Cherenkov Telescope Array: status, LSTs, MSTs

The CTA Consortium\(^1\)
represented by Juan Abel Barrio\(^2\)

\(^1\) cta-observatory.org/consortium_authors/authors_2018_07.html
\(^2\) Grupo de Altas Energías, Universidad Complutense de Madrid
Cherenkov Telescope Array

10 times better sensitivity
10 times larger energy range
Improved angular resolution

Two Sites (N/S)
~ 120 telescopes
Contents

Status of the project

Observatory

Telescopes: LST, MSTs
The Consortium institutes contribute to the bulk of CTA...

31 countries
207 institutes
1473 members (508 FTEs)

June 2018
CTA Sites

- CTA-North @ IAC - ORM
- La Palma, Spain
- CTA-South @ ESO - Paranal, Chile
- Cherenkov Telescope Array Sites
- IAC – Roque de los Muchachos, La Palma, Canary Islands
- CTA-North @ IAC - ORM
- CTA-South @ ESO - Paranal, Chile

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CTA Observatory

... and the Observatory builds and operates it

CTA data open after proprietary period

Provisional sharing: Core, Guest

Open (CTAO) + DDT + Hosts

CTA Council

Key Science Projects (CTAC)

Array sites
CTAO offices
Science Data Management Center

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Timeline

**Design**
2008 - 2012

**Prototyping → Pre-construction**
2012 - Ongoing

Project Phases

- **Pre-Construction**
  - Current Phase

- **Pre-Production**
  - 2019-2021

- **Production**
  - 2021-2025

Current Phase: Pre-Construction

- First Pre-Production Telescopes on Site

CTA Offices Open in Bologna

- Q1 2017
- Q3 2017
- Q1 2018

Infrastructure Design & Procurement

- Q3 2018
- Q1 2019
- Q3 2019
- Q1 2020

- ERIC Established

Financial Threshold Reached

- LST 1 Prototype Completed on North Site
Status of the project

Observatory

Telescopes: LST, MSTs
SSTs spanning for \(\sim 4.5 \text{ km}^2\), in the 5 - 300 TeV region

LSTs at the center of the array, for the 20 - 150 GeV range

MSTs in a \(\sim 1 \text{ km}^2\) area, for the 0.15 - 5 TeV domain
CTAO-IAC agreement signed, preparing infrastructures
Performance
Key Science Projects

- Galactic
  - PeVatrons
  - Galactic Centre
  - Galactic Plane Survey
- Extragalactic
  - Star Forming Systems
  - LMC Survey
- Transients
- Galaxy Clusters

Science with the Cherenkov Telescope Array
arXiv: 1709.07997

8. KSP: Extragalactic Survey
8.3 Data Products

This KSP will produce an extragalactic gamma-ray catalogue of detected sources. For each source, the catalogue will contain the:

- differential energy spectrum,
- significance of the detection,
- source location,
- integral flux,
- variability index,
- extension of the source, if applicable, and
- association with known objects, if made.

The catalogue will also contain the time intervals (modified Julian dates) for the observation periods and the time intervals for any detected flares.

In case of detection of a significant transient event, a public alert will be issued at the earliest possible moment (via, e.g., the Virtual Observatory network using VOEvent protocol, see the Transients KSP in Chapter 9). Interrupting the survey for self-triggers and/or external triggers will be possible but the conditions for such events should be carefully studied and covered by a separate proposal. Follow-up observations are not part of this KSP and are expected to be largely carried out through the GO Programme.

In order to maximize the scientific output of the extragalactic survey, we are planning to organize an extensive multi-wavelength effort to accompany the survey. We foresee obtaining simultaneous optical observations.
KSPs: surveys

Extragalactic survey:
¼ of sky with ~ 6 mCrab sensitivity during ~1000 h
Population studies, unknown sources

Galactic Plane survey:
Full GP with ~2-4 mCrab sensitivity during ~1600 h
~400 new VHE sources: SNR, PWN, PeV candidates

Results from simulations
KSP: transients

CTA transient targets:
- Sensitivity to ~minute to ~day transients
- GRBs, AGN flares, γ-ray binaries, GWs, etc

GRB detection requirements:
- Low energy threshold
- Fast repositioning

**Figure 12**: Simulated light curves of GRB 080916C at \(z = 4.3\) for CTA array. The EBL model of [223] was assumed. Top: Light curve for \(E > 30\) GeV from \(t_0 = 0\) sec, with 0.5 sec time binning. Upper middle: Same as top panel, but plotted from \(t_0 = 30\) sec. Lower middle: Same as upper middle panel, but with 0.1 sec time binning. Bottom: Light curves from \(t_0 = 30\) sec with 0.5 sec time binning, for \(E > 30\) GeV, \(E > 50\) GeV and \(E > 100\) GeV, from top to bottom.

