MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

cta
cherenkov
telescope
array

Transient observations with MAGIC and LST-1

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on behalf of MAGIC and LST-1 collaborations

MAX-PLANCK-INSTITUT
FÜR PHYSIK

1st Astro-COLIBRI multi-messenger astrophysics workshop

Introduction

- Main topic of this talk is the observation of transient sources with MAGIC and LST-1
  - check introduction about transient sources and their multi-messenger emission from the previous session

- Advantage of IACTs is that they are sensitive to short duration events, thanks to large collection area

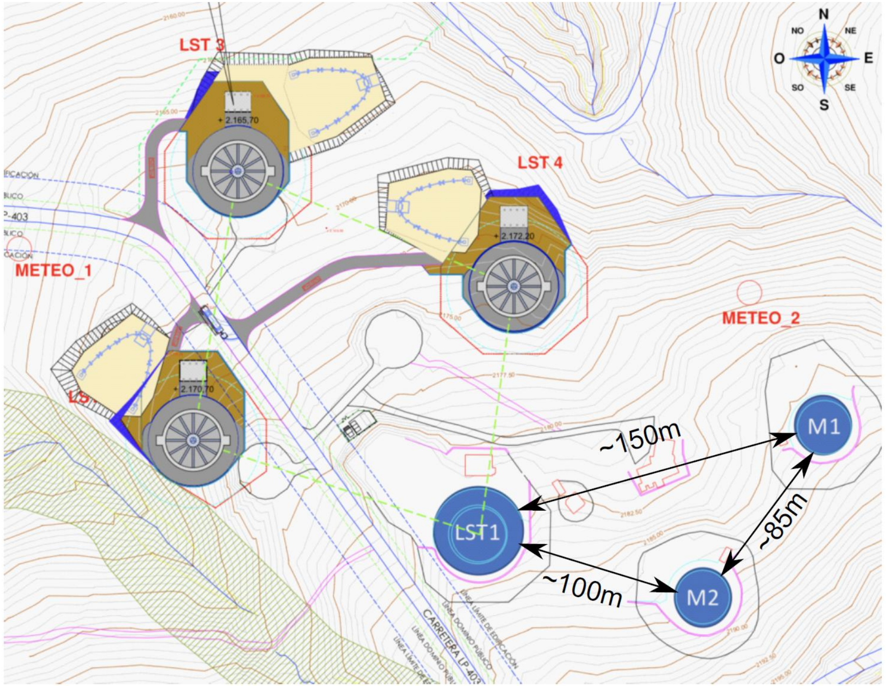
- In particular, MAGIC and LST-1 specialize in fast follow-up, and observations at low energies

MAGIC and LST-1

- MAGIC operates in ORM (Observatorio Roque de Los Muchachos, La Palma, Spain) since 2003 in mono mode, since 2009 in stereoscopic mode

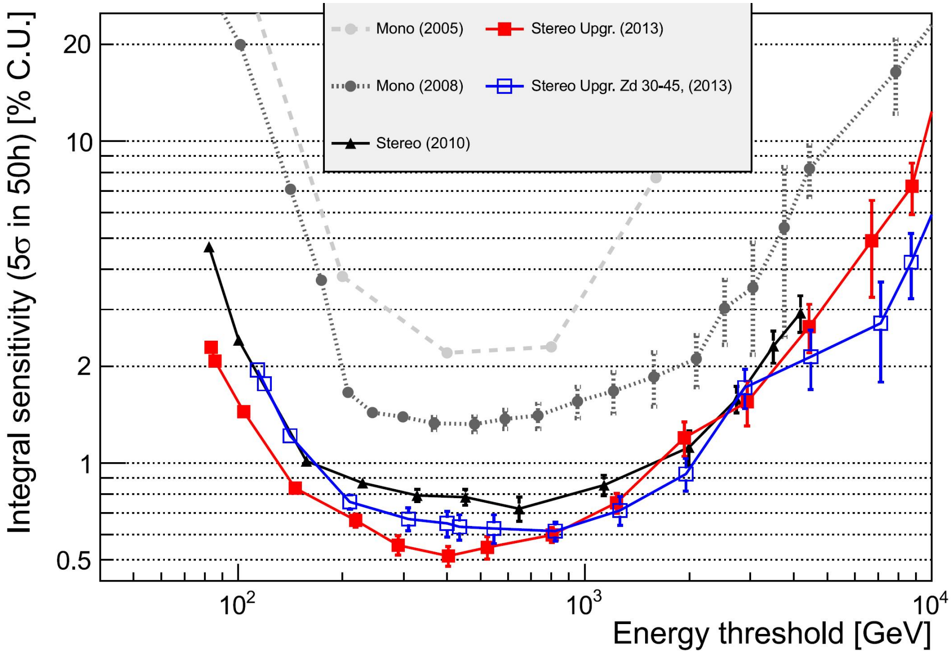
- LST-1 is the first Large-Sized Telescope prototype (out of 4) that will belong to the CTA Northern Array (together with 9 MSTs in the so-called alpha configuration), which again is at ORM

- Possibility of performing joint observations with the two systems --> increased sensitivity



