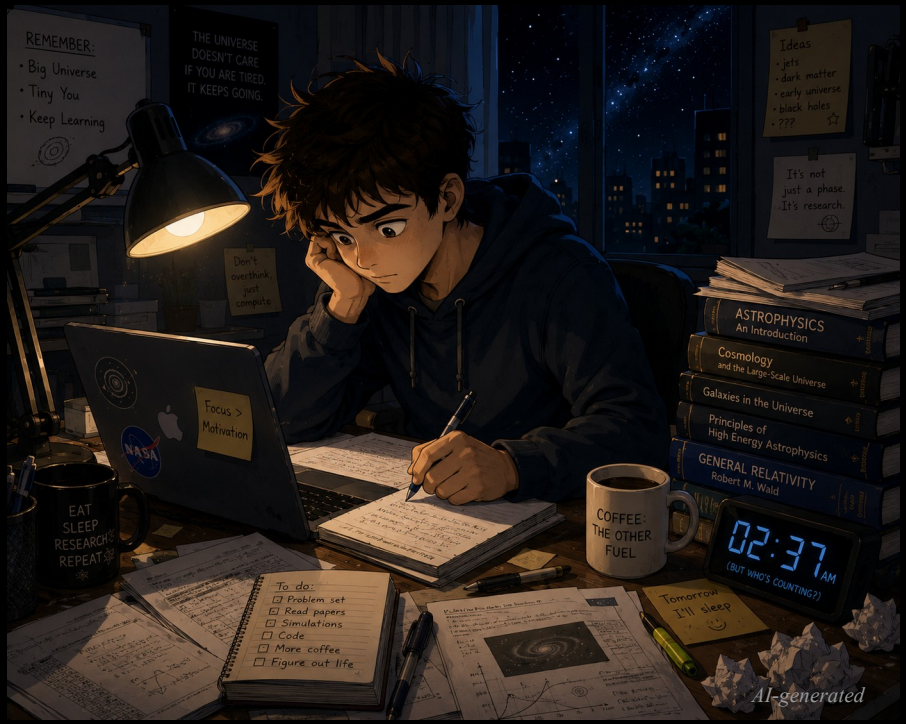


Broad-band SED archival data (SSDC website)

Nice!

And why don’t you study them all?



Extreme Blazars: Rare, Faint, and Distance-Limited

All blazars
parent population

Extreme blazars
intrinsically rare

X-ray detected
synchrotron peak is usually accessible

Gamma-ray detectable
often requires long exposures

VHE observable
spectral shape + EBL attenuation

Target sample
nearby & bright enough

They are rare
Only a small fraction of blazars have emission peaks shifted to very high energies.

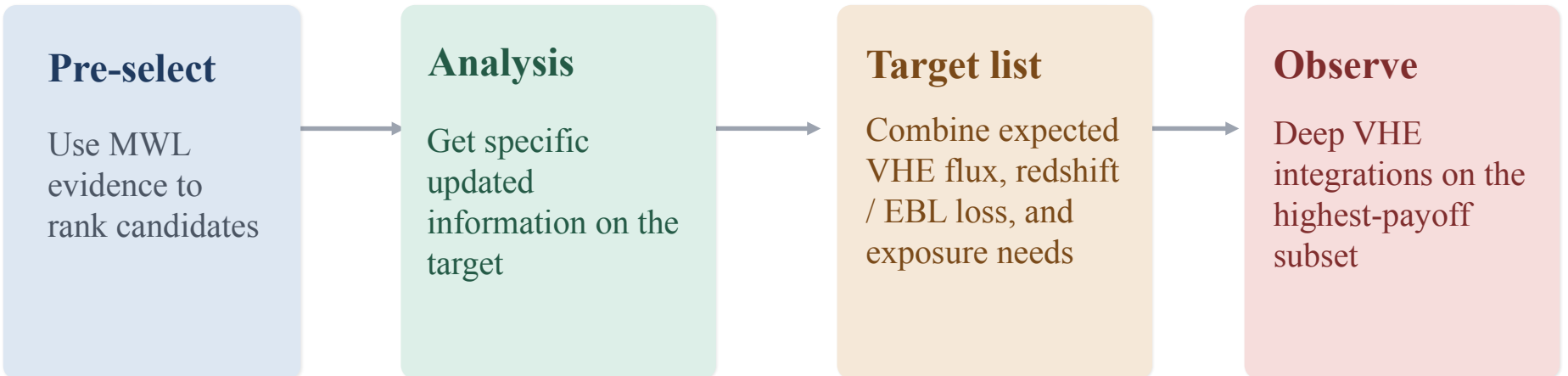
They are faint
X-rays remain detectable, but gamma-ray fluxes are faint and depend on the spectral properties.