6. Detection Rate Expectations

We now discuss expectations for the detection rate of GRBs with CTA. Two independent approaches are presented, one by Gilmore et al. (see also [224, 225]) and another by Kakuwa et al. (see also [226]). Although they share some similarities in the assumptions, the main difference lies in the modelling of the GRB population, the former based directly on observed GRB samples, and the latter using a somewhat more theoretical method. The treatment of the CTA performance is also different; Gilmore et al. employ a phenomenological model, whereas Kakuwa et al. utilize the official CTA performance files. The results obtained through the two approaches are generally within a factor of 2 of each other and can be considered consistent.

Note that the “delay time” as used below refers to the sum of all types of delays between the satellite-onboard burst trigger and the start of targeted CTA observations, including the time for the GRB alert to reach the telescopes from the satellite, any other kind of delay before the telescopes can start slewing, as well as the slewing time of the telescopes.

6.1. Observation-based population model

Despite being high-priority targets for current IACTs, GRBs have so far escaped detection at VHE and only yielded flux upper limits despite dozens of follow-up attempts (Section 3). High hopes come with the CTA observatory to finally succeed in this endeavor, thanks in particular to its order of magnitude improvement in sensitivity and much lower energy threshold. Unfortunately, because of their transient nature, GRBs are unlikely to be observed serendipitously in the limited field-of-view of IACTs. For example, assuming a whole sky rate of \(\sim 600\) GRBs/yr, a 5° diameter FoV and a 10% duty cycle, the telescopes will cover a patch of the sky where a GRB is expected to go off only once every \(\sim 35\) years. (However, note...''
Contents

Status of the project

Observatory

Telescopes: LST, MSTs
Large Size Telescope

- **Aim**
  - Max. sensitivity 20 -150 GeV
  - Fast slewing: 180° in 20 sec

- **Main specs, inspired by MAGIC**
  - 23 m Ø reflector
  - Light-weight structure ~100 tons
  - 4.5° FOV fast camera
  - Pointing error of 14” (offline)

- **International team**

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Juan Abel Barrio, GAE-UCM
Large Size Telescope

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- **International team**

- **Status and plans**
  - LST1 prototype 1st light in Oct.2018
  - LST2-4 @ CTA-North by 2022, several parts under production
  - Live: [http://www.lst1.iac.es/webcams.html](http://www.lst1.iac.es/webcams.html)
LST structure

- **Azimuth undercarriage**
  - Rail, bogies and central pin
  - Anti-uplifting system
  - 4 motors for fast azimuth slewing

- **Lower structure**
  - Tubular steel structure
  - Two elevation bearings

- **Dish**
  - Space frame with CFRP tubes (few aluminum and steel)
  - 1 motor for elevation slewing
LST structure

- **Azimuth undercarriage**
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- **Camera Support Structure**
  - Arc based on CFRP tubes
  - CFRP stabilizing headstays
LST optics

- **Optical properties**
  - 23 m Ø tesellated reflector
  - Overall parabolic shape, ~400 m²
  - 28 m focal distance, 0.1° pixels

- **Mirror facets**
  - ~200 1.5 m spherical mirrors, 6 radii
  - Cheap and light-weight (~50 kg)
  - Cold-slumped multi-layer sandwich
  - Spot size (D80) ~1/3 of pixel size
  - Multi-layer reflecting surface: evaporated Cr, Al, SiO₂, HfO₂, SiO₂
LST optics

- **Active Mirror Control (AMC)**
  - Correct dish & CSS deformations
  - CMOS camera in each mirror captures IR Optical Axis Reference Laser (OARL) spot
  - Actuators adjust mirror orientation

- **Auxiliary subsystems at dish center**
  - Star-Guider camera, Camera Displacement Monitor, PSF monitor camera
  - Inclinometers + OARL
  - Distance Meters
  - *Camera Calibration*
  - CDM provides camera position wrt OARL; SG provides camera position wrt stars
LST camera mechanics

- **Mechanical structure**
  - Light-weight ~3 m wide sealed camera (with entrance window)
  - Camera front modular design: 7 PMT-pixels + FEB
  - Camera back: trigger, data distribution & servicing

- **Cooling system**
  - Cold (water flow) supporting front plate
  - Air flow + heat exchangers for FEBs and camera back
LST camera electronics

- Focal plane instrumentation
  - 1855 Light-Concentrator + PMT modules, with peak QE above 40%, and Slow Control Board
  - 0.5 – 2000 pe dynamic range based on PACTA-ASIC dual-gain linear preamplifier

- Readout & Trigger
  - FEB based on DRS4 ASIC @ 1 GS/s with 300 MHz BW and 12-bit ADC
  - Analog sum trigger using ASICs at FEB mezzanine board
  - Trigger and clock distribution in daisy chain at Backplane Boards
  - 4-LST Trigger @ Trigger Interface Board
LST camera electronics