The MAGIC telescopes

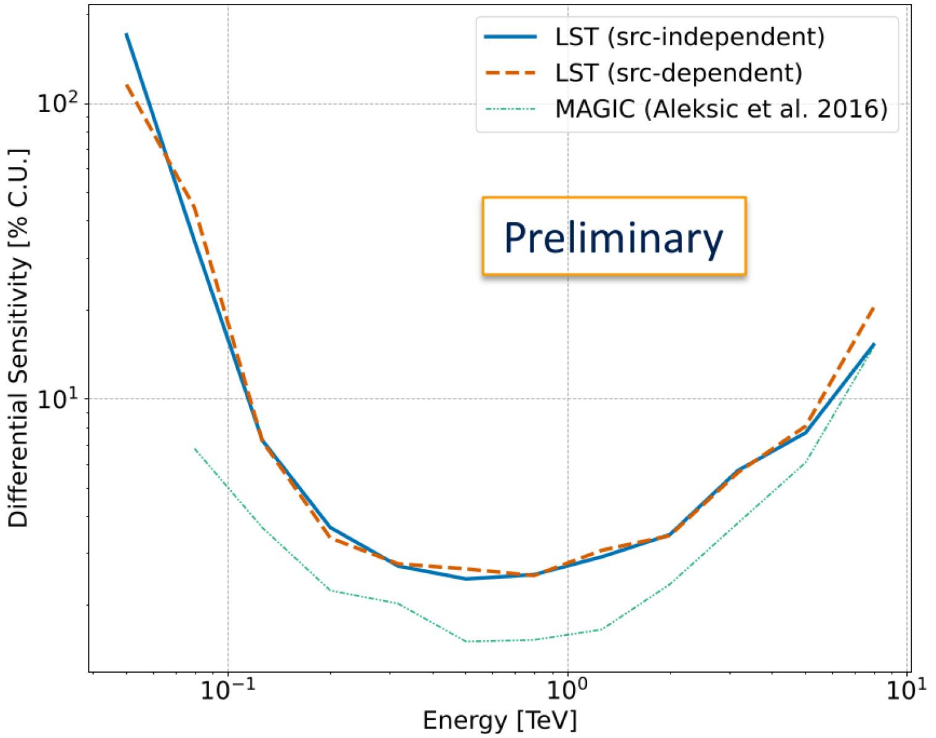
- Energy range: ~50 GeV-50 TeV (with SumTrigger E_{thr}~30 GeV)
- Field of view: 3.5deg
- Sensitivity: 0.7% Crab flux above 220 GeV in 50 h (10% Crab in 1h above 100 GeV)
- Light-weight telescopes: ~70 t
- Observations performed also with moon conditions and at high zenith angles
- Fast repositioning: 7deg/s (4deg/s in std mode)



The LST-1 telescope

- Inaugurated in 2018
- Since then, in commissioning phase (despite pandemic, volcanic eruption, supply-chain crisis, inflation etc.)
- ~800 hours of data taken since Jan 2020 --> evaluation of performance (paper soon to be published)

- 23m diameter reflector (vs 17m of MAGIC)
- Target E_{thr}: ~20 GeV
- Field of view: 4.5deg
- Light-weight telescope: ~120 t
- Fast repositioning: within 20s to any point in the sky



LST-1 sensitivity at zd<35deg (NB: mono!)

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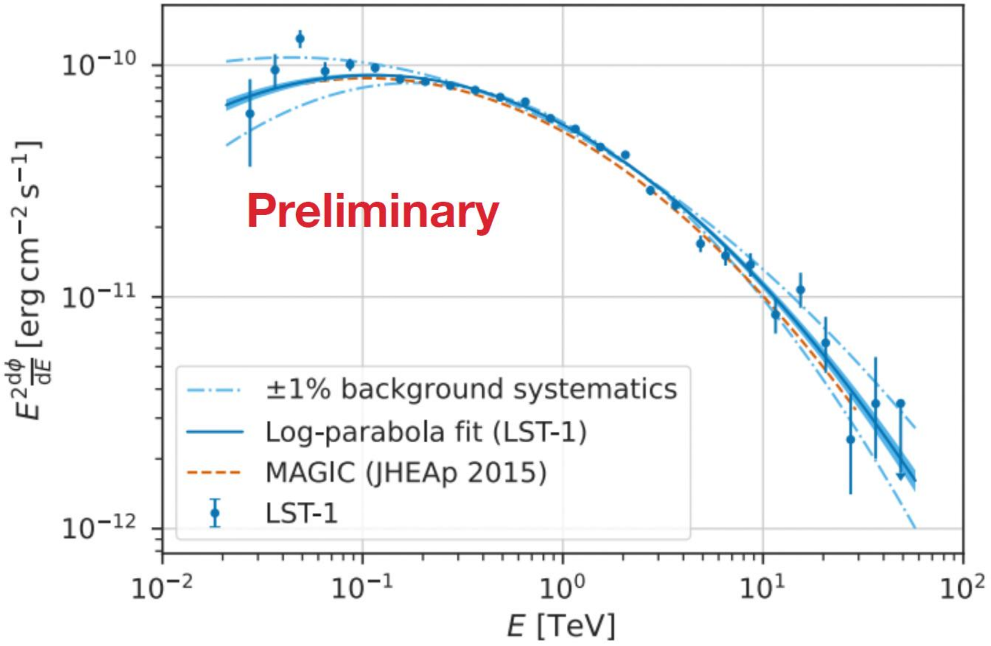
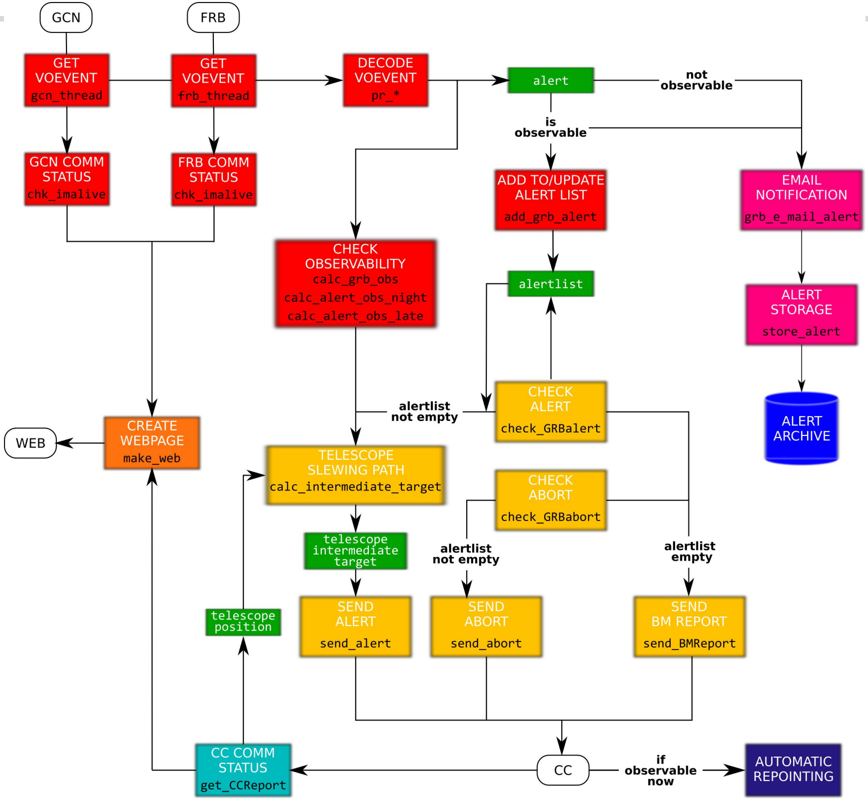
Crab Nebula spectrum (~34h)



First point at ~25 GeV!

