Transients with LST

Alessio Berti
Max Planck Institute for Physics

(with material from Alice Donini and
Monica Seglar-Arroyo)

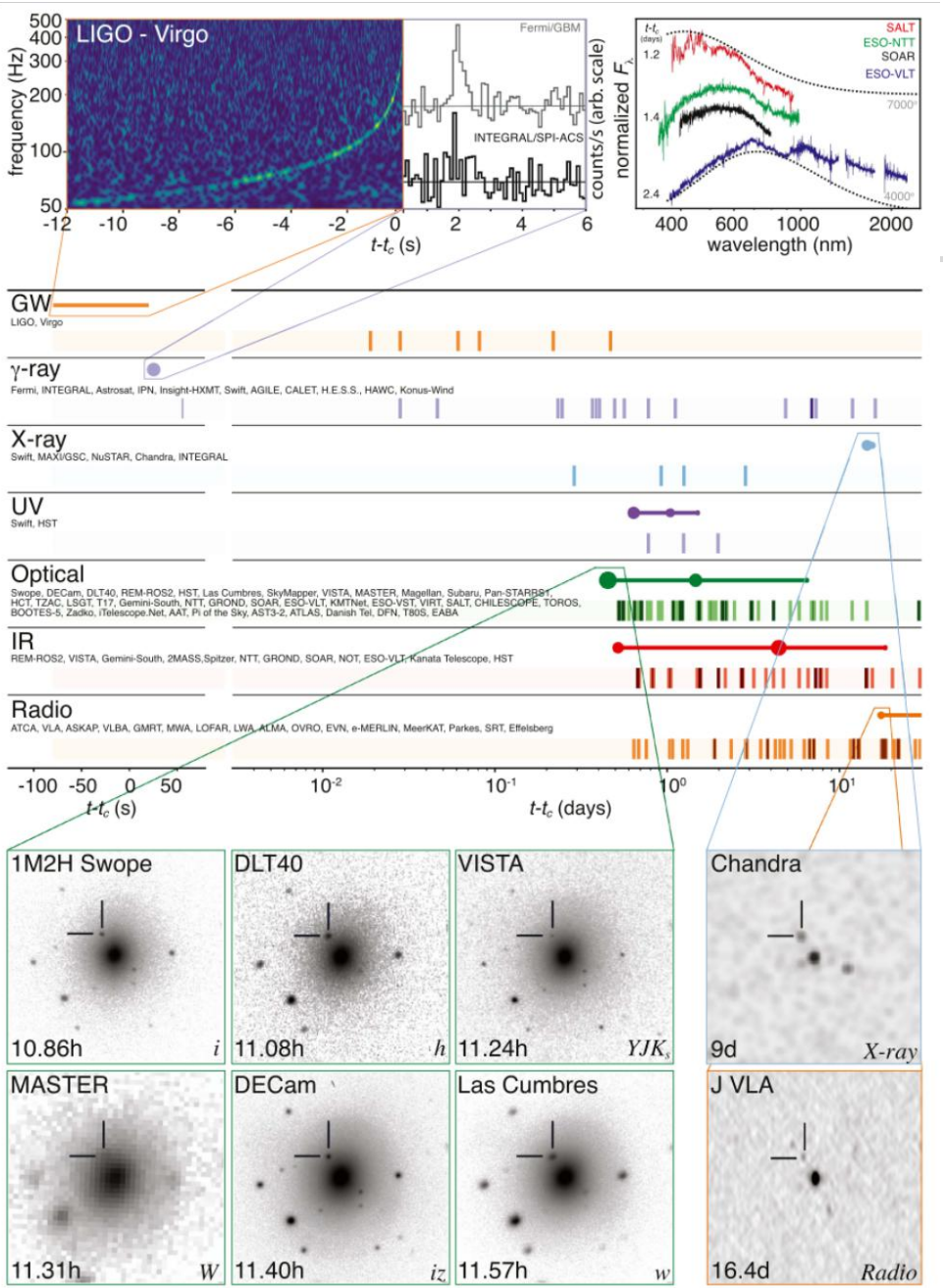
1st VHEGAM meeting

Transients

- A transient is an astrophysical event exhibiting time variability on different timescales, from milliseconds to years
- Also their duration may vary, they can be the brightest objects in the sky for few seconds and then fade away
- Examples of transient sources
  - gamma-ray bursts (GRBs)
  - gravitational wave sources
  - fast radio bursts
  - also flares can fit into this category
  - many more!

Transients

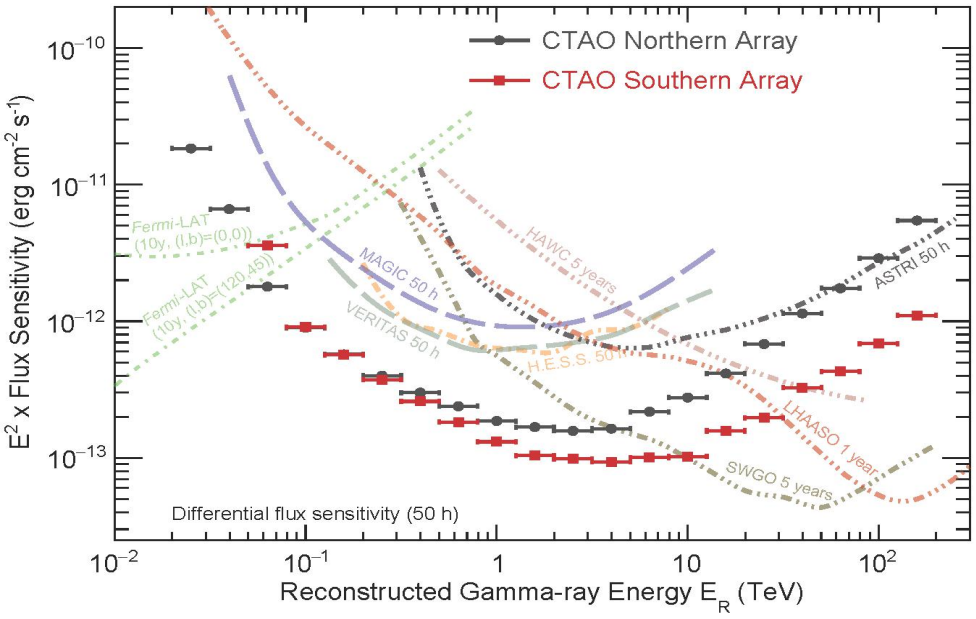
- In many cases, these sources are the result of explosive/catastrophic events e.g. the merging of very compact objects
- Acceleration of particles is expected and so also production of photons at different wavelengths, up to (very) high energies
- GW170817/GRB 170817A is a good example
  - merger results in GRB (off-axis) + kilonova
- Connection to multi-messenger astrophysics

