

Extreme blazars under the eyes of MAGIC

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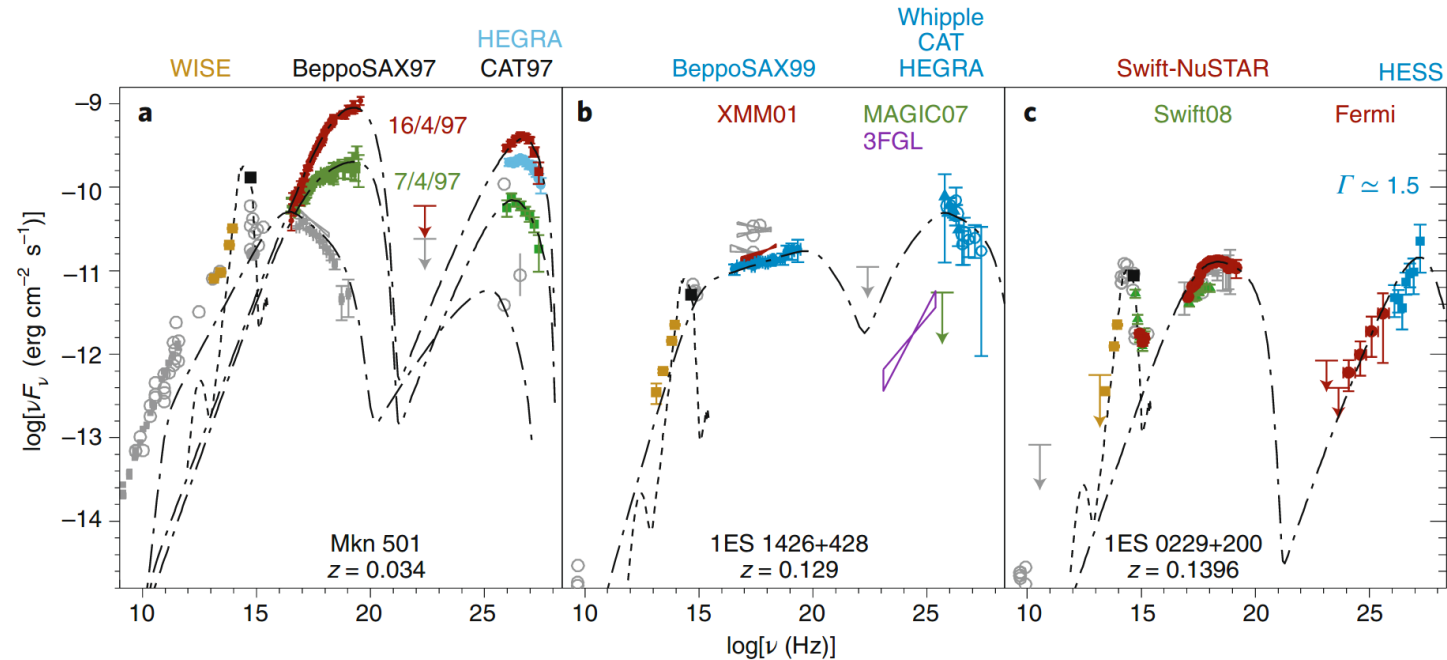
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Extreme high-frequency-peaked BL Lac objects (EHBLs)

- $\nu_{\text{synch., peak}} \geq 1 \text{ keV}$, $\Gamma_{\text{X-ray}} \leq 2$ (Costamante et al. 2001)
- Some EHBLs have gamma-ray SED components peaking $> 1 \text{ TeV}$ (hard-TeV EHBLs)
→ Most energetic persistent sources
- Laboratories to study acceleration & emission mechanisms in blazars
→ Challenge existing models
- Probes for extragalactic background light (EBL) & intergalactic magnetic field (IGMF)
- Main questions:
 - Is there a unique EHBL population?
 - Leptonic or hadronic scenario?
 - Acceleration processes?



Biteau et al. 2020

The MAGIC telescopes

- 2 x 17-m $\varnothing$ Cherenkov telescopes
- La Palma, Canary Islands, 2200 m a.s.l.
- Energy range: ~ 20 GeV to ~ 100 TeV
- Angular resolution: ~ 0.1 degrees
- Field of view: ~ 3.5 degrees