MAGIC alert system

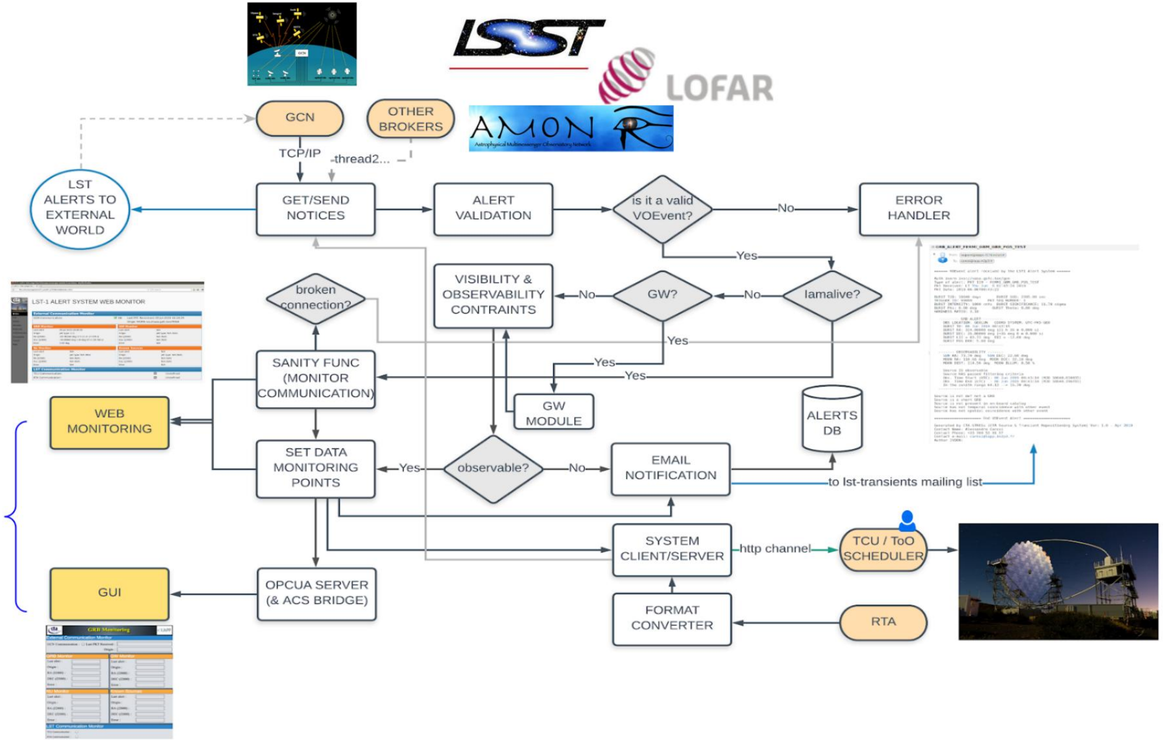
- Initially designed for GRB follow-up only, then adapted to neutrinos, GWs and FRB
- Working with VOEvents (initially with bynary alerts)
- Automatic reaction depending on alert type
- Coming soon update to new GCN Kafka system + GW handling



LST-1 transient handler

Similar to MAGIC one, with few additions

- GW tiling (used also for GBM notices)
- connection to Real Time Analysis (RTA) to send/receive scientific alerts
- OPCUA server connection for exper user testing and debugging



Studying GRBs with IACTs: challenges

Observing GRBs with IACTs 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 GRB coordinates (e.g. from Swift, Fermi)
   - this introduces a delay in the observation, so the most interesting phase of the GRB, the prompt, may be missed

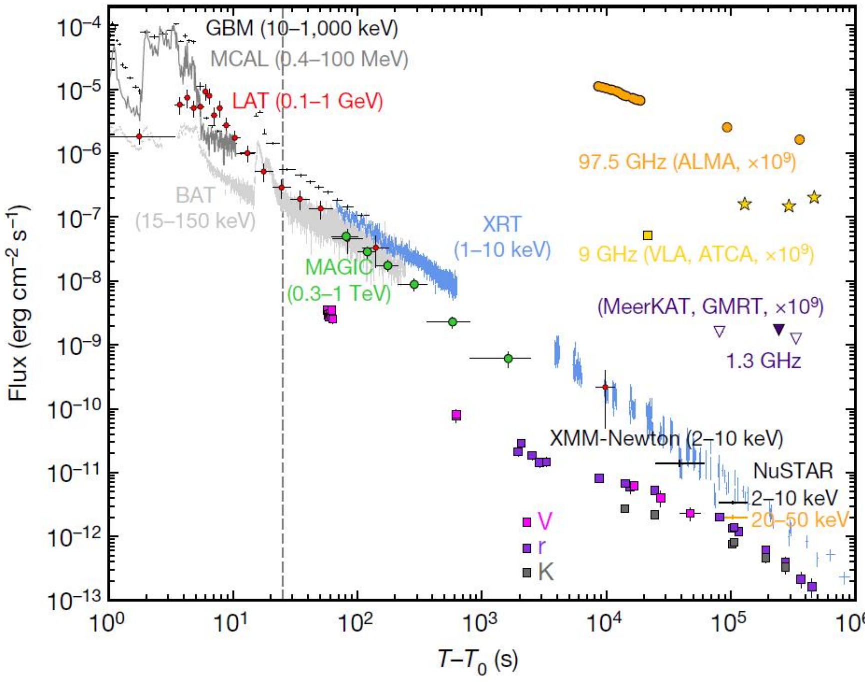
2. GRBs are distant sources (e.g. median redshift for long GRBs is ~2)
   - this translates on a huge absorption of the VHE flux due to the interaction of VHE photons with the ones from the EBL

