CTAO | LST COLLABORATION

(Some) LST-1 and MAGIC Science Results

Alessandro Carosi[*] for the CTAO-LST Project

(*) INAF - Osservatorio Astronomico di Roma

The LST-1 Prototype

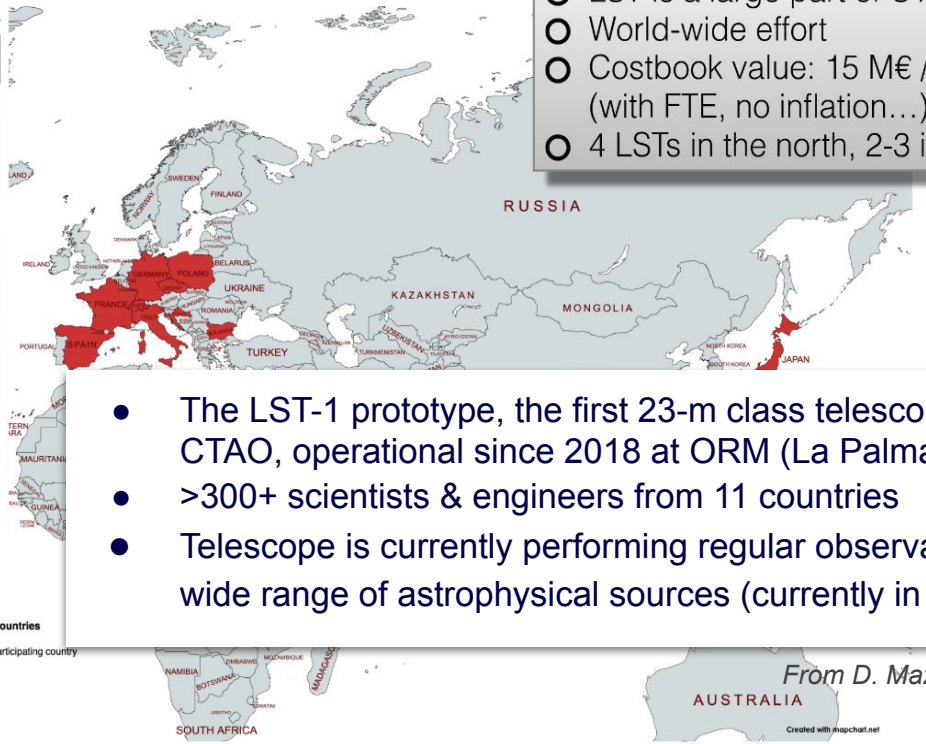
CTAO | LST COLLABORATION

TOTAL MEMBERS	TOTAL AUTHORS
492	333

Countries | Groups

COUNTRY	MEMBERS	AUTHORS	% MEMBERS	% AUTHORS	AVG MEMBERS LAST 12 MONTHS	AVG AUTHORS LAST 12 MONTHS
Brazil	14	2	2.85%	0.60%	7.58	2.00
Bulgaria	2	2	0.41%	0.60%	2.00	2.00
Croatia	8	7	1.63%	2.10%	7.25	7.25
Czechia	20	12	4.07%	3.60%	19.42	12.00

https://www.lst1.iac.es/collaboration.html



- 11 countries, 29 groups
- LST is a large part of CTAO
- World-wide effort
- Costbook value: 15 M€ / telescopes (with FTE, no inflation…)
- 4 LSTs in the north, 2-3 in the south?

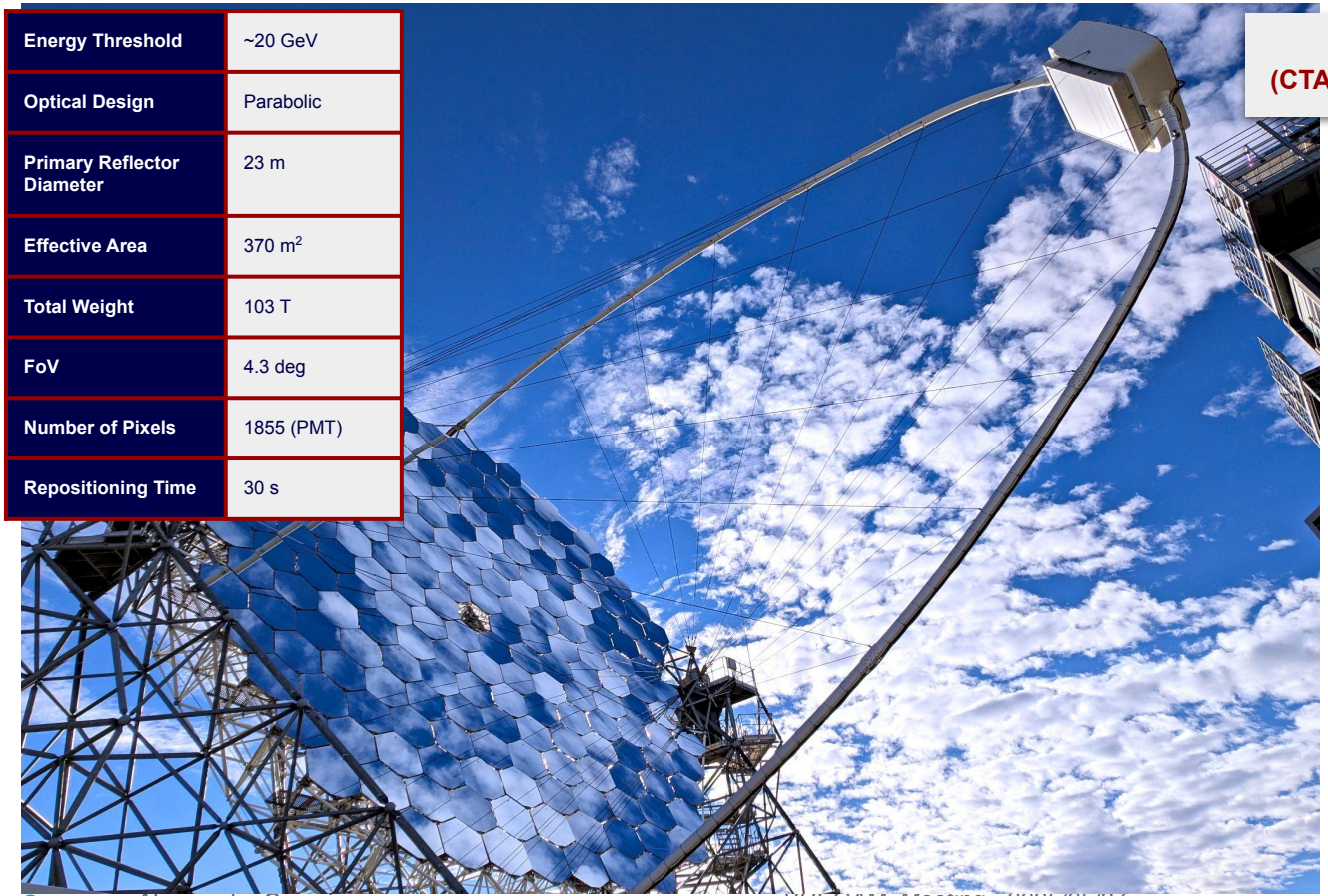
- The LST-1 prototype, the first 23-m class telescope for the CTAO, operational since 2018 at ORM (La Palma)
- >300+ scientists & engineers from 11 countries
- Telescope is currently performing regular observations on a wide range of astrophysical sources (currently in its cycle III)

From D. Mazin ppt@LST GM

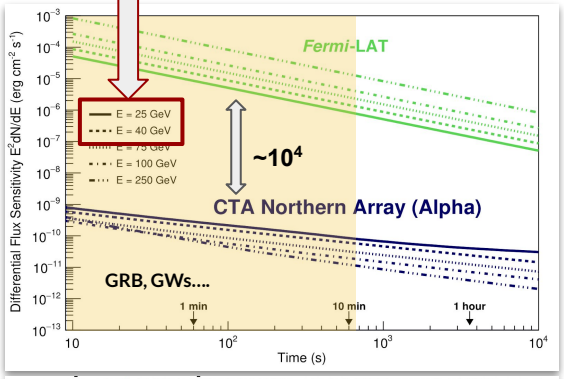
The LST-1 Prototype

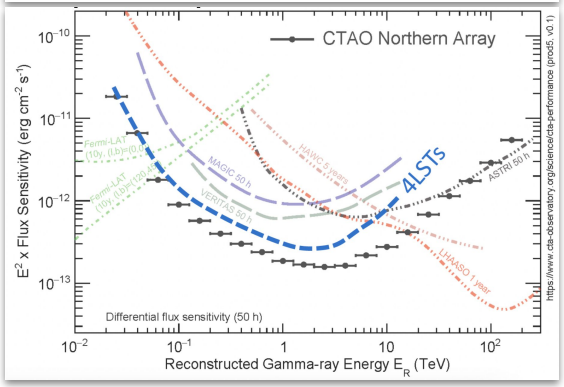
CTAO | LST COLLABORATION

Energy Threshold	~20 GeV
Optical Design	Parabolic
Primary Reflector Diameter	23 m
Effective Area	370 m^2
Total Weight	103 T
FoV	4.3 deg
Number of Pixels	1855 (PMT)
Repositioning Time	30 s

