Prospettive della Ground based gamma ray astronomy
Bologna
19Marzo 2009

the CTA Cherenkov Telescopes Array status report

Mosè Mariotti INFN Padova
Overview

- Il progetto CTA
  - Motivazioni del progetto
  - Layout dell’esperimento
  - CTA consortium

- Ongoing activities
  - Struttura e coordinamento del progetto
  - Ruolo dell’Italia e dell’INFN
  - Attività in corso

- Timeline and next steps
  - ASPERA call per finanziare il DS
CTA
An advanced facility for ground-based high-energy gamma ray astronomy

Science potential

- About 30 sources are now identified as VHE gamma sources.
- GLAST will see ~3000 GeV sources around 2010.
- Our target in VHE Energy:
  - ~100 VHE sources in 2010 by HESS-II and MAGIC-II.
  - ~1000 VHE sources in 2020 by CTA.
- CTA Sensitivity must be 10 times better than HESS and MAGIC.

Importance of all sky observatory:
- A full sky survey with relatively large FOV is favored.
- Extend HESS galactic plane survey to entire sky.

- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg.
- Broad and diverse program ahead, combining guaranteed astrophysics with significant discovery potential.
CTA Scientific Objectives

An advanced facility for ground-based high-energy gamma ray astronomy

- SNRs
- Pulsars and PWN
- Micro quasars
- X-ray binaries
- AGNs
- GRBs
- Origin of cosmic rays
- Dark matter
- Space-time & relativity
- Cosmology
- One order of magnitude improvement in sensitivity (100 GeV – 10 TeV)
- Larger energy range, towards 20-30 GeV and > 100 TeV
- Improved angular resolution and relatively large FOV
- Operational flexibility
- Full sky coverage
- Observatory open to the community
• A big challenge…but worth the effort !
• Very rich science
• Potential of very important discoveries
• Synergy with other telescopes, and satellites
• Important the link with FERMI
Next Generation: Wish list

GLAST  $E.F(>E)$ [TeV/cm²s]

MAGIC

H.E.S.S.

Crab

10% Crab

1% Crab

$E$ [GeV]

$E [10^{-14} - 10^{-11}]$
Next Generation: Wish list

- Improved angular resolution
  - source morphology
- Large FoV (6-8 deg)
  - extended sources, surveys
- High detection rate (large area)
  - transient sources

Exploring the cutoff regime of cosmic accelerators

Hi-z AGN and pulsars.
Fundamental physics:
Indirect DM searches, cosmology, propagation physics

More sources, extended sources
Population studies
Minimal detectable flux per band $\log_{10}E=0.2$, relative to a power-law Crab spectrum.

- Limit from event count, $\sim 1/T\cdot A$.
- Limit from proton background, $\sim 1/\sqrt{(T\cdot A)^{1/2}}$.
- Limit from electron background, $\sim 1/\sqrt{(T\cdot A)^{1/2}}$.
- Limit from systematic error on background, independent of $T\cdot A$. 

Sensitivity vs energy graph with the following specifications:
- Effective area: $3.0\times10^5 \text{ m}^2$.
- Time: 25.0 h.
- Angular resolution: 0.10 deg.
- Gamma-ray accuracy: 0.500.
- Proton accuracy: 0.0100.
- Background systematic error: 0.0100.
mCrab sensitivity in the 100 GeV–10 TeV domain

O(12-14m) telescopes

Not to scale!
Low-energy section

energy threshold of some 10 GeV
(a) bigger dishes

Not to scale!
Low-energy section

energy threshold of some 10 GeV
(a) bigger dishes
(b) dense-pack and/or
(c) high-QE sensors

Not to scale!
High-energy section

10 km² area at multi-TeV energies

Not to scale!
CTA as European Initiative

Close cooperation with Japan & US very desirable
- Joint technology development or
- Joint project
could help to fund 2nd site

Near future: concentrate on FP7 / EC aspects
Advanced Gamma-ray Imaging System

Science goal: to be finalized by WP
Budget: ~130M$, “Moderate Initiative”
Observatory: ~1km² array of mid-IACTs
IACTs: 150-50 identical telescopes (+...)
CT Aperture: 5-15 m (#CTs & aperture TBD)
Technology: demonstrated AC technique
R&D: Novel Camera, OS, Trigger, DAQ
OS & Camera:
  a) Prime focus telescope + PMTs (baseline for cost estimates based on VERITAS scaling)
  b) Aplanatic telescope + MAPMTs or II&CMOS
  c) Catadioptric (?)
Field of View: 5-12° (TBD through simulations, based on science goals, and cost study)
CTA as an observatory

- CTA will be a normal astrophysical observatory, open to the community, with professional operators, AOs, support for data analysis etc.
- Data will be public after some time (1 y?)
- Significant guaranteed time (~50%) for construction consortium

