Status of the Cherenkov Telescope Array

Presenter: Koji Noda (Max-Planck-Institute for Physics, Munich)
Monica Vazquez (Instituto de Astrofísica de Canarias, Tenerife)
for the CTA consortium

LHC Days in Split, 23 Sep 2016
Cosmic showers in the atmosphere

Gamma ray source

Particle shower

The gamma rays produce particle showers in the atmosphere
The charged particles in the shower emit Cherenkov light than can be detected by Cherenkov Telescopes

~ 10 km

~ 1°

~ 120 m
Spectrum of cosmic rays extends way beyond energies probed at particle colliders:

**Universe is a particle accelerator for free!**

Cosmic rays are mainly **protons**

Neutral cosmic rays interesting as not affected by interstellar & intergalactic magnetic fields (point back to source)

**Gamma-ray astronomy allow to study the most violent processes in the Universe**
### H.E.S.S., MAGIC, VERITAS

<table>
<thead>
<tr>
<th></th>
<th>H.E.S.S. (I+II)</th>
<th>MAGIC</th>
<th>VERITAS</th>
</tr>
</thead>
<tbody>
<tr>
<td># telescopes</td>
<td>4 + 1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Field of view</td>
<td>5° + 3.2°</td>
<td>3.5°</td>
<td>3.5°</td>
</tr>
<tr>
<td>Dish diameter</td>
<td>12 m + 28 m</td>
<td>17 m</td>
<td>12 m</td>
</tr>
<tr>
<td>Energy threshold</td>
<td>160 + &lt;100 GeV</td>
<td>50 GeV</td>
<td>85 GeV</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.8% Crab Unit (25 h, H.E.S.S.-I)</td>
<td>0.8% Crab Unit (50 h, $E \geq 220$ GeV)</td>
<td>1% Crab Unit (25 h)</td>
</tr>
</tbody>
</table>

Status of CTA: K. Noda (MPI, Munich)
The technique works so we want bigger and better!

Cherenkov Telescope Array (CTA)

Northern site:  
Observatorio del Roque de los Muchachos (ORM/IAC), La Palma (Spain)

Southern site:  
European Southern Observatory (ESO), Paranal (Chile)
### CTA telescopes

Three types of telescopes, to fully cover the interested energy range

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LST</td>
<td>MST</td>
<td>SCT</td>
</tr>
<tr>
<td>Energy range</td>
<td>20 - 200 GeV</td>
<td>200 GeV - 5 TeV</td>
<td>5 - 300 TeV</td>
</tr>
<tr>
<td>No. telescopes (N/S)</td>
<td>4 / 4</td>
<td>15 / 25</td>
<td>TBD</td>
</tr>
<tr>
<td>Optics type</td>
<td>Parabola</td>
<td>Davies-Cotton</td>
<td>Schwarzschild-Couder</td>
</tr>
<tr>
<td>Focal length / Primary Mirror diameter [m]</td>
<td>28 / 23</td>
<td>16 / 13.8</td>
<td>5.6 / 9.7</td>
</tr>
<tr>
<td>Field of View [deg]</td>
<td>4.5</td>
<td>7.7 (FlashCam)</td>
<td>8.0 (NectarCam)</td>
</tr>
<tr>
<td>Pixel [deg] (detector)</td>
<td>0.1 (PMT)</td>
<td>0.18 (PMT)</td>
<td>0.07 (SiPM)</td>
</tr>
<tr>
<td>No. of pixels</td>
<td>1855</td>
<td>1764 (F)</td>
<td>11328</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>GHz</td>
<td>250 MHz (F)</td>
<td>GHz</td>
</tr>
<tr>
<td>Weight</td>
<td>100</td>
<td>85</td>
<td>~85</td>
</tr>
<tr>
<td>Time for reposition [s]</td>
<td>&lt;20</td>
<td>&lt;90</td>
<td>&lt;90</td>
</tr>
</tbody>
</table>
CTA Sites Planned: North & South Hemisphere

ORM, La Palma (Spain)

ESO, Paranal (Chile)

- **LST: 23 m**
- **MST: 12 m**
- **SST: 4 m**

Circles:
- 400 m
- 800 m
- 1200 m
Gamma-Ray experiments: Flux Sensitivity

CTA South simulation = Namibia (lower GMF than Chile)

1 order of magnitude improvement in the sensitivity of CTA-N compared to MAGIC

Extended energy coverage: 20 GeV – 300 TeV
Gamma-Ray experiments: Angular Resolution

Best angular resolution of gamma-astronomy experiments $> 200$ GeV
Source count evolution
1989: 1 source (Whipple)
2000: 10 sources (Whipple/HEGRA/Durham)
2010: 100 sources (HESS, MAGIC, VERITAS)
2020: 1000 sources (CTA)?
CTA Science

• Understanding the origin of cosmic rays and their role in the Universe
  How and where are particles accelerated?
  How do they propagate?