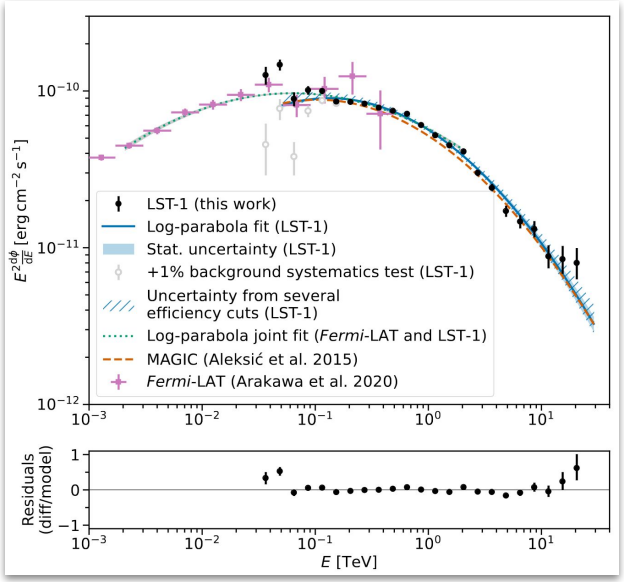


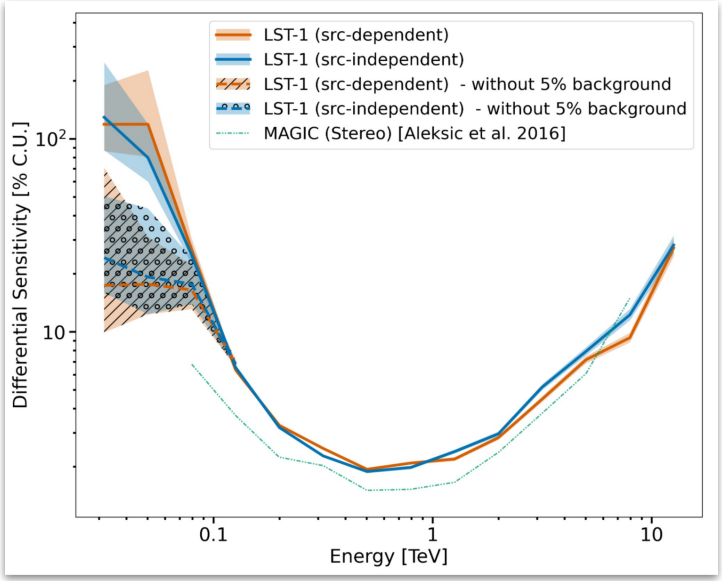
LST "sweet range"
(CTA sensitivity dominated by LSTs)





LST-1: performance





Performance evaluated with observations on Crab Nebula

Abe, H., et al.: ApJ, 956:80 (2023)

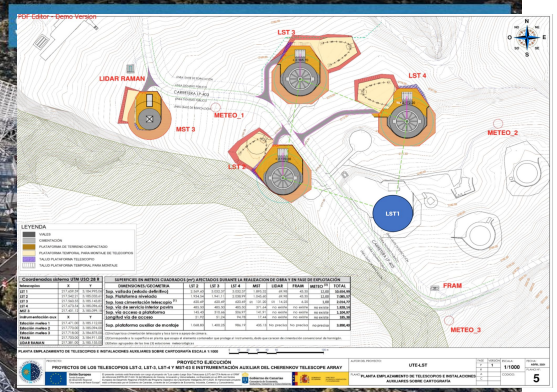
- Sensitivity evaluated with real Crab data: energy range widened to lower energy compared to MAGIC (SED measured down to 30 GeV)
- MAGIC (stereo system) ~1.5 x better sensitivity then LST-1 (mono) - As expected by the difference between mono and stereo systems
- Systematics from background begin to dominate below 50 GeV → will be reduced with stereo trigger

The ORM landscape

CTAO | LST COLLABORATION

LST-2-4 in La Palma

- LST-4: start commissioning / AIV Q4 2025?
- LST-3: start commissioning / AIV Q2 2026?
- LST-2: start commissioning / AIV Q4 2026?



LST1

LST2

LST4

LST3

- MAGIC telescopes also at ORM site
- + works progressing for LST-2, -3 & -4

(see A. Berti talk)

April 3, 2025

MAGIC

CTAO | LST COLLABORATION

MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

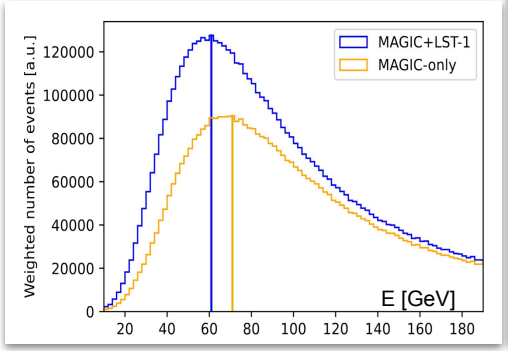
- MAGIC I from 2004, MAGIC II from 2009
- Mirror dish diameter: 17 m
- Active reflective mirror surface: 236 m2
- Upgrade of MAGIC I camera and readout system in 2012
- 1039 PMTs cameras (FoV 3.5°)
- Energy range: 30 GeV to 100 TeV
- Fast repositioning (180° in less than 30s)
- Energy threshold can be lowered to 15 GeV
- Sensitivity above 220 GeV is ~0.66% of the Crab nebula flux (for 50 hs)

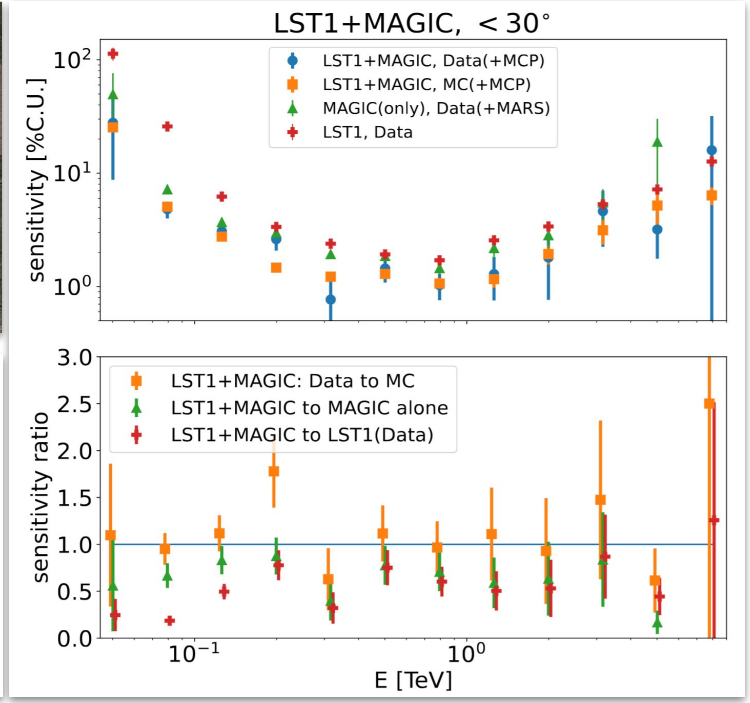
Image Credit: Urs Leutenegger

LST-1+MAGIC

CTAO | LST COLLABORATION

Seeing the excellent physics performance of the LST-1, and the fact that CTAO was delayed it was natural to setup some physics exploration jointly with MAGIC



