Transient sources with Cherenkov telescopes

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3rd Astro-COLIBRI workshop

Current operative Cherenkov telescopes systems

H.E.S.S., MAGIC and VERITAS operating since ~20 years

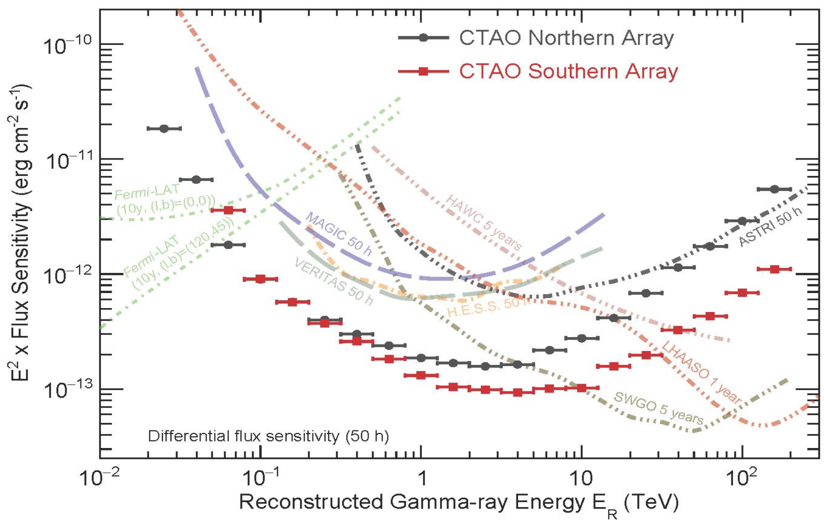
LST-1 started in 2018-2019 (LST-2 to 4 on their way)

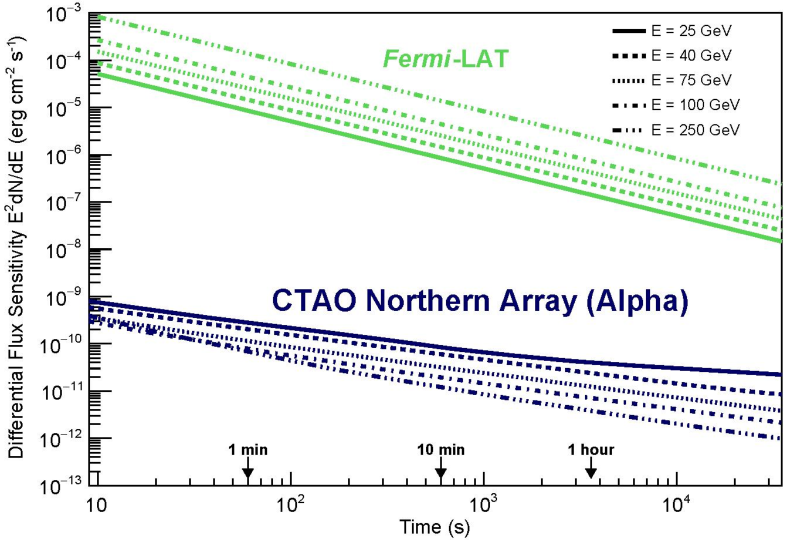
Indirect detection of gamma rays above tens of GeV

Studying transients with IACTs: why?

- They are very sensitive instrument on a broad energy range --> good characterization of spectra from ~20 GeV to several TeV for CTA
- They are “fast” instruments, sensitive to short duration events, detecting enough photons thanks to large collection area --> possibility to perform time analysis, searching for variability, change in spectrum, evolution of system

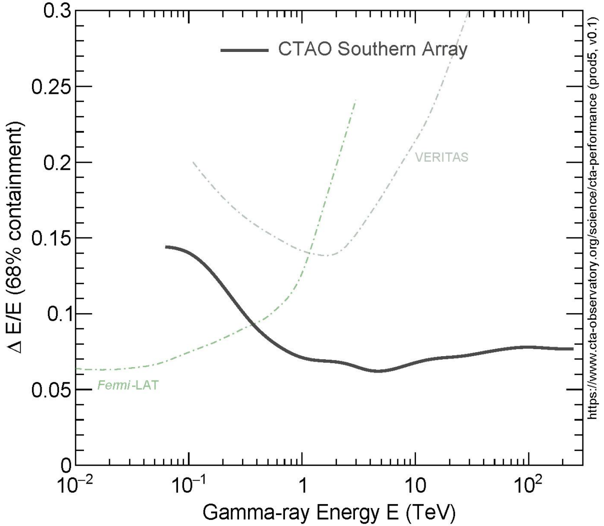
https://www.ctao.org/for-scientists/performance/