The more distant, the more absorbed
At VHE, EBL absorption suppresses the observed gamma-ray flux increasingly with distance.

Observation Strategy

We need to balance:

1) VHE feasibility
2) Exposure
3) Scientific leverage



Continuous learning process since >15 years: update strategy with detections, upper limits, and new MWL information

One or More Populations?

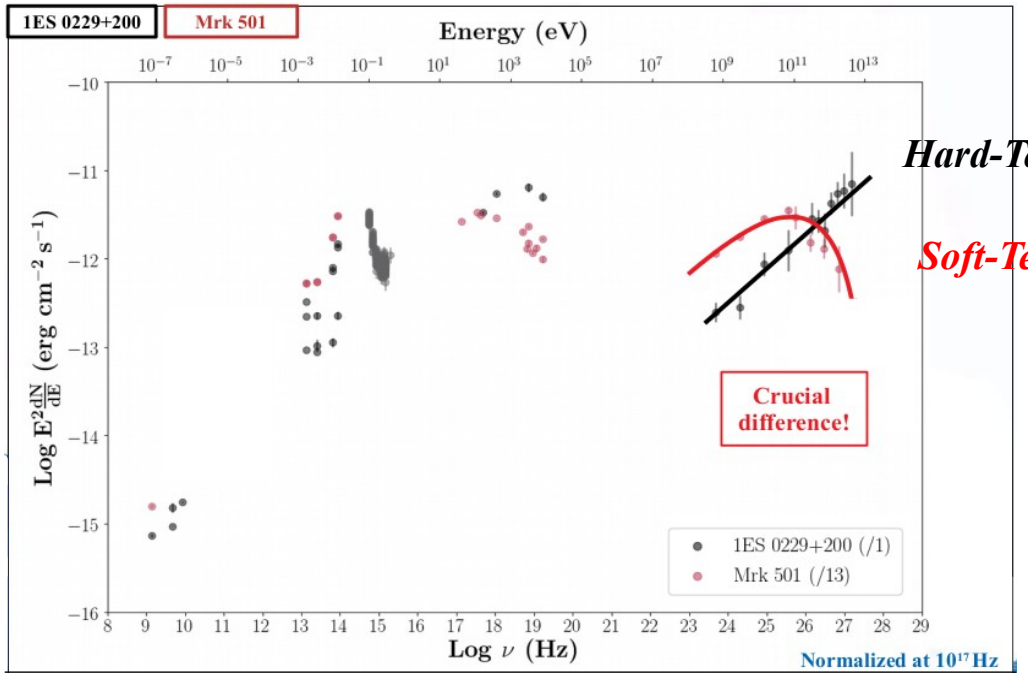
As we discover more TeV-emitting EHBLs, they are showing increasingly diverse spectral behaviour.

Current phenomenology suggests at least three observational classes:

1) **Hard-TeV EHBLs** → persistent, very hard TeV spectra; e.g. 1ES 0229+200
2) **NEW! Soft-TeV EHBLs** → EHBL-like synchrotron emission, but softer TeV spectra
3) **NEW²! Transient / flaring / intermittent EHBLs**

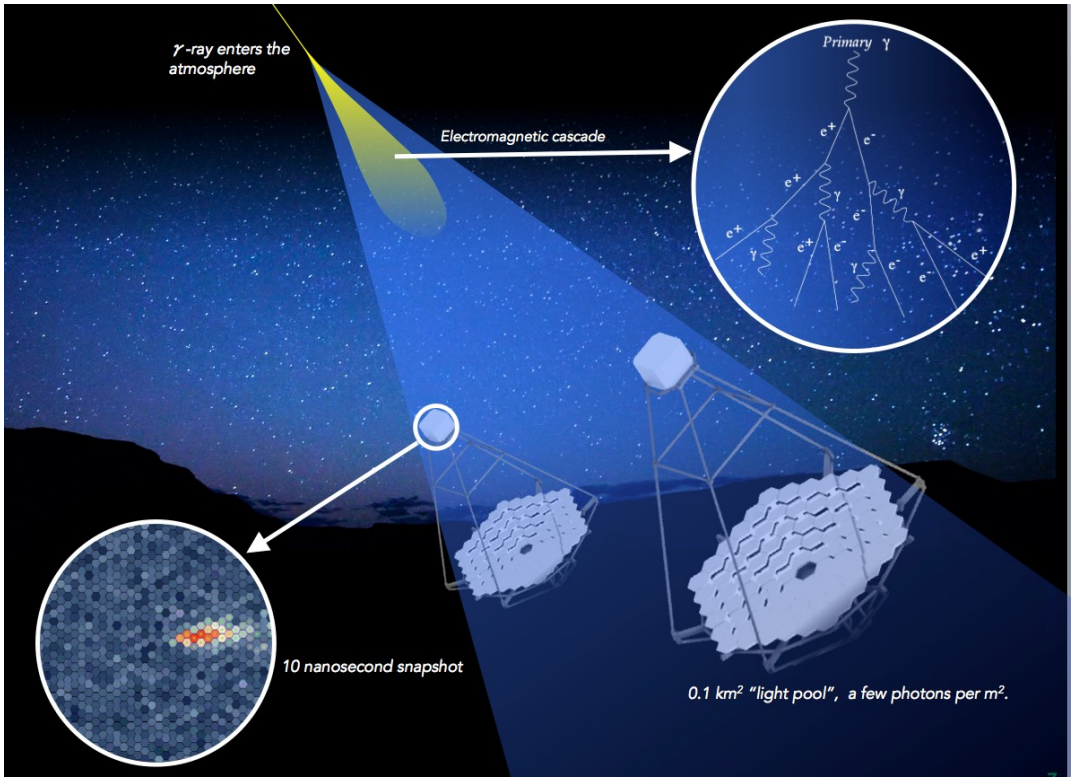
These may not be distinct populations: they could represent different states along a connected physical sequence.

