Cherenkov Telescope Array: The Next Generation Gamma-ray Observatory

ICRC 2017 (Busan, Korea), 13 July 2017

The CTA Consortium¹, represented by Rene A. Ong²

¹See http://www.cta-observatory.org/consortium_authors/authors_2017_07.html
²University of California, Los Angeles, CA, 90095, USA
2005-2017: VHE Astronomy Comes of Age

• Dominant expectation (pre-1990)
  – Will find the “cosmic ray” accelerators – probably SNRs
• Reality (2017)
  – Astonishing variety of VHE † emitters
    • Within the Milky Way
      – Supernova remnants
      – Bombarded molecular clouds
      – Stellar binaries - colliding wind & X-ray
      – Massive stellar clusters
      – Pulsars and pulsar wind nebulae
      – Supermassive black hole Sgr A*
      – Diffuse & extended emission
    • Extragalactic
      – Starburst galaxies
      – MW satellites
      – Radio galaxies
      – Flat-spectrum radio quasars
      – ‘BL Lac’ objects
      – Gamma-ray Bursts

† 0.05-50 TeV
Imaging Atm. Cherenkov Technique

Atm. Cherenkov showers:
- V. large light pool ~250 m diameter
- Rapid time structure ~ 5 ns
- Very calorimetric
- Fine angular structure (< 1’)  

Imaging technique:
- Excellent shower reconstruction
- Large background rejection

Well-demonstrated by current instruments: H.E.S.S., MAGIC, & VERITAS

But we have not reached limit of the technique!

Further improved by:
- More views of shower
- Higher resolution images
- Wider field-of-view
Larger area → More contained events, more images

- Light pool radius
  \[ R \approx 100-150 \text{m} \]
  \[ \approx \text{typical telescope Spacing} \]

- Sweet spot for best triggering & reconstruction...
  *most showers miss it!*

- Larger detection Area
- More Images per shower
- Better $\gamma$-ray reconstruction
- Lower energy threshold
Planning for the Future

What do we know, based on current instruments?

Great scientific potential exists in the VHE domain
  - Frontier astrophysics & important connections to particle physics

Imaging Cherenkov technique is very powerful
  - Have not yet reached its full potential → large telescope array

Exciting science in both Hemispheres
  - Argues for an array in both S and N

Open Observatory gives substantial reward
  - Open data/access, MWL connections to get the best science

International partnerships required by scale/scope
  - Challenges associated with putting pieces together (i.e. funding streams, communities, etc.)
The Consortium originated CTA and will contribute to the construction of the arrays.

32 countries, ~1402 scientists, ~208 institutes, ~480 FTE
CTA Main Scientific Themes

Cosmic Particle Acceleration
– How and where are particles accelerated?
– How do they propagate?
– What is their impact on the environment?

Probing Extreme Environments
– Processes close to neutron stars and black holes
– Processes in relativistic jets, winds and explosions
– Exploring cosmic voids

Physics frontiers – beyond the Standard Model
– What is the nature of Dark Matter? How is it distributed?
– Is the speed of light a constant for high-energy photons?
– Do axion-like particles exist?

→ See upcoming “Science with CTA” document
Requirements & Drivers

Energy coverage down to 20 GeV
(Discovery domain: GRBs, Dark Matter)

Energy coverage up to 300 TeV
(Pevatrons, hadron acceleration)

Good energy resolution, ~10-15%:
(Lines, cutoffs)

Large Field of view 8-10°
(Surveys, extended sources, flares)

Rapid Slew (20 s) to catch flares:
(Transients)

10x Sensitivity & Collection Area
(Nearly every topic)

Angular resolution < 0.1° above most of E range
(Source morphology)
CTA Design (S array)

Science Optimization under budget constraints

**Low energies**
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
*(LST’s)*

**Medium energies**
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
*(MST’s/SCTs)*

**High energies**
Up to > 300 TeV
10 km² eff. area @ 10 TeV
4m diameter
70 telescopes
*(SST’s)*
Flux Sensitivity

Major sensitivity improvement & wider energy range

Differential flux sensitivity

$E^2 \times \text{flux sensitivity (erg cm}^2 \text{s}^{-1})$

Energy $E_R$ (TeV)

CTA North 50 h

CTA South 50 h

MAGIC 50 h

H.E.S.S. 50 h

LAT Pass 8 (10y/LPA=0.66)

LAT Pass 8 (10y/LPA=2045)