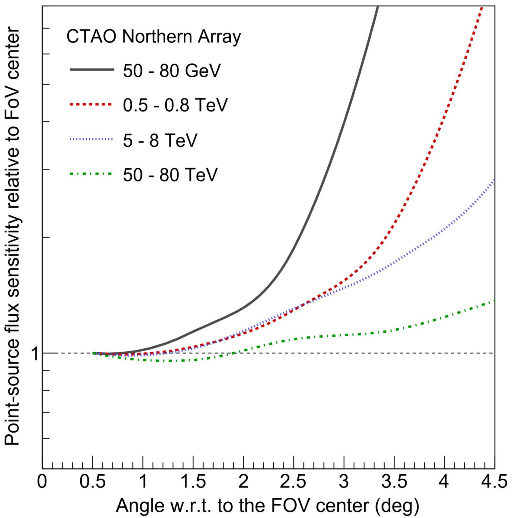




Studying transients with IACTs: why?

- The energy resolution is very good, ensuring reliable energy estimation and spectra
- Also, sources can be detected off-axis, given that degradation of sensitivity is moderate (at least starting from few hundreds of GeV) --> important for not well localized sources like neutrinos or GRBs detected by Fermi-GBM or relatively well localized GW events (O(few 10deg2))





https://www.ctao.org/for-scientists/performance/

Studying transients with IACTs: challenges

Observing transients with IACTs can be challenging...

1. field of view of IACTs is limited (they are pointing instruments, from 3-4deg), so they need to rely on external facilities to get the coordinates of the transient (e.g. from Swift, Fermi, LVK, IC)
   - this introduces a delay in the observation, so the most interesting phase of the transient (e.g. prompt phase for GRBs) may be missed

2. they may be distant sources (e.g. median redshift for long GRBs is ~2)
   - this translates on a huge absorption of the VHE flux due to the interaction of VHE photons with the ones from the extragalactic background light (EBL)

3. duty cycle is limited (only nights, with no strong moon, and good weather), so interesting events may happen when IACTs cannot operate or can operate but with worse sensitivity (e.g. strong moon, reduced atmospheric transmission etc.)

4. some instruments provide a large localization, so the best fit position may not be the real position of the source, which can fall outside the field of view

Studying transients with IACTs

Given these challenges, how can those be mitigated with IACTs?

- IACTs should have alert systems to connect to brokers delivering alerts on transient sources (e.g. GCN), and possibly triggering an automatic reaction