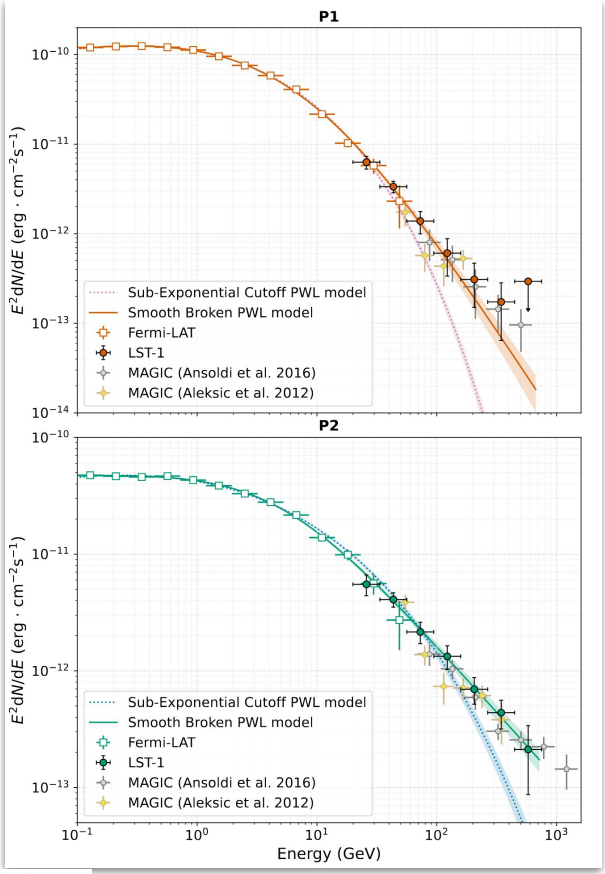


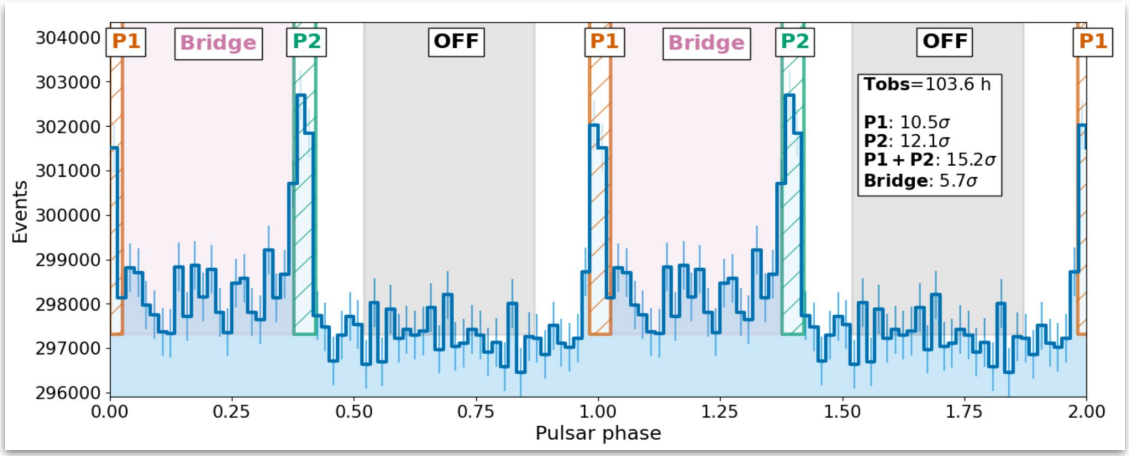
- Separation between MAGICs and LST-1 is ~100m. A dedicated pipeline is in place to analyze stereo MAGIC & LST data
- joint observations allow detection of 30% (40%) lower fluxes than MAGIC alone (LST-1 alone) (better background suppression)
- "Performance paper"
  A&A, 680, A66 (2023)

CTAO | LST COLLABORATION

Early Science Results

LST-1: early science





A detailed study of the very-high-energy Crab pulsar emission with the LST-1
A&A, 690, A167 (2024)

Detection of Crab Pulsar:

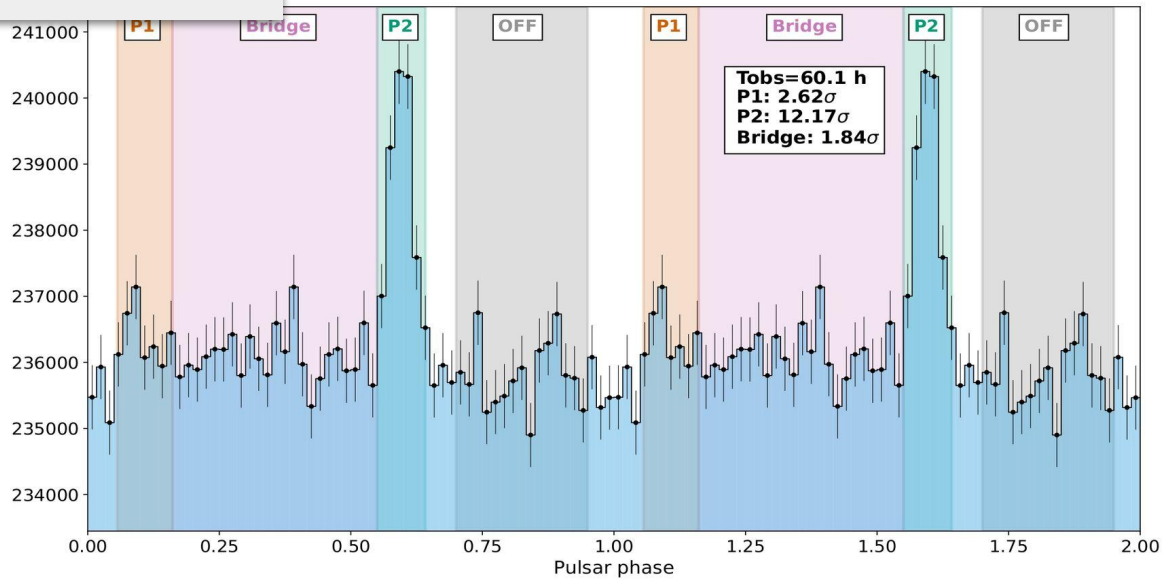
- Source physics + telescope performances (threshold, cross-calibration, energy resolution…)
- Clear detection of P1 and P2 → **Ethr down to ~20 GeV**
- Smooth transition between *Fermi*-LAT and LST-1

Geminga (PSR J0633+1746)

- Performance at lower energies confirmed by the detection of Geminga (PSR J0633+1746)

- Being a soft spectrum source, the detection of Geminga confirms the good performance in the 15-30 GeV band, one of the main scientific drivers of LST
- MAGIC: 6.3σ after 80 hours for P2
  (MAGIC coll., A&A 643 (2020) L14)

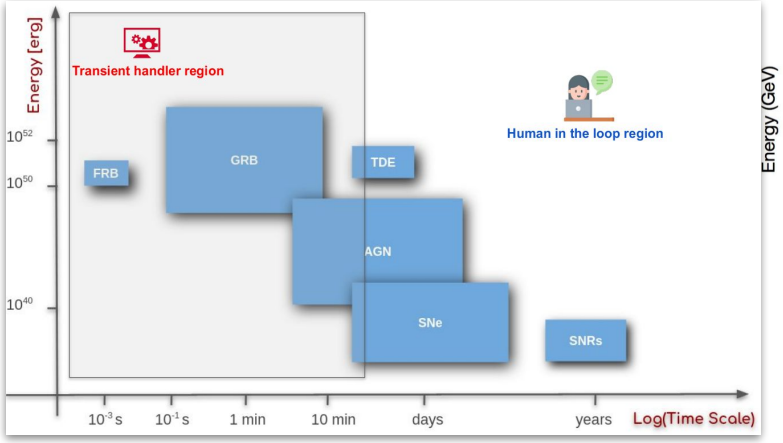
Detected at ~12σ in ~60h

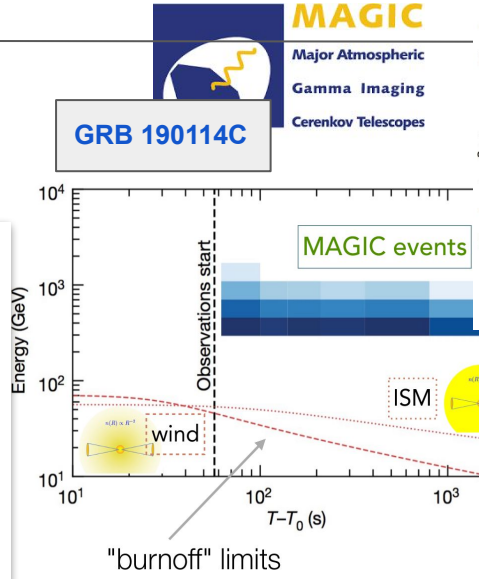


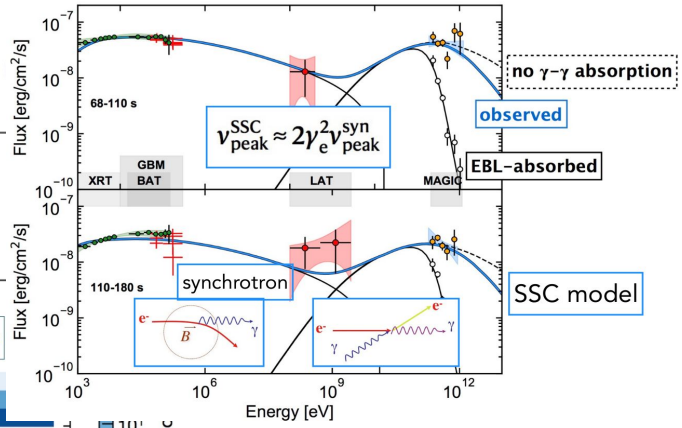
paper accepted for publication on A&A

Transients: GRBs

- Low energy threshold is crucial also for **transient observations.**







- Synchrotron burnoff limit largely exceeded
- First clear evidence of a second emission component (SSC - blazar-like)