LF+19

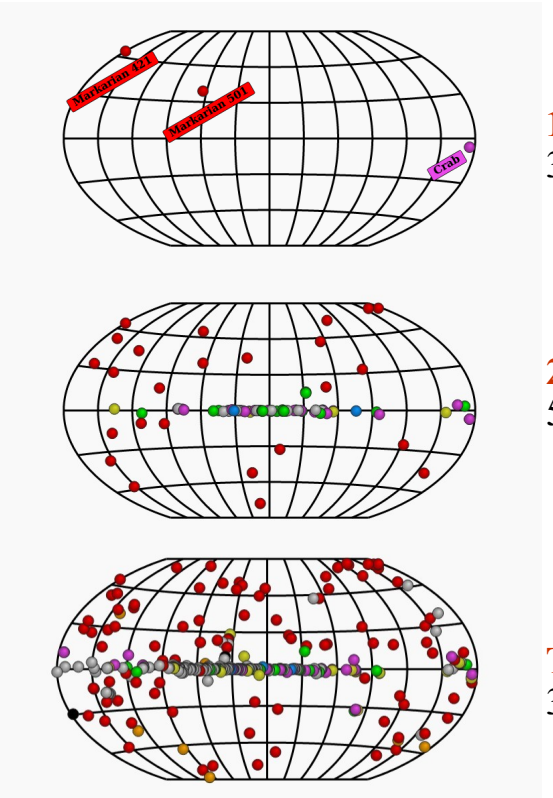


We need more sources at TeV gamma-ray energies!

The VHE Sky Seen by the Cherenkov Telescopes



Credits: R. White (MPIK) / K. Bernlohr (MPIK) / DESY



1996
3 sources

2008
59 sources

Today
337 sources

Credits: TeVCat

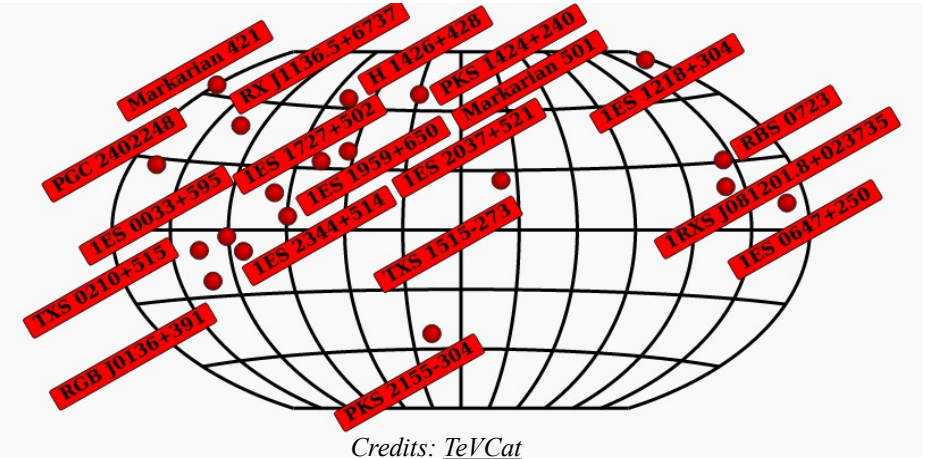
The MAGIC telescopes

- Energy range from ~50 GeV to ~50 TeV
- Energy resolution ~20%
- Field of view of about 3.5°
- Angular Resolution ~0.1°
- Integral sensitivity (5 σ in 50 hours) ~ 0.6% CU > 250 GeV of Crab Nebula VHE flux

"The major upgrade of the MAGIC telescopes, Part II" Astroparticle Physics, Volume 72, p. 76.