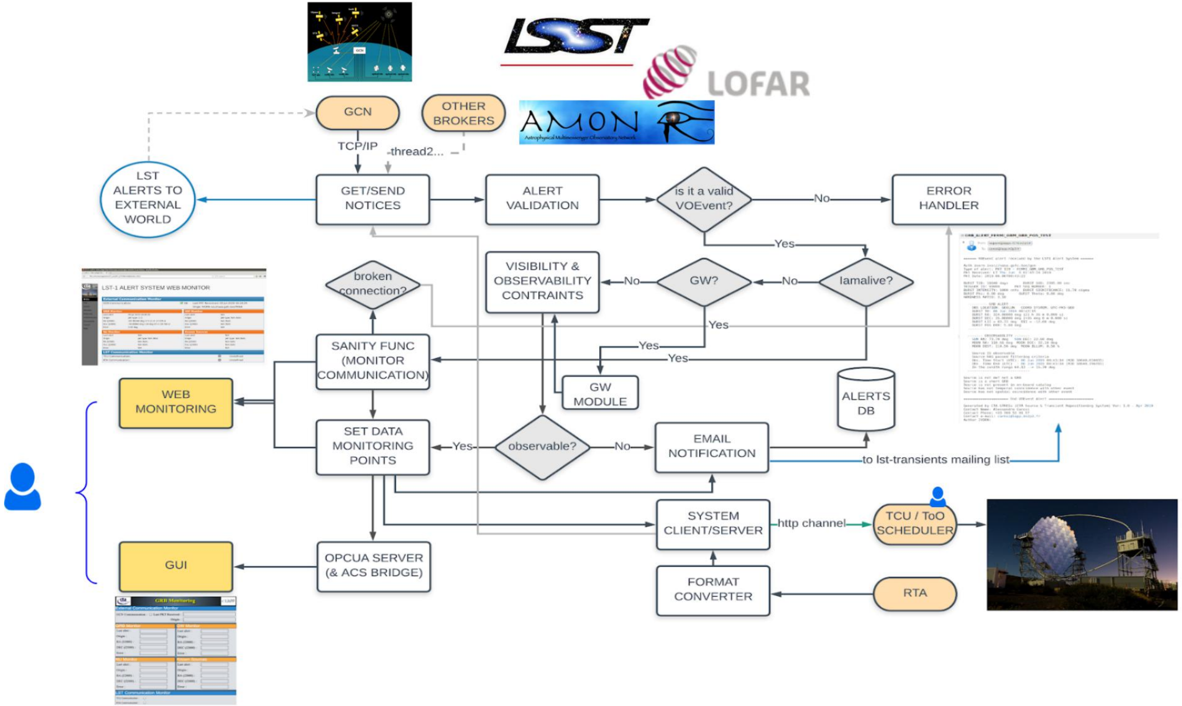
- IACTs should be able to repoint fast to the transient position from any position they were pointing at the moment of the alert, in order to reduce the latency for the beginning of the observation
    - some examples: MAGIC fast mode speed is 7°/s, LST-1 GRB mode speed is ~10°/s i.e. less than ~20s to reach any position in the sky

- IACTs should have a low energy threshold to detect gamma rays in an energy band where EBL absorption is less severe
    - CTA concept implements this with different types of telescopes: in particular, LSTs are those covering the lowest energy range starting from ~20 GeV.
    - MAGIC can reach a low energy threshold of ~50 GeV, and H.E.S.S.-II can go down to similar energies as LST-1

- Decision taking
    - Burst Advocates for “online” decisions, larger group for offline ones (based on e.g. GCN Circulars)
    - Real Time Analysis (RTA) to know if there is a detection or “hotspots”
    - Fast offline analyzers to get next day results (RTA is less sensitive)

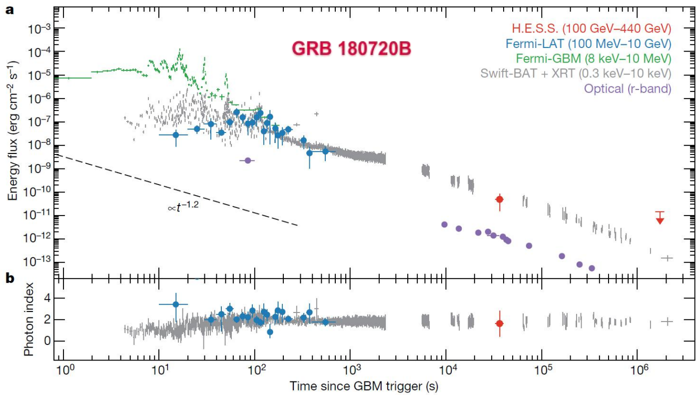
An example of alert system: LST-1

- Processes the alerts from brokers (at the moment GCN ones via Kafka)
  - for GW and other not well-localized sources, tiling via **tilepy** (APJS 274:1, 2024)
- Connected to the LST-1 Telescope Control Unit (TCU) --> triggers automatic observations depending on predefined criteria
- MAGIC has a similar system, and also VERITAS should have one now (afaik)
- H.E.S.S. one is more sophisticated, it is a full-fledged ToO follow-up system (A&A 666, A119 (2022))