Teraelectronvolt emission from the gamma-ray burst GRB 190114C (2019), MAGIC Collaboration Nature, 575, 45

- 1st GRB unambiguous detection at TeV energies
- 1st GRB observed over 20 orders of magnitude in energy
- 1st GRB with unambiguous detection of a new energetic emission component distinct from synchrotron
- 1st single broad-band modeling of a GRB including both components
- Brightest TeV source ever detected (>~ 100 crab)

Requirements:

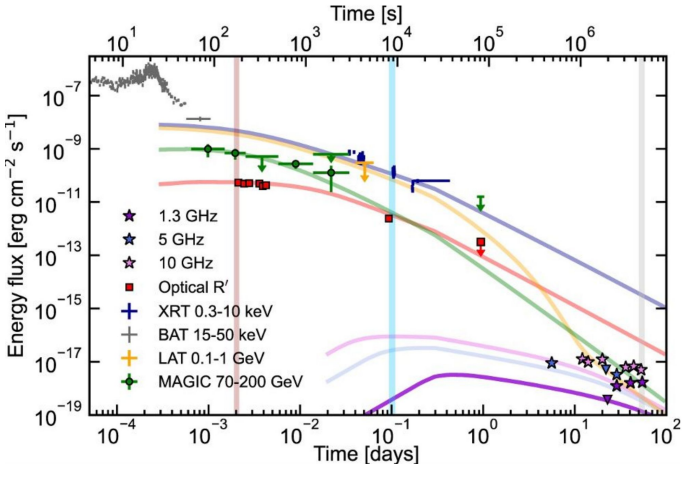
- low energy threshold
- fast repointing
- synergies with other facilities

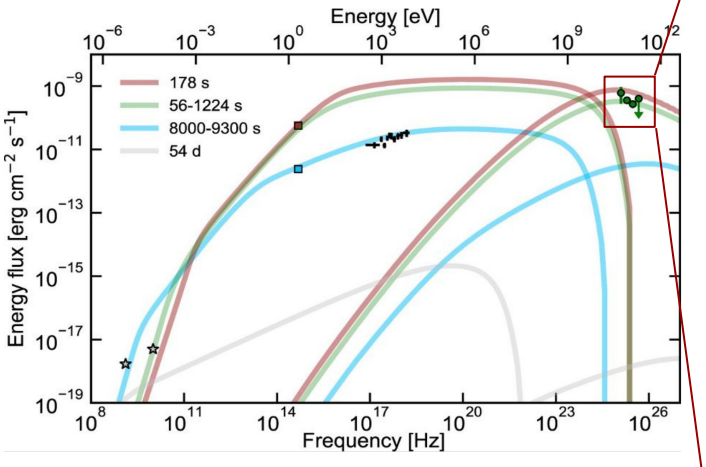
Transients Follow-up

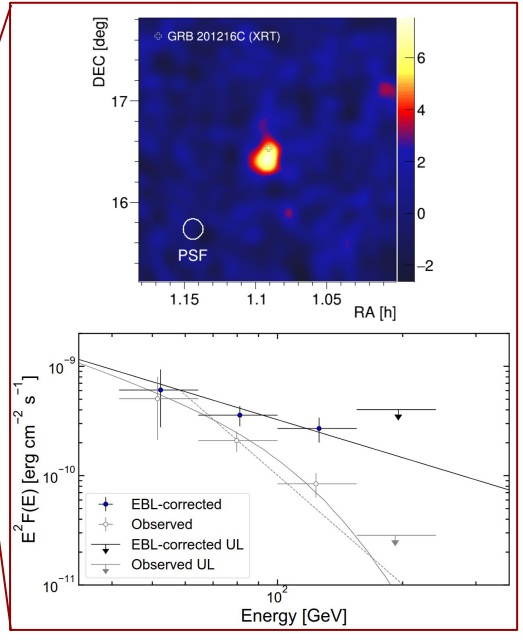
CTAO | LST COLLABORATION

GRB 201216C

Most distant VHE source to date (z=1.1)







MNRAS, Volume 527, Issue 3, January 2024,

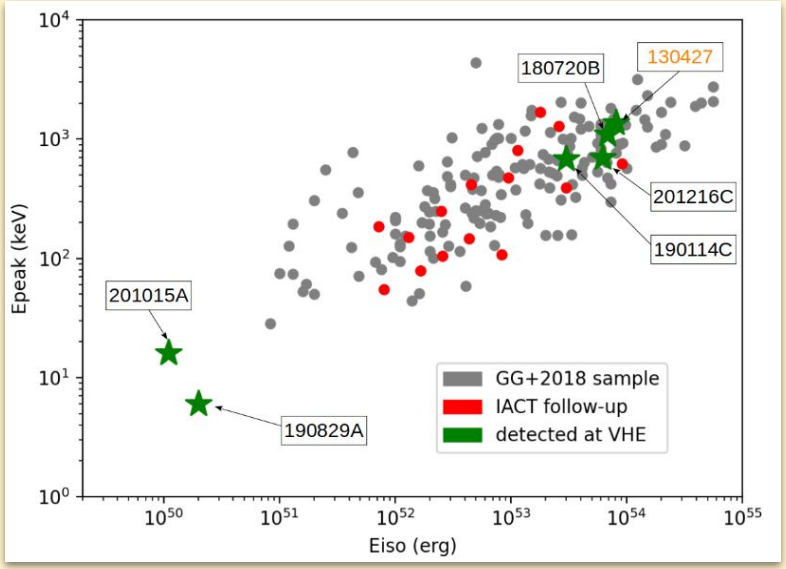
- Gamma-ray spectrum down to 40 GeV; source not visible above 150 GeV.
- One-zone SSC can explain broadband SED temporal evolution (like for GRB190114C)

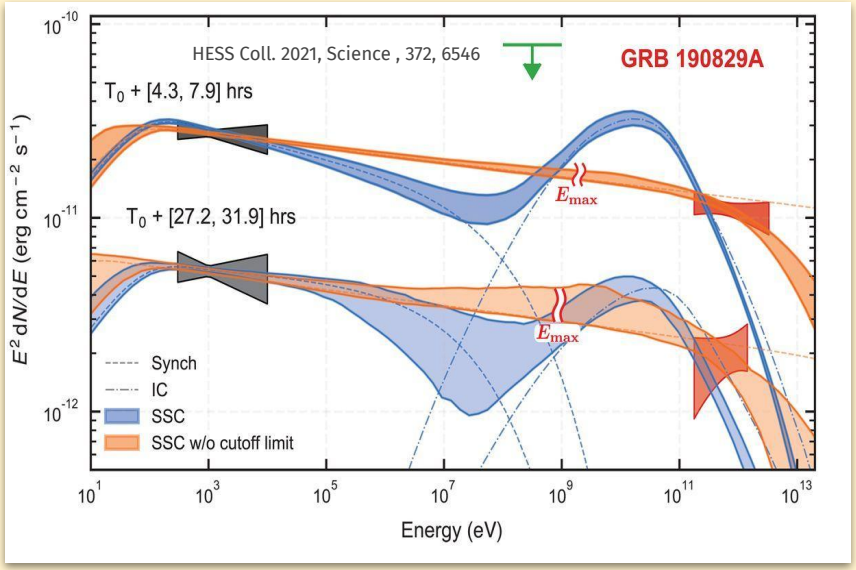
MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

Transients Follow-up

Most GRBs can be explained within the Synchrotron self-Compton scenario. Common scenario?
→ To be tested with more GRB detections

With LSTs, redshift ~2 events are not a dream anymore!





