The Cherenkov Telescope Array Observatory: project status and Italian participation

Patrizia Caraveo
INAF
Consequences on the techniques

- The earth atmosphere is opaque to gammas => **only sat-based detectors can detect primary gammas**

- The fluxes of h.e. gammas are low and decrease rapidly with energy
  - a perfect 1 m² detector would detect only 1 gamma-photon/2h above 10 GeV from the strongest sources

  => with the present space technology, VHE and UHE gammas can be detected only from atmospheric showers
  - Earth-based detectors, atmospheric shower satellites

- The flux from high energy charged cosmic rays is much larger
Ground-based vs Satellite

Satellite:
- small effective area ~1m²
  - lower sensitivity
- large FoV
- large duty-cycle
- large cost
- low energy
- low bkg

Ground based:
- huge effective area ~$10^4$ m²
  - Higher sensitivity
- small FoV (IACT)
- small duty-cycle
- low cost
- higher energy
- high bkg
Satellite-based and atmospheric: complementary, w/ moving boundaries

- Flux of diffuse extragalactic photons

![Graph showing the flux of diffuse extragalactic photons and a Grand Unified Photon Spectrum.](image)
Detecting Cherenkov radiation from EM showers

- Air at STP, rad. length $X_0 \sim 330$ m, refractive index $n \sim 1.0003$, Moliere radius $r_M \sim 65$ m.
- VHE gamma causes shower with max. at height $\sim 10$ km.
- Cherenkov light production threshold for $e^\pm$ is $E_c \sim 20$ MeV (STP).
- Total $e^\pm$ path length above $E_c \sim 10^4$ km for 1 TeV photon.
- Get $\sim 20$ Cherenkov photons/m in wavelength range $l = 300...400$ nm.
- Cherenkov angle $\sim 1^\circ$: at low shower particle energy, multiple scattering causes further spreading.
- Light pool radius $\sim 120$ m.
Detecting Cherenkov radiation from EM showers

- Attenuation length of order km (strong function of $\lambda$).
- Quantum efficiency of PM $\sim 20\%$, net result:
  - About 1 p.e./m$^2$ in few ns for (frequent) 100 GeV $\gamma$-ray.
  - About $10^3$ p.e./m$^2$ in few 10 to 100 ns for (infreq.) 10 TeV $\gamma$-ray.
- Limitations:
  - $E < 100$ GeV, night sky background.
  - $E = 0.1...5$ TeV, cosmic ray background (gamma/particles separation).
  - $E > 5$ TeV, rate.
- Need array of different telescopes.
Cherenkov Telescopes in Stereo Vision

Increase of the fiducial area → better sensitivity

Arc minute angular resolution
<table>
<thead>
<tr>
<th>Site</th>
<th>WIPPLE Arizona</th>
<th>HESS Namibia</th>
<th>MAGIC Canary Island</th>
<th>VERITAS Arizona</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat (°)</td>
<td>32</td>
<td>-25</td>
<td>29</td>
<td>32</td>
</tr>
<tr>
<td>Alt (km)</td>
<td>1.3</td>
<td>1.8</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Tel. Ø (m)</td>
<td>10</td>
<td>12</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>N. Tel.</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>FoV Ø (°)</td>
<td>2.3</td>
<td>5</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>Thresh. (GeV)</td>
<td>300</td>
<td>100</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Sensitivity (mCrab)</td>
<td>150</td>
<td>7</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>
The MAGIC telescopes

Mirror diam. 17 m
Coll. Area 240 m²
Focal length 17.5 m
FOV about 3 deg
Ang res. (d90) < 3 ’
Scientific highlights in the last 12 months

- Pulsed (~30 Hz) Crab signal from 25 to 420 GeV
- AGN: most relevant new case is PKS1222 (rapid flare; constraints on Extragalactic Background Light)
- Galactic sources: highlight is W51 (one more hint of acceleration of hadrons)
- Electrons+positrons 130 GeV-2 TeV

> 1 article/month since 2006
> 35, Active Galactic Nuclei (Blazars)

AGN ➔ TeV by electrons (strong correlation between x-ray and TeV flux variability, clearly suggests a unique parent population i.e. Electrons emitting X by synchrotron and Gamma by Inverse Compton).