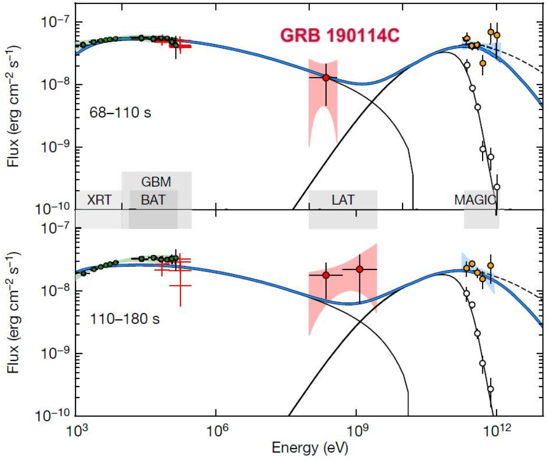


GRBs at VHE with IACTs

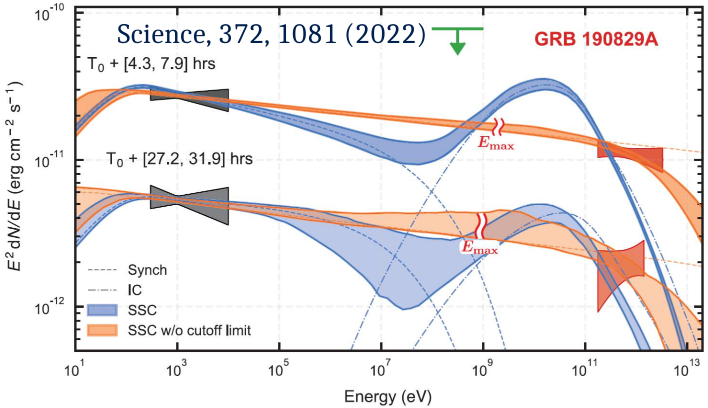
Nature, 575, 464 (2019)

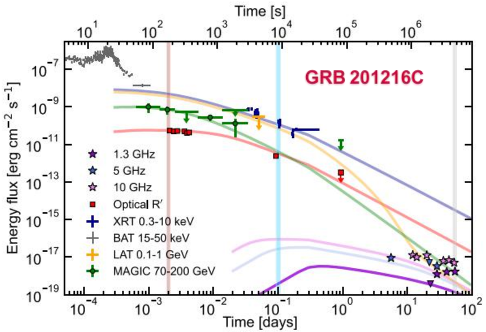


Nature, 575, 459 (2019)



Science, 372, 1081 (2022)





MNRAS 527, 5856 (2024)

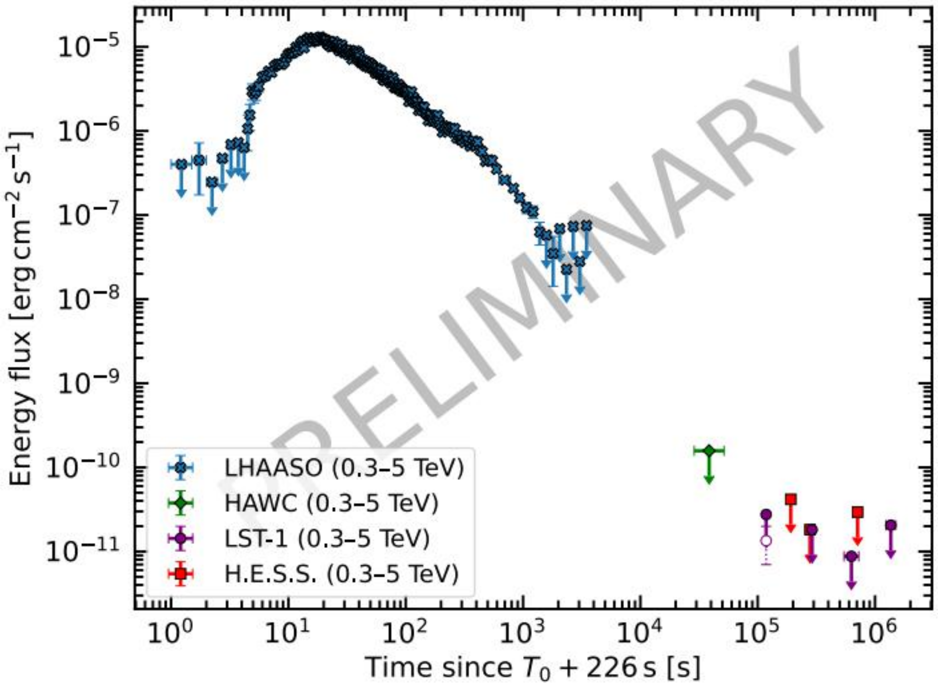
The BOAT: GRB 221009A

- Light curve with LHAASO, HAWC, LST-1 and H.E.S.S.