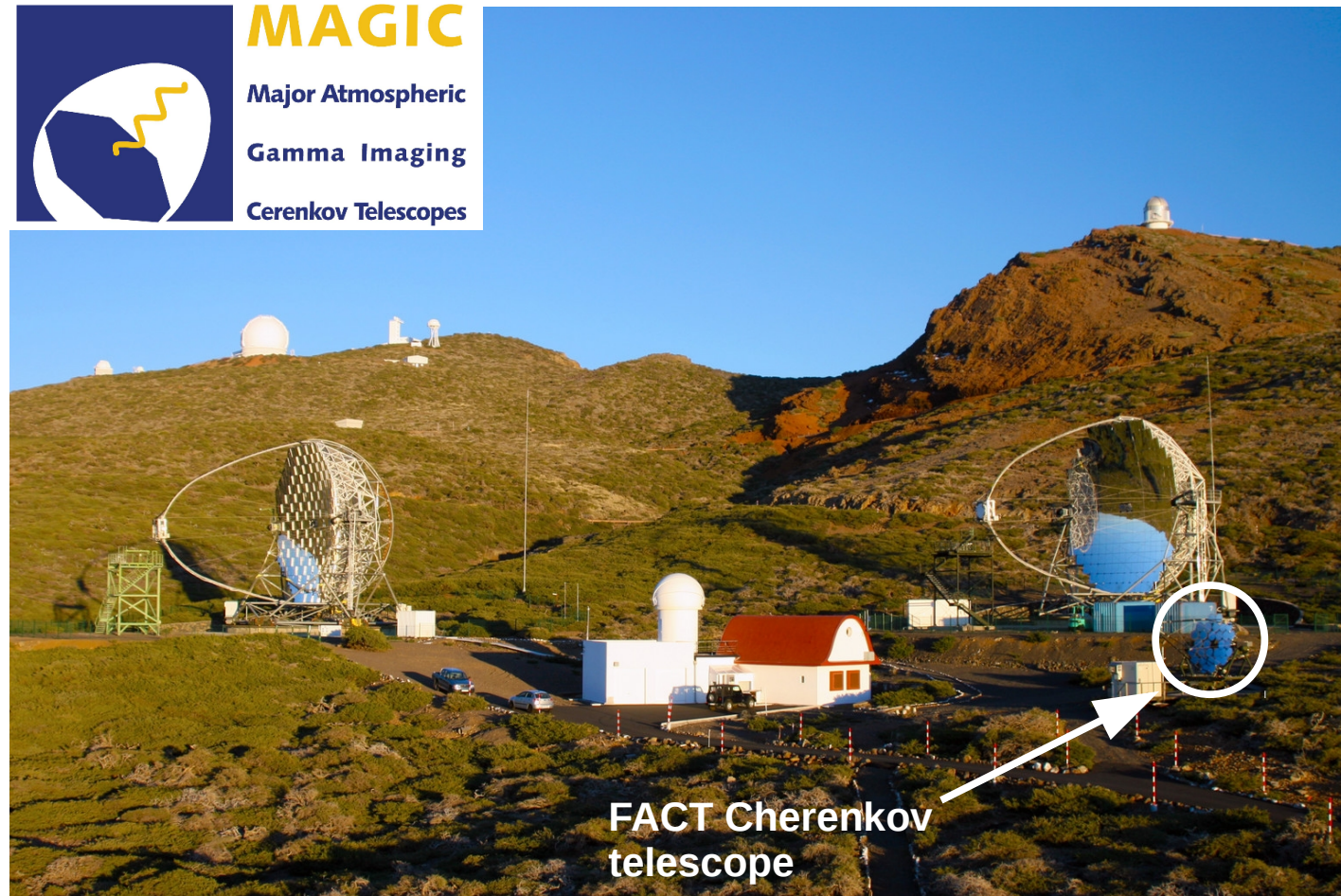


Photo credit: Robert Wagner

MAGIC hard-TeV EHLB catalog

- Only few hard-TeV EHLBs detected so far (e.g., the famous hard-TeV EHLB 1ES 0229+200)

- Goal:** extend their population

- Target selection using 5 criteria:

i) Power-law index $\Gamma_{\text{X-ray}} \leq 2$ in *Swift*-XRT

ii) Properties in the *Fermi*-LAT catalogs

iii) High $\text{Flux}_{\text{X-ray}}/\text{Flux}_{\text{radio}}$ value
(Bonnoli et al. 2015)

iv) Multiwavelength luminosity
(Fallah Ramazani et al. 2017)

v) Redshift less than ~ 0.2

- 10 targets selected,**
from which 9 are undetected at VHE

Source	RA (J2000) [°]	DEC (J2000) [°]	z	$\log(\nu_{\text{peak}})$ [Hz]	Selection Criteria
TXS 0210+515	33.57	51.75	0.049 ¹	17.3	i, ii, iv, v
TXS 0637-128	100.03	-12.89	0.136 ²	17.4	ii, v
BZB J0809+3455	122.41	34.93	0.082 ³	16.6	i, ii, iv, v
RBS 0723	131.80	11.56	0.198 ³	17.8	i, ii, iii, v
1ES 0927+500	142.66	49.84	0.187 ³	17.5	iii, v
RBS 0921	164.03	2.87	0.236 ³	17.9	iii
1ES 1426+428	217.14	42.70	0.129 ³	18.1	i, ii, v
1ES 2037+521	309.85	52.33	0.053 ¹	N.A.	i, ii, iv, v
RGB J2042+244	310.53	24.45	0.104 ⁴	17.5	ii, v
RGB J2313+147	348.49	14.74	0.163 ⁵	17.7	ii, v
1ES 0229+200	38.20	20.29	0.140 ¹	18.5	-

1ES 0229+200 used
as a reference source

MAGIC hard-TeV EHL catalog

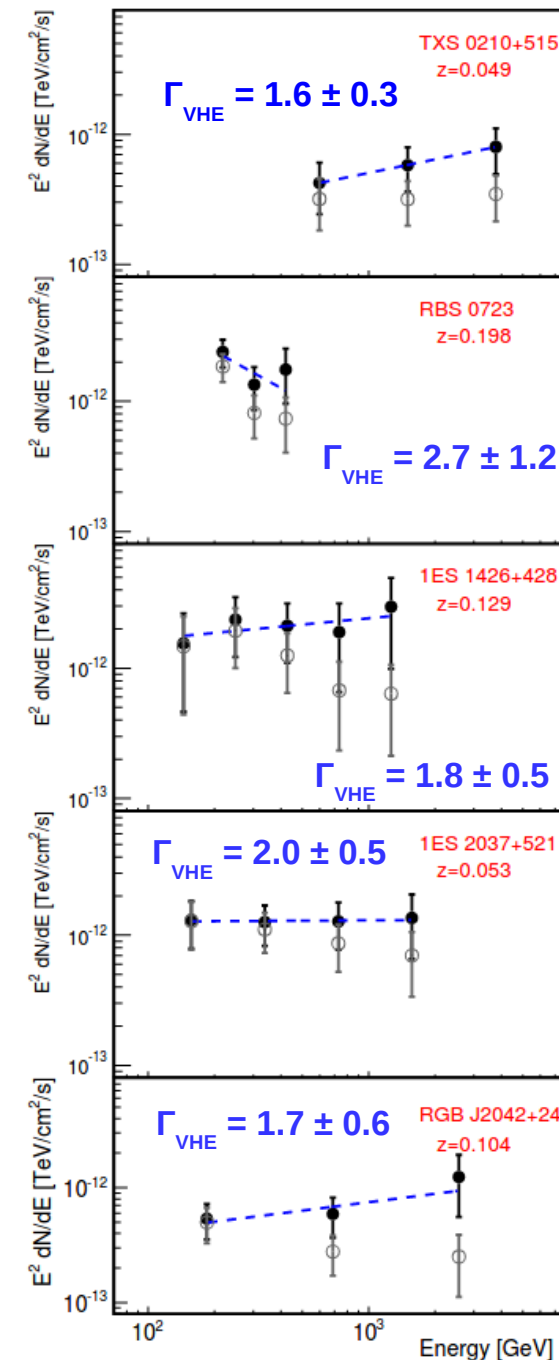
- 3 new VHE detections:
TXS0210+515, RBS0723 & 1ES2037+521
- 1 strong signal hint:
RGBJ2042+244
- 1ES1426+428 detected in 2012