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 GRB localization with a large uncertainty, so the best fit position may not be the real position of the source, which can fall outside the field of view

GRBs at VHE with MAGIC: GRB 190114C

- Bright long GRB
  - T_{90}~360 s
  - E_{iso}~$3x10^{53}$ (1-10000 keV)
  - z=0.4245
- Follow-up by MAGIC from T_0+57s for 4.4h hours, detection at 50σ level in the first 20 minutes above 300 GeV up to 1 TeV
- Flux level between 200 GeV and 1 TeV similar to that in X-ray band
- Flux decay in TeV and X-rays is similar, link between the two processes



Nature 575, 455-458 (2019) & Nature 575, 459-463 (2019)

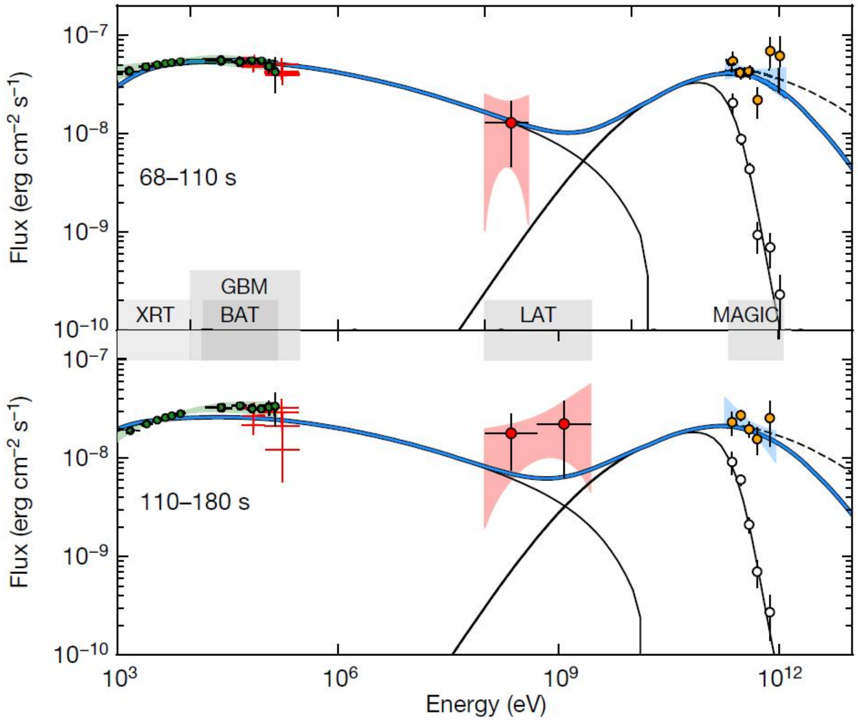
GRBs at VHE with MAGIC: GRB 190114C

- Energies of photons detected by MAGIC well above the synchrotron burnoff limit for a one zone model (<~ 100 GeV for all the MAGIC observation duration)
    - <u>emission process cannot be synchrotron!</u>

- MAGIC TeV data well described by SSC process, with Klein-Nishina and internal g-g absorption considered
    - possibility of fitting only one synchrotron component? see GRB 190829A in the next slides

- **<u>Discovery of a new emission component in the afterglow of a GRB!</u>**

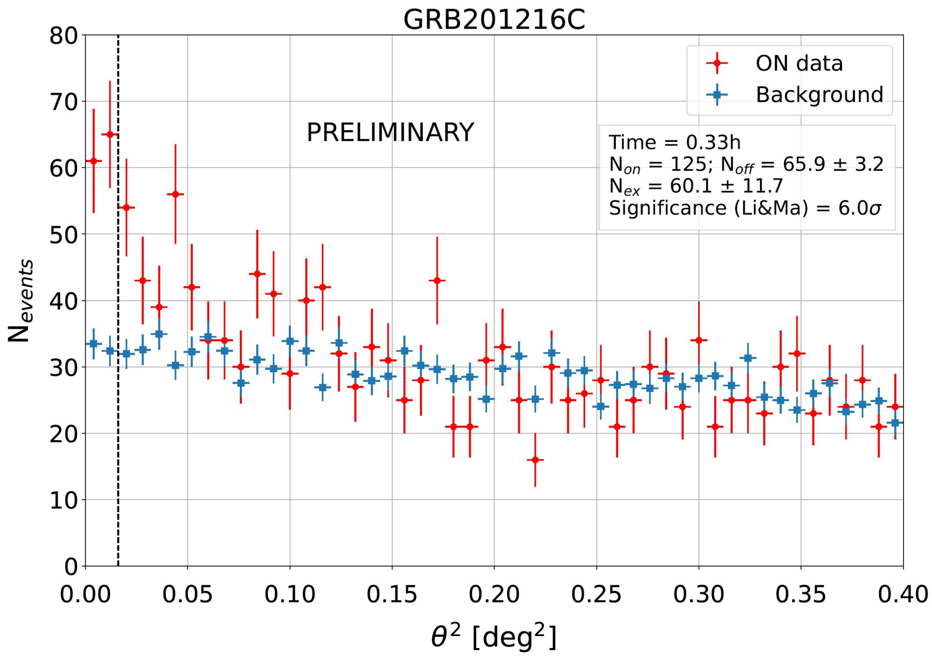
- Modeling parameters in agreement with previous GRB aferglow studies, and GRB 190114C does not seem exceptional
    - VHE emission might be common



Nature 575, 455-458 (2019) & Nature 575, 459-463 (2019)