- LST-1 performed the first follow-up among IACTs, under very strong moonlight
    - hint at ~4 sigma the first day of follow-up (T0+1.33 days)

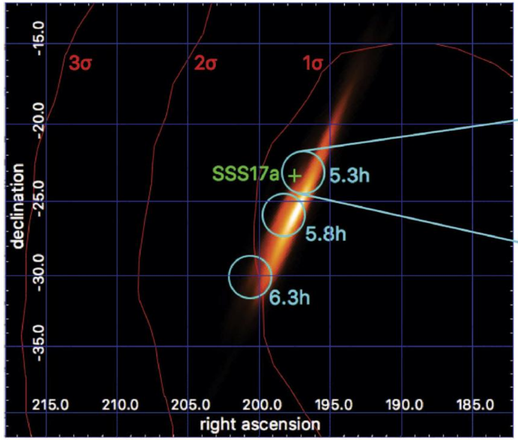
- LST-1 ULs are ~1 order of magnitude lower than HAWC, and at a similar level as H.E.S.S.

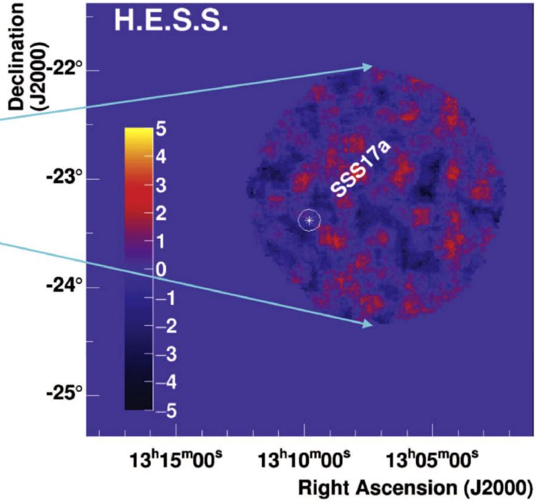
- For the H.E.S.S. data and interpretation, see https://iopscience.iop.org/article/10.3847/2041-8213/acc405



Presented 2 weeks ago at Gamma 2024 (https://indico.ict.inaf.it/event/2661/contributions/19210/)

GW events with IACTs

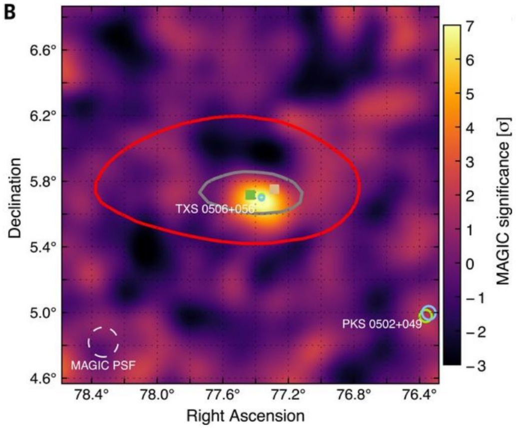


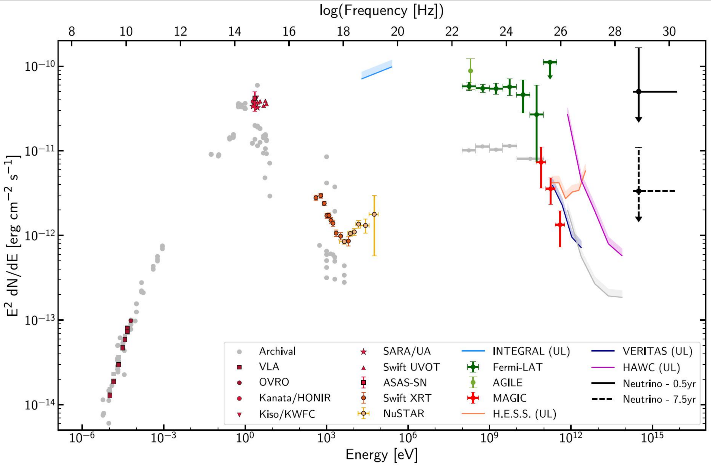


ApJL 850:L22 2017

- H.E.S.S. follow-up of GW170817A
  - scheduling covered the region where the EM counterpart, SSS17a, was later confirmed to be
  - delay of ~5h because alert came during day
  - further follow-up in the following days focused on the EM source