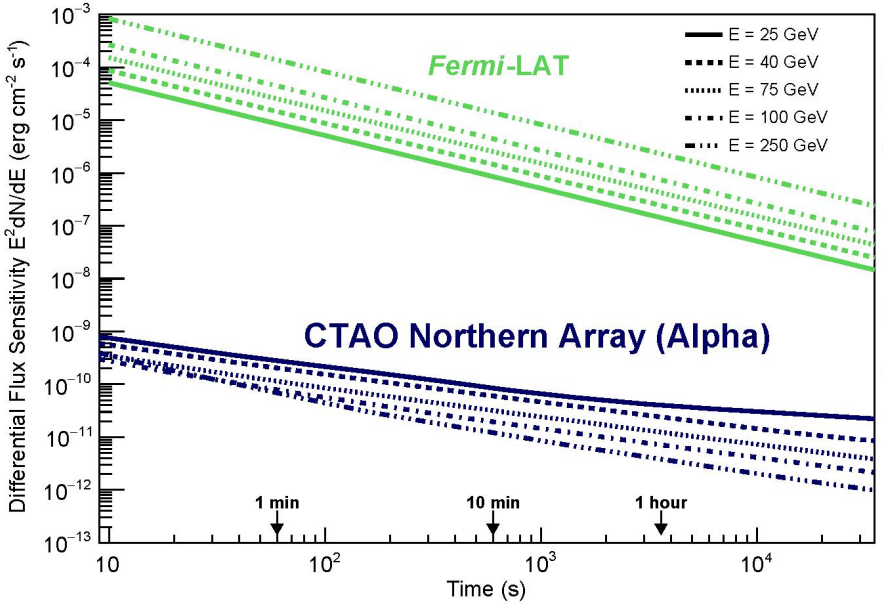


Transients with IACTs

- 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

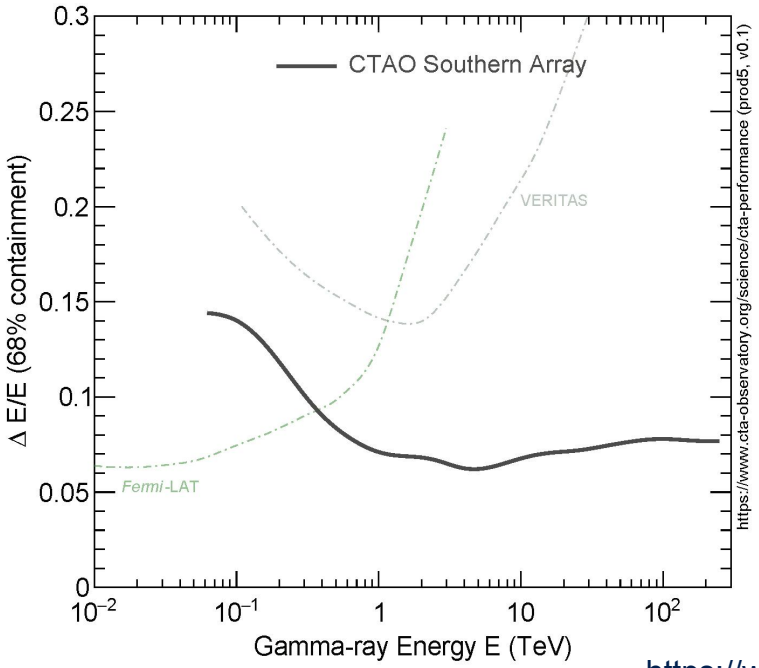
https://www.cta-observatory.org/

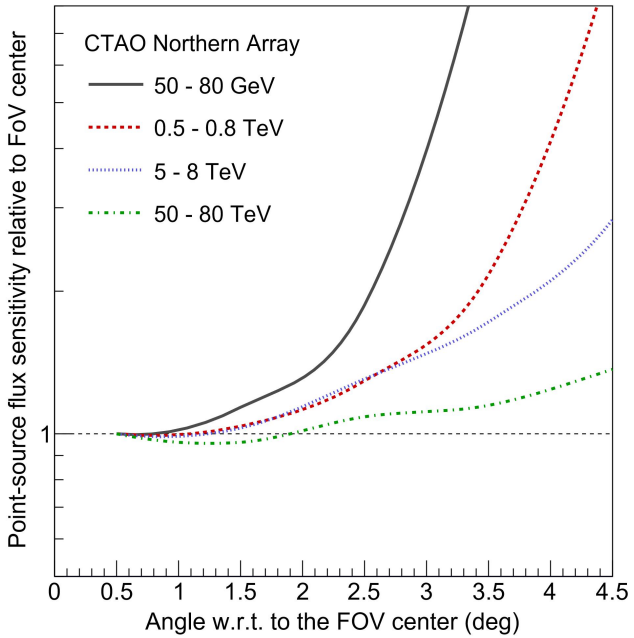




Transients with IACTs

- 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))