MAGIC Long-Term Program on Extreme Blazars

- **Extreme blazars are faint in gamma rays**, therefore difficult to detect, especially at VHE
- **~ 30 extreme blazars** currently known at TeV gamma-ray energies in total
- **17 extreme blazars** have been **detected by MAGIC**, of which **10 newly discovered by MAGIC**



Credits: TeVCat

Today we will increase this number!

2nd Catalog of Extreme Blazars by MAGIC

7 **new targets**

9 years of observations between 2017 and 2025

338 hours of MAGIC exposure time

262 hours of good-quality data

4 complementary analyses:

Tuorla optical data,

Swift-XRT and UVOT

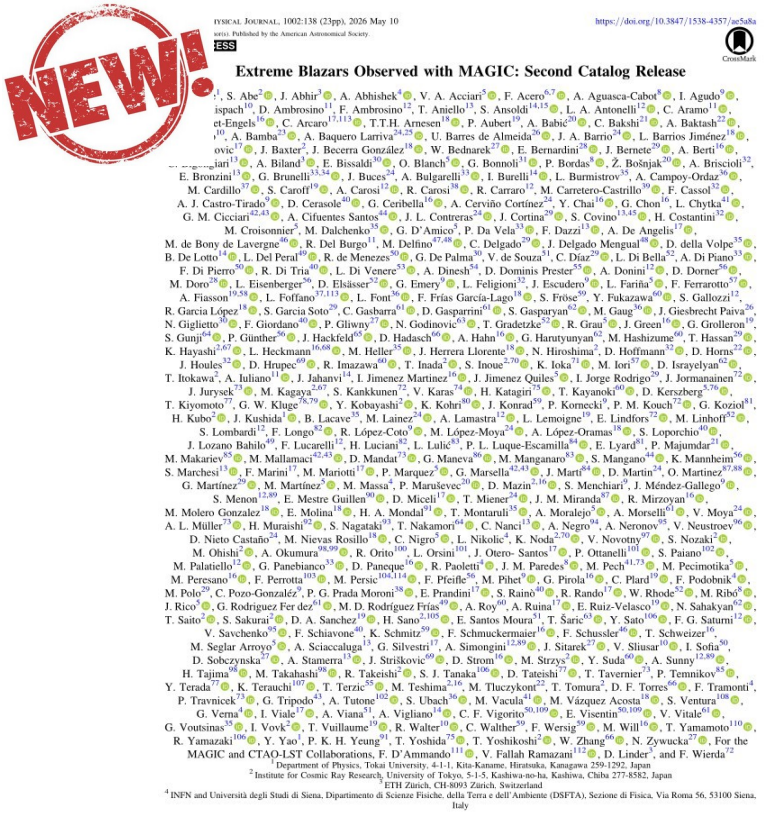
Fermi-LAT

- Large working group involved:

  Corresponding authors: Luca Foffano, Cornelia Arcaro,

  Analyzers: Axel Arbet-Engels, Filippo D'Ammando, Paolo Da Vela, Vandad Fallah Ramazani, Elisa Prandini, Mireia Nievas Rosillo, Joao Paiva, Sofia Ventura, Jenni Jormanainen, David Linder, Sweta Menon, Davide Miceli, Elisa Visentin

- Includes **MAGIC+LST** simultaneous observations that played a key role!



NEW!

IVSICAL JOURNAL, 1002:138 (23pp), 2026 May 10 https://doi.org/10.3847/1538-4357/ae5a8a

sor(s). Published by the American Astronomical Society.

ESS

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Extreme Blazars Observed with MAGIC: Second Catalog Release

:[1], S. Abe[2], J. Abhir[3], A. Abhishek[4], V. A. Acciari[5], F. Acero[6,7], A. Aguasca-Cabot[8], I. Agudo[9], ispach[10], D. Ambrosino[11], F. Ambrosino[12], T. Aniello[13], S. Ansoldi[14,15], L. A. Antonelli[12], C. Arano[11], el-Engels[16], C. Arcaro[17,113], T.T.H. Arnesen[18], P. Aubert[19], A. Babić[20], C. Bakshi[21], A. Baktash[22], ,[10], A. Bamba[23], A. Baquero Larriva[24,25], U. Barres de Almeida[26], J. A. Barrio[24], L. Barrios Jiménez[18], ovic[17], J. Baxter[2], J. Becerra González[18], W. Bednarek[27], E. Bernardini[28], J. Bernete[29], A. Berti[16], ...ari[13], A. Biland[3], E. Bissaldi[30], O. Blanch[5], G. Bonnoli[31], P. Bordas[8], Ž. Bošnjak[20], A. Briscioni[32], E. Bronzini[13], G. Brunelli[33,34], J. Buces[24], A. Bulgarelli[33], I. Burelli[14], L. Burmistrov[35], A. Campoy-Ordaz[36], M. Cardillo[37], S. Caroff[19], A. Carosi[12], R. Carosi[38], R. Carraro[12], M. Carretero-Castrillo[39], F. Cassol[32], A. J. Castro-Tirado[9], D. Cerasole[40], G. 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Yoshikoshi[2], W. Zhang[68], N. Zywucka[27], For the MAGIC and CTAO-LST Collaborations, F. D'Ammando[111], V. Fallah Ramazani[112], D. Linder[1], and F. Wierda[72]