Energy flux [erg cm^{-2} s^{-1}]

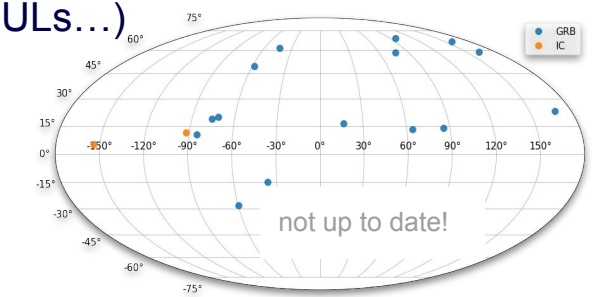
Transients Follow-up

- **LST is built for transients!** First follow-up started at the end 2020/beginning of 2021
- Many other follow-up performed on wide range of transients - some of them in joint mode
  - Dedicated TH and automatic procedure follow up procedure have been implemented
  - Fast mouvements recently commissioned
  - Large uncertainty alerts (i.e., GW) handled by tilepy (M. Seglar-Arroyo et al., ApJS 274, 1 (2024))
  - Initial science already possible (hopefully not for long, with ULs…)

31	GRB231110A	Swift BAT	23h 45m 11.040s	+82º 37' 15.960"	21:19:35 UT								automatic repointing
32	GRB231111A	Swift BAT	19h 20m 56.112s	+52º 26' 48.840"	14:17:19 UT								
33	GRB231115A	INTEGRAL	9h 56m 0.216s	+69º 40' 48.000"	15:36:23 UT	0.03	0.000677						Position of M82
34	GRB231215A	Swift BAT	0 h 39 m 0.000 s	+57 deg 38 m 31.920	09:47:25 UT	-	2.305	2023/12/15 19:53 UTC	29.3 --> 51.2	251.4 (4.2h)	600 (10h)	Fast analysis done	moon + dark conditions
35	GRB231216A	Swift BAT	2 h 39 m 2.088 s	+33 deg 35 m 45.240 s	18:41:08 UT	-	-	2023/12/16 19:43 UTC	32.2 --> 19.6	214.9 (3.6h)	60	Fast analysis done	moon + dark conditions
36	GRB240502A	INTEGRAL	7h 34m 30.96s	16d 43m 27.48s	05:28:47 UT	25s	-	2024/05/02 21:16 UTC	48 --> 70	120 (2h)	1020 (17h)	Fast analysis done	dark conditions
37	GRB240529A	Swift BAT	22h 21m 17.160s	51d 33m 18.720s	02:58:49 UT	-	2.695	03:29:21 UTC	46 --> 33	94	30	Fast analysis done	High NSB (>10)
38	GRB240615A	Fermi GBM	22h 21m 33.60s	42d 33m 00.0s	00:02:31 UT	-	-	01:34:09 UTC	53 --> 46	40	92	Fast analysis done	moon

											and TH
4	S240615dg (BBH)	LHV	1/100 years	bayestar.multiorder.fits,2 more info	98.94%	16/06/2024 02:13:52 UTC (received 11:42:59)	02:29:20 UTC	120	947 (15h)	Fast analysis done	joint observation with MAGIC

extracted from LST-1 wiki pages



Transients Follow-up

CTAO | LST COLLABORATION

- First follo
- Many oth
  - Dedi
  - Fast
  - Initia

...n joint mode

...mented

GCN Circular 38443

Subject LIGO/Virgo/KAGRA S241125n: gamma-ray upper limits from joint observations by the LST-1 and MAGIC telescopes
Date 2024-12-05T15:33:48Z (6 months ago)
From David Paneque at Max Planck Institute for Physics <dpaneque@mppmu.mpg.de>
Via Web form

D. Paneque (MPP Munich), M. Teshima (MPP Munich), M. Seglar Arroyo (IFAE Barcelona), D. Miceli (INFN Padova), A. Stamerra (INAF Rome), J. Jimenez (IFAE Barcelona), S. Menon (University & INAF Rome), A. Simongini (University & INAF Rome) on behalf of the LST and MAGIC Collaborations report:

We observed the Swift/BAT-GUANO gamma-ray counterpart candidate (GRB 241125A, DeLaunay, GCNC 38308) presumably related to the GW S241125n (LVK Collaboration, GCNC 38305, 38315). A total of 4h of pointed observations towards the gamma-ray counterpart candidate position were obtained, starting approximately on Nov 25, 20 UT (i.e. about 19h post trigger time).

A preliminary offline analysis of the LST-1 and MAGIC dataset shows no excess of gamma-rays above 300 GeV at the position of the Swift/BAT-GUANO candidate. These results have been obtained using the LST analysis software, lstchain (https://zenodo.org/records/14227973 , v0.10.13), and the MAGIC analysis software MARS (Zanin et al. 2013). Observations were affected by the presence of clouds and by reduced atmospheric transparency. A more in-depth analysis of this data set is ongoing.

LST-1 is the first telescope of the Large-Sized Telescope (LST) for the Cherenkov Telescope Array Observatory. It is located on the Canary island of La Palma, Spain. The telescope design is optimized for observing gamma rays in the range from 20 GeV to 3 TeV.

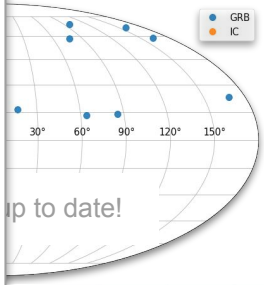
The LST-1 contact persons for these observations are Masahiro Teshima (mteshima@mpp.mpg.de) and Monica Seglar-Arroyo (mseglar@ifae.es). The preliminary offline analysis has been performed by Sweta Menon (sweta.menon@inaf.it) and Juan Jimenez (juan.jimenez@ifae.es).

MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located on the Canary island of La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

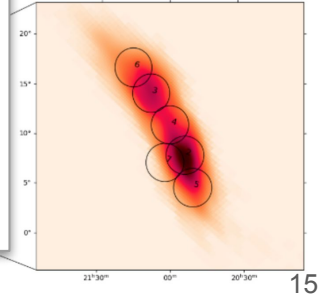
The MAGIC contact persons for these observations are David Paneque (dpaneque@mpp.mpg.de), Antonio Stamerra (antonio.stamerra@inaf.it) and Davide Miceli (davide.miceli@pd.infn.it). The preliminary offline analysis has been performed by Andrea Simongini (andrea.simongini@inaf.it).

31	GRB231110A	Swift BAT	23h 45 11.04(
32	GRB231111A	Swift BAT	19h 20 56.11
33	GRB231115A	INTEGRAL	9h 56m 0
34	GRB231215A	Swift BAT	0 h 39 m 0
35	GRB231216A	Swift BAT	2 h 39 m 2
36	GRB240502A	INTEGRAL	7h 34m 3
37	GRB240529A	Swift BAT	22h 21 17.16
38	GRB240615A	Fermi GBM	22h 21m 3

4	S240615dg (BBH)	LHV	1/100 y



...p to date!