CTA will most likely combine HEP and astrophysics worlds

- Observatory operation
- Significant contribution to construction by institute shops to reduce required investment
<table>
<thead>
<tr>
<th>Participant no.</th>
<th>Participant organisation name</th>
<th>Part. short name</th>
<th>Country</th>
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<td>1 (Coordinator)</td>
<td>Max-Planck-Gesellschaft</td>
<td>MPG</td>
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<td>28</td>
<td>Yerevan Physics Institute</td>
<td>YerPhi</td>
<td>Armenia</td>
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Italian groups interested in CTA “DS”

9 Istituti/osservatori INAF, 5 sezioni + 2 gruppi collegati (Siena e Udine) INFN

**Instituto Nazionale di Astrofisica (INAF),** with participating institutes:
- INAF-Head Quarter, Rome (INAF-HQ);
- INAF-Osservatorio Astronomico di Roma (OAR);
- INAF-Osservatorio Astronomico di Brera (OABr);
- INAF-Osservatorio Astrofisico di Arcetri (OAA);
- INAF-Osservatorio Astronomico di Bologna (OABo);
- INAF-Osservatorio Astronomico di Padova (OAPd);
- INAF-IASF Roma (IASF-Rm);
- INAF-IASF Palermo (IASF-Pa);
- INAF-IASF Bologna (IASF-Bo);
- INAF-IFSI Torino (IFSI-To);
- TNG Fundacion G. Galilei (TNG).

**INFN, with participating institutes:**
- INFN Sezione di Padova (INFN PD)
- INFN Sezione di Pisa (INFN PI)
- INFN Sezione di Pavia (INFN PV)
- INFN Sezione di Trieste (INFN TS)
- INFN Sezione di Roma2 (INFN RM2)
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<th>Party of MoU</th>
<th>Institutes represented by Party</th>
<th>Party / Institute Contact (incl. Email, Phone)</th>
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<tbody>
<tr>
<td>INFN Headquartiers: Roma, a Piazza dei Caprettari, 70, (cap 00186) presso il Palazzo Lante. Tel. +39 06 6840031 Fax +39 06 68307924 e-mail: <a href="mailto:presidenza@presid.infn.it">presidenza@presid.infn.it</a></td>
<td>INFN Sezione di Padova &lt;br&gt;Sede: Dipartimento di Fisica Galileo Galilei &lt;br&gt;Via Marzolo 8, 35131 Padova - Italy</td>
<td>Prof. Mosè Mariotti</td>
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<tr>
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<td>INFN Sezione di Pavia &lt;br&gt;Via Bassi, 6 - 27100 Pavia (Italy)</td>
<td>Dr. Paolo Cattaneo</td>
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<td>Prof. Andrae Vacchi</td>
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<tr>
<td>INFN gruppo collegato di Udine Sede: &lt;br&gt;Dipartimento Di fisicaVia delle Scienze, 208 - I-33100 UDINE, Italia</td>
<td>INFN Sezione di Milano Bicocca - &lt;br&gt;Dipartimento di Fisica G.Occhialini, &lt;br&gt;Edificio U2 - Piazza della Scienza 3 - I-20126 Milano - Italia</td>
<td>Prof. Aldo Treves</td>
</tr>
<tr>
<td>INFN sezione di Napoli Complesso Prof. Benedetto D'Ettorre Piazzoli Universitario di Monte Sant'Angelo, Via Cintia, I-80126, Napoli, Italy.</td>
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</table>
May 2006  HESS-MAGIC->CTA meeting, WG definition  Berlin
July 2006  WG Convener meeting  Frankfurt
Nov 2006  WG Convener meeting  Munich
March 2007  CTA meeting (organiz. EU FP7)  Paris
July 2007  WG Convener meeting  Heidelberg
Jan 2008  CTA Meeting (kick off WP)  Barcelona
Nov 2008  CTA Meeting  Padova
Feb 2009  WG Convener  Paris

May 2009  CTA General meeting  Cracovia
# Tentative Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Array layout</th>
<th>Telescope design</th>
<th>Component prototypes</th>
<th>Telescope prototype</th>
<th>Array construction</th>
<th>Partial operation</th>
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**FP7 DS application**