Source	Epochs	Detection significance [σ]	E_{thr} [TeV]	Flux [$10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$]	$\Gamma_{VHE, intr}$
TXS 0210+515	2015, 2016, 2017	5.9	0.2	1.6 ± 0.5	1.6 ± 0.3
TXS 0637-128	2017	1.7	0.3	< 8.9	–
BZB J0809+3455	2015	0.4	0.15	< 3.7	–
RBS 0723	2013, 2014	5.4	0.2	2.6 ± 0.5	2.7 ± 1.2
1ES 0927+500	2012, 2013	1.2	0.15	< 5.1	–
RBS 0921	2016	-0.4	0.15	< 8.6	–
1ES 1426+428 {	2010	2.1	0.2	< 9.3	–
	2012	6.0	0.2	6.1 ± 1.1	1.8 ± 0.5
	2013	1.8	0.2	< 5.1	–
1ES 2037+521	2016	7.5	0.3	1.8 ± 0.4	2.0 ± 0.5
RGB J2042+244	2015	3.7	0.2	1.9 ± 0.5	1.7 ± 0.6
RGB J2313+147	2015	-0.9	0.2	< 1.5	–
1ES 0229+200	2013-2017	9.0	0.2	2.1 ± 0.3	1.8 ± 0.1

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MAGIC hard-TeV EHL catalog

- 3 new VHE detections:
TXS0210+515, RBS0723 & 1ES2037+521
- 1 strong signal hint:
RGBJ2042+244
- 1ES1426+428 detected in 2012
- All spectra well fitted with power-law model
(de-absorbed using EBL model from Franceschini et al. 2008)
- Besides RBS0723, all sources are hard and compatible with gamma-ray SED peaking ≥ 1 TeV
- TXS0210+515 is the hardest source: $\Gamma_{\text{VHE}} = 1.6 \pm 0.3$



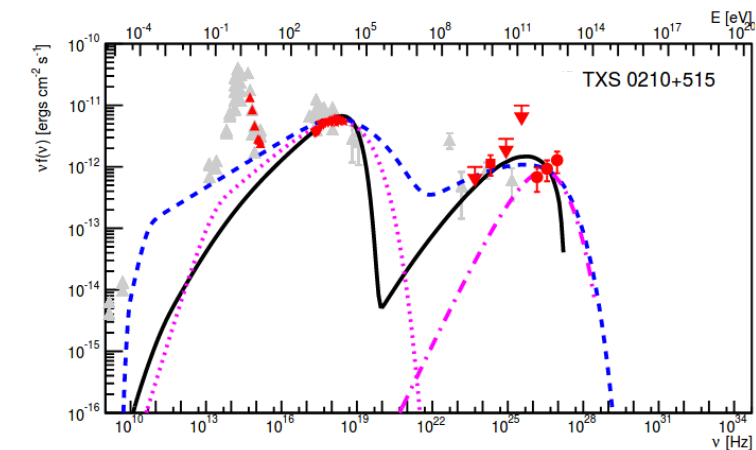
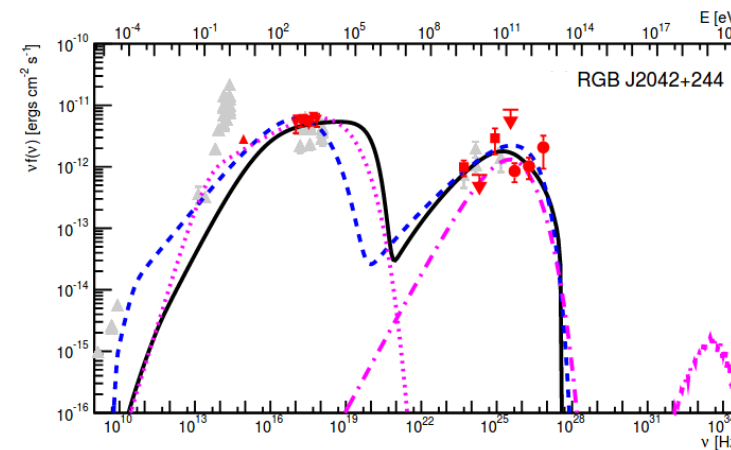
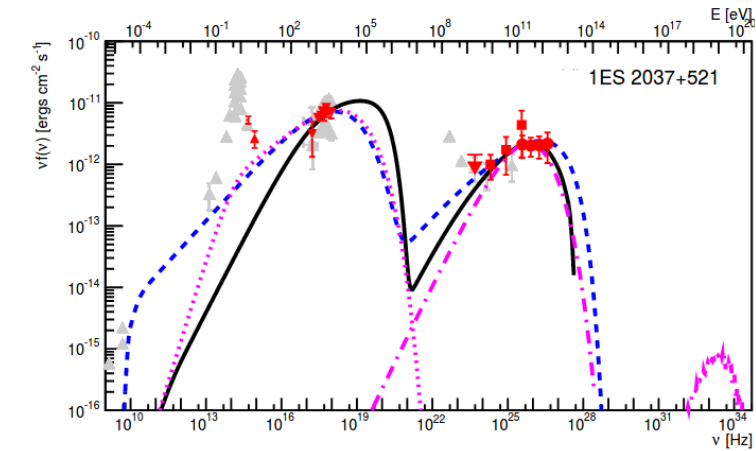
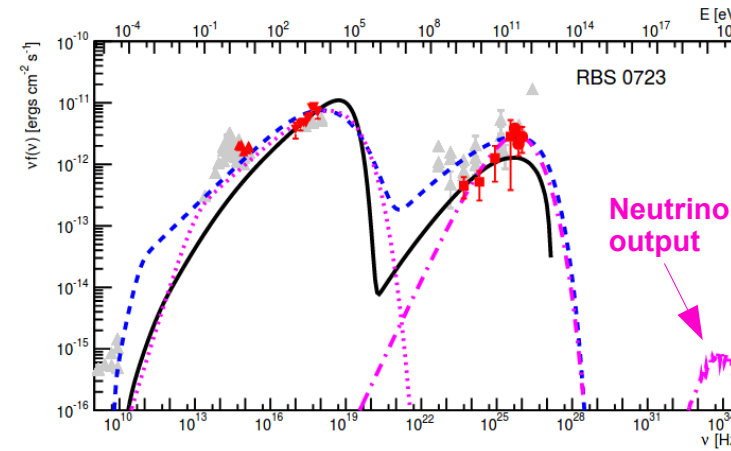
MAGIC hard-TeV EHL catalog