Some MAGIC discoveries of extra-galactic sources (MAGIC courtesy)

3C279 (z = 0.536)  
1ES1218 (z= 0.18)  
PG 1553 (Z>0.25)  
Mrk180 (z=0.045)  
1ES1011 (Z=0.212)

AGN ➔ spectra shape distribution ➔ Constraint on the EBL (Extragalactic Background Light) intensity can be derived by the AGN spectral cut-off assuming an average AGN emission spectrum; Correlation luminosity /spectral index can affect the result!
Far extragalactic sources: leadership by MAGIC

>40 Sources

1ES 1011+496 \( z = 0.21 \)  
1ES 0414+009 \( z = 0.29 \)  
S5 0716+71 \( z = 0.31 \pm 0.08 \)  
1ES 0502+675 \( z = 0.34 \)  
PKS 1510-089 \( z = 0.36 \)  
PKS 1222 \( z = 0.43 \)  
3C 66A \( z = 0.44 \)  
3C 279 \( z = 0.54 \)  

(Red: discovered by MAGIC. Orange: detected by MAGIC)

Extragalactic VHE \( \gamma \)-ray sources (\( E > 100 \text{ GeV} \))
TeV Astronomy today

- April 2012.
- 136 TeV gamma-ray sources.
  - 89 galactic.
  - 47 extra-galactic.

- Further progress requires improved sensitivity, better E/angular resolution, larger area...
The Physics Program and the first results

- Pulsars
- AGNs
- GRBs
- SNRs
- Origin of Cosmic Rays
- Cold Dark Matter
- Quantum Gravity effects
- Cosmological $\gamma$-Ray Horizon

- Quantum Gravity effects
Kifune Plot

-3000 sources by GLAST, AGILE

-1000 sources by CTA
CTA: the Array sensitivity curve

Hi-z AGN, GRBs, pulsars, dark matter

- Improved angular resolution
  source id. & morphology
- Improved energy resolution
cutoffs & spectral features
- large FoV (6-8 deg)
extended sources, survey
- multiple observation modes

Exploring the cutoff regime of cosmic accelerators

Population studies, extended sources, variability, precision TeV astronomy
Array layout: 2-3 Zones

- **High-energy section**
  - ~0.05% area coverage
  - Energy: $E_{th} \sim 1-2$ TeV

- **Medium-energy section**
  - ~1% area coverage
  - Energy: $E_{th} \sim 50-100$ GeV

- **Low-energy section**
  - ~10% area coverage
  - Energy: $E_{th} \sim 10-20$ GeV

- FoV increasing to 8-10 degrees in outer sections.

- Array layout: 2-3 Zones.
Performance of multi-telescope arrays

Examples of sub-arrays:

- Dense array of 12 and 24 m telescopes.
  - Good low E, but poor high E performance?

- Low density array of 12 m telescopes.
  - Good high/medium E, but poor low E performance?

- Array of 7, 12 and 24 m telescopes.
  - Provides sensitivity across complete energy range?
CTA Array scheme

- The centre of the installation is near the upper left corner.
- In the upper right part, clusters of telescopes of the 12-m class are shown at the perimeter.
- In the lower left part an option with wide-angle telescopes of the 3–4 m class is shown.
The Cherenkov Telescope Array concept

Low energy
Few 24 m telescopes
4…5° FoV
2000…3000 pixels
~ 0.1°

Medium energy
About twenty 12 m telescopes
6…8° FoV
2000 pixels
~ 0.18°

High energy
Fifty + 4…7 m telescopes
8…10° FoV
1000…2000 pixels
~ 0.2°…0.3°
CTA: Unifying European efforts

... and maintaining European lead

CTA involves scientists from:
- Czech Republic
- Germany
- France
- Italy
- Ireland
- UK
- Poland
- Spain
- Switzerland
- Armenia
- South Africa
- Namibia

from several communities:
- astronomy & astrophysics
- particle physics
- nuclear physics

about 250-300 scientists working currently in the field will be directly involved, user community significantly larger
CTA for the European Union:
the Preparatory Phase