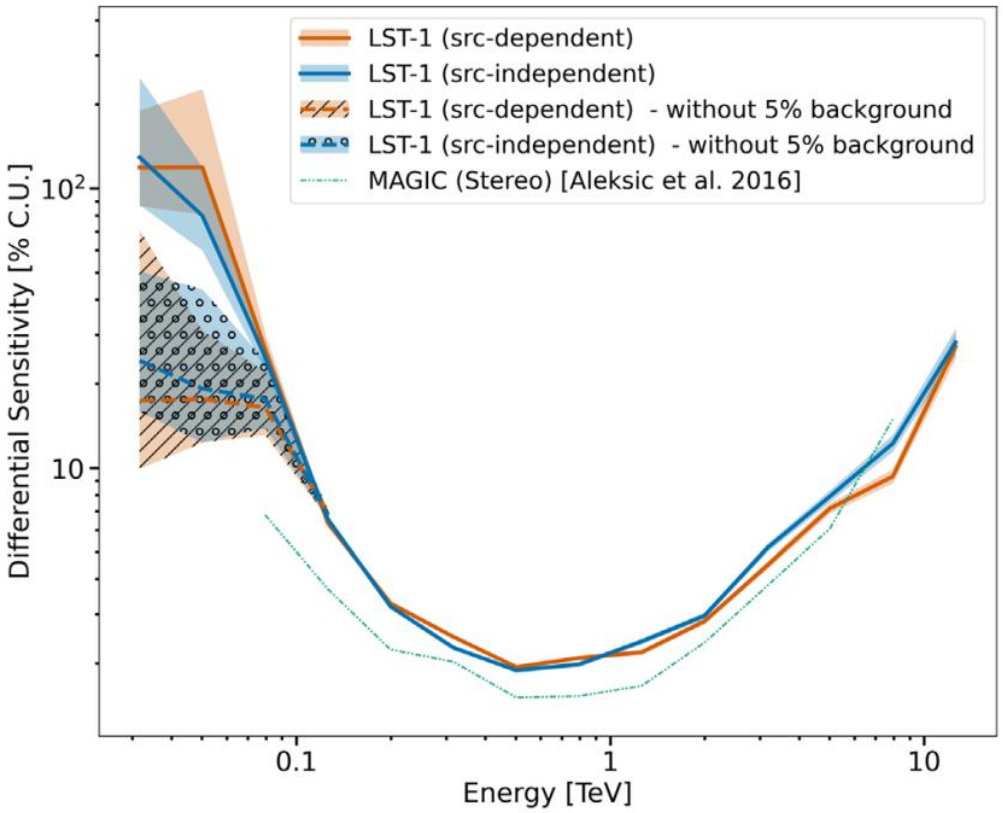




https://www.cta-observatory.org/

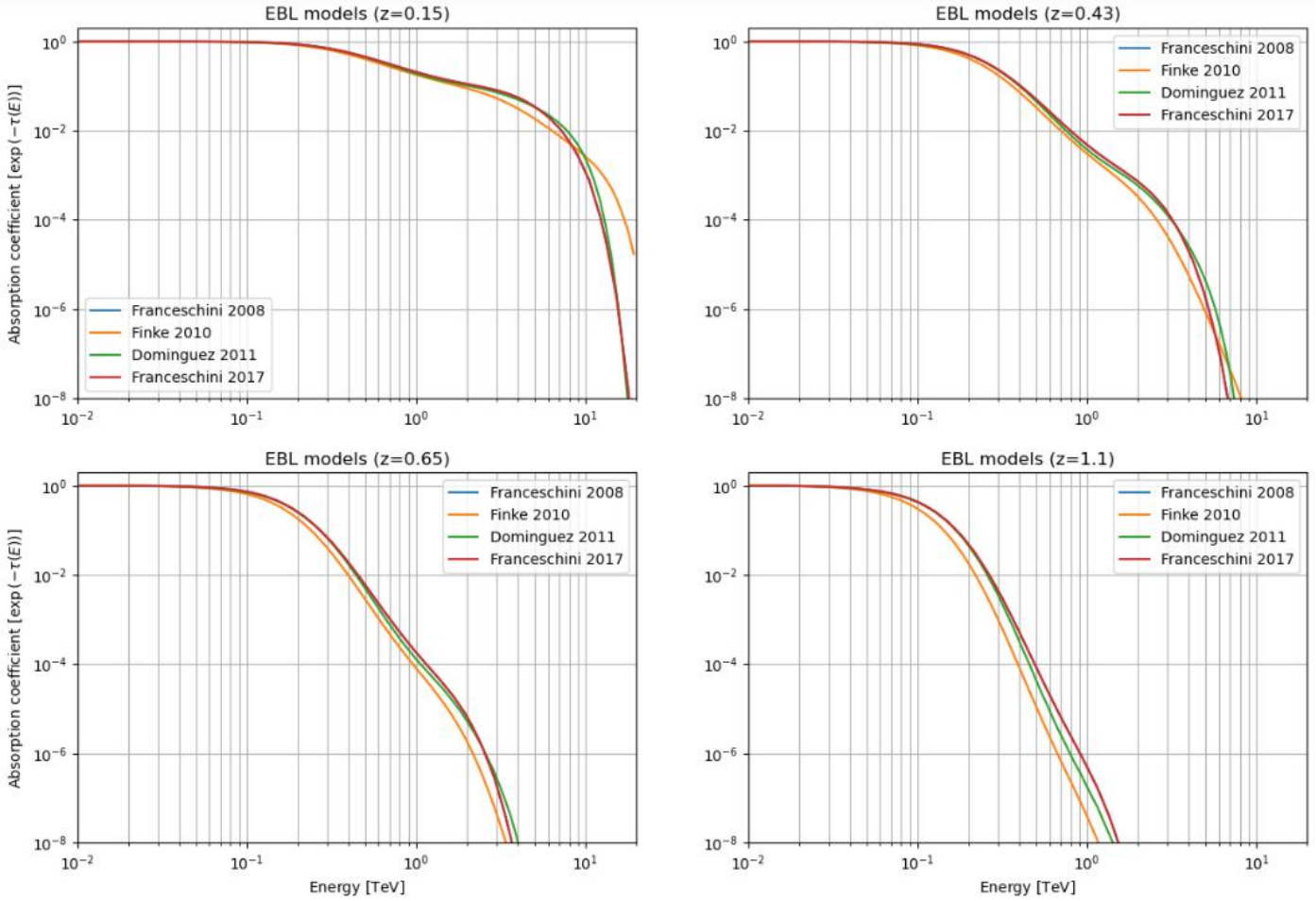
Transients and LST-1

- LST-1 is designed to follow-up transients, in particular GRBs
- It can go down to energies as low as ~20 GeV with good sensitivity
  - it can detect gamma rays in an energy range not (or little) affected by EBL absorption
- Fast repointing
  - any position in the sky in less than 20s
- Field of view of 4.5deg diameter
  - important when using strategies like tiling for GW



Why LST-1 low threshold (but not only) is important

- Comparison of different EBL models at different redshifts



Transient working group and program in LST-1

- Within LST, we have a Transient working group devoted to such searches
  - Conveners: Alice Donini, Monica Seglar-Arroyo
- In 2023 we had the first cycle of LST-1 mono proposals, and some of them were submitted by people of the Transient group
  - GRBs follow-up
  - GW follow-up
  - Tick-Tock source
- For 2024, plan to extend the program to other transients
  - FRBs
  - Neutrino from IC
- Basically all of them are Target of Opportunity proposals
  - we receive alerts from external observatories/instruments and we decide to observe them, in an automatic or manual way, according to some criteria

Studying transients with LST-1: challenges

Observing transients with LST-1 (or IACTs in general) is challenging...

1. field of view of IACTs is limited (they are pointing instruments), so they need to rely on external facilities to get the coordinates of transients (e.g. from Swift, Fermi, LVK, IC etc.)
   - this introduces a delay in the observation