- Emission interpreted in leptonic & hadronic models

- Blue: One-zone leptonic model (Asano et al. 2014)**
- Black: Spine-layer leptonic model (Tavecchio & Ghisellini 2008)**
- Pink: Proton-synchrotron model (Cerruti et al. 2015)**

- All sources well described by the three models...

...but very different magnetisation parameters



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(Asano et al. 2014)

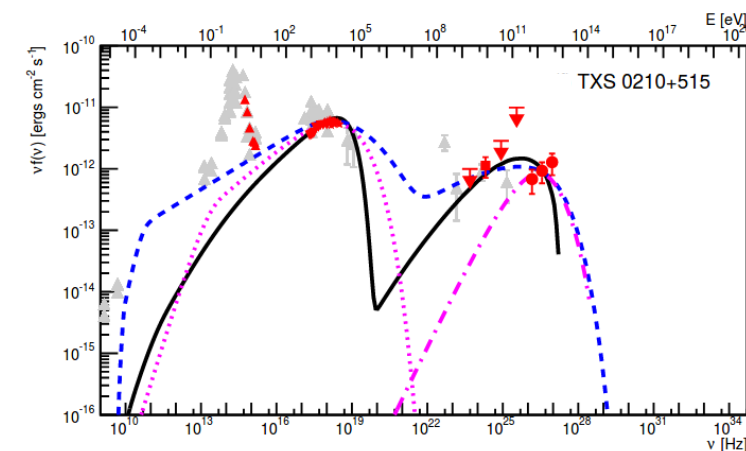
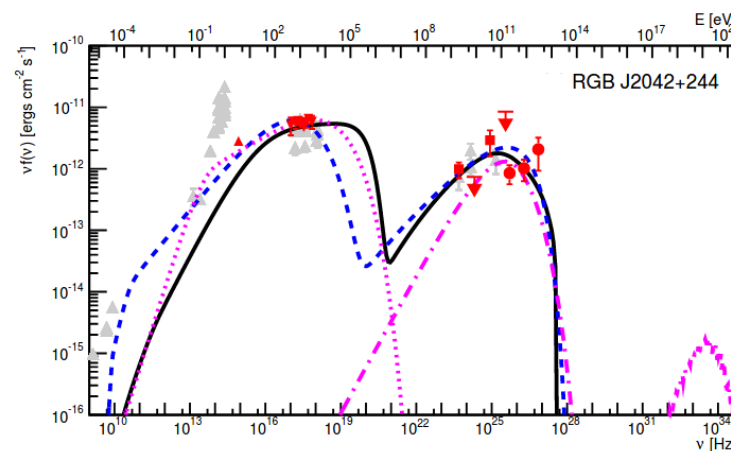
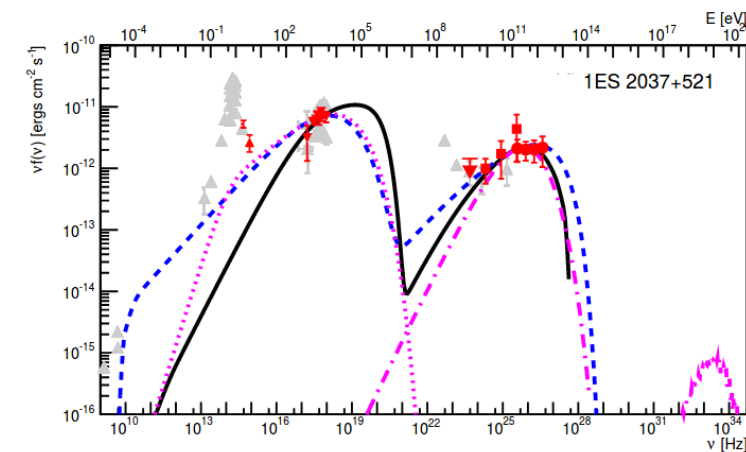
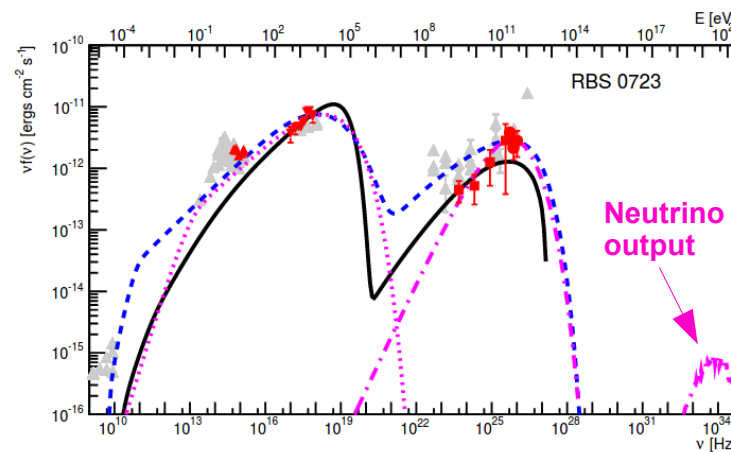
$$\rightarrow U_B/U_e \ll 1$$