Unambiguously strong European support:

- Project listed as priority in roadmaps of
  - ASTRONET (Astrophysics)
  - ASPERA (Astroparticles)
  - Targeted DS Common Call -> Up to €2.7M
  - ESFRI (European Strategic Forum for Research Infrastructures)
  - FP7 Preparatory Phase approved -> Up to €5.2M

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<thead>
<tr>
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<tbody>
<tr>
<td>CTA</td>
<td>150</td>
<td>10</td>
<td>2013</td>
</tr>
<tr>
<td>E-ELT</td>
<td>950</td>
<td>30</td>
<td>2018</td>
</tr>
<tr>
<td>ELI</td>
<td>400</td>
<td>50</td>
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<td>120</td>
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<td>2016</td>
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<tr>
<td>PRINS</td>
<td>1400</td>
<td>300</td>
<td>2009-2015</td>
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<tr>
<td>SKA (GLOBAL)</td>
<td>1500</td>
<td>100-150</td>
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<tr>
<td>SPIRAL2</td>
<td>196</td>
<td>6.6</td>
<td>2014</td>
</tr>
</tbody>
</table>

Extracts from W. Hofmann, CTA general meeting, 2010 and from M. Martinez, CTA general meeting, 2010
CTA performance goals

- Aim for factor of 10 improvement in sensitivity.
- Compare simulated HESS ~ 500 hour image of galactic plane...

...with expectation with increased sensitivity, same exposure.

- Expect to observe around 1000 sources (galactic and extra-galactic).
CTA performance goals

- Improve angular resolution by factor ~ 5.
- Substructure of SNR shock fronts can then be resolved:
  - Better understand energy dependent morphology of pulsar wind nebulae.
  - HESS J 1825-137, PWN size decreases with energy:
    - $> 2.5$ TeV
    - $1 - 2.5$ TeV
    - $< 1$ TeV
CTA performance goals

- Extend energy coverage to higher and lower energies:
- Understand processes in sources: hadronic showers or inverse Compton scattering?
- Increase detection rate, map activity on sub-minute timescales.
  - E.g. blazar PKS 2155-304 (HESS):
- Determine size of emission regions around active galactic nuclei.
- Study quantum gravity.
- Fast slewing, large FoV (fastest burst notification from Fermi g-ray burst monitor precision ~ 10°).
CTA performance goals

- Increase field of view w.r.t. current instruments by factor ~ 2 to 6...8°.
- Detect/map extended sources.
- Improve survey capability: galactic plane at ~ 0.001 Crab in 250 hours, full sky at ~ 0.01 Crab in 1 year.
- Southern array:
  - Galactic and extragalactic sources.
  - 10 GeV...100 TeV.
  - Angular resolution 0.02...0.2°.
- Northern array:
  - Mainly extragalactic sources.
  - 10 GeV...1 TeV.
  - Smaller field of view.
Small size telescope design – take one

- Single mirror DC is the optical model of the present Cherenkov telescopes
- Single mirror DC is the baseline for LST and MST of CTA.
The INAF ASTRI Program
(in a nutshell...)

The INAF ASTRI program for a SST-to-end prototype
The INAF ASTRI SST prototype

The ASTRI Program is an Italian “Progetto Bandiera” funded by the Ministry of Education, University and Research (MIUR) for a total amount of 8 M€uro to develop the “replica” technology for mirrors and new sensors for VHE astrophysics.

The main goal is the realization, within the CTA framework, of an end-to-end prototype of the CTA SST to be tested under field conditions.

INAF is in charge of the design of the mirrors and the camera, development of the software and other related activities. The telescope structure is designed by external firms.

INAF contributes with about 24 FTE/year to the project, and received 3 M€uro to cover the costs for the 2011. Annual reviews are foreseen by MIUR in order to allocate, on an annual basis, the rest of the budget according to the following scheme: 2012 (2 M€uro), 2013 (2 M€uro), and 2014 (1 M€uro).

A detailed description of the ASTRI Program has been given to the CTA Project Committee Meeting on 2011 July 5th and it is available at the PO INDICO repository.