- **Data Acquisition**
  - TCP/IP data delivery from FEBs via Ethernet switches
  - Event Building running at up to 15 kHz average rate, including data reduction, at Camera Server PC (2 CPUs, 22 cores)

- **Slow Control and Power Supply**
  - Embedded Camera Controller based on Compact RIO
  - Power Supply units deliver 24 V to FEBs via bus bars with Solid State Relays

- **Camera calibration**
  - Camera flat-fielding using a UV laser source at the centre of the dish
  - Single Photoelectron LED source

- **LST1 camera integration**
  - Integration and extensive tests finished by mid-July 2018
Contents

Status of the project

Observatory

Telescopes: LST, DC-MSTs
Davies-Cotton Medium Size Telescope

- **Aim**
  - Max. sensitivity in core range 0.15 – 5 TeV
  - Robust design for large scale O(40) production

- **Main specs, inspired by HESS/VERITAS**
  - 12 m Ø reflector, modified Davies-Cotton design
  - ~8° FOV ~3 m wide camera, with 0.18° pixels, in two designs: FlashCam and NectarCAM
  - Pointing error 7” (offline)

- **International team**

- **Status and plans**
  - MST structure since 2012 at Berlin, tested with FlashCam (fall 2017) and NectarCAM (fall 2018)
  - 2 pre-production MSTs with FlashCam in CTA-South by 2021
  - 1 pre-production MST with a NectarCAM in CTA-North by 2021
DC-MST structure & optics

- Positioner
  - Tower + head + yokes
  - Azimuth drive rotates head, elevation drives rotate yokes

- Optical Support Structure
  - Mirror area \( \sim 90 \text{ m}^2 \)
  - Optical PSF < 0.18°
  - Steel beams, providing an aprox. overall spherical shape with \( \sim 16 \text{ m} \) focal distance

- Camera support structure
  - Steel tubes connecting OSS and camera

- Mirrors facets and AMC
  - \( \sim 86 \) 1.2 m spherical mirrors, with similar technology as LST
  - Same actuators as LST
  - Single CCD for mirror adjustment and pointing correction
DC-MST FlashCam

- **Architecture**
  - Nearly-sealed camera with forced air cooling
  - 1758 PMT-based pixels in a Photon Detection Plane
  - Horizontal architecture, with PDP signals delivered via CAT6 cables to rack-based readout electronics
  - 0.2 – 3000 pe dynamic range based on single non-linear preamplifier

- **Readout & trigger**
  - Fully-digital readout & trigger, based on commercial 250 MS/s 12-bit FADCs
  - Flexible trigger decision based on digitized PMT signals
  - Up to 30 kHz deadtime-free Ethernet-based DAQ, based on 32 µs ring buffers at FPGA readout boards
DC-MST FlashCam

- **Status**
  - Full-size prototype tested in lab since 2016 using Cherenkov- and NSB-like light sources (*shown in RICH2016*)
  - Installation procedure for 1 week at the MST prototype Berlin site. Remotely operated without human intervention for 7 weeks
  - Huge Berlin NSB required absorbing foils in front of camera
  - Cosmic ray showers observed !!

- **Plans**
  - 2 pre-production MSTs with FlashCam in CTA-South by 2021
DC-MST NectarCAM

- **Architecture**
  - Sealed camera with forced air cooling
  - 1855 pixel camera with modular design: 7 PMT-pixels + FEB
  - 0.5 – 2000 pe dynamic range based on PACTA-ASIC dual-gain linear preamplifier
  - Sharing commonalities with LSTCAM

- **Readout & trigger**
  - FEB based on NECTAR ASIC (including 12-bit ADC) @ 1 GS/s with 300 MHz BW
  - Most readout and trigger steps encapsulated in ASICS
  - Multi-level flexible digital trigger
  - Deadtime < 5% at 7 kHz
DC-MST NectarCAM

- **Status**
  - Ongoing construction of a partially-equipped camera (60 modules) and full-size mechanics
  - Camera integration focusing on Berlin tests
  - Test-benches and set-ups for mass production already developed

- **Plans**
  - Field tests at Berlin prototype MST during fall 2018
  - Full Qualification-Model camera by fall 2019
  - New deadtime-free NECTAR ASIC under development

Juan Abel Barrio, GAE-UCM
Contents

Status of the project
Observatory
Telescopes: LST, SC-MSTs
Schwarzschild-Couder MST

- **Aim**
  - Max. sensitivity in core range 0.15 – 5 TeV
  - Enhanced $\gamma$-ray angular resolution

- **Main specs**
  - Dual-mirror Schwarzschild-Couder optics with 10 m Ø primary mirror
  - 8° FOV camera, with 0.07° pixels

