ATMOSPHERIC MONITORING AND CALIBRATIONS PLANS WITH CTA

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On behalf of the CTA atmospheric working group
CONTENT

- What is CTA
- Why do we need atmospheric monitoring
- Instruments and methods
- Implementation Strategy
- Networking
WHAT IS CTA
A project for a new generation of Cherenkov Telescopes
Gamma-ray precision astronomy and astrophysics from few tens of GeV to >100 TeV
Two sites: one Southern and one Northern with a hundred telescopes in total

http://www.cta-observatory.org/
CHERENKOV TELESCOPE ARRAY (CTA)
THE IACT TECHNIQUE

Imaging Atmospheric Cherenkov Telescopes

Very High Energy (VHE) gamma-ray $E \sim O(0.1 - 100 \text{ TeV})$

camera 1

~ 300 m

camera 2

particle shower

Cherenkov light

gamma-ray direction

telescopes

M. Doro - Gamma-ray Astrophysics - IFAE 2014
TARGETS

- **Galactic targets**
  - Pulsar
  - Supernova Remnants
  - Pulsar wind nebulae
  - Micro-quasars
  - Galactic center

- **Extragalactic targets**
  - Active Galactic Nuclei
  - Galaxy Cluster
  - Starburst galaxies
  - Merging Galaxies
  - Gamma-ray Bursts
A COLLABORATION THAT GROWS

- HESS+MAGIC+VERITAS collaborations + Europe + world interest (Japan, Argentina)
- US AGIS (Advanced Gamma-ray Imaging System) converged to CTA
- Regular meetings since 2007.
Design Concepts for the Cherenkov Telescope Array

The CTA Consortium

(Submitted on 22 Aug 2010 (v1), last revised 21 Oct 2010 (this version, v2))

Ground-based gamma-ray astronomy has had a major breakthrough with the impressive results obtained using systems of imaging atmospheric Cherenkov telescopes. Ground-based gamma-ray astronomy has a huge potential in astrophysics, particle physics and cosmology. CTA is an international initiative to build the next generation instrument, with a factor of 5–10 improvement in sensitivity in the 100 GeV to 10 TeV range and the extension to energies well below 100 GeV and above 100 TeV. CTA will consist of two arrays (one in the north, one in the south) for full sky coverage and will be operated as open observatory. The design of CTA is based on currently available technology. This document reports on the status and presents the major design concepts of CTA.

Comments: 120 pages, 54 figures, 5 tables (with minor editorial changes)
Cite as: arXiv:1008.3703v2 [astro-ph.IM]

FP7-supported Preparatory Phase: Fall 2010 – Fall 2013
⇒ Technical design, sites, construction and operation cost
⇒ Legal, governance and finance schemes
⇒ Small + medium-sized telescope prototypes

We are entering the Pre-Construction Phase
CANDIDATE SITES

Physical Map of the World

USA (Arizona)
Canaries (Spain)
Mexico
Chile
Argentina
Namibia
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<th>TELESCOPES (PRELIMINARY)</th>
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<th>4 Small-Sized Telescope</th>
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5 years
5 years
WHY DO WE NEED ATMOSPHERIC CALIBRATION
WHAT’S WITH THE ATMOSPHERE

- The atmosphere is the place where
  - The gamma-ray has the first interaction with atmospheric molecules
  - The electromagnetic and hadronic showers take place
  - The Cherenkov light is transmitted to the ground
- Goal is 10% uncertainty in the energy reconstruction
FACTORS RELEVANT TO IACT APPROACH

- All three aspects are influenced by atmospheric conditions and this is reflected in the data
  - On the energy threshold
  - On the energy bias and resolution
  - On the effective area
  - On the spectral reconstruction
  - On the pointing precision

- And on the observatory handling
  - Increase duty cycle
  - **Smart scheduling**? E.g. a) move to a source better visible under current observation conditions, b) move to a source that does not require so low energy threshold c) move to a source that does not require precision pointing
AMBITIOUS GOALS

- Overall systematic error on energy scale <15%
- Systematic error on Cherenkov light intensity <8%; goal 5%
- Systematic error related to atmosphere <7%
- Systematic error on collection area: <12%; goal 8%

- A much bigger effort than so far used for current generation of telescopes
- New expertise
- Collaborations with Auger and external experts is strong and can be reinforced further
Does the height of the aerosol overdensity matter? A MC study was made (Garrido+ 2012)

- 3 models
  - Changing global density
  - Changing “cloud” altitude
  - Changing “cloud” density

Comparison between
- Wrong MC
- Good MC
- Correction method
Using correct MC, energy and flux reconstruction is correct, at the only expense of a larger energy threshold.

Higher global density

Variable “cloud” position

In case the aerosol overdensity or cloud is below the electromagnetic shower, simple correction method can be used to restore correct energy and flux reconstruction:

For aerosol layers found until about 6 km a.s.l., the energy threshold of gamma-ray showers scales as the inverse of the total atmospheric transmission at 385 nm wavelength:

\[ E_{\text{thr}} = E_0 \cdot \left( \frac{T}{T_{\text{ref}}} \right)^{-0.9} \quad . \tag{3.3} \]

For aerosol layers found until about 6 km a.s.l., the bias of reconstructed energies of gamma-ray showers above the threshold scales with the total atmospheric transmission at 385 nm wavelength:

\[ B_{\text{above\ threshold}} = (T - T_{\text{ref}})/T_{\text{ref}} \quad . \tag{3.4} \]

For aerosol layers found until about 6 km a.s.l., the reconstructed energy correction of gamma-ray showers above the threshold scales with the total atmospheric transmission at 385 nm wavelength:

\[ \frac{E_\gamma}{E_{\text{rec}}} = T_{\text{ref}}/T \quad . \tag{3.6} \]
When the clouds or aerosol layer is at the shower development region or above, the total extinction is no longer a useful parameter.