GRBs at VHE with MAGIC: GRB 201216C

- Long GRB (T90=48s)
- Quite bright: $E_{iso} \sim 5 \cdot 10^{53}$ erg
- Distant: z = 1.1 → the farthest VHE source detected to date!
- But... additional challenge due to high EBL absorption and non-negligible difference between EBL models for such redshift
- Detection reported by MAGIC (see GCN 29075): 6 sigma in the first 20min of observation
- Paper close to be finalized



https://pos.sissa.it/395/788/

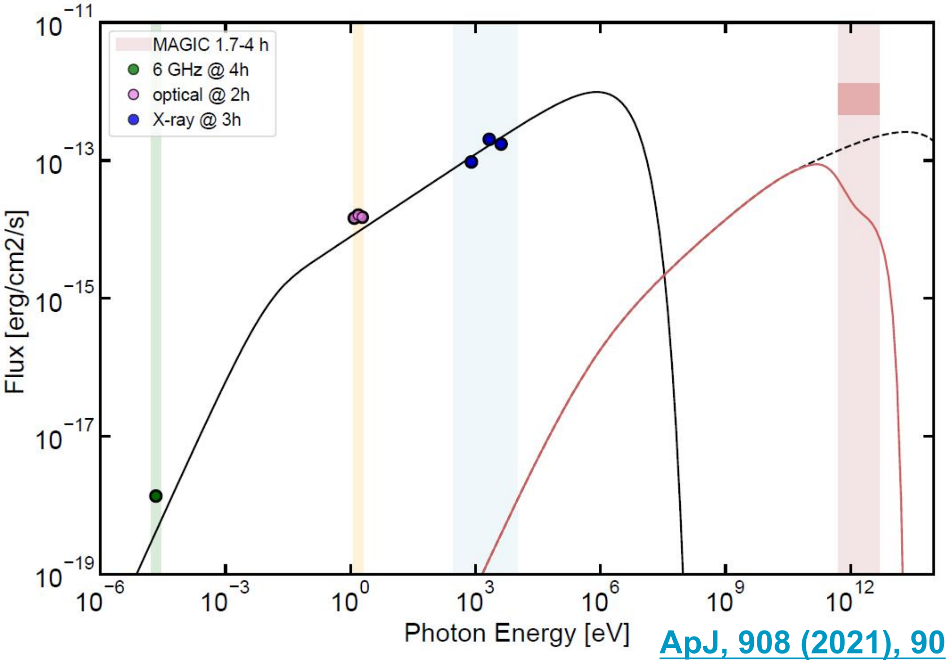
GRBs at VHE with MAGIC: GRB 160821B

- Short GRB at low redshift (z=0.16), fast follow-up by MAGIC (24s)

- Data affected by moon and partially by bad weather
- Hint of detection at 3.1 sigma pre-trial, 2.9 post-trial, the only one from IACT to date

- Kilonova emission confirmed --> progenitor most probably a BNS system
- Simplest emission model (synchrotron + SSC at external forward shock) is in tension with the TeV predicted flux

- Exciting perspectives for the next LIGO-Virgo-KAGRA run O4 (~March 2023)



ApJ, 908 (2021), 90

GRBs with LST-1

	T_0 [UTC]	T_{90} [s]	z	Start time [UTC]	Zenith [deg.]	Delay [s]	Trigger	VHE
GRB 201216C	23:07:31	48.0	1.1	20:57:03	40	79200	*Swift*	Y^{α}
GRB 210217A	23:25:42	4.2	-	23:40:22	44	880	*Swift*	N
GRB 210511B	11:26:39	6	-	03:37:54	45	58200	*Fermi*-GBM	N

Example of GRBs followed-up by LST-1 from Dec 2020 to June 2021

- GRBs are one of the key targets for LST-1 as well, given its low energy threshold: unfortunately, up to now, no detection
- At the moment, the reaction to GRB alerts is not automatic, the telescope operators can decide to postpone it (e.g. if some technical test must be performed)
- In the coming months we will have:
    - automatic repositioning without human in the loop
    - fast repositioning (commisioning of fast movement in elevation)

GRBs at VHE with IACTs: next challenges

1. Our understanding of the afterglow emission is still uncertain despite the recent detected events
   - synchrotron+SSC vs synchrotron in discussion; alternative models (e.g. hadronic)?
   - **we need more GRBs detected at VHE!**

2. Another major breakthrough would be the detection of VHE emission during the prompt phase
   - crucial info on the emission process, still heavily debated
   - current and new ground-based wide field of view instruments (HAWC, LHAASO, SWGO...) may be better suited for this task

3. VHE emission from short GRBs? Strong hint from GRB 160821B by MAGIC
   - interesting in relation to GW searches (O4 starting early 2023)

4. New physics
   - Lorentz Invariance Violation (would need the prompt emission from a distant GRB to be detected)
   - Axion-like particles (search for signatures in the spectra; GRBs detected at high redshift)
   - EBL studies?

GW events with IACTs

Similar challenges as for GRBs affect the follow-up of GW events

- localization can go from few tens to hundreds/thousands of deg^2, which can be as large as an IACT field of view in the best case scenario --> no clear source

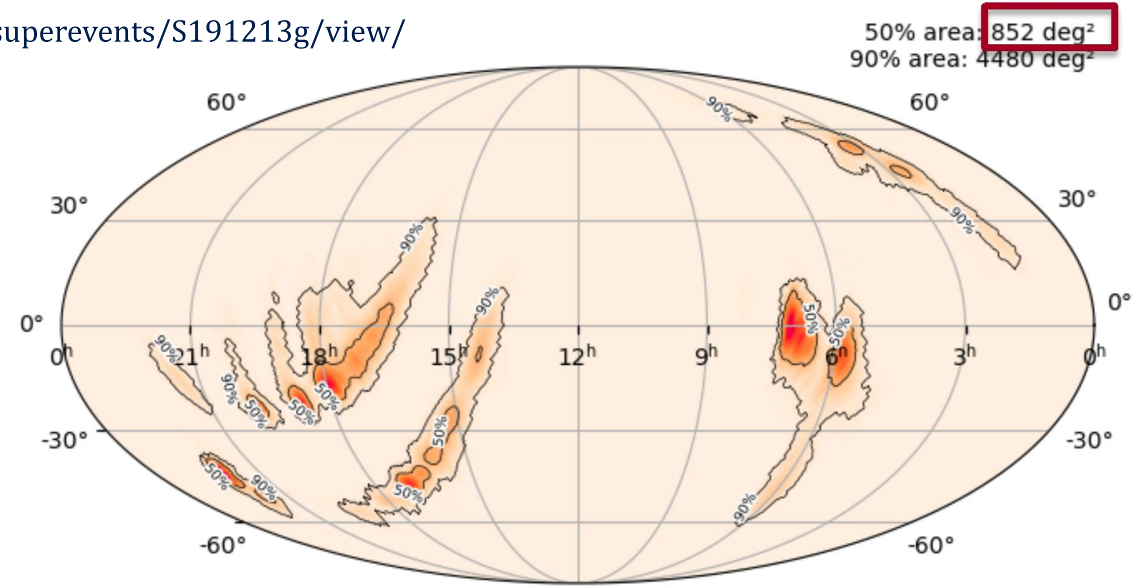
- additional delay introduced to get the signal from interferometers (~few minutes)

