The Cherenkov Telescope Array
Status and science goal for fundamental physics

DISCRETE 2014
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King’s College, London

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for the CTA consortium
$\gamma$-ray enters in the atmosphere

Electromagnetic cascade

10 nanosecond snapshot

$0.1 \text{ km}^2$ "light pool", a few photons per $\text{m}^2$
Current Cherenkov telescope arrays

**MAGIC** Canari Island, Spain
La Palma, 2225m a.s.l.
2 telescopes, Ø17m

- 2 - 5 Telescopes
- 500-2000 pixel camera
- 3.5 - 5.0° FoV
- ~0.1° angular res.
- ~15% energy res.
- sensitivity < 1% Crab
- ~30 GeV < E < ~50 TeV

**VERITAS** Arizona, USA
1275m a.s.l.
4 telescopes, Ø12m

**H.E.S.S.** Namibia
1800m a.s.l.
4 telescopes, Ø13m
+ 1 telescope, Ø28m
How to do better?

- More events
  - More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays

- Better events
  - More precise measurements of atmospheric cascades and hence primary $\gamma$-rays
    - Improved angular resolution
    - Improved background rejection power

→ More telescopes!

Simulation: superimposed images from 8 cameras
The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, ...
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS

Designed for operation up to 30 years
The Cherenkov Telescope Array
Angular resolution

- Fermi
- HESS
- CTA (Requirement)
CTA sites: candidates

Two sites to cover full sky at 20°-30° N, S

Warning: map not quite accurate
CTA sites: candidates

- Arizona (2)
- SPM - Mexico
- Argentina (2)
- Chile - Armazones
- Tenerife + additional lower priority candidates
- Aar/HESS Namibia
CTA sites: candidates

- **South**
  - Negotiations starting with Namibia and Chile → Decision soon
- **North**
  - Mexico, US and Spain still all under consideration → Decision 2015
- **Site development 2017**
CTA observation modes

- Monitoring 4 telescopes
- Monitoring 4 telescopes
- Deep field ~1/2 of telescopes
- Deep field ~1/3 of telescopes
- Monitoring 4 Telescopes
- Monitoring 1 telescope
- high sensitivity observations
- requested for targeted searches
CTA observation modes

Survey mode:
Full sky at current sensitivity in ~1 year

- systematic scan of part of the sky
- requested for blind searches
CTA Reach

- Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see whole Galaxy

- Field of view + sens.
  - Survey speed $\sim 300 \times$ HESS
CTA Science

Cosmic rays
Origin of cosmic rays
Acceleration physics
Impact on environment

Black holes
Role as particle accelerators
Acceleration physics
Probes of the Universe

Physics Frontiers
Nature of dark matter
Search for axion-like particles
Test of Lorentz invariance
CTA observatory

CTA will be an Open observatory

- CTA Consortium, which builds the telescopes, will get guaranteed time (~50%) with rest open to external proposals.
- CTA Consortium in the process of defining a “Key Science Program” to use the consortium time allocation
CTA observatory

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Aiming for project approval mid-2015
Deep survey of the Galactic Centre

500 h in the +/-5° around the Galactic Centre
Systematic surveys

Galactic plane survey
+/- 4° in latitude

Extragalactic survey
25% of the whole sky
Why indirect searches with HE gamma rays?

- Why indirect?
  - can reveal the abundance and distribution of dark matter

- High and very high energy gamma rays are powerful probes:
  - they do not suffer from propagation effects,
  - characteristic features such as lines or steps may be present in the energy spectrum at these energies

- Assuming thermodynamical equilibrium until the thermal decoupling
  - The natural value of the annihilation cross section is about $10^{-26} \text{ cm}^3\text{s}^{-1}$
Indirect dark matter search with gamma-rays

\[
\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2m_{\text{DM}}^2} \frac{dN_{\gamma}}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s]) ds
\]

**Particle Physics:**
- Cross sections
- Differential photon yield
- DM particle mass

**Astrophysics**

→ modelling required for the DM distribution in the object

**Primary channels**
- SM: b, W^+, Z, \tau^+, ...

**Final states**
- \gamma, e^+, p, \nu, ...

**Hadronisation and/or decay**
- \gamma, e^-, p, \nu, ...

- DM
- DM

- SM: b, W^-, Z, \tau^-, ...

- γ, e^+, p, ν, ...