- Black: Spine-layer leptonic model**
(Tavecchio & Ghisellini 2008)

$$\rightarrow U_B/U_e \sim 1$$

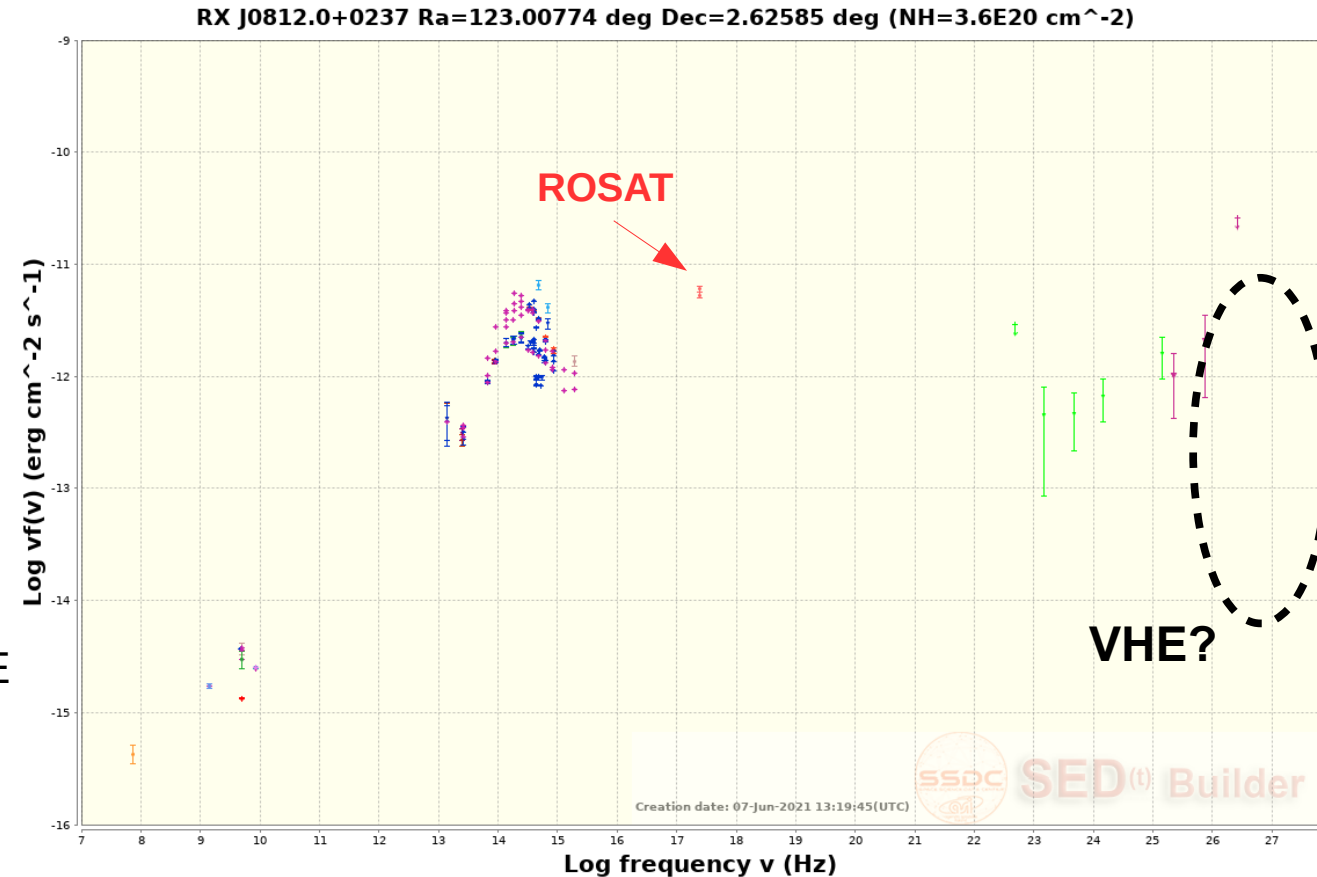
- Pink: Proton-synchrotron model**
(Cerruti et al. 2015)