- in the case of BNS systems, the resulting GRBs may be off-axis, thus reducing the incoming flux when the jet “opens up” along the line of sight
    - depending on the viewing angle, this may lead to a very faint GRB prompt (e.g. GRB 170817A), or to orphan afterglows

The only way to cope with all these issues is to devise an observational strategy for the follow up of the EM counterpart of GW events

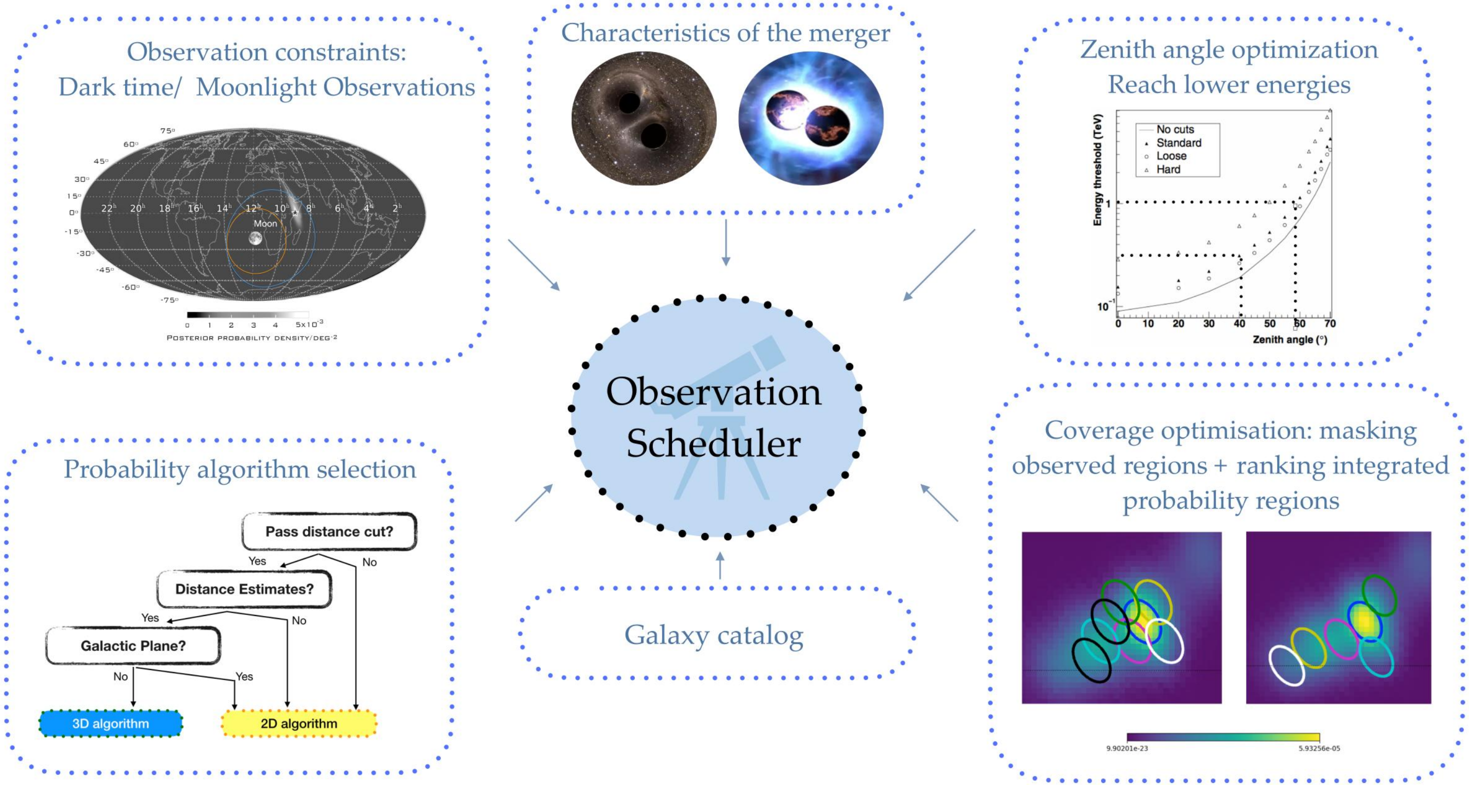
GW events with IACTs

https://gracedb.ligo.org/superevents/S191213g/view/



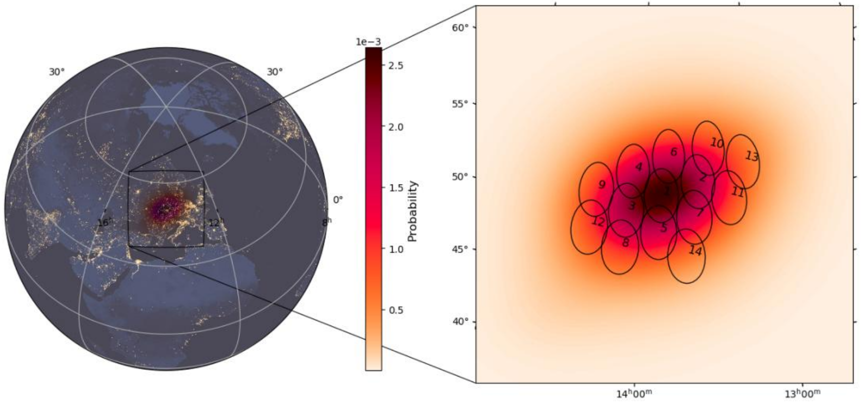
Example of localization from one BNS event (77%), S191213g, d~200 Mpc, LALInference algorithm