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https://doi.org/10.3847/1538-4357/ae5a8a

2nd Catalog of Extreme Blazars by MAGIC

Source	RA [deg]	Dec [deg]	z	Previous VHE detection	Result
RX J0805.4+7534	121.36	75.57	0.121	No	**First TeV detection ever**
RX J0812.0+0237	123	2.63	0.172	No	**First TeV detection ever**
1ES 1028+511	157.83	50.89	0.361	Yes, very recently	**(Second) TeV detection**
1ES 2037+521	309.85	52.33	0.053	Yes	**New result!**
1ES 1426+428	217.14	42.7	0.129	Yes	**New result!**
TXS 0637−128	100.03	−12.89	0.137	No	**New hint of TeV detection**
RBS 42	4.62	29.79	> 0.10	No	**Not detected**

2nd Catalog of Extreme Blazars by MAGIC

Source	Obs. period	Obs. Time [h]	Eff. time [h]	Significance [σ]	$E_{\rm th}$ [GeV]	Flux$_{\geq E_{\rm th}}$ $\times 10^{-12}$ [erg cm^{-2}s^{-1}]
RBS 42	2019	43.3	20.3	0.7	200	< 2.1
TXS 0637–128	2017-2025	39.9	29.1	3.3	250	1.29 ± 0.60
RX J0805.4+7534	2018-2024	61.7	50.6	6.0	150	4.41 ± 1.40
RX J0812.0+0237	2019-2020	56.8	49.0	5.6	150	4.11 ± 0.88
1ES 1028+511	[MAGIC-only] 2022-2024	43.5	25.3	5.7[a]	150	4.55 ± 1.15
	[MAGIC+LST1] 2022-24	15.6	6.0			
1ES 1426+428	2020	15.0	12.8	4.2	200	7.11 ± 1.58
1ES 2037+521	2018-2019	77.4	74.7	4.0	300	0.83 ± 0.23
Total	2017-2025	337.6	261.8			

[a]Results from the analysis of simultaneous MAGIC+LST1 data.

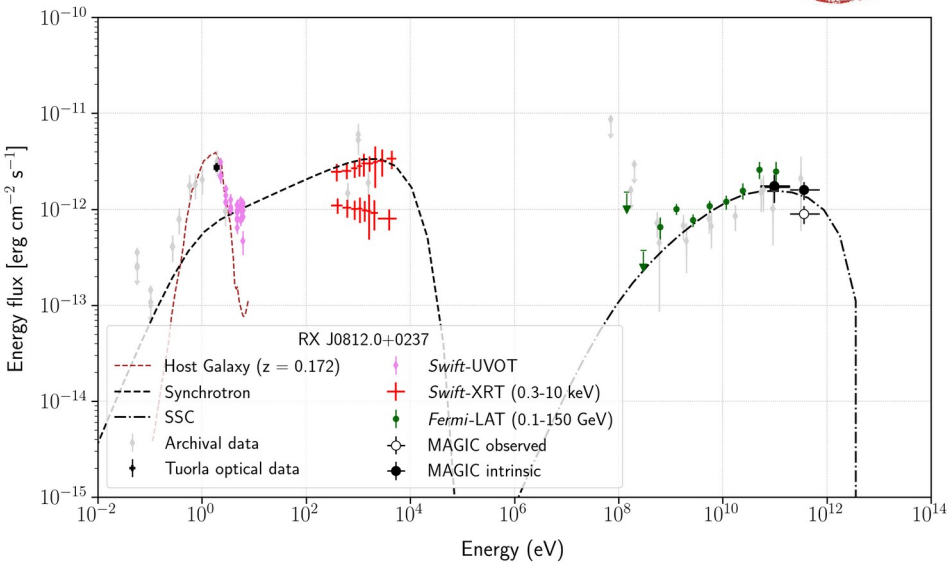
New TeV Extreme Blazar!

1RXS J081201.8+023735 (PI: LF) is a new moderately-soft TeV extreme blazar:

- New redshift estimation z = 0.1721 ± 0.0002 [Becerra Gonzalez+2021];
- Radio and X-ray fluxes comparable with typical values of 1ES 0229+200.