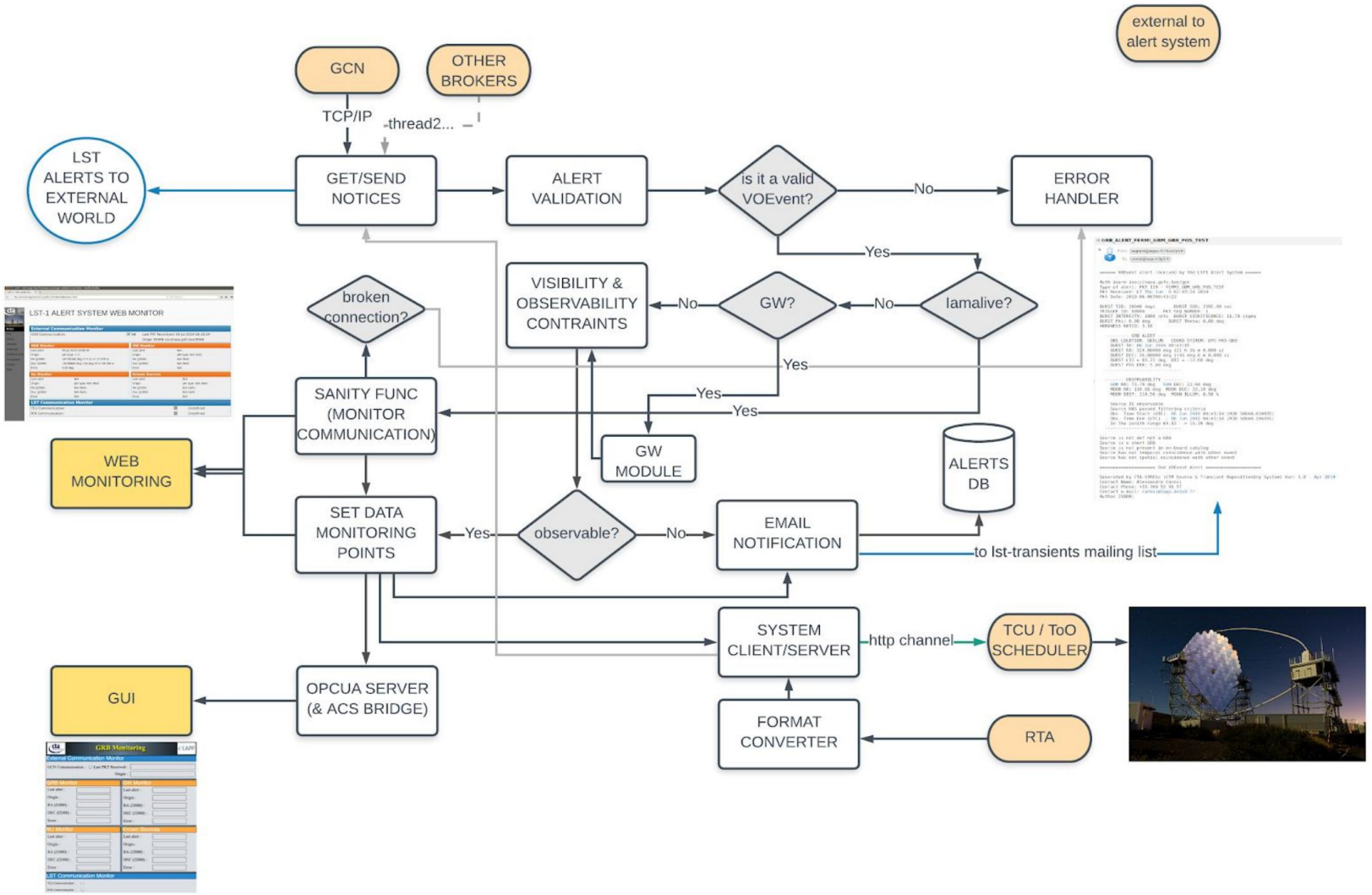
2. they may be distant sources (e.g. median redshift for long GRBs is ~2)
   - this translates on a huge absorption of the VHE flux due to the interaction of VHE photons with the ones from the extragalactic background light

3. duty cycle is limited (only nights, with no strong moon, and good weather)
   - interesting events may happen when LST-1 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 a single pointing is not enough
   - tiling strategies

One needs an observational strategy for each transient, and have it as much automatized as possible ==> Transient Handler

Transient Handler (TH)



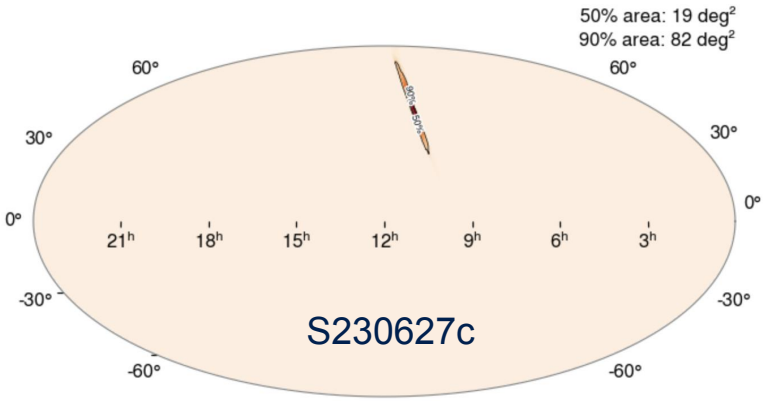
Transient Handler

- In short, the TH receives alerts on transient sources from external facilities, validates them (if needed), filters them according to predefined criteria, checks target visibility and can trigger automatic reaction of the telescope
  - filters on localization, source type probability, brightness, false alarm rate etc.
  - filters depend on the specific transient

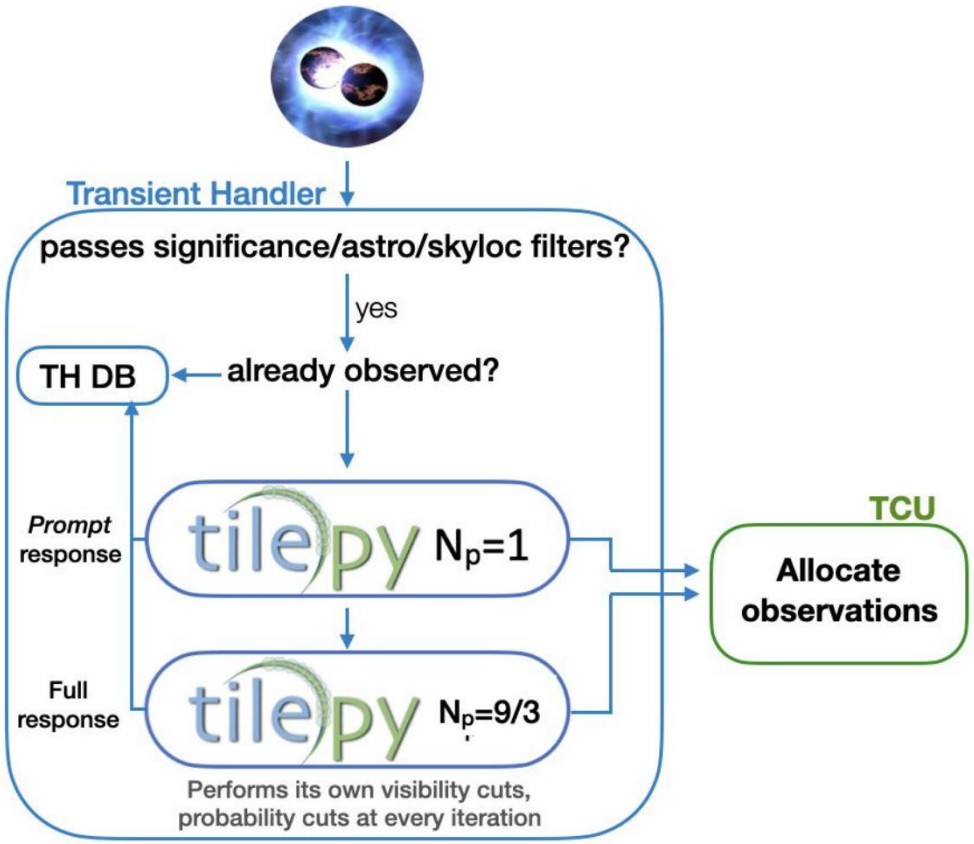
- Last year we did some updates in the TH, especially because of the currently ongoing observation run O4 of LIGO-Virgo-Kagra (LVK, up to know, only with LIGO)
  - New protocol to receive alerts from the Gamma-ray Coordinates Network (GCN) ==> needed to receive new alert types
  - Implementation of the GW follow-up strategy
  - Creation of alerts database (ongoing), needed to fully complete the previous point
  - Compliant with current IT rules at the IT computing center
  - More information for Burst Advocates in alert emails
    - also, tools for tiling
  - tests for the automatic procedure

