The Gamma-ray Cherenkov Telescope for CTA

- Introduction.
- Cherenkov radiation from air showers.
- The CTA concept.
- Evolution of imaging atmospheric Cherenkov telescopes.
- The SSTs and the development of the Gamma-ray Cherenkov Telescope.
- Next steps for the GCT.
- Summary.

Tim Greenshaw, Liverpool University
Detecting high energy $\gamma$ rays

- VHE $\gamma$ causes EM shower with max. at alt. ~ 10 km.
- Cherenkov angle ~ 1°: get ~ 10 ns light flash on ground with radius ~ 120 m.
- Detect with camera made of PMs.
Detecting high energy $\gamma$ rays

- Cherenkov emission, attenuation in air, QE of photomultiplier lead to:
  - 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.
  - $E \sim 0.1...5$ TeV, Cosmic Rays (need $\gamma$/h sep).
  - $E > 5$ TeV, rate.

- Array of telescopes with different sizes copes best with these different regions.
The Cherenkov Telescope Array concept

Low energy
Four 23 m telescopes
4.5° FoV
~2000 pixels
~0.1°

Medium energy
About twenty-five 12 m telescopes
8° FoV
~2000 pixels
~0.18°

High energy
About seventy 4 m telescopes
9° FoV
1000…2000 pixels
~0.17°…0.23°
CTA sensitivity
The first Atmospheric Cherenkov Telescope

- Galbraith and Jelley, Harwell, 1953.
The first dual mirror ACT?

- An early “dual mirror” gamma ray telescope, Porter and Jelley, Glencullen (Ireland), 1962.
- Gun mount and searchlight mirrors from WWII.
The SSTs – take one

- Davies-Cotton 7 m telescope designed for CTA.

- This is a viable solution for the SST.

- But, the camera:
  - Has a diameter of about 1.6 m.
  - Weighs about 2 tonnes.
  - Is expensive, in no small part because of the price of the PMTs.

- The cost of the camera dominates that of the telescope.

- Making it cheaper would allow the construction of more telescopes and hence improve CTA performance.
The SSTs – take two

- Can we use cheaper sensors (e.g. SiPMs) in a compact camera?
- Must have $F \sim 2 \, \text{m}$ so $\sim 6 \times 6 \, \text{mm}^2$ pixels commercially available match required angular resolution of $\sim 0.2^\circ$.
- Need reasonable area, $D > 3 \, \text{m}$, hence “fast” focal ratio ($f = F/D$ small).
- Primary aberrations:
  - Spherical $\sim 1/f^3$.
  - Coma (1st order) $\sim \delta/f^2$.
- Require sophisticated optics to correct for aberrations at large field angles.
- Look at two-mirror telescope designs, c.f. 9 m dual mirror telescope originally proposed by Vassiliev for AGIS.
Gamma-ray Cherenkov Telescope optics

- Design (Liverpool, Durham 2010):

- Images of point source at infinity:

- For field angles below about 5°, over 80% of the light from a point source at infinity (or at 10 km with refocusing) is contained in a 6 × 6 mm² pixel.
Mechanical design

- Durham 2011.
  - Long fork.
  - Central tube supports camera.
  - Tripod supports secondary mirror
  - Electronics in counterweight.
  - Aluminium structure.

  - Short fork.
  - Primary dish support separated from secondary support.
  - Camera attached to secondary.
  - Shaped counterweight.
  - Steel structure, aluminium mirrors.
Mechanical design

- Paris 2015.
- Four masts to support secondary.
- Same motors on both axes.
- Primary mirror rotation mechanism to facilitate mirror installation.
- Camera removal mechanism.
Mechanical structure

- Prototype structure assembled in April, visited by ESO team in September.
Dual Mirror – alternative Italian design

- Primary mirror with sector panels
- Secondary mirror
- Camera
- Mast structure
- Elevation universal joint (Cardan joint)
- Concrete pedestal and foundation
- M1 dish
- Counterweight
- Worm drive
SST-1M prototype

- Davies-Cotton optics.
- Mirror 4 m diameter.
- Focal length 5.6 m.
- Mass ~ 9 t.
- SiPM based camera.
- Diameter ~ 1 m.
- Mass ~ 200 kg.
ASTRI prototype

- Primary 4.3 m diameter.
- Focal length 2.2 m.
- Mass ~ 20 t.
- Camera diameter about 0.4 m.
- Mass ~ 70 kg.

