Synergies between CTA and THESEUS

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The Cherenkov Telescope Array (CTA)

Imaging Atmospheric Cherenkov Telescope (IACT) Array: observe Cherenkov emission from gamma-ray initiated cascades in the atmosphere

Consortium: 32 countries, ~1400 scientists, ~208 institutes

Observatory: data openly available after proprietary period, GO programmes, ToOs and DDTs
The Cherenkov Telescope Array (CTA)

2 sites (North and South) for a whole-sky coverage

https://www.cta-observatory.org/about/array-locations/
The Cherenkov Telescope Array (CTA)

All the systems do not have to point to the same direction
The Cherenkov Telescope Array (CTA)

LST
0.02-1 TeV
FoV > 4.4°

MST
0.1-10 TeV
FoV > 7°

SST
5-300 TeV
FoV > 8°
construction already started in 2017
construction period of ~6 years
initial science with partial arrays possible before the end of construction
CTA expected performances

- ~ 5-10 more sensitive than the current IACTs
- broader energy coverage (20 GeV-300 TeV)

- better angular resolution (~3 arcmin at ~ 1 TeV)

# CTA science themes

**Cosmic particle acceleration** *(origin, acceleration site and feedback on star formation and galaxy evolution)*

**Probing extreme environment** *(processes at the vicinity of NSs and BHs, relativistic jets, winds and explosions)*

**Exploring frontiers in Physics** *(dark matter, Lorentz invariance violation)*

## The CTA consortium, ArXiV:1709.07997

## Key Science projects (KSPs)

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Understanding the Origin and Role of Relativistic Cosmic Particles</strong></td>
<td>1.1</td>
<td>What are the sites of high-energy particle acceleration in the universe?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>What are the mechanisms for cosmic particle acceleration?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>1.3</td>
<td>What role do accelerated particles play in feedback on star formation and galaxy evolution?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td><strong>Probing Extreme Environments</strong></td>
<td>2.1</td>
<td>What physical processes are at work close to neutron stars and black holes?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>2.2</td>
<td>What are the characteristics of relativistic jets, winds and explosions?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>2.3</td>
<td>How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Exploring Frontiers in Physics</strong></td>
<td>3.1</td>
<td>What is the nature of Dark Matter? How is it distributed?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>Are there quantum gravitational effects on photon propagation?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>3.3</td>
<td>Do Axion-like particles exist?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>
The transient sky with CTA

- **rapid response to external alerts**, and to deliver alerts to other observatories

- wide FoV+unprecedented sensitivity: **serendipitous detection of transient** (low-latency real-time analysis pipeline to detect gamma-ray events and issue an alert within 60s)

⇒ **characterise different classes of transients:**

  - GRBs
  - multimessenger (MM) transients
  - TDEs, SN shock breakouts, FRBs
  - AGN flares
  - galactic transients (microquasars, PWN flares, novae, magnetars, X-ray binaries, …)
The transient sky with CTA

- **improved sensitivity** for short timescales w.r.t. Fermi-LAT in the range of overlap
- **limited FoV** compared to Fermi-LAT
  - **prompt reaction** to external triggers is critical
  - **fast repointing**: <20s for LSTs and 60s for MSTs and SSTs to and from the obs. sky
  - **divergent pointing and tiling observations** (under study)
The Transients key science project

- a programme responding to a broad range of multi-wavelength and multi-messenger alerts
- rapid feedback to a wide scientific community (selected information communicated in the form of GCNs, Astronomer’s Telegrams, IAU circulars)
- specific strategies will be put in place for different classes of transients (for more detailed guidelines see “Science with the CTA”, ArXiV:1709.07997)

**Proposed max obs. time for follow-up targets in the Transients KSP**

<table>
<thead>
<tr>
<th>Priority</th>
<th>Target class</th>
<th>Observation times (h yr(^{-1}) site(^{-1}))</th>
<th>Early phase</th>
<th>Years 1–2</th>
<th>Years 3–10</th>
<th>Years 1–10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GW transients</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>HE neutrino transients</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Serendipitous VHE transients</td>
<td>100</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>GRBs</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>X-ray/optical/radio transients</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Galactic transients</td>
<td>150</td>
<td>30</td>
<td>0(?)</td>
<td>0(?)</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td><strong>Total per site (h yr(^{-1}) site(^{-1}))</strong></td>
<td><strong>390</strong></td>
<td><strong>125</strong></td>
<td><strong>95</strong></td>
<td><strong>95</strong></td>
<td><strong>1520</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total both sites (h yr(^{-1}))</strong></td>
<td><strong>780</strong></td>
<td><strong>250</strong></td>
<td><strong>190</strong></td>
<td><strong>190</strong></td>
<td><strong>2020</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Total in different CTA phases (h)</strong></td>
<td><strong>1560</strong></td>
<td><strong>500</strong></td>
<td><strong>1520</strong></td>
<td><strong>1520</strong></td>
<td><strong>2020</strong></td>
</tr>
</tbody>
</table>
Synergies with THESEUS

THESEUS will provide:
- external triggers and accurate location for follow-up of high-energy transients as:
  * long/short GRBs
  * TDEs, SN shock breakouts
  * X-ray binaries
  * MM transients
- multi-wavelength characterisation of CTA targets:
  * AGNs/blazars
  * MM emitters

Synergies bw X- and gamma-ray observations:
- X-rays associated to shock waves, accretion or outflows, and hence with particle acceleration
- non-thermal X-rays: synchrotron+IC studies
GRBs with CTA

- expected detection: \(~1\) GRB/yr/site
- improved photon statistics w.r.t. Fermi/LAT:
  - constrain the high-energy spectral component
    - high-energy cutoff
    - measure of the outflow Lorentz factor
  - resolving GRB light curves in more details
    - variability studies
    - Lorentz invariance Violation

![Graph showing GRB light curves with Excess [Bin] vs Time from GRB [sec] and Energy vs E^2 dN/dE (TeV/cm^2/s)](image)

The CTA consortium, ArXiv:1709.07997
Inoue et al., Aph 43, 252, 2013
GRBs with CTA

GRB follow-up strategy:

- **Prompt follow-up** by the full array of all accessible GRB alerts
- Possibility to make **tilings** for large areas
- **Extended observations for detected GRBs** with the full array
- Possible late-time follow-up of high-energy GRBs not accessible promptly

**GRB follow-up strategy and obs. time per site**

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Expected event rate (yr⁻¹)</th>
<th>Exposure per follow-up (h)</th>
<th>Exposure per year (h yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt follow-up of accessible alerts</td>
<td>~12</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Extended follow-up for detections</td>
<td>0.5–1.5</td>
<td>10–15</td>
<td>10–15</td>
</tr>
<tr>
<td>Late-time follow-up of HE GRBs not accessible promptly</td>
<td>~1</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

The CTA consortium, ArXiV:1709.07997
Conclusions

CTA will be a versatile telescope for wide range of science topics

transition from experiment to observatory: open to community access

improved sensitivity on short timescales w.r.t. Fermi/LAT and other IACTs: probe the transient sky at very high energies

CTA full potential reached only by strong synergies with multi-wavelength instruments