HAWC 1 year

HAWC 5 year

VERITAS 50 h

www.cta-observatory.org (2017-07-05)
Galactic Discovery Reach

Current Galactic VHE sources (with distance estimates)

HESS/VERITAS
Galactic Discovery Reach

Current Galactic VHE sources (with distance estimates)

HESS/VERITAS

CTA
Galactic Discovery Reach

Current Galactic VHE sources (with distance estimates)

Survey speed: x300 faster than current instruments
Angular Resolution

8° CTA FoV

Example: Cen A

0.1°
Typical
HESS/MAGIC/VERITAS
Resolution

15° CTA > 1 TeV

HESS centroid
error

2°
CTA > 1 TeV

HESS centroid
error

Fermi
(10 GeV)

HESS
(3 TeV)

CTA
(3 TeV)
Key Science Projects (KSPs)

- Dark Matter Programme
- ExGal Survey
- Star Forming Systems
- Transients
- Extragalactic
- Galaxy Clusters
- Galactic Plane Survey
- Galactic Centre
- LMC Survey
- PeVatrons
- AGN
Key Science Projects (KSPs)

Transients

Galaxy Clusters

Extragalactic

Star Forming Systems

AGN

Galactic Plane Survey

PeVatrons

Galactic Centre

CTA Science talks:
R. Zanin 15/07 GA044
T. Hassan 18/07 GA145
A. Morselli 19/07 DM015
Large Telescope (LST)

- 23 m diameter
- 390 m$^2$ dish area
- 28 m focal length
- 1.5 m mirror facets

- 4.5° field of view
- 0.1° PMT pixels
- Camera Ø over 2 m

- Carbon-fiber structure for 20 s positioning

- Active mirror control

- 4 LSTs on South site
- 4 LSTs on North site

Prototype construction Underway (La Palma)

Talk by M. Teshima – this session
Medium Telescope (MST)

Prototype MST near DESY (Berlin)

- 100m² mirror dish area
- 16 m focal length
- 1.2 m mirror facets
- 8° field of view
- ~2000 x 0.18° PMT pixels
- 25 MSTs on South site
- 15 MSTs on North site

Prototype FlashCAM camera
Medium 2-mirror Telescope

Schwarzschild-Couder Telescope (SCT)

- 9.7 m primary
- 5.4 m secondary
- 5.6 m focal length, f/0.58
- 50 m² mirror dish area
- PSF better than 4.5’ across 8° FOV

- 8° field of view
- 11328 x 0.07° Si-PM pixels

→ Improved γ-ray angular resolution

Prototype SCT at Whipple Obs, Arizona

Talk by V. Vassiliev – this session
Small Sized Telescopes (SSTs)

- 3 different prototype designs
- 2 designs use two-mirror approaches (Schwarzschild-Couder design)
- All use Si-PM photosensors
- 8-10 m² mirror area, FOV > 9°

SST-1M
Krakow, Poland
Talk by C. Alispach
– this session

SST-2M ASTRI
Mt. Etna, Italy
Talk by M.C. Maccarone
– this session

SST-2M GCT
Meudon, France
Talk by H. Sol
– Monday, 13:30-15:00
CTA Sites

- CTA-North
  La Palma (Spain)

- CTA-South
  ESO/Paranal (Chile)
La Palma – CTA North

- Canary Islands, Spain
- Observatorio del Roque de los Muchachos
- Existing observatory, under management by Instituto de Astrofísica de Canarias (IAC)
- Site of LST 1 & existing MAGIC telescopes
- Current work: topographical study, building concepts, tender for geotechnical study soon
ESO PARANAL – CTA South

- Atacama Desert, Chile, south of Cerro Paranal
- Existing observatory, under management by European Southern Observatory (ESO)
- Near a set of existing (VLT) and future (ELT) telescopes
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Current work: geotechnical studies (boreholes), topographical survey, concepts for roads, power, ducting, & buildings

- 4 LSTs
- 25 MSTs
- 70 SSTs
• 2016-7: Hosting agreements, site preparations start
• 2018: Start of construction
• Funding level at ~65% of required for baseline implementation → start with threshold implementation → additional funding & telescopes needed to complete baseline CTA
• Construction period of ~6 years
• Initial science with partial arrays possible before construction end
We’ve learned a lot from previous/present experiments

With many discoveries, VHE $\gamma$-ray astronomy has become a major and exciting field of research.