$$\rightarrow U_B/U_e \gg 1$$



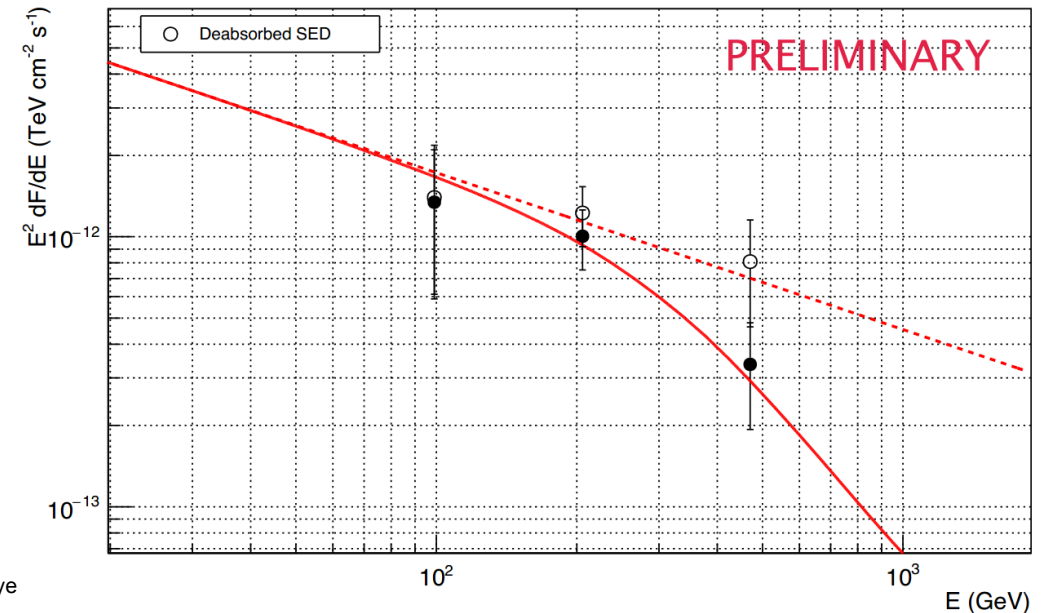
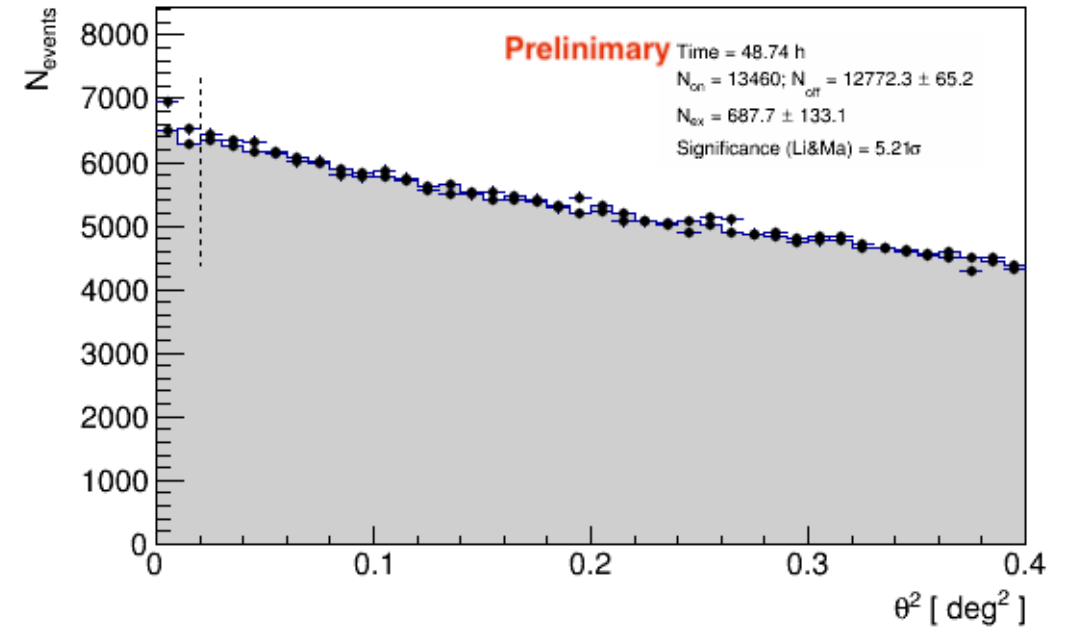
RX J0812.0+0237

- RX J0812.0+0237: blazar at redshift $z=0.172$ (Becerra González et al. 2021)
 - SED characteristics similar to EHL 1ES 0229+200 in radio, X-ray & *Fermi*-LAT bands
 - ROSAT measurement: $\nu_{\text{synch., peak}} \geq 1 \text{ keV}$
- RX J0812.0+0237: promising EHL emitting at VHE



