The Cherenkov Telescope Array capabilities for GRB follow-up


(*) Speaker - Université de Genève - DPNC

for the CTA Consortium
GRB at VHE: a long-awaited result

VHE Transient Astrophysics is “warming up” in the last years:

- GRB detection at VHE: a long-awaited result after a 20-years quest! (see presentation on Monday session)

  - MAGIC GRB 190114C… (2019, Nature, 575, 455/459)

and more events announced after these (GRB 160821B, GRB 180720B, GRB 201015A, GRB 201216C....)
The Cherenkov Telescope Array

A facility for Very High Energy gamma-ray astrophysics in the next decades

- near full sky coverage
- wider energy range (~20 GeV - 300 TeV)
- higher sensitivity: ~5-10x current IACT
- better angular resolution: ~5x current IACT
- larger FoV: 2.5x current IACT

- 2 sites (north & south)
- 3 telescope size classes
- tens of telescopes

alpha configuration:
North: 4 LST + 9 MST
South: 14 MST + 37 SST

extragalactic science, transients...
galactic, > 100 TeV

https://www.cta-observatory.org
The LST-1 prototype, the first 23-m class telescope for the CTA, is finalizing its commissioning phase and entering regular scientific operations.

- Low energy threshold (down to ~20 GeV)
- Larger effective area at multi-GeV range and better sensitivity compared to space-based instruments for short-time scale signal (~ $10^4 \times$ Fermi-LAT @ ~ some mins. timescale)
- Fast slewing capabilities (~180°/20s)
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LST “sweet range” (CTA sensitivity mainly dominated by LSTs)

![Diagram showing differential flux sensitivity for different energy ranges and time scales](image)
The Transient Key Science Projects

Transient KSP

- Initially written in 2014
- several interactions since → discussion on modifications to proposed observation allocations (many news since 2014!)

<table>
<thead>
<tr>
<th>Priority</th>
<th>Target class</th>
<th>Observation times (h yr(^{-1}) site(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GW transients</td>
<td>Early phase 20</td>
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<tr>
<td>2</td>
<td>HE neutrino transients</td>
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<td>3</td>
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<th>Years 3–10</th>
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<tbody>
<tr>
<td>Total per site</td>
<td>390</td>
<td>125</td>
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<tr>
<td>Total both sites</td>
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<td>250</td>
<td>190</td>
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<tr>
<td>Total in different CTA phases (h)</td>
<td>1560</td>
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arXiv:1709.07997
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NEW DISCOVERIES → TO BE UPDATED!!
For many years, we anticipated to catch the ‘right’ GRB to detect VHE emission...but our idea of ‘right’ was probably limited (bright, powerful, GeV emitter....)
Why we still need the CTA

For many years, we anticipated to catch the ‘right’ GRB to detect VHE emission...but our idea of ‘right’ was probably limited (bright, powerful, GeV emitter....)

CTA will open the possibility to study a new parameter space region of GRB physics

- Which are the emission mechanisms? VHE during afterglow and/or prompt? **Do all GRB have a VHE component?** Why haven’t we detected GRB before ?!

- We have had some detections (such as GRB 180720B and GRB 190114C) that were somehow 'expected' (bright, powerful etc). However, we also have something that is (apparently) different (GRB 190829A). Are we observing the first (or one of the first) event of a new GRB population? Or do we just have to think that the parameters space of the possible VHE-emitter GRBs is much larger than we thought in the past?
Initial “empirical” approach:

- Some LAT-detected GRBs used as a template to extrapolate expected VHE spectrum & light curves
- Detection rates estimated by means of a simplified GRB population assuming 2 possible spectral model: bandex (Band emission up to VHE range) & fixed (Band+power-law)

Expected detection rate ~ 0.5 GRB yr\(^{-1}\)
(depending on the assumed GRB model and array layout and performance)
CTA capabilities for GRB follow up

New “theoretical” approach:

**POSyTIVE:** POPulation SYnthesis Theory Integrated model for Very high Emission.

**POPyTIVE:**
- The GRB population detected by Fermi-GBM
- The complete sample of Swift GRBs (BAT6 - SBAT4)

Simulation of a GRB population by assuming a few properties:

- **broken power law distribution of the rest frame peak energy** $E_{\text{peak}}$
- **$z$ distribution** (long GRB formation rate is assumed to be proportional to the cosmic star formation rate)
- **$E_{\text{peak}} - E_{\text{iso}}$** assumed (Amati relation)
- **Bulk Lorentz factor distribution obtained from sample GRB for which onset time of the afterglow has been measured** (Ghirlanda+2018)
CTA capabilities for GRB follow up

Prompt Emission

\[ F_{\text{prompt}}(\nu, t) \]

Detectability

Afterglow Emission

\[ F_{\text{after}}(\nu, t) \]

Gamma Ray Burst Population

- Visibility
- Synchrotron self-absorption & photon-photon annihilation taken into account (prompt)
- KN effect considered (afterglow)
- Free parameters calibrated over real sample

- Synchrotron + SSC model (Bošnjak+ 2014 & Sari+2001)

(*) From Bernardini+ 2019: POSyTIVE - a GRB population study for the Cherenkov Telescope Array, PoS(ICRC2019)598
CTA capabilities for GRB follow up

Predicted VHE spectrum & light curves (including EBL attenuation) used to feed dedicated CTA analysis pipeline based on ctools and gammapy

Results to be published in a dedicated *consortium publication*....
Towards first observations

- First regular follow-up with LST-1 started at the beginning of 2021:
  - a bunch of events observed so far (swift malfunctioning)
  - still human-in-the-loop follow-up but implementation of dedicated automatic procedure ongoing
  - initial science already possible

<table>
<thead>
<tr>
<th>Event</th>
<th>$t_0$ [UTC]</th>
<th>$T_{90}$ [s]</th>
<th>$z$</th>
<th>Start time [UTC]</th>
<th>Zenith [deg.]</th>
<th>Delay [s]</th>
<th>Trigger</th>
<th>VHE</th>
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<tbody>
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<td>48.0</td>
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<td>Swift</td>
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<td>-</td>
<td>03:37:54</td>
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<td>IC 210210A</td>
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<td>-</td>
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</table>
Conclusions

- GRBs are one of the main targets for the CTA transient key science program and they represent a frontier subject for VHE astrophysics.
- Within the CTA transient working group, dedicated activities have started to prepare such type of observations and to evaluate CTA capabilities in GRB follow up. Initial work based on empirical approach already provided estimated detection rate up to ~few GRB/year depending on the GRB spectral characteristic and array configuration.
- A new theoretical approach is currently under development in order to simulate a realistic GRB population calibrated over a large sample of real data at different wavebands. The obtained extrapolation in the VHE band coupled with the use of dedicated analysis pipeline making use of the last available IRFs will allow a robust estimate of the expected detection rate and the determination of the GRB-physical parameters space accessible by CTA.