Example of transient: GW case

- GW selection criteria automated in the TH, division in 4 internal cases
  - **Significance**: only highly significant triggers
  - **Classification**: 4 internal cases (based on progenitor classification, coincidence with EM/Nu emission etc.)
  - **Sky localization:** depending on the classification of the event
    - Adapted to the number of ITF involved



GW tiling



GW alert processing flow

- classification of alert based on the previous 4 internal cases
- if passed, tiling is run searching for one pointing only (“first round”)
- if a pointing is found, the alert is sent to TCU ==> first observation starts
- second round of tiling (“full round”) to find the remaining pointings, depending on the case (3 or 9 more)
- also those sent to TCU to complete the observation slots

Latest observations with LST-1 through the TH

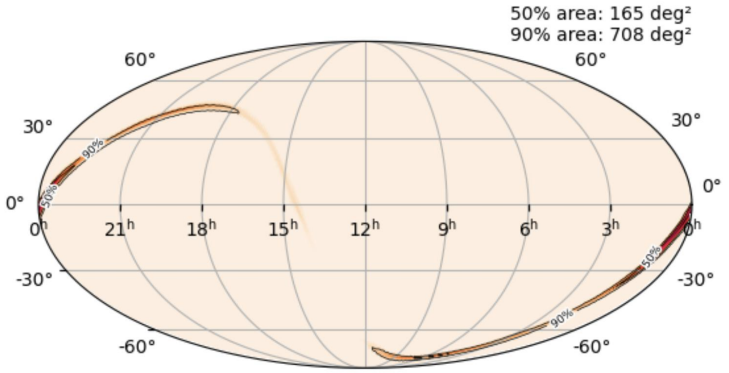
- 3 GW follow-ups out of (4 GW considered): 3th discarded as it was too broad
  - S230919bj
  - S230922g
  - S231206cc

- Several GRBs
  - GRB 230812B
  - GRB 230816A
  - GRB 230818A
  - GRB 231110A
  - GRB 231111A
  - GRB 231115A
  - GRB 231118A
  - GRB 231215A
  - GRB 231216A

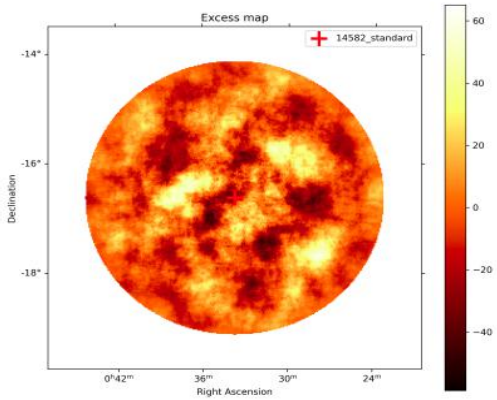
Latest observations with LST-1 through the TH: S230919bj

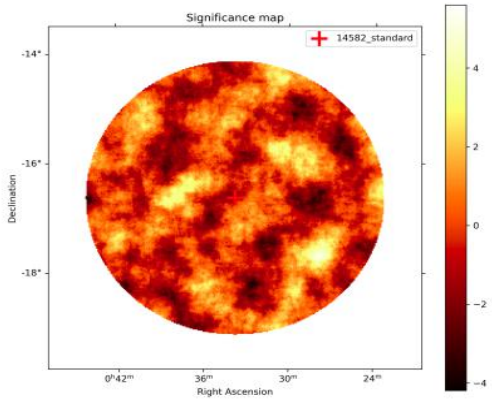
- Binary Black Hole merger, 19 Sep. 2023 (21:57 UTC)
- FAR ~1/100 years (initially 10-42)
- Trigger type 4: significant BBH (for end-to-end no-human-in-the-loop commissioning; NB: this one should not have triggered!) => OBSERVABLE alert, shifters called the BA, BA gave green light
- Three observations, covering ~10%

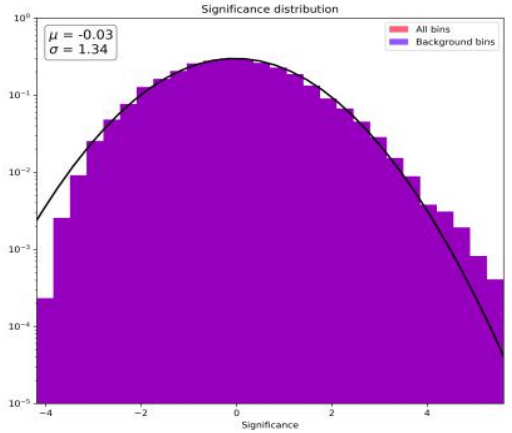
Observ Time UTC	RA[deg]	DEC[deg]	PGW
2023-09-19 22:20:00	5.9766	-12.0247	0.0363
2023-09-19 22:40:00	3.5156	-7.4816	0.0357
2023-09-19 23:00:00	8.4375	-16.646	0.0349



- First two pointings unexploitable, RTA of 3rd pointing below







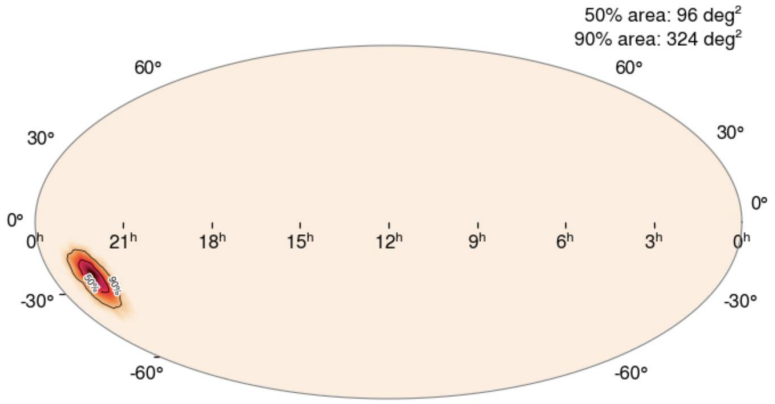
Latest observations with LST-1 through the TH: S230922g

- Binary Black Hole merger, 22 Sep. 2023 (21:57 UTC)
- FAR ~1/1.6432e+16 years
- Trigger type 4: significant BBH (for end-to-end no-human-in-the-loop commissioning)

- Set of issues: the 2nd was not observed (problems with the time in TH), but it became not observable (zd>75deg) anymore when shifters called. The 3rd pointing was ongoing at the moment of the call. Failed to go to the 4th (they could take data on the last pointing for 15min)