GW events observation scheduler for LST-1

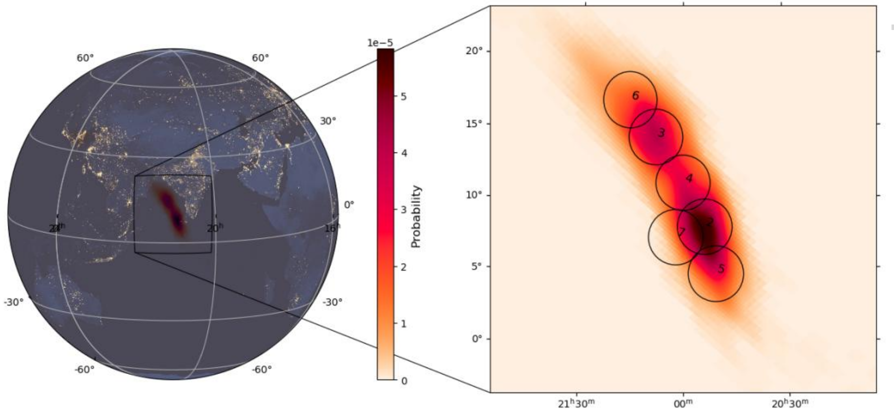


Scheduler algorhitm based on: Ashkar, H., et al. 2021, JCAP 03, 045

GW events with LST-1



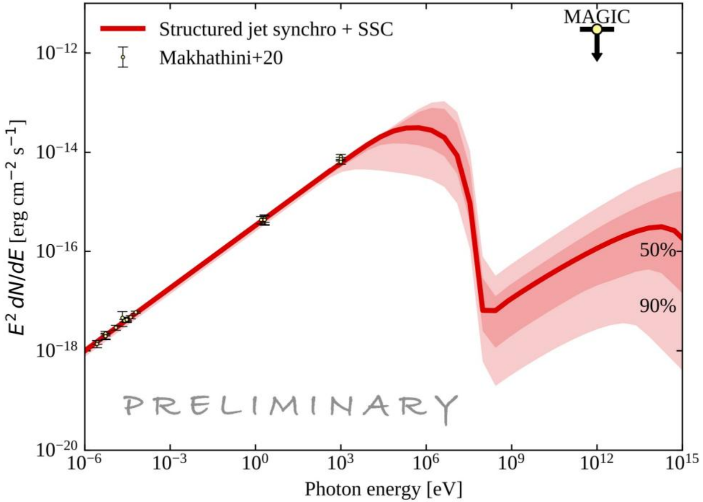
GRB 200303A by Fermi-GBM

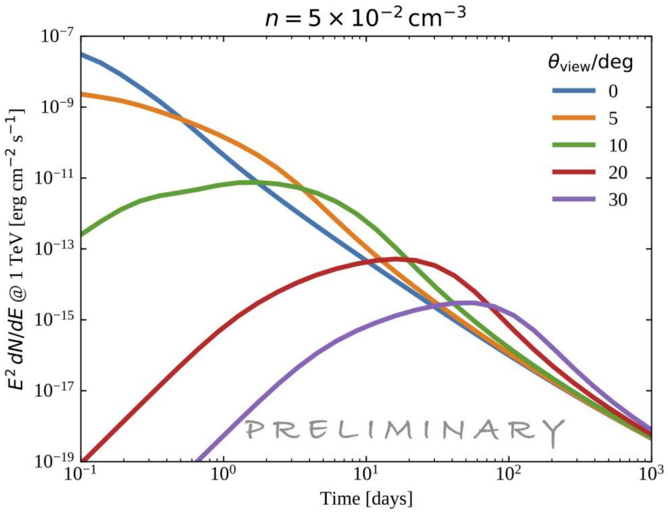


GW190915_235702 by LVC

- The aforementioned observation strategy is being implemented within the LST-1 Transient Handler
  - not only GWs, tiling can be applied also to poorly localized GRBs
  - coverage of most of the localization region
  - RTA will tell if there is a detection and send a science alert to interested parties + change the observation schedule to keep observing the position

GW events with MAGIC: GW 170817





https://pos.sissa.it/395/944/

- MAGIC follow-up of GW170817A
  - at the time of the alert, the EM counterpart was too low on the horizon
  - follow-up ~150 days after merger, but UL not sensitive to constrain possible TeV emission
  - a larger medium density and smaller viewing angle make the emission brighter, and so possibly detectable

Studying neutrino events with IACTs

The case of neutrino combines a bit the challenges from GRBs and GWs

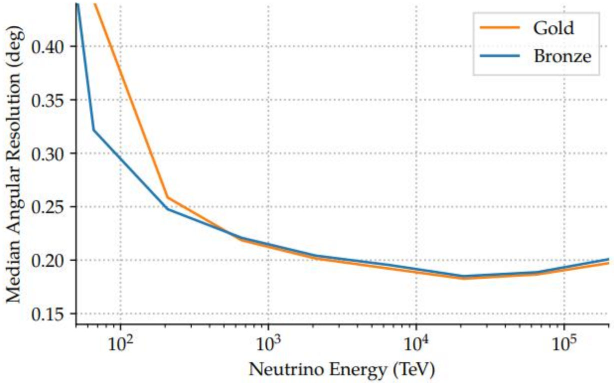
IceCube is the experiment currently sending neutrino alerts

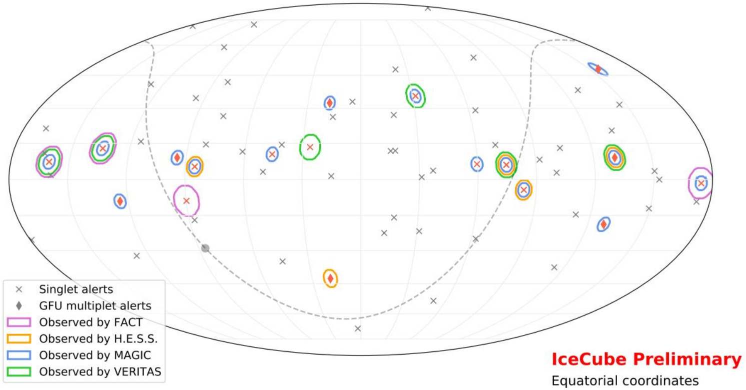
- two public streams
  - GOLD, events having on average 50% probability of being astrophysical
  - BRONZE, events having on average 30% probability of being astrophysical

