Cherenkov Telescope Arrays

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  • Characteristics of Cherenkov light
  • why Imaging Atmospheric Cherenkov Telescopes (IACTs) are designed in the way they are

● Cherenkov Telescope Array - the next generation observatory
Technique: Cherenkov light is secondary radiation from Extensive Air Showers

- First interaction ~20km
- Shower maximum ~8-12km
- Cherenkov flash lasts a couple of nanoseconds and makes a pool of light on the ground

* not to scale
Technique: an imaging Cherenkov telescope

placing a telescope anywhere in the lightpool means a relatively small detector can have a large effective collecting area.

* not to scale
Technique: a stereoscopic Cherenkov telescope array

- improves background rejection
- gives better angular resolution
- gives better energy resolution

Having several telescopes:

- ~80-120m

* not to scale
Focal Plane Instrumentation: an IACT camera

Cherenkov image is faint

200-600nm Cherenkov light density on ground from a 100 GeV primary

so large collectors (i.e. big mirrors) are needed
Focal Plane Instrumentation: an IACT camera

Cherenkov image is faint

The Cherenkov signal can easily be swamped by background light, so these instruments do not operate under bright conditions, i.e. under moonlight*

*though some do run at reduced gain when the moon is far from full

so duty cycle of an IACT can be as low as ~10%
Focal Plane Instrumentation: an IACT camera

Cherenkov image is faint, brief

![lightpool contained in a pancake of a few nanoseconds duration](image)

so using fast electronics with a narrow integration window increases signal/noise by reducing night sky background contamination.
Focal Plane Instrumentation: an IACT camera

Cherenkov image is faint, brief & blue

Spectrum of Cherenkov light

![Spectrum of Cherenkov light](image)

- Cherenkov spectrum
- After atmospheric attenuation
- After mirror reflection
- After PMT quantum efficiency

~340nm
Focal Plane Instrumentation: an IACT camera

Cherenkov image is faint, brief & blue. It is also quite large.

so optical quality in the reflector and the pixel size can be quite modest (i.e. optical PSF relatively large at ~few arcminutes)

but reasonably good off-axis performance is needed since image is not centred in camera.

The optical support structure is usually of Davies-Cotton design as a compromise between timing and off-axis performance.
Focal Plane Instrumentation: an IACT camera

So an IACT camera is a wide, coarse pixellated assembly of fast electronics.

- **5° fov**
- **0.12° pixel size**
- **0.16° pixel spacing**

Light cones reduce dead space between pixels.
The main IACTs today

VERITAS
4x 110m² reflectors on irregular grid

H.E.S.S.
4x 108m² reflectors on 120m square grid
H.E.S.S. II will add central ~600m² dish

MAGIC - 236m² reflector
MAGIC II adds second telescope 85m distant
The future

**Cherenkov Telescope Array**

*An advanced facility for ground-based gamma-ray astronomy*

An observatory consisting of two arrays – one in the southern hemisphere, one in the northern – operated by a single consortium aiming to explore the 10 GeV - 100 TeV sky.

**CTA** is included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). It is one of the “Magnificent Seven” of the European strategy for astroparticle physics published by ASPERA, and *highly ranked* in the “strategic plan for European astronomy” (leaflet) of ASTRONET.


Also there is the **Advanced Gamma Ray Imaging System (AGIS)**

[http://gamma1.astro.ucla.edu/agis/](http://gamma1.astro.ucla.edu/agis/) being planned in the U.S.
Desirable CTA sensitivity

- **GLAST**
- **MAGIC**
- **H.E.S.S.**

- **E \times F(>E) [TeV/cm²s]**

- **E [GeV]**

- **10% Crab**
- **1% Crab**

Aim for 5-10x sensitivity improvement over current generation of instruments
How will this increase in sensitivity be achieved?

In order to achieve sensitivity over a wide range of energies use a mix of telescope sizes and spacings.

*not to scale*
Possible CTA sensitivity

but lots of telescopes means lots of €$\text{E}_\text{Y}$ so a balance must be found

~3000 m$^2$ mirror area

~5000 m$^2$ mirror area

~4000 m$^2$ mirror area

few 10$^4$ m$^2$ with dense coverage (5--10%)

few 10$^5$ m$^2$ with medium coverage (1--2%)

O(10$^7$) m$^2$ with sparse coverage (0.03--0.05%)

up to 7

up to 49

up to 100
Time line for CTA Design study

Year 1:
- optimise telescope layout;
- evaluate possible technology

Year 2:
- construct & test components of prototype

Year 3:
- prototype telescopes to be constructed and tested in the field

Year 4:

Time line for CTA

- design study
- construction
- ...operation...
Primary aims of the design study are

➢ to narrow down the multidimensional space of design options and technology options, optimising the relation between performance and cost;

➢ to lay out a clear path for how such a facility can be constructed and operated;

➢ to build and test prototype telescope(s) that are suitable for mass production for a large array of telescopes.
The Design Study

11 working packages

**PHYS**  Astrophysics and astroparticle physics
**MC**  Optimisation of array layout, performance studies and analysis algorithms
**SITE**  Site evaluation and site infrastructure
**MIR**  Design of telescope optics and mirror
**TEL**  Design of telescope structure, drive and control systems
**FPI**  Focal Plane Instrumentation
**ELEC**  Readout electronics and trigger
**ATAC**  Atmospheric monitoring, associated science and instrument calibration
**OBS**  Observatory operation and accessibility
**DATA**  Data handling, processing, management and data access
**QA**  Risk assessment and quality assurance
simulates 275 telescopes
pick sub-arrays based on sensitivity/cost
i.e. 100 telescopes
for €150M

**CTA MC study**

- 23m parabolic 28m focal length
- 12m Davies-Cotton f/d=1.3
- 10m Davies-Cotton f/d=1.0
- 7m Davies-Cotton f/d=1.3
Suitable sites for CTA are being looked at

- high
- flat
- dry
- clear
- dark
- reasonably accessible
- etc, etc...
IACTs are large light buckets viewed by fast electronics. 

Arranging many IACTs in an array improves performance/sensitivity.

A large effort is starting to design the next generation observatory of IACTs.

The duty cycle of an IACT is such that a good amount of time could be forseen as available for using these large light buckets for other purposes, such as intensity interferometers...