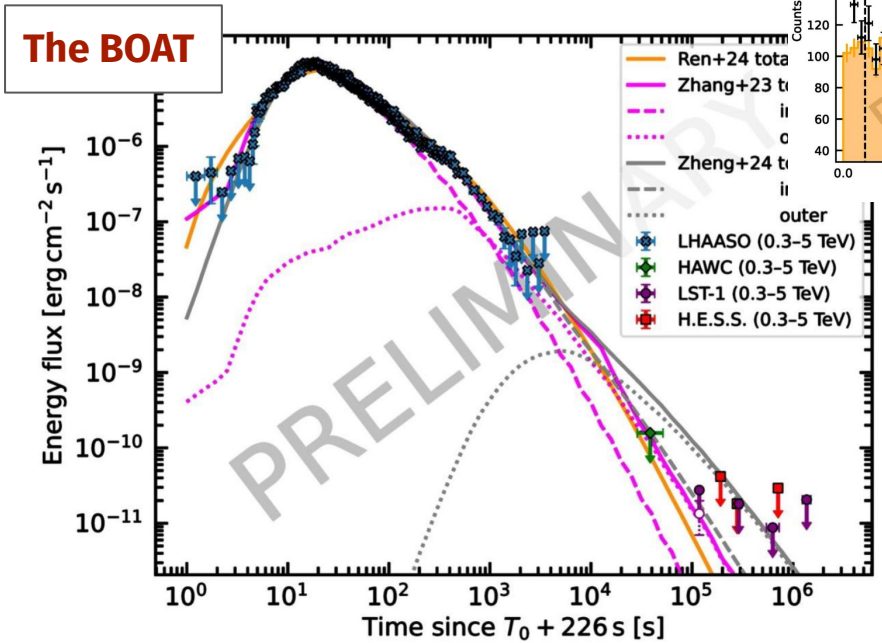


BOAT follow up by LST-1

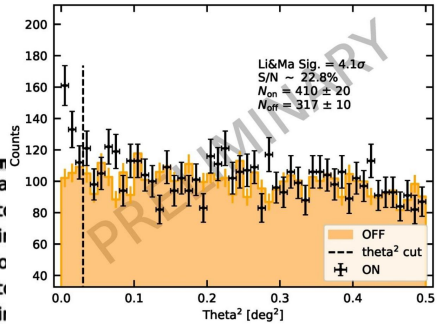
CTAO | LST COLLABORATION

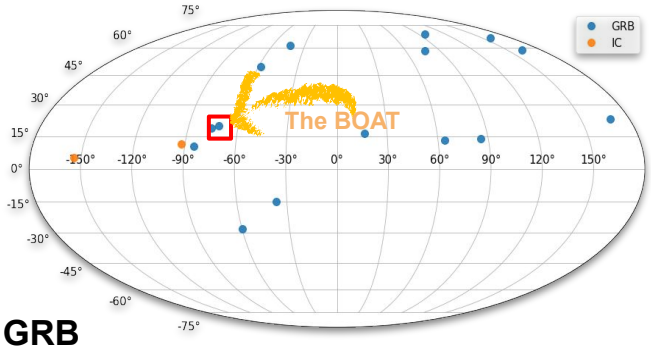
GRB deeply entering in the
TeV regime with the **GRB 221009**

The BOAT



from A. Aguasca-Cabot@gamma24
paper accepted for publication on ApJL





Super-powerful GRB

E_{iso} ~ 2x10^{54} erg
z = 0.151
detected up to **~13 TeV** with LHAASO but not with IACT

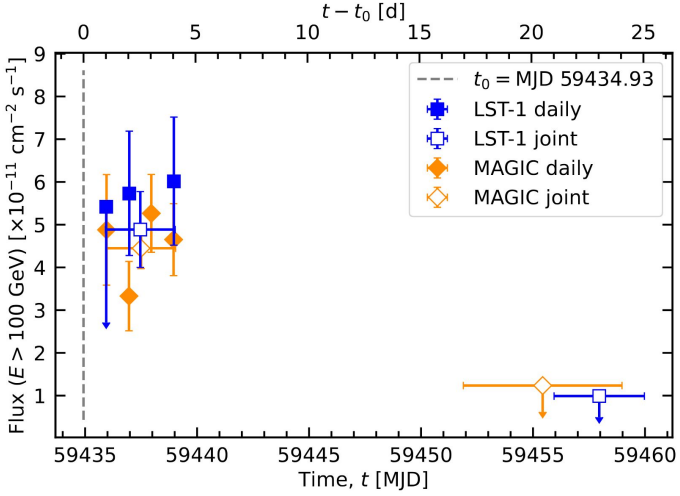
LST observation:

- 2022/10/10 ~21:34 UTC T_0 + 1.1 x 10^5 sec (~31 h, red. HV)
- First two observing nights under strong moonlight
  + Several days under dark/low moonlight afterwards

Large effort for analysis optimization of moon data

RS Ophiuchi Nova

Novae are thermonuclear explosions caused by accumulation of material from donor star on a surface of a white dwarf (WD)



- System **is not** disrupted after the nova event -> cycle restarts
  - Most novae detected only once:
  - Outburst once every (hundreds of) thousand years
- Some novae show repeated outbursts within few years/human lifetime: recurrent novae (RN)
  - 10 known RN in the Galaxy with repetition rate <100 y
  - For a symbiotic nova to be RN, the WD must be massive (≥1.1 M ⊙) (if M > 1.44 M ⊙ → Sn Ia)

Observation day	Γ	ϕ_0 [10^{-10} TeV^{-1} cm^{-2} s^{-1}]
Day 1	−4.2 ± 0.3	3.3 ± 1.3
Day 2	−3.65 ± 0.13	5.9 ± 1.0
Day 4	−3.50 ± 0.15	5.9 ± 1.1
Day 1, 2 and 4	−3.73 ± 0.10	5.2 ± 0.7

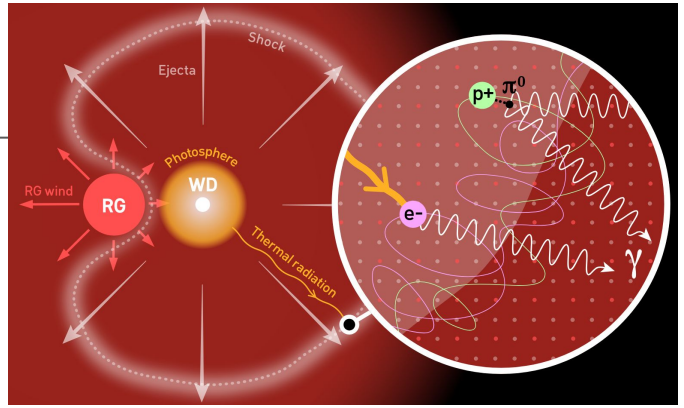
RS Oph is a recurrent symbiotic nova which displays major outbursts every 14.7 years

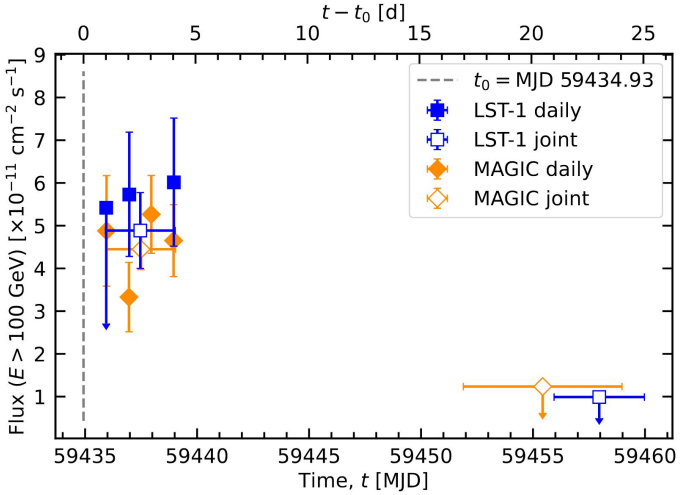
Observed and detected on August 2021 by both MAGIC and LST-1

Novae established as a new type of VHE emitters

RS Ophiuchi Nova

Novae are thermonuclear explosions caused by accumulation of material from donor star on a surface of a white dwarf (WD)

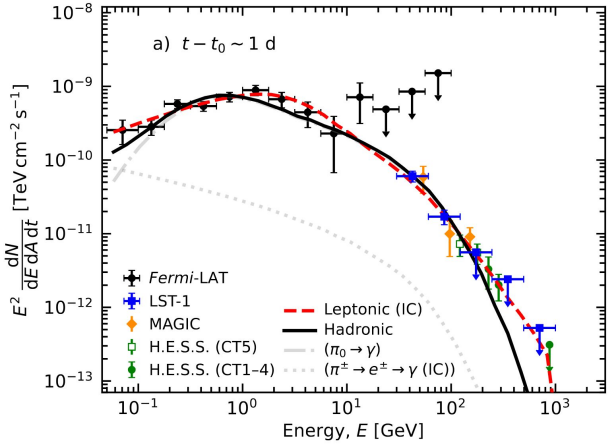


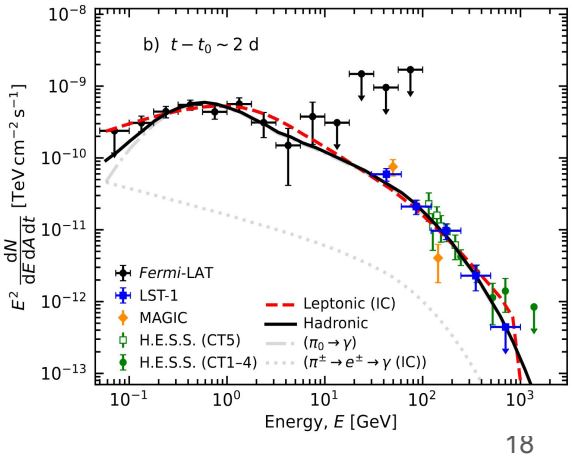


LST Coll. 2025, A&A, 695A.152A
MAGIC Coll. 2022, Nat Astron 6, 689

- Evidence for a spectral hardening as novae evolves and increase in cutoff energy
- Hadronic model preferred