Results:

- Confirmed extreme blazar: peak above 10^{17} Hz
- Different states in X-rays
- Photon flux (>320 GeV): 5.2 ± 1.0 cm^{-2} s^{-1}
- Observed photon index: 2.9 ± 0.3



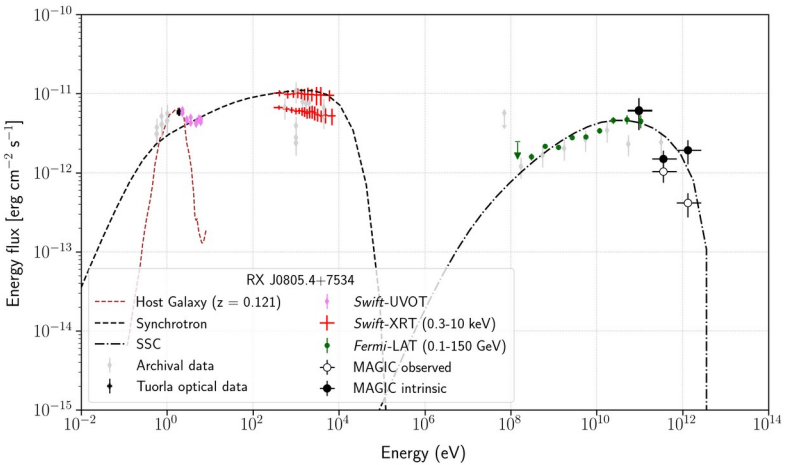
New TeV Extreme Blazar!

RX J0805.4+7534 is a new TeV extreme blazar:

- Moderate redshift z = 0.121;
- Selected as an interesting candidate based on MWL correlations (Fallah Ramazani+2017) adopting MWL correlations

Results:

- Confirmed extreme blazar: peak above 10^{17} Hz
- Different X-ray states?
- Photon flux (>930 GeV): 4.0 ± 0.1 cm^{-2} s^{-1}
- Observed photon index: 2.8 ± 0.4



New TeV Extreme Blazar!

1ES 1028+511 is a very distand extreme blazar:

- Relatively **high redshift** of 0.36;
- Announced by VERITAS in 2024: ATeL Furness+2024, Mem. SAIt 75, 282;

  → They report 6.1σ signal detection after 49 h.

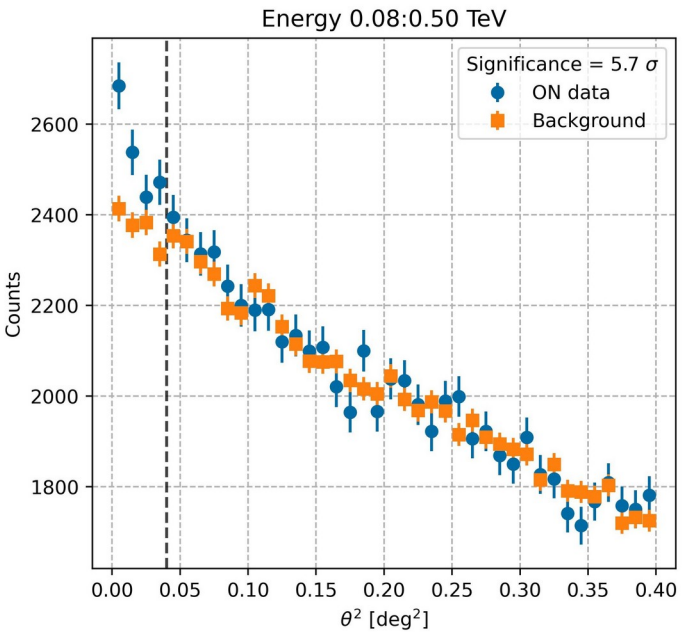
Results:

- Joint simultaneous observations of MAGIC + LST-1;

  → We report 5.7σ signal detection after 23.6 h good-quality data;

  → New Confirmation of this Extreme Blazar at VHE gamma rays!

Simultaneous observations of MAGIC + LST-1 were key to detect this source at low energies in much less time!



New Results

Focus on 2 long-term known monitored sources:

1ES 1426+428: observed for 13h

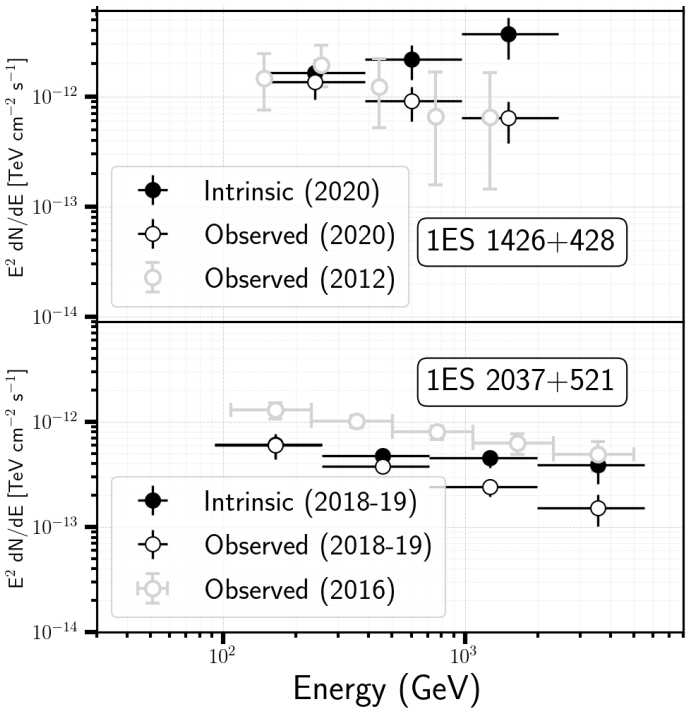
Result: 4.2σ, spectrum and flux similar to previous observations

1ES 2037+521: observed for 75h,

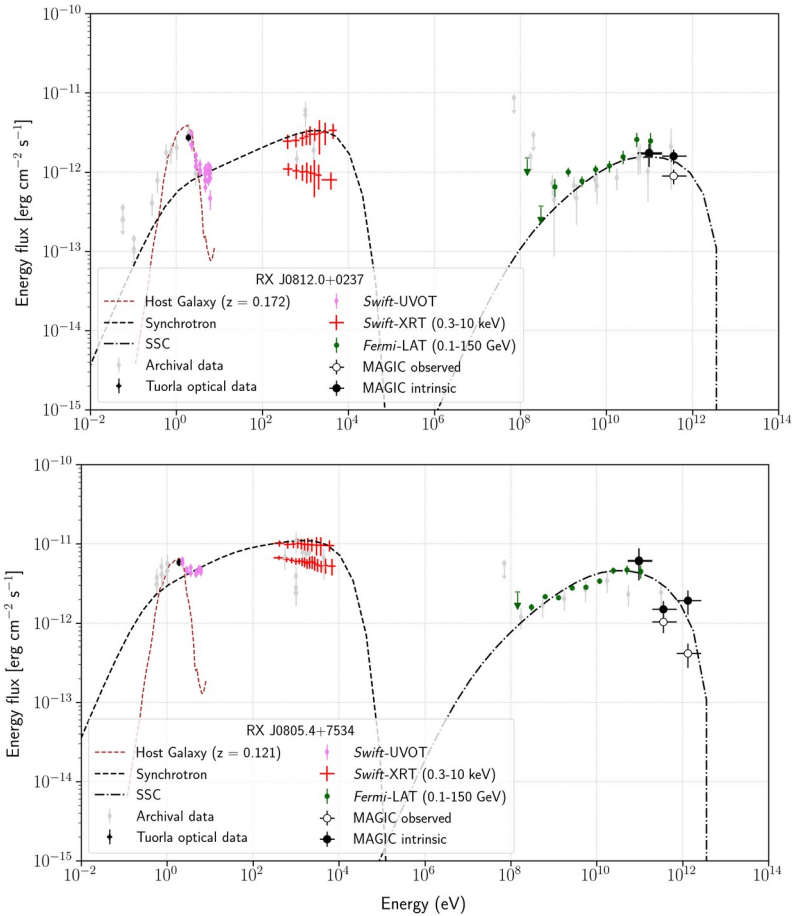
Result: 4.0σ, compatible spectrum, lower flux

(detected in 52h the 1st MAGIC EHBL catalog)

→ **variability** discussed



Results and Interpretation



Modeling of known TeV emitters (new hints or new detections) with a standard 1-zone SSC model:

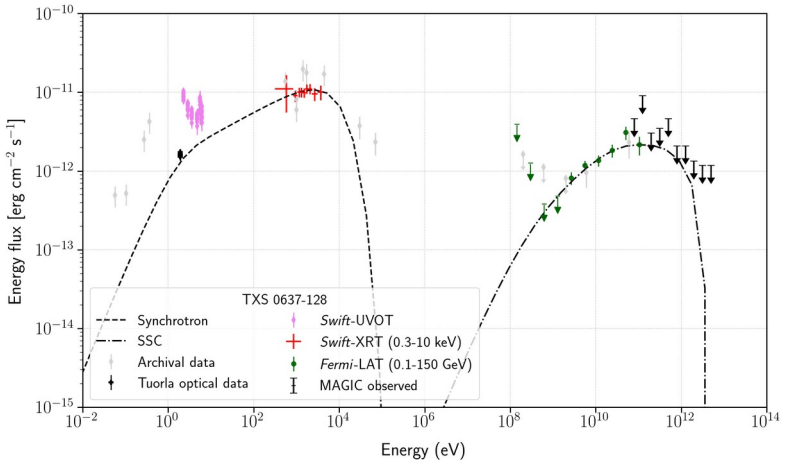
- Mostly soft-TeV extreme blazars
- Rather low magnetic fields
- High gamma min