**“Kick-off”: Barcelona, Jan 24-25**
## Organization of the Design Study

### Work Packages (following FP7 application, May 2007)

<table>
<thead>
<tr>
<th>WP</th>
<th>Code</th>
<th>Description</th>
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<tr>
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<td>MNG</td>
<td>Management of the design study</td>
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<td>WP2</td>
<td>PHYS</td>
<td>Astrophysics and astroparticle physics</td>
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<td>WP3</td>
<td>MC</td>
<td>Optimization of array layout, performance studies, …</td>
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<td>SITE</td>
<td>Site evaluation and site infrastructure</td>
</tr>
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<td>WP5</td>
<td>MIR</td>
<td>Telescope optics, mirrors, mirror alignment</td>
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<tr>
<td>WP6</td>
<td>TEL</td>
<td>Telescope structure, drive, control, robotics</td>
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<tr>
<td>WP7</td>
<td>FPI</td>
<td>Focal plane instrumentation, mechanics and photo detectors</td>
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<td>WP8</td>
<td>ELEC</td>
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<td>WP9</td>
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<td>Atmospheric monitoring, associated science &amp; instrument calib.</td>
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<tr>
<td>WP11</td>
<td>DATA</td>
<td>Data handling, data processing, data management and access</td>
</tr>
<tr>
<td>WP12</td>
<td>QA</td>
<td>Risk assessment and quality assurance, production planning</td>
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</tbody>
</table>

→ **Strong inter-dependencies**
• Draft of a Memorandum of Understanding for the CTA Design Study

• Discussion on the CTA management: during next CTA meeting there will be the election of the spokesman.....
... and there are ‘a few’ challenges

Will need
O(50-100) telescopes, core array
O(10000) m² mirror area
O(70) m² photo sensitive area
O(100k) electronics channels

→ Factor of 10 in sensitivity
   with only factor of 10 in M€

Find an optimized array layout
that has the required performance

Optimize design for effective production /
commissioning, and for
stability and high reliability
Work packages of interest for INFN and INAF

WP1  MNG  Management of the design study
WP2  PHYS  Astrophysics and astroparticle physics
WP3  MC  Optimization of array layout, performance studies, …
WP4  SITE  Site evaluation and site infrastructure
WP5  MIR  Telescope optics, mirrors, mirror alignment
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Optimize design for effective production /
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WP ELEC: Camera Readout Options

1) Existing solutions
   - Proven to work
   - Need to be adapted & integrated w/ RO-scheme
   - Low risk

2) NeCTAr project (2009-2011)
   - Highly integrated FE chip
   - Cost reduction

Existing pipeline chips:
   - e.g. SAM (H.E.S.S. 2), DRS4 (MAGIC 2)
   - GHz sampling;
   - Large dynamic range
   - 256 - 1024 cells depth

O(nsec) Cherenkov flashes
⇒ O(100 MHz - GHz) sampling
30 Byte / pixel / evt
(20 nsec @ ~ 800 MHz x 2 gain)
2000 channels
10 kHz camera triggers
\[\rightarrow \text{ca. 600 MByte/sec}\]

For optimum use of pulse shape, data needs to be analyzed by using info from all Pixels / correlations (e.g. HEGRA), and not just per pixel

\[\rightarrow \text{Bus – System into CPU?}\]
Ethernet-based front-end readout: tests

FPGA MAC sender:
100 MBit and GBit Eth interface successfully implemented (and used)

switch & server bandwidth:
48 groups (nodes) sending data transferred into one server
\[ \rightarrow \] 700 MByte/sec (loss free)
(using standard commercial components)

\[ \rightarrow \sim 5\text{MB/sec} \]

PC Server
8 x 1 GB Ethernet

\[ \uparrow \]

8 x 1 GB Ethernet

\[ \downarrow \]

100 x RJ 45 GBit Ethernet

\[ \rightarrow \]

3 x 48 Port GB Ethernet Switch

\[ \rightarrow \sim 5\text{MB/sec} \]

Buffer/FPGA

Pixel 1

Pixel 16

FADC or analogue pipeline w/ ADC

FADC or analogue pipeline w/ ADC

Mosè Mariotti Univ. Padova

www.cta-observatory.org
1) Each telescope obtains central clock pulses O(MHz) → Synch (modulo offset)

2) Each CT has local PLL or quartz as frequency-mult (counter reset by 1) ) → nsec timing

3) Combination of 1) and 2) gives relative nsec timing between telescope triggers
“Soft” System Trigger with “hard” timing

Central CPU dedicated to SysTrg
Finds coincidences and sends info to CTs

Local arrival times (nsec accuracy) of evts sent via Ethernet to a central CPU

Buffer arrival time of local triggers (CPU)

Clock

Trigger
• Contents
  • Exploited technology pros and cons
  • Work in progress
    • Mirrors technology
    • Alignments/active control actuators mechanics
  • Critical points
  • Future plans
CTA MIR_WP report

• Investigation/development on different mirror technology

• Replica type
  • cold glass slumping: INAF Italy AOB (~ proven)
    • Industry partner ready for a complete offer
  • Cold slump “Saclay, development” (r&d)
  • Hot slumping: INAF Italy (r&d)
  • Carbon-epoxy (r&d)