Observation day	Γ	ϕ_0 [10^{-10} TeV^{-1} cm^{-2} s^{-1}]
Day 1	-4.2 ± 0.3	3.3 ± 1.3
Day 2	-3.65 ± 0.13	5.9 ± 1.0
Day 4	-3.50 ± 0.15	5.9 ± 1.1
Day 1, 2 and 4	-3.73 ± 0.10	5.2 ± 0.7



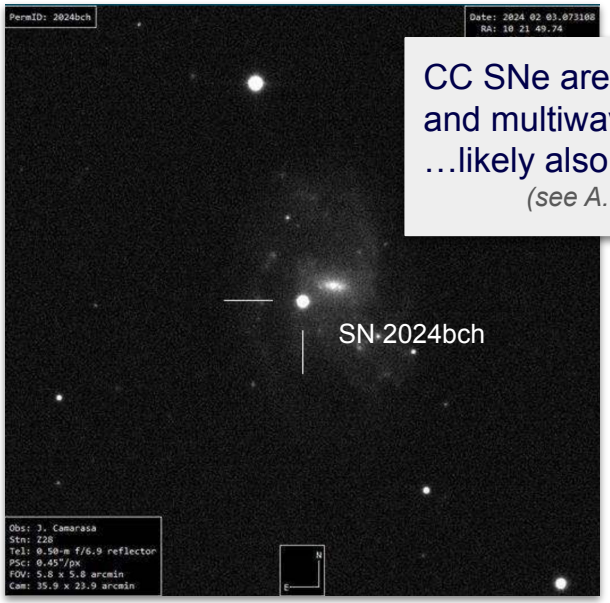


CC SNe

LST+MAGIC joint

- Discovered 2023-05-19 07:45:07 UTC in M101
- z= 0.000804 the closest CCSNe observed by MAGIC (~6.4 Mpc)
- Type II SN Likely RSG progenitor
- MAGIC and LST-1 observations started on May 20th 2023

paper in preparation



CC SNe are Multimessenger and multiwavelength source …likely also at VHE

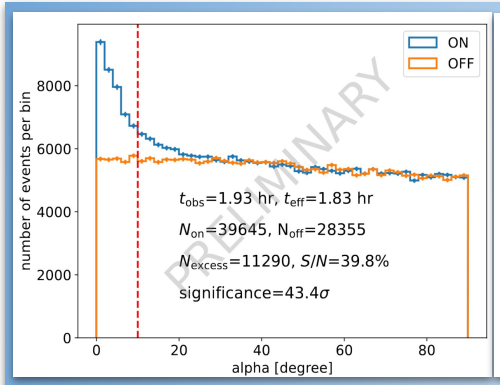
(see A. Simongini ppt)

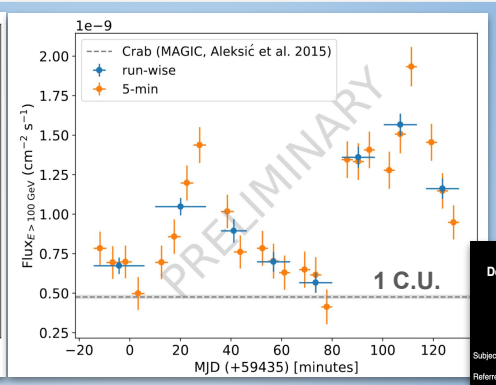
- Discovered on Jan 29, 2024, D = 17-20 Mpc
- CCSN of type IIn-L
- 14 h of LST-1 over 6 nights.

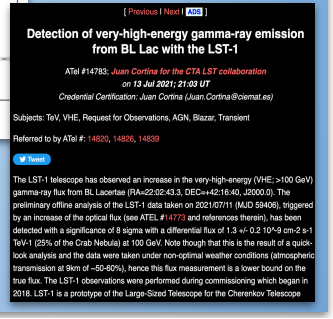
paper submitted to A&A

(old) extragalactic friends

CTAO | LST COLLABORATION






[Previous | Next | ADS]

Detection of very-high-energy gamma-ray emission from BL Lac with the LST-1

ATel #14783; *Juan Cortina for the CTA LST collaboration*
on 13 Jul 2021; 21:03 UT
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: TeV, VHE, Request for Observations, AGN, Blazar, Transient

Referred to by ATel #: 14820, 14826, 14839

Tweet

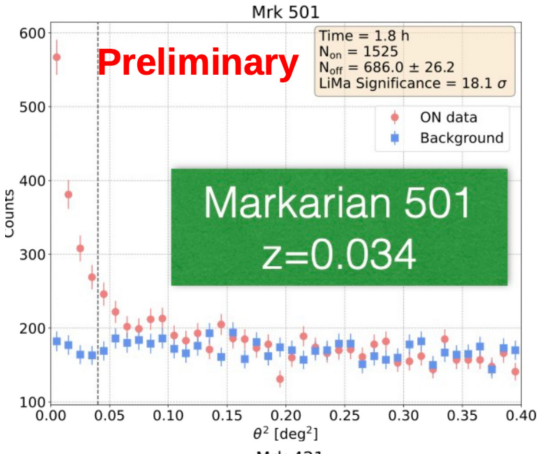
The LST-1 telescope has observed an increase in the very-high-energy (VHE; >100 GeV) gamma-ray flux from BL Lacertae (RA=22:02:43.3, DEC=+42:16:40, J2000.0). The preliminary offline analysis of the LST-1 data taken on 2021/07/11 (MJD 59406), triggered by an increase of the optical flux (see ATEL #14773 and references therein), has been detected with a significance of 8 sigma with a differential flux of 1.3 +/- 0.2 10^-9 cm-2 s-1 TeV-1 (25% of the Crab Nebula) at 100 GeV. Note though that this is the result of a quick-look analysis and the data were taken under non-optimal weather conditions (atmospheric transmission at 9km of ~50-80%), hence this flux measurement is a lower bound on the true flux. The LST-1 observations were performed during commissioning which began in 2018. LST-1 is a prototype of the Large-Sized Telescope for the Cherenkov Telescope

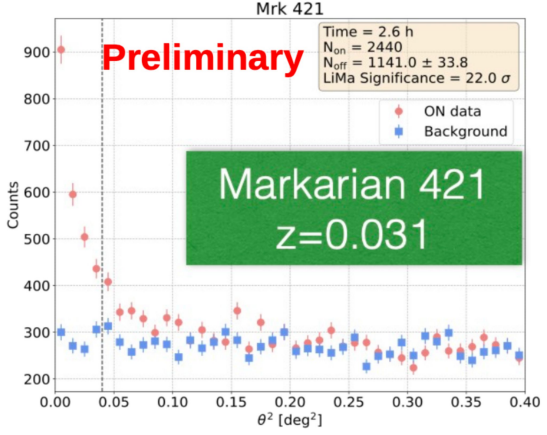
- First **LST-1 ATel**: BL Lac flare on July 11th 2021, **ATel #14783**
  - Source monitored also in August 2021 (brightest BL Lac flare episode)
  - detected sub-hour-scale intra-night variability 3–4 times higher than the flux of the Crab Nebula above 100 GeV

- Detection and monitoring of several known AGNs up to z~0.5
  (Mrk 421, Mrk 501, 1ES 1959+650, 1ES 0647+250, PG 1553+113…)

paper submitted

	Mrk421	Mrk 501	1ES1959+650	1ES0647+250	PG 1553+113
AGN type	HBL	EHBL	HBL	HBL	HBL
Redshift	0.031	0.034	0.048	0.45±0.05	0.433
Obs. date	2020/12/12 -2022/05/23	2020/07/10 -2022/06/29	2020/07/11 -2022/05/05	2020/12/16 -2020/12/21	2021/04/08 -2022/05/23
Obs. time BF/AF cut (h)	68.5/31.9	67.2/39.7	21.3/11.8	8.8/8.2	12.2/9.9
Significance	31 σ	21 σ	12 σ	7 σ	16 σ
Condition	Dark (No Moon) + Clear Sky				