- **US teams with international contributions**

- **Status and plans**
  - Prototype SC-MST (pSCT) finished by Aug. 2018 at VERITAS site → 1-year commissioning
SC-MST structure & optics

- Positioner and drive assemblies
  - Identical to DC-MST ones

- Optical System
  - Primary (M1) mirror 9.7 m Ø (~50 m²)
  - Secondary (M2) mirror 5.4 m Ø
  - M1 and M2 made of aspheric panels (high curvature specially for M2)
  - Optical PSF < 0.07° across full 8° FOV
  - Very complex Global Alignment System
  - Camera in the focus of M2
  - Baffles to prevent sun-light and stray light
SC-MST structure & optics

- Positioner and drive assemblies
  - Identical to DC-MST ones

- Optical System
  - Primary (M1) mirror 9.7 m Ø (~50 m²)
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  - Very complex Global Alignment System
  - Camera in the focus of M2
  - Baffles to prevent sun-light and stray light

- Status and plans
  - M1 mounted with alignment in progress
  - Camera mounted
  - M2 mirror panels under assembly, to be installed during summer 2018
SC-MST Camera

- **Architecture**
  - SC optics $\rightarrow$ larger plate scale (0.07° per 6 mm) than DC $\rightarrow$ smaller camera (~1 m wide) covering 8° FOV with 11328 SiPMs pixels arranged in 177 modules
  - 1 module = 4 SiPM tiles = 64 image pixels = 4 trigger pixel
  - Sealed camera with forced air and Peltier cooling
  - Sharing commonalities with the GCT-SST camera
  - Focal plane module with SiPM and temperature control

- **Readout & trigger**
  - FEB including preamp, TARGET7 ASIC @ 1 GS/s with 300 MHz BW, trigger and Slow Control
  - Digital trigger system at camera backplane FPGA
  - Distributed Array Trigger among SC-MST to reduce readout trigger to ~5 kHz

1 image pixel 6 x 6 mm

1 tile = 1 trigger pixel
SC-MST Camera

- Status and plans
  - pSCT equipped with 25 modules: 16 (US-Hamamatsu) + 6 (IT-INFN-FBK) modules produced and lab-tested. 3 more INFN modules in progress
  - Partially-populated (25/177) camera just installed in pSCT and currently observing NSB
  - Start camera commissioning with cosmic-ray showers as soon as M2 is installed in August 2018.
Conclusions

- VHE gamma-ray astronomy is a mature branch of astronomy
- CTA will be an open all-sky observatory
  - Focus on cosmic particle acceleration, extreme environments and fundamental physics
  - Key role in multi-messenger astronomy
  - Legacy dataset
- Improved sensitivity and energy coverage, based on proven technologies
- CTA-North at La Palma, Spain; CTA-South near Paranal, Chile
- LST and MST prototype telescopes under construction
- Full CTA construction is ramping up !!!
Conclusions

VHE gamma-ray astronomy is a mature branch of astronomy

- Focus on cosmic particle acceleration, extreme environments and fundamental physics
- Key role in multi-messenger astronomy
- Legacy dataset

- Improved sensitivity and energy coverage, based on proven technologies

- CTA-North at La Palma, Spain; CTA-South near Paranal, Chile
- LST and MST prototype telescopes under construction

Full CTA construction is ramping up !!!

Visit us at www.cta-observatory.org
CTA Sites

Site selection: 2012-2015 process

5 Northern site candidates
2 sites in Arizona
Mexico

5 Southern site candidates
2 sites in Argentina
Chile

2 Sites in Namibia
Tenerife
La Palma

2 Sites in Argentina

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## Key Science Projects

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<tbody>
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<td>Understanding the Origin and Role of Relativistic Cosmic Particles</td>
<td>1.1 What are the sites of high-energy particle acceleration in the universe?</td>
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<td>1.2 What are the mechanisms for cosmic particle acceleration?</td>
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<td>1.3 What role do accelerated particles play in feedback on star formation and galaxy evolution?</td>
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<td>Probing Extreme Environments</td>
<td>2.1 What physical processes are at work close to neutron stars and black holes?</td>
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<td>Exploring Frontiers in Physics</td>
<td>3.1 What is the nature of Dark Matter? How is it distributed?</td>
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<td>3.2 Are there quantum gravitational effects on photon propagation?</td>
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<td>3.3 Do Axion-like particles exist?</td>
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Science with CTA, arxiv: 1709.07997
CTA operating principle

Effective area & angular resolution improvement

Light pool radius $R \sim 100-150 \text{ m}$
~ typical telescope spacing

Sweet spot for best triggering and reconstruction: **most showers miss it!**

D.A. Williams 2013

Large detection area
More images/ shower
Lower trigger threshold

Funk & Hinton 2009

![Diagram showing light pool radius and sweet spot for triggering and reconstruction](image)