• Probing extreme environments
  Processes close to black holes, neutron stars, …
  Processes in relativistic jets, winds and explosions?

• Exploring frontiers in Physics
  What is the origin of dark matter? How distributed?

• …
Galactic Plane Survey

CTA simulation of 10° region in Galactic longitude
Physics inside GRBs: jet properties, central engine (BH), particle acceleration,
Tools to probe the Universe (Extragalactic Background Light, Inter Galactic
Magnetic Field, Tests of UHECR origin), test of Lorenz Invariance Violation,

Detection rate depends on slewing to target quickly

Simulated spectrum measurement for example burst

S. Inoue et al. for CTA, Astroparticle Physics 43 (2013) 252-275
Dark Matter in Galactic Centre Halo

Deep 500 h observation

Dark matter annihilation

Thermal relic cross section

Complementary to indirect dark matter searches at colliders

Production at colliders

Sensitive to thermal relic cross section in broad energy range

$\langle \sigma_{\text{ann}} \rangle$: thermally averaged annihilation cross section

Halo: Avoid “normal sources”
Sub-project Status

focusing on telescope prototyping
(Other WGs: infrastructure, array control, data management & computing,„„)
Large Size Telescopes (LST)

23 m diameter

Carbon fibre structure (fast-repointing)
1.5 m glass-on-aluminum honeycomb mirror facets
Active mirror alignment using cameras on each facet
Pointing in 20 s to any sky position

Lowest energies (< 200 GeV)
Transient phenomena: Active Galactic Nuclei, Gamma-Ray Bursts, pulsars, Dark Matter,

Artist: Akihiro Ikeshita (sponsored by ICRR, University of Tokyo)
LST Prototype: First Stone Ceremony
9 Oct 2015 (La Palma, Spain)

PI: Prof. Teshima (ICRR, Tokyo; MPI, Munich)

Prof. Kajita (director ICRR, Tokyo)
Prof. Rebolo (director IAC)
LST Prototype @ La Palma: construction on-going!

9 Sep 2016
Croatian contribution in LST

Requirement for LST pointing accuracy “10 arcsec per axis” is \~ an order better than MAGIC. New method needed.

Current method: direct comparison between star fields and the PMT camera (LEDs)

Accuracy not sufficient for LST, due to fast oscillations of the PMT camera structure

New method = 2-camera solution: additional CCD to disentangle the camera oscillation, called Camera Displacement Monitor (CDM)

Development of CDM: FESB (Nikola Godinović and Darko Zarić) + MPI (KN)
Mechanical design of a water-tight box for the CCDs: Rijeka group + MPI
Medium Size Telescope

Modified Davies-Cotton design
- 12 m diameter
- 90 m² effective mirror area
- 1.2 m mirror facets
- 16 m focal length
- 8° field of view with 0.18° PMT pixels

Mid energies (100 GeV – 10 TeV)
DM, AGN, Super Nova Remnant, Pulsar Wind Nebulae, binaries, starbursts, Extragalactic Background Light, InterGalactic Matter

Prototype DESY Zeuthen

Status of CTA: K. Noda (MPI, Munich)
Medium Size Telescope: SCT double-mirror design

Mid energies (200 GeV – 10 TeV)
DM, AGN, SNR, PWN, binaries, starbursts, EBL, IGM

Schwarzschild-Couder design
- 9.7 m primary diameter
- 5.4 m secondary diameter
- 40 m² effective mirror area
- 5.6 m focal length
- 8° field of view
- 0.07° PMT pixels

Prototype in Arizona

http://cta-pset.physics.ucla.edu
Small Size Telescope: ASTRI & SST-1M

Prototype in Sicily

Schwarzschild-Couder
- 4.3 m primary diameter
- 1.8 m secondary diameter
- 6 m² effective mirror area
- 2.2 m focal length
- 9.6° field of view
- 0.17° SiPM pixels

Prototype in Krakow

Davies-Cotton design
- 4 m diameter
- 8.5 m² effective mirror area
- 5.6 m focal length
- 9° field of view
- 0.24° SiPM pixels

Highest energies (> 5 TeV)
Galactic science, PeVatrons, Fundamental Physics
(Axion-like particles, Lorenz Invariance Violation)
Small Size Telescope: GCT

GCT prototype: Observatoire de Paris, Meudon

26/11/2015: First light!

- 4 m primary diameter, 2 m secondary diameter
- 6 m² effective mirror area
- 2.3 m focal length
- 8.6° field of view
- 0.16° MAPM/SiPM pixels
CTA Construction Timeline

- **Pre-Construction Phase**
  - Finish End of 2016

- **Pre-Production Phase**
  - 2017 - 2018
  - First Telescopes on Site (earliest) 2017

- **Production Phase**
  - 2019 - 2024

**Current Timeline**

- Jul 2015
- Oct 2015
- Jan 2016
- Apr 2016
- Jul 2016
- Oct 2016
- Jan 2017
- Apr 2017

- Site Negotiations Begin
- Instrument Contribution Expressions of Interest Received
- Initial Evaluation of Resources
- International Agreement
- Call for Offers
- Headquarters Site Decision
- Initial Design Acceptance
- Work Begins On Site
- Financial Ability to Continue
Bright future ahead in Gamma-Ray astronomy!