• Manufactured one by one
  • Diamond turning aluminum (INFN Padova, MPI Munich)
    • Industrial partner interested
Aluminum master 1040 x 1040 mm

Front and rear of a produced segment
Size = 985 x 985 mm Weight = 9.5 Kg.
Nominal radius = 35 m
• Work on mirrors at INAF OAB

1. MASTER

2. BACKING SHEET
   - HONEYCOMB
   - REFLECTING SHEET

3. CURING CHAMBER

4a. MIRROR PANEL
   - REFLECTING SHEET (thinner)
   - MASTER

4b. CURING CHAMBER

5. PVD COATING
   - AL + SiO₂

5. PVD COATING
   - AL + SiO₂

Cold approach
1
• Industrial Partner Offer

• Based upon the experience with 120 m^2 of MAGIC II Medilario technology presented a production plan showing the capability to:

  Produce 10 000 m^2 in 4 years,
  price below 2000/m^2
• Work on mirrors in Poland (Warsaw)

- Composite mirror: No experience on long term stability!
- Aim at producing sandwich mirrors from thin glass sheets and masterpiece reproduction technique (this was presented in Padova)

- Different techniques are currently tested, the core of the block being polyurethane foam (injected or not injected, see attached pictures). In some configurations, a resin is placed between the glass and the foam block, to increase stiffness and better holding of the glass shape. This ensemble is coated with composite materials (glass or carbon fibers).

- Made 3 aluminized mirrors, not yet characterized.
QuickTime™ and a decompressor are needed to see this picture.
• Work on mirrors at INFN-PD

• Positive experience with MAGIC al-mirs
  ➢ Very reduced optical degradation (<1%/year), virtually no need to exchange
  ➢ Good optical quality (PSF~0.5mrad)
  ➢ Resistance to atmospheric conditions
  ➢ Relatively cheap price (~3keuro/m²)
  ➢ Easy handling and installation (~18kg/m²)

• Repeat experience with CTA
  ➢ Increased size (1.5-2m²)
  ➢ Possibility of a-spheric mirrors to reduce aberrations for large telescopes
  ➢ Increase reflectivity and improve design
  ➢ Decrease cost?
• Work on mirrors at INFN-PD

- New head for large diamond machine under construction in INFN composite Labs
  - Full carbon fiber structure
- Joint development from INFN and LT-Ultra

Tool for:
- Machining up 1.5 M aluminum mirror
- Build high precision large mould for “replica technology”
CTA primary mirror aperture:
20-30 m diameter

Telescope space frame unable
to maintain geometry with
the required precision

Gravity induced sag is
elevation-dependent

Require active mirror control
(AMC) to align individual
facets

also desired for initial facet
alignment
• AMC mechanics

• Stepper motor driving M8x1 arbor
• Mechanical driving range 37mm
• Single power supply connector, IP67/68
• No glued parts, complete dis-/assembly in few minutes
• Small magnet included in die for position sensing
• Back side cap made of UV-resistant plastics, RF transparent
• Projected cost per actuator (4000 units)

Drive controller (incl. assembly): CHF 45 (EUR 30)
AMC mechanics: CHF 216 (EUR 144)
IP67/68 connector couple: CHF 9 (EUR 6)
Total: CHF 270 (EUR 180)
CTA MIR_WP report on AMC: UniZH

• Outlook & feedback

- Two AMC prototypes are completed
- Long-duration / endurance testing will start soon on institute rooftop
- Feedback from TEL/MIR working groups required to improve design and match CTA requirements
• AIM of the ongoing activity

• Improve Quality (geometry and reflectivity) of mirrors coming from “replica” process
• Lower the cost of Diamond Milled aluminum mirrors
• Define a production plan for diamond milled mirrors (rate is too low)
• More resources to be invested on protection coating to increase reflectivity and prevent aging
CTA MIR_WP report

- Mirror TEST STAND for quality control and Qualification

- Heidelberg
- Padova
- Munich
- INAF Brera

PLAN -> cross calibration of setups and methods
## Tentative Timeline

### FP7 DS application

- **“Kick-off”: Barcelona, Jan 24-25**

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### Notes
- **Design**
- **Prototype**
- **Array**
- **Conceptual Design**
- **Detailed Design**
CTA in Europe... ApPEC
Funds for astroparticle in ApPEC

QuickTime™ and a decompressor are needed to see this picture.
ASPERA R&D... call for proposal
Conclusions

• CTA is the most relevant ground-based High-Energy Astroparticle physics - astrophysics projects for the next decade

• INFN and INAF have very strong scientific and strategic interest for a qualified and strong participation (e.g., PRIN 2009)

• Coordination INFN-INAF (for positive interference)

• recommendation...Joint CTA