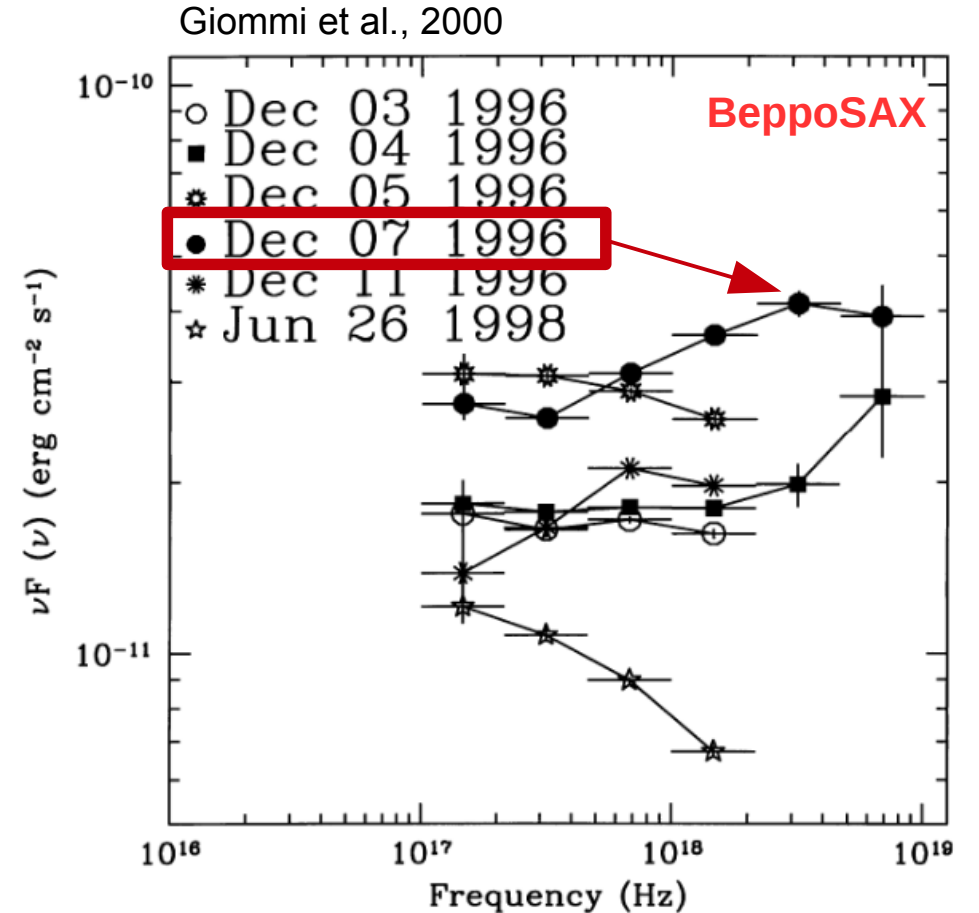
MAGIC VHE detection of RX J0812.0+0237

- MAGIC gathered ~50hrs of good-quality data
- Significant detection: 5.2σ
- EBL deabsorbed spectrum well described by power law with index $\Gamma_{\text{VHE}} = 2.58 \pm 0.33$
- MAGIC data accompanied by UV/X-ray/Fermi-LAT monitoring
- Paper in preparation, stay tuned!



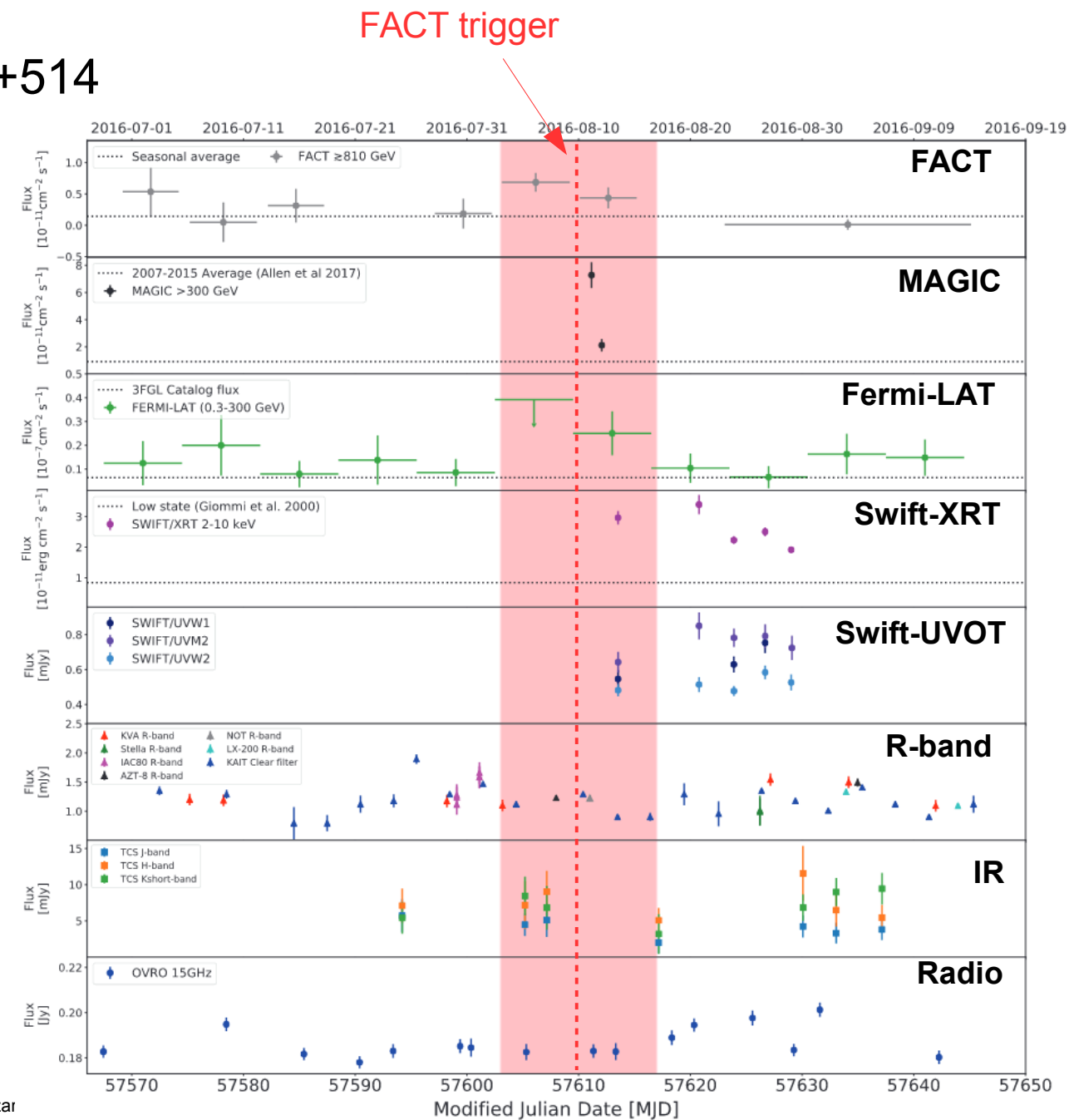
Intermittent EHBL behaviour of 1ES 2344+514