Prof. Kajita (Physics Nobel prize 2015) during LST first-stone ceremony @ORM

9/10/2015
BACKUP
Cosmic Rays

Energetic particles coming from outer space

98% hadronic particles
(87% protons, 12% helium, 1% nuclei)

2% electrons

< 1% antiparticles, neutrinos, gamma-rays

Status of CTA: K. Noda (MPI, Munich)
Single Cherenkov Telescope

Detect the Cherenkov light produced by charged particles in the shower.
Array of Cherenkov Telescopes

Improved reconstruction of the shower direction and energy

gamma ray

Multiple views of the same shower

γ-ray direction

stereoscopic reconstruction
The **Fermi satellite** measures high-energy gamma-rays with energies in the range: 100 MeV-300 GeV

The **flux** of gamma rays with $E > 100$ GeV is **very low** so **large collection areas** are needed, so need to **move** to ground-based detectors: **Cherenkov Telescopes!!!**
The Large Magellanic Cloud

- 10% of MW star formation (2% vol.)
- Hosts extreme
- Approximately face on
- Well known distance – 50 kpc

Deep CTA observation will reveal source populations and diffuse emission
- Probing particle acceleration & propagation
- Highly complementary to GPS
- Link of star formation to CRs?
Cherenkov Radiation

- Emitted whenever a charged particle traverses a medium at a speed larger than that of light in the medium.

- The radiation results from the reorientation of electric dipoles induced by the charge in the medium. When $v > c/n$ the contributions from different points of the trajectory arrive in phase at the observer as a narrow light pulse.
Particle showers in the atmosphere

Signal: photons

100 GeV photon

Electromagnetic shower

Primary $\gamma$

$E_C = 80$ MeV

Background: hadrons

100 GeV proton

Hadronic shower

proton

Larger transverse momentum in hadronic interactions

$\rightarrow$ wider showers
Shower Reconstruction

Shower reconstruction & background rejection based on image shape analysis

Hillas parameters:
Length, width, distance, $\alpha$ …

gamma shower

hadron shower (background)
# CTA Telescopes: Large, Medium & Small

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>LST</td>
<td>MST</td>
<td>SST-1M</td>
</tr>
<tr>
<td>Number North array</td>
<td>4</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Number South array</td>
<td>4</td>
<td>25</td>
<td>70</td>
</tr>
<tr>
<td><strong>Optics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optics layout</td>
<td>Parabolic mirror</td>
<td>Davies-Cotton</td>
<td>Davies-Cotton</td>
</tr>
<tr>
<td>Primary mirror diameter (m)</td>
<td>23</td>
<td>13.8, 9.7</td>
<td>4</td>
</tr>
<tr>
<td>Secondary mirror diameter (m)</td>
<td>–</td>
<td>–, 5.4</td>
<td>–, 1.8</td>
</tr>
<tr>
<td>Eff. mirror area after shadowing (m²)</td>
<td>368</td>
<td>88, 40</td>
<td>7.4, 6</td>
</tr>
<tr>
<td>Focal length (m)</td>
<td>28</td>
<td>16, 5.6</td>
<td>5.6, 2.15</td>
</tr>
<tr>
<td><strong>Focal plane instrumentation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photo sensor</td>
<td>PMT</td>
<td>PMT, silicon</td>
<td>silicon</td>
</tr>
<tr>
<td>Pixel size (degr.), shape</td>
<td>0.10, hex.</td>
<td>0.18, hex., 0.07, square</td>
<td>0.24, hex., 0.17, square, 0.15-0.2, square</td>
</tr>
<tr>
<td>Field of view (degr.)</td>
<td>4.5</td>
<td>7.7/8.0, 8.0</td>
<td>9.1, 9.6</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>1855</td>
<td>1764/1855, 11328</td>
<td>1296, 1984</td>
</tr>
<tr>
<td>Signal sampling rate</td>
<td>250 MHz / GHz</td>
<td>GHz</td>
<td>250 MHz, S&amp;H</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount</td>
<td>alz-az, on circular rail</td>
<td>alt-az positioner</td>
<td>alt-az positioner</td>
</tr>
<tr>
<td>Structural material</td>
<td>CFRP / steel</td>
<td>steel, steel</td>
<td>steel</td>
</tr>
<tr>
<td>Weight (full telescope, tons)</td>
<td>100</td>
<td>85, ~85</td>
<td>9</td>
</tr>
<tr>
<td>Max. time for repositioning (s)</td>
<td>20</td>
<td>90</td>
<td>60</td>
</tr>
</tbody>
</table>

Status of CTA: K. Noda (MPI, Munich)