Outstanding science potential and the power of the atmospheric Cherenkov technique $\rightarrow$ CTA

Cherenkov Telescope Array (CTA)*

Outstanding sensitivity & resolution over wide energy range
Far-reaching key science program
Open observatory with all data released to public

CTA prototyping/design is largely completed; now ready to develop both sites and enter pre-production of telescopes

In next decade, CTA will provide data of a quality not yet seen in the HE/VHE $\gamma$-ray band

*We gratefully acknowledge financial support from the agencies and organizations listed here:  http://www.cta-observatory.org/consortium_acknowledgments.
# CTA Talks at ICRC 2017

## GA Parallel, Friday, July 14: 16:30-18:30

<table>
<thead>
<tr>
<th>Name</th>
<th>GA</th>
<th>Title</th>
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<tbody>
<tr>
<td>Rene Ong</td>
<td>GA325</td>
<td>Cherenkov Telescope Array: The Next Generation Gamma-ray Observatory</td>
</tr>
<tr>
<td>Masahiro Teshima</td>
<td>GA202</td>
<td>Large Size Telescope of the Cherenkov Telescope Array</td>
</tr>
<tr>
<td>Cyril Alispach</td>
<td>GA300</td>
<td>Performance of a small size telescope (SST-1M) camera for gamma-ray astronomy with the Cherenkov Telescope Array</td>
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<tr>
<td>Maria Concetta Maccarone</td>
<td>GA022</td>
<td>ASTRI for the Cherenkov Telescope Array</td>
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<tr>
<td>Vladimir Vassiliev</td>
<td>GA051</td>
<td>Prototype 9.7m Schwarzschild-Couder telescope for the Cherenkov Telescope Array: Project Overview</td>
</tr>
<tr>
<td>Jan Ebr</td>
<td>GA077</td>
<td>Atmospheric calibration of the Cherenkov Telescope Array</td>
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## GA Parallel, Saturday, July 15: 13:30-15:00

<table>
<thead>
<tr>
<th>Name</th>
<th>GA</th>
<th>Title</th>
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<tbody>
<tr>
<td>Roberta Zanin</td>
<td>GA044</td>
<td>Observing the Galactic Plane with the Cherenkov Telescope Array</td>
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## GA Parallel, Monday, July 17: 13:30-15:00

<table>
<thead>
<tr>
<th>Name</th>
<th>GA</th>
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<tbody>
<tr>
<td>Helene Sol</td>
<td>GA123</td>
<td>Observing the sky at extremely high energies with CTA: Status of the GCT project</td>
</tr>
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</table>

## GA Parallel, Tuesday, July 18: 16:30-18:30

<table>
<thead>
<tr>
<th>Name</th>
<th>GA</th>
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<tbody>
<tr>
<td>Tarek Hassan</td>
<td>GA145</td>
<td>Extragalactic source population studies at very high energies in the Cherenkov Telescope Array era</td>
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</table>

## GA Parallel, Wednesday, July 19: 16:30-18:30

<table>
<thead>
<tr>
<th>Name</th>
<th>GA</th>
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<tbody>
<tr>
<td>David Kieda</td>
<td>GA094</td>
<td>Stellar Intensity Interferometric Capabilities of IACT Arrays</td>
</tr>
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</table>

## DM Parallel, Wednesday, July 19: 16:30-18:30

<table>
<thead>
<tr>
<th>Name</th>
<th>DM</th>
<th>Title</th>
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<tbody>
<tr>
<td>Aldo Morselli</td>
<td>DM015</td>
<td>The Dark Matter Programme of the Cherenkov Telescope Array</td>
</tr>
</tbody>
</table>
[CRI097] A Monte Carlo simulation study for cosmic-ray chemical composition measurement with Cherenkov Telescope Array
Board #: 147
Presented by Michiko OHISHI on 18 Jul 2017 at 15:00

[GA019] Design, development and characterization of a calibration system for the camera of the Large Size Telescope proposed for CTA
Board #: 173
Presented by Michele PALATIELLO on 13 Jul 2017 at 15:00

[GA021] Atmospheric monitoring and array calibration in CTA using the Cherenkov Transparency Coefficient
Board #: 179
Presented by Stanislav STEFANIK on 13 Jul 2017 at 15:00

[GA023] Tools and Procedures for the CTA Array Calibration
Board #: 185
Presented by Maria Concetta MACCARONE on 13 Jul 2017 at 15:00