- two private streams (through a memorandum of understanding between interested parties), soon (?) to become public
  - multiplets coming from specific source
  - all-sky multiplets

Both MAGIC and LST-1 follow-up neutrino alerts, with preference on GOLD alerts for the public stream

- also follow-up of multiplets alerts
- all IACTs NToO paper in preparation

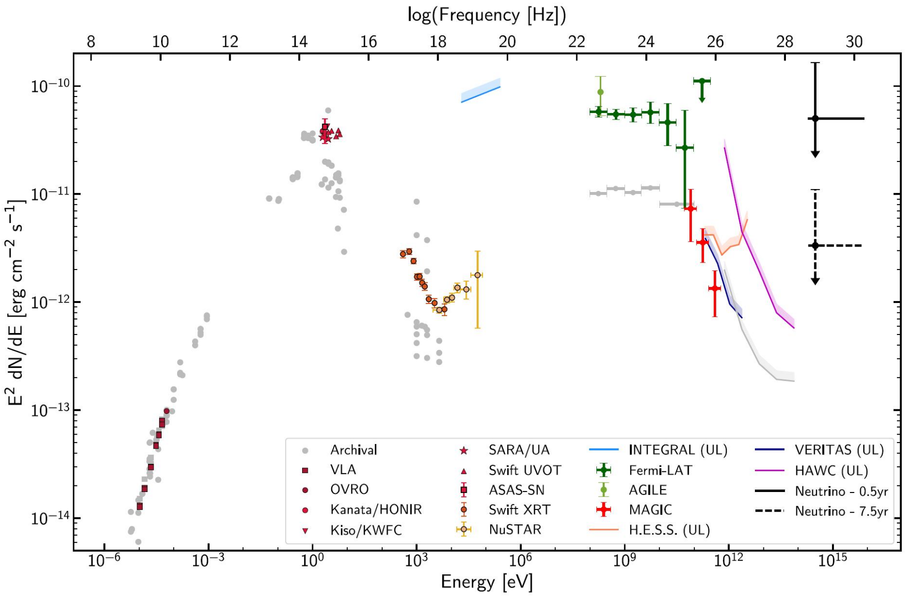




TXS 0506+056: MAGIC detection

- (V)HE gamma rays were 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 acceleration 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)



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

RS-Oph: LST-1 and MAGIC detection

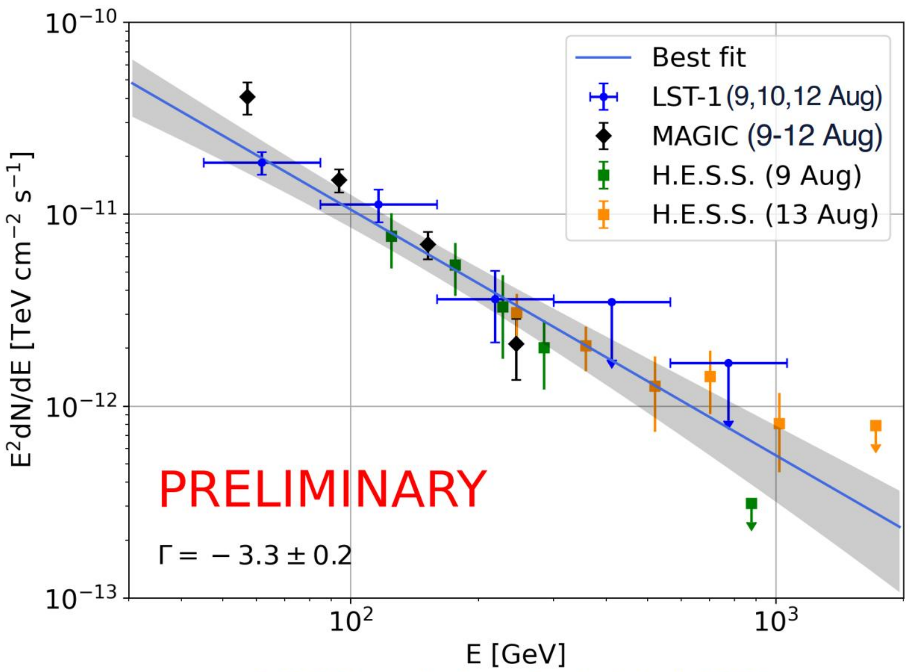
- RS Oph is a recurrent symbiotic nova
  - white dwarf with red giant companion
  - period ~15 years

- Flare on 8th August 2021, both in optical and Fermi-LAT

- Detected by H.E.S.S., then also by MAGIC
  - first nova detected at VHE
  - suggests hadronic emission scenario

- Follow-up by LST-1 on 9th August
  - detection by LST-1 at 7.5sigma in 6.4h!
  - consistent SEDs and LCs

- Paper in preparation



MAGIC results from Acciari et al. 2022
H.E.S.S. results from H.E.S.S. Collaboration 2022.

Prospects for transient observations with MAGIC and LST-1

Both MAGIC and LST-1 spend a lot of observation time on transient sources

- last years were full of discoveries, thanks to high telescope performance, good strategies and MWL/MM interaction and coverage

- showed only main transient targets, but also FRBs, flaring stars, other Galactic transients, AGN flares etc. are within the respective transient programs (possibly coordinated by different working groups)
- other classes of sources under discussion
    - e.g. TDEs, nice connection with neutrinos
        - find best targets and observation strategies

- technical developments
    - move to new GCN Kafka system
    - produce scientific alerts
        - under discussion within MAGIC
        - envisioned within CTA to send them based on RTA results

- MAGIC+LST-1 joint observations on interesting transient targets: increase sensitivity!

- looking forward to interact with the other communities to work together and have new discoveries!