Studying neutrino events with IACTs





IceCube et al., Science 361, 146 (2018)

- Most famous example: TXS 0506+056, where emission of (V)HE gamma rays was detected by Fermi-LAT, MAGIC and VERITAS
    - chance coincidence of neutrino and flare disfavored at 3sigma level
    - hadronic model is needed to account for the production of neutrinos, and for this acceleration of protons up to UHE is needed --> blazar may be accleration sites for UHECRs
- But, picture is more complicated...
    - blazar may contribute to only part of the neutrinos
    - sources may be faint in gamma rays
    - other sources may contribute to neutrino flux e.g. tidal disruption events (AT2019dsg)

Sharing of observations/results for transient sources

- IACTs collaborations historically are closed, with private data
- With CTA closing in, current IACTs are becoming more open and sharing more information
- Nice initiative by H.E.S.S.: https://grbhess.github.io/
    - shares the observations of GRBs
- Also, H.E.S.S. allows external people to submit ToOs: https://www.mpi-hd.mpg.de/HESS/pages/home/too/
- Also, started to share datasets in DL3 format (see https://gamma-astro-data-formats.readthedocs.io/en/v0.3/)

grbhess.github.io

For an explanation of the columns and entries, please click here

GRB ID	Triggering instrument	Alert time (T0)	GRB RA (J2000)	GRB Dec (J2000)	H.E.S.S. window start	H.E.S.S. window end	Obs mode	Reaction	Contact
GRB 240905E	SWIFT-BAT	2024-09-05 18:26:03 UTC	345.7993 deg (23h03m11.832s)	35.4951 deg (+35d29'42.36")	Cancelled (observation constraint)		Pointed	Manual	Mathieu de Bony
746882332 (retracted)	Fermi-GBM	2024-09-01 11:18:47 UTC	353.96 deg (23h35m50.4s)	-26.78 deg (-26d46'48")	Cancelled		Tiled	Manual	Mathieu de Bony
GRB 240825A	SWIFT-BAT	2024-08-25 15:52:59 UTC	344.5512 deg (22h58m12.288s)	1.036 deg (+01d02'09.6")	2024-08-25 19:51:28 UTC (T0 + 3.97h)	2024-08-25 22:50:45 UTC (T0 + 6.96h)	Pointed	Manual	Mathieu de Bony
745194848 (retracted)	Fermi-GBM	2024-08-12 22:34:03 UTC	42.74 deg (02h50m57.6s)	21.46 deg (+21d27'36")	Cancelled (not a GRB)		Tiled	Manual	Mathieu de Bony
745192855 (retracted)	Fermi-GBM	2024-08-12 22:00:50 UTC	71.39 deg (04h45m33.6s)	-39.74 deg (-39d44'24")	Cancelled (not a GRB)		Tiled	Manual	Mathieu de Bony
745121685 (retracted)	Fermi-GBM	2024-08-12 02:14:40 UTC	28.31 deg (01h53m14.4s)	-63.35 deg (-63d21'00")	2024-08-12 02:32:48 UTC (T0 + 0.3h)	2024-08-12 04:13:18 UTC (T0 + 1.98h)	Tiled	Manual	Mathieu de Bony
GRB 240809A	SWIFT-BAT	2024-08-09 08:30:29 UTC	237.5511 deg (15h50m12.264s)	-2.3211 deg (-02d19'15.96")	2024-08-09 17:44:01 UTC (T0 + 9.1h)	2024-08-09 21:21:44 UTC (T0 + 12.85h)	Pointed	Manual	Mathieu de Bony