[GA024] Sun/Moon photometer for Cherenkov Telescope Array \u2013 first results
Board #: 240
Presented by Jakub JURYSEK on 13 Jul 2017 at 15:00

[GA039] Performance of the Cherenkov Telescope Array
Board #: 150
Presented by Gernot MAIER on 13 Jul 2017 at 15:00

[GA040] Raman LIDARs for atmospheric calibration in CTA
Board #: 230
Presented by Georges VASILEIADIS on 13 Jul 2017 at 15:00

[GA041] Control Software for a Small-Size Telescope (SST-1M) proposed for the Cherenkov Telescope Array
Board #: 188
Presented by Roland WALTER on 13 Jul 2017 at 15:00

[GA042] End-to-end data acquisition pipeline for the Cherenkov Telescope
Board #: 187
Presented by Roland WALTER on 13 Jul 2017 at 15:00
[GA059] Studies of the nature of the low-energy, gamma-like background for Cherenkov Telescope Array  
Board #: 214  
Presented by Julian SITAREK on 13 Jul 2017 at 15:00

[GA061] Towards final characterization and performance of the GCT prototype telescope structure for CTA  
Board #: 176  
Presented by Cedric PERENNES on 13 Jul 2017 at 15:00

[GA102] Searching for PeVatrons in the CTA Galactic Plane Survey  
Board #: 149  
Presented by Cyril TRICHARD on 13 Jul 2017 at 15:00

[GA131] A Compact High Energy Camera (CHEC) for the GCT of CTA  
Board #: 183  
Presented by Harm SCHOORLEMMER on 13 Jul 2017 at 15:00

[GA136] Prototype 9.7m Schwarzschild-Couder telescope for the Cherenkov Telescope Array: status of the optical system  
Board #: 209  
Presented by Daniel NIETO on 13 Jul 2017 at 15:00

[GA141] Baseline telescope layouts of the Cherenkov Telescope Array  
Board #: 233  
Presented by Paolo CUMANI on 13 Jul 2017 at 15:00

[GA146] Exploring deep learning as an event classification method for the Cherenkov Telescope Array  
Board #: 210  
Presented by Daniel NIETO on 13 Jul 2017 at 15:00

[GA147] A Trigger Interface Board to manage trigger and timing signals in CTA Large-Sized Telescope and Medium-Sized Telescope camera  
Board #: 208  
Presented by Marcos LOPEZ on 13 Jul 2017 at 15:00

[GA155] ASTRI SST-2M prototype and mini-array simulation chain, data reduction software, and archive in the framework of the CTA  
Board #: 184  
Presented by Maria Concetta MACCARONE on 13 Jul 2017 at 15:00
[GA158] A pointing solution for the medium size telescopes for the Cherenkov Telescope Array  
Board #: 186  
Presented by Domenico TIZIANI on 13 Jul 2017 at 15:00

[GA185] Studying cosmological gamma-ray propagation with the Cherenkov Telescope Array  
Board #: 099  
Presented by Florian GATÉ on 13 Jul 2017 at 15:00

[GA279] Gammapy - high level data analysis for extragalactic science cases with the Cherenkov Telescope Array  
Board #: 118  
Presented by Julien LEFAUCHEUR on 13 Jul 2017 at 15:00

[GA284] The ARCADE Raman Lidar and atmospheric simulations for the Cherenkov Telescope Array  
Board #: 231  
Presented by Laura VALORE on 13 Jul 2017 at 15:00

[GA166] Development of a strategy for calibrating the novel SiPM camera of the SST-1M telescope proposed for the Cherenkov Telescope Array  
Board #: 238  
Presented by Imen AL SAMARAI on 13 Jul 2017 at 15:00

[GA278] Gammapy - A prototype for the CTA science tools  
Board #: 215  
Presented by Matteo CERRUTI on 13 Jul 2017 at 15:00


Visit the CTA Exhibit!
Caveat: Observatory timelines are very uncertain; this represents a notional picture based on available information.
Science with the Cherenkov Telescope Array

200 page document describing core CTA science

Will soon be put on axViv and become a regular book
CTA: An Open Observatory

Data Products and Support

Proposals

Definition, Components, KSP

CTA Users

Users of high-level data products
Sky maps, catalogs

Users of archival data
data open after 1 year

Open Time users

CTA Consortium with Key Science Projects

All data on public archive after ~1 yr proprietary period
CTA South Array

2 km
Telescope Types

- LST
- MST + SCT (missing)
- SST