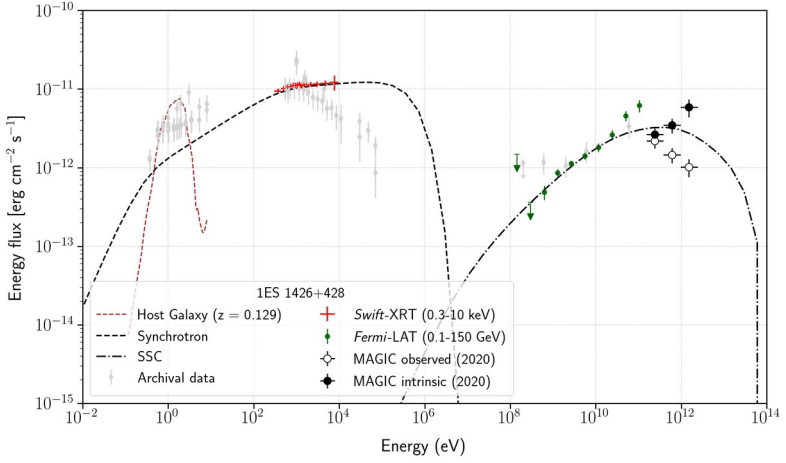
→ SSC still provides feasible physical results

Parameter Values Derived from the SSC Leptonic Model Used in This Study

Source	Γ	B (G)	R (cm)	k_e (cm^{-3})	γ_{min}	γ_{br}	γ_{max}	p_1	p_2
TXS 0637–128	15	0.12	2×10^{16}	1×10^{-7}	7000	1×10^{4}	6×10^{5}	1.6	2.4
RX J0805.4+7534	15	0.12	2×10^{16}	4×10^{-7}	3000	4×10^{4}	7×10^{5}	2.4	2.8
RX J0812.0+0237	15	0.06	2×10^{16}	2×10^{-6}	6000	1×10^{4}	8×10^{5}	1.8	2.5
1ES 1028+511	30	0.2	7×10^{15}	5×10^{-5}	2000	1×10^{4}	3×10^{5}	2.4	2.8
1ES 1426+428	27	0.15	5×10^{16}	1.2×10^{-7}	5000	3×10^{4}	5×10^{5}	2.3	3.0
1ES 2037+521	12	0.11	2×10^{16}	1.5×10^{-7}	1000	4×10^{4}	8×10^{6}	2.0	2.7

Results and Interpretation





In the case of 1ES 1426+428, the SSC model seems to be limited

Table 7
Parameter Values Derived from the SSC Leptonic Model Used in This Study

Source	Γ	B (G)	R (cm)	k_e (cm^{-3})	γ_{min}	γ_{br}	γ_{max}	p_1	p_2
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Conclusions

Extreme blazars are a new emerging class in VHE gamma rays:

- As we discover new sources, we find **unexpected differences among them**
- **Theoretical interpretation** still far to understand the whole picture

MAGIC has always played an important role in the search for new sources!

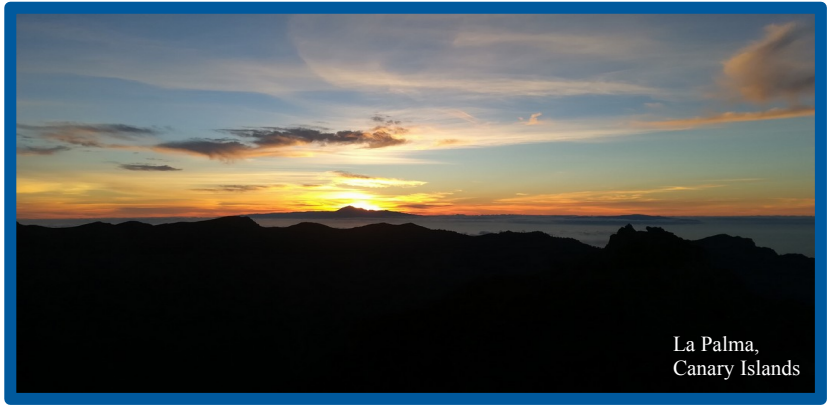
- Long-term observational program: new sources are discovered every year
- Today we announce **a 3rd catalog of extreme blazars**, currently in preparation

CTAO will certainly increase our opportunities to find new sources and new answers!

But the best strategies are being discovered today!

→ Current IACTs are pathfinders for CTAO

→ The joint effort between MAGIC and LST-1 telescopes show evidence of **improved performance** when detecting these sources!



Thank you