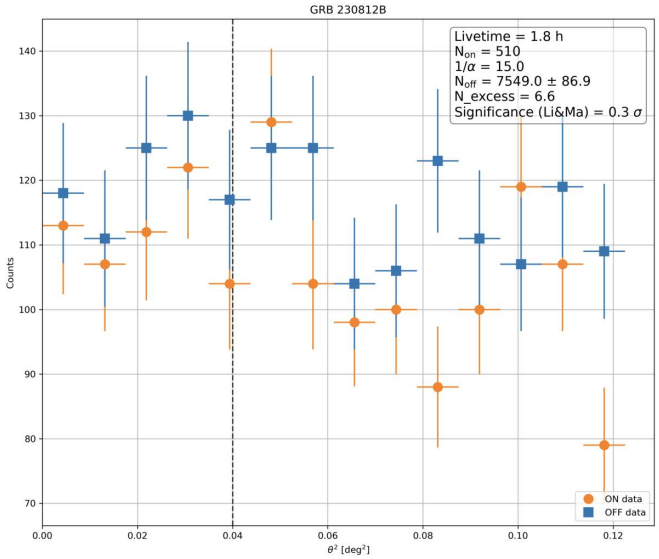
- We covered a total of ~17% of the error region (~30% could have been covered)

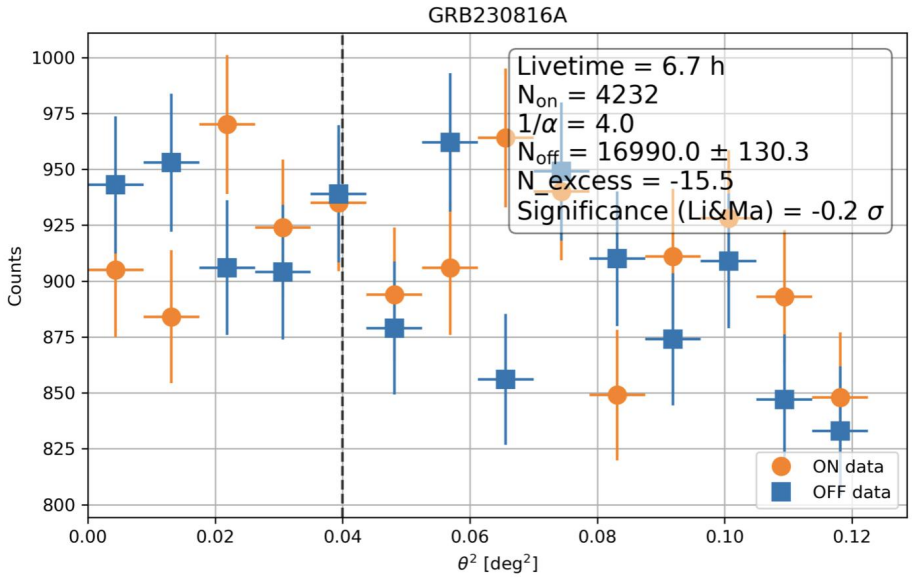
Observat Time UTC	RA[deg]	DEC[deg]	PGW
2023-09-22 02:04:20	334.6875	-21.0618	0.0886
2023-09-22 02:24:20	333.9844	-23.6433	0.0847
2023-09-22 02:44:20	335.3906	-18.5244	0.0831
2023-09-22 03:04:20	338.9062	-21.7028	0.0552



Latest observations with LST-1 through the TH: GRBs

- GRB 230812B: *Fermi/GBM (after trigger, XRT and LAT arrived),* z = 0.360
  - Direct use of RTA DL3 with gammapy 1.1
  - Livetime : 1.76 h (coordinated with MAGIC+tiling) Significance : 0.29 sigma
- GRB 230816A: *Swift/BAT*
  - Direct use of RTA DL3 with gammapy 1.1
  - Livetime : 6.68 h (coordinated with MAGIC) Significance : -0.21 sigma
- GRB 230818A