It is therefore important to know the **differential atmospheric transmission**. We need instruments with height resolution!
Up to >6 km a.s.l.: $E_{\text{thr}} = E_0 / T$ (400 nm)

Up to >6 km a.s.l. (until 5 TeV): \[
\frac{E_{\text{rec}} - E_\gamma}{E_\gamma} = \frac{(T-0.73)}{0.73}
\]
(can be corrected using only total atmospheric transmission)

Up to >6 km a.s.l. (until 5 TeV): $\frac{A_{\text{aerosols}}}{A_{\text{ref}}} = 0.45 + 0.75^* T$

When taking full Lidar information into account, spectral retrieval is possible (Fruck+ this conference)
STRATEGY
TASKS

- TASK 1 Site Climatology
- TASK 2 Off-line data selection
- TASK 3 Off-line data correction
- TASK 4 On-line smart scheduling
- TASK 5 Weather forecast, alerts and protection
Aim
- Characterization of the site and instruments and method validation

Primary Instruments
- Commercial weather stations
- Satellites, closeby climate center, historical data
- National radar
- Aeronet solar stations
- Radiosondes

Secondary Instruments
- Ceilometers
- Raman lidars
- All-sky Camera (see dedicated talk by Mandat)
- FRAM (see talk by Mandat)
- UV-scope
Aim

- Certify good quality data

Primary Instruments

- Raman Lidar
- FRAM
- UV-scope
- CTC

Secondary Instruments

- ASC
- Radiometer
- Lunar or stellar photometer
Task 3: Off-line Data Reconstruction

Aim

• Retrieve correct energy and flux through atmospheric data

Primary Instruments

• Raman Lidar
• FRAM
• UV-scope
• CTC

Secondary

• ASC
• Radiometer
• Lunar or stellar photometers
AIM

- Find the optimal target to observe in case of peculiar atmospheric conditions in one pointing direction

Primary Instruments

- ASC
- Ceilometer
- CTC

Secondary Instruments

- Raman lidar
- UV-scope
- FRAM
- Lunar or stellar photometers
Aim

- Short and long weather forecast, alert to protect instrumentation

Primary Instruments

- Commercial weather stations
- National Weather Radars
- Satellites, closeby climate stations • Rain remote sensors
- Thunder-sensors
- Ceilometers

Secondary Instruments

- Radiometer
- Cherenkov Transparency Coefficient
INSTRUMENTS AND METHODS
INSTRUMENTS IN OUR PORTFOLIO

Pointing forecast
- All-Sky Camera
  - NSB monitoring
  - Advanced
  - Development for Auger

Actual Pointing directions
- UVscope
  - Portable instrument
  - Working since 15 years already
  - No development needed

Climatology
- Weather stations
  - Will make use of commercial solution
  - Large experience in current IACTs

Ceilometer
- Development with Vaisala company
- Instrument working at HESS

FRAM
- Instrument working at Auger site

Lidars
(see next slide)

Aeronet sun photometer

Lidars
(see next slide)
OVERALL RAMAN LIDAR PICTURE

IFAE/UAB Lidar
- Re-use of CLUE experiment
- Large mirror 1.8m + 4 wavelengths
- Advanced status and documentation
- First light obtained

LUPM Lidar
- Re-use of CLUE
- Large mirror 1.8m + 4 wavelengths
- Improved components steering
- Previous experience of the group with HESS lidar

CEILAP Lidar
- Full custom design
- 6 individual mirrors + 6 read-out channels
- Advanced status
- Previous experience of the group with many lidars

INFN Lidar
- Initially developed for Auger site
- Custom build
- Compact
- 2 wavelengths
- Previous experience of the group with Auger lidar

Adelaide Wind Lidar
- Only preliminary contacts taken
- Funds under discussion
- Projects is already in the portfolio of the group
A method measuring the transmission of the atmosphere to Cherenkov light based on measuring trigger rates and calibrated optical throughput of all telescopes.

- Developed and used for HESS
- Good performance for data selection
- Good prospects for data correction
- Make use of standard instrument output data
- Works for low-aerosol layer (no cirrus)
IMPLEMENTATION STRATEGY
NETWORK
We need to make contact (Aeronet, ACTRIS, etc)

- **CTA instruments**
  - Coverage in remote sites
  - Non-commercial instruments

- **Global Network**
  - Data validation
  - Feedback
CONCLUSIONS
Gamma rays are detected as secondary Cherenkov photons from events in the atmosphere.

Characterization of the atmosphere is thus necessary for correct energy and flux reconstruction.

CTA has a wide program.

CTA would like to build an atmospheric monitoring center embedded in international networks.
BASIC REFERENCES

- All-Sky-Camera.