- Note, astronomical telescopes are protected from the elements…
- …but ACTs generally aren’t!
A shelter for the GCT

- “Pram cover” shelter used to protect the GCT prototype in Paris.
- Cost benefit on southern site, reduced frequency of mirror recoating.
Camera design

Goal – produce low cost camera with full-waveform readout
Trigger: 4 neighbouring pixels are summed, then discriminated.

6 mm (0.17°) pixel

0.34° super pixel
Camera

64 Pixel Module

x 32

64 Pixel Module

TARGET Module

FPGA

UDP Data

Any 2 neighbouring super-pixels

Following camera trigger data read out to central location

TARGET ASIC

Backplane Board

DACQ Boards

Data

Clock, Timestamps

Control

Timing Board

Safety Boards
Development of the camera

- Leicester 2012, start construction of camera with MAPMs – CHEC-M.
- Electronics based around TARGET (Hawaii/SLAC and Erlangen).
- Backplane, common with SCT (Washington University).
- DAQ using White Rabbit for timing (Amsterdam).
- Flashers (Durham) and Peripherals Board (Liverpool) complete camera.
Development of the camera

- Leicester 2015, CHEC-M complete.
Camera tests

- Camera in dark box with laser mounted on robot arm.

- Lab. tests results (here with external trigger).
Completing the GCT prototype

- Camera shipped to Paris, arrived Friday 13\textsuperscript{th} November.
- Checked in lab and mounted on telescope on 20\textsuperscript{th} November…
Verify camera operation on telescope

- Check that operation is safe, e.g. TARGET module temperatures.
- Check electronics performance, e.g. transfer functions.
- Check that MAPMs are functioning as expected – look for single photo-electron peak:

![Graph showing temperature over time](image1)

![Graph showing ADC count versus offset](image2)

![Histogram showing events per bin](image3)
First tests of the GCT prototype on sky

- Thursday 26th Nov, night sky background 20 to 100 times higher than CTA site…
First tests of the GCT prototype on sky

- ...but successfully observed Cherenkov light from ~50 TeV showers.
First tests of the GCT prototype on sky

- Thursday 26th November.
First tests of the GCT prototype on sky

- Thursday 26\textsuperscript{th} November.
First tests of the GCT prototype on sky

- Thursday 26th November.
Inauguration of the telescope

- Party on 1st Dec. 2015!
What have we learnt?

- We need to work on mirrors and mirror production processes.
- Can see by eye that two panels of the secondary are of poor quality (despite nominally all being same).
- Try casting aluminium, machining, applying nickel layer, polishing, coating with aluminium and SiO$_2$.
- Nickel layer improves surface quality, but also needed if mirror to be recoated, otherwise old Al coating cannot be stripped off.
- Good quality control needed.
- Casting should also reduce cost.
- (Applies also to structural elements.)
Glass mirror studies

- Hot slump glass mirrors using concave mould.
- Proof-of-principle studies.
- Grind a ceramic mould with radius of curvature of 3 m.

- Level mould in oven and slump 4 mm thick glass sheet, 35 cm diameter, using carefully controlled temperature cycle.
First glass mirror studies

- Measure RoC of glass samples and of mould.
- Glass follows shape of details of mould.

- Mould shrinks slightly after baking.
- Part 1, slumped simultaneously with mould baking, during power cut.
- Part 2, smaller RoC than mould.
- Next steps, larger samples, petal shapes, smaller RoC, coating…
Next steps for the GCT

- Complete commissioning and testing of GCT camera and structure.
- Complete SiPM-based camera and test.
- Design pre-production camera and telescope.
- Produce three pre-production instruments and install on southern site from end 2017.
- Produce further 32 telescope and deliver 35 systems to CTA Observatory.
ESO Paranal site in Chile
Progress with GCT good.

First of CTA’s prototypes to observe Cherenkov light images of air showers.

Comprehensive prototype telescope and camera test programme underway.

Design and review pre-production structure by end of 2016.

Test SiPM camera early in 2017.

Plan to install first telescopes on southern and northern sites in 2017.