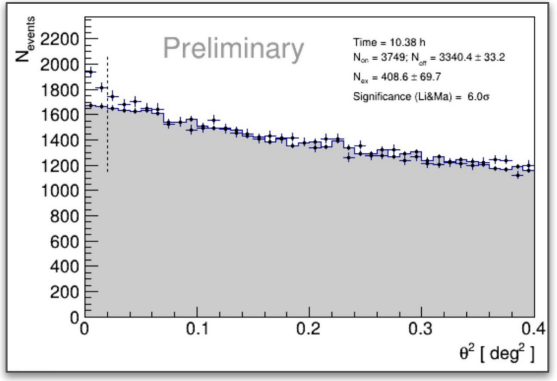


Detection of OP 313

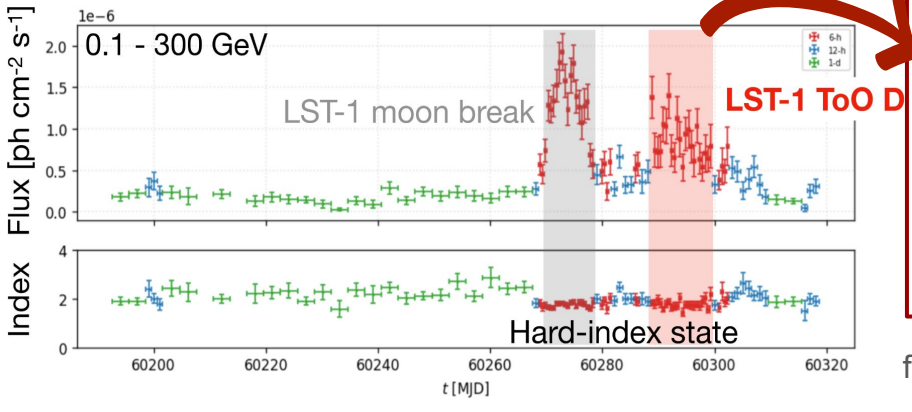
CTAO | LST COLLABORATION

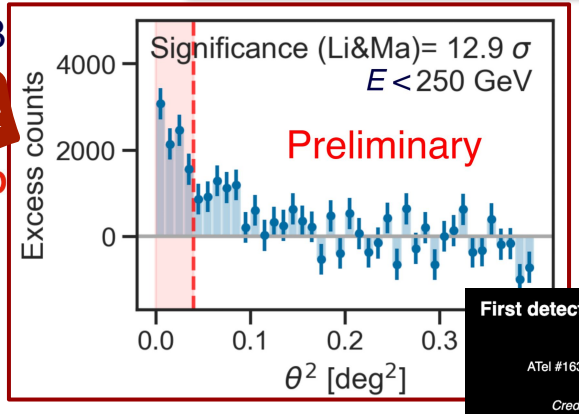
Most distant AGN detected by an IACT, **z = 0.997**

- VHE observations with MAGIC and LST-1 triggered by *Fermi*-LAT in November 2023.
- Only ten FSRQ ever detected in VHE
- First VHE source discovered by LST-1
- Average VHE flux of ~0.28 C.U. during December flare (~15 h)
- Lot of work ongoing: MWL SED modeling, EB



LST+MAGIC joint





Joint-publication with detailed analysis currently under internal review

from D. Morcuende@RICAP24

First detection of VHE gamma-ray emission from FSRQ OP 313 with LST-1

ATel #16381; *Juan Cortina (CIEMAT) for the CTAO LST collaboration*
on 15 Dec 2023; 14:31 UT
Credential Certification: Juan Cortina (Juan.Cortina@ciemat.es)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar, Quasar

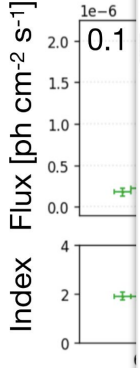
Post

The Large-Sized Telescope (LST-1) on La Palma has been monitoring the very distant Flat Spectrum Radio Quasar (FSRQ) OP 313 (z=0.997, Schneider et al. 2010, AJ, 139, 2360) since November 2023. Following the announcement of enhanced gamma-ray emission by

Det

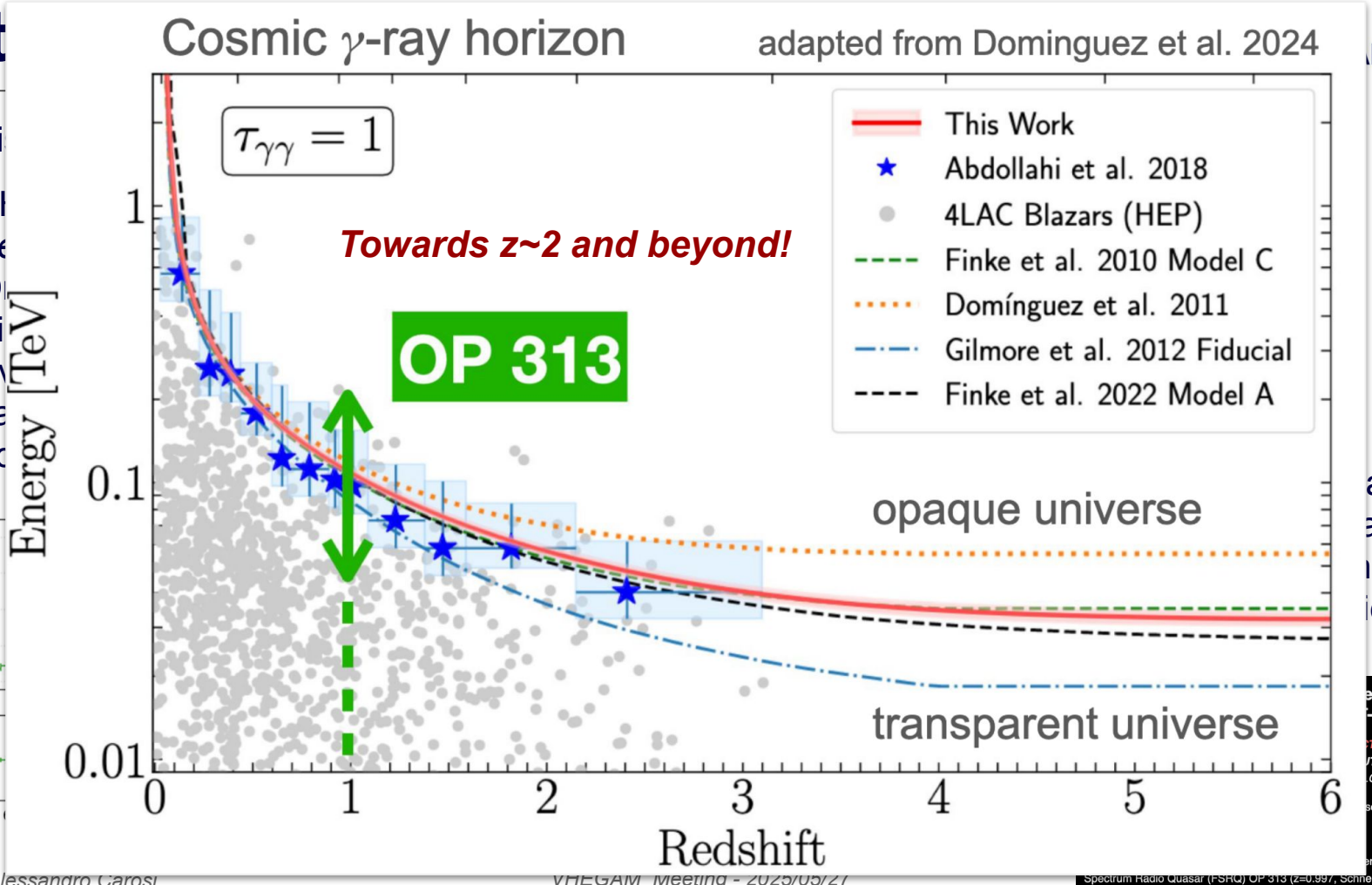
Most di

- ❑ VH
  Fe
- ❑ O
- ❑ Fi
- ❑ Av
  fla
- ❑ Lo



Cosmic γ-ray horizon

adapted from Dominguez et al. 2024



...BORATION

...ation with
...alysis
...ider
...iew

...emission from FSRQ
...-1
...CTAO LST collaboration
...IT
...Cortina@ciemat.es)
...servations, AGN, Blazar, Quasar

...en monitoring the very distant Flat
Spectrum Radio Quasar (FSRQ) OP 313 (z=0.997, Schneider et al. 2010, AJ, 139, 2360)
since November 2023. Following the announcement of enhanced gamma-ray emission by

Conclusions

- The prototype telescope LST-1 was inaugurated at the CTAO Northern Array site in La Palma in 2018. Telescope is now ending the commissioning phase.
- LST-1 Science program has been established and is growing rapidly. **Cycle III of observations has recently started in a joint-mode with MAGIC**.
- Observations and results are coming and they cover a wide range of scientific targets (Galactic sources, transients, TeV Blazars, FSRQs…)....and that's not all! Many other results not mentioned here such as fundamental physics study, dark matter, LIV, interferometry….
- Bright future ahead: moving forward to the LSTs array soon.

CTAO | LST COLLABORATION

Thanks for the attention!