Summary

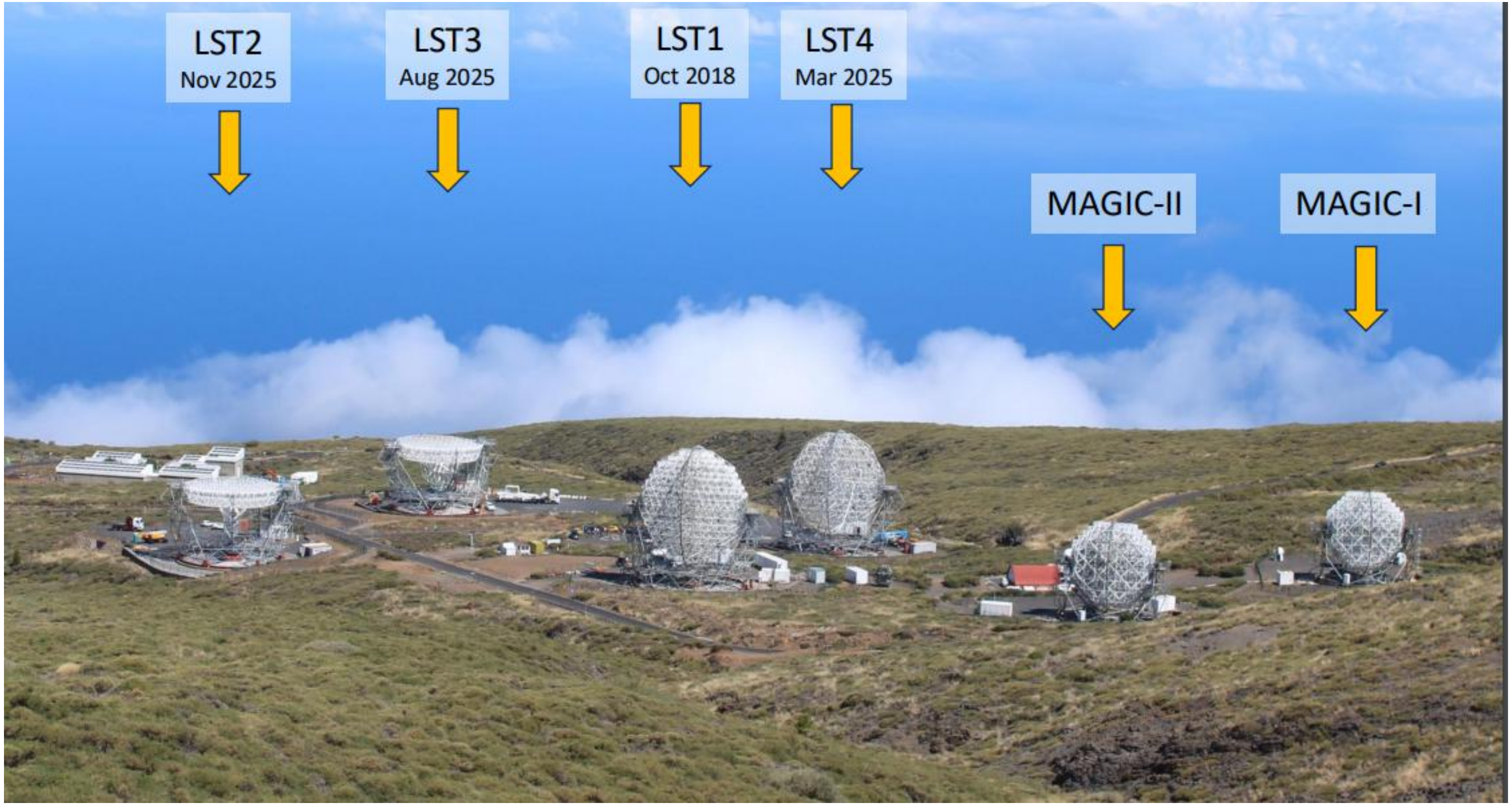
- IACTs deeply involved in follow-up of transient sources, also in a multi-messenger context

- Already some key results (e.g. GRBs), thanks to extended observation programs and follow-up strategies

- Tools like Astro-COLIBRI can help in finding interesting events to observe, to organize follow-ups, and possibly to coordinate with other instruments/observatories

- Did not mention FRBs, Galactic transients (e.g. SGRs, novae) due to time, but they are very hot topics right now
    - e.g. T Coronae Borealis may explode soon!

LSTs are “growing” :)



BACKUP