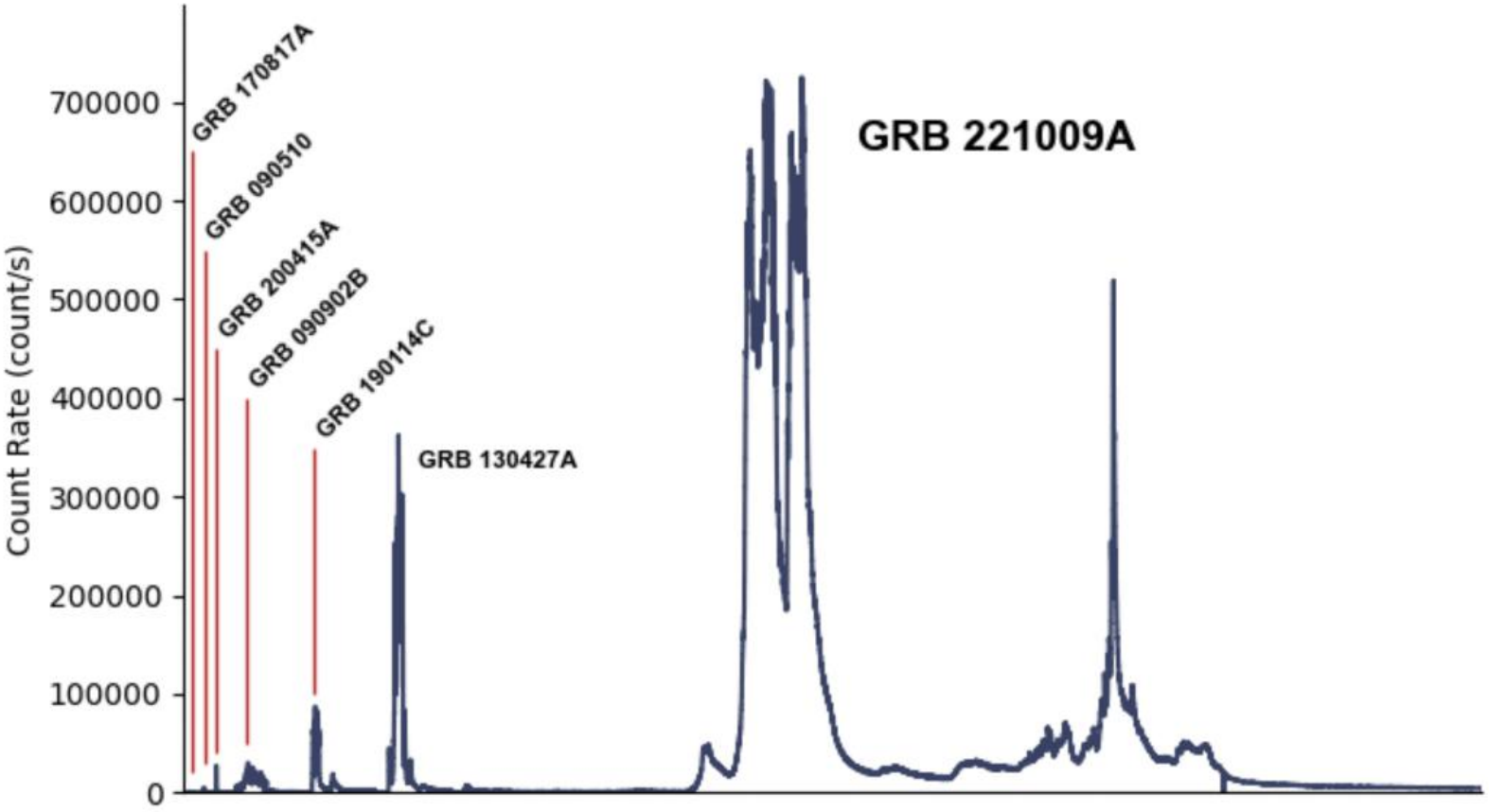




Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT

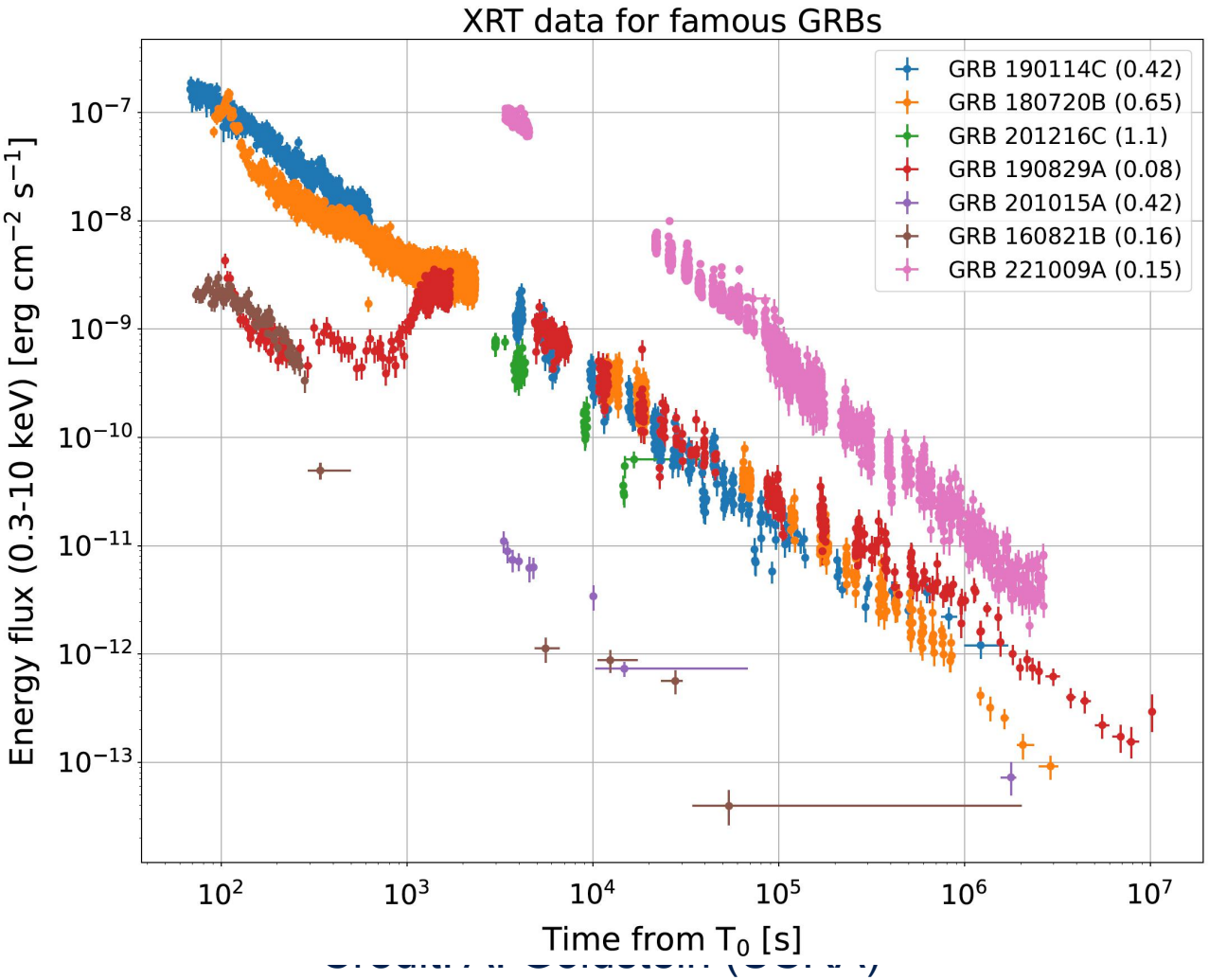
- Initially classified as bright galactic transient by Swift (Swift J1913.1+1946)
  - reported $T_{0,BAT}$: 2022-10-09 14:10:17 UT
- Fermi-GBM later reported to have a detection from a very bright and long GRB positionally consistent with the Swift alert
  - reported T_0 : 2022-10-09 13:16:59.99 UT (this is the T_0 I will use)
    - i.e. 3197 prior to Swift-BAT
    - i.e. Swift-BAT triggered on the afterglow, because it was insanely bright!
  - event renamed to GRB 221009A (for friends, the BOAT)
  - BUT: no automatic alert sent due to downlink problem :(
- Detection also by Fermi-LAT, 99 GeV photon at T_0+240s
  - pileup, needs custom tools for analysis for interval T_0+203 and T_0+294
- Very close (z=0.15) and bright (Eiso ~ 2×10^{54} erg)
- LHAASO detection (first 2ks): highest photon energy 18 TeV!
  - no detection by HAWC (observation after ~8h from trigger)

Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT



Credit: A. Goldstein (USRA)

Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT



Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT

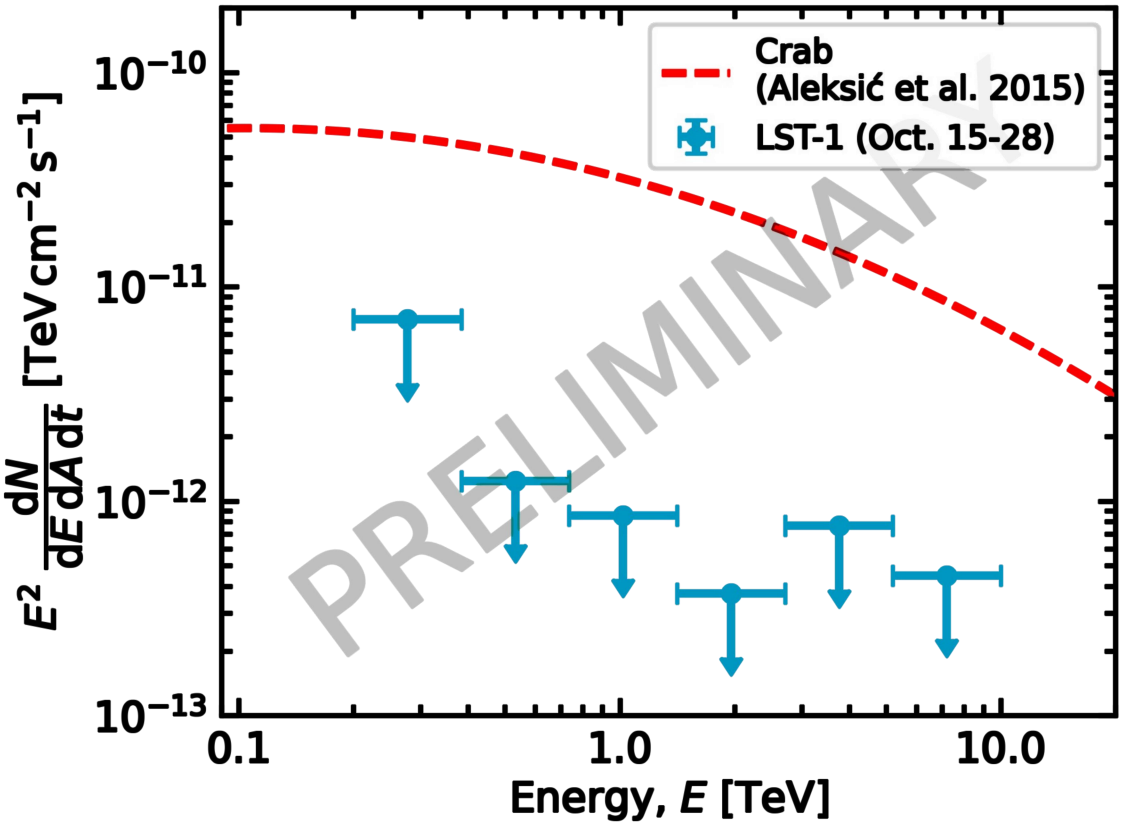
- The perfect GRB for IACTs:
  - bright
  - close
  - low zenith (from La Palma)

- Of course not everything was right:
  - trigger during the day (but not a big problem in this case)
  - trigger during full moon
  - no GBM notice: we would have missed the prompt

- Effort on LST side to have remote observations (with some people onsite for safety) on the day after the trigger
  - data taken under different moon conditions in the first days (day 1 to 5)
    - still under detailed investigation
  - dark data from day 6 on
    - analyzed, no signal (see next slides)

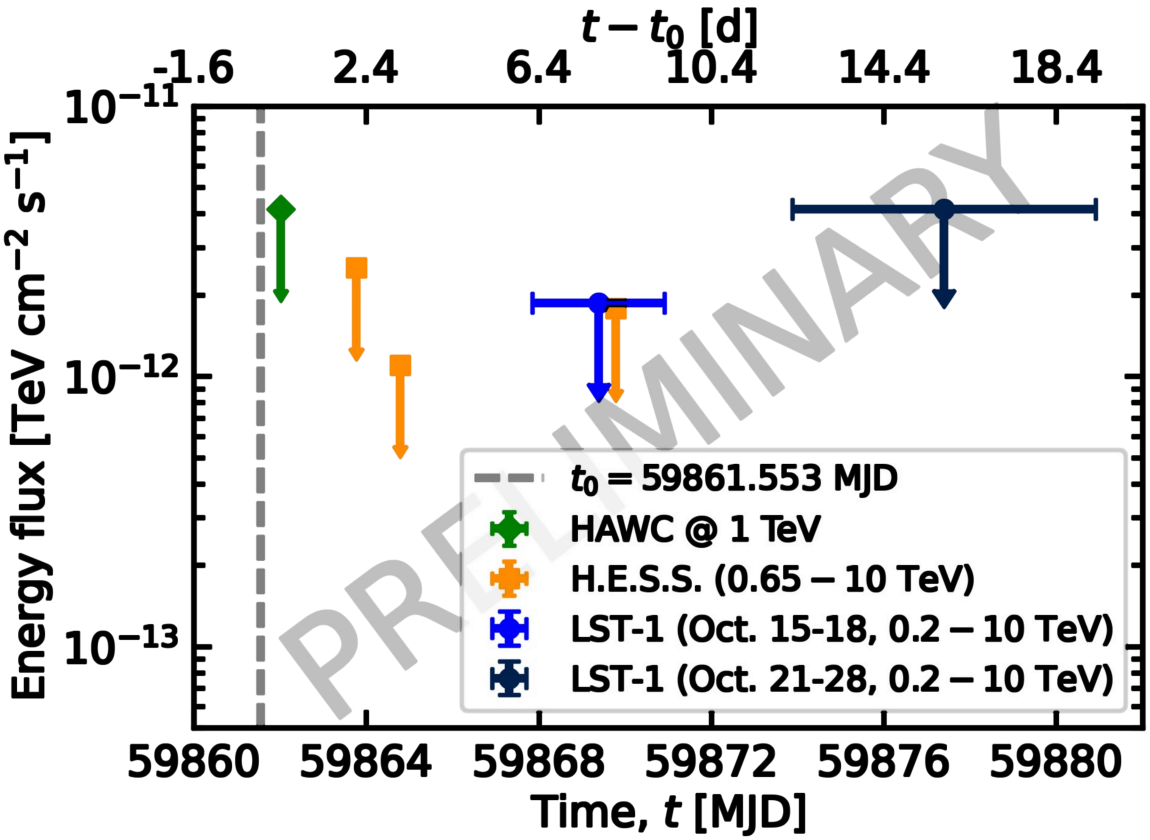
Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT

- LST-1 differential upper limits (E>200 GeV, assumed E^-2 spectrum)



Latest observations with LST-1 through the TH: GRB 221009A aka the BOAT

- LST-1 integral upper limits (200 GeV < E < 10 TeV)



Burst Advocates

- For the prompt reaction during the night, we rely on the Transient Handler
- What about alerts received during the day? Or who decides when to stop/extend an observation during the night? ==> Burst Advocates
- Concept similar to the one adopted in Fermi and also other IACTs
- Burst Advocates in LST
  - 2 people on call per observation period (main BA+deputy)
  - During day: taking decision if an alert should be followed up
  - During night: being on call to support shift crew for ongoing alerts received by Transient Handler
    - check incoming information about the events, decide when to stop/extend the observation (e.g. using RTA)
  - Do a next day analysis or make sure someone is handling it and share the results within the Transient group
  - Sending ToO request for LST observations

Tasks within the Transient group

- If you are interested in Transient sources, signing up as BA is a way to contribute
- From next year, BA could become a LST-1 duty
  - details to be fixed
- First part of 2024 filled, second part of 2024 partly filled
- Other tasks
  - software maintenance/development (e.g. if you are interested in the TH, or implementing new strategies for follow-up)
  - analysis (e.g. next day, or past events not analyzed)
- If you are interested, write to Alice Donini or Monica Seglar-Arroyo

Outlook

- Transient sources are always exciting, LST-1 of course got involved in the business
- Interesting preliminary observations in the first Cycle and results on GWs and GRBs
  - plan is to continue in Cycle II and extend the targets category, room for improvement
- TH at the base of the follow-up
  - many updates in the last year
  - more expected (e.g. tiling for Fermi-GBM events)
  - improvement on TCU side, tests on the automatic procedure performed in the last months, more planned
- BAs needed to trigger or follow observations, fundamental role!
- Some papers on the way (e.g. GRB 221009A)