- γ, e^-, p, ν, ...
Spectral signatures

**Continuum emission**
(“Secondary photons”)
→ from fragmentation of quarks/massive gauge bosons (via $\pi_0$ decay)

**Gamma-ray lines**
→ from two-body annihilation into photons
→ forbidden at tree-level, generically suppressed by $O(\alpha^2)$

**Virtual Internal Bremsstrahlung (VIB)**
→ radiative correction to processes with charged final states
→ generically suppressed by $O(\alpha)$
Dark matter targets

Galaxy satellites of the Milky Way
- Many of them within the 100 kpc from GC
- High M/L
- Low astrophysical background

Galactic Centre
- Proximity (~8kpc)
- Possibly high DM concentration:
  DM profile: core? cusp?
- High astrophysical bck / source confusion

Substructures in the Galactic halo
- Lower signal
- Cleaner signal (once found)

Galactic halo
- Large statistics
- Galactic diffuse background

Also galaxy clusters

- DM density profile matters …
- Astrophysical background matters as well

DM targets for CTA

Milky Way halo | Large Magellanic Cloud | Dark targets: Dwarf galaxies Clumps

Studies are in progress to decide best way to use observation time
Strongest gamma-ray constraints to date

Nearby (~100kpc) dwarf galaxies

Inner Galactic halo

15-dpsh stacking
100% tautau

Fermi coll. PRD 2014

Natural scale

H.E.S.S. coll. PRL 2011
Dwarf satellites of the Milky Way

Choice of targets will be limited by the CTA site

- Southern site: Sculptor, Carina
- Northern site: Draco, Ursa Minor, Segue 1, Willmann 1, ...

Most promising dwarf candidates

- Classical dwarf
- Ultra-faint dwarf
Dwarf satellites of the Milky Way

- Need boost of at least 10-100 to reach thermal relic cross section
- New experiments will surely detect new dwarf galaxies (and better constraints known) in the time from here to CTA
Dark matter subhalos: observation strategy

- Flexible observation modes
- Survey program
  - Galactic plane
  - a quarter of the sky
  → Promising for wide-field searches of Galactic DM subhalos

Monitoring
4 telescopes

Deep field
~1/3 of telescopes

Survey mode:
large regions of the sky at current sensitivity

Very deep field
Dark matter subhalos

- Clumps of DM could be gamma-ray dark emitters
- Some of them could be Unidentified Fermi Sources
- Fermi could be blind of them if DM is above few hundreds of GeV
Dark matter subhalos: wide field survey

What the Galactic plane may look like… numerous sources will shine
Dark matter subhalos: wide field survey

- Clumps of DM could be gamma-ray
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Observation strategy:
- Avoid the Galactic plane where numerous sources will shine, those imply a decrease in the clump sensitivity
- But not too far from the galactic centre region since clump distribution is peaked towards the centre of the halo
Dark matter subhalos: wide field survey

- Clumps of DM could be gamma-ray
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- Wide field survey:
  a quarter of the sky
  @10 mCrab sensitivity
  → natural scale can be probed
Galactic halo

- Galactic center obvious target for DM searches, but crowded region
- Galactic halo at short distance from GC is well-defined

→ Avoid sky regions with strong astrophysical gamma ray signals
→ Focus at the same time on regions with an expectedly large DM density
Galactic halo

Preliminary

- 500 h in the inner 5° around GC
- Careful selection of signal and background region
- Control of diffuse gamma-ray background
- Control of background systematics
- Results robust for cuspy profile but not for a core profile

Natural scale is within the reach of CTA:
for the first time in indirect detection with IACTs, CTA has the sensitivity to probe the expected parameter region for popular models

Final observational pointing strategy not decided
Will CTA be competitive?

Indirect detection

DM

SM

Direct detection

Production at collider

Good sensitivity at high (> 1 TeV)
LSP mass

Cahill-Rowley+ 2014
Will CTA be competitive?

- CTA is complementary to LHC and direct searches.
- If LHC-14 do not discover DM, CTA has still chance if DM is heavy.

Cahill-Rowley+ 2014
Dark matter sensitivity predictions

- Final observational pointing strategy not decided
- Control of background systematics
- Sensitivity to natural scale for the Galactic halo
Conclusions

- CTA will be the first open IACT observatory
  - Factor 10 improvements on existing facilities
  - Full sky coverage

- Major recent progress towards realizing the observatory
- On track for completion ~2020
  - CTA expected to start science in 2017

- Great possibility to discovery dark matter
  - CTA will be a key player for TeV DM

- And very many other science opportunities