- Some blazars are EHBL only temporarily
- 1ES 2344+514 exhibits strong X-ray variability;
→ EHBL during flares
- Few MWL study of 1ES 2344+514,
mostly in low state w/o EHBL behaviour
(Aleksic et al. 2013, Albert et al. 2007)



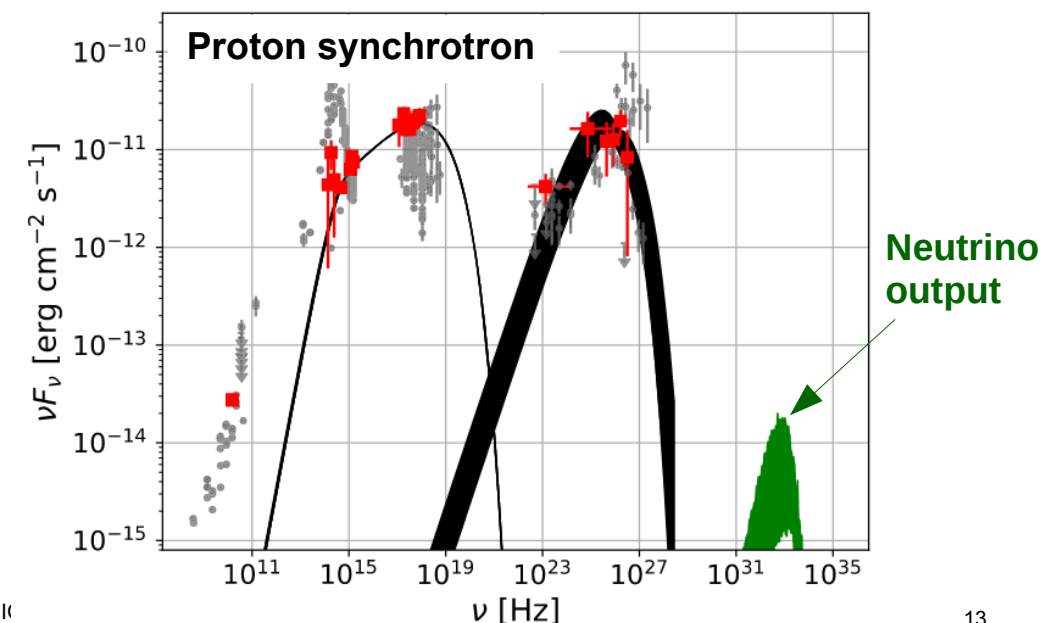
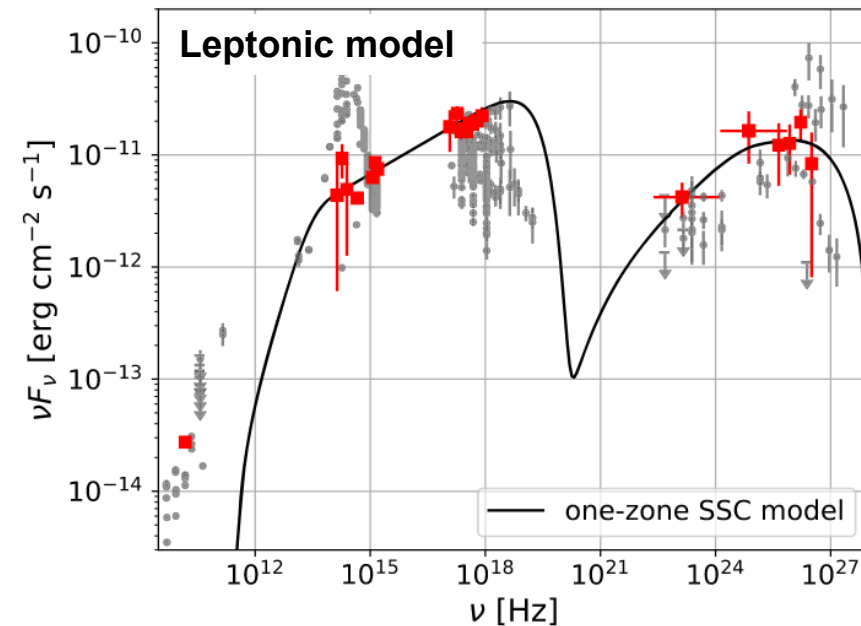
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- Few MWL study of 1ES 2344+514,
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(Aleksic et al. 2013, Albert et al. 2007)
- Extensive MWL campaign in Summer 2016,
triggered by FACT telescope monitoring program
 - VHE flux at historical maximum (60% Crab)
 - Best energy coverage of 1ES 2344+514 in
flaring activity



Intermittent EHLB behaviour of 1ES 2344+514

- Investigate leptonic (SSC) & proton-synchrotron models
- Both scenarios achieve good description of data
- Leptonic model: electron energy up to $\sim 1\text{TeV}$ without strong cut-off & B field $\sim 0.02\text{ G}$
- Hadronic model: proton energy up to $10^{18}\text{-}10^{19}\text{ eV}$
- In both scenarios, system out of equipartition by several orders of magnitude
 - Leptonic: $U_B/U_e \sim 10^{-3}$
 - Hadronic: $U_B/U_p \sim 10^2 - 10^4$



Conclusions and Outlooks

- MAGIC has a strong & successful EHLB observing program
 - Several new EHLBs and hard-TeV blazars detected at VHE
 - Monitoring and ToO observations of known EHLBs (e.g., 1ES2344+514, 1ES1959+650, Mrk501, etc...)
- Explore emission mechanisms from these extreme accelerators using extensive MWL data samples
- No clear preference between hadronic & leptonic models (yet!)
- On-going deep exposures of hard-TeV blazars
- On-going data taking for a 2nd MAGIC EHLB catalog
 - Stay tuned!

